Cornell University
Department of Physics

Faculty Research
2011-12

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B.A., 1976, Carleton College. M.S., 1979, University of Chicago. PhD., 1984, University of Chicago. Research Associate, Stanford Linear Accelerator Center, 1984-1988. Assistant Professor, Cornell University, 1988-1993; Associate Professor, Cornell University, 1993-1998; Professor, Cornell University, 1998-present; Director of Graduate Studies, Physics Department, Cornell University, 2001-2006. Presidential Young Investigator, 1990-1996. Visiting Foreign Scholar, KEK, Japan, 1997-1998. Fellow, American Physical Society, 1999. Director, On leave at CERN, 2010-2011.

Research Areas
Experimental particle physics, Beyond the Standard Model physics, LHC, ILC, particle detector technology and instrumentation

Current Research
Why *does* the Standard Model work? What is *beyond* the Standard Model? What is the Higgs mass, and what keeps it there? What gives the Higgs potential its unique and all-important shape?

Thoughts of this sort have lead physicists to invent countless scenarios for *New Physics*, scenarios which sometimes require additional spatial dimensions, sometimes new "fermionic" dimensions of spacetime, and invariably predict new particles and new interactions. But until we get enough data from very high energy collisions, we can't know what the right scenario is. Even then we will have to work very hard to figure out what the data are telling us!

Our group is part of the CMS Collaboration at CERN. In 2009 the LHC began physics operations, and we are now collecting data at 7-TeVcenter-of-mass energy -- high enough to begin to probe the crucial region where new physics should show up. This should lead to the appearance of new phenomena, and the number of questions that can be pursued in this environment will be enormous. Here are just a few of the things which interest me most and are likely to dominate my research directions:

- If the new physics is Supersymmetry (this is where the fermionic spacetime dimensions come in) then what are the masses of the neutralinos and charginos? What are the best strategies for extracting these signals from the data? Where in the vast parameter space of Supersymmetry does the pattern of masses seem to put us? Is the lightest neutralino a possible candidate for the Dark Matter of our universe? In fact, is the pattern of observations consistent with "R-parity" conservation? This is needed for there to be a dark matter candidate in the first place. Can we be clever enough to extract from the complicated and incomplete LHC data any information at all -- even hints -- about the masses or spin of the new particles?
- If the new physics is the existence of "extra" spatial dimensions, can we distinguish this from Supersymmetry? Many of the phenomena will look rather similar, especially in LHC data. Will our initially very limited view up the Kaluza-Klein towers allow us to count the number of extra dimensions or measure their size, even roughly? What is the dark matter candidate in this case? What symmetry keeps it from decaying, and can we see evidence for this symmetry?
- Beyond the question of the neutralinos and charginos, in the Supersymmetric scenario, what other supersymmetric partners do we see, and what are their masses? Can we see sleptons and squarks? The heavy Higgs particles H, A, and H^+, H^-?
- And last but not least, what if the world beyond the Standard Model is nothing like the usual suspects would have it? What are the phenomena? Do we see missing energy events? If not, what shall we do about Dark Matter? Do we at least see the Standard Model Higgs? If not.... what

should we be looking for? What are the issues that matter if everything we have thought of for the last 25 years has to be set aside??

These questions are just some of the many that one could pursue. They attract me both because of their close connection to cosmology and the unresolved identity of Dark Matter (which plays such a crucial role in the evolution of the universe), and because of their access -- their *experimental* access -- to the staggeringly fundamental question of what spacetime actually is, and how many dimensions (of what type!) there are in the universe we inhabit.

As a starting point in this vast landscape of questions and unknowns, I am working on the problem of mass determination of New Physics particles produced under conditions where incomplete information severely complicates the problem of mass measurement. Working with me are two graduate students, Nic Eggert and Nathan Mirman, and two undergraduates, Ben Nachman and Adam Dishaw. We are presently working on a benchmark problem, a simultaneous measurement of the top, W, and neutrino masses in top quark decay. This purely Standard Model measurement is kinematically very similar to what we expect to deal with in Supersymmetry, so it is an excellent place to test, validate, and hone the measurement techniques. These techniques depend on a set of novel kinematic variables which have been much discussed in the phenomenology literature over the last decade, but have not been used in an actual experiment. Until now, that is... On the side I also work on the general problem of measuring and calibrating missing transverse momentum, which is critical to the mass determination schemes.

In the background, I have projects in detector development both for future CMS tracking and for ILC accelerator diagnostics. I also enjoy outreach projects and have a strong commitment to our undergraduate research program.

Graduate Students

Nic Eggert (CMS) and Nathan Mirman (CMS)

Professor Tomas A. Arias

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Research Areas

Linking the ab initio quantum mechanical description of materials to the physical behavior of real materials, involving identification of problems where the quantum perspective can make a significant impact, exploitation of theoretical techniques and supercomputer architectures to carry out large scale quantum calculations, and development of new theoretical techniques to link ab initio calculations with phenomena on larger scales. Current application areas include mechanical properties of nanoscale systems including carbon nanotubes, fundamental processes involved in crystal growth, quantum mechanics of systems in contact with a solution, physics of novel solar cell systems

Current Research
The focus of our research group is to calculate ab initio (from first principles) how the rich variety of complex phenomena in condensed matter systems arises from the well-understood, simple underlying interactions among electrons and nuclei. This work is multi-faceted and involves developing understanding of interacting many-body systems, unraveling physics spanning wide ranges of length- and time- scales, and learning how to describe thermal effects occurring in phase spaces with complex topologies. Answering the questions which underlie these issues requires work in a broad range of disciplines including mathematics, numerical analysis, software development and supercomputer architecture, many-body theory, and condensed matter physics. My students contribute to a rich mix of applications and more far-reaching theoretical problems of their own choice according to their tastes and talents. Our students generally publish three to four papers before graduation.

Current topics of interest include development of wavelet and excited-state methods for electronic structrure calculations, phonon-phonon couplings in one-dimensional systems (carbon nantubes), internal friction in materials, interaction of carbon nanotubes with surfaces, surface chemistry, organic solar cells, photoelectrochemical cells, and development of new fundamental descriptions of the interaction of water with quantum systems.

Graduate Students
Jeehye Lee, Kendra Weaver, Ravishankar Sundararaman and Katie Schwartz

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Research Areas
Accelerator Physics, Photoinjectors, Space Charge Dominated Beams, Next Generation X-ray Sources, Energy Recovery Linacs

Current Research
My field of research is accelerator and beam physics, a discipline rich in complex non-linear dynamics phenomena, theoretical and computational challenges. We design, build, and use the state-of-the-art experimental equipment for exploration of beam physics questions and provide tools for inquiry into the fundamental aspects of nature. Relativistic electron (and sometimes positron) accelerators are also known as the brightest human-made light sources in the widest range of photon energies.

Some of the topics in my research include photoinjectors, space charge dominated beams, linear and nonlinear beam dynamics, next generation X-ray sources such as energy recovery linacs and free-electron lasers.

Check out my Research page at http://www.lepp.cornell.edu/~ib38/research.html

Some of the members of my group & close collaborators: Drs Luca Cultrera, Bruce Dunham and Xianghong Liu.

Graduate Students
Colwyn Gulliford, Siddharth Karkare and Jared Maxson

Undergraduate Students
Rick Merluzzi, Yoon Woo Hwang, Andrew Gasbarro, Ashwathi Iyer and Benjamin Pichler.

Professor Rachel Bean
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B.A Hons (Natural Sciences), Cambridge University, England, 1995. MSc (Quantum Fields and Fundamental Forces), Imperial College, London, England, 1999. Ph.D. (Theoretical Physics), Imperial College, London, England, 2002. Postdoctoral Researcher, Dept. of Astrophysical Sciences, Princeton University, 2002-2005. Assistant Professor, Astronomy, Cornell University, 2005-2011. Associate Professor, Astronomy, Cornell University, 2011-present. Research Corporation Cottrell Scholar, 2008-present, NSF CAREER award, 2009-present, White House Office of Science and Technology Presidential Early Career Award 2010.

Research Areas
Particle cosmology and theoretical astrophysics

Current Research
My research interests include theoretical cosmology and what we can learn from testing theory with astrophysical observations. My theoretical interests involve understanding how the initial conditions that seeded structure were imprinted in the early universe, how high energy particle theory can affect the evolution of the universe, and understanding the theoretical origin of dark matter and dark energy. My research also involves understanding the constraints and implications for theories using astrophysical observations of, for example, the cosmic microwave background, large scale structure and supernovae.

Graduate Students
I am currently working with the following students: Joyce Byun, Istvan Laszlo, Evi Müller

Professor Eberhard Bodenschatz
Adjunct Professor of Physics
Adjunct Professor of Mechanical and Aerospace Engineering

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Vordiplom, Physics, 1982, University of Bayreuth. Diplom, 1985, Physics, University of Bayreuth. Dr. rer nat., 1989, Physics, University of Bayreuth. Research Associate, University of Bayreuth, 1987-1989. Postdoctoral Associate, University of California at Santa Barbara, 1989-92. Assistant Professor, Physics, Cornell, 1992-1998. Associate Professor, Physics, Cornell, 1998-2004. Professor, Physics, Cornell, 2003-2005. Director, Max Plank Institute for Dynamics and Self-Organization 2005-present. Adjunct Professor, Physics, Cornell, 2005-present. Adjunct Professor, Mechanical and Aerospace Engineering, Cornell, 2005-

present. Professor of Physics University of Göttingen, 2007-present. Visiting appointments at: University of California at San Diego; Institute for Theoretical Physics, Santa Barbara. Fellowships and service: Alfred P. Sloan Fellow, 1993-1995. Cottrell Scholar, 1995. Editor in Chief New Journal of Physics, Director of the Materials Research Society, Member of the Advisory Board of arXiv, Member of the Steering Committee of the Kavli Institute for Theoretical Physics, UC Santa Barbara.

Research Areas

Experimental investigation of nonlinear systems in physics, geophysics, biology, and medicine: turbulence, cloud micro physics, thermal convection, cell migration and chemotaxis, cardiac arrhythmias; particle tracking, digital microscopy, high performance image processing, development of advanced measurement techniques, cell and tissue engineering, and computational analysis and modeling.

Current Research

Nonlinear out-off-equilibrium systems impact all levels of our everyday lives from ecology, sociology and economics, to biology, medicine, chemistry and physics. Typically these systems show self-organization and complex, sometimes unpredictable spatio-temporal dynamics. Although different in detail, the temporal and spatial structure of these systems can often be described by unifying principles.
Searching for and understanding these principles is at the center of our group's research. To achieve this goal, we are focusing on well-defined problems in the physics of fluid dynamics, of cellular biology, and of medical relevance. Currently we are investigating experimentally and theoretically pattern formation and spatiotemporal chaos in thermal convection. We study particle transport in the fully developed turbulence of simple and complex fluids with its implication to fundamental theories, but also to practical issues like turbulent mixing and particle aggregation. We collaborate on the topic of turbulence with Zellman Warhaft and Lance Collins from Mechanical and Aerospace Engineering, G. Ahlers from UCSB, D. Lohse from Twente, Alain Pumir from ENS Lyon, Ray Shaw from the Michigan Tech., Holger Siebert from the Leibniz Institute for Tropospheric Research in Leipzig, and Joerg Schumacher from the Technical University Illmenau. Together with the cardiologists Robert Gilmour and the physicist Flavio Fenton at the Veterinary School at Cornell University, Gerd Hasenfuss at the Heart Center of the University of Göttingen, Valentin Krinski at the MPIDS, Stefan Luther at the MPIDS, and Alain Pumir from ENS Lyon we investigate the dynamics of the mammalian heart at the cellular and organ scale. In collaboration with groups at the University of California at San Diego, at the University of Göttingen, at the MPIDS and the University of Potsdam we conduct experiments in biophysics and nano-biocomplexity using micro-fluidic devices to probe and to understand the spatio-temporal dynamics of intra-cellular and extra-cellular processes.

Postdocs associated with this group

Greg Bewley, Azam Gholami, Mathieu Gibert, Xiaozhou He, Noriko Oikawa, Ganapati Sahoo, Ewe-Wei Saw, Marco Tarantola and Hengdong Xi

Senior Research Associates associated with this group

Holger Nobach, Haitao Xu and Vladimir Zykov

Visiting Scientists

Guenter Ahlers (UCSB), Carsten Beta (Potsdam), Denis Fuenfschilling (Nancy), Valentin Krinsky (Nice) and Eckart Meiburg (UCSB)

Graduate Students

Christoph Blum, Kelken Chang, Simon Klein, Sebastian Lambertz, Fabio Di Lorenzo, Jennifer Mutschall, Jose Negrete, Steffen Risius, Christian Westendorf and Florian Winkel

Professor Itai Cohen
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B.S., Physics, 1995, University of California at Los Angeles. Ph.D., Physics, 2001, University of Chicago. Post-doctoral Associate, Physics and Division of Engineering and Applied Science, Harvard University, 2001-2005. Assistant Professor, Physics, Cornell University, 2005–2011. Associate Professor, Physics, Cornell University, 2011– present.

Research Areas

My lab studies emergent physical phenomena that arise from interactions between solid structures – ranging from microscopic particles to macroscopic solid surfaces – and the fluids in which they are embedded. These complex materials are typically out-of-equilibrium and driven beyond their linear response regime. Understanding their mechanical behavior often requires the development of new experimental techniques, analysis tools, and theoretical models. Working towards a fundamental understanding of how these materials respond to various stimuli including shear, electromagnetic fields, acoustical vibrations, and confinement will have a profound effect on our society, ultimately leading to the development of strain stiffening gels for next generation replacement tissues, detergents and pastes whose flow properties can be manipulated, and even small insect mimicking machines that flap their wings to fly.

Current Research

We focus on three areas at the forefront of this broad field: **I) Colloidal suspensions** – where the interactions between microscopic particles suspended in a fluid control the material properties; **II) Biological tissues –** where the organization of cells and biopolymer networks within the fluid controls tissue properties; **III) Fluid-membrane interfaces** – where the interaction between a fluid and a liquid or solid interface controls the resulting flows. Understanding the nested physical principles that act on different length scales in such materials remains one of the most challenging and interesting problems in the field of Soft Condensed Matter Physics.

Confocal Rheometers

One of our main goals is to develop instruments and techniques for simultaneous imaging of the material structure and measurement of its flow properties. To this end, we have built shear cells that can be loaded onto a confocal microscope. These devices allow us to simultaneously image the 3-D structure of materials such as a colloidal suspension or biological tissues while measuring the amount of force necessary to shear them. In this way, the link between material structure at the micron scale and the material properties at the macroscopic scale can be investigated quantitatively.

Fast Video Image Analysis

We have developed 3D image analysis techniques for extracting insect flight kinematic data from high speed videos. Our main goal has been to automate our image extraction so that significantly larger data sets can be attained and analyzed.

Lab Philosophy

This research is inherently interdisciplinary in nature. To this end, we collaborate withnumerous other groups on campus with the aim of producing research results that are greater in scope than the simple cumulative contributions of each individual research group. Nevertheless, my group's ability to design and build table top experiments that combine custom built force measuring devices with techniques in photolithography, microscopy, confocal microscopy, light scattering, high speed imaging, and image analysis, allows us to develop novel approaches for investigating these materials and make unique contributions to these studies.

