Physics

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Physics has for more than a century been the cornerstone of a liberal arts education for our technical society and the engine that drives many modern scientific and technological breakthroughs. The Department of Physics at the University of Illinois at Urbana-Champaign, consistently ranked among the top ten physics graduate programs in the nation and currently #3 in undergraduate engineering physics, is known worldwide for excellence and innovation. We are committed to training new generations of researchers and teachers, to forging new partnerships with government and industry, and to applying the tools of physics to seek opportunities for creativity and discovery and to address problems that challenge our society. Device applications based on transistors, semiconductors, and superconductors, medical advances in magnetic resonance imaging, the invention of light-emitting diodes and supercomputers, the development of radar, and the proliferation of the Internet have all arisen directly from fundamental research in physics at Illinois.

Major experimental and theoretical programs in the Department of Physics range from fundamental to applied science and are currently supported by external funding at a level of more than $18 million annually. In addition to our department’s preeminence in traditional physics disciplines, such as condensed matter physics (ranked #1 nationally), nuclear and particle physics, and astrophysics, we are increasingly recognized for our emerging programs in biological physics, complex systems, computational physics, mathematical physics, and the physics of quantum information. Physics research reaches out via interdisciplinary collaborations with other science and engineering departments at the University of Illinois—many also ranked within the top ten U.S. programs in their disciplines. A relatively new focus is physics education research; we are creating and implementing innovative teaching techniques in science and engineering curricula and are recognized nationally for our introductory physics courseware.

Faculty members, postdoctoral research associates, graduate students, and, increasingly, undergraduate students carry out research in a variety of state-of-the-art facilities on campus, including the Frederick Seitz Materials Research Laboratory, the Micro and Nanotechnology Laboratory (MNTL), the Beckman Institute, the Institute for Genomic Biology (IGB), and the National Center for Supercomputing Applications (NCSA), as well as at national and international laboratories such as Fermilab, Argonne National Laboratory, Jefferson National Laboratory, Brookhaven National Laboratory, the Centre Européenne pour la Recherche Nucléaire (CERN), the Deutsches Elektronen-Synchrotron (DESY), and the Paul Scherrer Institute. The department is also home to the National Institutes of Health Resource for Macromolecular Modeling and Bioinformatics, a Howard Hughes Medical Institute investigator, a Nobel Laureate, and eight members of the National Academy of Sciences.

Faculty and Their Interests

Peter M. Abbamonte
Experimental condensed matter physics, resonant soft x-ray scattering; electron self-organization, oxide devices; quantum phase transitions; collective excitations

Aleksei Aksimentiev
Theoretical biological physics, molecular motors, mechanical proteins, silicon biotechnology, biomolecular modeling

Gordon A. Baym
Theoretical physics, matter under extreme conditions, neutron stars, early universe, ultrarelativistic heavy ion collisions, condensed matter theory, Bose–Einstein condensation in trapped atomic systems

Douglas H. Beck
Experimental nuclear and particle physics; nucleon structure; fundamental symmetries; electric dipole moments
Alexey Bezryadin  
Experimental condensed matter, nanometer-scale mesoscopic physics, molecular electronics, quantum phase transitions in one-dimensional superconductors, DNA electronics

David M. Ceperley  
Computational condensed matter physics, electronic structure, quantum statistical mechanics, Monte Carlo methods, low-temperature physics, high-pressure physics

Yia-Chung Chang  
Theoretical condensed matter physics, electronic structure, density functional theory, strongly correlated electron systems, low-dimensional electronic systems

Yann R. Chemla  
Experimental biological physics, high-resolution optical tweezers, molecular motors, nucleic acid and protein translocases

Tai-Chang Chiang  
Experimental condensed matter physics, surface science; atomically uniform films; electronic properties of impurities, surfaces, and quantum structures

Robert Clegg  
Experimental biophysics with an emphasis on kinetics and optical spectroscopy

S. Lance Cooper  
Experimental condensed matter physics, optical effects in solids, Raman scattering, spectroscopic studies of low-carrier-density magnetic systems, spectroscopic studies of the magnetic oxides

Karin Dahmen  
Theoretical condensed matter physics, non-equilibrium dynamical systems, including pattern formation in homogeneous systems and inhomogeneous systems having quenched disorder

Paul T. Debevec  
Experimental nuclear physics, muon physics, fundamental interactions and properties of elementary particles

James N. Eckstein  
Experimental condensed matter physics; correlated electron systems; quantum electronic properties of complex oxide materials and heterostructures; quantum properties of thin-film devices

Bob I. Eisenstein, Emeritus  
Experimental high-energy physics, weak interactions of B mesons

Aida X. El-Khadra  
Theory and phenomenology of fundamental particle interactions, including QCD, weak interactions, lattice field theory, heavy quark physics, standard model parameters

Steven M. Errede  
Experimental high-energy physics, collider physics, electroweak interactions, strong interactions, fundamental forces

C. Peter Flynn  
Experimental condensed matter physics, materials physics; defects and diffusion; magnetism; low-energy electron microscopy; crystal growth

Eduardo Fradkin  
Field theory and condensed matter physics; high-temperature superconductors, strongly correlated systems, electronic liquid crystal phases, fractional quantum Hall effect, topological states of quantum matter, topological quantum computing

Charles Gammie  
Theoretical astrophysics, including theory of star and planet formation, accretion disks and related phenomena, galactic structure, astrophysical fluid dynamics, computational astrophysics

Russell W. Giannetta  
Experimental condensed matter physics, including superconductivity, low-temperature physics, mesoscopic physics; magnetic resonance; nanostructures

Gary E. Gladding  
Experimental high-energy physics, mixing of charmed mesons; physics education research

Paul Goldbart  
Theoretical condensed matter physics, random systems, mesoscopic physics, superconductivity and superfluidity
Nigel Goldenfeld
Theoretical condensed matter physics, pattern formation in spatially extended systems, high-temperature superconductivity, biocomplexity, statistical mechanics, polymers, liquid crystals, disordered systems

Ido Golding
Experimental biological physics; spatio-temporal dynamics in living cells—real-time studies having single-event resolution

George Gollin
Experimental high-energy physics, interactions of the electroweak gauge bosons

Andrew V. Granato, Emeritus
Experimental condensed matter physics, properties of simple liquids and glasses, amorphous materials

Laura H. Greene
Experimental condensed matter physics, highly correlated electron systems, high-temperature superconductivity, novel materials

Matthias Grosse Perdekamp
Experimental high-energy nuclear physics, nucleon structure, spin-dependent structure of the proton, quark transversity distribution in the proton, spin-dependent quark fragmentation functions

Taekjip Ha
Experimental biological physics, DNA-protein, protein-protein interactions, protein and RNA folding, membrane biophysics, fluorescence microscopy of biological systems, single-molecule spectroscopy and manipulations

David Hertzog
Experimental nuclear physics, precision muon physics

Lillian Hoddeson
History of 20th-century science and technology, including electronics, atomic weapons, modern physics, big science, oral history

Leland E. Holloway, Emeritus
Experimental high-energy physics

Alfred Hubler
Nonlinear and complex dynamics, control of chaos, pattern formation, information flows; science education

Icko Iben, Jr., Emeritus
Structure and evolution of stars, comparisons between theoretical models of stars and observed properties of stars

E. Atlee Jackson, Emeritus
Dynamic lessons from nature's evolutionary processes, human creativity

Thomas Junk
Experimental high-energy physics, search for the Higgs boson

Sheldon Katz
Theoretical high-energy physics; algebraic geometry and its interaction with theoretical physics, especially string theories and supersymmetric field theories

Miles V. Klein, Emeritus
Experimental condensed matter physics; optical effects in solids; electronic, vibrational, and magnetic excitations in solids

Paul G. Kwiat
Experimental atomic, molecular, and optical physics; foundations of quantum mechanics; quantum information physics

Frederick K. Lamb
Theoretical astrophysics; neutron stars, black holes, pulsars, x-ray stars, and strong gravitational fields; space policy, nuclear weapons, and arms control

Susan A. Lamb
Theoretical astrophysics; galaxy collisions and star formation

Anthony J. Leggett
Theoretical condensed matter physics, macroscopic manifestations of quantum mechanics, foundations of QM, superfluid $^3$He, thermal and acoustic properties of glass, high-temperature superconductivity, Bose-condensed alkali gases, formation of topological defects in quenching

Robert G. Leigh
Theoretical high-energy physics, quantum field theory, supersymmetric gauge theory, superstring theory

Benjamin L. Lev
Experimental ultracold atomic and molecular physics, quantum optics, and quantum information science
Tony M. Liss
Experimental high-energy physics, proton-antiproton collisions, top quark physics

Naomi C. R. Makins
Experimental nuclear physics, hadronic structure, origin of spin in the proton and neutron, nucleon structure

Richard M. Martin
Theoretical condensed matter physics, the electronic structure of condensed matter

Nadya Mason
Experimental condensed matter physics, nanometer-scale mesoscopic physics, quantum properties of carbon nanotubes, low-dimensional superconductivity, quantum phase transitions

Telemachos Mouschovias
Theoretical astrophysics, interstellar gas dynamics, theory of star formation in the presence of magnetic fields, magnetohydrodynamics, numerical solution of partial differential equations

Alan M. Nathan
Experimental nuclear physics; physics of sports

Munir H. Nayfeh
Experimental and theoretical atomic physics, laser atomic spectroscopy, silicon nanotechnology

Mark Neubauer
Experimental particle physics; particle astrophysics; neutrino physics; Higgs boson; electroweak diboson physics

Yoshitsugu Oono
Theoretical statistical physics in the broadest sense (nonequilibrium, including biological, hydrodynamical, and dynamical systems), applied mathematics

Jen-Chieh Peng
Experimental nuclear physics, heavy ion physics, parton structures of the nucleons and nuclei, including production and decays of charm and beauty mesons

Philip W. Phillips
Theoretical condensed matter physics, quantum critical phenomena, quantum magnetism, strongly correlated electrons

Kevin T. Pitts
Experimental high-energy physics, CP violation in bottom quark decays, searches for new phenomena

Klaus Schulten
Theoretical biological and computational physics, statistical physics

Mats Selen
Experimental high-energy physics, production and decays of heavy b and c quarks; experimental astrophysics; physics education

Paul Selvin
Experimental biological physics, new forms of resonance energy transfer techniques, structure and dynamics of biological macromolecules, fluorescence

Stuart L. Shapiro
Theoretical astrophysics and general relativity theory; physics of black holes and neutron stars; computational physics and astrophysics; hydrodynamics and stellar dynamics

Ralph O. Simmons, Emeritus
Experimental condensed matter physics, properties of noble gas solids and liquids

Charles P. Slichter, Emeritus
Experimental condensed physics, nuclear magnetic resonance, NMR studies of high-temperature superconductors

John D. Stack
Theoretical high-energy physics, quantum field theory, lattice field theory, QCD

Michael Stone
Theoretical condensed matter physics, statistical physics, mathematical physics, quantum field theory

Jeremiah D. Sullivan, Emeritus
Physics and society: nuclear nonproliferation, arms control and international security, science policy

Jon J. Thaler
Observational cosmology, dark matter and dark energy, elementary particles in the evolution of the universe

Dale J. Van Harlingen
Experimental condensed matter physics, superconductivity, microfabrication of superconductor devices, scanning probe microscopy, mesoscopic systems
Smitha Vishveshwara
Theoretical condensed matter physics, strongly correlated systems: disordered systems, localization physics, phase transitions, critical dynamics

Benjamin D. Wandelt
Theoretical astrophysics and cosmology, cosmic microwave background, structure formation, dark matter, early universe

William D. Watson, Emeritus
Theoretical astrophysics, interstellar medium, atomic and molecular processes

Richard L. Weaver
Theoretical condensed matter physics; ultrasonics, stochastic waves, disordered and complex structures, structural acoustics.

Michael Weissman
Experimental condensed matter physics, 1/f noise, spin glasses, amorphous materials, inhomogeneous phase transitions

Scott Willenbrock
Theoretical high-energy physics, including strong, weak and electromagnetic interactions, Higgs phenomenon, grand unification

James E. Wiss
Experimental high-energy physics, photoproduction and e+ e- annihilation of charm particles, precision study of the B meson

James P. Wolfe
Experimental condensed matter physics, optical properties of semiconductors, phonon imaging

Atomic, Molecular, Optical Physics, and Quantum Information Science

Inhomogeneous Phases of Bosons Trapped in an Optical Lattice
R. Barankov, C. Lannert, S. Vishveshwara*
National Science Foundation; U.S. Department of Energy, DEFG02-91ER45439; U.S. Office of Naval Research, N00014-04-1-0490

The latest technologies in the field of cold trapped atoms are able to realize a plethora of phases in the presence of an optical lattice created by interfering laser beams. We consider the feasibility of creating a phase of neutral bosonic atoms in which multiple Mott-insulating states and superfluid states of matter coexist in a shell structure and propose an experiment to spatially resolve such a structure. These spatially inhomogeneous phases of bosons arise from the interplay between the confining potential and the short-ranged repulsion. We develop a technique for analyzing these phases and predicting salient features such as collective mode behavior.

Bose–Einstein Condensation and Related Problems in Trapped Atomic Gases
G. A. Baym,* S. Baharian, S. A. Gifford, K. Shen, Z. Yu
National Science Foundation, PHY 05-00914

This program aims to develop the theory of ultracold trapped atomic gases, including Bose-Einstein condensation and superfluid fermions. The research on atomic systems is a vital facet of a long-standing complementary effort to discover and gain theoretical understanding of unusual states of matter that appear under extreme conditions, for example, of temperature, rotation, and density. The strong theoretical connections between ultralow temperature condensed atomic systems and many-particle systems in other areas of physics, including condensed matter, astrophysical, and nuclear systems, allow important cross-fertilization between these areas.

CAREER: Quantum Simulation Using Ultracold Atom Gases
B. DeMarco*
bdemarco@uiuc.edu
National Science Foundation, PHY 04-48354

This CAREER proposal aims to realize quantum simulation by integrating existing techniques and new technologies into atomic gas Bose–Einstein condensation experiments. By employing ultracold atoms trapped in an optical lattice, quantum simulation will be used to study physics relevant to materials, technology, and fundamental science that cannot be completely understood using traditional computational techniques or available experimental methods.

Simulation of Frustrated Magnetism and Disorder Using Ultra-Cold Atoms
B. DeMarco*
Army Research Office, W911NF-08-1-0021

We will work on simulating two types of condensed matter models—geometrically frustrated quantum magnetism and the disordered Bose-Hubbard model—using ultra-cold atom gases. These models have been intensely studied for several decades in the context of a wide array of diverse

* Denotes principal investigator.
materials: frustrated quantum magnetism has been investigated in the context of high-temperature superconductivity and novel magnetic materials, and the disordered Bose-Hubbard model has been applied to superconducting thin films, solid 4He, and superfluids confined in granular media. Certain aspects of these models have proven difficult to understand because traditional theoretical approaches, such as perturbation theory and direct numerical simulation, have met limited success. Outstanding issues that we will address include the identification of quantum magnetism models that give rise to spin liquids, and the ground state phase diagram and transport properties of the disordered Bose-Hubbard model. Our approach will be to use ultra-cold 87Rb atoms confined in an optical lattice to simulate these condensed matter models. The first precision tests of the disordered Bose-Hubbard model and the first unambiguous realization of a spin liquid are anticipated outcomes our research.

Hyper-Entanglement for Advanced Quantum Communication
P. G. Kwiat*
Department of Interior, NBCHC070006

Hyper-entanglement—the property that quantum systems, photons in our case, may be simultaneously entangled in multiple degrees of freedom—promises to enhance the capabilities of current quantum communication protocols, and to enable new ones. We will extend our experience in the creation, manipulation, and characterization of hyper-entanglement in the photon pairs produced via spontaneous parametric down-conversion, and employ them for several relevant advanced quantum communication applications: quantum super-dense coding, production and application of bound entanglement, optimized teleportation beyond single qubits, and entanglement-enhanced quantum fingerprinting.

Our research in these areas will substantially increase understanding of the benefits—and limitations— of using hyper-entanglement for quantum information processing, extending the capabilities of current communication protocols, and enabling new ones.

Optical Quantum Computing
P. Kwiat*
U.S. Army Research Office, W911NF-05-0397

In cooperation with the University of Queensland, Applied Physics Lab, Louisiana State University, University of Vienna, Imperial College in London, University of Toronto

Quantum computing uses the unique quantum properties of small systems to enable exponential computational speedups for certain classes of problems. Simple gates have been realized in several systems; the cleanest of these have been using photons as the quantum bits ("qubits"). Now we are investigating the feasibility of transitioning these small-scale results to a much larger system, eventually capable of performing universal computations. We are exploring two approaches in detail. The first uses the newly devised "cluster" state paradigm, thereby reducing resources requirements by several orders of magnitude. The second approach, relying on weak nonlinear effects, reduces the resource requirements even further.

Our attempts to further the progress of optical quantum computing—if successful—could lead to enormous speedups for solving certain computational problems.

Photonic Quantum Information Systems
P. Kwiat*
Army Stanford University, 28000E

In cooperation with Stanford University

Our goal is to develop the following optical quantum technologies for quantum information processing (including computation, cryptography, and metrology) and apply them to critical problems in these areas: Entangled-photon sources and characterization, quantum state transducer, photon storage and quantum memory, periodic single photon source, and photon number-resolving solid-state photomultipliers (SSPMs). These are central resources for many quantum communication applications. Developing resources for optical quantum information processing—sources, detectors, and storage—will open new vistas for ultraprecise, high-speed quantum communications and serve as enabling technologies for optical quantum computing.

* Denotes principal investigator.
Ultrasonic Analog for a Random Laser
R. L. Weaver,* O. Lobkis,
A. Yamilov (Univ. of Missouri)
http://www.physics.uiuc.edu/people/WeaverR/
r-weaver@uiuc.edu
University of Illinois

Auto-oscillating and spontaneously emitting piezoelectric
devices are found to emit more energetically when
stimulated by an incident wavefield. Emission is at the
same frequency as the stimulating field, and with a phase
relation corresponding to super radiance. We observe
narrow single emission lines, sensitivity to linear cavity
properties, complex multimode emissions, and line
narrowing. Line widths are narrower than we can measure,
with theoretical Schawlow–Townes widths as low as 10-9
Hz. Systems of several such oscillators self-organize into
a coherent state with power emission that rises faster than
the first power of the number of oscillators. More recently,
the system has been realized at audible frequencies using
unbalanced DC motors on a flexible elastic plate.

Complex Systems

Geobiology and the Emergence of Terraced
Architecture during Carbonate Mineralization
B. Fouke* (Geol.), N. Goldenfeld,*
A. Murray* (Desert Research Institute, Univ. of Nevada)
National Science Foundation, EAR 02-21743

The goal of this project is to determine how the biodiversity
and activity of specific living microbes and/or microbial
communities are required to create the terraced
architectures universally observed in high-temperature and
low-temperature carbonate spring deposits. Results will
provide a fundamental knowledge of microbe-water-
mineral interactions during carbonate precipitation that are
needed to more accurately reconstruct the history of
microbial life on earth and other planets.

Experimental Study of Adaptation to the Edge of Chaos
and Critical Scaling in the Self-Adjusting Peroxidase-
Oxidase Reaction
A. Hubler*
a-hubler@uiuc.edu
National Science Foundation, PHY 01-40179

We are studying a model for self-adjusting dynamical
systems that treats the control parameters as slowly
varying, rather than constant. The dynamics of these
parameters are assumed to be governed by some low-pass
filtered feedback from the dynamical variables of the
system. Under the influence of noise, at least in numerical
models, the probability of chaotic breakout shows a
universal scaling with the duration of the breakouts. We
are applying the model to biochemical oscillators as the
simplest possible adaptive system relevant to
environmental dynamics. The system we are investigating,
the peroxidase-oxidase oscillator, exhibits nonlinear,
complex, and even chaotic behavior, yet it is simple enough
that meaningful measurements can be made and
quantitative models can be evaluated.

Modeling and Prediction of the Growth of Fractal
Networks with Graph Theoretical Methods
A. Hubler*
National Science Foundation, DMS 03-25939 ITR

In cooperation with the Materials Computation Center

Currently, no known model describes the dynamics of the
observables during the growth of the fractal network.
However, some preliminary studies suggest that a
minimum spanning tree growth model might be able to
reproduce the dynamics of all observables. In addition to
such graph theoretical models, the underlying physical
equations will be used to describe certain aspects of the
pattern formation. Eventually, this may lead to merging the
graph theoretical and physical models. This system has a
large number of stable attractors. We will explore
regularities in the attractor structure.

Prediction and Control of Chaos
A. Hubler*
National Science Foundation, DMS 03-25939 ITR

In cooperation with the Materials Computation Center

We study prediction of high-dimensional time continuous
systems with low-dimensional time discrete models. For
instance, if the equation of motion for the center of mass
of a physical pendulum is discretized with Euler's method,
the dynamics can be chaotic due to numerical instabilities.
Preliminary studies suggest that this type of chaos can be
found in the experiment, if the time step of the
discretization matches the period of the leading vibrational
mode of the object. Thus, the discrete version of the
equation of motion for the center of mass describes more
features of the dynamics than the time continuous version.

