Physics at Brown

News for Alumni and Friends **2004 Issue**

Chung-I Tan

Welcome to another issue of the Brown Physics Newsletter. I am delighted to greet you, on behalf of the Department. First, we wish to honor the memories of both Professor Phil Bray and Professor Mildred Widgoff, who passed away in March and July 2004 respectively. They have left indelible marks with their passionate concern for the welfare of their students, colleagues, the Department and the University. As the Physics Chair in the mid-sixties, Phil played an integral role in ushering in then new physics to Brown; many current senior faculty and recent emeriti were brought to Brown because of Phil. Mildred was a pioneering woman physicist, who also served the Department faithfully for many years as Executive Officer. We miss them both greatly.

I would like to thank Dave Cutts who was tireless during the past six years in continuing to revitalize the Department. We highlighted in 2003 the work of Professor Greg Tucker; it is a pleasure to note that he was promoted to Associate Professor in July, 2004. In this issue, we highlight the accomplishments of Professor Richard Gaitskell, who came to Brown in 2001, having previously served as a Senior lecturer at University College London. Rick has just been promoted to an Associate Professor with tenure; his work on the search for the dark matter particle is described on page 8.

We continue the tradition here of showcasing our most junior faculty, Professor Dima Feldman and Professor Vesna Mitrovic, who bring vitality as well as new directions to the Department. They have settled well into their research and teaching at Brown. We would also like to share with you the exciting news of Professor Ian Dell'Antonio's receiving a Presidential Early Career Award for Scientists and Engineering (PECASE). This honor follows a previous NSF CAREER grant for junior faculty, based on Ian's work using gravitational lensing to detect dark matter. Professor Jay Tang, who joined us as our first biophysicist, has developed two new interdisciplinary courses in biological physics: one is a regular course designed for advanced undergraduate science and engineering students, and another for graduate students. The development of these courses is described on page 7.

We also continue to highlight the research of our recent Galkin Foundation Fellows, Kevin Goldstein and Luk Chong Yeung. Working with advisor Professor David Lowe, Kevin considered aspects of incorporating dark energy consistently in quantum field theory on a curved space-time. Luk performed research with Professor Leon Cooper and other researchers at the Institute for Brian and Neural Systems; her work relates to how synapses grow and change.

The Physics Department has been supporting the effort of the Dean of the College in offering freshman seminar courses. One such course, "Beautiful Theories of Physics", was highlighted in the last issue. We have followed up this year with a seminar course by Professor Brad Marston, "An Introduction to Environmental Physics", also described on page 7. The Department is not only interested in revising and updating our existing courses, but also in new courses, both at the undergraduate and graduate level. In addition to the biophysics course mentioned earlier, a sophomore-junior course on Mathematical Methods for Physics was introduced last year with great success. We have also re-introduced an undergraduate course on Subatomic Physics. In addition, we have revamped our astro/cosmology courses and aspects of our graduate program.

Other highlights of 2004 include the continuing popularity of the Ladd Observatory, as an outreach site and as a resource for students. Many exciting initiatives have been planned, and we hope to be able to report some of these in the near future.

As I began my tenure as the Physics Chair, a trusted friend who had been the Chair at another Physics Department advised me: To be successful, you must focus on the welfare of your constituency, your students, both graduate and undergraduates, your faculty and staff, the administration, and the community. In this issue we highlight some of the events that have taken place during 2004. Much has been accomplished in recent years, but much remains to be done. With a dedicated staff, committed faculty, enthusiastic students, supportive administration, and engaged alumni and friends, the future looks bright.

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BROWN

Galkin Fellow Luk Chong Yeung: Modeling Neuronal Synapses

Luk Chong Yeung

Luk Chong Yeung, a 2003-2004 Galkin Foundation Fellow in the Physics Department, has proposed a model in which calcium plays a key role in the functioning of brain cells. Neurons are gated by certain receptors that allow selected ions to rush into or out of the cell. An especially interesting receptor is the N-methyl-D-aspartate (NMDA) receptor, which is permeable to calcium currents. Once inside the neurons, calcium triggers an intricate series of metabolic cascades that change the strengths of the connections, or synapses, between two neurons. This malleability of neurons, known as synaptic plasticity, is believed to be the fundamental basis of memory, learning and neural development.

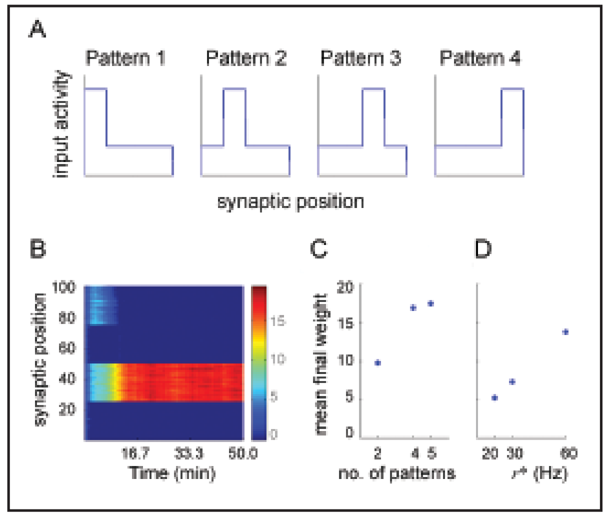
Luk Chong and her collaborators showed that neuronal activity controls the gating properties of the NMDA receptors, thus dictating not only how much downstream synaptic plasticity should occur, but also when it should stop. Their model appeared in the October 2004 issue of the Proceedings of the National Academy of Sciences.