Postdocs

Tsevi Beatus and Xiang Cheng

Graduate Students
John Mergo, Jesse Silverberg, Neil Lin and Brian Leahy

Undergraduate Students
Ben Nachman and Sam Dillavou

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B.S., 1974, University of Maryland. Ph.D., 1980, Cornell University. 1979-1984, Device Physics Research Department at Bell Laboratories. 1984-1989, Research Manager, Quantum Structures Research Group at Bellcore. 1989-present, Professor of Applied and Engineering Physics, Cornell University. 1989-1995, Director, National Nanofabrication Facility, Cornell University. 1998-2000, Director, School of Applied and Engineering Physics, Cornell University. 2000-2001& 2002-1010 Director, Nanobiotechnology Center, Cornell University. 2001-2002, Interim Dean, College of Engineering, Cornell University.

Research Areas
Physics of Nanostructures

Current Research
The emphasis of our work is on experimental study of the properties of systems of small dimensions. This work involves optical and physical properties of nanostructured materials. A growing number of projects include biological studies of micro/ nanofabricated structures. As a part of this work we investigate new methods and push the limits of creating and examining small structures. These studies include optical studies of single molecules.

Postdocs
Thomas Alava, David Latulippe, Aline Cerf, Vivek Adiga, Jaime Benitez and Chris Kelly

Graduate Students
Rob Barton, Ben Cipriany, Daniel Joe, Kylan Szeto, Chris Wallin and Paul Zhu

Professor Csaba Csaki
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B.Sc. Physics, 1993, Eötvös University, Budapest, Hungary. Ph.D. Physics, 1997, Massachusetts Institute of Technology. Miller Fellow, UC Berkeley, 1997-1999. J. Robert Oppenheimer Fellow, Los Alamos National Laboratory, 1999-2001. Assistant Professor, Physics, Cornell University, 2002-2007. Associate Professor, Physics, Cornell University, 2007-2011. Professor of Physics, Cornell University 2011-present. DOE Outstanding Junior Investigator, 2001-2007.

Research Areas
Elementary particle physics, quantum field theory

Current Research

My research is in the field of elementary particle theory, focusing on physics beyond the standard model. The ongoing LHC collider experiments are expected to shed light on some of the deepest mysteries of particle physics, for example on the origin of mass, and the origin of different scales in physics. The goal of my research is to understand what the plausible theories for physics beyond the standard model are, and what their experimental consequences would be. I am currently focusing on two possible directions. The first is theories with extra spatial dimensions, which could lead to new mechanisms for electroweak symmetry breaking. The second direction is supersymmetry, which is a new form of symmetries that would relate fermionic and bosonic particles to each other, and resulting in the most elegant extensions of the standard model.

Graduate Students

Mathieu Cliche and Philip Tanedo.

Professor J.C. Séamus Davis

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B.Sc., 1983, University College Cork, National University of Ireland. Ph.D., 1989, University of California, Berkeley. Graduate Research Assistant, University of California, Berkeley, 1984-1989. Postdoctoral Research Associate, University of California, Berkeley, 1990-1993. Assistant Professor, Physics, University of California, Berkeley, 1993-1997. Faculty Physicist, L. Berkeley National Laboratory, 1998-2002. Associate Professor, Physics, University of California, Berkeley, 1998-2000. Professor, Physics, University of California, Berkeley, 2001-2002. Professor, Physics, Cornell University, 2003-2007. Senior Physicist, Brookhaven National Laboratory, 2006-present. SUPA Distinguished Research Professor, St. Andrews University, Scotland, 2007-present. J.G. White Distinguished Professor of Physical Sciences, Cornell University, 2007-present. Director, Center for Emergent Superconductivity, Brookhaven National Laboratory, 2009-present. Ehrenfest Lecturer, University of Leiden, Holland, 2002. Pagels Lecturer at the Aspen Center for Physics, 2008. Loeb Lecturer in Physics, Harvard University, 2008. Einstein Lecturer, Weizmann Institute, Israel, 2009. Visiting Professor, University of British Columbia, Vancouver, CA, 2009. Umezawa Lecturer, U. of Alberta, Canada, 2009. Von Borries Lecturer, U. of Tubingen, Germany, 2010. NSF National Young Investigator Award, 1994. Packard Fellow in Science and Engineering, 1994. Alfred P. Sloan Research Fellow, 1996. Miller Research Professor, 2000. Outstanding Performance Award, L. Berkeley National Laboratory, 2001. Fellow of the Institute of Physics, 2002. Fellow of the American Physical Society, 2005. Fritz London Memorial Prize, 2005. H. Kamerling-Onnes Prize, 2009. Member of US National Academy of Sciences, 2010.

Research Areas

We undertake a range of experimental low-temperature research into the fundamental macroscopic quantum physics of superconductors, superfluids, supersolids and heavy fermion systems, as well as developing new techniques for visualization and measurement of complex quantum matter.

Superfluid Josephson Effects

Superfluid ^{3}He Josephson junctions use nano-aperture arrays fabricated at Cornell Nanofabrication Center. Using these devices, we discovered Josephson oscillations in superfluid ^{3}He (***Nature 388***, 449 (1997)), the current-phase relationship of a superfluid Josephson junction (***Science 278***, 1435-1438 (1997)), □-states within Josephson junction of a *p*-wave superfluid weak link (***Nature 392***, 687-690 (1998), ***Nature 396***, 554-557 (1998)) and the first superfluid DC-SQUID (***Nature 412***, 55 (2001)).

These projects were in collaboration with Prof. R. Packard of U.C. Berkeley.

Solid and 'Supersolid' ^4He

A supersolid phase has been reported at high pressure in solid ^{4}He. We have recently developed the first SQUID-based torsional oscillator system for supersolid studies. Using this new approach, we found evidence for a 'superglass' state in solid ^{4}He (***Science 324***, 632 (2009)) and were able to identify a unified relationship between rotational, relaxational, and shear dynamics of this quantum solid (***Science 332,*** 821, (2011)). At present we are exploring the limits of DC mass flow through the putative 'supersolid' state of ^{4}He.

These projects are in collaboration with Dr. A.V. Balatsky of LANL, New Mexico, USA, and Dr. M. Yamashita of Kyoto University, Japan.

Copper-based High Temperature Superconductivity

In 1999 we introduced spectroscopic imaging STM for visualization of electronic structure in complex electronic matter. We have used this approach extensively for studies of copper-based high temperature superconductors. We imaged electronic bound-states at individual impurity atoms (***Science 285***, 88 (1999)) including non-magnetic Zn impurity atoms on in $Bi_2Sr_2CaCu_2O_{8+d}$, ***Nature 403***, 746 (2000) and magnetic Ni impurity atoms in $Bi_2Sr_2CaCu_2O_{8+□}$ (***Nature 411,*** 920 (2001)). We discovered the granular structure of high-T_c superconductivity in underdoped $Bi_2Sr_2CaCu_2O_{8+d}$ (***Nature 413,*** 282 (2001), ***Nature 415***, 412 (2002)). We also found intense incommensurate electronic structure modulations (***Science 266***, 455 (2002), ***Nature 430,*** 1001 (2004), ***Science 314***, 1914 (2006)) and breaking of 90-degree rotational symmetry inside each CuO_2 unit cell (***Science 315***, 1380 (2007), ***Nature 466***, 374 (2010), ***Science 333***, 426 (2011)).

We introduced the quasiparticle interference imaging for STM determination of momentum-space electronic structure in complex electronic materials (***Science 297***, 1148 (2002), ***Nature 422***, 520 (2003)) and used these techniques to determine effects of dopant atom and the approach of Mott insulator state (***Science 309***, 1048 (2005), ***Nature 454***, 1072 (2008)). We studied the microscopic pairing mechanism via the interplay of electron-lattice interactions and superconductivity in $Bi_2Sr_2CaCu_2O_{8+□}$ (***Nature 442***, 546 (2006)) and we also found the spectroscopic fingerprint of phase incoherent d-wave superconductivity (***Science 325***, 1099 (2009)). At present we are exploring the microscopic pairing mechanism of copper-based superconductivity.

The $Bi_2Sr_2CaCu_2O_{8+d}$ project is in collaboration with Prof. S. Uchida of Tokyo University and Dr. H Eisaki of AIST Tsukuba, Japan, the $Ca_{2-x}Na_xCuO_2Cl_2$ project is in collaboration with Prof. H. Takagi of Tokyo University and RIKEN, Japan. Theoretical collaborations are with Prof. D.-H. Lee of UC Berkeley, and Profs. E.-A. Kim and M. Lawler of Cornell University.

Iron-Based High Temperature Superconductivity

In 2009 we introduced spectroscopic imaging STM and quasiparticle interference imaging for visualization of electronic structure in iron-based superconductors. We are using this approach to observe the nematic electronic structure in iron-based superconductors (***Science 327***, 181 (2010)). At present we are using the same approaches to study the pairing symmetry and mechanism of iron-based superconductivity.

The iron-based high-T_c superconductivity project is in collaboration with Prof. P. Canfield of Ames National Lab., Dr. H. Eisaki of AIST, Tsukuba, Japan, and Prof. A. Mackenzie of St. Andrews University, Scotland. Theoretical collaborations are with Profs. E.-A. Kim and M. Lawler of Cornell University.

Electronic Quantum Matter in Transition Metal Oxides

In 2008 we introduced spectroscopic imaging STM for visualization of electronic structure in complex transition metal oxides Heavy d-electron quasiparticle interference and real-space electronic structure of the electronic nematic material $Sr_3Ru_2O_7$ were studied. At present we are using the same approaches to search for the signature of the nematic phase transition in this system.

The $Sr_3Ru_2O_7$ project is in collaboration with Prof. A. Mackenzie of St. Andrews University, Scotland.

Heavy Fermion Superconductivity & Quantum Criticality

In 2010 we introduced spectroscopic imaging STM and quasiparticle interference imaging for visualization of electronic structure of heavy fermions (***Nature 465,*** 570 (2010)). At present we are using the same approaches to explore the properties and effects of Kondo Holes, and the mechanism of heavy fermion superconductivity.

The URu_2Si_2 project is in collaboration with Prof. G. Luke, McMaster University, Canada and Dr. A. Balatsky, LANL, New Mexico, USA.

New Approaches to Visualization of Complex Electronic Matter

We are developing a 20-Tesla Spectroscopic Imaging STM. This will be the highest field SI-STM system in the world and provide research capabilities for visualization of complex electronics matter in very high magnetic fields.

The 20T-STM project is in collaboration with Prof. G. Boebinger of NHMFL, Tallahassee, Florida.

Gravitation at the Nanoscale

We are studying the limits of force and position sensing with nano-mechanical systems and SQUID-based accelerometers at millikelvin temperatures — with a view to developing new force sensing tests for fundamental physics. Of immediate interest is a type of Cavendish Experiment that is designed to detect gravity at micron scale distances and departures from Newton's Law of Universal Gravitation into the nanometer range.

Visiting Scientists

Dr. Tien-Ming Chuang (Academica Sinica, Taipei), Dr. Jinho Lee (Brookhaven Nat. Lab., NY), Dr. Inhee Lee (Brookhaven Nat. Lab., NY).

Postdocs

Dr. Kazuhiro Fujita, Dr. Sourin Mukhopadhyay, Dr. Milan Allan, Dr. Andreas Rost, Dr. Mohammad Hamidian, Dr. Freek Massee.

Graduate Students

Inês Firmo, Vikram Gadagkar, Ethan Kassner, Chung Koo Kim, and Yang Xie

Professor Jerry Feigenson

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B.S. Chemistry, 1968, Rensselaer Polytechnic Inst; Ph.D., 1974, Chemistry, California Institute of Technology; Assistant Professor, Biochemistry, Cornell University, 1974-82; Associate Professor, Biochemistry, Cornell University, 1982-89. Professor, Molecular Biology & Genetics, 1990 - present, Cornell University. Visiting appointments at: Scripps Inst. of Oceanography; Keio University Dept. of Physics, Japan. Honors & Awards: 1980-85 Established Investigator of the American Heart Association; 1996, 2004, and 2011 Outstanding Educator from Merrill Presidential Scholar; 2000 Stephen & Margery Russell Distinguished Teaching Award; 2007 Harry T. Stinson Award for greatest impact on Cornell Biology majors.

Research Areas

Phase behavior of lipid bilayer mixtures and biological membranes

Current Research

My current research is to determine the phase behavior of multicomponent lipid mixtures that are chemically simple models for biological membranes. A fascinating aspect is that the phase coexistence (of two immiscible, 2-dimensional liquids) is driven by cholesterol, and is *structured on the nanometer scale*. We systematically examine each membrane lipid within such complex mixtures, mainly by use of fluorescence microscopy and spectroscopy, and also with ESR and x-ray diffraction studies. We recently started phosphorescence lifetime measurements in order to get information about the microsecond to milliseconds lifetimes of the nanometer-scale phase domains. An interesting aspect is that the behavior of a cell plasma membrane outer half of the bilayer is quite different from the inner half.

Graduate Students

Robin Smith Petruzielo (Physics), Lynda Goh (Biochemistry), Tatyana Konyakhina (Biophysics) and Jon Amazon (Biophysics).

Undergraduate Students

Christina Wang, James Young, Charles Ma, Susan Duan and Mark Wang

Professor Craig J. Fennie
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Ph.D., Physics, 2006, Rutgers University. Nicholas Metropolis Fellow, Argonne National Laboratory, 2006-2008. Assist. Prof. of Applied & Eng. Physics, Cornell University, July 2008–present. ARO Young Investigator Award, 2010-2013. NSF CAREER award, 2011-2016.

Research Area

Theoretical Materials Physics, New Materials by Design

Current Research

We are a cross-disciplinary, highly collaborative group focused on the use of theory to uncover new structurally and chemically complex bulk solids, nanostructures, and interface materials with a particular interest in Correlated Oxides, (multi)Ferroics, and Energy Materials.

Due to their highly tunable ground states, structurally and chemically complex oxides are one of the most promising classes of materials in which to realize new emergent phenomena that could not only challenge our current understanding of condensed matter but also provide real solutions for technological advances. The main thrust of our research is to establish an understanding of how to control the interplay between the diverse microscopic degrees of freedom prevalent in these systems in order to create new and *targeted* macroscopic properties, and to design the never-before-seen material realizations. In order to accomplish these goals we use a combination of microscopic models, symmetry principles, and crystal chemistry to develop a general set of chemically and physically intuitive mechanisms and design rules. We then use first-principles computational techniques such as density-functional theory to screen potential realizations of these rationalized design criteria; first-principles density-functional methods recently have proved a powerful tool for studying the properties of complex materials at the level of atoms and electrons, without the need for empirical input.

Current Projects

Multiferroics and Ferroelectrics: Role of dimensionality and strain in layered perovskites; “Rotation-driven” ferroelectrics; Using interfaces to create strongly-coupled magnetic-ferroelectrics.
Correlated Oxides: Controlling the electronic structure of ruthenate Ruddlesden-Poppers with epitaxial strain; Novel states of matter at complex oxide interfaces.

Energy Materials: Interface phases and heterostructured materials for electrocatalysis; tuning the electronic and optical properties of ferroelectric photocatalyst.
New areas: A Topological Insulator in an oxide?; spintronics

Crucial to the success of our collaborative and multidisciplinary program in theoretical materials physics is a continued dialog with experimentalists. We are an active member of two CCMR IRGs, one on correlated oxides and the other on spintronics, and the EFRC Thrust on complex oxides for electro and photo catalysis.