Resonance Spectroscopy with Chaotic Forcing
Functions
A. Hubler,* K. Dahmen*
National Science Foundation, DMS 03-25939 ITR

In cooperation with the Materials Computation Center

This work explores the final response of multidimensional
chaotic map dynamics to additive aperiodic forcing

* Denotes principal investigator.
functions with equal variance. The forcing function, which produces the largest response, is called resonant forcing function. The same approach will be used to determine resonant forcing function of time continuous systems, such as the Lorenz attractor. For physical systems, such as a chaotic coupled pendulum dynamics, we anticipate that the conserved quantity has a physical meaning. It is probably equal or related to the reaction power. In addition, we will explore resonances of real nonlinear oscillators with a bidirectional instantaneous coupling with virtual systems.

**Energy Flow in Complex Elastodynamic Structures**
R. L. Weaver,* O. Lobkis, N. Wolff

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*National Science Foundation CMS 05-28096, with supplements from NSF IREE and NSF REU*

Numerical simulations, analytic theory, and laboratory measurements are used to study the statistics of linear waves in complex systems. Particular attention is paid to wave energy density (or probability for quantum waves), and its mean flow and fluctuations. We seek methods to predict mean flow and fluctuations over long times, based on information in ray optics or direct numerical simulations over short times.

**Cosmology**

**Laboratory for Cosmological Data Mining**
R. Brunner (Astron.),* B. Wandelt*
bwandelt@uiuc.edu

*National Science Foundation National Resource Allocations Committee (NRAC)*

*In cooperation with NCSA and TeraGrid*

To tackle the challenges of cosmology, different approaches have been developed, including measuring the cosmic microwave background (CMB) radiation, studying galaxy clusters, and understanding quasars (supermassive black holes) and their relation to large-scale structure in the universe. All of these approaches, however, require the cosmological interpretation of astronomical datasets. The challenge is to read the cosmologically significant signatures in highly dimensional and complex data. These types of analyses require the development and application of new computational tools. The project "Laboratory for Cosmological Data Mining," one of the top 20 supercomputing allocations of the TeraGrid, has been granted very large supercomputing resources to address fundamental problems in the cosmological interpretation of astronomical data and to use them to extract cosmological information from existing data sets.

**Cosmic Beginnings and Cosmic Fate**
B. D. Wandelt*
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*National Science Foundation, AST 07-08849*

This project presents a broad and ambitious program of research and education entitled "Cosmic beginnings and cosmic fate." My research plan focuses on two challenges that arise in the era of precision cosmology. They are the quests to determine the initial conditions of the universe and to discover the physical properties of dark energy. The proposal shows how new statistical techniques for Bayesian covariance analysis can take full advantage of the information contained in the cosmic microwave background and other cosmological probes. The application of these techniques will bring us closer to an understanding of the initial conditions of the cosmos and of the physical properties of the dark energy.

**MSPA: Bayesian Cosmostatistics**
B. Wandelt*
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*National Science Foundation, AST 05-07676*

This project is aimed at developing groundbreaking tools for the statistical analysis of large data sets. The idea is to build a lossless, yet feasible way to link raw data to the underlying cosmologically and astrophysically important information. This information will be represented in an easily communicable form, accessible to all. Ultimately, information from complementary data sets will be combined in a meta-analysis that tests the current standard paradigm of cosmology. Although the particular focus is on cosmic microwave background (CMB) data sets, the range of possible applications is much broader and, among others, includes data analysis of gravitational lensing data and large-scale structure. As WMAP produces yearly releases of new data, the Planck satellite launches in 2007, the South Pole Telescope comes online, and other cosmological data become available, this program of research should enable currently unimaginable analyses, provide the ultimate resource of cosmological knowledge, and reveal the information that will drive the next paradigm shift in cosmology.
Parallel Algorithms for Cosmological Statistics at NCSA
B. Wandelt*
bwandelt@uiuc.edu
University of Illinois

In cooperation with the Department of Astronomy

The goal of this project is to take advantage of the opportunities afforded by the availability of cosmic microwave background (CMB) data. The project will build on preparatory work completed by students and a postdoc working with B. Wandelt over the past year and combine their expertise in cosmology with the computing excellence and facilities at NCSA. This project will demonstrate that this combination of assets will enable us to overcome challenges that currently prevent the application of more sophisticated methods to CMB data sets and allow us to build production quality parallel implementations of our advanced computational methods. We will apply them to forthcoming annual releases of the WMAP data set. As a result, these codes will be uniquely capable of handling the complexities of future CMB data sets, promising an enduring role for NCSA at this fast-moving frontier of cosmology.

Planck Core Science Program
B. Wandelt*
bwandelt@uiuc.edu
SBC NASA, JPL 1236748

The Planck mission is a joint ESA/NASA mission to produce the definitive maps of the cosmic microwave background. The CMB is relic radiation from the Big Bang. B. Wandelt leads the harmonic analysis subtopic within the power spectrum estimation working group. We are developing new statistical, mathematical, and computation tools to extract the cosmological information in the Planck data when it will be available after launch (projected 2008).

Probing for New Physics in Cosmological Data
B. D. Wandelt*
bwandelt@uiuc.edu
Center of Advanced Studies Beckman Fellowship, University of Illinois

The aim of this project is to link astronomically observable phenomena with physics at the highest energy scales, relevant to the processes that acted during the earliest moments of time (the Big Bang). These phenomena include views of the early universe afforded by the latest maps of the cosmic microwave background, as well as the observed properties of dark matter and dark energy. An active member in the Planck satellite mission, B. Wandelt has invented sophisticated statistical and mathematical tools that allow the physical interpretation of cosmic microwave background data. During his Center appointment, Wandelt developed novel statistical tests based on mapped fluctuations in the cosmic microwave background sky and probe for new physics beyond the paradigm of cosmology. He combined information from a broad range of complementary cosmological observations, such as the large-scale distribution of galaxies, the primordial abundances of the light elements, the spectra of quasars, and cosmic expansion and acceleration.

Experimental Biological and Biomolecular Physics

A Microsecond Mixer for Measuring Chemical Kinetics
R. Clegg, Z. Majumdar
National Science Foundation, DBI 02-52678

The topic of this research is the development of an improved, practical, easy to use, micro-fluidic, turbulent rapid mixer, capable of completely mixing two liquid solutions within microseconds and routine kinetic measurements. The significance and potential applications of this novel development are great as the present times for mixing two fluids completely is about 1 millisecond. The present instrument is being constructed with MEMS technology using the extensive microfabrication facilities available to us, and has a 100% mixing time in 10 microseconds. We will decrease this time by one order of magnitude and incorporate critical optical and microfluid handling features to improve the performance and reliability of the measurements.

Structural, Functional, and Integration Studies of Biocatalysts for Development of Solar Driven, Bio-Hybrid, H2-Production Systems
M. Ghirardi* (NREL), K. J. Schulten*
U.S. Department of Energy, NREL XEA-6-55419-01

In cooperation with the National Renewable Energy Laboratory

This research is focused on developing clean and efficient renewable means for hydrogen (H2) production by engineering biocatalysts, integrating them into state-of-the-art photochemical cells, and creating bio-hybrid, H2-production systems. The project is a collaboration between experimental and theoretical labs.

* Denotes principal investigator.
Information Processing in Living Cells: Beyond First Approximations
I. Golding*
University of Illinois, Department of Physics

Living systems have become a major area of research for physicists. In my lab, we attempt to better understand the way individual bacterial cells represent and process information from the environment through the activity of their genes. The work employs a set of skills broader than those generally mastered within a single discipline, including the techniques of microbiology and molecular genetics, real-time imaging of live cells to make dynamic measurements, and data analysis using the engineer’s toolbox of signal and image processing, all accompanied by the theoretical tools of dynamical systems theory, stochastic processes, nonequilibrium phenomena and more. As such, this practice of modern in vivo biology, combined with the high intellectual effort of a quantitative approach, will contribute significantly to a young scientist’s training experience, better preparing them for the future world of "Systems Biology."

CAREER: Advanced Single Molecule Techniques on DNA-Protein Interactions
T. Ha*
National Science Foundation, PHY 01-34916

The scientific component of this project focuses on the development and utilization of advanced single-molecule techniques to study the fundamentals of DNA-protein interactions. In this work, single molecule fluorescence detection and spectroscopy will be combined with nanomechanical manipulations, biofriendly surface engineering, and site-directed mutagenesis to construct suitable DNA structures and engineered proteins and to study their dynamic interactions at the single molecule level. The educational component of the project focuses on the expansion of the physics undergraduate program through a course that will introduce students in physics, chemistry, bioengineering, and biology to both traditional and modern techniques in biophysics.

High Resolution Single Molecule Study of RecA
T. Ha*
http://bio.physics.uiuc.edu/
National Science Foundation, PHY 06-46550

This is a study of the mechanism of DNA recombination protein called RecA, using newly developed physical tools including single molecule fluorescence and manipulation. Research will be performed by graduate and undergraduate students, and we will train the new generation of young scientists in physics and in biology. We propose to develop single molecule assays to probe the homology search, homologous pairing, and strand exchange reactions by RecA. These assays include single molecule 2-color and 3-color fluorescence resonance energy transfer on fluorescently labeled oligonucleotides and mechanical manipulation and fluorescence imaging of kilobase length DNA. The approaches are general and will be used to study the less understood relatives, Rad51 in Eukaryotes and RadA in Archaea. We will also probe the dynamic nature of the RecA filament on single stranded DNA as a function of sequence, pH, and ATP concentration.

Mechanism of Cohesion and Related SMC Complexes in Chromosomal Biology
T. Ha,* K.-P. Hopfner (Univ. of Munich), F. Uhlmann (Lincoln’s Inn Fields Lab, London)
http://bio.physics.uiuc.edu/
Human Frontier Science Collaborative Grant, HFSP RGY76-2005

The goal is to understand the ATP dependent mechanism of SMC proteins using the combination of crystallography, genetics, live cell imaging, and single molecule biophysics.

Porous Biomimetic Nanocontainers
T. Ha,* J. Yody, H. Balci
http://bio.physics.uiuc.edu/
National Institutes of Health, PHS 1 R21 GM074526

This project encapsulates biological macromolecules inside porous nanoscale (30-100 nm diameter) phospholipids vesicles. Pores will be formed by Staphylococcal toxin alpha-hemolysin. These ultrasmall, biocompatible containers allow passage of small molecules, such as ATP and magnesium ions, while limiting diffusional motion of macromolecules inside the zeptoliters volume, thereby enabling new types of biophysical analysis at single-molecule level. While the method keeps molecules essentially free of surface artifacts, vesicles can be tethered to a supported bilayer so single molecule reactions can be observed for seconds or even minutes. We will use well-characterized systems, such as the hairpin ribozyme and Holliday junction, to probe the pore formation process.

This technique has the potential of transforming the way single-molecule fluorescence measurements are performed in many laboratories around the world. Furthermore we will use these techniques to make new biological discoveries on the activities of RNA enzymes and helicases.

* Denotes principal investigator.
Single Molecule Study of Helicase Mechanisms
T. Ha,* S. Myong, C. Joo, R. Roy, S. Kim
http://bio.physics.uiuc.edu/
National Institutes of Health, PHS 5 R01 GM65367-02

We study conformational changes of DNA helicases and functions using novel fluorescence assays. Specific helicases are from the SF1 helicase family that includes *E. coli* Rep and UvrD helicases. We will answer many fundamental questions, including: Is oligomerization of helicase necessary for DNA unwinding and, if so, why? How many base pairs are unwound per biochemical cycle? What are the functional roles of helicase conformational change? What is the origin for directionality of DNA unwinding? To achieve these goals, we will use both ensemble and single molecule measurements of dyes attached to various sites on DNA and helicase.

Single-Molecule Studies of Genomic Maintenance
T. Ha*
http://www.hhmi.org/research/investigators/ha.html
Howard Hughes Medical Institute

We use sophisticated physical techniques to manipulate and visualize the movements of single molecules to understand basic biological processes involving DNA and other molecules. The goal is to develop new experimental and analytical tools to study the mechanism of genomic maintenance at the single molecule level.

My lab develops single-molecule techniques to study the molecules that are important in maintaining the stability of the genome and in preventing serious threats to human health, such as cancer.

Biophotonics: Next Generation of Ultrabright Nonorganic Markers for Ultrasensitive Fluorescent Biosensors
M. Nayfeh,* E. Gratton,* P. Selvin*
National Science Foundation, BES 01-18053

The objective of this research is to develop biophotonic markers for fluorescent biosensors that are smaller, brighter, less fragile, and more practical than existing markers. The specific components of this research include: an examination of the time dynamics of emission, photostability, and bleaching under a variety of incident excitation intensities, in the UV, visible, and near-infrared range of frequencies; an examination of the solubility of particles and their integrity of brightness under diverse environmental conditions, such as those encountered *in vivo*; development of cladding methods to improve biocompatibility; development of methods to refine synthesis and scale the throughput to meet high-demand commercial applications; and examination of the feasibility of modifying the particles by attaching additional molecules to their surfaces to produce "smart" particles that are able to seek out specific biological targets for imaging, targeted drug delivery, or destruction of a pathogenic invader.

Second Harmonic Imaging of Cells Using Silicon Nanoparticles
M. H. Nayfeh,* L. Abuhassan
National Science Foundation; U.S.–Jordan Cooperative Research 03-23307

The project focuses on the development of new methods for synthesis of silicon nanoparticles, studies that allow better understanding of the semiconductor nature of the silicon nanoparticles, and their interface with biology. Moreover, the project focuses on developing procedures for depositing thin films of the particles on cells to allow fluorescent or harmonic imaging of cells.

Advanced Fluorescence Energy Transfer on Actomyosin
P. Selvin,* J. Reifenberger
National Institutes of Health, PHS 2 R01 AR44420, 8/01-7/06

The focus of this project is to study the conformational changes within the actomyosin complex using fluorescence resonance energy transfer (FRET) combined with genetically engineered "cysteine-light" myosins. FRET provides us with the ability to measure structures within proteins on the 20–100 Ångstrom distance scale while the mutated myosins allow us to label the protein at very specific sites with our dyes. We use FRET to study the different states of smooth muscle myosin and myosin VI (which actually walks backwards on actin) as they interact with actin during the ATPase cycle.

CAREER: Conformational Changes in Voltage-Controlled Ion Channels Measured by Advanced Fluorescence Techniques
P. Selvin*
National Science Foundation, MCB 99-84841

This research project is an interdisciplinary plan involving physics, chemistry, and biology. Fluorescence techniques will be used to study conformational changes in ion channels that are responsible for nerve conduction. The principle technique, called luminescence resonance energy transfer, measures distances between two points on the ion channel with angstrom precision. The mechanism by which channels open and close in response to membrane voltage changes will be elucidated. Initial results are...
beginning to distinguish between models of how voltage sensing works. Specifically, the voltage sensing protein segment does not undergo a large translation, but likely translates and/or rotates a small amount.

**Genetically Targetable Labels for Light & EN**  
P. R. Selvin,* R. Tsien,* (Univ. of California-San Diego)  
*National Institutes of Health, PHS Sub UCSD PO 10249294  

*In cooperation with the University of California-San Diego*  

Goals of this research include development of new GFP-like fluorophores.

**Nanometric Fluorescence Imaging of Single Motor Proteins**  
P. Selvin,* J. Reifenberger  
*National Institutes of Health, 1R01 GM068625-01A1*  

Kinesin and the unconventional myosins V and VI are molecular motors responsible for the transport of organelles within a living cell. By attaching a fluorophore to the motor protein we are able to track the dye with 1.5-nm spatial resolution and 0.5-s time resolution, and thereby determine if these molecular motors walk along their respective track using a “hand-over-hand” technique or an “inchworm” method. Using this technique, we have shown Myosin V moves in a hand-over-hand mechanism (Yildiz et al., Science, 2003).

**Turning On and Off Voltage-Gated Ion Channels: Is the On–Off Switch a Plunger, Rotating Knob, or Corkscrew?**  
P. Selvin,* D. Posson  
**Research Corp, CS0706, Cottrell Scholars Fund,**  

A particularly important class of ion channels are opened and closed by changes in voltage across the membrane. Despite decades of effort, how voltage opens and closes these channels is poorly understood. A highly charged segment of protein called S4 acts as a voltage-sensor, most likely moving when the membrane voltage changes. We directly measure this movement with a fluorescence technique called luminescence resonance energy transfer, which is sensitive to angstrom level changes in protein structure. In this way, we can understand whether S4 translates a lot or a little and whether rotations are involved.

**NIRT: Single Molecule Detection in Living Cells using Carbon Nanotube Optical Probes**  
M. Strano (Chem. Biomol. Engr.), T. Ha,* K. J. Schulten  
*National Science Foundation 07-08459*  

The goal of this project is to investigate and utilize optical transduction mechanisms at the single nanotube level.

Researchers will develop design rules for macromolecular assembly onto carbon nanotubes by calculating intermolecular potential functions and simulating optical properties. Kinetic theory and molecular modeling will assist our project in optimizing the strategies for SWNT coating, cellular uptake, and signal enhancement. Theory and modeling will be integrated into the entire development effort, providing guidance for selection of biomolecules chosen for coating, explaining the mechanism of nanotube internalization and trafficking, and furnishing the quantum mechanical theory for nanotube optical spectra and their interpretation in terms of nanotube-adsorbate interactions.

**Sequencing a DNA Molecule Using a Synthetic Nanopore**  
G. L. Timp,* J-P. Leburton (Elect. & Comput. Engr.); A. Aksimentiev, K. J. Schulten, S. Sligar (Biochem.)  
*National Institutes of Health, R01 HG003713*  

*In collaboration with Beckman Institute for Advanced Science and Technology*  

This project explores the feasibility of sequencing a DNA molecule using a revolutionary type of silicon integrated circuit that incorporates a nanopore mechanism with a molecular trap through a combination of experimental and theoretical approaches.

Fast and affordable technology for sequencing DNA has the potential to revolutionize medicine by providing a means for accurate diagnostics of about 6,000 genetic and multifactorial diseases, and for tailoring drugs and treatments to the person's genetic makeup.

**Experimental Condensed Matter Physics**  

**Competing Ground States in Transition Metal Oxides**  
P. M. Abbamonte*  
*U.S. Department of Energy, DEFG02-91ER45439*  

*In cooperation with the Frederick Seitz Materials Research Laboratory*  

The goal of this project is to determine the degree to which the electronic degrees of freedom in highly correlated materials self-organize and form inhomogeneous ground states. Of particular interest are Wigner crystallization and the so-called "stripe phase" reputed to occur in insulating materials closely related to the high temperature superconductors. This project is based on resonant soft
Interface and Edge Effects in Oxide Devices
P. M. Abbamonte*
U.S. Department of Energy, DEFG02-91ER45439
In cooperation with the Frederick Seitz Materials Research Laboratory

This project is focused on investigating interface effects in artificial transition metal oxide structures fabricated with molecular beam epitaxy and electron beam lithography techniques. Of particular interest is the electronic reconstruction at interfaces between dissimilar correlated materials, such as exist in copper- or manganese-oxide superlattices, and the possibility of edge-induced ordering in oxide quantum wires and quantum dots. These systems are studied with resonant soft x-ray scattering, which is highly sensitive to electronic effects at interfaces.

Nonlocal Screening and Attosecond Phenomena
P. M. Abbamonte*
U.S. Department of Energy, DEFG02-91ER45439
In cooperation with the Frederick Seitz Materials Research Laboratory

This project is focused on imaging quantum mechanical processes in condensed matter by applying analytic phase inversion techniques to data from inelastic x-ray scattering experiments. Currently, we are trying to image the formation of excitons from delocalized electron-hole pairs, their dressing by optical phonons, and the formation of F centers in simple salts like LiF. We are also studying antiscreening in low-dimensional systems and ion solvation processes in liquid water.

Nanopore Devices for Manipulation and Characterization of Single Molecules
A. Bezryadin*
bezryadi@uiuc.edu
Beckman Institute for Advanced Science and Technology

Many important biological molecules, such as DNA and proteins, can be pushed by an electric field applied to a solution containing these biomolecules. In particular, some molecules can be forced to pass through an extremely small hole in an impenetrable membrane. We employ this phenomenon to characterize different properties of the molecule, e.g., the sequence of the DNA. We have developed methods that allow us to fabricate membranes having nanopores comparable in size to the diameter of the DNA or other molecules.

Quantum Properties of Ultrasmall Homogeneous Superconducting Nanostructures
A. Bezryadin*
bezryadi@uiuc.edu
U.S. Department of Energy, DEFG02-07ER46453

This project is focused on fundamental problems of phase coherence in quasi-one-dimensional superconducting systems. A novel nanofabrication method developed by the researcher is used to investigate fundamental properties of ultrasmall superconductors. By depositing various metals on single-wall carbon nanotubes, nanowires as thin as 5 nm in diameter are created. The following basic problems are being studied: the interplay between the fermionic and bosonic mechanisms of superconductivity suppression in one dimension; the effects of a "dissipative" environment on quantum superconductor-insulator transitions; and macroscopic quantum effects in homogeneous superconducting nanostructures. A focused electron beam is applied locally and allows us to modify the crystal structure and the shape of the wire. We study the superconductor-insulator transition in ultrathin wires (~5-15 nm) and the effect of quantum interference in devices composed of two or many parallel nanowires. A detailed theoretical description is under development for such molecular scale superconducting structures.