“The beauty of the brain is that it is plastic and robust at the same time,” Luk Chong said. “If the model is verified experimentally, we’ve solved an important piece of the puzzle of how these seemingly antagonistic properties can and, in fact, must coexist in the cell.”

The formulation of this model generalizes previous work from the same research group, lead by Professor Leon Cooper. Prior investigations have described how different forms of neuronal activity are translated into intracellular calcium signals leading to synaptic plasticity. While this model accurately reproduced experimental results on how synapses grow stronger or weaker under different conditions, it did not account for how they stabilize. In other words, in the earlier model the synaptic strengths could grow without ever reaching a fixed point.

In the new model, stability is achieved through a homeostasis - an inherent ability of biological systems to self-adjust against modifications in the environment, to maintain a sustained level of equilibrium. NMDA receptors allow calcium influx, which in turn modifies the responsiveness of these receptors, such that subsequent ion transport is made more difficult. The interplay between fast changes in the synaptic strength and a slow negative feedback mechanism, gives rise to a robust simulated neural network, able to respond differently and “remember” different stimulation patterns (see figure).

When Luk Chong worked on this model, she was a Brown graduate student and a Galkin Foundation Fellow, pursuing her doctoral degree in physics and working at the Institute for Brain and Neural Systems, directed by Professor Leon Cooper. She now holds a Postdoctoral Research Associate position at the Brown University Neuroscience Department. In addition to Luk Chong and Professor Cooper, the research team included two



Stability and competition coexist in the model. A) Four patterns of stimulation are presented randomly, with the same probability, to the simulated neuron. B) 100 synapses start with the same initial strength, but over time, develops selectivity for one of the stimulating patterns (pattern 2 in this example). This is an example of symmetry breaking in neural networks. C) The results are independent on the number of stimulating patterns or D) the relating amplitudes of the stimuli.

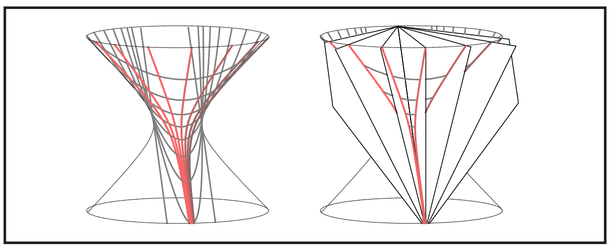
former Brown Physics Ph.D.s, Harel Shouval, an assistant professor of neurobiology and anatomy at the University of Texas Medical School at Houston, and Brian Blais, a professor of physics at Bryant University.

The Galkin Foundation Fellowships are funded through a generous donation by Mr. Warren Galkin, Class of 1951. Each year the Fellowship recognizes exceptional promise and achievement in physics by a senior graduate student.

Research Highlights of 2003-2004 Galkin Fellow Kevin Goldstein

Kevin Goldstein, a 2003-2004 Galkin Foundation Fellow, focused his dissertation research on fundamental issues in cosmology. He investigated a mysterious aspect of the universe called "dark energy". Astronomical evidence suggests that about seventy percent of the universe consists of dark energy, which is very peculiar because it has a negative pressure. Einstein originally introduced dark energy or, more specifically, a cosmological constant into general relativity for aesthetic reasons – he wanted to ensure that his equations predicted a stable, unchanging universe. Later Willem de Sitter found solutions of Einstein's equations with a cosmological constant describing an expanding universe, and this spacetime is now known as de Sitter space. A universe like our own, dominated by dark energy, will look more and more like de Sitter space as time progresses.

Despite the ubiquity of dark energy, there seems to be no natural way for its abundance to arise naturally in the context of modern quantum theories. Until recently it was not even clear whether a positive cosmological constant could be realized in string theory - the most promising quantum theory of gravity. In any case we don't really know where dark energy comes from. We know where it is going – unfortunately driving the universe to a lonely, cold, dark and virtually empty demise.



A graphical representation of trajectories of observers through an inflating universe.

Kevin Goldstein's thesis explored incorporating dark energy consistently into quantum field theory on a curved background, based on a series of four articles that appeared in the journals Physical Review D, Nuclear Physics B, and Physics Letters B. These articles have received a good amount of attention, being cited in around 90 subsequent articles to date. Specifically, together with his adviser, Prof. David Lowe, Kevin investigated the implications of various different vacuum states called the "alpha-vacua" on de Sitter space. In quantum field theory on a curved background, the zero-particle state or vacuum is observer dependent. Often it is not a priori clear which state one should consider as the vacuum. One is lead to consider the alpha-vacua by the reasonable requirement that the vacuum does not break the symmetries of de Sitter space. The conventional vacuum, called the Bunch-Davies vacuum, is the one that looks like the flat-space vacuum in the limit of the cosmological constant going to zero.

Their investigations could have importance for understanding the inflationary period of the big bang and the effect of dark energy at the present time. The alpha-vacua could provide a window into high energy physics through their imprint on the cosmic microwave background and may also presently be a source of ultra-high energy cosmic rays. From a purely theoretical perspective, formulating interacting quantum field theory in these states is a challenging problem which they considered in quite some detail.

Postulating that the early universe under went a period of extremely rapid expansion or inflation solves many of the outstanding problems inherent to the standard model of cosmology. It also introduces the possibility that we may be able to extract information about physics at the Planck scale, where the force of gravity becomes comparable in strength to the other forces of nature. During inflation, trans-Planckian scales expand to macroscopic size, which might lead to an observable cosmological imprint. One way of modeling trans-Planckian effects is to consider the alpha-vacua, and the consequences of this for the microwave background fluctuations were investigated.