Graduate students
Turan Briol, Andrew Mulder, Brian Abbett and Mihir Khadilkar

Post-Doctoral Fellows
Nicole Benedek, Hena Das, Saurabh Ghosh, Andrea Salguero, Johanness Voss

Professor Eanna Flanagan
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B.Sc., 1987, Mathematical Science, University College Dublin, Ireland, M.Sc., 1988, Mathematical Science, University College Dublin. Ph.D., 1993, California Institute of Technology. Postdoctoral fellow, California Institute of Technology, 1993-94. Enrico Fermi fellow, University of Chicago, 1994-96. Assistant Professor, Physics and Astronomy, Cornell, 1996-2001. Associate Professor, Physics and Astronomy, Cornell, 2001-2005. Professor, Physics and Astronomy, Cornell, 2006-present. Alfred P. Sloan fellow, 1997-99. Radcliffe fellow, 2002-03. Xanthopoulos prize in gravitation, 2004. Fellow of the American Physical Society, 2008.

Research Areas
General relativity, structure of singularities, radiation reaction of point particles; theoretical astrophysics; gravitational wave astronomy; early Universe cosmology and extra dimensions, brane world cosmology; dark energy, modifications of general relativity; semi-classical gravity

Current Research
My research group works on the physics of strong gravitational fields. We develop quantitative models of processes involving neutron stars, black holes, and the early Universe, which will be useful when compared with data from gravitational wave detectors like the Laser Interferometer Gravitational Wave Observatory (LIGO). Other research topics include the exploration of models of the early Universe involving extra dimensions and membranes, and models of the recent acceleration of the Universe involving modifications of general relativity.

Graduate Students
Jolyon Bloomfield, Naresh Kumar and Justin Vines.

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A.B, 1974, Harvard College. Ph.D., 1978, Princeton University. Research Assistant and Postdoctoral Research Associate, University of Virginia, Charlottesville, 1977-82. Assistant Professor, Physics, Cornell University, 1982-88; Associate Professor, Physics, Cornell University, 1988-present. Visiting Professor, Physics, University of Bristol, England, 1991. Member, American Physical Society.

Research Areas
Experimental biological physics and liquid physics.

Current Research
Our group's interests have been focused on the behavior of liquid, colloidal and living systems on length scales that are much greater than atomic. Currently, our main effort has been directed at understanding the social behavior of microbes as well as the physicochemical apparatus that enables their intercellular communication. We have been particularly interested in the remarkable transition from unicellular to multicellular life that the organism *Dictyostelium discoideum (*``Dicty'') makes in reaction to the removal of its food supply. Recent work by graduate researcher Igor Segota exploited microfluidic technology to measure key elements of the signal-response system necessary for this transition to social life. Specifically, we have been studying the movement of individual amoebae in response to a static gradient of a signaling chemical. Based on earlier work by graduate researcher Elijah Bogart and with assistance from undergraduate researchers Archana Rachakonda, Catherine Lussenhop, Eitan Neidich and Surin Mong, Segota has shown (for this and other work described here, please see our recent papers at http://people.ccmr.cornell.edu/~kip/) that there is a failure in current theory for the fidelity of information passing in such systems. Our current efforts are aimed at replacing this flawed application of Shannon's theory of communication. We are also preparing new experiments that explore the signal processing that chemical-sensing cells perform in the intercellular medium. In other work recent undergraduate researcher Ryan Monaghan and graduate researcher Kayvon Daie have been altering the signaling medium through which extracellular messages may pass and discovering the consequent changes in the means by which Dicty manage to congregate. These perturbations have exploited novel wetting and microfluidic environments. We have also developed theory to match these observations by considering the problem of synchronizing many oscillators via long range chemical signaling.

In recent years, with graduate researchers Igor Segota, Elijah Bogart, Kayvon Daie and Albert Bae and undergraduate researchers Xiao-Xiao Zhou, Amish Deshmukh, Sharon Lau and Archana Rachakonda, Elisabeth Sebesta, Myron Zhang, Benjamin Yavitt, Ariana Strandburg-Peshkin, Sungsu Lee, Kevin Tharratt, Anthony Hazel and Viyath Fernando we have been exploring collective effects in microbial growth. Through bulk suspension cultures and microfluidic flow systems they have been discovering how colonies of cells in suspension make the decision to proliferate, expanding on our earlier work (C. Franck, et al. Phys. Rev. E v. 77, p. 0141905 (2008)). We have developed theories for the necessary intercell signaling through both chemical and mechanical mechanisms. Our latest results heavily favor the former possibility. Our recent work has explored the diversity of growth behaviors possible in this system. We have been developing theory to match by considering intrinsic noise and cell adhesion effects. Our work relies on genetically modified organisms, microscopy (including confocal) augmented by digital image processing, and macroscale and microscale reactor biotechnology. This work strives towards our goal of uncovering the quantitative basis of communication and computation in living matter. In our most recent work, Kevin Tharratt has discovered an exciting memory effect where different growth behaviors are found to be heritable. In an effort to increase the throughput of our observation, we have been developing new automated cell counting systems based on light scattering. Hopefully, we will obtain sufficient instances of growth dynamics to decide between rival theories. Finally we are starting to observe and analyze cell images that we expect to reveal the dynamics and explore the collective nature of cell proliferation in unmixed systems.

Professor Alexander Gaeta
Professor and Director of Applied and Engineering Physics

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Ph.D., 1991, Optics, University of Rochester. Postdoctoral Fellow, University of Rochester, 1991. Assistant Professor, Applied and Engineering Physics, Cornell University, 1992-98. Associate Professor, Applied and Engineering Physics, Cornell University, 1998-2004. Professor, Applied and Engineering Physics, Cornell University, 2004-present. Director, Applied and Engineering Physics, Cornell University, 2011-present. Director, Center for Nanoscale Systems, Cornell University, 2007-present. Fellow, Optical Society of America. Fellow, American Physical Society.

Research Areas
Quantum and Nonlinear Optics

Current Research
Our research is concerned with the interaction of laser light in matter spanning from fundamental quantum optics to the development of novel photonic devices. Current topics include:

- Ultrafast nonlinear optics
- Generation and manipulation of quantum states of light
- Nonlinear nanophotonics
- Spatio-temporal propagation dynamics of intense femtosecond laser pulses
- Ultrahigh-speed all-optical processing
- Nonlinear optical interactions in photonic crystal fibers

Graduate students
Alessandro Farsi, Adrea Johnson, Ryan Lau, Kasturi Saha, Sam Schrauth, Vivek Venkataraman, and Henry Wen

Postdocs
Moti Fridman, Stéphane Clemmen, Michael Lamont, Yoshi Okawachi, Bonggu Shim

In the coming year I will be taking on at least 2 grad students.

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B. A., 1985, University of Chicago. Ph.D., 1993, University of Chicago. Research Associate, University of Rochester, 1993-97. Assistant Professor, Physics, Cornell University, 1997-2004. Associate Professor, Physics, Cornell, 2004-present. Analysis Coordinator, CLEO Collaboration, 1996-97. Software Coordinator, CLEO III, 1997-2000. Member, American Physical Society.

Research Areas
Precision measurements, CP violation, weak interactions, electroweak symmetry breaking, heavy quark physics, experimental particle physics.

Current Research
My research interests center on precision measurements of fundamental parameters in particle physics. I am continuing these pursuits with the new "g-2" experiment, E989, planned to run at Fermilab in 2015. The experiment goals are a determination of the anomalous magnetic moment of the muons– that is, the deviation of its Landé g factor from 2 – to a precision of ~ 0.1 parts per million. At this level of precision, the measurement is sensitive to contributions to the magnetic moment from new fundamental particles outside of the Standard Model. The level of contribution of Beyond Standard Model processes to g-2 varies widely according to the nature of the model, and a g-2 measurement at the precision planned will therefore provide an excellent constraint on the nature of new particles that will be observed directly at the Large Hadron Collider (LHC). The heart of the experiment is the muon storage ring, and I am joined in the Cornell effort by Dave Rubin, who brings considerable accelerator physics expertise. I am involved in work with the detectors that will be used to measure the daughter electrons from the muon decays. The experiment is currently in its design stage, so a student joining now has the rare opportunity to be involved all stages of a modern High Energy Physics (HEP) experiment.

The Cornell HEP group's major focus is the CMS experiment at the LHC. The LHC will be the first collider that will allow us to probe the processes involved in electroweak symmetry breaking, the process by which electromagnetism and the weak interaction come to appear so different at our day-to-day energy scale, and by which all the particles that we know obtain their mass. The collision energies will also be large enough that we may very well produce, and observe directly, new types of fundamental particles!

I am currently exploring techniques to measure the production charge asymmetry of the W bosons produced at CMS. This asymmetry directly probes the up and down quark and antiquark content of the proton, which must be understood extremely well to find new fundamental particles at the LHC and measure their properties. I am also part of a small Cornell group that has been developing a powerful new tool for use in LHC physics analyses, the "MET significance". A common feature of the new processes that we night to find at the LHC are that they often involve production of massive particles that escape without detection because they interact so weakly. As a result, large missing energy is a very interesting signature. The MET significance provides a measure, in every collision, about whether the observed missing energy is real, or is commensurate with arising from the finite measurement capabilities of the detector. It therefore can play a significant role in suppressing backgrounds to physics signatures of interest.

I also lead LEPP's software group, which focuses on design and support of the data analysis infrastructure that will enable physicists to analyze the 2 Petabytes of data expected yearly. In addition to our CMS activities, we are collaborating with computer scientists at the University of Utah on projects that can utilize and track data and scientific provenance information to allow better capture and review of the scientific process.

Recent graduates: Richard Gray, Nadia Adam, Matt Shepherd, Tom Meyer, Veronique Boisvert

Graduate Students
Aleko Khukhunaishvili

Professor Yuval Grossman
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B.Sc., 1990, Physics and Computer Science, Bar-Ilan University. M.Sc., 1993, Theoretical Physics, Weizmann Institute of Science. Ph.D., 1996, Theoretical Physics, Weizmann Institute of Science. Research Associate, Stanford Linear Accelerator Center, Stanford University, 1996-2000. Assistant Professor, Theoretical Physics, Technion, 2000-2003. Associate Professor, Theoretical Physics, Technion, 2003-2007. Associate Professor, Physics, Cornell University, 2007-present. Professor, Physics, Cornell University, 2010- present.

Research Areas
Theoretical high energy physics: Flavor physics (B, D and kaon), neutrino physics, leptogenesis, LHC physics

Current Research
My research is in the field of high energy physics phenomenology. My interests span a wide range of topics in phenomenology: model building, astroparticle physics, neutrinos and collider phenomenology. My main focus is on interpreting experimental data and suggesting new analyses to be done with running and near future experiments. This is the reason that in recent years, I mainly worked on B physics and neutrino physics. In the next few years I expect to continue to work on topics closely related to experiments. That is, beside B and neutrino physics, I see myself involved in topics related to the LHC.

Graduate Students
Josh Berger, Mario Martone, Itay Nacshon, Dean Robinson and Yu-Hsin Tsai

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S.B., 1972, Massachusetts Institute of Technology. Ph.D. 1977, Princeton University. Research Associate, Princeton University, 1977. Assistant Professor, Physics, Princeton University, 1978-85. Associate Professor, Physics, Princeton University, 1985-91. Professor, Physics, Princeton University, 1991-97. Professor, Physics, Cornell University, 1997-present. Director, Cornell High Energy Synchrotron Source (CHESS), Cornell University, 1997-present. Visiting appointments at Exxon Research, Research & Engineering; Institute for Theoretical Physics, U.C. Santa Barbara; Robert Wood Johnson Medical School, Dept. of Pathology. Fellow, American Physical Society.

Research Areas
Biological physics; polymer and other soft condensed matter physics; x-ray and synchrotron radiation science; scientific instrumentation and technique development; development of novel x-ray detectors

Current Research
I direct two related, but independent research efforts:

The Cornell High Energy Synchrotron Source (CHESS) - one of the most powerful and productive synchrotron x-ray facilities in the world. Work at CHESS involves the development of new x-ray synchrotron sources (which is a combination of x-ray and accelerator physics, in collaboration with accelerator physics colleagues in the department) and new ways of using synchrotron radiation.

A biophysics and soft-condensed matter laboratory aimed at understanding the structure and properties of proteins, lyotropic liquid crystals, block co-polymers and mesoporous composites. Examples of experiments underway in Clark Hall include the effects of pressure on protein assemblies, mesomorphism in polymers, the synthesis and properties of nanocomposites, the interaction between membrane proteins and lipid bilayers, the phase behavior of lipid and surfactant liquid crystals, and the development of fast x-ray detectors to probe dynamic matter. The work is diverse and is characterized by collaborations with biologically- and chemically-oriented scientists, the development of new instrumentation and techniques, and the use of synchrotron radiation. We are always looking for a few graduate students who really enjoy doing experimental science.

Research Associates and visiting faculty associated with the group

Mark Tate, Hugh Philipp, Suntao Wang, and Chae Un Kim (CHESS) and Marianne Hromalik (SUNY Oswego)

Graduate Students

Yi-Fan Chen, Kate Green, Jeney Wierman. Co-advised with others: Hiroaki Sai, and Robin Baur

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B.Sc., 1961, Massachusetts Institute of Technology. Ph.D., 1967, California Institute of Technology. Research Associate, CERN, 1967-68. Assistant Professor, Physics, Cornell University, 1968-74. Associate Professor, Physics, Cornell University, 1974-80. Professor, Physics, Cornell University, 1980-present. Visiting appointments include: Stanford Linear Accelerator Center; Osservatoria Astrofisico di Arcetri, Florence Italy; SSC Central Design Group, LBL. Alfred P. Sloan Fellow, 1971-74. Fellow, American Physical Society. Member, American Association for the Advancement of Science.

Research Areas

Accelerator Physics; Superconducting RF acceleration systems and instrumentation for particle accelerators.

Current Areas

My research activities are primarily focused on accelerator physics. Beam size measurements using optical synchrotron radiation are the main activities that I am working on at the moment. This involves using a combination of double slit interferometry and taking advantage of the phase reversal of the electric field vector in the horizontal plane for vertically polarized synchrotron radiation. The depth of the intensity minimum is a very sensitive way to measure small vertical beam sizes. This is part of the CesrTA program. In addition, I am working with our superconducting RF group currently led by Prof. Georg Hoffstadter in developing high gradient superconducting RF cavities suitable for use in an electron positron linear collider. I have developed a technique based on second sound in superfluid helium to locate the site when the quench occurs in these cavities when they are driven to very high gradients. An array of sixteen tranducers can locate the quench site to a few millimeters. This is more accurate and very much simpler than the thermometer arrays used in the past involving many hundreds of thermometers limited to only two cells of a multi-cell cavity. Research Scientists Mingqi Ge and Andriy Ganshyn are working with me on this program. Recently, we have received funding to continue our program on low frequency superconducting RF cavities (200 MHz) suitable for muon beam acceleration. One graduate student would be welcome to participate in either of these programs.

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Research Areas
Theory of frustrated magnetism (classical and quantum), interacting electron systems, quasicrystals, and biological physics

Current Research
My research falls into the areas of frustrated magnetism (classical and quantum), interacting electron systems, quasicrystals, and statistical/biological physics. Much of my work is geometrical, involving nontrivial patterns in space.