Small superconducting devices allow us to test fundamental laws of quantum mechanics, in particular the question of whether QM applies to a macroscopic object or not. These questions are of great importance in such areas as quantum computation.

Ultrasmall Superconducting Systems and Devices
A. Bezryadin*
U.S. Department of Energy, DEFG02-91ER45439
In cooperation with the Frederick Seitz Materials Research Laboratory

We study novel electronic devices produced by molecular templates. This includes a novel type of superconducting quantum interferometers, produced with DNA molecules acting as templates. The observed quantum oscillation is useful in detecting hidden characteristics of superconductors, such as phase gradients. We also study the role of spins in determining the behavior of nanoscale superconducting devices. Our recent work indicates that the majority of superconducting nanodevices depends on the presence of local magnetic moments on the surface of these systems. One goal is the development of new tools for fabricating systems with a feature size of about 2 nm. Some promising results are obtained when a focused electron beam is applied to nanowires.

* Denotes principal investigator.
Controlling Spins with Real-Time Feedback
R. Budakian*
http://www.physics.uiuc.edu/people/Budakian/
U.S. Department of Energy, DEFG02-91ER45439

In addition to ultrasensitive spin detection, Magnetic Resonance Force Microscopy (MRFM) is also yielding schemes for coherence-preserving preparation, control, and read-out of the quantum states of spin systems. As such, it has considerable potential in the field of quantum information processing. Recently, we have demonstrated a spin manipulation protocol whereby the naturally occurring statistical fluctuations can be controlled in real time. Through active feedback, spin order was created that could be captured, stored, and later read out. The goal of this research is to enhance the detection sensitivity to allow direct feedback control on single electron spins.

Force Detected Electron Nuclear Double Resonance (FD-ENDOR)
R. Budakian*
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U.S. Department of Energy, DEFG02-91ER45439

Direct detection of nuclear spins requires roughly a factor of 1,000 higher force sensitivity than electron spin detection, due to the smaller magnetic moment of the nucleus. In ENDOR spectroscopy, the hyperfine coupling between the electron and nuclear spin is exploited to indirectly infer the state of the nuclear spin through its influence on the electron spin resonance. In molecules having large hyperfine coupling, ENDOR—MRFM could be used to significantly enhance detection sensitivity of nuclear spins. The goal would be to introduce electron spins into complex molecules using site directed spin labels and image the local nuclear spin structure through ENDOR.

Investigating Unconventional Superconductivity
R. Budakian,* D. J. Van Harlingen*
U.S. Department of Energy, DEFG02-91ER45439

Understanding the microscopic interactions that give rise to Cooper pairs is a crucial piece of the puzzle in discovering the mechanism responsible for superconductivity. Recently, strong experimental evidence has appeared to support the claim that Sr$_2$RuO$_4$ is a p-wave superconductor that breaks time reversal symmetry, a consequence of which would be the existence of persistent currents. We are developing a scanning SQUID microscope operating inside a dilution refrigerator with an integrated optical scanner. This device will be used to directly image the chiral currents thought to exist in unconventional superconductors.

Probing Quantum Coupling between Superconductors and Magnetic Nanoparticles
R. Budakian*
U.S. Department of Energy, DEFG02-91ER45439; National Science Foundation

The ability to reliably control and interact with quantum systems is of central importance to quantum information processing and quantum computation. One of our current projects seeks to manipulate the quantum state of nanometer size magnetic particles by coupling them to superconductors. It is expected that the interaction of the particle with the superconductor lowers the barrier for the macroscopic moment of the particle to tunnel. Using scanned probe techniques, our experiments seek to understand the quantum interaction between magnetic nanoparticles and nanometer scale superconducting islands.

Study of Mechanical Properties of Silicon Nanowires
R. Budakian,* L. Lauhon
University of Illinois

Theoretically, the force sensitivity of a cantilever scales inversely with its cross-sectional dimensions. Through a collaboration with Professor Lincoln Lauhon (Department of Materials Science and Engineering, Northwestern University), we are exploring using 10–20-nm diameter single-crystal silicon nanowires as cantilevers for MRFM. Professor Lauhon can furnish high-quality nanowires having epitaxial attachment to the substrate. Such nanowire cantilevers could potentially possess a force sensitivity in the 10–100 zeptonewton (10–21 N) range, a factor of 10–100 improvement over existing cantilevers. We are currently designing the first set of experiments to characterize the mechanical properties of the nanowires.

Ultrasensitive Cantilevers for Single Nuclear Spin Detection
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Army OSU 60005852/RF01038633

Chris Hammel, Ohio State University, Department of Physics

Ultra-sensitive cantilevers having sub-attonewton force sensitivity will be required to achieve single nuclear spin detection, as well as for rapid imaging and state detection of electron spins. These cantilevers have submicron features that makes optical detection challenging. In addition, optical detection does not permit operation at ultralow temperatures necessary for high force sensitivity. We will fabricate cantilevers with integrated

* Denotes principal investigator.
superconducting structures for high sensitivity displacement detection using dc SQUID (superconducting quantum interference device) magnetometry. This new technique overcomes the size restrictions of optical detection and should enable ultralow temperature operation.

**Electronic and Atomistic Effects in Quantum Structures**

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*National Science Foundation, DMR 05-03323*

*In cooperation with the Synchrotron Radiation Center, Stoughton, Wisconsin, and the Argonne National Laboratory*

This project examines the electronic structure of selected low-dimensional systems including atomically uniform films. The experimental work involves mapping, by angle-resolved photoemission, of the spectral weight function within the valence bandwidth and over the entire surface Brillouin zone. Of special interest are novel electronic states derived from multiple scattering at surfaces and interfaces, and effects of hybridization interaction and coherent coupling across boundaries.

**Quantum Physics of Surface-Based Nanoscale Systems**

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*U.S. Department of Energy, DE-FG02-07ER46383*

*In cooperation with the Frederick Seitz Materials Research Laboratory; Synchrotron Radiation Center, Stoughton, Wisconsin; and Argonne National Laboratory*

This project examines the effects of geometric confinement of electrons and symmetry reduction in metallic nanoscale and low-dimensional systems. These effects may lead to interesting and useful properties that are markedly different from their bulk counterparts. Systems under investigation include surfaces, thin films, and self-organized surface structures made of metals, semiconductors, and complex materials. Of special interest are quantum variations in properties as a function of system size, shape, chemical composition, and boundary conditions. The experiments include angle-resolved photoemission at the Synchrotron Radiation Center in Stoughton, Wisconsin, and x-ray scattering at the Advanced Photon Source, Argonne National Laboratory.

**Quantum Size Effects in Nanoscale Systems**

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*Petroleum Research Fund, American Chemical Society*

Recent advances in crystal growth have made it possible to prepare atomically uniform films. Electrons in such films form discrete quantum well states or sub-bands, which are probed by angle-resolved photoemission. Our goal is to understand the kinetics, energetics, and atomic processes involved in the formation of such films and the relationships between the quantum electronic structure and physical properties. The knowledge is then extended to studies of novel nanostructures that form spontaneously during deposition or annealing.

**Exploring Charge- and Spin-Organization in Magnetic Semiconductors and Other Complex Materials**

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*National Science Foundation, DMR02-44502*

The goal of this program is to use various optical spectroscopies to elucidate the exotic phenomena and diverse phase transitions of complex magnetic systems, particularly magnetic semiconductors such as EuO, EuB6, and GaMnAs. We are particularly interested in investigating self-organization of spins that give rise to "colossal" behavior, such as colossal magnetoresistance. Clarifying this behavior is key to elucidating the complex physics of these systems, as well as to exploring the potential utility of these magnetic systems as "functional materials."

**Optical Spectroscopic Studies of Quantum Phase Transitions in Highly Tunable Materials**

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Some of the most scientifically interesting and technologically promising phenomena, such as spontaneous organization of charge, spin, and orbital structures, and "colossal" sensitivities of properties to external parameters, occur near low temperature phase boundaries. This research program employs pressure- and field-tuned inelastic light scattering to spectroscopically study the evolution of spin, charge, and lattice dynamics of different correlated systems while pressure- and/or field-
tuning the material through low temperature (quantum) phase transformations.

The principal focus of this program is to elucidate: quantum phase transitions in charge- and orbital-ordering systems; quantum "melting" of charge density wave phases into metallic and superconducting phases of layered dichalcogenides; and the relationship between strong correlations and nanoscale and/or interfacial structure. A new facet of this project involves the growth of "highly tunable" single crystals using floating-zone and other methods.

**Digital Synthesis**

J. N. Eckstein*

*U.S. Department of Energy, Argonne National Lab

*In cooperation with the Argonne National Lab

Digital synthesis is the accurate assembly of clean samples by independently specifying the composition of each atomic layer. We investigate how new collective states emerge at the interface between two parent materials. We also use the properties of one material in a multilayer stack to modify the properties of another material. This includes modifying the global quantum mechanical wavefunction of samples involving competing order.

**Meta-Materials Made Using Oxide Molecular Beam Epitaxy**

J. N. Eckstein*

*U.S. Department of Energy

*In cooperation with the Frederick Seitz Materials Research Laboratory

By accurately combining oxide “building blocks” we can create new super-molecular structures that have new electronic properties. We use molecular beam epitaxy to do this work. These films exhibit new band structure and optical transitions. The new optical properties are being investigated for possible application in photocatalytic materials. The emergence of collective order driven by electron-electron interactions can also be programmed or suppressed by the nanoscale material design. This is a particularly exciting research direction, since ordered phases such as superconductivity, magnetism, charge, and orbital ordering all occur in oxide phases, driven by the complex electronic structure that transition metal oxide components have. By extending the stage from naturally occurring phases to artificial meta-materials, we are aiming at creating new ordered phenomena, perhaps with unique and more superlative properties.

**Growth and Properties of Single-Crystal Films**

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*U.S. Department of Energy, LEEM, DEFG02-91ER45439

*In cooperation with the Frederick Seitz Materials Research Laboratory

The growth processes of single-crystal films prepared by MBE are investigated with a view to applications in rare earth magnetism, surface science, atomic mobility in materials, and the evolution of materials in radiation fields. A specific synthesis route starting with commercial sapphire buffered by bcc refractory metals is being explored. This research uses a low-energy electron microscope (LEEM). It permits exploration of surface morphology and reconstruction during actual growth and under conditions of ultrahigh vacuum at temperatures up to 1400°C. Through diffraction and imaging, the evolution of surface morphology (including reconstructions, surface steps, slip bands, and threading dislocations) and bulk morphology (including screw, edge, and interfacial dislocations and subboundaries) can be examined in real time and during actual growth.

**NMR Studies of Organic Conductors**

R. Giannetta,* C. P. Slichter*

*University of Illinois Critical Research Initiative (CRI)

*In collaboration with Argonne National Laboratory

This project will focus on the evolution from magnetism to superconductivity in organic superconductors. Nuclear magnetic resonance (NMR) will be used to explore these materials at low temperatures and at pressures up to several kbar. A particular focus will be the search for evidence of a quantum spin liquid, a unique type of magnetic phase. At higher pressures we will use NMR to study the kind of superconductivity that emerges.

**Penetration Depth in Organic Superconductors**

R. W. Giannetta*

*National Science Foundation, DMR 05-03882

Organic conductors are synthetic metals composed of regular arrangements of complex, carbon-based molecules. By changing temperature and pressure they can be transformed into insulators, magnets, superconductors and other new states of matter. This project focuses on superconductivity in these materials. High-resolution magnetic penetration depth measurements will be used to study how organic superconductivity evolves from antiferromagnetism and other kinds of microscopic ordering.

* Denotes principal investigator.
Properties of Simple Liquids and Glasses
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National Science Foundation, DMR 01-38488

Critical tests of the interstitialcy theory of condensed matter states are being made by measuring the temperature dependence of the elastic constants of crystals just below the melting temperature in the crystalline state and just above the glass temperature in the supercooled liquid state. Observation of predicted results would confirm a simple, quantitative, easily visualized model according to which simple liquids are crystals containing a few percent of self-interstitials in thermal equilibrium, and glasses are frozen liquids.

The Kinetics of Structural Relaxation and Plastic Deformation of Bulk Metallic Glasses
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U.S. Civilian Research and Development Foundation, CRDF RPI 2320-V0-02

Investigations are conducted to give new information about the degree of metastability, kinetics of structural relaxation, "defect structures," plastic deformation, and related mechanical properties of bulk metallic glasses. These materials have high strength, and can be poured into molds with final shape, without environmental waste.

Quantum Mechanics on a Macroscopic Level
National Science Foundation, DMR 07-06013

Our experimental condensed matter physics group studies quantum mechanics on a macroscopic level in materials that are "strongly correlated electron systems." In particular, we investigate the mechanisms of unconventional superconductivity by planar tunneling and point-contact Andreev reflection (PCAR) spectroscopies. These measurements are used to map out the electronic structure of high-temperature, heavy-fermion, borocarbide, and other unconventional superconductors. Recent work using PCAR in heavy-fermion superconductors has revealed exciting competition between antiferromagnetic and superconducting phases. The superconducting order parameter symmetry is also determined by this technique in novel superconductors. Finally, our measurements show that theories beyond those existing are needed to describe the Andreev process at the heavy fermion superconducting interface.

Dissipation in Nanostructured Superconductors
N. Mason*
http://www.physics.uiuc.edu/people/Mason/
University of Illinois Research Board, 06036

The primary aim of this research is to better understand the effect of dissipation on superconductors. Dissipative, or “lossy,” processes are particularly harmful for quantum phenomena such as superconductivity because they cause a loss of quantum coherence. The experiment involves creating nanostructured superconducting model systems, composed of two-dimensional nanoscale patterns of normal metals and superconductors. Parameters relevant to dissipation (such as pattern sizes and shapes) will be controllably varied, and collective phenomena, the development of long-range superconducting order, and quantum phase transitions in the system will be studied.

Materials Science
N. Mason*
U.S. Department of Energy, DEFG02-91ER45439
In cooperation with the Frederick Seitz Materials Research Laboratory

We are taking advantage of modern fabrication techniques to make a variety of nanostructures, such as quantum dots and wires, as well as arrays of superconducting dots. Our aim is to investigate effects of electron-electron interactions, disorder, dissipation, decoherence, and sample-geometry in these structures. Work on carbon nanotubes and graphene includes measurements of spin injection, superconducting proximity effects, and Luttinger-liquid effects.

Nayfeh-Montgomery Asset Management Sponsored Research Agreement
M. H. Nayfeh*
Sungen Energy 2006-07234

We examine the nature of the interface between silicon nanoparticles and metal. The work aims at homing in on metal (workfunction) versus nanoparticle size/bandgap to produce appropriate Shottky barrier diode-like rectification for photo-induced charge separation and collection. One application of this project is to sandwich the silicon nanosolid between two metal films and integrate on glass substrates. With appropriate connections, this may act as a nanosilicon photovoltaic solar cell that converts solar radiation to electrical energy, with future applications in glass windows in buildings. We also study novel cascade architecture, which utilizes multiple layers of nanoparticles and metals.

* Denotes principal investigator.
Magnetic Behavior of Oxides and Nanophase Materials
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In cooperation with the Frederick Seitz Materials Research Laboratory

The project explores superconductivity in new classes of materials where strong interactions (correlations) among electrons or unusual symmetry leads to behavior distinctly different from that observed in simple materials, such as metallic elements. The behavior of the magnetic penetration depth is the main experimental tool. A second line of research examines strongly correlated magnetic materials in which intrinsic separation between metallic and insulating phases leads to potentially useful electronic properties. The former project involves collaboration with Los Alamos National Laboratory.

Excitations in Quantum Solids $^{3}$He and $^{4}$He
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In cooperation with Accel Instruments GmbH

Helium solids exhibit extraordinary properties, owing to their small atomic masses and weak interatomic interactions. In this work, synchrotron x-ray and pulsed neutron scattering, as well as highly precise measurements of thermodynamic pressure, have been used to investigate structural and dynamic properties. The data are compared critically with path-integral computations and with other models for incommensurate crystal behavior, to study single-particle dynamics, collective dynamics, and the occurrence of crystalline defects and their properties in these quantum solid systems.

Momentum Densities and Molecular Motions in Condensed Gas Solids and Liquids
R. O. Simmons,* D. A. Arms (Argonne Natl. Lab), D. N. Timms (Univ. of Portsmouth), S. M. Bennington, J. Mayers (Rutherford Appleton Lab)
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In cooperation with Frederick Seitz Materials Research Laboratory, Argonne National Laboratory, and Rutherford Appleton Laboratory, U.K.

Excitations in condensed matter systems are characterized by the dynamic structure factor $S(Q, E)$, where $Q$ and $E$ are the wave vector and energy transfers, respectively, in a scattering process. From scattering of eV neutrons from a pulsed spallation source, atomic momentum densities can be measured and internal molecular motions be determined. Prototype systems studied include high-pressure fluid $^{4}$He and molecular motion of $H_{2}$ embedded in solid Ar. Direct comparisons can be made to quantitative simulations using realistic interatomic potentials.

Current-Phase Relations of SFS $\pi$-Josephson Junctions
D. J. Van Harlingen,* M. Colci-O'Hara, M. Stehno
Civilian Research Development Fund, RUP1-2691-CG-05

We are fabricating and characterizing superconductor-ferromagnet-superconductor (SFS) Josephson junctions that exhibit a transition with temperature and/or barrier thickness into a state with a negative critical current. These so-called $\pi$-junctions generate a spontaneous flux when embedded in a closed superconducting loop, making them promising for quantum computing applications. We are focusing on measurements of the current-phase relation, which allows us to demonstrate the crossover from the ordinary 0-state to the $\pi$-state and to search for higher order tunneling harmonics. Arrays of SFS junctions are also being imaged by scanning SQUID microscopy to study spontaneous supercurrents induced by the $\pi$-state.

Scanning Magnetic Microscopy of Complex Materials
D. J. Van Harlingen,* M. Stoutimore, D. Bahr
U.S. Department of Energy, DEFG02-91ER45439
In cooperation with the Frederick Seitz Materials Research Laboratory

We are developing novel scanning probe microscopes for the imaging of magnetic fields in superconducting and magnetic materials and devices. The present effort is directed toward extending the spatial resolution (to below 1 μm) and temperature range (to below 10 mK) of scanning SQUID microscopy (SSM), a technique we pioneered that uses a sensitive superconductor device as a magnetic flux detector. Key experiments include the search for spontaneous supercurrents in superconductors having complex order parameters, the motion of vortices in asymmetric ratchet potentials, and the detection of exotic spontaneous flux phases in magnetic superconductors. We are also using SSM to image spontaneous vortices in SFS (superconductor-ferromagnet-superconductor) Josephson junction arrays.

* Denotes principal investigator.
Symmetry and Mechanisms of Unconventional Superconductors
D. J. Van Harlingen,* D. Caplin, F. Kidwingira, J. Strand
U.S. Department of Energy, DEFG02-91ER45439

In cooperation with the Frederick Seitz Materials Research Laboratory

We are carrying out experimental measurements of the transport and tunneling properties of unconventional superconductors designed to determine the order parameter symmetry and to elucidate the pairing mechanism responsible for the superconductivity. Present symmetry work is focused on phase-sensitive Josephson interferometry tests of the ruthenate superconductor Sr$_2$RuO$_4$ and the heavy fermion superconductor UPt$_3$ that are suspected to exhibit complex $p$-wave symmetry. Mechanism work is directed to exploring the anomalous normal "pseudogap" state of the high temperature cuprate superconductors via fabrication and measurement of nanowires, with recent attention to testing for the existence of dynamical charge stripe domains.

Noise and Aging in Disordered Magnetic Materials
M. B. Weissman,* V. Orlyanchik
National Science Foundation, DMR-06 05726

This project uses random fluctuations ("noise"), to answer basic questions about disordered magnetic systems, especially ones whose electrical resistance depends on magnetism. Non-Gaussian noise in small samples provides a probe of the detailed internal glassy states. It should allow discrimination, for example, between models of cobaltites as nearly independent ferromagnetic domains imbedded in a spinglass matrix or as glasses of interacting ferromagnetic domains. Small-scale fluctuation experiments on spinglasses should help settle the question of how many non-symmetry-related states are available. Aging investigations, also very sensitive to the form of glassy correlations, will be used in conjunction with the noise work.

Noise and Aging in Relaxor Ferroelectrics
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This research applies low-frequency noise and aging techniques to unsolved problems of disordered condensed matter. For relaxor ferroelectrics, noise and aging provide new probes to understand why some unconventional glassy freezing prevents the formation of simple ferroelectric order. The key question under study is whether the glassy order describes the interactions between little ferroelectric domains, or describes an additional type of order found within each domain.

Imaging Quasiparticles and Excitons with Light and Sound
J. P. Wolfe,* J. Jang, T. Head
U.S. Department of Energy, DEFG02-91ER45439/36

We are investigating basic excitations in semiconductors and superconductors on two fronts: applying phonon imaging to understand the unusual superconducting properties of Pb, and using optical spectroscopy and imaging techniques to study excitons at high densities in the semiconductor Cu2O. In an attempt to reach conditions for Bose–Einstein condensation of excitons, we are investigating the basic kinetic processes—carrier thermalization, Auger recombination, and interconversion of excitons—using time-resolved photoluminescence and imaging. Our experiments in the conventional (yet puzzling) superconductor Pb measure anisotropic phonon-quasiparticle scattering in an effort to understand earlier anomalous specific heat measurements that suggest a spin-density-wave ground state.