While the observational significance of the alpha-vacua was clear, the theoretical consistency of the physics of these vacua was questioned. It was suggested that there were problems with renormalizability, locality, causality, and stability of these models. To address these issues they sought to formulate the field theory using an imaginary-time technique. This involved considering the theory on a four dimensional hypersphere. They showed that the theory was renormalizable with local counter-terms, and that the theory was stable as long as quantum gravity fluctuations are neglected.

Goldstein and Lowe found that for all states, except the conventional vacuum, continuing from imaginary to real time leads to a non-local action. The non-locality relates points on opposite sides of the cosmological horizon, so does not produce observable violations of causality.

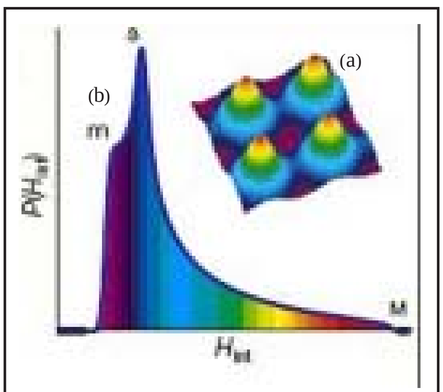
Finally, together with their collaborator, Gian Alberghi, from Bologna University, they found that the current existence of a cut off alpha-vacuum would provide a new top-down mechanism for the production of ultra-high energy cosmic rays. Furthermore, they found this idea to be consistent with present observations of ultra-high energy cosmic rays.

Professor Mitrovic Launches a New Magnetic Resonance Laboratory

Condensed matter physics has a multitude of strong interconnections with engineering, chemistry, material sciences, biology, and other fields. One of its most important tasks is to understand fundamental quantum properties of materials. By exploiting these remarkable properties we can hope to obtain new industrial devices.

Professor Vesna Mitrovic joined the Brown Faculty in January, 2004, bringing a new research program of fundamental condensed mater physics. The main research focus of her group is the investigation using magnetic resonance (NMR) spectroscopy of remarkable quantum phenomena arising in materials. Over the years, condensed matter physics has been very successful in explaining many 'classical' properties of materials, such as for example why some materials behave as magnets, others as metals, or as superconductors, and others as insulators. However, more recently a number of new materials have been discovered that do not fit within these traditional categories or phases as they exhibit a mixture of spectacular properties characteristic of more that one phase. In particular at low temperatures, many exotic phases are observed when materials behave strictly according to the rules of quantum mechanics. Mitrovic's research addresses the questions of how the mixed phases behavior exists, where it originates and what it might promise. NMR is her technique of choice since at the same time it is sensitive to multiple properties, such as the magnetic, conducting, and superconducting properties, of the materials.

The group has just moved to newly renovated research space in the basement of the Barus-Holley building. This space was once devoted to Hendrik Gerristen research activities in the field of optics. A separate beautiful student office space accompanies the large 'blue' laboratory space. The group is very happy finally to have a permanent home. Renovation of the space was an interesting experience. On several occasions, the dimensions of some of the furniture and the holes for the pumping lines were given to construction workers in units of millimeters, but were interpreted as if inches. As the first rain fell after the construction crew left the site, the cryo-pit in the laboratory became a small swimming pool. The contractors have returned to redo the hydro-insulation. Their first attempt to correct the problem has failed and the pit area of the laboratory is still under construction.



(a) real space distributions of the magnetic field in a Type-II superconductor
(b) probability distribution of magnetic field, corresponding to NMR spectrum measurements

Vesna Mitrovic

Mitrovic's research group studies low dimensional magnetism and the physics of superconductors. More precisely, they work on investigating the 2 dimensional quantum magnet compound in collaboration with a group at Oxford and with Professor Brad Marston's theory group at Brown. The compound is at the same time a so-called frustrated magnet. In such a system it is not possible to satisfy (minimize) all the interactions to find the minimum energy ground state. Often this sitruation leads to there being no single unique ground state but a variety of similar low energy states of the system in which unhappiness (non-minimization of energy) is shared around as much as possible. With their low energy tool sensitive to magnetism the group hopes to shed light on these exotic low energy states.

Our understanding of the magnetism on the most fundamental level could lead to the development and creation of novel methods for manipulating the electron spin, 'spintronics', or development of new magnetic recording materials. These studies are important since it has become clear, in spite the spectacular progress in conventional technology based on electron charge manipulation over the last half-century, that further advances will require alternative concepts such as electron spin manipulation.

In the field of superconductivity, the main goal is to reveal the role of magnetism in establishing unconventional superconductivity. These studies often require of extreme conditions of intense magnetic field and low temperatures. The main pieces of equipment in Mitrovic's laboratory are 9 T high homogeneity magnet, cryostats (to allow studies at low temperatures), and custom-built state-of-the-art NMR spectrometers. The spectrometers are optimized for the study of superconducting and magnetic materials. The new lab has taken shape thanks to the assistance of graduate student Marc-André Vachon and several undergraduate students.

In Memory of Philip Bray and Mildred Widgoff

Phil Bray

A celebration for life was held for Philip Bray, Friday May 7th, 2004. The Hazard Professor of Physics emeritus at Brown University, died in late March at the Evergreen Nursing Home, East Providence.

Phil Bray had taught at Brown for 35 years, retiring in 1990 as Hazard Professor of Physics before being named Hazard Professor of Physics Emeritus.

He began teaching at Brown in 1955 as an Associate Professor of Physics, became a full professor in 1958, and had been department chairman for five years.

