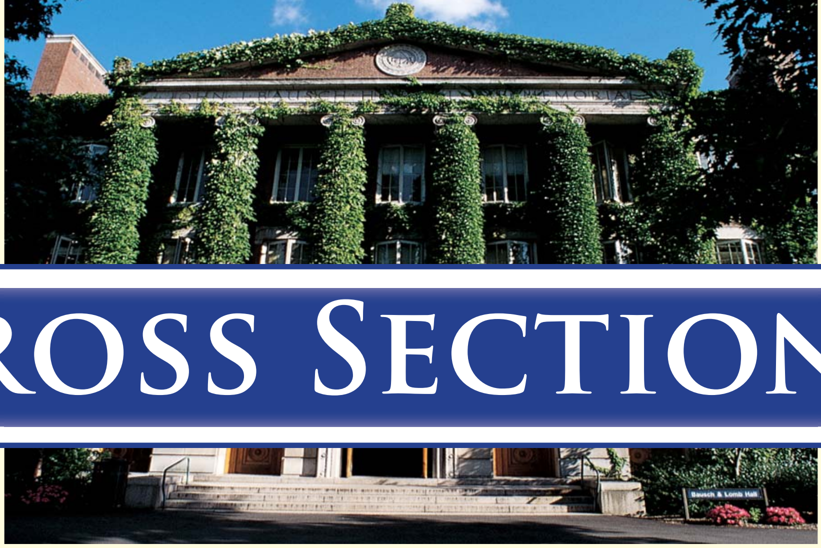
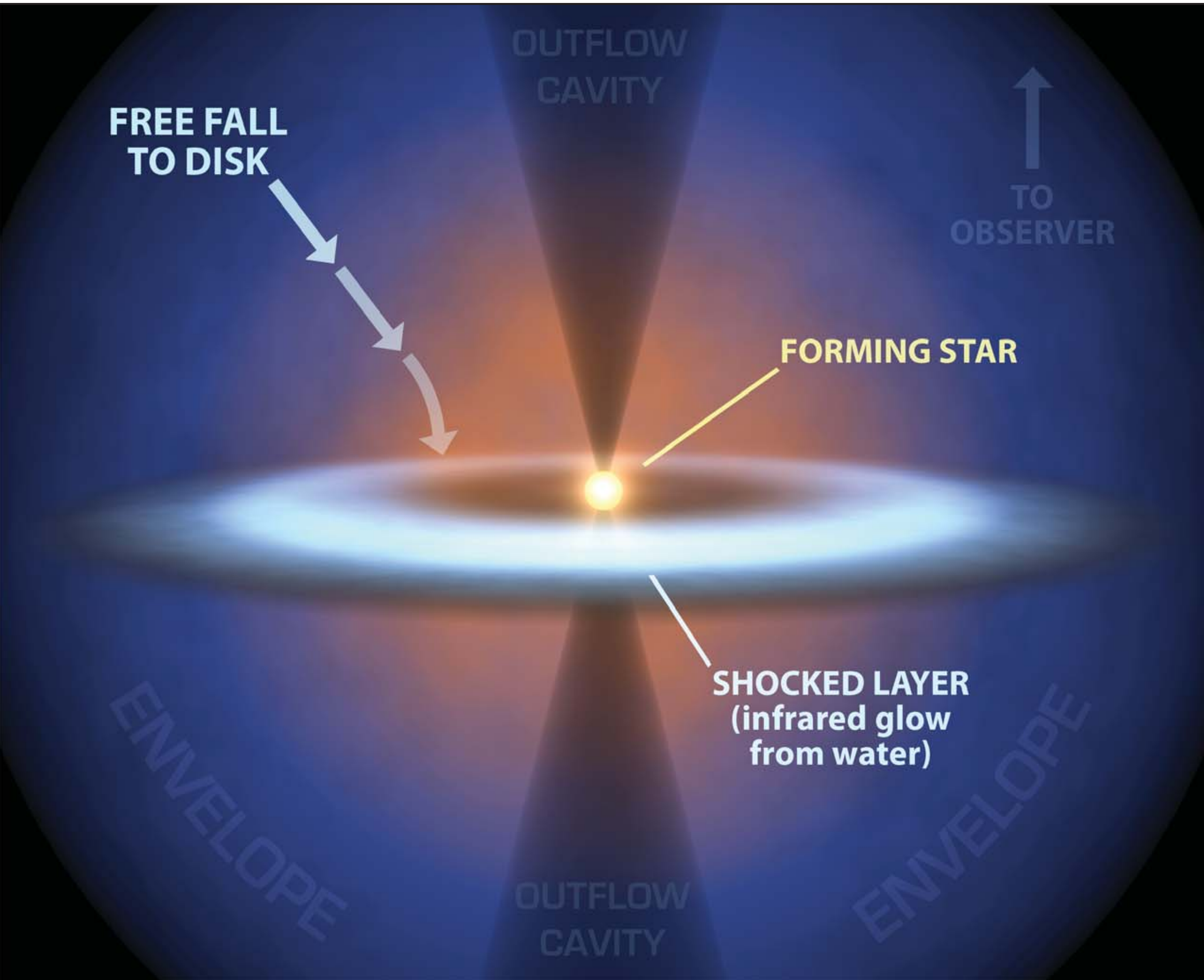