Experimental Nuclear Physics

Nuclear Physics Laboratory
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M. Grosse Perdekamp, P. Kammel, N. C. R. Makins,
A. M. Nathan, J. C. Peng, S. E. Williamson, Y.-J. Kim,
R. McNabb, R. Seidl, P. Winter, L. Zhu, D. Chitwood,
P.-H. Chu, S. Clayton, J. Crnkovic, D. Ely, A. Esler,
B. Kiburg, S. Knaack, J. Koster, R. Lamb,
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National Science Foundation, PHY 02-44889, PHY 06-01067

The group doing experimental medium energy nuclear physics at Illinois pursues its studies at a variety of accelerator facilities throughout the world, using high-energy beams of electrons, photons, and muons. The individual thrusts within the laboratory are listed below.

Photon Scattering
In cooperation with MAXlab, Lund, Sweden

Low-energy Compton scattering from deuterium is currently being studied in order to determine the electric and magnetic polarizabilities of the neutron. For any composite particle, the polarizabilities are fundamental

* Denotes principal investigator.
properties that characterize the ability of the constituents to rearrange themselves in response to external electric or magnetic fields. The experiment takes place at the MAXlab tagged photon facility in Lund, Sweden.

**Precision Measurement of Muon Capture in Hydrogen**

*In cooperation with Paul Scherrer Institute, near Zürich, Switzerland*

This experiment is a precision measurement of the capture rate of negative muons on protons, a process that is sensitive to the weak interaction couplings of the nucleon, in particular, the so-called pseudoscalar coupling, $g_P$. The measurement will provide a rigorous test of theoretical predictions based on effective field theories of QCD. The Illinois group provides the co-spokesperson and is responsible for a major detector system.

In 2007, a first result for the capture rate was reported, which allowed a precise and unambiguous extraction of $g_P$ (Phys. Rev. Lett., July 2007). The results support the current theoretical view. Further data taking increased the available statistics by an order of magnitude. These new data are presently being analyzed by the University of Illinois at Urbana-Champaign group at NCSA and a final result for the capture rate to better than 1% precision is anticipated. Building on the developed novel experimental techniques, a new proposal to measure muon capture on the deuteron has been prepared. It studies the weak interaction in the two-nucleon system, which is highly relevant for solar neutrino-and astrophysics.

**The Muon Lifetime Experiment**

*In cooperation with Paul Scherrer Institute, near Zürich, Switzerland*

The standard model is a concise description of elementary particles: quarks and leptons, and their interactions, the strong and the electroweak. Experiments must provide three independent quantities to characterize completely the electroweak interaction, and these quantities are taken from the most precise measurements. The group at the University of Illinois at Urbana-Champaign measured the muon lifetime to 11 parts per million in a commissioning run of the MuLan experiment, which led to a new and precise determination of the Fermi coupling constant of the electroweak interaction (Phys. Rev. Lett., July 2007).

Since then, we have acquired a data set more than 100 times larger, which is presently being analyzed using NCSA facilities. Our group is a co-leader of the experiment and built the novel large acceptance detector, as well as developed the custom, time-structured muon beam.

**Measurement of the Strange Quark Sea in the Nucleon**

*In cooperation with Thomas Jefferson National Accelerator Facility, Newport News, Virginia*

Just as the Lamb shift measures the contribution of virtual particles to the energy spectrum of the hydrogen atom, in the "G0 Experiment" at Jefferson Laboratory, we investigate the contribution of virtual quarks to the structure of the nucleon. This experiment utilizes the parity-violating interference between electromagnetic and weak neutral currents in the scattering of longitudinally polarized electrons from the proton. The effort involves a large international collaboration led by the Illinois group. Results from the first phase of the experiment were published in 2005 and suggest that while the effect is small, it is probably not zero. Data taking in the second phase of the experiment has been completed and analysis is in progress.

**Spin Structure of the Nucleon**

*In cooperation with Brookhaven National Laboratory, Upton, New York and Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany*

The scattering of electrons from protons at high energies probes the momentum distributions of the quarks out of which the proton is constructed. If, in addition, the electron beam and the proton target are polarized, we can measure, for example, the fraction of the overall proton angular momentum that is contributed by the spins of the quarks. The HERMES collaboration at DESY has found, together with several other groups, that this fraction is surprisingly small—about 1/4. This experiment is exploring various implications and related quantities; one of our scientific staff is leading the analysis of this large international collaboration. One of the areas of concentration concerns the correlations of spins and of "orbital" motion of quarks within the proton.

A second type of experiment will involve polarized proton-proton scattering in the RHIC ring at BNL. These measurements, the only ones of their type in the world, are aimed at providing information complementary to that obtained in electron scattering experiments regarding the spin structure of protons and neutrons. For example, the additional contributions of the carriers of the force between quarks—the gluons—to the proton spin can be determined in significantly greater detail. New information regarding the relativistic effects on the quark spin correlations will be measured here in a different way and at significantly higher energies. As part of this study, a necessary input to unraveling the contributions has been extracted from a different experiment in Japan (Belle at KEK) by an Illinois group. In a multiyear collaborative project, our group is
also leading development of a new detector filter ("trigger") system in order to better extract the information of interest from collisions that produce very high data rates.

Search for a Neutron Electric Dipole Moment
In cooperation with Oak Ridge National Laboratory, Oak Ridge, Tennessee

In many models of physics beyond the so-called standard model of the subatomic particles and interactions, the particles acquire a small, permanent electric dipole moment. Such a property is surprising because in elementary particles such as these, it signals a violation of the invariance of time-reversal, i.e. certain processes do not precisely reverse if one looks at them "backwards." Such processes seem to be required to generate the predominance of matter over antimatter in the universe. Neutrons, as generated by the Spallation Neutron Source at Oak Ridge, are attractive particles in which to look for the effect, in part because they are neutral. However, in order to accumulate a sufficient number of neutrons, they must be trapped in superfluid helium. Our group is developing the polarized helium-3 subsystem, including superfluid valves, which will be used for a modified NMR detection system for the experiment.

The DayaBay Neutrino Oscillation Experiment
J.-C. Peng,* S. R. Ely
U.S. Department of Energy, LBNL-6810324

In cooperation with Institute of High Energy Physics, Beijing, China

We are members of a collaboration to study the oscillation of neutrinos using the DayaBay nuclear power plant in China. The goal of this experiment is to measure the yet unknown mixing angle $\theta_{13}$ with a sensitivity of ten times better than the most sensitive previous experiment. The magnitude of the $\theta_{13}$ is one of the outstanding unknown quantities in particle physics. The DayaBay experiment will be carried out using large liquid scintillator detectors placed inside tunnels. The experiment is scheduled to begin in early 2009. We have carried out a detailed simulation study on the performance of the muon veto system, which is a crucial component of this neutrino oscillation experiment.

Collaborative Research: Development of a Fast Muon Trigger to Study the Quark-Gluon Structure of the Proton
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National Science Foundation, PHY05-21542

In cooperation with the Brookhaven National Laboratory

We are developing a novel scientific technique for the study of proton substructure: the detection of W bosons in high energetic polarized proton-proton collisions with the PHENIX detector at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory. The goal of the project is to study the origin of the proton spin. The new method will enable precision measurements of quark and anti-quark spin contributions to the proton spin. Illinois leads a collaboration of 75 scientists, engineers, and graduate students from 19 institutions in China, Korea, Japan, and the United States who work on the development of the required detector instrumentation.

Study of Proton Substructure
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RIKEN BNL RHIC Physics Fellow Agreement

In cooperation the Japanese RIKEN Institute and the joint U.S.–Japanese RIKEN BNL Research Center at Brookhaven National Laboratory

The proton is a fundamental building block of all nuclear matter in the universe. At the same time the proton is complex composite object with quarks, anti-quarks, and gluons being the constituents. A joint U.S.–Japanese effort is under way at Brookhaven National Laboratory to advance our understanding of proton spin structure in polarized high energy collisions at the Relativistic Heavy Ion Collider. RHIC Physics Fellow agreements provide support for faculty members to spend 50% of their time at Brookhaven National Laboratory for a period of 5 years.

The PHENIX Muon Piston Calorimeter
M. Grosse Perdekamp*
National Science Foundation, 06-01067

In cooperation with Brookhaven National Laboratory, University of California at Riverside, University of Colorado at Boulder, Hiroshima University, Kurchatov Institute of Nuclear Physics, University of Massachusetts at Amherst, Oak Ridge National Laboratory, RIKEN BNL Research Center, Stony Brook University

The goal of the PHENIX Muon Piston Calorimeter is to study the transverse spin structure of the proton. In 2005

* Denotes principal investigator.
and 2006, we constructed two new electromagnetic forward calorimeters for the PHENIX experiment at Brookhaven National Laboratory. The calorimeters are based on lead-tungstate technology developed by our Russian and Japanese collaborators for the CMS and ALICE experiments at the Large Hadron Collider in Europe. We took the first data with the calorimeters in 2006 and 2007. We expect to have first results in the fall of 2007.

Experimental Particle Physics

ATLAS High-Energy Physics Research
U.S. Department of Energy, DE-FG02-91ER40677

In collaboration with physicists of the ATLAS Experiment at CERN (Geneva, Switzerland)

The ATLAS experiment will study 14-TeV proton-proton collisions at the Large Hadron Collider (LHC) at CERN (near Geneva, Switzerland), to provide insight into the nature of electroweak symmetry breaking and to search for new phenomena beyond the predictions of the Standard Model. The University of Illinois at Urbana-Champaign ATLAS group currently has major responsibilities for the hadron calorimeter and muon subsystems, and is also involved with the development of a fast track trigger as a future upgrade for ATLAS. Illinois has been involved with ATLAS since 1994, carried out early R&D work and built a major portion of the ATLAS hadron calorimeter. Installation of the ATLAS detector in the LHC collision hall is currently under way and is now nearly complete. Data-taking on ATLAS is expected begin in early 2008.

AcCELERATOR PHYSICS R&D TOWARD THE LINEAR COLLIDER
http://www.hep.uiuc.edu/home/g-gollin/

In cooperation with the Stanford Linear Accelerator Center

Recent precision data, in combination with the impending completion of the Large Hadron Collider at CERN, have made it clear that a large electron-positron linear collider will play an essential role in understanding the origins of electroweak symmetry breaking in the fundamental interactions. To study the properties of the as-yet unobserved Higgs scalar, the international HEP community has begun to address research and development issues necessary to design the collider. Though the accelerator physics issues are challenging, many of them are well suited to investigation by university groups. At Illinois, we are pursuing two projects: investigation of novel schemes for injection/extraction kickers (concerning a new technique to inject/eject the beams from the ILC’s damping rings) and high availability/reliability control systems architectures for the ILC.

Investigation of Acoustic Localization of RF Cavity Breakdown for the Linear Collider R&D Effort
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U.S. Department of Energy, DE-FG02-03ER41281

Electrical breakdown in warm accelerating structures produces electromagnetic and acoustic signals that may be used to localize (in a noninvasive fashion) the breakdown site inside a cavity. Other indications of breakdown (microwave, x-ray, and dark current measurements) have proven insufficient to elucidate the basic physics of cavity breakdown. During tests of the NLC design, it will be important to record information describing electrical breakdown in order to understand why cavities break down and how cavity design and operating conditions influence accelerator reliability. The goal of this project is to understand the acoustic properties of heat-treated copper in order to relate the acoustic signatures of breakdown events to the underlying minor electromagnetic catastrophes taking place inside the accelerating structures.

High Availability Electronics for the International Linear Collider (ILC)
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In cooperation with the Stanford Linear Accelerator Center

This research focuses on hardware and software engineering for the evaluation of commercial off-the-shelf (COTS) solutions in particle physics electronics, as well as the development of application-specific prototypes using COTS elements. The goal is to advance the state-of-the-art of standard instrumentation for particle accelerator controls, beam instrumentation, and physics experiments.

* Denotes principal investigator.
Methodologies and Tools for Designing and Implementing Large-Scale Real-Time Systems
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National Science Foundation, Information Technology Research Program; subcontracted from Vanderbilt University, #15917-S3

In cooperation with the Coordinated Science Laboratory, University of Illinois at Urbana-Champaign; Vanderbilt University; Syracuse University; University of Pittsburgh; and Fermi National Accelerator Laboratory

This research group is a collaborative effort between computer scientists and high energy physicists researching the design and implementation of high-performance, heterogeneous, fault-tolerant, and fault-adaptive real-time systems that are embedded (i.e., are an integral part of the hardware they serve).

The Collider Detector at Fermilab
U.S. Department of Energy, DE-FG02-91ER40677

In collaboration with physicists of the Collider Detector at Fermilab (CDF) group

The TeVatron, a superconducting accelerator at Fermilab, collides a beam of 980 GeV protons with a beam of 980 GeV antiprotons. The Collider Detector at Fermilab (CDF) group has built a large detector to make precision measurements of the properties of the W and Z bosons, top quarks, and B hadrons, and to search for new phenomena, such as the production of Higgs bosons and supersymmetric particles. The detector contains systems for charged particle tracking, energy measurement, and particle identification. The Illinois group's responsibilities include the central muon detectors, tracking triggers, operations, and trigger upgrades. The Illinois researchers play leading roles in the main physics measurements and searches conducted by the collaboration.

CAREER: Heavy Flavor Physics with the CDF Detector and Saturday Physics Honors Statewide
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National Science Foundation, PHY 03-49179

The CDF experiment is a large, multipurpose detector measuring very high-energy proton-antiproton collisions at the Fermilab Tevatron, which is located in Batavia, Ill. In the Tevatron, protons and antiprotons collide with one another more than 1 million times per second. The Illinois group is developing high-speed digital electronics to process data from the collisions so that interesting collision events can be retained for later analysis. The collisions produce massive particles, such as bottom and top quarks. Ongoing studies of these particles continue to help improve our understanding of the fundamental building blocks of nature. In addition, this CAREER award provides support for the Department of Physics Saturday Physics Honors program for high school students. The Saturday Honors program offers presentations for the general public on research topics being pursued at the University of Illinois.

CLEO
M. A. Selen,* J. Wiss,* M. J. Haney, N. Lowery, S. Mehrabyan, N. Lowrey, E. White
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U.S. Department of Energy, DEFG02-91ER40677

In cooperation with Carleton University, Carnegie Mellon University, Cornell University, University of Chicago, University of Florida, George Mason University, Indiana University, University of Kansas, Luther College, University of Minnesota, Northwestern University, University of Oklahoma, University of Pittsburgh, Purdue University, Rensselaer Polytechnic Institute, University of Rochester, Syracuse University, University at Buffalo, State University of New York, University of Puerto Rico, Wayne State University

The CLEO-c experiment at the Cornell electron positron storage ring (CESR) studies properties of the charmed quark. The primary goals of these studies are threefold: understanding of the origin of the Cabibbo-Kobayashi-Maskawa (CKM) mixing matrix, for which no dynamical theory exists; understanding of time reversal symmetry violation, which appears to be a necessary prerequisite to the observed matter-antimatter asymmetry of the universe; and testing of the "standard model" of particle physics, whose very precise predictions have been tested very accurately, but which, nonetheless, is known to be incorrect. Deviations from these predictions will indicate where the flaw lies.

High-Energy Photoproduction
J. Wiss,* D. Kim
University of Illinois

In collaboration with other institutions

Researchers study charmed particles produced by high-energy photons. We completed data taking at Fermilab in the summer of 1997, after amassing a huge charm sample.

* Denotes principal investigator.
We study rare charm decays, charm lifetimes, excited charm spectroscopy, and QCD based models for charm photoproduction and decay. The Illinois group made major contributions to the FOCUS hardware and software. Last year our group developed a novel technique to make the first nonparametric analysis of hadronic charm decay.

Observational Cosmology

The Dark Energy Survey (DES) and the Large Synoptic Survey Telescope (LSST)

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In cooperation with the Department of Astronomy and the National Center for Supercomputing Applications (NCSA)

The DES and LSST astronomical surveys will study the history of the universe, covering more than 95% of the time since the big bang. By measuring supernovas and the development of large-scale structure formation (galaxies and clusters of galaxies), we will begin to understand the nature of dark matter and dark energy, which together form 96% of the energy in the universe. These projects constitute an important component of ground-based observational cosmology for the next decade. For the projects, the University of Illinois Physics Department, Astronomy Department, and NCSA will contribute to the construction of gigapixel scale cameras and the management of petabyte scale datasets.

Other Physics Research

Development of High-Speed Motion Capture Techniques for Studies in the Physics of Baseball

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Hank Kaczmarski, Beckman Institute, and Les Carlton, Kinesiology

This research will develop motion capture techniques that will allow studies of motion that require simultaneously both high spatial and temporal resolution. Initially these techniques will be used to study various aspects of the physics of baseball, including the aerodynamics of a high-speed spinning baseball and the spin of a batted ball. Successful implementation of these techniques will likely open new avenues of research in the study of complex human motion, with high likelihood of external funding.

Polarimetric Imaging and Spectroscopy of the Corona from 500-1500 nm during Total Solar Eclipses

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In cooperation with the University of Hawaii

This is a University of Illinois at Urbana-Champaign project linked to a project lead by Prof. Shadia R. Habbal at of the University of Hawaii. Prof. Nayfeh's group will characterize the polarized photoluminescence of silicon nanoparticles of different sizes. The nanoparticles are synthesized at the University of Illinois. Experiments will be conducted on particles in motion or immobilized on surfaces. The particles will be excited by uv radiation as well as from radiation in the wavelength range of their emission. Not only will the laboratory measurements serve as valuable benchmarks for coronal measurements performed at eclipse sites by the full team of researchers, but a synergism between the two will develop whereby coronal measurements will trigger relevant laboratory investigations.

Mesoscopic Elastic and Seismic Waves

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In cooperation with the Université Joseph Fourier (Grenoble)

Recent attention to diffuse fields in seismology, inspired in part by laboratory experiments done at Illinois, is leading to new methods for probing the interior of the earth. We observe and exploit mesoscopic residual correlations in nominally incoherent multiply scattered elastic wave fields, on the moon, in the seismic coda, in local geophone noise, and in long period worldwide background seismicity. Most recently we have established that higher level field correlations (correlations of the coda of correlations of ambient seismic noise) contain the same desired information on the Greens function of the earth, and can be superior to simpler field correlations.

* Denotes principal investigator.
Continued Development of Interactive Examples for Concept-Based Problem Solving in Introductory Undergraduate Physics Courses
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Traditional introductory physics courses typically fail to significantly improve students’ integration of physics concepts into their calculations and problem solving. The primary goal of the proposed project is to extend our development of “Interactive Examples” (IEs), web-based exercises that promote concept-based problem solving, to our initial course for underprepared students and to our calculus-based thermal physics and quantum physics courses.

Previous support from the National Science Foundation allowed us to create complete sets of IEs for the calculus-based mechanics and electricity and magnetism courses. We have demonstrated a statistically significant improvement in student performance after IEs were introduced into these courses. We are currently engaged in an ongoing evaluation process to understand the mechanisms responsible for this improvement. Guided by the principles learned from this evaluation process, we are refining our existing IEs, and creating new IEs for the remaining components of our introductory sequence.

A website (http://research.physics.uiuc.edu/PER/ie.html) provides all of our IEs to the general public. In addition, we host courses from about a dozen institutions, ranging from two-year colleges to research 1 universities on our server so that their students can receive credit for doing these exercises. Our extension of IEs to our course for underprepared students targets improved retention of women and minorities in engineering; of the 199 students who have completed the course in the last two years, 67 were minority students and 77 were women (the representation of students in this course is about five times greater than expected for minorities and two times greater for women).

CSEMS Initiative: Retaining Minority Students in Engineering through Improved Outcomes in Mandatory Physics Courses
G. E. Gladding,* P. E. Parker, N. J. Brown, M. A. Selen*
National Science Foundation, NSF DEU 00-94841

A novel instructional approach developed by the Department of Physics at the University of Illinois at Urbana-Champaign will be teamed with the National Science Foundation's Computer Science, Engineering, and Mathematics Scholarships (CSEMS) program in a combination of classroom teaching and supportive services to retain talented, financially disadvantaged minority students in bachelor's degree CSEMS curricula at Illinois.

Improving Retention of Underrepresented Groups in Engineering
G. Gladding,* M. Scott
Illinois Board of Higher Education, HECA

Recognizing that many students are underprepared for the introductory calculus-based courses, the Department of Physics has developed an optional preparatory course (Physics 100) and elective enrichment tutorial sections for the standard introductory engineering physics courses for students at risk of failure. State-of-the-art educational technologies have been integrated with innovative pedagogy based on physics-education research to provide essential skills in mathematics and basic knowledge in traditional physics topics. Preliminary results show that the approach can significantly reduce the failure rate in Physics 111, General Mechanics, the first of the required three- or four-course mandatory physics sequence for Illinois engineering students.

Research Experiences for Undergraduates in Physics
G. E. Gladding,* D. Hertzog*
http://www.physics.uiuc.edu/Education/undergrad/REU/
National Science Foundation, NSF Grant PHY06-47885

Since 1993, the Department of Physics has hosted "Research Experiences for Undergraduates" (REU), a summer program to provide students with an engaging introduction to a broad range of forefront research in physics. The program is supported by the National Science Foundation (NSF). Faculty involved in the REU program endeavor to provide meaningful hands-on research experiences in a first-class environment so that these students develop their own research literacy skills.