Throughout his career he had taught classes as diverse as physics for premed students and specialized graduate-level courses, and had been a mentor to many of his students, as well as a catalyst to his colleagues. According to Nobel laureaute and fellow physics Professor Leon Cooper, "Phil made many contributions to physics and the Brown University Physics Department . . . his enormous enthusiasm energized us all." Professor Bray was a pioneer and expert on nuclear magnetic studies, authoring more than 230 articles in scientific publications. He was a Fellow of the American Physical Society, the American Academy of Arts and Sciences, the American Ceramic Society, Sigma Xi, and the American Association for the Advancement of Science. He had previously been an assistant Professor of Physics at Rensselaer Polytechnic Institute, Troy, N.Y. Phil received a bachelor's degree from Brown in 1948, and his master's and doctoral degrees from Harvard University, where his research supervisor had been Nobel Prize winner Norman F. Ramsey.

Among his many awards were the George W. Morey Award from the American Ceramic Association, and the Sir Nevill Mott Award from the Journal of Non-Crystalline Solids for his contributions to glass science. In 1996, a conference on borate crystals and glasses was held in his honor in Abington, England. He was the recipient of a Guggenheim Fellowship in 1969, and the Winston Churchill Overseas Fellowship at Cambridge University in 1985. He was an Army veteran of World War II. A longtime member of Barrington Congregational Church, he became an active member of Providence First Unitarian Church after he moved to the city. He leaves two daughters, Carolyn Bray of Providence and Katherine Bray of Los Angeles, and a son, Philip James Bray Jr. of Providence. He was the father of the late Richard Bray, and brother of the late William H. Bray.

Mildred Widgoff

Mildred Widgoff, a Professor of Physics (Emerita) at Brown University and a Fellow of the APS, died at home in Barrington, RI, July, 21, 2004 after a short illness.

She received a BA in physics from the University of Buffalo in 1944 where she was elected to Phi Beta Kappa. She was recruited into the Manhattan Project and participated in the work at Columbia University. In 1952, she joined the research staff of the Brookhaven National Laboratory and in 1955 became a Research Fellow at the Harvard University Cyclotron Laboratory. In 1958 Mildred became an Assistant Professor (Research) at Brown while continuing at Harvard as a consultant in the early days of the Cambridge Electron Accelerator (CEA).

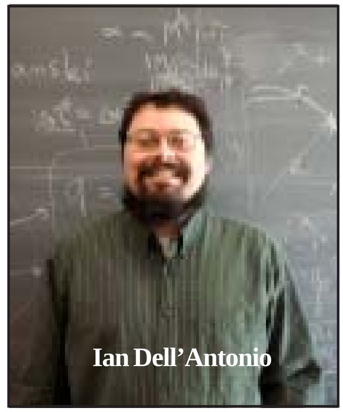
She became a Professor of Physics at Brown in 1974 and Emerita in 1995. Mildred took on the principal direction of the teaching laboratories, organizing instruction and curricular development within them; she much preferred it to lecturing. She played an active role in the affairs of the university and in the Department of Physics where she served as its Executive Officer from1968 to1980. Active also in the affairs of the physics community, she served as Chair of one of the earliest APS Committees on the Status of Women in Physics and was a past-Chair of the New England Section of the APS. She served on NSF panels on awards for women faculty and participated with a group at Brown working to improve the teaching of physical sciences in the inner city schools.

Mildred's research career presents a panorama of the fields we now call particle physics and particle astrophysics. It spans both a broad range in the development of our understanding of the physics but also, for an experimentalist, a series of revolutions in the detector technology for achieving it.

Mildred had one of the most positive outlooks of anyone we know. She genuinely loved being with people, doing physics and making things work. With her students she was a devoted mentor and a caring friend. In an era not famous for providing easy paths for women in science, Mildred was patient with us, a successful scientist and a pathfinder for others. She was a unique and beloved colleague.

She leaves a son Jonathan Shapiro,a Professor of Mathematics at California State Polytechnic University and she was the mother of the late Eve Shapiro of Boston.

Professor Dell'Antonio Wins PECASE Award


Ian Dell'Antonio

On May 2004, the White House announced the recipients of the 2002 *Presidential Early Career Awards for Scientists and Engineers*, the nation's highest honor for professionals at the outset of their independent research careers.

On May 4, 2004, Ian Dell'Antonio received a Presidential Early Career Award for Scientists and Engineers (PECASE) given by the White House Office of Science and Technology. PECASE awards are "the nation's highest honor for professionals at the outset of their independent research careers". PECASE awardees are nominated by individual federal departments and agencies: in the case of the National Science Foundation, between 10 and 20 scientists are honored across all of NSF-supported research areas each year. For the division of Astronomical Sciences (which supports Dell'Antonio's research), this is only the fourth award made since the program started. The NSF selects PECASE nominees from its most meritorious awardees of the NSF CAREER grants for junior faculty. The project that led to this award is the topic of the 2001 CAREER grant entitled "Measuring Cosmology and the Evolution of Structure via Gravitational Lensing". Dark Matter has proved elusive—it has yet to be detected except through its gravitational effects. Therefore, the best way to study it is to employ a technique sensitive to gravitational effects, such as gravitational lensing. Gravitational lensing exploits the fact that the presence of matter induces a curvature in space-time, which alters the path of light traveling close to the mass. As a result, the apparent positions and shapes of distant objects beyond the mass are distorted. Measuring this distortion allows us to measure the mass, and thus the distribution of dark matter. The Deep Lens Survey (DLS; PIs Dell'Antonio, Tyson (UCDavis), Wittman (UCDavis)) is a major observational project that uses gravitational lensing to study the distribution of mass over a wide swath of the sky. This project has already devoted about 130 nights of 4-meter telescope time over the past five years to produce extremely sensitive images of about 10 million very distant galaxies. By examining the shapes of the distant galaxies, Dell'Antonio and his collaborators construct maps of the intervening mass distribution. Because dark matter interacts (essentially) only via gravity, it is relatively simple to study the clustering of dark matter theoretically as a function of cosmological model. Therefore, the DLS will allow them to determine which cosmological model best matches the observed Universe in terms of mass distribution. In addition, the evolution of the clustering with redshift is a sensitive probe of the nature of the dark energy, the substance that is causing the acceleration in the expansion rate of the Universe. Because cluster formation "freezes out" at a time when the matter and dark energy densities are equivalent, the evolution of clustering measures the amount of dark energy. Even further, by measuring how the clustering has developed with time Dell'Antonio's research measures the amount of acceleration dark energy produces (the cosmological parameter *w*), and also whether this parameter has changed over cosmic time (w'). This last term is extremely important, because it offers a clue to the nature of the dark energy. A cosmological constant, for example, would have w=-1 and w'=0, so a non-zero w' would be an indication of an even more exotic form of dark energy. By itself, however, gravitational lensing cannot resolve the issue, because the distortion gives a measure of the mass along the line of sight, but not where along the line of sight the mass is. The researchers have pioneered a technique called tomography that uses the amount of distortion of distant galaxies as a function of their distance to measure the distance of the distorting lens. To calibrate this relation, they have undertaken additional observations using the Chandra and XMM-Newton satellites and the Hubble telescope and are obtaining thousands of galaxy redshifts using the largest spectrographs in the world. One early result is that the properties of the mass clumps selected via their mass differ from the properties of objects selected from their optical luminosity. In other words, our eyes (and our telescopes) give us a biased picture of the content of the Universe. The DLS project will conclude its observations towards the end of 2005, and the analysis of the evolution of *w*, key to a better understanding of cosmology, will be complete by 2007.