Cross Sections

Department of Physics and Astronomy
University of Rochester
Spring 2008



Message from the Chair

It is my pleasure to welcome you to the Spring 2008 edition of CROSS SECTIONS. The year since our last edition was exciting and full of change. After nine years of outstanding leadership, Arie Bodek has stepped down as Chair and is just finishing a well-earned year of academic leave. Since July 2007, I have been serving as the 13th Chair of the Department, and enjoying it. What is especially exciting has been our faculty recruitment efforts. This Spring we hired two new junior faculty members. One new face for 2008 will be observational astronomer Eric Mamajek. Eric is currently at the Center for Astrophysics at Harvard-Smithsonian. Also arriving is Aran Gracia-Bellido, a high-energy experimentalist currently at the University of Washington. Aran is part of the D0 collaboration at Fermilab and plans to shift his focus to the CMS collaboration at LHC/CERN. The good news is that we're not done. We have two more searches authorized for this coming year, and I look forward to reporting to you about them in a future issue.

As always, the year did not pass without several of our faculty, students and alumni receiving awards, fellowships, and other forms of national and international recognition. For example, Joe Eberly has just finished a year as President of the Optical Society of America. It was a very proud day in October when Judy Pipher was inducted into the National Women's Hall of Fame, and not long thereafter, we were delighted to have among our undergraduates two winners of Goldwater Fellowships (John Golden and Samuel Harrold) and one Fulbright Scholar (Ben Schmitt). To read more about these and other successes, you need only turn a few more pages, and we hope you will enjoy these and other stories.

Our graduate and undergraduate programs remain vital--we have about 120 graduate students at any given time, and our number of undergraduate majors has increased, hovering around 30 per year. Our research programs remain in full swing and among the best. For the latest news about the Department, please visit us at www.pas.rochester.edu.

Meliora--Nicholas P. Bigelow

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To submit alumni and research news, contact:

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On the Cover

Infrared Water Emission from Protoplanetary Disk. This diagram illustrates the earliest journeys of water in a young, forming star system. Stars are born out of icy cocoons of gas and dust. As the cocoon collapses under its own weight in an inside-out fashion, a stellar embryo forms at the center surrounded by a dense, dusty disk. The stellar embryo "feeds" from the disk for a few million years, while material in the disk begins to clump together to form planets.

Credit: NASA/JPL-Caltech/T. Pyle (SSC)

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Embryonic Solar System Assembly Seen for the First Time

Using NASA's Spitzer Space Telescope, a team of astronomers led by Professor Dan M. Watson (*right top*) of the University of Rochester has observed the onset of planetary-system formation, a process nobody has seen until now. The group's exciting first look at the creation of an embryonic solar system yields many new insights about the physics and chemistry of evolving astronomical objects.

Publishing their results in the August 30, 2007 issue of Nature, the researchers note that the Spitzer Space Telescope enabled them to see water, in the form of ice, "raining" from a cloud enveloping the infant star NGC 1333-IRAS 4B approximately 1,000 light years away from Earth. The ice is vaporizing as it lands supersonically on a dense, dusty disk surrounding the baby star, a long-sought phenomenon called a disk-accretion shock. In time, planets will form within the dusty disk.

"What's special about the Spitzer Space Telescope," says Professor Watson, "is that it lets us see through dense dust and gas clouds. In fact, we're now able to see what used to be invisible material at the cores of protostellar condensations." Of the 30 protostars -- embryonic solar systems -- studied by Watson's team, only NGC 1333-IRAS 4B displayed what was going on during the formation of what someday will be planets.

Using infrared light emitted by the water vapor, the scientists calculate the current "rainfall rate" to be about 23 Earth masses per year, and the water present in the shock-heated surface of the disk could fill Earth's oceans about five times. They also report that the disk's radius exceeds the distance between Earth and Pluto, and that its temperature is 170 Kelvin, or -154 degrees Fahrenheit.

Why is there a disk of gas and dust around the embryonic star? Galaxies like ours have a lot of material in the form of gas and dust between the stars. This interstellar medium exists as a wide variety of clouds, including dense molecular clouds where the stars and planetary systems form. Fragments of material coalesce into clumps, cool, and can collapse very quickly under their own weight. These fragments spin faster as the collapse proceeds due to the conservation of angular momentum. Centrifugal force impedes the collapse in two directions, and the cloud collapses fastest in the direction of the axis of rotation. This process flattens the cloud, so the result of collapse and spin is to create disk-shaped assemblies of matter.