Students work on an extraordinary range of projects, such as using digital photography techniques to locate optical targets on the surface of the $2.75 million superconducting magnet that will comprise the toroidal spectrometry for the G0 nuclear physics experiment; developing 3-D visualizations of complex astrophysical phenomena drawn from huge experimental datasets; constructing a distortion pedal to emulate the sounds of overdriven tube amplifiers; and employing molecular beam epitaxy to grow thin films for electronic and magnetic devices.

* Denotes principal investigator.
In addition to busy research schedules, the students also participate in a number of programmatic and social activities intended to foster a sense of cohesiveness and integration into the REU community. Illinois faculty offer weekly seminars to introduce the students to a wide variety of interesting research opportunities in physics.

Conceptual Analysis and Student Learning in Physics
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Cognition and Student Learning Program, Institute for Education Sciences, U.S. Department of Education R305B070085

A problem-solving intervention for physics instruction that helps students perform conceptual analyses of problems will be developed and evaluated. Unfortunately, physicists and students approach problem solving quite differently. To physicists, the beauty of physics lies in its hierarchical nature—a few general principles can be applied across a wide variety of contexts. Students tend to view problem solving in physics in terms of manipulating equations, thus limiting their conceptual understanding, retention, and ability to advance to more complex materials. This project attempts to promote conceptual problem analyses to help students organize and retain physics knowledge.

GAANN: Preparing the Future Physics Professoriate
J. D. Stack,* G. E. Gladding,* J. Mestre*
U.S. Department of Education, P200A060085

The Graduate Assistance in Areas of National Need Program (GAANN) identifies physics as one of the areas of national need. We propose to establish a GAANN fellowship program in the Physics Department of the University of Illinois at Urbana-Champaign to increase the number of U.S. citizens, nationals, and permanent residents who will pursue teaching and research careers in physics.

Theoretical Astrophysics

ITR: MHD Simulations in Full General Relativity
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National Science Foundation, PHY 02-05155

In cooperation with the University of Virginia Astronomy Department

Astrophysical systems with relativistic gravity, strong electromagnetic fields, and rotation are the focus of intense scientific attention. These systems include accreting black holes and neutron stars, coalescing binary neutron stars and black holes, rapidly rotating neutron stars formed in core-collapse supernovae, and collapsing massive stars. These systems are the likely source of detectable gravitational waves, powerful x-ray emission, and gamma-ray bursts. Theories of these strong field systems must rely heavily on numerical simulations for guidance because the relevant solutions are intrinsically three dimensional, unsteady, and complex, but the required numerical tools do not yet exist. The main goals of this proposal are to develop numerical tools for magnetohydrodynamics (MHD) in full general relativity and apply them to problems at the forefront of current research.

Precision Bothrology: Toward a Physical Theory of Sgr A*
C. F. Gammie*
National Science Foundation, AST07-09246

In cooperation with the Department of Astronomy

This project aims to model Sgr A*, the luminous plasma surrounding the black hole at the center of our galaxy. This system is a potential Rosetta stone for black hole studies, as its distance, mass, and electromagnetic spectrum are better characterized than for any other black hole system. The main goal of this proposal is to develop models that, for the first time, consistently include general relativistic magnetohydrodynamics and general relativistic radiative transfer. The models will be used to make predictions for future very long baseline interferometry imaging of Sgr A* at millimeter and submillimeter wavelengths, and to predict the spectrum, polarization, and variability of Sgr A* from the far infrared to the x-rays.

Rapid X-ray Variability of Accreting Neutron Stars and Black Holes
F. K. Lamb,* S. Boutloukos
NASA, NAG 5-12030

The x-ray emission of neutron stars and black holes reflects the properties of matter under extreme conditions and strongly curved space-time. Analytical studies, scaling arguments, and numerical calculations on workstations and supercomputers are being used to determine the effects of the equation of state of dense matter, the existence of an innermost stable circular orbit, and general relativistic frame-dragging on the rapid x-ray variability of accreting neutron stars and black holes. These effects are then studied using instruments such as NASA's Rossi X-Ray Timing Explorer and Chandra Observatory.

* Denotes principal investigator.
The properties of strong gravitational fields, gravitational radiation, and ultradense, relativistic matter are among the most interesting and important current problems in physics and astrophysics. They are being addressed by computing the oscillations of spinning neutron stars, the gravitational radiation emitted by such oscillations, and the x-ray emission produced by thermonuclear explosions on neutron stars. They are also being addressed by investigating how the high-frequency oscillations observed in the x-ray flux of accreting neutron stars and black holes are produced and how they can be used to determine the properties of strong gravitational fields and ultradense matter.

Role of Magnetic Fields in Star Formation
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The series of physical processes that convert interstellar matter (of mean density 1 cm\(^{-3}\)) to stars like the sun (of typical mean density 10\(^{24}\) cm\(^{-3}\)) have been at the center of astrophysical research and thought for decades. Our three-decade-old effort to formulate a theory of star formation (through both analytical calculations and state-of-the-art numerical simulations involving multifluid nonideal MHD) has led to an understanding of the complex physical and chemical processes responsible for the formation of interstellar clouds, the means of support of these clouds against their self-gravity, their fragmentation, and the collapse of the protostellar fragments—up to densities of about 10\(^{15}\) cm\(^{-3}\). At all stages of the star formation process studied so far, magnetic fields play a crucial role. This role extends from the formation of interstellar clouds (through the Parker instability), to support of the dense molecular clouds against gravity, the resolution of the thorny angular momentum problem of star formation, the initiation of fragmentation (by ambipolar diffusion), the determination of the initial mass function of the protostellar fragments, and to the control of the mass infall or accretion rate onto a forming star. Dozens of predictions have been made, most of which have been confirmed by observations and, most importantly, not a single one of which has been contradicted by any observation. Our current effort is two-prong: pursue the calculations to even higher densities, until nuclear reactions are initiated in the core of a forming star; and produce additional specific predictions testable by observations. To this end, a collaborative research effort has started between our group and that of an observer colleague, Leslie Looney.

Testing the Magnetic Theory of Star Formation
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Past successes of the theory (i.e., predictions confirmed by observations) include the variation of the synchrotron-radiation intensity from the interarm to the spiral-arm regions of spiral galaxies as well as its variation along spiral arms; the formation of cloud complexes and embedded OB associations and giant HII regions; the rate of rotation of interstellar clouds; the differential motion between neutral and ionized matter in self-gravitating interstellar clouds; the relation between the magnetic-field strength and the gas density in protostellar fragments (or cores); the mass-to (magnetic) flux ratio of protostellar fragments; the spectral linewidths in magnetically supported clouds; the angular momentum of the protosolar nebula; the remanent magnetization in meteorites; the spasmodic (or episodic) accretion onto a protostar from the surrounding envelope; and so forth. Recently, we have undertaken a systematic test of the theory with new observations in collaboration with the group of an observer colleague, Leslie Looney. A controversy (to our mind, artificial) has been created during the last ten years or so as to whether magnetic fields (through ambipolar diffusion) or highly-superAlfvénic turbulence are/is responsible for the fragmentation of molecular clouds. Specific tests have been designed that will distinguish between the two competing fragmentation mechanisms.

Collapse, GRBs, Black Holes, and Gravitational Waves: MHD Simulations in Full General Relativity
S. L. Shapiro*
NASA, NNG04GN90H

We continue to make substantial progress on the construction and application of a new relativistic MHD code that simultaneously solves Einstein's equations of general relativity for the gravitational field, Maxwell's equations for the electromagnetic field, and the equations of relativistic MHD for the plasma. We have succeeded in assembling and testing software modules for this code, and applying the code to solve some outstanding astrophysical problems involving the collapse of hypermassive, magnetized neutron stars. Hypermassive neutron stars are likely to arise during the merger of binary neutron stars. Magnetic-induced collapse of these stars may provide the source of short-hard gamma-ray bursts.

* Denotes principal investigator.
The existence of binary and rotating neutron stars is beyond dispute. However, the two-body problem remains the most important unsolved problem in classical general relativity. The solution has important consequences for the detection of gravitational waves by laser interferometers now under construction and for resolving other astrophysical puzzles, such as the origin of gamma-ray bursts and planets around pulsars. Likewise, the dynamical stability of rotating neutron stars is not fully understood, and the final fate of unstable stars is not known. Similarly, the collapse of an unstable, rotating supermassive star has not been studied in general relativity, yet it remains a prime candidate for the formation of a supermassive black hole. Recent advances in this project have made it possible for researchers to solve these fundamental, closely related computational problems, essentially for the first time.

Theoretical Studies in Gravitation and Astrophysics
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National Science Foundation, PHY 06-50377
This project involves research in general relativity and theoretical astrophysics and addresses problems involving general relativity, the generation of gravitational radiation, relativistic hydrodynamics and MHD, radiative transport, and stellar dynamics. A common thread uniting different theoretical topics is the crucial role of gravitation, especially relativistic gravitation as described by Einstein's field equations of general relativity. Some of the topics for investigation include the inspiral and coalescence of binary neutron stars and black holes; the generation of gravitational waves from binaries and other promising astrophysical sources of gravitational radiation detectable by LIGO and LISA; gravitational collapse; the stability of rotating neutron stars and supermassive stars and the final fate of unstable stars; and the formation of supermassive black holes in the cores of galaxies and quasars. The approach will involve large-scale computations on parallel machines, as well as analytical modeling.

Molecular Mechanism of Calcium Pump
A. Aksimentiev,* C. Maffeo
University of Illinois
Ca-ATPase is a molecular pump residing in the sarcoplasmic reticulum of skeletal muscle cells that transports calcium ions across a lipid membrane against the concentration gradient. Several atomic structures of the calcium pump at different stages of the pumping cycle have been obtained, however, the sequence of events interlacing these x-ray snapshots is not known. Through large-scale MD simulations researchers are trying to determine the pattern of stress lines concealed in the x-ray structures that drives the system from of state to another, transporting calcium ions across the cell membrane.

Transport of Ions, DNA and Proteins across Cell Membranes
A. Aksimentiev,* D. Wells, H. Gutman (Tel Aviv Univ., Israel), L. Movileanu (Syracuse Univ.)
University of Illinois Department of Physics
Transport across compartmental boundaries and, in particular, across the cell wall is controlled by membrane proteins that act as selective channels and transporters. The ability of membrane channels to sort single molecules is of great interest to bioengineering and, as a result, membrane channels like alpha-hemolysin have been adopted for in vitro devices or used as an inspiration for manufacturing artificial channels. In collaboration with leading experimental groups, researchers investigate transport of ions, nucleic acids, and proteins through alpha-hemolysin, aiming to uncover generic principles governing transport of solutes across the cells boundaries.

Role of Horizontal Gene Transfer as a Control on the Coevolution of Ribosomal Proteins and the Genetic Code
N. D. Goldenfeld,* Z. Luthey-Schulten* (Chem.), C. Woese* (Microbiol.)
U.S. Department of Energy, 2005-05818
This project will attempt to uncover the major evolutionary transitions that accompanied the development of protein synthesis by the ribosome and associated components of the translation apparatus. Specifically, our work focuses on the elements of translation, ranging from the emergence of the canonical genetic code to the evolution of specific protein folds, mediated by the predominance of horizontal gene transfer in early life. A unique element of this study
is the explicit accounting for the impact of phenotype selection on translation, through a coevolutionary control mechanism.

**FIBR: The Emergence of Life: From Geochemistry to the Genetic Code**
H. Morowitz* (Santa Fe Inst. & George Mason Univ.); S. Copley* (Univ. of Colorado, Boulder); N. D Goldenfeld,* Carl Woese (Microbiol.);* Eric Smith* (Santa Fe Inst.)
National Science Foundation EF-0526747

This interdisciplinary project will synthesize these separate but convergent clues to early life from primordial geochemistry, biochemistry, molecular biology, thermodynamics, evolutionary biology, and the dynamics of genomes to provide a coherent account of the evolution of metabolism and the development of the modern genetic code. This research will place strong constraints on the likely environment, manner, and core metabolism of early life on Earth.

**U.S./U.K. Experiment—Cyberinfrastructure in Support of Research**
R. Penington,* K. J. Schulten*
National Science Foundation, through the National Center for Supercomputing Applications

*In cooperation with the National Center for Supercomputing Applications*

The project is a collaboration between the United States and the United Kingdom, and aims at applying GRID computing to biomolecular problems. The U.S. partner will take advantage of available distributed computational facilities, both in the United States and in the United Kingdom to study various physicochemical properties for a large group of proteins.

**Mechanisms of Membrane Proteins through In Situ Modeling**
K. Schulten*

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National Institutes of Health, PHS 1 ROI GM67887

Membrane proteins function as mediators for exchange of material and information across cell membranes as well as converters of electro-osmotic, mechanical, and chemical energy in cells. These proteins are the targets of most pharmacological interventions and their function is related to many diseases. Often the function of a membrane protein is coupled to the membrane environment through mechanical or electrostatic forces. Advances in biomolecular modeling using large parallel computers now permit the *in situ* simulation of membrane proteins, the latter requiring, however, simulation volumes of more than 100,000 atoms. Planned research will focus on protein of the aquaporin family; the mechanosensitive channel MscL; and the chloride channel CIC.

**Molecular Mechanisms of Cellular Mechanics**
K. J. Schulten*
National Institutes of Health, R01 GM073655

The focus of this research is on investigating the mechanism of function of various macromolecules in the mechanical function of cells. The project will mainly apply the method of steered molecular dynamics simulation to test and develop hypotheses regarding the structure-function relationship of the studied systems that will be tested further by our experimentalist collaborators.

**Resource for Macromolecular Modeling and Bioinformatics**
K. J. Schulten*
National Institutes of Health, PHS 5 P41 RR05969

The Resource develops and maintains computational tools that are used by biomedical researchers for simulation and visualization of biomolecular systems and for remote collaboration. Moreover, through several collaborations, the Resource directly serves other research groups by providing its scientific and technical expertise.

**Simulations of Supramolecular Biological Systems**
K. J. Schulten*
University of Illinois

This grant is an umbrella grant providing computer time for a wide variety of projects conducted by the Theoretical and Computational Biophysics Group. All projects employ large-scale molecular simulations to investigate various properties of molecular systems.

**Single Molecule Detection in Living Cells and Tissues Using a New Class of Optical Sensors Based on Single Walled Carbon Nanotubes**
M. Strano (Chem. Biomol., Engr.),* K. J. Schulten
University of Illinois, Beckman Seed Proposal

This project investigates the application of carbon nanotubes in designing nanodevices that are of potential use in a variety of biological applications. The project is a combined experimental and theoretical one in which simulation methodologies are used to design nanotube structures and to investigate their interaction with macromolecules such as DNA. The results of the simulations will be used to design new molecules, which will be synthesized and tested by experimental methods.

* Denotes principal investigator.
Theoretical Condensed Matter Physics

Superconductivity in Carbon Nanotubes
C. Bena* (Saclay), K. Le Hur* (Yale Univ.), S. Vishveshwara*
National Science Foundation DMR 06-05813
In cooperation with Yale University and Saclay, France

The phenomenon of superconductivity in single-walled carbon nanotubes, which form strongly interacting quantum wires and are forerunners of nanoscience applications, is yet to be entirely understood. Experiments reveal that nanotubes can support supercurrents while thus far, theoretical work indicates that nanotubes ought to be resilient to superconductivity due to the strong repulsive interactions of electrons in the tube. This project aims to resolve the apparent contradiction by studying nanotubes in full contact with a superconducting substrate. It is found that in such a situation, superconductivity can be induced in the nanotube in rather surprising ways, which include the possibility of the presence of two gaps in the electronic excitation spectrum, both associated with superconductivity.

Dynamical Layer Decoupling in a Stripe-Ordered High $T_c$ Superconductor
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National Science Foundation, DMR-0442537; and Department of Energy, A9024 DOE DEFG02-91ER45439
In cooperation with the Frederick Seitz Materials Research Laboratory (Illinois), Department of Physics, Stanford University; Department of Physics, Yale University; and Brookhaven National Laboratory

In the stripe-ordered state of a strongly-correlated, two-dimensional electronic system, under a set of special circumstances, the superconducting condensate, like the magnetic order, can occur at a nonzero wave-vector corresponding to a spatial period double that of the charge order. In this case, the Josephson coupling between near neighbor planes, especially in a crystal with the special structure of La$_{2-x}$Ba$_x$CuO$_4$, vanishes identically. We propose that this is the underlying cause of the dynamical decoupling of the layers recently observed in transport measurements at $x$=1/8.

Ice: A Strongly Correlated Proton System
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National Science Foundation, DMR 04-42537
Department of Physics, Boston University, and Ecole Normale Supérieure, Lyon (France)

We discuss the problem of proton motion in hydrogen bond materials with special focus on ice. We show that phenomenological models proposed in the past for the study of ice can be recast in terms of microscopic models in close relationship to the ones used to study the physics of Mott-Hubbard insulators. We discuss the physics of the paramagnetic phase of ice at 1/4 filling (neutral ice) and its mapping to a transverse field Ising model and also to a gauge theory in two and three dimensions. We show that $H_3^+$O and HO$^-$ ions can be either in a confined or deconfined phase. We obtain the phase diagram of the problem as a function of temperature $T$ and proton hopping energy $t$ and find that there are two phases: an ordered insulating phase which results from an order-by-disorder mechanism induced by quantum fluctuations, and a disordered incoherent metallic phase (or plasma). We also discuss the problem of decoherence in the proton motion introduced by the lattice vibrations (phonons) and its effect on the phase diagram. Finally, we suggest that the transition from ice Ih to ice XI observed experimentally in doped ice is the confining-deconfining transition of our phase diagram.

CMG Collaborative Research: Quantum Monte Carlo Calculations of Deep Earth Materials
D. M. Ceperley,* B. Clark, J. Kim
National Science Foundation, EAR 05-30643
In cooperation with Virginia Polytechnic Institute, Frederick Seitz Materials Research Laboratory, and Sandia National Laboratories

In this project, we are developing methods for use in quantum Monte Carlo that can be scaled to system with more electrons. This involves evaluating sparse matrix algorithms for calculating the fermion determinants, and testing the algorithms on various solids, in particular those relevant to earth materials. The project is in collaboration with other workers in quantum Monte Carlo at Cornell University, Carnegie Institute, North Carolina State University, and Virginia Polytech Institute.
Computational Methods for Electronic Structure
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National Science Foundation, DMR 04-04853

In cooperation with the Frederick Seitz Materials Research Laboratory, and the National Center for Supercomputing Applications

The long-range goal of this research is to develop theoretical and computational methods to predict accurately the properties of many-electron systems and then to apply the methods to important condensed matter systems. One focus is to find the fundamental distinction between metals and insulators going beyond concepts developed in one-electron theory using the topology of the wavefunctionals and quantitative calculations using quantum Monte Carlo (QMC) methods. Recent work has been on one-dimensional systems with Coulomb interactions to find excitations and to develop useful functionals for density functional theory.

The ability to solve correlated electron problems on high performance computers is a key future technology in many scientific fields, including physics, materials science, chemistry, biophysics, and geo-physics.

First Principles Simulations of Energetic Materials
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Army, UM C00005071-31

In cooperation with the Frederick Seitz Materials Research Laboratory, National Center for Supercomputing Applications, and University of Missouri

The research is a long-term effort to enable first-principles simulations of energetic materials. The focus will be on accurate methods that will become robust tools for prediction of the properties of materials under extreme conditions. The primary applications will be materials at high temperature and pressure, with selected benchmarks for definitive comparison with experiments, and for predictions beyond the capabilities of experiments. Our work will focus primarily upon quantum Monte Carlo (QMC) methods, because they are the only known approach that can directly simulate materials from the fundamental equations for interacting nuclei and electrons.

Institute for Quantum Simulations of Materials and Nanostructures
D. M. Ceperley,* J. Kim, J. Gergely
U.S. Department of Energy, USC SUB 0600182

In cooperation with the Frederick Seitz Materials Research Lab, National Center for Super Computing, University of California-Davis, Stanford University, and MIT

Several recent efforts at simulating liquid water have employed ab initio molecular dynamics methods with forces from density functional theory and imaginary-time path integrals to study quantum effects of the protons. Although these methods have met with many successes, errors introduced by the approximations and choices of simulation parameters are not fully understood. The primary goal of this project is to produce path integral Monte Carlo studies of liquid water to provide benchmarks. Based on MC results, we will assess whether typical simulations are sufficiently converged and the relative efficiency of the methods and improvements.

Materials Computation Center
http://www.mcc.uiuc.edu/
National Science Foundation, DMR 03-25939

In cooperation with the Frederick Seitz Materials Research Lab and the departments of Physics, Materials Science and Engineering, Chemistry, Computer Science, and Electrical and Computer Engineering

The Materials Computation Center is an interdisciplinary collaborative effort of 14 principle investigators with internal and external advisory boards. Its purpose is to serve the university and national community in the field of materials computation. The emphasis is upon development of algorithms and software that are essential for utilizing the rapidly growing computational power available for scientific computations. The goal is to build up the entire field of computational materials science and educate young scientists. The MCC sponsors summer schools each year with approximately 60 students. It also facilitates travel of young people in the United States to Centre Européen de Calcul Atomique et Moléculaire (CECAM) workshops.