In biological physics, I have been interested in the capsid (exterior shell) geometry of viruses. My big current interests are the physical basis of left/right symmetry-breaking in animals (e.g. snails) and in plants, as it involves dynamic arrays of fibers (actin or microtubules) just under the cell membrane (grads Jimmy Shen, AEP, and Ricky Chachra, TAM). Besides this I have a project (Dr. Bo Xu, formerly Princeton, and undergrad Hanrong Shen '11) modeling the partial differential equations for how the chemical signal distinguishing left/right propagates in Zebrafish embryos.

I'm also excited about modeling the mechanics of plant roots as imaged in current experiments at Cornell [undergrad Matt Lapa '12 and other collaborators].

In magnetism, we pursue the statistical physics and/or the quantum ground state of highly frustrated antiferromagnets on the Pyrochlore and related lattices containing corner-sharing triangles, including the classical ground states. [undergad Matt Lapa '12]

We also explore simpler, classical realizations of exotic “topological order” (usually considered quantum mechanical [grad Zach Lamberty]. Currently, we are studying quantum spins and statistical mechanics on percolation clusters[grads Hitesh Changlani and Shivam Ghosh].

In interacting electron systems, I work the border of analytic theory and computation. We are studying the (highly degenerate) ground states of a spinless fermion lattice model with “supersymmetry” [with Dr. Stefanos Papanikolaou, a postdoc in the Sethna group]. We work on the phenomenology of STM measurements on high-Tc cuprates [grad Sumiran Pujari].

In quasicrystals, we want to determine the atomic structure and understand why quasicrystals form. On the atomic scale, we try to use microscopically-derived effective potentials to predict details of the atomic arrangements [visitor Dr. Marek Mihalkovic, undergrad Justin Richmond-Decker, grad Woosong Choi]. Another side is the statistical physics of "random tiling models, a likely explanation of the well-ordered icosahedral quasicrystals, and close packings of unequal spheres as a mathematical toy model related to structure prediction.

Graduate Students
Sumiran Pujari, Zach Lamberty, Hitesh Changlani (shared), Shivam Ghosh, Jimmy Shen (AEP Dept)

(also associated with grads Ricky Chachra, Woosong Choi, and Ben Machta of Sethna group).

Undergraduate Students
Matt Lapa and Justin Richmond-Decker

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Diplom, 1991, Darmstadt University of Technology, Germany. M.S., 1992, and Ph.D., 1994, as NSCL Fellow and Natural Science Fellow, Michigan State University. Dr. habil. (doctor habilitatus), 2000, Darmstadt University of Technology. Research Associate, Deutsches Elektornen-Synchrotron (DESY), Hamburg, Germany, 1994-1996. Faculty, Darmstadt University of Technology, 1996-1998. Accelerator Physicist, DESY, 1998-2002. Associate Professor, Cornell University, 2002-2008. Professor, Cornell University, 2008-present,.Fellow, German National Merrit Foundation.

Research Areas
Physics of Beams; Accelerator Technology

Current Research

The Physics of Beams is the study of accelerated beams as a special state of matter. It has many applications in particle accelerators, spectrometers, electron microscopes, and lithographic devices. These instruments have become so complex that an empirical approach to properties of the particle beams is by no means sufficient and a detailed theoretical understanding is necessary. Historically it has proved fruitful that studies in beam physics have been performed in the context of projects that developed or built one of these instruments, and I have worked on several such projects, on the 4 mile circular accelerator HERA in Hamburg, where I contributed to the understanding of the non-linear dynamics and long term stability of the stored particles, of polarization dynamics, and of space charge forces acting from one particle beam to another. I am coordinating the accelerator science work for the Energy Recovery Linear Accelerator (ERL) Project at Cornell where my interests concern nonlinear beam dynamics, multi bunch instabilities, space charge within a tightly focused beam, the creation of synchrotron light, and the back-reaction of coherently emitted light on the beam. This accelerator will constitute a novel x-ray light source with beams significantly better than those of the world's most advanced facilities. X-ray beams from charged particle accelerators have become an essential tool in today's investigation of all types of materials, from airplane wings to cell membranes and from pollutants in leaves to matter under earth-core pressures. The development of the ERL, envisioned and invented at Cornell, that provides more brilliant beams in shorter pulses will move such investigations to new frontiers.

Accelerator Technology describes the technology used to accelerate large currents of tightly focused beams to high energies. These beams are then used to study elementary particles, to produce synchrotron light for analysis in biophysics, in crystallography, in surface physics, or in the material sciences, for cancer therapy, and for a variety of other applications. Studies with synchrotron light are currently performed by CHESS at Cornell. The technology involved in accelerators is very rich and I am currently mostly interested in the technology required for the Cornell ERL where the energy of accelerated particles is recovered in superconducting cavities in order to accelerate new particles. These particles are produced in a photo cathode electron gun which involves a very complex system of lasers. Subsequently they are accelerated in a superconducting radio-frequency (SRF) linac. I am head of Cornell's SRF laboratory, which is involved not only in SRF for ERLs but also for high-energy elementary-particle accelerators like the ILC, a muon collider, and Fermilab's Project-X.

Research Associates
Christopher Mayes (Linear and Nonlinear Particle Optics, Coherent Synchrotron Radiation, ERL layout)
Valery Shemelin (SRF cavity design, multipacting, measurement of HOM properties)
Andrei Ganshyn (Cryogenic SRF-cavity testing, cryogenic technology, second-sound quench detection)
Mingqi Ge (SRF surface analysis, temperature mapping of high-Q cavities)
Fumio Furuta (High-accelerating-voltage SRF cavities, cryogenic cavity testing, advanced SRF cavity shapes)

Graduate Students
Steve Full (Ion instabilities in rings and ERLs) and Hyeri Lee (Beam dynamics in SRF cavities)

Group meetings:
Tuesdays 10am, SRF students meeting, 311 Newman Lab
Tuesdays 11am, SRF group meeting, 311 Newman Lab
Thursday 1pm, hard X-ray ERL meeting, 380 Wilson Lab

Further information can be obtained by contacting research associates at Wilson Laboratory and at *http://www.lns.cornell.edu/accelphys/* and *http://www.lepp.cornell.edu/Research/AP/SRF/WebHome.html*

Graduate and undergraduate students interested in beam physics and the application of particle accelerators are encouraged to join this group. There are many opportunities for student involvement.

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B.S., Physics, 1998, Seoul National University. M.S., Physics, 2000, Seoul National University. Ph.D., Physics, 2005, University of Illinois at Urbana-Champaign. Postdoctoral Scholar, Stanford University, 2005-2008. Assistant Professor, Physics, Cornell University, 2008-present. Excellence in Teaching Award, University of Illinois at Urbana-Champaign, 2005. John Bardeen Award, University of Illinois at Urbana-Champaign. 2010-2014, NSF CAREER Award

Research Areas
High Temperature Superconductivity; Electronic Liquid Crystals; Complex Oxides; Topological phases

Current Research
My research interests lie in the theoretical study of the collective phenomena condensed matter systems exhibit, and in understanding how such phenomena emerges from microscopic physics. Especially, I have been interested in the physics of strongly correlated systems: systems consisting of many strongly interacting degrees of freedom. Strong correlations can lead to a surprisingly rich diversity of novel phenomena that are highly non-trivial from a single particle perspective. Over the last few decades, new experimental discoveries, through the development of new experimental probes and the fabrication of ever more exotic materials and devices, have been raising unexpected and conceptually deep questions. The possibility of obtaining a non-trivial understanding through a close interaction and synergy with experimental colleagues make the theoretical study of this field exciting and rich.

Among various topics that fall under the above category, I am currently focusing on 1) High Temperature Superconductivity, 2) Electronic Liquid Crystals, and 3) Topological phases.

High Temperature Superconductivity
Unconventional superconductors include cuprate perovskites known for their high Tc superconductivity as well as strontium ruthenates which are candidate chiral p-wave superconductors. The wealth of amazing properties cuprate perovskites display is not limited to high Tc superconductivity, but it also includes quantum antiferromagnetism and the delicate interplay between superconductivity and other forms of order such as charge-density-wave and spin-density wave and glassy states. In addition to the relatively recent discovery of odd-parity superconductivity in strontium ruthenates, the even more recent unexpected discovery of superconductivity in transition metal oxypnictides has rejuvenated excitement in the field.

Electronic Liquid Crystals
Phases with intermediate order include electronic liquid crystals and inhomogeneous phases. Electronic liquid crystalline phases have now been sighted in a number of strongly correlated systems, such as high Landau level quantum Hall state, cuprate perovskites and bilayer ruthenates. The phases with intermediate order can occur as a compromise between momentum space and real space ordering tendencies, when neither the kinetic energy nor the interaction energy is dominant. Recent observations of these phases in well-controlled experiments have opened up a wealth of questions such as mechanisms for electron nematics and their relation to other forms of order, detection and interpretation of intermediate phases.

Topological phases
Topological phases are characterized by the emergence of an effectively enlarged symmetry: topological invariance. This concept is defined by an invariance of the macroscopic properties under smooth deformations of the system. In practice, it implies robustness against local perturbations and against changes of shape or size of the sample, with the prototype of such phenomena being the quantum Hall (QH) effect. The current resurgence of the field is led by new proposals for realizing topological phases, in conjunction with developments in mesoscale fabrication technology. The time is ripe to make progress in this cross-disciplinary field where mathematics, condensed matter physics, field theory, and quantum information meet.

The above discussed are complex and challenging problems which require a variety of theoretical approaches. One system could display more than one of the above intriguing phenomena. My group will pursue much needed understanding of major open problems through simple but relevant model problems amenable to solutions using basic tools, as well as through problems that require sophisticated analytical and numerical tools.

Graduate Students
Darryl Ngai and Kyungmin Lee

Postdoc
Mark Fischer

Professor Michael Lawler
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Research Areas
Condensed Matter Theory

Current Research
My primary interests lie in the field of strongly correlated condensed matter physics. In this field, we seek to gain an understanding of the behavior of many strongly interacting particles. This is a far from well understood subject. However, we are fortunately aided in our exploration of it by an intimate connection between experiment and theory. Below are some of the topics related to this phenomenon that form my particular interest.

Frustrated Quantum Mechanical Systems
The concept of frustration in the classical limit can be illustrated as follows. In the classical limit one can pretend that Heisenberg's uncertainty principle has been "turned off". Hence one can know the exact position and momentum of particles and also the precise direction their spins. These classical particles are then "frustrated" when they have many equal energy configurations so that Newton’s law cannot tell us what they will do next. This can happen, for example, when interacting classical spins are placed on certain lattices such that there are many spin configurations, each of which minimize the total energy.

A central question in the field is what happens when we turn on Heisenberg’s uncertainty principle in a classically frustrated system? The spins can no longer point in a specific direction and it turns out that the laws of quantum mechanics then help the spins decide what they want to do. Should this happen, then the spin system can actually be governed by the laws of quantum mechanics at a macroscopic scale.

Recently, experimentalists have fabricated a number of materials (Herbertsmithite, NIO, κ-BETD, diamond lattice spinels, ...) that may shed much light on the above central question. For some time now, we have had theories of quantum spin liquids based on the emergence of either fermions or bosons interacting via gluons, photons or “visons” as the new particles describing an emergent exotic phase. With these new materials, we can finally compare such theories with experiment, a comparison bound to lead to a new understanding of strongly correlated systems.

Recent papers:
[1] “Emergent gauge dynamics of highly frustrated magnets”, M. J. Lawler, Unpublished. See arXiv:1104.0721.
[2] “Neel and Valence Bond Crystal Order on a Distorted Kagome Lattice: Implications For Zn-Paratacamite”, Erik S. Sørensen, Michael J. Lawler, Yong Baek Kim, Phys. Rev. B, **79**, 174403 (2009)
[3] "Gapless spin liquids on the three dimensional hyper-kagome lattice of Na4IR3O8", MJL, Arun Paramekanti, Yong Baek Kim and Leon Balents, arXiv:0806.4395

Quantum Liquid Crystals
It stands to reason that increasing the strength of interactions between particles in a gas phase will cause them to want to crystalize, to form a solid phase. If the particles are electrons, Wigner discovered in 1931 that this indeed happens. However, a transition to a Wigner crystal phase need not happen directly, but could in principle happen through a series of intermediate phases each progressively more crystalline. Examples of such intermediate phases include the electron “nematic” phase, which spontaneously breaks rotational symmetry, and an electron “smectic” or stripe phase, which involves the formation of an array of one-dimensional electronic “rivers”.

While symmetry provides a guiding principle in the theory of quantum liquid crystals, it alone cannot characterize a quantum world. As such, the general theory is fundamentally incomplete. It is very exciting, therefore, to study quantum liquid crystals found in nature, such as the nematic states found in Sr3Ru2O7 and quantum Hall systems and the stripe phases in cuprate superconductors. An interesting question, for example, is what happens at a continuous phase transition between two quantum liquid crystals? Or, can the stripes in a stripe phase slide freely next to each other? Can electrons in quantum liquid crystals pair easily to form a superconductor? At the heart of these questions is the quantum nature of these new phases, and their answers rely on the deep connection between experiment and theory achievable in condensed matter physics.

Recent papers:
[1] “Topological Defects Coupling Smectic Modulations to Intra-unit-cell Nematicity in Cuprates”. A. Mesaros, K. Fujita, H. Eisaki, S. Uchida, J. C. Davis, S. Sachdev, J. Zaanen, M. J. Lawler, Eun-Ah Kim, Science **333**, 426 (2011)
[2] “Intra-unit-cell electronic nematicity of the high-Tc copper-oxide pseudogap states”, M. J. Lawler, K. Fujita, Jhinhwan Lee, A.R. Schmidt, Y. Kohsaka, Chung Koo Kim, H. Eisaki, S. Uchida, J.C. Davis, J.P. Sethna, Eun-Ah Kim, Nature **466**, 347 (2010)
[3] “Nematic Fermi Fluids in Condensed Matter Physics”, Eduardo Fradkin, Steven A. Kivelson, Michael J. Lawler, James P. Eisenstein, Andrew P. Mackenzie, Annu. Rev. Condens. Matter Phys. **1**, 157 (2010)

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B.S., 1982, Massachusets Institute of Technology. Ph.D., 1987, Harvard University. Postdoctoral Fellow, Princeton University, 1987-89. Assistant Professor, Physics, Cornell University, 1989-95. Associate Professor, Physics, Cornell University, 1995-2003. Professor, Physics, Cornell University, 2003-present. Visiting appointments at: Institute for Theoretical Physics, U.C. Santa Barbara; Centre d'Energie Atomiquie (Saclay), Paris, France; University of Montreal; University of Paris at Jussieu; University Autonoma de Madrid, Spain; Isaac Newton Institute for Mathematical Sciences, Cambridge, UK; Galileo Inst. for Theoretical Physics, Florence, Italy; Ecole Normal Superieur, Paris, France; CBPF, Rio de Janeiro. Awards: Phi Beta Kappa, 1982. Alfred P. Sloan foundation Fellow, 1992. National Young Investigator Award, 1993.

Research Areas
Quantum field theory for condensed matter, mathematical physics, finite temperature field theory, disordered system, high temperature superconductivity

Current Research
High temperature superconductivity in the Hubbard model. Cold atoms.Quantum gases in the unitary limit. BEC/BCS crossover.