World Year of Physics Lectures

2005 is the World Year of Physics and the Brown Physics Department joins the rest of the world in this event by hosting a series of Einstein lectures. These lectures are supported in part by generous contributions from the Galkin Foundation and an anonymous donor.

Mar 7, 2005
Leon Cooper, Brown University
"*Albert Einstein and Constitutional Law: One Hundred Years*"
Mar 14, 2005
Howard Berg, Harvard University
"*Some Physics that* E.Coli *Knows*"
April 18, 2005
Leonard Susskind, Stanford University
"*The Cosmic Landscape: String Theory and the Illusion of Intelligent Design*"

Check our web page for the latest news:
http://physics.brown.edu/physics

New Courses

Biological Physics - PH 101

In January 2002 Assistant Professor Jay X. Tang arrived at Brown, complete with graduate students and a moving van full of research equipment. The Department's first biophysicist, Prof. Tang transferred to Brown from Indiana. In addition to jump-starting an active research effort in biological physics, he has developed two new courses in this interdisciplinary area. The first of these courses was given for the second time in the fall of 2004 as PH 161-Biological Physics.

Physics 161 is designed for advanced undergraduate science and engineering majors and graduate students. The course covers a broad range of topics including: the basic structures of proteins, nucleotides, and biological membranes; thermodynamics and chemical equilibrium; statistical mechanics; solution electrostatics and depletion effect; diffusion and transport; hydrodynamics of low Reynolds number fluid physics; cellular mechanics and motions; and basic concepts in neuron science such as action potential and nerve impulses. PH 161 registered 15 students in its first official offering and is planned to be offered each fall semester.

Encouraged by the strong student interest in this area and recognizing the need to cover more specialized topics beyond a one semester introduction, Prof. Tang worked with others to offer an advanced biological physics course, thereby forming a two-semester sequence. A beta-version of this latest effort will be offered in the spring semester of 2005, and in the future will be known as PH 262. While both 161 and 262 are appropriate for advanced undergrads and graduate students, PH 262 will also satisfy requirement as an elective graduate physics course.

This second course, titled Selected Topics in Molecular Biophysics, covers theories and applications of selected techniques in molecular biophysics. The topics include optical microscopy, photon spectroscopy; X-ray scattering, NMR, MRI, biomechanics, AFM, bio-electrochemistry, electrophysiology, biomolecular simulations, etc. Professor Tang developed this course through an interdisciplinary collaboration with other faculty, including Professors Jim Valles of Physics, Dale Mierke of Molecular Pharmacology, Physiology & Biotechnology, and Joanne Yeh of Molecular and Cellular Biology. The course is team taught by up to twenty faculty members from several science departments and the Division of Engineering. While it has yet to be formally reviewed by the College Curriculum Committee, the pilot version's success is generating strong momentum for a campus wide program of multidisciplinary research and training in biological physics and related areas. There is no doubt that the Physics Department will play an indispensable role in this exciting new era of interdisciplinary teaching. Such a development goes hand in hand with the healthy expansion of Brown University.

Intro to Environmental Physics PH11

Professor Brad Marston has long been interested in using fundamental science to understand environmental problems. This Fall he offered the course "Introduction to Environmental Physics: The Quantum Mechanics of Global Warming" as part of Brown's new First-Year Seminars program. For courses in this program, enrollment is limited to a maximum of 20 students. The program seeks to foster active participation and lively discussions in a congenial setting, to encourage freshman to get to know their professors, and to consider the many research possibilities at Brown for undergraduates.

Physics 11, "The Quantum Mechanics of Global Warming", focuses on the physics of the environment. Physicists like to use simple models to investigate general scientific laws and organizing principles. Most other scientists carry out detailed studies of specific, complex, systems – this organism, that ecosystem, watershed, or evolutionary or geological history. A comprehensive understanding of the environment requires a synthesis of the two scientific approaches. The seminar provides an introduction to this way of thinking and reasoning. Attaining a quantitative understanding of the natural world around us through the use of simple models is a primary goal of the course. Students learn about climate change, energy and entropy, the dispersal of pollutants, solar power, and other aspects of environmental physics, by working directly with models. The subtitle "The Quantum Mechanics of Global Warming" reflects a recurring theme: Quantum mechanics plays a crucial, albeit often overlooked, role in our understanding of the Earth's climate. Lectures are supplemented with many physics demonstrations, a visit to the Barus & Holley rooftop observatory to study the sun, and critical readings of science papers as well as news and opinion pieces in the popular press. Emphasis is placed on the working through of quantitative homework problems that illustrate key phenomena. A final quantitative project caps the course.