* Denotes principal investigator.
Optical Lattice Emulation of Correlated Fermions
D. M. Ceperley*
Defense Advanced Research Projects Agency, W911NF-07-1-0464

In cooperation with the departments of Physics at Rice University, University of Pittsburg, Cornell University, Ohio State University, and Princeton University

The goal of this research is to develop and build an optical lattice emulator (OLE) that uses ultracold atoms to simulate strongly correlated fermion systems of great interest in quantum condensed matter and materials physics. The grand challenge goal that our entire program will be working toward is to simulate the doped two-dimensional fermionic Hubbard model with repulsive interactions and to search for the expected d-wave superfluidity in that system. This will answer the long-standing question of whether or not this model does indeed contain the basic mechanisms behind high-temperature superconductivity, as many researchers have proposed.

Quantum Monte Carlo Endstation for Petascale Computing
D. M. Ceperley,* J. Kim, J. Meminis, J. Krogel
U.S. Department of Energy, DE-FG05-08OR23335

In cooperation with the Frederick Seitz Materials Research Lab and the departments of Physics, the National Center for Supercomputing Applications (NCSA), Oak Ridge National Laboratory, Cornell University, College of William and Mary, and North Carolina State University

The goal of this research is to develop the Quantum Monte Carlo computational infrastructure so that it can be applied at the petaflop level, providing an unprecedented opportunity for breakthrough science projects in nanoscience, materials science, physics, and chemistry. This project is a national consortium to develop such software, led from NCSA at the University of Illinois Urbana-Champaign.

Quantum Simulations for Dense Matter
D. M. Ceperley,* R. M. Martin,* F. Lin, M. Morales
U.S. Department of Energy, DE-FG52-06NA26170

The goal of this research is to predict the properties of "warm dense matter," which is temperature and pressures where outer electrons are ionized but not extreme plasma conditions. These are regimes being studied by laser compression, and quantum Monte Carlo is the only approach that can make first principles calculations for such systems. Present work is on conductivity of hydrogen to study the metal-insulator-dissociation transitions.

Fractional Statistics and Duality: Strong Coupling Behavior of Edge States of Quantum Hall Liquids in the Jain Sequence
C. Chamon, E. Fradkin,* A. López
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National Science Foundation, DMR-0442537

In cooperation with the Department of Physics, Boston University, and OECE, Oxford University (UK)

While the values for the fractional charge and fractional statistics coincide for fractional Hall (FQH) states in the Laughlin sequence, they do not for more general FQH states, such as those in the Jain sequence. This mismatch leads to additional phase factors in the weak coupling expansion for tunneling between edge states that alter the nature of the strong tunneling limit. We show here how to construct a weak-strong coupling duality for generalized FQH states with sharp edges. The correct dualization of fractionally charged quasiparticles into integer charged fermions is a consistency requirement for a theory of FQH edge states with a simple edge. We show that this duality also applies for weakly reconstructed edges.

Fundamental Research on Infrared Detectors
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U.S. Department of Defense, MURI/ARO DAAD19-01-1-0591

The goal of this project is to study the electronic structures of defect complexes (vacancies, vacancy-donor pair, and dislocations) in semiconductors and their effect on carrier capture rates, an important limiting factor for radiation and infrared detectors in materials such CdZnTe and HgCdTe. We have performed ab initio pseudopotential and full potential calculations of the total energy and atomic relaxation of neutral and charged Cd vacancies (with a supercell including up to 128 atoms) as well as [110] Cd line defects with an efficient code, which takes advantage of the high point symmetry of the system. Similar studies are being carried out for Hg related defects in HgCdTe. For high point symmetry systems, the use of symmetrized basis functions reduces the computation time by about two orders of magnitude.

* Denotes principal investigator.
High Quantum Efficiency Infrared Photodetector Arrays Based on Nanowire Heterostructures
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NRO JPL NASA, 000-05-C-0023
University of Illinois Department of Electrical and Computer Engineering; Jet Propulsion Laboratory, California Institute of Technology

We explore the feasibility of InGaAs quantum wire structures due to strain-induced lateral ordering as an infrared photodetector. It is expected that quantum-wire infrared photodetector (QWRIP) is capable of infrared detection in 15 μm - 40 μm range, complementary to mercury-cadmium-telluride detectors. High quantum wire density and normal incidence response of QWRIP could result in better detectivity than either a quantum well infrared photodetector (QWIP) or a quantum dot infrared photodetector (QDIP) and with a higher long-wavelength ir operating temperature than QWIP or blocking impurity band detector. QWRIP also has unique polarization sensitivity, and it can be integrated with QWIP for added functionality.

Modeling of Spintronics Devices
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NASA; DARPA-SpinS program
Jet Propulsion Lab subcontract

We explore fast methods for obtaining spin-resolved band structures for electrons and holes. We use a tight binding (TB) method that includes spin-orbit interaction and bulk inversion asymmetry and requires the least number of bands. The TB parameters are found from comparison of the calculated bands to ab initio calculations, adjusted to correct the band gap. The model is used to study the spin lifetime in semiconductor heterostructures, taking into account the D’yakonov-Perel’ (DP) spin relaxation mechanism. The interplay of effects due to bulk inversion asymmetry (BIA) and structure inversion asymmetry (SIA) for different crystallographic orientations is considered.

Dynamics of Disordered Nonequilibrium Systems: Hysteresis, Noise, and Domain Wall Dynamics in Systems Ranging from Magnets to Earthquakes
K. A. Dahmen*
National Science Foundation, DMR 03-14279
In cooperation with the Materials Computation Center and the Frederick Seitz Materials Research Laboratory

Magnets, earthquake faults, and many other systems respond to slowly changing external conditions with discrete, impulsive events that span a huge range of sizes (Barkhausen noise or avalanches in the case of magnets, and earthquakes in the case of the earth). Researchers study Barkhausen noise in disordered magnets as a representative of these systems and compute predictions for the universal aspects of the behavior on long length scales as a function of disorder, field sweep rate, history, and temperature. This research uses ideas from phase transitions, the renormalization group, and disordered systems theory.

Hysteresis and Noise from Electronic Nematicity in High Temperature Superconductors
K. A. Dahmen,* E. H. Fradkin,* E. W. Carlson (Purdue), S. Kivelson (Stanford, UCLA)
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National Science Foundation, DMR 04-42537; U.S. Department of Energy, A9024 DOE DEFG02-91ER45439
In cooperation with the Frederick Seitz Materials Research Laboratory, University of Illinois at Urbana-Champaign, Department of Physics of Purdue University, and Department of Physics of Stanford University

An electron nematic is a translationally invariant state that spontaneously breaks the discrete rotational symmetry of a host crystal. In a clean square lattice, the electron nematic has two preferred orientations, while dopant disorder favors one or the other orientations locally. In this way, the electron nematic in a host crystal maps to the random field Ising model (RFIM). Since the electron nematic has anisotropic conductivity, we associate each Ising configuration with a resistor network, and use what is known about the RFIM to predict new ways to test for local electronic nematic order (nematicity) using noise and hysteresis. In particular, we have uncovered a remarkably robust linear relation between the orientational order and the resistance anisotropy that holds over a wide range of circumstances.

* Denotes principal investigator.
Applications of Field Theory to Condensed Matter Physics
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National Science Foundation, DMR-04-42537

In cooperation with the Departments of Physics at Stanford University, University of Virginia, and University of California, Los Angeles

This project is aimed at advancing the theoretical understanding of condensed matter systems, each involving many strongly coupled degrees of freedom, including phases of doped Mott insulators, electronic liquid crystal phases, smectic nematic-isotropic transitions, and superconductivity; the quantum Hall effect, strong coupling behavior of quantum Hall tunnel junctions, and Ginzburg-Landau theory for non-abelian states; and superfluids and superconductors, spin liquids, and other topological phases, non-Abelian braid statistics and applications to topological quantum computing. The underlying theme is that the problems of condensed matter physics raised by such systems are best attacked using the ideas of quantum field theory.

Entanglement Entropy of 2-D Conformal Quantum Critical Points: Hearing the Shape of a Quantum Drum
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National Science Foundation, DMR-0442537

In cooperation with the Department of Physics, University of California Berkeley

The entanglement entropy of a pure quantum state of a bipartite system \( A \cup B \) is defined as the von Neumann entropy of the reduced density matrix obtained by tracing over one of the two parts. Critical ground states of local Hamiltonians in one dimension have entanglement that diverges logarithmically in the subsystem size, with a universal coefficient that for conformally invariant critical points is related to the central charge of the conformal field theory. We find the entanglement entropy for a standard class of \( z=2 \) quantum critical points in two spatial dimensions with scale invariant ground state wave functions: in addition to a nonuniversal "area law" contribution proportional to the size of the \( AB \) boundary, there is generically a universal logarithmically divergent correction. This logarithmic term is completely determined by the geometry of the partition into subsystems and the central charge of the field theory that describes the equal-time correlations of the critical wave function.

Fractional Statistics in the Quantum Hall Bulk
National Science Foundation

Indian Institute of Science, Bangalore, India

While quantum particles have conventionally been grouped as either bosons or fermions based on their quantum statistics, the two-dimensional world allows for the exciting possibility of "anyons" whose statistics interpolates between the two. These anyons, apart from their fundamental science appeal, could form the basis for some topological quantum computation schemes. The quantum Hall system is the best known candidate for hosting anyons. This project seeks to predict properties of anyons and to propose means of detecting them. One part of the project explores the behavior of two anyons in the bulk of the quantum Hall system while another shows that signatures of fractional statistics can be found in current correlations between anyon currents flowing along the edge of a quantum Hall bar.

Quantum Materials at the Nanoscale
E. Fradkin,* L. Greene, J. Eckstein,* S. L. Cooper,* P. Abbamonte,* S. Papanikolaou, K. Sun, B. Muñoz Fregoso
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U.S. Department of Energy, DEFG02-91ER45439

In cooperation with the Frederick Seitz Materials Research Lab, Stanford University, Brookhaven National Laboratory, Oxford University (UK).

In many materials, strong interactions between electrons generate spontaneous organization at the nanoscale (stripes of charge and/or spin polarization). This organization can play a significant role in the formation and electronic properties of remarkable states of matter such as high Tc superconductivity. This nanoscale self-organization is explored via a coordinated program of experimental and theoretical investigations. The nature of charge and magnetically ordered states are explored in a range of materials, such as doped cuprates, dichalcogenides, and ruthenates, via resonant x-ray scattering and pressure-tuned optical spectroscopy. These will be compared to theoretical models of spontaneous nanoscale ordering that will be developed.

* Denotes principal investigator.
Collaborative Research: Statistical Mechanics of Turbulence
G. Gioia* (Mech. Sci. & Engr.), N. D. Goldenfeld*
National Science Foundation, DMR 06-04435

This project studies the friction experienced by a turbulent fluid as it flows through a pipe, taking into account the roughness of the walls. Our work uses calculations of momentum transport coupled with ideas from phase transition theory to predict the friction factor as a function of Reynolds number and wall roughness, for three dimensional pipes, and also two dimensional turbulent soap films.

Quantum Materials at the Nanoscale
P. M. Goldbart,* A. Bezryadin,* J. N. Eckstein,*
R. Budakian, D. Pekker, F. Bora
U.S. Department of Energy, DEFG02-91ER45439

Work on this project focuses on superconductivity at the nanoscale. The Bezryadin group has developed experimental methods for fabricating ultrafine superconducting wires via deposition onto individual molecules (either carbon nanotubes or DNA) and has measured various physical properties (e.g., electrical resistivity, critical currents) of these wires and their dependence on temperature and magnetic fields. The Goldbart group is developing theoretical models to describe superconductivity under these extreme conditions, and is thus explaining a variety of striking observations made by the Bezryadin group, including the anomalous strengthening of superconductivity by magnetic fields in ultrafine wires, and magnetic-field-modulated quantum interference oscillations observed in the resistance of multiwire structures. In connection with experiments under way in J. Eckstein's group, Goldbart's group is developing a theory of charge transport across semiconductor-superconductor interfaces. Goldbart's group is also analyzing quantum tunneling of magnetic moments as well as vortex penetration into nanoscale superconductors in connection with experiments being performed by the Budakian group.

The Statistical Physics of Random Solids
P. M. Goldbart,* X. Mao
National Science Foundation, DMR06-05816

This project aims to develop new theoretical concepts and techniques that will lead to a deeper understanding of the structure and response of random media, such vulcanized rubber, gels, and glasses. The tools used are statistical mechanics with quenched disorder and field theory, as well phenomenological probabilistic methods. Sought are calculable statistical characterizations of random media reflecting their heterogeneity, especially characterizations that are universal, applying to broad classes of random-solid-forming systems. Also sought is an understanding of the elastic properties, especially in settings in which entropy dominates. Recent work incorporates the effects of additional freedoms, such as compositional fluctuations in cross-linked polymer blends and liquid-crystalline ordering in nematic elastomers.

Various Topics in Solid-State Quantum Computation
R. B. Kassman,* M-H. Yung, A. J. Leggett,* M. C. Yeh
National Science Foundation, EIA01-21568

We are investigating the energy level structure of an atom situated at the interface of two semiconductors with different dielectric constant; the feasibility of an experiment to test quantum mechanics vis-à-vis the GRWP theory of wave packet reduction using SQUIDs; and the effect of higher order, environment-induced interactions on the operation of a solid-state quantum computer.

Theory of Nodal Nematic Quantum Phase Transition
E.-A. Kim, M. J. Lawler, P. Oreto, E. Fradkin,*
S. A. Kivelson
National Science Foundation, DMR-0442537; U.S. Department of Energy, A9024 DOE DEFG02-91ER45439.

In cooperation with the Frederick Seitz Materials Research Laboratory, Department of Physics of Stanford University, and Department of Physics of University of Toronto, Canada

We study the character of the quantum phase transition (QPT) from a symmetric to an (Ising) nematic phase deep in an assumed d-wave superconducting state in a two dimensional square-symmetric (C4v) crystal. Where previous perturbative (δ expansion) studies found runaway flows produced by the coupling to nodal quasiparticles (qp's), we find (using a 1/N expansion) a nonperturbative fixed point corresponding to a continuous QPT. Quantum fluctuations strongly enhance the dispersion anisotropy of the nodal excitations and cause strong scattering leading to marginally defined qp's, except in a small neighborhood of the Fermi surface. Disorder has a strong effect on the nematic state and leads to a natural mechanism for the Fermi arcs observed in ARPES experiments.

* Denotes principal investigator.
How Optimal Inhomogeneity Produces High Temperature Superconductivity
S. A. Kivelson (Stanford, UCLA), E. H. Fradkin*
http://w3.physics.uiuc.edu/~efradkin/homepage/efradkin@uiuc.edu
National Science Foundation, NSF DMR-0442537; Department of Energy, A9024 DOE DEFG02-91ER45439

The focus of this project is a "dynamic inhomogeneity-induced pairing" mechanism of high temperature superconductivity (HTC) in which the pairing of electrons originates directly from strong repulsive interactions. Repulsive interactions can be shown, by exact solution, to lead to a form of local superconductivity on certain mesoscale structures, but the strength of this pairing tendency decreases as the size of the structures increases above an optimal size. Moreover, the same physics responsible for pairing within a structure provides the driving force for the Coulomb frustrated phase separation that leads to the formation of mesoscale electronic structures in many highly correlated materials. From this perspective, the formation of mesoscale structures (such as "stripes") in the cuprate superconductors may not be a problem for the mechanism of superconductivity but rather a part of the mechanism itself. This mechanism is not based, as is the BCS mechanism, on the pairing of preexisting well defined and essentially free quasiparticles. Rather, it is based on the physics of strong correlations and low dimensionality. In this approach, coherence and quasiparticles are emergent phenomena.

Local Quantum Criticality in the Nematic Quantum Phase Transition of a Fermi Fluid
M. Lawler, E. Fradkin*
http://w3.physics.uiuc.edu/~efradkin/homepage/efradkin@uiuc.edu
National Science Foundation, DMR-0442537

We discuss the finite temperature properties of the fermion correlation function near the fixed point theory of the charge nematic quantum critical point (QCP) of a metallic Fermi system. We show that though the fixed point theory is above its upper critical dimension, the equal time fermion correlation function takes on a universal scaling form in the vicinity of the QCP. We find that in the quantum critical regime, this equal-time correlation function has an ultra-local behavior in space, while the low-frequency behavior of the equal-position auto correlation function is that of a Fermi liquid up to subdominant terms. This behavior should also apply to other quantum phase transitions of metallic Fermi systems.

Aspects of Cuprate Superconductivity
A. J. Leggett*
aleggett@uiuc.edu
John D. and Catherine T. MacArthur Foundation; University of Illinois Center for Advanced Study

Researchers are exploring a scenario for cuprate superconductivity in which a major factor is the reduction, due to increased screening by the Cooper pairs, of the long-wavelength, mid-infrared-frequency part of the Coulomb interaction.

Experimentally Oriented Studies of Basic Conceptual Issues in the Foundations of Quantum Mechanics
A. J. Leggett*
aleggett@uiuc.edu
John D. and Catherine T. MacArthur Foundation

Researchers are studying the application of the quantum-mechanical formalism to the description of various experiments that severely test one's understanding of its meaning. In addition, researchers study possible alternative explanations of ostensibly relevant experiments in the literature.

Theoretical Studies of Dilute Alkali Gases and Amorphous Materials
A. J. Leggett,* M. C. Yeh, D. C. Vural, P. Ghosh, G.-J. Zhu, S.-Z. Zhang, V. Vakaryuk, M. Pham, J-T. Yu
aleggett@uiuc.edu
National Science Foundation, DMR-03 50842

We are attempting to explore the hypothesis that the amazing universality observed in the properties of amorphous materials below 1 K is a consequence of the coupling of localized modes (of an arbitrary nature) by the long-range elastic interaction. We are also investigating the problem of formation of topological defects in quenching, both in the context of alkali gases in optical lattices and in that of very degenerate Fermi systems. We also investigate the "BEC-BCS crossover" problem in the system of very dilute Fermi alkali gases.

Mottness and Strong Coupling
R. G. Leigh,* P. Phillips,* T-P. Choy
University of Illinois

This ongoing project concerns high Tc superconductivity in the cuprates. This system, besides being one of the great unsolved problems in physics, has many similarities to strongly coupled systems familiar to particle physicists. An interesting aspect of models is UV/IR mixing (a

* Denotes principal investigator.
phenomenon that has occurred in several places recently in theoretical physics): the high energy scales feed into low energy physics. In constructing a consistent low energy description, we find that new degrees of freedom (independent of the electronic degrees of freedom) emerge in the low energy theory and make important contributions to a variety of phenomena that have been, or could be, studied experimentally.

**Random Field Ising Model In and Out of Equilibrium**
Y. Liu, K. A. Dahmen*

*National Science Foundation, DMR 03-14279 and DMR 03-25939*

We present numerical studies of a zero-temperature Gaussian random-field Ising model (zt-GRFIM) in both equilibrium and nonequilibrium. We compare the no-passing rule, mean-field exponents, and universal quantities in 3-D (avalanche critical exponents, fractal dimensions, scaling functions, and anisotropy measures) for the equilibrium and nonequilibrium disorder-induced phase transitions. We show compelling evidence that the two transitions belong to the same universality class.

**Development of Fundamental Methods for Prediction of Properties of Materials under Extreme Conditions**
R. M. Martin,* D. M. Ceperley,* S. Chiesa, M. Casula, T. Beaudet

rmartin@uiuc.edu

U.S. Army, A6062 Army UMC00005071-3

*In cooperation with the Army Research Lab, University of Missouri, and other universities in the MURI grant*

The goal of this research is to enable accurate first-principles simulations of the properties of materials under extreme conditions, especially at high temperatures and pressures. The work focuses primarily upon quantum Monte Carlo (QMC) methods, including diffusion, Path Integral, and Coupled Electron Ion Monte Carlo. The primary applications are to materials containing first-row elements H, C, N, and O, including selected benchmark calculations for definitive comparison with experiments, and simulations of materials under conditions beyond the capabilities of direct experimental analysis.

**Devil's Staircases, Quantum Dimer Models, and Stripe Formation in Strong Coupling Models of Quantum Frustration**
S. Papanikolaou, K. S. Raman, E. Fradkin*

http://w3.physics.uiuc.edu/~efradkin/homepage/efradkin@uiuc.edu

*National Science Foundation, DMR-0442537*

We construct a two-dimensional microscopic model of interacting quantum dimers that displays an infinite number of periodic striped phases in its T=0 phase diagram. The phases form an incomplete devil's staircase and the period becomes arbitrarily large as the staircase is traversed. The Hamiltonian has purely short-range interactions, does not break any symmetries of the underlying square lattice, and is generic in that it does not involve the fine-tuning of a large number of parameters. Our model, a quantum mechanical analog of the Pokrovsky-Talapov model of fluctuating domain walls in two-dimensional classical statistical mechanics, provides a mechanism by which striped phases with periods large compared to the lattice spacing can, in principle, form in frustrated quantum magnetic systems with only short-ranged interactions and no explicitly broken symmetries.