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Research Areas
Radio Frequency Superconductivity, Accelerator Physics and Particle Accelerators, ultra-fast Feedback Controls

Current Research
RF Superconductivity

Superconducting radio frequency (RF) cavities are feet-long structures, providing extremely high electric field gradients (tens of MV/m) for the acceleration of particle beams. The electric field inside these cavities oscillates at resonant microwave frequencies (GHz), with exceptional high quality factors of 1E10 to 1E11. By using superconducting materials operated at temperatures between 1.5K and 4K for the walls of the cavities, we can achieve such high quality factors. The evolution in the performance of superconducting cavities has revolutionized the performance and scientific reach of particle accelerators for a variety of science applications, including high energy physics, nuclear physics, synchrotron radiation based research, and high power lasers. Future particle accelerators like the International Linear Collider, the X-ray Free Electron Laser at DESY, a muon accelerator, and the Energy Recovery Linac Light Source planned here at Cornell University all rely on the performance we hope to achieve in next generations of superconducting cavities.

Cornell's Superconducting Radio Frequency (SRF) group is a world leader in the application of superconductivity for accelerating cavities in high energy particle accelerators. We have an extensive, state of the art infrastructure for the design, fabrication, preparation and test of superconducting cavities. Our research program is multi-faceted and interdisciplinary, and therefore ideal suited for graduate research. It ranges from studying the behavior of superconductors in high fields at microwave frequencies to designing RF cavities and whole superconducting linear accelerators to studying the non-linear beam dynamics in superconducting linacs.

<u>Current and Future Research Activities</u>
Superconducting cavities involve research in extreme areas like superconductors of lowest surface resistance, ultra high vacuum and super fluid Helium cryogenics, highest magnetic and electric radio-frequency fields (tens of MV/m), oscillators with quality factors exceeding 10^{10} and vibration control of feet-long structures in the nm range. My current research concentrates on the following areas:

- Understanding of the behavior of superconducting surfaces at low temperatures when exposed to very high electric and magnetic fields at microwave frequencies. The present understanding of the physics of superconductors in high microwave fields has large holes. In the next years we hope to find answers to open questions like: Why does the RF surface resistance increase strongly at high RF fields? What is the critical magnetic field for a superconductor in microwave fields? Can new superconducting materials (niobium-3-tin, new high Tc superconductors …) yield even higher fields and/or lower surface resistance? Answering these questions is of great importance for the future viability of superconductors to provide even higher fields for future frontier energy accelerators.
- Electron beam emittance preservation and beam dynamics in superconducting RF linacs. When a particle beam passes though a superconducting linac, it interacts with the cavity environment. This can lead to excessive fields (Higher-Order-Modes) excited by the beam in the cavities, degradation of the beam quality (emittance growth) and beam instability. Our Cornell ERL injector prototype, which is just starting operation, will give us a unique tool for studying questions like: What is the spectrum of electromagnetic fields excited by the beam? Where is the excited high frequency (10 GHz – 100 GHz) power absorbed? What effects contribute to

emittance growth in an SRF linac, and do measurements agree with numerical simulations of these various effects?

- Developing the superconducting linac technology for future particle accelerators like the Cornell Energy Recovery Linear Accelerator (ERL) and the International Linear Collider. In addition to developing the cavities for these superconducting accelerators, we are developing related and technologically challenging components like RF input couplers, Higher-Order-Mode dampers and frequency tuners. For the ERL, we are designing, building and testing entire, complex SRF cryomodules. This work relates to a wide breath of scientific and engineering questions.
- Ultra-fast feedback systems for particle accelerators. Advanced feedback systems enable us to operate superconducting cavities at highest quality factors while providing particle beams of highest energy stability. One of the key challenges we are presently working on is active vibration compensation for the superconducting cavities in order to stabilize them on an nm scale.

Graduate Students

Nick Valles is studying the behavior of superconductors at highest magnetic RF fields. He is measuring the critical magnetic RF field of the superconductor niobium at low temperatures. He is also working on complex optimization routines for the design of superconducting RF cavities for particle accelerators like the Cornell ERL.

Yie Xi's research focuses on developing a sample test system to measure high field RF properties of higher temperature superconductors like niobium-3-tin and MgB2. In addition his work includes surface analysis of material samples to find correlations between the RF performance of superconductors and their surface properties like roughness and crystal dislocations.

Sam Posen is working with us on exploring the fabrication, physics and performance of higher temperature superconductors like niobium-3-tin in microwave fields. He is fabricating Nb3Sn in an ultra-high vacuum furnace he designed. He is also working on designing and optimizing the next generation cryomodules for the Cornell ERL.

Undergraduate Students

Byeonghee Yu is simulating the performance of superconducting RF cavities during cryogenic testing. Jihwan Oh is working on a new temperature mapping system to measure the distribution of the RF losses in the walls of superconducting RF cavities.

There are many opportunities for motivated undergraduate and graduate student to get involved. Presently, we have openings for one new graduate student. Contact me if you are interested in our work and would like to try us out for a few weeks!

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A.B., Physics and Mathematics, 2000, Harvard University. Ph.D., Physics, 2005, Stanford University. Research Associate, Princeton University, 2005-2007. Assistant Professor, Cornell University, 2007-present. Alfred P. Sloan Research Fellow, 2009-present.

Research Areas

String theory; cosmology

Current Research

My research is in string theory, which is a theory that combines quantum field theory and gravity in a consistent framework. I am interested in using string theory to understand the early universe, and in developing compactifications of string theory that lead to realistic four-dimensional physics.

Recent observations have yielded striking evidence for an inflationary epoch, or something very similar, in the early universe. To date, however, there is no compelling theoretical underpinning for inflation. String theory can provide a robust framework for studying the early universe and for addressing some long-standing puzzles in inflation. If we are fortunate, the interface between string theory and inflationary cosmology may also bring string theory into contact with cosmological observations. This is arguably the most promising route to a test of string theory.

The primary task in this work is to understand the properties of the four-dimensional effective theories associated to specific compactifications of string theory. Questions about the inflaton field can often be mapped into questions about the geometry of the internal space or about the potential governing deformations of this space. One can try to understand the general properties of the effective theories arising from string theory, and at the same time construct explicit examples that illustrate these properties in detail.

Examples of my recent work in this direction include explicit models of D-brane inflation; applications of the AdS/CFT correspondence to determining the structure of D-brane inflation models; a model of large-field inflation based on axion shift symmetries and axion monodromy; signatures of axion monodromy inflation in the CMB spectrum and bispectrum; D-brane probes of nonperturbative effects in flux compactifications; a set of analytic techniques for generating local solutions of supergravity; explorations of inflation in high-dimensional field spaces; and characterization of the dynamics of relativistic D-branes.

I am also interested in using related techniques to understand the phenomenology of particle physics models that arise in string theory. Recent work in this direction includes a study of sequestering in string compactifications.

Graduate Students
Thomas Bachlechner, Sohang Gandhi, Ben Heidenreich and David Marsh

Postdocs
Paul McGuirk and Timm Wrase

Professor Paul McEuen
Goldwin Smith Professor of Physics
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Research Areas
The science and technology of nanostructures, particularly carbon-based systems such as nanotubes and graphene; novel fabrication techniques at the nanometer scale; scanned probe microscopy of nanostructures; assembly and measurement of chemical and biological nanostructures

Current Research
Our research focuses on the fabrication and study of nanostructures. We use these structures to span the gap between the macroscopic and molecular worlds, exploring electronics, optics, mechanics, chemistry and biology at the nanoscale. Current areas of research include the use of carbon nanotubes for optoelectronics, mechanics, and single-molecule biological sensing, and the use of graphene as an atomic membrane that is only one atom thick.

Postdocs
Matt Graham

Graduate Students
Samantha Roberts, Jonathan Alden, Melina Blees, Arthur Barnard, Isaac Storch and Kathryn McGill.

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B.Sc., Mathematics/Physics, 1996, University of British Columbia. Ph.D., Physics, 2001, University of Illinois at Urbana Champaign. Postdoctoral fellow, Physics, The Ohio State University 2001-2003. Assistant Professor, Physics, Cornell, 2003-2009. Alfred P. Sloan Fellow, 2005-2007. Associate Professor, Physics, Cornell, 2009-Present.

Research Areas
Ultracold atomic gases, quantum optics, strongly correlated matter, and exotic quantum phenomena.

Current Research
I study the theory of atoms cooled to nK temperatures. At these temperatures, the classical image of atoms as small billiard balls must be replaced by a quantum mechanical picture of wave-packets. Although, I am focused on basic science questions, this research may impact applications in quantum computing, precision measurement, and navigation.

I am particularly interested in how simple inter-atomic interactions lead to complex collective behavior. I am driven by a belief that studying these atomic systems can help refine our understanding of fundamental physics.

Much of my recent efforts have been dedicated to finding ways of taking important physics from other fields (solid state physics, nuclear physics, and high energy physics) and asking how one can design cold atom experiments to elucidate the phenomena.

My group works closely with a number of experimentalists, both at Cornell and elsewhere. We use an eclectic blend of analytic and numerical techniques.

Graduate Students
Eliot Kapit, Stefan Natu, Bhuvanesh Sundar, and Yariv Yanay.

Professor David A. Muller
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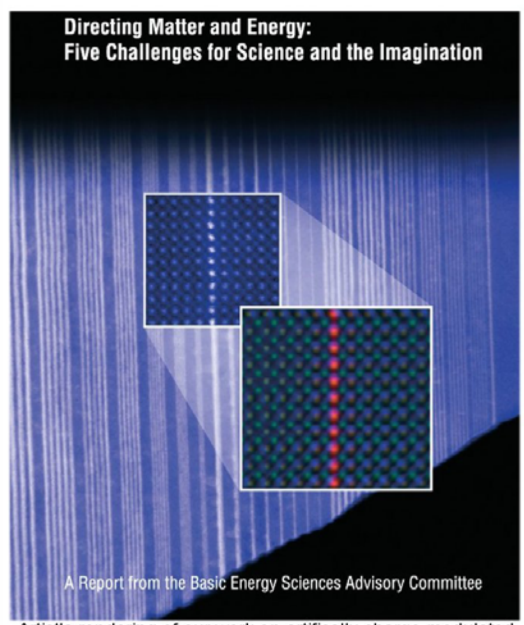
B.Sc. Hons., 1991, Physics, University of Sydney; Ph. D., 1996, Physics, Cornell University; Postdoctoral Associate, Applied Physics, Cornell, 1996-7; Member of Technical Staff, Bell Labs, (Murray Hill) 1997–2003; Assoc. Prof. of Applied Physics, Cornell University, July 2003–2010; Prof of Applied Physics, 2010-present; Co-Director of the Kavli Institute at Cornell for Nanoscale Science, 2010-present; Provost's Award for Distinguished Scholarship, Cornell University 2010; Burton Medal, Microscopy Society of America, 2006; Chau Teaching Award, 2006; TR100: named one of the top 100 young innovators in 2003 by Tech Review Magazine; Cosslett Award, Microbeam Analysis Society, 2002; Best Paper awards, Acta Materiala 1997, Microscopy and Microanalysis 2003&2004.

Research Areas
Imaging Nanotechnology, Physics of Renewable Energy, Atomically-Engineered Materials and Devices

Current Research
Our research at Cornell University is focused on understanding the behavior of materials and devices at the atomic scale. Using some of the most powerful electron microscopes in the world, placed in specially-designed and environmentally isolated rooms, we are able to explore the chemistry, electronic structure and bonding inside objects as diverse as transistors, turbine blades, two-dimensional superconductors and fuel cells. All of these systems are made up of different materials, and where they join at the atomic scale, the boundary conditions on the quantum mechanical wavefunctions force very different behavior from what might be expected of the bulk materials. At these boundaries, where everyday intuition breaks down, we are searching for new and unexpected phases and physics. The impact of this research on devices, both larger and small, could be significant.



Artist's rendering of our work on artifically charge-modulated oxide heterostructures (Nature 419 p 378)

We are interested in students who enjoy both physics theory and experiment, can think in both real and reciprocal space, and care about both why things are, and what they might be used for. Openings are likely in the area of atomically-engineered materials for energy generation, conversion and storage, mapping optical densities of states in photonic structures using relativistic electrons and studies of two-dimensional electronic phases in complex oxides.

More up-to-date details on people and news events can be found at *http://people.ccmr.cornell.edu/~davidm/*

Postdocs
Ye Zhu

Graduate Students
Pinshane Huang, Megan Holtz, Robert Hovden, Qingyun Mao, Julia Mundy (with Schlom) and Yingchao Yu (with Abruna).

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Research Areas
Computational systems biology; complex systems, networks, dynamics, critical phenomena, and pattern formation; biological information processing; gene regulation, signaling and metabolism in bacteria and plants; virulence, host-pathogen interactions, and infectious disease dynamics; scientific computing and software design.

Current Research
My research lies at the intersection of physics, biology, computer science, and computational science, focused on problems such as information processing in biological systems (manifested in processes such as gene regulation, signal transduction, and host-pathogen interactions), dynamics on complex networks (at various scales, from the chemical kinetics of intracellular networks to the spread of infectious diseases in populations), the design and development of software systems for modeling complex biological phenomena, and increasingly on evolutionary processes in such systems (such as the evolution of photosynthetic metabolism and the co-evolution of pathogens and host immune systems).

Graduate Students
Eli Bogart, Jason Hindes, Lei Huang (Computational Biology) and Sarabjeet Singh (Theoretical & Applied Mechanics)

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B.Sc equivalent, Physical-Technical Institute, Moscow, 1952. First Ph.D, Yerevan Physics Institute, Armenia, 1958. Second Ph.D, Budker Institute of Nuclear Physics, Novosibirsk, 1963. Research, Theoretical Department, Institute for Theoretical and Experimental Physics (ITEP), Moscow, 1953-56. Research, Budker Institute of Nuclear Physics, 1963-64. Research, chief of electro-magnetic interaction lab, professor (1970), Yerevan Physics Institute, 1956-72. Research, Institute of Terrestrial Magnetism and Dissemination of Radio Waves, Moscow region, 1972-73. After a detour through the Gulag, Senior Scientist, Laboratory of Nuclear Studies, Cornell University, 1987-2008. Professor, Physics and Government, Cornell University, 2008-present. Visiting Scientist, CERN, 1988-89. Consultant, Brookhaven National Laboratory, 1998-2009. American Physical Society Nicholson Medal, 1995. American Physical Society Andrei Sakharov Prize, 2006. Fellow, American Academy of Arts and Sciences. Fellow, American Physical Society.

Research Areas

Experimental elementary particle physics, theoretical foundations of quantum mechanics.

Current Research

As a founding member of the EDM (Electric Dipole Moment) Collaboration at Brookhaven National Laboratory, I continue to investigate systematic errors, spin coherence time and other theoretical issues related to the proposed measurement of the proton and deuteron EDM. My work on the theoretical foundations of quantum mechanics continues to focus on the origin of quantum indeterminism.

A note on past research: My research in the Soviet Union was mostly in accelerator physics. I worked on the design of ITEP's 7 GeV proton-synchrotron, developing a theory of non-linear betatron oscillations as well as betatron and synchro-betatron resonances (which was the first time a Hamiltonian approach was used in this area). At the Yerevan Physics Institute I did the conceptual design of the 5 GeV electron-synchrotron, sometimes simultaneously working with the Budker Institute, and publishing papers on radiation damping (in particular, on the sum rule) and excitation, spin resonances, and spin diffusion. I also proposed a 100x100 GeV electron-positron collider, an idea not accepted at the time. After arriving in the West I helped create and develop at CERN the idea of ion "shaking," with consequent doubling of the number of accumulated anti-protons. In the United States I have worked on alternative designs for the proposed B-factory at Cornell; participated in measuring the magnetic dipole moment of the muon at BNL; done the theoretical work for proposals to measure the electric dipole moment of the deuteron at BNL; contributed theoretical work to Spin@COSY; and investigated the origin of quantum indeterminism.