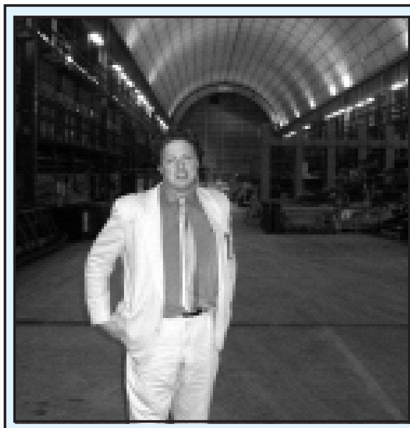
In Search of Dark Matter

Rick Gaitskell with Grad Students Luiz DeViveiros and Peter Sorensen

Given current astrophysical and cosmological data, it is apparent that more than 95% of the composition of the universe is still unknown. The unidentified components are "known unknowns" [1]: their general properties are understood, but their compositions are not. There appears to be a dark baryonic [2] component (several percent, mostly known), a cold dark non–baryonic component (< 25%, unknown composition), and a dark energy component (~70%, of unknown generation). It is extraordinary that the luminous material in the universe (what you see in the heavens) is only 1% of our universe. Professor Rick Gaitskell is conducting experiments to determine the precise nature of the entirely new type of particles that could form the dominant (dark) matter. It is rather unexpected that his work in astrophysics takes him from the basement of Barus and Holley to "observatories" which are 1 km underground!

Our best motivated theories, at present, suggest that at any instant the coffee cup in front of you (full or not) contains around 10 dark matter particles. The dark matter particles do not stay in your cup for very long. They are moving with typical velocities of a few hundred km/s in orbit within the galaxy, and have masses that are around that of ordinary atoms, but are made of entirely new matter known as supersymmetric [3] particles. These particles are "dark"(very weakly interacting) and typically pass right through the cup, you, and the earth, interacting with a single atom in your coffee cup, maybe as often as once a day, or possibly only once a century. (Theoretical physics is not always an exact science!) We need to construct large, very sensitive detectors to look for these occasional interactions. Unfortunately, on the surface of the earth your coffee cup is struck every second by at least one neutron, one cosmic ray and several hundred gamma rays. To escape this background we go deep underground, and shield the detector from external radioactivity. With 1 km of rock above you the cosmic ray rate through your coffee cup would be reduced to less than 1 per month. Similarly with 25 cm of high purity lead the external gamma ray interaction rate would be reduced to 10 per day.(Use of water, or polyethylene, shielding can also be used to reduce the neutron event rates to negligible levels.) Still, the total residual interaction rates are higher than our dark matter sensitivity goals, so we employ detectors which, as well as being very sensitive, large and radioactively clean, are able to discriminate (to a high degree) between dark matter interactions and more conventional particle interactions.

For the past 5 years Rick has been conducting an experiment in the Soudan Mine, in Minnesota, looking for dark matter events in high purity, cryogenic germanium detectors. This experiment has seen nothing, but it does have the distinction of being the most sensitive dark matter experiment in the world — that has seen nothing! The rate of dark matter interactions has been shown to be less than 1 event per coffee mug per month. In order to push our sensitivities further we are now constructing larger experiments with even higher sensitivities (see figure). If you would like to learn more about dark matter, and the continuing quest for its discovery please visit the link http://particleastro.brown.edu. On this web page there are a number of useful links, including a recent review article by Rick. The sky, and your coffee, will never quite seem the same again.



Rick Gaitskell in one of the experimental caverns at the Gran Sasso Underground Laboratory, Italy. Rick and his collaborators will be constructing, and operating, a new dark matter detector based on liquid Xenon (XENON10) here in 2005/6.

[1] Rumsfeld D. Department of Defense news briefing, Feb. 12 (2002) "As we know/There are known knowns./There are things we know we know./We also know/There are known unknowns./That is to say/We know there are some things/ We do not know./ But there are also unknown unknowns,/ The ones we don't know/We don't know."

[2] Protons and neutrons are baryons; thus "baryonic" refers to the matter that you and I, the earth, the sun, etc. are made of. "Non-baryonic" matter is of some unknown kind.

[3] The best theoretical extension of our current "standard" model of particle physics is known as Supersymmetry, in which a new class of particles, as yet undiscovered, mirrors, one for one, the known fundamental particles.

Correlated Electrons and Disorder

Professor Feldman is a condensed matter theorist who joined the department in 2003. His research interests include mesoscopics, strongly correlated electrons, and disordered systems.