**Quantum Criticality and Lines of Fixed Points in a Doped Quantum Dimer Model**
S. Papanikolaou, E. Luijten, E. Fradkin*

http://w3.physics.uiuc.edu/~efradkin/homepage/efradkin@uiuc.edu

*National Science Foundation, DMR 0442537; U.S. Department of Energy, A9024 DOE DEFG02-91ER45439.*

*In cooperation with the Frederick Seitz Materials Research Laboratory*

We study a doped quantum dimer model with a ground-state wave function whose amplitudes are the Gibbs weights of a classical dimer model with attractive interactions for parallel neighboring dimers, and a fugacity of holes. We investigate the phase diagram via analytic methods and Monte Carlo simulations. We confirm the existence of a Kosterlitz-Thouless transition at zero doping from a quantum critical phase to a columnar phase. At low hole density we find a dimer-hole liquid and a columnar phase, separated by a critical line with varying exponents. The line ends at a multicritical point where the transition becomes first order, and the system phase separates.

* Denotes principal investigator.
**Strong Electron Correlations and Quantum Critical Phenomena**  
P. Phillips,* D. Galanakis, T. P. Choy, S. Chakraborty  
*National Science Foundation, DMR 06-05769  

This project focuses on the discovery and understanding of new states of matter that occur when the interactions among electrons are very large and lead to strong correlations in their motion. High temperature superconductors are examples of a class of materials in which strong interactions among electrons lead to new states of matter. Among the states of matter that the PI will study are the insulating state that arises as a consequence of strong interactions among electrons, known as a Mott insulator, and new states of matter that may be hidden in a transformation that takes place between superconducting and insulating states observed in thin films. The PI will focus on developing theoretical tools and new ideas to elucidate the underlying physics of key experimental systems and to understand how new metallic states arise.

**Random Matrix Theory and Transport of Wave Intensities in Complex Structures**  
R. L. Weaver,* O. Lobkis  
http://www.physics.uiuc.edu/people/WeaverR/index.htm  
r-weaver@uiuc.edu  
National Science Foundation, CMS 05-28096  

In cooperation with the Universidad Nacional Autónoma de Mexico (UNAM)

We concern ourselves with prediction of mesoscopic wave phenomena from statistical knowledge of classical trajectories. A diffusing particle picture for the flow of mean probability in complex systems is used to estimate the dynamical features of mean square time-domain S-matrices for waves coupled in and out through one perfectly open channel. A random process with that mean square, and with the additional constraint of unitarity, is then found to lead to plausible S-matrices with familiar mesoscopic wave dynamics. Features that are generated by this procedure include enhanced backscatter, quantum echo, power law tails, level repulsion, spectral rigidity, and Anderson localization.

**Fermi Liquid Instabilities in the Spin Channel**  
C. Wu, K. Sun, E. Fradkin,* S. Zhang  
http://w3.physics.uiuc.edu/~efradkin/homepage/  
efradkin@uiuc.edu  
National Science Foundation, DMR-0442537; U.S. Department of Energy, A9024 DOE DEFG02-91ER45439  

In cooperation with the Frederick Seitz Materials Research Laboratory

We study the Fermi surface instabilities of the Pomeranchuk type in the spin triplet channel with high orbital partial waves \( (F_3) \) with \( \langle l=0 \rangle \). The ordered phases are classified into two classes, dubbed the \( \alpha \) and \( \beta \)-phases by analogy to the superfluid \(^3\text{He}-A\) and \(^3\text{He}-B\)-phases. The Fermi surfaces in the \( \alpha \)-phases exhibit spontaneous anisotropic distortions, while those in the \( \beta \)-phases remain circular or spherical with topologically nontrivial spin configurations.

* Denotes principal investigator.
in momentum space. In the α-phase, the Goldstone modes in the density channel exhibit anisotropic overdamping. The Goldstone modes in the spin channel have nearly isotropic underdamped dispersion relation at small propagating wavevectors. Due to the coupling to the Goldstone modes, the spin wave spectrum develops resonance peaks in both the α and β-phases, which can be detected in inelastic neutron scattering experiments. In the \( p \)-wave channel β-phase, a chiral ground-state inhomogeneity is spontaneously generated due to a Lifshitz-like instability in the originally nonchiral systems. Possible experiments to detect these phases are discussed.

**Theoretical High-Energy Physics**

**Elementary Particle Theory**  
A. X. El-Khadra,* R. G. Leigh,* S. S. Willenbrock,*  
M. Edalati, M. E. Gamiz Sanchez, S. Wiesenfeldt,  
C. Bouchard, S. Dong, R. T. Evans, J. Jottar, R. Jain,  
W. Link, N. Nguyen Hoang, S. Nowling, R. Putman,  
J. Sayre, C. Zhang  
*U.S. Department of Energy, DEFG02-91ER40677*

The high-energy theory group has a wide variety of research interests. Topics include the top quark, electroweak symmetry breaking, quantum chromodynamics and lattice field theory, standard-model phenomenology, dynamical supersymmetry breaking, duality in supersymmetric field theory and string theory, M theory, and grand unification.

**Lattice QCD at High Precision**  
A. X. El-Khadra,* R. T. Evans  
*06237 RB El-Khadra*

The theory of the strong interactions, quantum chromodynamics, has resisted attempts at a quantitative understanding of its nonperturbative dynamics, which limits our knowledge of the fundamental parameters of the standard model. My work is motivated by the application of lattice QCD to the phenomenology of the standard model. Most recently, we were able to successfully predict the D and D\(_s\) meson decay constants after a careful analysis of all systematic errors. We are currently calculating other important weak processes in the D and B meson systems. This research is essential to the experimental physics program at the precision frontier.

**Standard Model Phenomenology with Lattice QCD**  
A. X. El-Khadra,* M. E. Gamiz Sanchez, C. Bouchard,  
R. T. Evans, R. Jain  
*U.S. Department of Energy, DEFG02-91ER40677*

The theory of the strong interactions, quantum chromodynamics, has resisted attempts at a quantitative understanding of its nonperturbative dynamics, which limits our knowledge of the fundamental parameters of the standard model. My work is motivated by the application of lattice QCD to the phenomenology of the standard model. Most recently, we were able to successfully predict the D and D\(_s\) meson decay constants after a careful analysis of all systematic errors. We are currently calculating other important weak processes in the D and B meson systems. This research is essential to the experimental physics program at the precision frontier.

**Topological Invariants and Matrix Models**  
S. Katz*  
katzs@uiuc.edu  
*National Science Foundation, DMS02-44412*  
*Harvard University*

This is an interdisciplinary physics/mathematics project. We have found connections between topological string theory and mathematics, enriching both fields. One area of progress is the development of a duality between string theory and the statistical mechanics of melting crystals, the string coupling constant corresponding to the inverse temperature. On this campus, we have focused on aspects related to the Donaldson–Thomas theory, which relates holomorphic Chern–Simons gauge theory, topological string amplitudes, and algebraic geometry in mutually enriching ways. Other local projects include topological D-branes, the development of topological string theory on supermanifolds, and theories with (0,2) supersymmetry.

**Some Problems in Algebraic Geometry with Connections to String Theory**  
S. Katz*  
*National Science Foundation, DMS 05-55678*

A series of problems are proposed in algebraic geometry, inspired by string theory. Some problems in string theory relating to algebraic geometry are also proposed. These include the study of algebro-geometric invariants related to topological string amplitudes: Gromov-Witten, Gopakumar-Vafa, and Donaldson-Thomas invariants, all conjecturally related to each other. Particular problems include a rigorous definition of Gopakumar-Vafa invariants and their generalization from Calabi-Yau threefolds to more general threefolds, their computation in

* Denotes principal investigator.
examples, and verification of the GW-GV correspondence, beginning with toric varieties and contractible curves. These invariants will be extended to threefolds that are not Calabi-Yau. Computational methods for Gromov-Witten and Donaldson-Thomas invariants are proposed. Several connections to physics will be pursued, including black hole entropy techniques.

The project is a continuation of the exciting process of cross-fertilization between string theory in physics and geometry in mathematics. In string theory, the fundamental particles of nature are small vibrating strings, and physical properties depend on the geometry of the space that strings propagate in, much as the shape of a drum affects the sound that it makes. Physically relevant properties can be determined by calculations in pure geometry, in this instance calculations of intrinsic interest in mathematics. When physical methods of duality provide more than one mathematical model, a consequence is a deep, unexpected insight into geometry. In this project, the principle investigator will develop tools to investigate the mathematical validity of some of these predictions and will expand the geometric investigation beyond the physically relevant context. The researcher also will apply geometric techniques to advance understanding of string theory, especially as it describes the statistical mechanics of a black hole. The primary mathematical content is the counting of curves in curved spaces called Calabi-Yau threefolds, which form the small extra dimensions in string theory. The techniques of Donaldson-Thomas theory have been applied to directly compute Gopakumar-Vafa invariants.

**Confinement in Quantum Chromodynamics**
R. G. Leigh*
*U.S. Department of Energy

In cooperation with Virginia Tech University

The solution of Yang–Mills theory, used to describe the interactions of quarks and gluons, is a long-standing unsolved problem. This theory is strongly coupled at low energies, and confines the quarks and gluons into gauge-invariant states (glueballs, mesons, baryons). A basic problem is to derive the mass spectrum of this theory. Recently, we have employed a reparameterization of the theory to derive an expression for the wave-functional of the Yang–Mills vacuum in a certain approximation, and employed this to derive the masses for the glueball spectrum (glueballs are the gauge-invariant particle-like states in this theory without quarks). The remarkable thing about this prediction is that they agree to within a few percent with the "experimental" lattice data. We are continuing this work in attempts to include quarks and to go to 3+1 dimensions.

**Entanglement Entropy**
R. G. Leigh*, E. Fradkin, S. Nowling, S. Dong
*U.S. Department of Energy

The concept of entanglement entropy between two subsystems makes an appearance in black hole physics and more recently in condensed matter physics (for example, it has been discussed in the context of quantum hall fluids). It has also recently been given an interpretation holographically, in field theories that have a gravitational dual description. We have initiated a research program of computing entanglement entropy in interacting field theories. The most explicit computations have been done in free two-dimensional field theories. It is clear that the phenomenon is much more general, and there is an interesting universal structure present.

**Gravitational Duality**
R. G. Leigh,* A. C. Petkou
*U.S. Department of Energy

In cooperation with the University of Crete

This is a series of studies employing methods of AdS/CFT duality, particularly in the case of a four-dimensional gravitational system and the corresponding three-dimensional field theory. This research involves the study of underlying structure of the duality and of interesting properties of three-dimensional conformal field theories, which have applications in other areas of physics.

**Superstring Theory**
R. G. Leigh*
rgleigh@uiuc.edu
*U.S. Department of Energy
University of Helsinki

Superstring theory is our only candidate for a consistent unification of quantum field theory and gravity. It provides a framework in which an understanding of the components of the standard model of particle physics may be sought. Research here includes studies of the nonperturbative aspects of string theory, including the special role played by D-branes, which are multidimensional solitonic states. We study possible realizations of the standard model and also consider cosmological aspects of the theory.

* Denotes principal investigator.
Web-Based High-Energy Particle Physics Event Generation
T. Stelzer*
tstelzer@uiuc.edu
National Science Foundation, PHY 04-26272

The primary goal of this project is to develop tools to facilitate the generation of event samples for complex high-energy particle physics processes. There are several components to the project, which will result in an upgraded software program running on a dedicated computing farm with an interactive web-based interface. Users will be able to request a process of interest via a simple web form. All of the relevant subprocesses and all of the Feynman diagrams associated with each subprocess would then be generated and displayed. The user can also request the desired process to be run, resulting in a cross-section calculation, a standard set of distributions, and an event sample, which can also be downloaded for further analysis.

Strong and Electroweak Interactions and their Unification
willen@uiuc.edu
U.S. Department of Energy, DEFG02-91ER40677 Task P

The theory of the strong nuclear force, called quantum chromodynamics, allows for perturbative calculations at high-energy colliders. We are developing a method to make these calculations more precise, by isolating the truly perturbative physics from the nonperturbative physics. In addition, we are computing some of the most important processes beyond leading order in perturbation theory. We are also studying grand-unified models in which the strong nuclear force is unified with the electroweak force. These models predict physics beyond the standard model.

Theoretical Nuclear Physics

Theoretical Nuclear Physics
gbaym@uiuc.edu
National Science Foundation, PHY 03-55014, continued as PHY 07-01611

Studies of dense nuclear matter and quark-gluon plasmas, with application to neutron stars and nuclei, including finite temperatures and superfluidity, ultrarelativistic heavy-ion collisions, and radiation from ultrahot sources, are under way. Studies also include nuclear forces and nuclear structure with subfemtometer resolution; quark models of hadron structure; collective motion at finite temperature; and relations with ultracold atomic physics, including rapidly rotating Bose-Einstein condensates and trapped fermions.

Journal Articles

Atomic, Molecular, Optical Physics and Quantum Information Science


* Denotes principal investigator.


VanDevender, A. P. and Kwiat, P. G. **High-speed transparent switch via frequency upconversion.** *Optics Express,* 15:8, 4677-4683 (Apr. 2007) (http://dx.doi.org/10.1364/OE.15.004677).


**Complex Systems**


Cosmology


Experimental Biological and Biomolecular Physics


Kim, H., Ling, S. C., Rogers, G. C., Kural, C., Selvin, P. R., Rogers, S. L., and Gelfand, V. I. Microtubule binding by dynactin is required for microtubule organization but not cargo transport. Journal of Cell Biology, 176:5, 641-651 (Feb. 2007) (http://dx.doi.org/10.1083/jcb.200608128).


Experimental Condensed Matter Physics


**Dressed spin of $^3$He.**  

**Neutron transversity measurement at Jefferson Lab with a polarized $^3$He target.**  

Salahi, M., Peng, J.-C., and Terlaky, T.  
**On Mehrotra-type predictor-corrector algorithms.**  

**Measurement of angular distributions of Drell-Yan dimuons in $p+d$ interactions at 800 GeV/c.**  

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**Experimental Particle Physics**

**First measurement of the $W$ boson mass in run II of the Tevatron.**  

**Measurement of the $p+p \rightarrow t\bar{t}$ production cross section and the top quark mass at $\sqrt{s} = 1.96$ TeV in the all-hadronic decay mode.**  

**Search for exclusive $\gamma\gamma$ production in hadron–hadron collisions.**  

**Search for new particles leading to $Z + \text{jets}$ final states in $p+p$ collisions at $\sqrt{s} = 1.96$ TeV.**  


Abulencia, A., Budd, S., Ciobanu, C. I., Errede, D., Errede, S., Gerberich, H., Grundler, U., Junk, T. R., Kraus, J., Marino, C. P., Pitts, K. T., Rogers, E., Tafford, A., Veramendi, G., Zhang, X., et al. Measurement of the ratios of branching fractions \( \mathcal{B}(B^0_s \rightarrow D_s^- \pi^+ \pi^- \pi^+ \pi^-) / \mathcal{B}(B^0 \rightarrow D^- \pi^+ \pi^+ \pi^-) \) and \( \mathcal{B}(B^0_s \rightarrow D_s^- \pi^-) / \mathcal{B}(B^0 \rightarrow D^- \pi^+) \). *Physical Review Letters*, 98:6, 061802 (Feb. 2007) (http://dx.doi.org/10.1103/PhysRevLett.98.061802).


Abulencia, A., Budd, S., Ciobanu, C. I., Errede, D., Errede, S., Gerberich, H., Grundler, U., Junk, T. R., Kraus, J., Marino, C. P., Pitts, K. T., Rogers, E., Tafford, A., Veramendi, G., Zhang, X., et al. **Measurement of $\sigma_{\Lambda_c^0} / \sigma_{b0} \times B(4_b \rightarrow \Lambda_c^+ \pi^-)/B(\bar{B} \rightarrow D^+\pi^-)$ in $pp$ collisions at $\sqrt{s} = 1.96$ TeV.** *Physical Review Letters, 98:12, 122002 (Mar. 2007)* (http://dx.doi.org/doi:10.1103/PhysRevLett.98.122002).


Besson, D., Cawlfield, C., Eisenstein, B. I., Karliner, I., Kim, D., Lowrey, N., Naik, P., Selen, M., White, E. J., Wiss, J. E., et al. Radiative decays of the $\Upsilon(1S) \rightarrow \gamma \pi^0 \eta$, $\gamma \eta$ and $\gamma \eta'$. *Physical Review D*, 75, 072001 (Apr. 2007) (http://dx.doi.org/doi:10.1103/PhysRevD.75.072001).


**Other Physics Research**


Theoretical Astrophysics


Prodanović, T., Fields, B. D., and Beacom, J. F.  Diffuse gamma rays from the Galactic Plane: Probing the "GeV excess" and identifying the "TeV excess".  *Astroparticle Physics*, 27:1, 10-20 (Feb. 2007) (http://dx.doi.org/10.1016/j.astropartphys.2006.08.007).


Theoretical Biological and Biomolecular Physics


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**Theoretical Condensed Matter Physics**


Weaver, R. L. *Wave diffusion and mesoscopic dynamics, towards a universal time-dependent random scattering matrix.* New Journal of Physics, 9, 8 (Jan. 2007) (http://dx.doi.org/10.1088/1367-2630/9/1/008).


**Theoretical High-Energy Physics**


**Theoretical Nuclear Physics**


**Books**

**Experimental Condensed Matter Physics**


**Experimental Nuclear Physics**


**Book Chapters**

**Complex Systems**


**Experimental Biological and Biomolecular Physics**


Papers Presented at Conferences and Symposia

Complex Systems

Hubler, A. W. and Phelps, K. C.  

Experimental Condensed Matter Physics

Park, W. K., Greene, L. H., Sarrao, J. L., and Thompson, J. D.  

Weissman, M. B.  

Experimental Nuclear Physics

Hertzog, D. W.  

Hertzog, D. W.  

Ogawa, A. and Grosse Perdekamp, M.  

Seidl, R., Ogawa, A., and Grosse Perdekamp, M.  

Experimental Particle Physics

The CDF II level 1 track trigger upgrade. 15th IEEE Real Time Conference (Batavia, IL, Apr. 2007) (2007) (http://dx.doi.org/10.1109/RTC.2007.4382856).


Physics Research and Education


Feil, A. and Mestre, J.  
Theoretical Astrophysics


Theoretical Condensed Matter Physics


Theoretical High-Energy Physics


Theoretical Nuclear Physics

Multimedia

Theoretical Astrophysics


Theses

Atomic, Molecular, Optical Physics and Quantum Information Science


Complex Systems


Experimental Biological and Biomolecular Physics


Experimental Condensed Matter Physics


Experimental Nuclear Physics


Experimental Particle Physics


### Theoretical Astrophysics


### Theoretical Biological and Biomolecular Physics


### Theoretical Condensed Matter Physics


### Theoretical High-Energy Physics


### Theoretical Nuclear Physics


### Patents


### Awards and Honors

**Peter M. Abbamonte**

International Research Fellowship, National Science Foundation, 2000-2001
Incomplete List of Teachers Ranked as Excellent, Spring 2007

**Gordon A. Baym**

Fellow, Alfred P. Sloan Foundation, 1965
Fellow, American Physical Society, 1968
Fellow, American Academy of Arts and Sciences, 1981
Member, National Academy of Sciences, 1982
Fellow, American Association for the Advancement of Science, 1983
Fellow, Alexander von Humboldt Foundation, 1983-1988
Professor, University of Illinois Center for Advanced Study, 1985-1986
University Scholar, University of Illinois, 1987-1988
Tau Beta Pi Daniel C. Drucker Eminent Faculty Award, University of Illinois College of Engineering, 1999
Member, American Philosophical Society, 2000
Hans Bethe Prize of the American Physical Society, 2002
Fisher Distinguished Professor of Engineering, 2002
Lars Onsager Prize, American Physical Society, 2008

Douglas H. Beck
Fellow, Alfred P. Sloan Foundation, 1991
Beckman Fellow, University of Illinois Center for Advanced Study, 1992
Young Investigator Award, National Science Foundation, 1992
Associate, University of Illinois Center for Advanced Study, 1996
Fellow, American Physical Society, 2002
University Scholar, University of Illinois, 2001-2003

Alexey Bezryadin
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2002
Research Fellow, Alfred P. Sloan Foundation, 2002
Fellow, University of Illinois Center for Advanced Study, 2003
Xerox Faculty Research Award, University of Illinois College of Engineering, 2004

Raffi Budakian
World Technology Award, 2005

David M. Ceperley
Arnold O. Beckman Award, University of Illinois Center for Advanced Study, 1989
Xerox Award for Faculty Research, University of Illinois College of Engineering, 1990
Fellow, American Physical Society, 1992
Fellow, American Academy of Arts and Sciences, 1999
Eugene Feenberg Memorial Medal, 1995
Rahman Prize, American Physical Society, 1997
Member, National Academy of Sciences, 2006
Founder Professor of Engineering, 2006

Shau-Jin Chang, Emeritus
Fellow, American Physical Society
Fellow, Alfred P. Sloan Foundation, 1972-1976

Yia-Chung Chang
Fellow, American Physical Society, 2001

Tai-Chang Chiang
IBM Faculty Development Award, 1984

Xerox Award for Faculty Research, University of Illinois College of Engineering, 1984
Presidential Young Investigator Award, National Science Foundation, 1985-1989
Fellow, American Physical Society, 1986