Teaching

Spring '12. (Phys. 6574) Applications of Quantum Mechanics II.

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B.S., 1973, Illinois Institute of Technology. M.S., 1977, Cornell University. Ph.D., 1979, Cornell University. Post-Doctoral Research Associate, Cornell University, 1978-79. Assistant Professor, Physics, Texas A & M, 1979-84. Associate Professor, Physics, Texas A & M, 1984-86. Associate Professor, Physics, Cornell, 1986-93. Professor, Physics, Cornell, 1993-present. Visiting appointments at: Walther-Meissner Institut fur Tieftemperaturforschung; Royal Holloway, University of London. Alfred P. Sloan Fellow, 1982-86. John Simon Guggenheim Fellow, 1994-95.

Research Areas

Low temperature physics, including the physics of highly confined superfluid 3He; disordered superfluids; glass at low temperatures, micro- and nano-mechanical resonators, their design, optimization, non-linear characteristics, and the role of stress on these structures and graphene resonators.

Current Research

The study of superfluid ^{3}He in aerogel: We use high Q oscillators to look for phase transitions and assay the superfluid fraction of 3He in aerogel in the millikelvin temperature range. We are exploring the A-B transition, effects of magnetic field to probe the nature of the superfluid as well as uniaxial compression to "orient" the superfluid order parameter. We have constructed and operated a micromachined cell to probe superfluid 3He in the "2D" limit, where the superfluid is confined between two well characterized silicon surfaces separated by distances on the order of a few coherence lengths. Other topics under active investigation are the elastic properties of glasses (particularly silicon nitride under stress) at low temperatures, dielectric properties of glasses and also the heat capacity and thermal conductivity of high stress silicon nitride.

Nanomechanical systems: A second area of interest is concerned with applications and innovations with nano-electromechanical devices. This work is carried out in collaboration with Harold Craighead (A&EP), and is also supported by Analog Devices. In this work we will explore and optimize the operational characteristics of NEMS/MEMS devices in ambient conditions, as well as integrate devices to CMOS circuitry in a generic process to facilitate their adoption in future applications and seek to apply these devices to sensing.

Graphene: A third (developing) area of interest is in the use of graphene to separate diverse environments (*eg* vacuum/air). The mechanical properties of the membrane can provide insight into the state of the confined system – ie pressure, diffusion, phase transitions. This work is being carried out in collaboration with the McEuen and Craighead groups.

Postdocs
Vivek Adiga and Thomas Alava

Research Associates
Eric Smith, Maxim Zalalutdinov (based at the Naval Research Labs)

Graduate Students
Daniel Joe, Rob Barton, Nik Zhelev and Bob DeAlba

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Research Areas
Experimental particle physics; physics beyond the standard model; weak interactions.

Current Research
At high energies, our model of elementary particles breaks down. My research uses data from the Large Hadron Collider (LHC), which now collides protons with center-of-mass energies of 7 TeV, to seek the new phenomena and particles that solve this problem. Many of the most interesting events will produce energetic electrons, and my student Avishek Chatterjee is searching for supersymmetry in events with electrons or muons and large missing energy. His current focus is on developing techniques for separating true supersymmetry events from background events with similar topologies.

In the farther future, International Linear Collider (ILC), a proposed electron-positron accelerator, has the potential to explore the phenomena seen at the LHC in detail.

Graduate Students
Avishek Chatterjee

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Research Areas
Theoretical elementary particle physics; Cosmology

Current Research
My research is mainly focused on theory and phenomenology of electroweak symmetry breaking. While the fact that the symmetry is broken is universally accepted as one of the cornerstones of the standard model of particle physics, the mechanism responsible for this breaking is at present unknown. Several alternative mechanisms have been proposed by theorists. Each model predicts a rich variety of new physical phenomena such as new particles, interactions, and possibly even new compact dimensions of space. I am interested both in constructing new models of electroweak symmetry breaking, and in devising strategies for testing them experimentally. The latter area is especially exciting since relevant experiments are currently under way at the Large Hadron Collider (LHC) in Geneva, Switzerland. Examples of my recent or ongoing research in this direction include analyses of novel collider tests of supersymmetric models via the "Yukawa sum rule"; and a study of the power of the LHC detectors to discriminate among the models with similar signatures, conducted in collaboration with members of the Cornell high-energy experimental group.

I am also interested in theoretical cosmology, especially topics on the interface of particle physics and cosmology such as theoretical models for dark energy, dark matter, and inflation. For example, many models of electroweak symmetry breaking predict new particles which could constitute all or most of the cosmological dark matter. If such particles exist, it will be possible to produce them in the lab at next generation colliders such as the LHC. Recently my collaborators and I have developed an approach that allows predicting the production rates in a model-independent way, using the precise measurement of the cosmological dark matter abundance by the WMAP experiment.

Doing research with my group requires good working knowledge of quantum field theory and the standard model of particle physics, as well as some understanding of basic experimental techniques used in high energy physics.

Postdocs
Monika Blanke

Graduate Students
Bibhushan Shakya and Mike Saelim

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Research Areas
New nanofabrication techniques; electronic properties on molecular length scales; spin transport and high-speed dynamics in magnetic devices; correlated-electron states in magnets and superconductors; quantum properties of defects and impurities

Current Research
Our group's research focuses on the electronic and magnetic properties of nm-scale samples. The work in the group consists of making nanometer-size devices using equipment at the Cornell NanoScale Science & Technology Facility (CNF), and then performing measurements in Clark Hall (usually) at low temperatures. Students and postdocs in the group are pursuing a wide variety of projects.

In collaboration with the groups of Bob Buhrman, Sunil Bhave, Farhan Rana, and several groups outside Cornell, we are investigating the “spin-transfer torque effect.” This is a phenomenon by which the magnetic orientation of a small magnet can be manipulated by transferring angular momentum from a current of spin-polarized electrons, rather than by using magnetic fields. We are using the spin torque as a tool for studying the fundamental physics of ferromagnetic and antiferromagnetic dynamics. This project is also progressing quickly toward applications for magnetic memory devices and high-speed signal processing.

In collaboration with the groups of Paul McEuen, Jiwoong Park, Garnet Chan, Will Dichtel, and Tito Abruña, we are measuring electron and spin transport through single molecules. We are able to make single-molecule transistors, in which one molecule bridges between a source and a drain electrode, while the resistance of the molecule can be changed by applying a voltage to a third gate electrode, by stretching the molecule mechanically, or by exposure to laser light. The primary challenges in this field now are to achieve reproducible behavior in different devices and to conduct controlled, systematic studies of the mechanisms that affect electron flow through molecules.

Currently the group is also in the process of starting new projects, including investigations of the spin transport properties of topological insulators, construction of an ultra-low temperature optical microscope, time-resolved x ray microscopy of magnetic dynamics, and the nanoscale optical properties of graphene-based devices.

Postdocs
Takahiro Moriyama

Graduate Students
Jennifer Grab, Ted Gudmundsen, Colin Heikes, Wan Li, David MacNeill, Alex Mellnik, Greg Stiehl, Eugenia Tam, Chen Wang and Lin Xue

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Research Areas
Lepton colliders; beam-beam interaction; particle beam optics; non-linear dynamics of particle beams; transverse coupling in beams; resonance phenomena; beam diagnostic instrumentation; RF superconductivity; circular colliders, electron cloud, low emittance tuning, collective effects, muon g-2

Current Research
The International Linear Collider is a proposed new electron-positron collider that would allow for the exploration of energy regions beyond the reach of today's accelerators. In the debris of the very high energy collisions, 1 TeV in the center of mass, we will look for, among many other thinks, the identity of dark matter and the existence of extra dimensions.

In the ILC, two facing linear accelerators, each 20 kilometers long, hurl beams of electrons and positrons toward each other at nearly the speed of light. Each beam contains ten billion electrons or positrons compressed to a minuscule three-nanometer thickness. As the particles speed down the collider, superconducting accelerating cavities give them more and more energy. They meet in an intense crossfire of collisions.

In the linear collider, positrons are produced by pair production in the collision of photons on a high Z target. The phase space volume of the hot positrons that emerge from the target is very large. In order to achieve an adequate collision rate of the electron and positron beams at the interaction point, the phase space volume (emittance) of the positrons must be reduced by nearly three orders of magnitude. The beams are cooled in damping rings.

The current density of the very low emittance damped bunches will be greater than has ever been achieved in a storage ring. That density will be limited by electron cloud effects and intra beam scattering. In order to explore the relevant beam physics well in advance of the completion of the design of the ILC damping rings, the Cornell Electron Storage Ring (CESR) was reconfigured during the summer of 2008 as a linear collider damping ring test accelerator (CesrTA). During the approximately 100 days /year of machine time dedicated to the CesrTA project, we are developing and testing low emittance tuning techniques. We have built and are presently testing an xray beam size monitor. We are measuring the evolution of the electron cloud with the retarding field analyzers and the dynamical effects of that cloud on the circulating beam of positrons using newly installed high precision and high speed beam position monitors.

Graduate students Jim Shanks, Joe Calvey, and Mike Ehrlichman are involved in the development and study of low emittance tuning methods and instrumentation for measuring electron cloud density and energy spectrum, and intra-beam scattering. G.Ramirez, R.Schwartz, H. Williams, and K. Butler,are undergraduates involved in various aspects of the research program.. The research associates in the CesrTA group are Mark Palmer, David Sagan, Jim Crittenden, Shlomo Greenwald, Yulin Li, Robert Meller, Kiran Sonnad, Dan Peterson, David Kreinick, Walter Hartung, Suntao Wang and David Rice. All of us spend many hours in the CESR control room during CesrTA machine studies periods. CesrTA is an international collaboration. Institutions from around the world, including KEK(Japan), SLAC(Stanford), LBNL(Berkeley), Fermi National Accelerator Lab, Brookhaven National Lab, Cockroft Institute (Great Britain), and CERN(Switzerland) are contributing equipment, numerical simulations and help with the experimental effort.

I am also a member of the collaboration for the new muon g-2 experiment at Fermi-Lab. The goal of the experiment is to measure the anomalous magnetic moment of the muon with 0.14ppm accuracy. This corresponds to a four fold reduction in the experimental uncertainty in the best measurement to date. Discrepancy with the standard model calculation of the anomaly is presently at the level of 3σ. The present comparison is already suggestive of possible new physics contributions to the anomaly. The experimental data will also be used to improve the muon electric dipole moment limit by a factor of nearly 100.

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Research Areas
Experimental Elementary Particle Physics

Current Research
The standard model of particle physics has been extremely successful. It incorporates the strong, electromagnetic, and weak forces. The electromagnetic and weak forces are unified in the standard model. So far the standard model is consistent with all direct observations. One crucial piece of the standard model is still missing; the Higgs particle. The Higgs particle is responsible for generating masses in the standard model. The discovery of the Higgs is one of the primary goals of the LHC (Large Hadron Collider at CERN), which started operating late 2009.

However successful the standard model has been, it is still believed that it can not be the 'ultimate' theory. At a theoretical level there are 'fine tuning' or 'hierarchy' problems that tells us that new particles have to exist in order to stabilize the mass of the Higgs. On a different level there are cosmological observations that tell us that the universe is dominated by new forms of energy, dark energy, and matter, dark matter that we have not yet observed!

Cornell joined the CMS experiment at the LHC in 2005. My main involvement in CMS has been with the 66M channel pixel detector. The CMS pixel detector is placed closest to the proton-proton interaction point. The excellent spatial resolution of the pixel detector is used to reconstruct vertex positions and seed the track finding. Cornell has been the major contributor to the online software and calibration of the pixel detector. We are also involved with the commissioning and operation of the detector. With planned increases in the luminosity of the LHC over the next decade, we will have to upgrade the detectors of CMS. I'm involved with studies and R&D for upgrades to the tracking detectors. Future tracking detectors will need to provide information to the trigger, which means that some level of data reduction, e.g. by selecting high momentum tracks, is needed on the detector. We are studying different ideas for building modules with two closely spaced sensors that can provide a local correlation to allow rejection of low momentum tracks. With graduate student Souvik Das, I have looked at tau identification in CMS for the W to tau channel. I'm based at CERN 2010-2011 where I'm currently run coordinator for the CMS experiment.

In addition to my work on CMS I'm a member of the CLEO collaboration. My work here has focused on the study of hadronic D and Ds decays. Precise measurements of these decays allow us to better constrain parameters of the standard model. I'm also interested in simulations of particle decays, and improving the performance of the detector by developing better techniques for calibration.

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Research Areas
Materials science, including crackling noise and avalanches in magnetic systems, tweed in shape-memory alloys, accelerated simulations of surface growth, Arrhenius law for double jumps; glasses, including metallic glasses, low temperature glasses, slow relaxation, and scaling theories of the glass transition; disordered systems, including Griffiths phase in spin glasses, spin glasses on the Bethe lattice, sliding charge-density waves; liquid crystals; Blue Phases as networks of defect lines and in curved space; boojums in chiral smectic films; quantum instanton methods for atomic tunneling; early Berry's phase work in high-temperature superconductors; atomic tunneling from an STM/AFM tip; theory of vortex core states in superconductors; dynamical systems, including transition to chaos from quasiperiodic motion using renormalization group; noise in crumpling paper

Current Research
We've recently been interested in common, universal features we find in nonlinear optimization problems with many parameters; these *sloppy models* came up in our biological work on signal transduction. In materials physics, we have a new theory of dislocation dynamics in metals – explaining the formation both of grain boundies and dislocation patterns as singularities formed by the dynamics, similar to the shock wave singularities in sonic booms and traffic jams. We are also continuing research on crackling noise, both in magnetic systems and in plastically deformed metals.

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Research Areas
Investigating the electronic structure and interactions in strongly correlated quantum materials, such as high-temperature superconductors, colossal magnetoresistive manganites, Mott insulators, Luttinger liquids, and artificially engineered quantum matter in epitaxial thin films. Experimental probes include angle-resolved photoemission spectroscopy and synchrotron-based x-ray techniques including x-ray absorption spectroscopy and resonant soft x-ray scattering

Current Research
Our research focuses on studying how strong quantum correlations between electrons in solids can give rise to dramatic and unexpected phenomena, such as high-temperature superconductivity, colossal magnetoresistance, or electron fractionalization. Much like how matter can come in solid, liquid, and gaseous forms, solids can also exist in many different "quantum states of matter", spanning from the mundane (metals and insulators) to the more exotic, like the examples given above. One of the frontiers of modern condensed matter physics is in studying and understanding these new and surprising quantum states of matter, many of which are still being discovered.

The goal of our research is to better understand the properties and mechanisms driving these systems by observing how electrons move and interact within these quantum materials. In order to visualize this complicated dance performed by the billions of electrons within these materials, we need sophisticated experimental probes. The primary tool of our group is angle-resolved photoemission spectroscopy (ARPES), which is a direct descendant of Einstein's celebrated photoelectric effect. With this probe, we can create three-dimensional maps of how electrons propagate within a solid. By analyzing these maps, we can study the quantum many-electron interactions in novel materials. Using this information, we try to understand the origins of exotic and unexpected phenomena in condensed matter, such as high-temperature superconductivity, electron fractionalization, or the nanoscale ordering of the electrons' charge, spins, or orbitals.