One possible definition of physics is "the science about the states of matter". These vary in an enormous range from the cold and tenuous plasma in the inter-star space to the extremely dense nuclear matter to the common gas, liquid, and solid states. One might be tempted to think that after many years of intensive research the physics of solids is a closed chapter. Nothing is further from the truth, as the challenges posed by the progress of modern microelectronics show. Modern technology allows confining semiconductors on the nanoscale in one or two dimensions. As we now know, the states of matter formed by electrons in such confined systems cannot be described as one- and two-dimensional analogs of electronic matter in three-dimensional semiconductors. The understanding of those novel states and the transitions between them is one of the key problems in condensed matter physics. The fractional quantum Hall effect provides an example. In the early 20th century, one way to determine the electron charge was based on the random fluctuations of the electric current in conductors. Such fluctuations known as shot noise originate from the discreteness of the electric charge. In the 90's, physicists from Weizmann Institute of Science and Grenoble repeated similar experiments with two-dimensional electron systems in a strong magnetic field. The measured charge turned out to be a fraction of an electron charge, such as e/3 or e/5. Thus, electrons split into several pieces. We know that nucleus and elementary particles undergo transformations at very high energies available in accelerators. In the quantum Hall effect a similar thing happens at very low energies, on the order of millikelvin. Needless to say those fractionally charged particles are neither conventional fermions nor bosons. One of the directions of Professor Feldman's research is an attempt to understand how the fractionally charged particles propagate and what happens at the phase transitions between quantum Hall phases with different fractional charges.

Another related direction of Professor Feldman's research program is the physics of quantum wires. As the dimensions of electronic devices scale down, the diameter of wires approaches the electron wavelength. At such scales the intuition based on macroscopic electrodynamics ceases to work and remarkable new physics emerges. One of the key features of quantum wires is the universality of their properties. For example, the dc electric resistance of a uniform quantum wire is always h/e^2 divided by an integer, where h is the Plank constant and e the electron charge. This result does not depend on the material or geometry of the wire. One would not be surprised when a property of, say, an atom could be described in terms of fundamental constants only. In condensed matter physics, such situation is truly remarkable and makes the physics of quantum wires a beautiful subject. Professor Feldman's work focuses on one of the most important challenges in the field: transport in non-equilibrium conditions, e. g., in the presence of time-dependent fields. The competition of non-equilibrium effects with strong the electron interaction results in very unusual behavior.

Dima Feldman

For example, as professor Feldman has shown, an impurity which backscatters incoming electrons can enhance the current in the forward direction.

The third research direction of Professor Feldman's group is disorder effects in condensed matter. Theorists like idealized models of perfectly uniform crystals, but in the real world impurities are inevitably present. This poses some of the most difficult problems in theoretical physics. One might think that no universal behavior could be found in systems with different random realizations of the impurity distribution. Surprisingly, the random impurities are in fact responsible for many of the most beautiful and universal effects in condensed matter. Again, the quantum Hall effect provides an example: the perfect quantization of the quantum Hall resistance is possible only because of disorder!

Recently Professor Feldman worked in the field of random porous media. Random porous media such as soil are present everywhere. What happens when a porous matrix confines complex liquid? Experiments with liquid crystals have shown that the usual phases such as nematics and smectics are destroyed in the confinement. The common feature of all liquid crystalline states observed in random media is slow dynamics that resembles relaxation in glasses. Professor Feldman was able to obtain a detailed description of the glassy phase formed by nematic liquid crystals. The nature of other liquid crystal glass states remains a puzzle. Its solution would have an impact far beyond soft matter physics. Indeed, glasses are perhaps the most ubiquitous and least understood states of matter. Spin glasses in magnetism, vortex glasses in superconductivity, Coulomb glasses in semiconductors: the theory of these systems is still an open field where new exciting discoveries are waiting.

Physics at Brown

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We welcome your comments and contributions!

2004 PhD Recipients

NAJMA AHMAD
"The geometry of shape recognition via the Monge-Kantorovich optimal transport problem"

LU CHEN
"Highly Efficient Light Emission in Group-III Nitride Nanostructures"

SORASAK DANWORAPHONG
"Laser Induced Thermal Diffusion Shock Waves"

YONG-HAMB KIM
"Thermodynamics of low temperature detectors"

XIAOYONG LIU
"Magnetic Tunnel Junctions for Low Magnetic Field Sensing"

Frank Wezniak '54 and Dave Cutts

ELENI MAKARONA
"AllnGaN-based Ultra-violet Light Emitters- Microscopic Physics of Device Operation"

ALEXANDER MELNITCHOUK
"Search for non-SM Light Higgs Boson in the h®gg Channel"

ZEEYA MERALI
"The Topology of Large-Scale Structure in Galaxy Redshift Surveys"

ILKER OZDEN
"Interactive Coupling of Electronic and Optical Man-made Devices to Biological Systems"

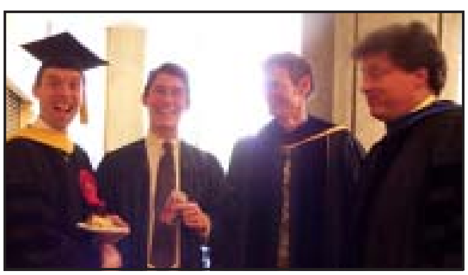
Sang Raul Park and Sean Ling

SANG RYUL PARK
"Neutron Scattering and AC Susceptibility Studies of Vortex Matter in Type II Superconductors"

WISIT SINGHSOMROJE
"Generating and Detecting Phonon Solitions in MgO"

Bob Pelcovits, Dave Cutts, Kenli Okada, Sean Ling, Rick Gaitskell and Frank Wezniak '54

2004 Senior Honors Recipients



Jim Valles, Kenli Okada, Dave Cutts, and Rick Gaitskell

ADAM AVAKIAN, "Matrix Models and 2-dimensional Gravity"

BERNARD MARES, JR., "The geometry of Lie groups"

KENLI OKADA, "AdS Stability and Brane World Perturbations"

ERNO PALLA, "Ultrasonic Studies of Type II Superconductors: Niobium Sample"

Chung-I Tan, Sean Ling and Dylan Spaulding

Professor Valles with Carl Quindel and his father

DYLAN SPAULDING, "The Accuracy of Photometric Morphological Traits in Simulated Galaxy Populations"