S. Lance Cooper
Andersen Award for Excellence in Undergraduate Advising, University of Illinois College of Engineering, 1992, 1996
Sony Faculty Scholar, 2003-2006
Fellow, American Physical Society, 2003
Excellence in Lecturing Award, University of Illinois Student Senate, 2006
Accenture Award for Excellence in Academic Advising, 2006, 2007
Multi-Year Faculty Achievement Award, University of Illinois College of Engineering, 2007

Karin Dahmen
Research Fellow, Alfred P. Sloan Foundation, 2001
Beckman Fellow, University of Illinois Center for Advanced Study, 2001

Paul T. Debevec
Fellow, American Physical Society, 2002

Brian DeMarco
Top Ten Scientific Breakthroughs, "Onset of Fermi degeneracy in a trapped atomic gas," Science Magazine, 1999
Outstanding Doctoral Thesis Award (DAMOP thesis prize), Atomic, Molecular, or Optical Physics, American Physical Society, 2002
Young Investigator Award, U.S. Office of Naval Research, 2004
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2004
Winner, Amazing Light Competition, 2005
Geneseo Outstanding Young Alumnus Award, State University of New York, 2006
Beckman Fellow, University of Illinois Center for Advanced Study, 2006-2007
Sloan Research Fellowship, 2006-2007

James N. Eckstein
Arnold O. Beckman Research Award, Research Board, University of Illinois, 2001
Fellow, American Physical Society, 2005

Bob I. Eisenstein, Emeritus
Everitt Award for Teaching Excellence, University of Illinois College of Engineering, 1983
Aida X. El-Khadra
Outstanding Junior Investigator Award, U.S. Department of Energy, 1996
Research Fellow, Alfred P. Sloan Foundation, 1997
Xerox Award for Faculty Research, University of Illinois College of Engineering, 1997
Beckman Fellow, University of Illinois Center for Advanced Study, 1998-1999
Collins Award for Innovative Teaching, University of Illinois College of Engineering, 2000
Frontier Fellow, Fermilab, 2002
Center for Advanced Study Associate, 2007-2008

Steven M. Errede
Fellow, American Physical Society
Fellow, Alfred P. Sloan Foundation
Rossi Prize, American Astronomical Society, 1989
Associate, University of Illinois Center for Advanced Study, 1991
University Scholar, University of Illinois, 1991

C. Peter Flynn
Fellow, American Physical Society
Fellow, American Society of Metals

Eduardo Fradkin
Associate, University of Illinois Center for Advanced Study, 1990
Fellow, J. S. Guggenheim Foundation, 1998
Fellow, American Physical Society
Arnold O. Beckman Award, 2006-2007

Charles Gammie
Faculty Fellow, National Center for Supercomputing Applications, University of Illinois, 2001
Presidential Early Career Award for Scientists and Engineers (PECASE), 2002
Beckman Fellow, University of Illinois Center for Advanced Study, 2002-2003
Faculty Early Career Development Program (CAREER) Award for Outstanding Research/Teaching, National Science Foundation, 2001
Fellow, American Physical Society, 2006
Sony Faculty Fellow, 2005-2008

Russell W. Giannetta
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2003
Fellow, American Physical Society, 2007

Gary E. Gladding
Associate, University of Illinois Center for Advanced Study, 1988

Rose Award for Teaching Excellence, University of Illinois College of Engineering, 1998
Fellow, American Physical Society, 1999
Teaching Excellence Award, University of Illinois College of Engineering, 2000
BP Amoco Award for Innovation and Excellence in Undergraduate Teaching, University of Illinois, 2001
Fellow, American Physical Society, 2002
Collins Award for Innovative Teaching, 2004
Excellence in Undergraduate Teaching Award, American Association of Physics Teachers, 2005

Paul Goldbart
Beckman Associate, University of Illinois Center for Advanced Study, 1988, 1995-1996
Presidential Young Investigator Award, National Science Foundation, 1991
Xerox Award for Faculty Research, University of Illinois College of Engineering, 1992
University Scholar, University of Illinois, 1996
Fellow, American Physical Society, 2001
Nordsieck Award for Excellence in Teaching, 2005
Fellow, Institute of Physics (UK), 2007

Nigel Goldenfeld
Fellow, American Physical Society
Fellow, Alfred P. Sloan Foundation, 1987
Beckman Fellow, University of Illinois Center for Advanced Study, 1988
Xerox Award for Faculty Research, University of Illinois College of Engineering, 1991
University Scholar, University of Illinois, 1994-1997
Nordsieck Award for Excellence in Teaching, 2002
Swanlund Chair, University of Illinois, 2007

Ido Golding
Academic Achievement Award, Dothan Foundation, 2000
Fellowship, Lewis Thomas Bristol-Myers Squibb, 2001

George Gollin
Presidential Scholar, 1971
Harvard National Scholar, 1971-1975
Phi Beta Kappa
Beckman Associate, University of Illinois Center for Advanced Study, 1997
College of Engineering Advisors List for Advising Excellence, 2001
Nordsieck Award for Teaching Excellence, 2003
Rose Award for Teaching Excellence, University of Illinois College of Engineering, 2004

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Andrew V. Granato, Emeritus
Fellow, American Physical Society
Fellow, Acoustical Society of America
Fellow, J. S. Guggenheim Foundation, 1959
Associate, University of Illinois Center for Advanced Study, 1971-1972
Senior U.S. Scientist Award, Alexander von Humboldt Foundation, Germany, 1976
Zener Medal, 11th International Conference on Internal Friction and Ultrasonic Attenuation in Solids, 1996

Laura H. Greene
Beckman Award, University of Illinois, 1993
Maria Goeppert-Mayer Award, American Physical Society, 1994
Beckman Associate, University of Illinois Center for Advanced Study, 1995-1996
Fellow, American Association for the Advancement of Science, 1996
Fellow, American Academy of Arts and Sciences, 1997
E. O. Lawrence Award for Materials Research, U.S. Department of Energy, 1999
Fellow, American Physical Society, 1993
Swanlund Endowed Chair, 2000
Fellow, Phi-Kappa-Phi Honor Society, 2001
Visiting Professor, Centre National de la Recherche Scientifique, Orsay, France, 2004
Distinguished Alumna, The Ohio State University, 2005
Phi Beta Kappa Visiting Scholar, 2005-2006
Member, National Academy of Sciences, 2006
Editor-in-chief of Reports on Progress in Physics, 2007-Fellow, Institute of Physics (UK), 2007

Matthias Grosse Perdekamp
RIKEN Fellow, Brookhaven National Laboratory
Relativistic Heavy Ion Collider (RHIC), 2002-2007

Taekjip Ha
Searle Scholar, 2001
Research Corporation Innovation Award, 2001
Outstanding Young Researcher Award, Association of Korean Physicists in America, 2001
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2002
Fluorescence Young Investigator Award, 2002
Research Fellow, Alfred P. Sloan Foundation, 2003
Beckman Fellow, Center for Advanced Study, 2003

Xerox Award for Faculty Research, University of Illinois College of Engineering, 2003
Cottrell Scholars Award, 2003
Howard Hughes Medical Institute (HHMI) Investigator, 2005
Fellow, American Physical Society, 2005
Michael and Kate Bárány Award for Young Investigators, Biophysical Society, 2007

David Hertzog
Fellow, University of Illinois Center for Advanced Study, 1989
Everitt Award for Teaching Excellence, University of Illinois College of Engineering, 1994
W. M. Keck Award for Teaching Excellence, University of Illinois, 1994
University Scholar, University of Illinois, 2000
Fellow, American Physical Society, 2000
BP Amoco Award for Innovation in Undergraduate Teaching, University of Illinois, 1997, 2003
Fellow, J. S. Guggenheim Foundation, 2004

Lillian Hoddeson
Fellow, American Physical Society, 1993
Sally Hacker Prize, 1999
Associate, University of Illinois Center for Advanced Study, 1998
Alumni Scholar, University of Illinois Liberal Arts and Sciences, 2000
Fellow, J. S. Guggenheim Foundation, 2000
LAS Faculty Fellow, History and Cognitive Psychology, 2001
Thomas Siebel Chair in the History of Science, University of Illinois, 2007

Leland E. Holloway, Emeritus
Fellow, American Physical Society
Associate, University of Illinois Center for Advanced Study, 1977-1978

Alfred Hubler
Robert Maxwell Fellow, Santa Fe Institute, 1991
Associate, University of Illinois Center for Advanced Study, 1991
BP Amoco Foundation Award for Innovation in Undergraduate Instruction, University of Illinois, 1996

Icko Iben, Jr., Emeritus
Member, National Academy of Sciences
Fellow, J. S. Guggenheim Foundation
George Darwin Prize
University Scholar, University of Illinois, 1985
E. Atlee Jackson, Emeritus
Fellow, American Physical Society

Sheldon Katz
Regents Professor, Oklahoma State University, 1999-2002
Southwestern Bell Professor, Oklahoma State University, 1997-99
Department Head, University of Illinois Department of Mathematics, 2006

Miles V. Klein, Emeritus
Fellow, American Academy of Arts and Sciences
Fellow, American Physical Society
Emeritus Member, University of Illinois Center for Advanced Study
Member, National Academy of Sciences, 1998
Fellow, Alfred P. Sloan Foundation, 1963
Associate, University of Illinois Center for Advanced Study, 1979-1980
University Scholar, University of Illinois, 1989
Frank Isakson Award, American Physical Society, 1990
Fellow, American Association for the Advancement of Science, 1991

Ulrich E. Kruse, Emeritus
Fellow, American Physical Society

Paul G. Kwiat
Sigma Xi, 1987
Sigma Pi Sigma, 1987
Lise-Meitner Postdoctoral Fellowship, 1993-1995
J. R. Oppenheimer Postdoctoral Fellowship, 1995-1998
Fellows Prize, Los Alamos National Lab, 1999
Bardeen Chair, University of Illinois Department of Physics, 2001
Fellow, American Physical Society, 2002
Fellow, Optical Society of America, 2004
J. David Murley Milestone Award, 2004
Descartes Prize, 2004
Young Scholars Award, Amazing Light Competition, 3rd Place, 2005

Frederick K. Lamb
Fellow, American Physical Society
Fellow, J. S. Guggenheim Foundation
Fellow, Royal Astronomical Society, U.K.
Fellow, Alfred P. Sloan Foundation, 1974

Brand and Monica Fortner Endowed Chair in Theoretical Astrophysics, University of Illinois College of Engineering, 1998
Member, American Academy of Arts and Sciences, 2005
Leo Szilard Prize, American Physical Society, 2005

Anthony J. Leggett
Maxwell Medal and Prize, Institute of Physics, U.K., 1975
Fellow, Royal Society, U.K., 1980
Eleventh Fritz London Memorial Award, 1981
Ninth Simon Memorial Prize, Institute of Physics, U.K., 1981
John D. and Catherine T. MacArthur Chair, University of Illinois, 1983
Member, University of Illinois Center for Advanced Study, 1983
Fellow, American Physical Society, 1985
Fellow, American Institute of Physics, 1985
Member, American Philosophical Society, 1991
Paul Dirac Medal, Institute of Physics, U.K., 1991
Member, American Academy of Arts and Sciences, 1996
Member, National Academy of Sciences, 1997
Foreign Member, Russian Academy of Sciences, 1999
Honorary Fellow, Institute of Physics, U.K., 1999
Eugene Feenberg Memorial Medal, 1999
Wolf Foundation Prize in Physics, 2002-2003
Nobel Prize in Physics, Royal Swedish Academy of Sciences, 2003
Knight Commander, Order of the British Empire (KBE), 2005

Robert G. Leigh
Arnold O. Beckman Award, University of Illinois, 2004
Fellow, American Physical Society, 2007

Tony M. Liss
Fellow, American Physical Society
University Scholar, University of Illinois
Arnold O. Beckman Award, University of Illinois Center for Advanced Study, 1988
Fellow, Alfred P. Sloan Foundation, 1991
Beckman Associate, University of Illinois Center for Advanced Study, 1995-1996
Xerox Award for Faculty Research, University of Illinois College of Engineering, 1997

Naomi C. R. Makins
Research Fellow, Alfred P. Sloan Foundation, 1999
Richard M. Martin
Fellow, American Physical Society
Senior Scientist Award, Humboldt Foundation, 1994
Fellow, American Association for the Advancement of Science, 1996
Sabbatical Scholar, Lawrence Livermore National Laboratory, 2000-2001
General Councilor, American Physical Society, 2004
CU International Humanitarian Award, 2005

Nadya Mason
Junior Fellow, Harvard Society of Fellows, 2002-2005
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2007-2010

Jose P. Mestre
Selected one of “125 Alumni to Watch,” University of Massachusetts, 1988
Distinguished Faculty Lecturer, University of Massachusetts, 2000-2001
Chancellor’s Medal, University of Massachusetts, 2001

Jack M. Mochel, Emeritus
Fellow, American Physical Society
Research Fellow, Alfred P. Sloan Foundation, 1968

Telemachos Mouschovias
Trumpler Award, 1977
Fellow, Alfred P. Sloan Foundation, 1980
Fellow, University of Illinois Center for Advanced Study, 1980
Fellow, J. S. Guggenhein Foundation, 1993-1994
Alexander von Humboldt Re-invitation Award, 1994

Alan M. Nathan
Fellow, American Physical Society
Associate, University of Illinois Center for Advanced Study, 1998-1999

Munir H. Nayfeh
Grainger Emerging Technology Award, 2003

Mark Neubauer
Arnold O. Beckman Research Award, University of Illinois, 2007

Jen-Chieh Peng
Fellow, Los Alamos National Laboratory, 1996
Fellow, American Physical Society, 1993

Philip W. Phillips
General Councilor, American Physical Society
Beckman Associate, University of Illinois Center for Advanced Study, 1998-1999
Xerox Award for Faculty Research, University of Illinois College of Engineering, 1998
Edward Bonchot Award, American Physical Society, 2000
Fellow, American Physical Society, 2002
University Scholar, 2003
Bliss Faculty Scholar, College of Engineering, 2005

Kevin T. Pitts
Beckman Fellow, University of Illinois Center for Advanced Study, 2001-2002
Collins Scholar, University of Illinois, 2000
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2004
Award for Excellence in Undergraduate Advising, Honorable Mention, University of Illinois, 2005, 2006
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2007

Klaus Schulten
Parker Fellow, 1970-1972
Nernst Prize, Deutsche Bunsengesellschaft fur Physikalische Chemie, 1981
Ludwig-Schaefer Award, Columbia University, 1985
DuPont Young Faculty Award, 1989
Arnold O. Beckman Award, University of Illinois Center for Advanced Study, 1989
Fellow, American Physical Society, 1993
Mr. & Mrs. James R. Martin University Scholar, University of Illinois, 1996
Swanlund Endowed Chair, University of Illinois, 1996
Humboldt Award, Alexander von Humboldt Foundation, 2004
Scientific Advisory Board of the Max-Planck-Institute Dortmund (Germany)
Mats Selen
Research Fellow, Alfred P. Sloan Foundation, 1995
Presidential Faculty Fellow Award, National Science Foundation, 1995
Xerox Junior Award for Faculty Research, University of Illinois College of Engineering, 1996
Research Corporation Cottrell Scholar Award, 1996
Everitt Award for Teaching Excellence, University of Illinois College of Engineering, 1997
Honorary Knight of St. Pat, University of Illinois Engineering Council, 1997
Teaching Excellence Award, College of Engineering, 1998
Collins Award for Innovative Teaching, University of Illinois College of Engineering, 2001
Engineering Council Award for Excellence in Advising, University of Illinois, 2001
Xerox Senior Award for Faculty Research, University of Illinois College of Engineering, 2002
Co-spokesman of the CLEO-e particle physics experiment, 2004
Fellow, Center for Advanced Study, 2004
Fellow, American Physical Society, 2006

Paul Selvin
Honors Program, University of Michigan, 1979-1982
Graduate Student Fellowship, National Science Foundation, 1983-1986
Mass Media Science and Engineering Fellow, American Academy of Arts and Sciences, 1990
Congressional Fellow, Office of Technology Assessment, 1990
Research Innovation Award, Research Corporation, 1999
Young Fluorescence Investigator Award, Biophysical Society, 1999
Beckman Fellow, University of Illinois Center for Advanced Study, 2000
Cottrell Scholar, Research Corp, 2000
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2000
Xerox Award for Faculty Research, University of Illinois College of Engineering, 2000
Fellow, American Physical Society, 2004
John Bardeen Sony Faculty Scholar, University of Illinois Department of Physics, 2004-2007
Michael and Kate Bárány Award for Young Investigators, Biophysical Society, 2004
Biophysical Society Council, 2004
Faculty Member of the Precision Proteomics Research Theme, Institute for Genomic Biology, 2005

The International Raymond and Beverly Sackler Prize in Biophysics, Tel Aviv University, 2006
University Scholar, University of Illinois, 2006-2007

Stuart L. Shapiro
Research Fellow, Alfred P. Sloan Foundation, 1979
Teaching Citation, 1985, 1988, 2003
Fellow, American Physical Society, 1998
Fellow, J. S. Guggenheim Foundation, 1989
IBM Supercomputing Competition, First Prize, 1991
Forefronts of Large-Scale Computation Award, 1990
Fellow, Institute of Physics (U.K.), 2005

Ralph O. Simmons, Emeritus
Fellow, American Association for the Advancement of Science
Fellow, American Physical Society
Rhodes Scholar, 1950-1952
University Scholar, University of Illinois, 1986-1989
Associate, University of Illinois Center for Advanced Study, 1986-1987
Senior U.S. Scientist Award, Alexander von Humboldt Foundation, Germany, 1991-1992
Distinguished Alumni Achievement Award, University of Illinois College of Engineering, 2007

Charles P. Slichter, Emeritus
Member, American Academy of Arts and Sciences
Member, American Philosophical Society
Member, National Academy of Sciences
Professor, University of Illinois Center for Advanced Study
Fellow, American Association for the Advancement of Science
Fellow, American Physical Society
Fellow, International Society of Electron Spin Resonance
Honorary Doctor of Science, University of Waterloo
Research Fellow, Alfred P. Sloan Foundation, 1955
Irving Langmuir Prize, American Physical Society, 1969
Wakefield Recognition Award, University of Illinois College of Engineering, 1975
International Society of Magnetic Resonance Prize, 1986
Tau Beta Pi Daniel C. Drucker Eminent Faculty Award, University of Illinois College of Engineering, 1989
Comstock Award, National Academy of Sciences, 1993
Oliver E. Buckley Prize in Condensed Matter Physics, American Physical Society, 1995
Honorary Doctor of Law, L.L.D., Harvard University, 1996

Michael Stone
Outstanding Advisors List, University of Illinois College of Engineering, 2005

Jeremiah D. Sullivan, Emeritus
Member, American Academy of Arts and Sciences
Fellow, American Association of the Advancement of Science
Fellow, American Physical Society
Research Fellow, Alfred P. Sloan Foundation, 1968
Leo Szilard Lectureship Award, American Physical Society, 2000

Jon J. Thaler
Fellow, American Physical Society, 1998
Associate, Center for Advanced Study, University of Illinois, 2005-2006

Dale J. Van Harlingen
Member, National Academy of Sciences, 2003
Fellow, American Academy of Arts and Sciences, 2000
IBM Research Award, 1982
Xerox Award for Faculty Research, University of Illinois College of Engineering, 1995
Fellow, American Physical Society, 1996
Oliver E. Buckley Prize in Condensed Matter Physics, 1998
University Scholar, University of Illinois, 1998
Fellow, J. S. Guggenheim Foundation, 2001
Donald Biggar Willett College of Engineering Professorship, 2003
Professor, University of Illinois Center for Advanced Study, 2005

Smitha Vishveshwara
Faculty Early Career Development Program (CAREER) Award, National Science Foundation, 2007

Benjamin D. Wandelt
Faculty Fellow, National Center for Supercomputing Applications, 2003-2004
Center for Advanced Study Beckman Fellow, 2004-2005
Sofja Kovalevskaja Award (declined), 2006
Marcel Grossman Fellowship, 2006
Friedrich Wilhelm Bessel Research Award, Alexander von Humboldt Foundation, 2006

William D. Watson, Emeritus
Fellow, American Physical Society
Research Fellow, Alfred P. Sloan Foundation, 1974
Associate, University of Illinois Center for Advanced Study, 1977-1978

Richard L. Weaver
Fellow, Acoustical Society of America, 1996
Associate editor, Journal of the Acoustical Society of America, 2001-
Hetenyi Award, Society for Experimental Mechanics, 2004
Engineering Council Excellence in Advising Award, 2006, 2007

Michael Weissman
Fellow, American Physical Society

Scott Willenbrock
Superconducting Super Collider (SSC) Fellowship, Texas National Research Laboratory Commission, 1992-1993
Fellow, University of Illinois Center for Advanced Study, 1996-1997
Outstanding Teacher of Freshmen Award, Alpha Lambda Delta National Honor Society, 1998
Rose Award for Teaching Excellence, University of Illinois College of Engineering, 2001
Fellow, American Physical Society, 2007

James E. Wiss
Research Fellow, Alfred P. Sloan Foundation, 1982
Fellow, American Physical Society, 2000

James P. Wolfe
Fellow, American Physical Society
Fellow, University of Illinois Center for Advanced Study, 1979
Beckman Fellow, University of Illinois Center for Advanced Study, 1982
Senior U.S. Scientist Award, Alexander von Humboldt Foundation, Germany, 1988-1989
Frank Isakson Award, American Physical Society, 2003