We also use a number of techniques complementary to ARPES in order to gain additional insight into the electronic structure of quantum materials. These are synchrotron-based x-ray probes such as x-ray absorption spectroscopy (XAS) and resonant soft x-ray scattering (RSXS) which allow us to gain access to the distribution of charge, spins, and orbital states in solids, and currently perform experiments at CHESS, the Stanford Synchrotron Radiation Lightsource, the Canadian Light Source, and the Advanced Light Source.

Our group has finished developing a new state-of-the-art ARPES system which is currently being used to study unconventional superconductors and correlated electron systems. Our group has recently begun a unique collaboration with Prof. Darrell Schlom's group (Materials Science & Engineering) to study artificially engineered quantum materials grown by molecular beam epitaxy and studied *in situ* using high-resolution ARPES.

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Research Areas
Laser and spectroscopic techniques are used to probe the dynamical properties of intrinsic localized modes: in micromechanical arrays, in anharmonic crystals and in magnetic solids.

Current Research
The exploration of energy localization in discrete nonlinear lattices, both classical and quantum mechanical, is an ongoing focus. Inelastic neutron scattering is used to study intrinsic localized mode in crystals. A holographic Fourier transform spectrometer is being developed for single shot electron bunch length measurements of the ERL prototype, the FEL at Jefferson Lab., FLASH at DESY and the LCLS at SLAC.

Collaborators in this research: Nick Agladze, Vladimir Hizhnyakov, Mike Manley, John Page, Masayuki Sato, Gwyn Williams, and Jonathan Wrubel.

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Research Areas
General relativity and relativistic astrophysics; numerical relativity; black hole and neutron star physics; computational physics

Current Research
My major research interests include general relativity, relativistic astrophysics, and computational astrophysics. I am engaged in a long-term project to solve Einstein's equations of general relativity by computer. One of the ultimate goals of this project is to predict the gravitational wave form from coalescing black holes in binary orbit about each other. It is expected that such events will be among the first signals detected as the Laser Interferometer Gravitational Wave Observatory (LIGO) comes into operation. My recent research has spanned many other topics in relativistic astrophysics. I have worked on naked singularities in general relativity; the properties of rapidly rotating neutron stars, including possible observational signatures in pulsars; exploding neutron stars; relativistic stellar dynamics, and planets around pulsars. Most of this work is done in collaboration with other members of the Theoretical Astrophysics Group, including graduate students.

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Research Areas
Experimental Elementary Particle Physics, Heavy Quark Physics, Hadron Collider Physics

Current Research
My research focus is data analysis at the Compact Muon Soleniod (CMS) experiment at the Large Hadron Collider (LHC) at CERN.

The LHC is colliding protons at the highest energies ever reached with accelerators- a new energy scale that opens up the exciting possibility of great scientific discoveries. Explanations for the origin of electroweak symmetry breaking, the existence of dark matter, and the discovery of supersymmetric particles are finally within our reach. We are currently in the process of measuring “standard candle” processes, such as the top quark production cross section, to validate our analysis tools and to calibrate the CMS detector response to proton collisions. New phenomena, such as signatures of processes involving dark matter, could appear soon, as we are integrating data and are gaining sensitivity rapidly. In addition, data analysis at the CDF experiment at the Tevatron is still ongoing, and interesting results are emerging. More details about my current work, all our ongoing analysis groups, and how to learn more about Physics at the LHC and the Tevatron , can be found here:

http://www.lepp.cornell.edu/Research/EPP/CMS/WebHome.html

In addition to data analysis at the CDF and CMS experiments, I am also interested in R&D for novel pixel detectors, such as monolithic detectors or 3D integrated detectors, to be used at future detectors at the Super-LHC or the International Linear Collider. Our sensitivity to New Physics depends critically on our ability to track particles with very high precision in a very challenging environment. Currently, most of this work is taking place at the Cornell Nanofabrication Center. See the link below for more information:

http://www.lepp.cornell.edu/Research/EPP/CMS/CornellDetector.html#CornellUpgrade

Research work in my group involves development of data analysis algorithms and Monte Carlo simulation of New Physics phenomena expected to be observed at the LHC, as well as detector R&D of novel silicon pixel devices. After an initial learning phase at Cornell, students usually travel to or live at CERN, Switzerland, for detector commissioning, data taking and years of exciting new physics discoveries.

I also have a small research group at the CDF experiment at the Tevatron. For more information, see:

http://www.lepp.cornell.edu/Research/EPP/CDF/WebHome.html

and a small group on ILC pixel detector development:

http://www.lepp.cornell.edu/Research/EPP/ILC/IlcDetector.html

Recent talks I have given, and recent publications can be found here:

https://wiki.lepp.cornell.edu/lepp/bin/view/People/JuliaThom

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Research Areas

Materials physics problems in structural genomics; new technologies for macromolecular crystal growth and crystallography; physics of cryopreservation of biological samples; recovering ancient Greek and Roman inscriptions; physics and nonlinear dynamics of charge density wave conductors; biomass combustion.

Current Research and Educational Activities

Materials Physics Problems in Structural Genomics:

High-resolution structures of proteins and other biological macromolecules provide insight into molecular function and a basis for rational approaches to the design of new medicines. The bottleneck in determining macromolecular structures by X-ray crystallography is the difficulty of obtaining high-quality macromolecular crystals and of maintaining this quality throughout the data collection process. Our program has been investigating the physical properties of protein crystals; protein crystal disorder and disordering mechanisms; liquid drop pinning and dynamics on surfaces and its application in crystallization technology; radiation damage and its mitigation; crystal cryopreservation; and application of our methods to obtain new and/or improved information about macromolecular structure and function. Techniques used include synchrotron-based x-ray imaging and diffraction, quasi-elastic light scattering, fluorescence microscopy, and microfabrication. Some of our discoveries have been commercialized by Mitegen, LLC.

Physics of Cryopreservation of Biological Samples

Cooling samples to low temperatures is important not only in protein structure determination, but in the long-term preservation of cells and tissues. The basic methods used by biological, medical and veterinary practitioners to freeze and store biological samples have remained largely unchanged for at least two decades, and were arrived at empirically rather than through systematic studies based on understanding of fundamental principles. We are studying both fundamental and applied problems in cryopreservation including the physics of aqueous glass formation, and have developed a method that increases cooling rates by two orders of magnitude over current best practice.

Electronic and Structural Properties of Charge-Density-Wave Conductors:

Low-dimensional electronic materials that undergo transitions to charge or spin-density wave states are among the most remarkable conducting materials ever discovered. They exhibit extremely diverse phenomena having analogs in superconducting, magnetic, and pattern forming systems. Our current projects include fabrication and characterization of
CDW microstructures and characterizing the spatiotemporal dynamics and phase diagram of driven density waves..

Biomass Combustion:

Most biomass energy research in the US has focused on converting biomass to ethanol for use as a transportation fuel. The energy content of the ethanol produced is usually only a small fraction of the available plant energy, and can be comparable to the external energy inputs required for the conversion. Direct combustion of the biomass to generate heat is much more efficient, but this typically involves either high emissions or high capital costs. We are collaborating with a local company and with faculty in Mechanical and Aerospace Engineering on an approach that could yield low emissions, low cost combustion systems, and allow much broader use of biomass energy.

Recovering Ancient Inscriptions:

Although we use "written in stone" to indicate permanence, even this form of archival storage has a finite lifetime. A substantial fraction of all ancient stone inscriptions have been partially or completely eroded, and in many cases their original message remains hidden from us. In collaboration with Kevin Clinton of Cornell's Classics Department and Don Bilderback and Detlef Smilgies of Cornell’s High Energy Synchrotron Source (CHESS), we have reported the first application of X-ray fluorescence imaging to the study of ancient inscriptions. This technique is allowing us to explore the tools and pigments used in the original inscription, and to recover text from eroded regions.

Physics Education:
Future U.S. economic competitiveness depends upon our ability to recruit and train a highly skilled workforce in science, technology, engineering and the health professions. Physics is a critical gateway to all of these disciplines, and provides the foundation for fundamental understanding, analyzing data and solving problems. Following Cornell's long tradition of innovation in physics education, we have been developing teaching methods and materials that engage students of diverse backgrounds and interests, and that help them to develop both mastery of and a broader appreciation for physics. We have also developed a program to recruit, train and mentor future high school physics teachers.

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Research Areas
Particle theory; superstring theory; cosmology; brane world

Current Research
Elementary particle theory and the interface between cosmology and superstring theory. At the moment, the research is mainly focused on how the superstring theory describes nature. Specifically, the focus is on the recent brane world idea. In this picture, the standard model particles (such as the photon, the gluons, the electron and the quarks) live in the 3+1 dimensional brane while gravitons live in the higher dimensional bulk. Inflation takes place when extra branes are present. String theory properties lead to a robust brane inflationary scenario. Cosmic strings are produced towards the end of inflation, when the extra branes collide. Cosmological implications of this scenario are studied. To understand this scenario in the context of the cosmic landscape in string theory, the wavefunction of the universe and its properties are also studied. An inflationary scenario based on this picture is also proposed and studied.

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Research Areas
Quantum Monte Carlo, Electronic Structure Theory

Current Research
We are interested in problems where an accurate description of electronic correlations is important. The main theoretical/computational tool we employ is the quantum Monte Carlo method.

There are three main classes of methods that are used for the study of electronic structure. The first class of methods are the quantum chemistry methods, the simplest of which, the Hartree-Fock method, is too crude an approximation for most problems of interest. The more sophisticated quantum chemistry methods, such as the configuration interaction method (expansion of the wave function as a linear combination of determinants) are prohibitively expensive for large systems. The second class of methods are the density functional methods. These contain an uncontrolled approximation for the "exchange-correlation" energy, so although they are adequate for many problems, there is no systematic way to improve them in those cases where greater accuracy is needed. We have concentrated on quantum Monte Carlo methods because they offer an excellent compromise between accuracy and computation time.

A great advantage of quantum Monte Carlo methods is that one has considerable freedom in the choice of the trial wave function. So, any intuition one has for the many-body wave function can be tested out. In order to best exploit its potential advantages, we have invested considerable time in improving various aspects of quantum Monte Carlo methodology. These include :
a) novel forms of trial wave functions,
b) optimization of linear and nonlinear wave function parameters in the presence of noise,
c) more accurate imaginary time propagators,
d) calculation forces on nuclei (a simple Hellman-Feynman approach does not work)
e) evaluation of excited state energies
The methods we have developed are incorporated in a program called CHAMP (Cornell-Holland Abinitio Materials Package), that is being used by collaborators at other institutions.
f) Methods to ameliorate the Fermion sign problem.

Another area of interest for us in the past has been to employ quantum Monte Carlo calculations to compute nearly exact Kohn-Sham density functional quantities to study the deficiencies of the commonly used density functionals and to understand the relationship between Kohn-Sham eigenvalues and excitation energies for finite systems.

Current applications, that we are interested in, include the study of correlations of electrons in planar quantum dots subjected to magnetic fields, high-pressure phases and defects in semiconductors, spin states of transition metal atoms surrounded by ligands.

Some of our work is in collaboration with Garnet Chan in the Chemistry department at Cornell and with groups at the University of Paris, Duke, Rhode Island, Twente Universiteit, University of Basel, University of Erlangen and at SISSA, Trieste.

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Research Areas
Ultracold atomic gases and magnetic superfluids; quantum optics; magnetic microscopy with Bose-Einstein condensates; the use of ultracold atomic and molecular gases for the realization and study of novel forms of correlated quantum matter.

Current Research
My research interests lie in the experimental study of ultracold atomic gases. Cooled down to a mere fraction of a degree above absolute zero (less than 100 nanoKelvin), these gases display beautiful and often bizarre properties which can be ascribed to the dominant role of quantum mechanics and particle statistics.

The interest in ultracold gases stems partly from the fact that these gases lend themselves to a variety of experimental techniques that can be used to modify their properties in precise ways, for instance, by changing how the atoms interact with each other, or by varying the geometry of their 'containers' to create effectively one, two or three dimensional quantum fluids. As such, these gases are model systems to create new and exotic forms of quantum matter as well as to simulate the behavior of a variety of quantum materials in order to address fundamental questions in topics ranging from strongly correlated electronic materials, quantum phase transitions, nuclear physics, quantum measurement and even cosmology! Specifically, I aim to pursue such studies with ultracold fluids that have internal (spin) degrees of freedom i.e. spinor gases. Of particular interest is the behavior of such magnetic fluids in low dimensions and in the presence of disorder.

Recently, my research has revolved around the nature of these spinor quantum fluids in the presence of both short-range interactions as well as long-range magnetic dipolar interactions. Under such circumstances, we've observed that the quantum fluid spontaneously 'crystallizes' into ordered magnetic domains [1] - a behavior reminescent of classical magnetic systems except that it occurs in what is ostensibly still a superfluid, besides being a tenuous gas that is almost a million times more dilute than air! I plan to conduct future studies that will elucidate the nature of this weird form of matter.

In addition, experimental techniques for the manipulation of ultracold gases have reached a level of sophistication whereby mesoscopic aggregates of such gases in precisely engineered quantum states can be created and stored in tailored environs for long durations. Given the exquisite sensitivity of cold atoms to ambient fields, these techniques can be used to realize a pristine metrological resource with immense potential for the measurement of electric and magnetic fields, inertial sensing and surface studies. Alongside applications of ultracold fluids for the simulation of paradigmatic many-body systems, I am also interested in interfacing such fluids with mesoscopic 'solid-state' devices. The primary goals of this research avenue would be surface studies and magnetic microscopy [2] of correlated electronic materials; as well as issues of fundamental interest that arise from the coupling between seemingly disparate macroscopic quantum systems.

[1] M. Vengalattore et al, *Spontaneously modulated spin textures in a dipolar spinor BEC*, Phys. Rev. Lett. 100, 170403 (2008);
[2] M. Vengalattore et al, *High resolution magnetometry with a spinor BEC*, Phys. Rev. Lett. 97, 200801 (2007);

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Research Areas
Broad Themes:
Physics of Living Organisms, Biological Fluid Dynamics, Complex Motions, Soft Condensed Matter Physics, Nonlinear Dynamics, Statistical Physics, Applied Mathematics and Computations

Specific Topics:
Insect Flight, Falling Paper, Computational Methods for Navier-Stokes Equations, Immersed Interface Method, 3D Multiple Rigid Body Dynamics, Particle-Fluid Interactions, 3D Motion Tracking

Prior Research
Turbulence, Turbulent Diffusion, Random Matrices

Current Research
We are interested in understanding life in fluids. A current question we ask is 'why does a living organism move the way it does?' The organism's movement is in part dictated by physics, and in another part by the organism's response to its own movement.

We have been seeking mechanistic explanations for the complex movement of insect flight. To understand insect flight, we started from the outer scale, solving the Navier-Stokes equations coupled to the wing motions, analyzing the unsteady aerodynamics of flapping flight, and are gradually working toward the inner scale, deducing the actuations and control algorithms. In this approach, the physics of flight informs us about the internal control or 'computing' scheme for a specific behavior.

To analyze the dynamics of insect flight, we have been developing efficient computational algorithms for the Navier-Stokes equations, deducing reduced order models from table-top experiments, and carrying out analyses of dynamical systems. We have also been collaborating with experimentalists to infer control laws from flight data. These efforts have led to new insights into the essential mechanisms underlying flapping flight and will continue to give us intuitions about the interactions among different building blocks inside the organism.