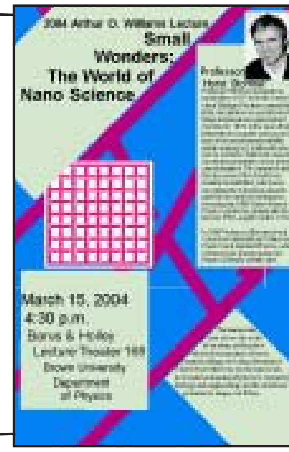
ETHAN THOMPSON, "String/Gauge Correspondences and Wilson Loops"

Frank Wezniak '54, Trustee Emeritus Awarded Diplomas

Humphrey Maris Appointed Hazard Professor of Physics

In 1868, the Brown Corporation chose Alexis Caswell to be President of Brown University and urged him to take immediate measures to increase the endowment. At his urging in 1869 two Rhode Island industrialists, Rowland Gibson Hazard, a member of the Corporation, and his a son Rowland II, later a trustee and Fellow. They donated $40,000 in 1869 for a Professorship. Caswell in his report to the Corporation said, “I recommend that it be designated as the Hazard Professorship of Physics. The particular branch of the science which it will most effectively embrace may properly be left to further consideration.” Humphrey Maris succeeds Charles Elbaum as the esteemed Hazard Professor of Physics.

Our Lecture in honor of Professor Arthur O. Williams was given by Nobel Laureate Horst Stormer, Columbia University and Bell Labs



Greg Tucker

Greg Tucker was promoted to Associate Professor of Physics, with tenure, on July 1. An astrophysicist, Greg is a member of the WMAP satellite team whose analysis of the cosmic microwave background radiation was termed “Breakthrough of the Year” by Science Magazine. His son Alexander was born on June 30, 2004, the third anniversary of the WMAP launch.

Conan Kelly joined the department as a new IT and financial support team member in January of 2003. Conan spent the last nine years at a private liberal arts college, in Galesburg, IL. He was first associated with Knox College as an undergraduate student and then stayed to work as a full-time staff member with the Computer Center. Though he came to enjoy cornfields and open spaces, he’s excited by the new coastal scenery.

We have heard . . .

Kamran Diba, PhD ‘02 *with Prof. Lowe, was recently appointed Research Assistant Professor at Rutgers University. He is working there with Prof. Buzsáki’s neuroscience group on multi-tetrode, and silicon microprobe recordings in the hippocampus. His new homepage can be found at http://osiris.rutgers.edu/~diba/*

Margaret Gardel ScB ‘98 *received her PhD from Harvard University in Soft Condensed Matter Physics and is currently a postdoctoral Pappalardo Fellow (2004-2007) in MIT’s Physics Department*

Ambarish Ghosh, PhD ‘05 *is just starting a postdoc at Harvard University.*

Denis Konstantinov, PhD ‘05 *is a postdoc at RIKEN in Japan.*

Kostas Orginos, PhD ’98 *with Professor Tan, has accepted a tenure-tracked Assistant Professorship offer from the College of William and Mary, starting September, 2005. He is currently a senior Research Associate at MIT, working in the area of Lattice Gauge Theory.*

Ken Silva and J**acquelyn Mahendra**’s manuscript, “Digital Video Microscopy in the Millikan Oil-Drop Experiment,” will be published in AIP, American Institute of Physics, sometime during the second quarter (March 2005-July 2005). Dean Hudek writes, “Jacquelyn worked with Ken on adding digital video capture to the Millikan Oil-Drop Experiment the summer before last. This new technique makes it much easier for our introductory students to successfully perform this important, but sometimes frustrating, experiment.”


2004 Spring Picnic
Pembroke Field

Physics at Brown

Physics at Brown Newsletter
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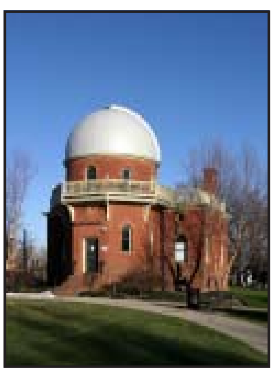
ALUMNI, WE'D LIKE TO HEAR FROM YOU!
News? Comments?
Please write to the above address or e-mail us at newsletter@physics.brown.edu

Ladd Observatory: *Serving the Brown Community*



The Physics Department's **Ladd Observatory** continues to enrich large audiences which range from students in our astronomy courses to youth groups drawn from all over Rhode Island. One of Brown's most popular outreach programs is the Tuesday evening Ladd Open House. These evenings feature guided viewing of the heavens using Ladd's historic telescope as well as other telescopes mounted on the outside observing deck, together with popular talks by physics faculty and others in the museum setting of Ladd's main floor.

Ladd Observatory, which completed its 113rd year in 2004, is a unique historic site (nationally registered) as well as an active, functioning observatory. Ladd Director David Targan (who is also an Assoc. Dean and physics professor) gave a closing plenary talk about Ladd at the National Conference on Historic Scientific Instruments held in June. The special character of Ladd is well appreciated by this community of scholars.

Activities at Ladd received a further important stimulus through President Simmons' Leadership Fund, which provided several grants supported by the Atlantic Philanthropies. One project involves Brown students developing materials on science and astronomy to use with teachers in local schools, exploiting the wonder engendered by visits to Ladd to reach out to young people and to share the joy of science. Another project focuses on Ladd's historic role a century ago as the source of accurate time keeping, supplying the correct time to surrounding commerce and industry. We are now able both to restore the old instruments at Ladd as well as to support student investigations of the history of timekeeping and of Ladd's important place in this history.

For information about Ladd Observatory and our Open House see *www.physics.brown.edu/Ladd* .