Ongoing projects
3D Dynamical Analysis of Insect Flight. Computation Methods for the Navier-Stokes Equations, Optimization, Stability and Control Analysis of Flapping Flight, Hydrodynamic Interactions and Collective Behavior, Prey-capture dynamics, Motion tracking

Graduate Students
Song Chang, Acmae El Yacoubi and James Melfi Jr

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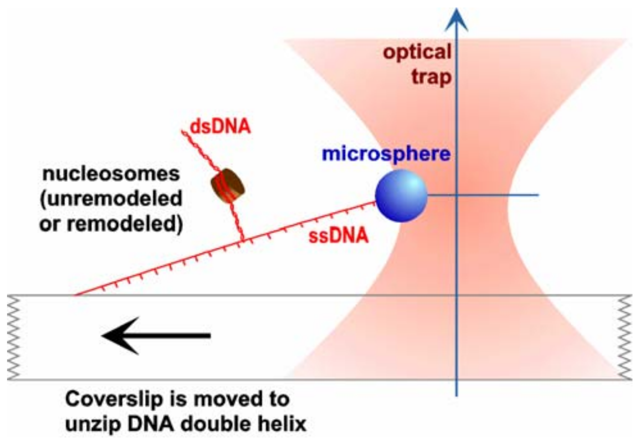
B.S., 1985, Physics, Nanjing University. Ph.D. student, 1985-86, Institute of Physics, Chinese Academy of Sciences. M.S, 1988, Physics, University of Southern Mississippi. Ph.D., 1993, Biophysics, University of Michigan at Ann Arbor. Postdoctoral Fellow, Biophysics, Princeton University, 1994-97. Assistant Professor, Physics, Cornell University, 1998-2004. Associate Professor, Physics, Cornell University, 2004-2009. Professor, Physics, Cornell University, 2009- present. Outstanding Student Award, Nanjing University, 1985. University of Michigan Biophysics Fellowship, 1988-89. National Cancer Institute Fellowship, 1994. Damon Runyon-Walter Winchell Foundation Postdoctoral Fellowship, 1995-97. Damon Runyon Scholar Award, 1999-00. Dale F. and Betty Ann Frey Scholar of the Damon Runyon-Walter Winchell Foundation, 1999. Alfred P. Sloan Research Fellow, 1999-01. Beckman Young Investigator Award, 1999-02. Keck Foundation Distinguished Young Scholar in Medical Research Award, 2000-07. Provost's Award for Distinguished Scholarship, 2008. Fellow, American Physical Society, elected 2009. Howard Hughes Medical Institute Investigator, 2008-present.

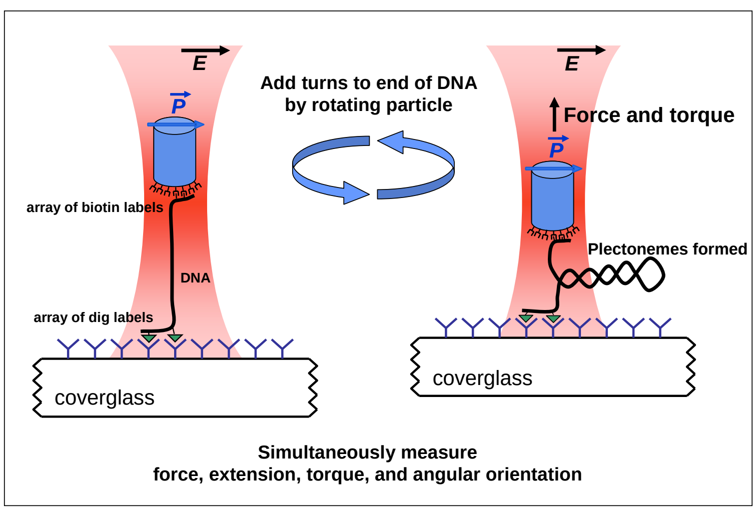
Research Areas
Single molecule mechanical manipulations of biological molecules; high-resolution optical trapping and detection; single molecule fluorescence imaging and detection; nanofabrication; molecular motor mechanisms; biopolymer kinetics and dynamics; protein-DNA interactions (especially those involved in gene expression); genomics; modeling of diffusion, kinetics, and dynamics of biomolecules

Current Research
We are a single molecule biophysics lab. We develop state-of-the-art optical trapping techniques to probe the motions and dynamics of molecular motors that translocate along DNA, as well as the regulation of these motions by the presence of other proteins that interact with the same DNA substrate. We also develop theoretical models to elucidate the mechanism of the molecular motors based on thermodynamics and statistical mechanics. Here we'll highlight a couple of novel experimental approaches that we have recently developed.

We have developed the unzipping technique as a versatile and powerful single-molecule method to explore protein-DNA interactions. A single DNA double helix is unzipped in the presence of DNA-binding proteins using a feedback-enhanced optical trap. When the unzipping fork in a DNA reaches a bound protein molecule, we observe a dramatic increase in the tension in the DNA, followed by a sudden tension reduction. Analysis of the unzipping force throughout an unbinding event reveals information about the precise spatial location and dynamic nature of the protein-DNA complex.



Conventional optical traps are only capable of applying a force on a trapped particle. Our angular optical trap is also capable of applying a torque on the particle. This opens up new possibilities for experiments on biological molecules, many of which are known to generate rotational motions and work against topological obstacles. As an example, shown in the left panel is a DNA molecule that is torsionally constrained at one end to a nanofabricated quartz cylinder, and at the other end to a microscope coverglass surface. As the cylinder is rotated via rotation of the input laser polarization, turns are added to the end of the DNA molecule, resulting in a supercoiled DNA with the formation of plectonemes. The rapid dynamics of supercoiling is monitored by simultaneous detection of four signals: force, position, torque, and angular orientation of the cylinder.



Postdocs
Shanna Fellman, Jie Ma, Mohammad Soltani, and Bo Sun.

Graduate Students
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B.S. ,1974, Massachusetts Institute of Technology. Ph.D., 1978, Harvard University. Postdoctoral Research Associate, Cornell University, 1978-79; Chaim Weizmann Postdoctoral Fellow, Center for Radiophysics and Space Research, Cornell University, 1979-81. Assistant Professor, Astronomy, Cornell University, 1981-87; Associate Professor, Astronomy, Cornell University, 1987-93; Professor, Astronomy, Cornell University, 1993-present. Professor, Physics, Cornell University, 1997-present. NSF Postdoctoral Fellow, 1981-82; Alfred P. Sloan Foundation Fellow, 1984-88; Bok Prize Lecturer, Harvard University, 1989. Member, American Astronomical Society.

Research Areas
i) Long term variation in the rotation of neutron stars, specifically neutron star precession and implications for the physics of superfluids in their interiors.
ii) Nonlinear mode coupling in rotating neutron stars, and the saturation of the r-mode instability driven by gravitational radiation.
iii) Astronomical manifestations of remnants of string/brane inflation, particularly cosmic strings, and prospects of constraining models for the early Universe observationally.

Current Research
My research covers a range of topics in theoretical astrophysics, ranging from cosmology particularly the nature of dark energy and the cosmological constant, and the possibility for detecting observational signatures of superstring inflation and neutron star astrophysics particularly long term variations in pulsar rotation.

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B.S., Business and Engineering Administration, 1947, MIT. Allegheny Ludlum Fellowship, 1953-1955. MIT Overseas Fellowship, 1954. Sc.D., Metallurgy, minor Physics and Mathematics, 1955, MIT. Assoc. Professor of Engineering Physics, Cornell University, 1961-1965. Professor of Applied Physics, Cornell, 1965-present. Co-founder, Biophysics Program, Cornell, 1972. Guggenheim Fellowship, 1974-1975. Fellow American Physical Society, 1975. Fellow American Association for the Advancement of Science, 1989. S.B. Eckert Professor in Engineering, 1998-present. Director, School of Applied and Engineering Physics, Cornell, 1983-1988. Biological Physics Prize of the American Physical Society, 1991. Founding Fellow American Institute for Medical and Biological Engineering, 1992. National Academy of Engineering, elected member, 1993. National Academy of Sciences, elected member, 1995. American Academy of Arts and Sciences, elected member, 1997. Ernst Abbe Lecture Award, Biophysical Society and Royal Microscope Society, 1997. Director, Developmental Resource for Biophysical Imaging and Opto-electronics, 1998-2007. Faculty of Biological Sciences, Cornell, 1988-present. Scholar in Residence, NIH Fogarty International Center for Advanced Study, 1989-1990. Director, Biophysics Program, Cornell, 1989-1992. Michelson-Morley Award of Case Western Reserve University, 1999. Jablonski Award of the Biophysical Society, 1999. Rank Prize in Opto-electronics-International, 2000. Wenner-Gren Distinguished Lectureship-Sweden, 2001. Harvard/MIT Joint Physical Chemistry Lecturer, 2001. Biophysical Society National Lecturer, 2002. Richard C. Lord Lectureship, MIT, 2004. Rohm and Haas Lectureship, University of North Carolina, 2005. Leonardo Lecture, Istituto Scientifico San Raffaele, Italy, 2006. Ernst Abbe

Memorial Award of the New York Microscopical Society, 2007. Houston Memorial Lectureship, Rice University, 2009. Hollaender Award in Biophysics, National Academy of Sciences, 2010.

Research Areas
Biological Physics, Fluctuations in Complex Systems, Physical Optics, Biomedical Instrumentation

Current Research
Research Interests: The solution of seemingly impossible experimental problems in biological and medical physics drives our creation of new experimental technologies, which have focused primarily on the dynamics of the biomolecular processes of life. This challenge requires benign, effectively diagnostic methods that frequently push the physical limits of resolution in space, time, molecular structure and sensitivity.

Seemingly Impossible Biological Problems. Several of these technological innovations: Multiphoton Microscopy (MPM), Fluorescence Correlation Spectroscopy (FCS), nanoscopic molecular tracking in and on living cells and recently, nanostructured molecular dynamic probes in nanoscopic zero-mode waveguides are being applied to seemingly impossible biological problems. The challenges of neuroscience have led to physics and molecular mechanisms of auditory transduction, recording of reconstituted natural ion channels, their fluctuations and mechano-sensitivity, cooperativity in neural networks, imaging of serotonin and its secretion, imaging the molecular development of the lesions of Alzheimer's Disease and Parkinson's Disease. Recently, our optical imaging of fast neuronal action potentials has made possible neural system signaling response in living neural networks in the brain and spinal cord.

Clinical Medicine. As our biophysical research has evolved, we are now enabling direct medical applications of our nonlinear microscopy via medical endoscopy in clinical medicine. Thus, our current multiphoton imaging research focuses on *in vivo* imaging of intrinsic tissue fluorescence and second harmonic generation to recognize human disease states *in situ* in real time. This strategy now enables medical *in vivo*, *in situ* medical endoscopes that incorporate multiphoton microscopy, with collaborators at Weill Cornell Medical College. This research demands our invention and development of nanoscopic nonlinear optical tools for *in vivo* internal medical imaging based on Multiphoton Microscopy.

A few new postdoctoral associates may be accommodated in 2011-2012.

Graduate Students
David Huland (Biomedical Engineering with PhD Advisor Prof. Chris Xu), and David Rivera (A&EP with PhD Advisor Prof. Chris Xu).

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B.S. 1980 (Princeton), M.S. 1982 (California at Berkeley), Ph.D. 1988 (Cornell).Wise was a member of the technical staff at Bell Laboratories before coming to Cornell. He received the Newport Research Award of the Optical Society of America as a graduate student in 1986. He joined the Cornell faculty in 1988, and was named an NSF Presidential Young Investigator in 1989. He has received five awards for excellence and innovation in teaching.

Research Areas
Semiconductor Nanostructures, Ultrafast Nonlinear Optics

Current Research
We work in the following areas:

- electronic, vibrational, and optical properties of semiconductor nanostructures
- nanoscale charge transfer, which is relevant to nanostructure-based solar cells
- spatiotemporal aspects of nonlinear pulse propagation, generation of space-time solitons
- development of fiber lasers that generate ultrashort (10-100 fs) high-energy light pulses based on new phenomena, such as self-similar pulse evolution and formation of dissipative solitons

Postdoctoral Associates
Byun-Ryul Hyun, Liangfeng Sun, Luming Zhao, Andy Chong

Graduate Students
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Research Areas
Elementary Particle Physics

Current Research
My research involves understanding the most basic building blocks of matter. At this point, we have a pretty good idea what matter is made of (quarks and leptons, at its base), but we don't really understand the relations between the parts or, in the language of particle physics, the symmetries that govern our current best theory. Some of the questions we are struggling with are: What is the origin of mass? Why is there a discrepancy between the number of matter and antimatter particles in the universe? What is the reason for the masses of the experimentally observed particles? Are the four forces we know about (gravity, strong, weak, electromagnetic) actually all manifestations of one unified force? How does gravity fit into quantum mechanics?

Understanding these relations is the goal of my current research at the CDF experiment at Fermilab's Tevatron collider and at the CMS Experiment at the CERN LHC.

This is an exciting time in particle physics: we have started taking data with the LHC and are exploring an energy regime never before created in the lab. In the next few years, we will see what the TeV energy scale holds. The first data will be the most interesting – come join us!

Graduate Students
Don Teo and Stephen Poprocki

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B.S., Physics, 1989, Fudan University. Ph.D., Applied Physics, 1996, Cornell University. Postdoctoral Member of Technical Staff, 1997-1999, Bell Laboratories, Member of Technical Staff, 1999-2002, Bell Laboratories, 2002-2007. Assistant Professor, 2007-present, Associate Professor, Applied and Engineering Physics, Cornell University. 2007-present, Director of Graduate Studies of Applied Physics. CUSPEA scholar 1989, Bell Laboratories Team research award 2002, Tau Beta Pi Teaching award 2004, College of Engineering teaching award 2005 and 2008. National Science Foundation CAREER award 2006. Fellow of the Optical Society of America, 2010.

Research Areas
Optics; Biomedical Imaging; Fiber Optic

Current Research
Our research consists of three main areas: biomedical imaging, optical instrumentation, and optical communications. Our emphasis is on the practical applications of photonics and fiber optics, ranging from new concepts and devices to full-scale systems. Techniques involved include both numerical modeling and experimental investigations.

Fiber Optics. Our work *in fiber optic* involves both numerical modeling and experiments. Examples of our research include pulse propagations in fibers and waveguides, and their novel applications in fiber laser, fiber optic imaging, and fiber optic communications.

Biomedical Imaging. We are creating new imaging tools for both biomedical research and clinical diagnostics. Our research includes novel fiber optic probes, multiphoton imaging based endoscopy, new techniques for imaging deep and fast beyond the surface layers of living tissues.

Optical Instrumentation. Our research in *optical instrumentation* focuses on real-world applications and dynamically evolves around the research area of the group. Our current efforts are devoted to the manipulation of light fields, with applications targeting both biomedical imaging and fiber optic communications. Examples of our current research include the development of novel optical fibers for generating femtosecond pulses, applications of the concept of "time-lens" for creating arbitrary waveforms in the optical domain, and optical buffer for high speed data transmission.

Post-docs
Ke Wang

Graduate Students
Demirhan Kobat, , Adam Straub, David Rivera, Jim Chen, David Huland, Kriti Charan and Nick Horton.