Thus, the collapsing cloud fragment becomes a slightly flattened spheroid shape called the envelope. Inside the envelope is a dense disk called the protoplanetary disk, which eventually turns into a system of planets. At the center of the disk is the protostar, a rounder shape that evolves into an actual star.

The protostar gathers mass as the envelope rains down on the protoplanetary disk, and matter from the disk falls onto the protostar. During the first 10,000 years after the initial formation of the embryonic solar system structures, the protostar ends up accreting most of its eventual mass.

So what does the future hold for the embryonic NGC 1333-IRAS 4B system?

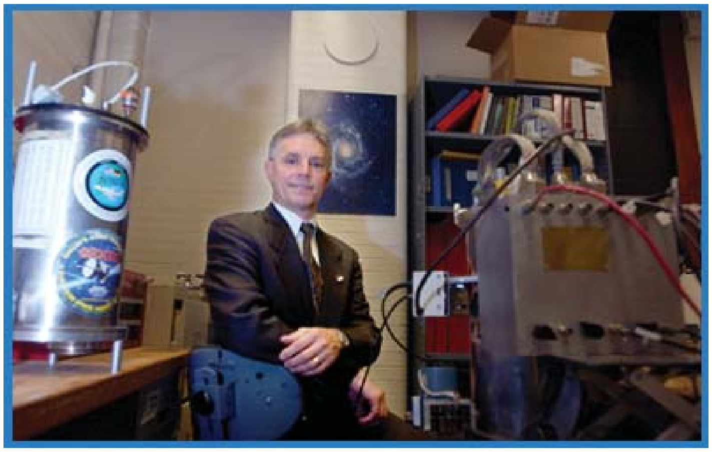
University of Rochester Professor William J. Forrest *(right bottom)*, a key collaborator on the Spitzer project, supplies some clues. "NGC 1333-IRAS 4B is in good shape for making a system of planets within the disk. This observation strongly supports a fundamental premise of star formation: stars can't form directly, but rather, first form a disk surrounding the nascent star. It is from disks that planets can form."

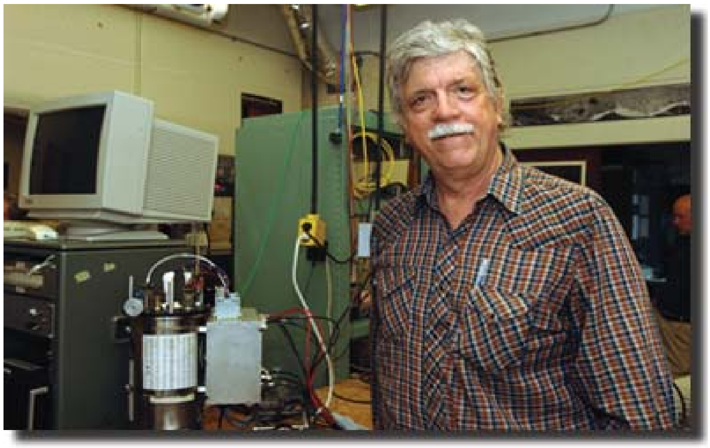
Professors Forrest and Watson were both on the team that built the Spitzer Space Telescope and its Infrared Spectrograph from 1983 to 2003. They've been studying these embryonic systems for a long time. They point to one other significant aspect of embryonic solar system assembly that they have now observed:

A protostar has an extremely slow spin rate. If a protostar were to retain all of the material that rains down upon it, the protostar would never settle down. Instead, it would break apart. The pressure and magnetism in a protostar keep this from happening by ejecting much of the material that is trying to fall onto the protostar. The material is ejected out the poles of the protostar, carrying with it most of its spin. Hence, the material that does accrete to the protostar has little spin to it and is able to settle down onto the protostar. As long as the envelope is moving material onto the disk, this ejection, or outflow, of material continues.

NGC 1333 IRAS 4B is known to have such an outflow. It is through the tunnel carved by this outflow, shaped somewhat like a cone, that the NASA Spitzer team is able to view the core of the developing solar system.

Authors of the Nature paper include Professors Dan Watson and William J. Forrest of the University of Rochester Department of Physics and Astronomy; Chris Bohac and Chat Hull, both former undergraduate students of Dan Watson; and Jim Houck of Cornell University, who heads the Spitzer Infrared Spectograph team.





Water's Early Journey in a Solar System (Artist Concept)
Credit: NASA/JPL-Caltech/R. Hurt (SSC)

NOBELIST STEVEN WEINBERG PRAISES PROFESSOR CARL HAGEN AND COLLABORATORS FOR HIGGS BOSON THEORY

In October 2007, Nobel Prize Winner Steven Weinberg reminded a new generation of physicists about the crucial contribution regarding the Higgs boson theory made by Professor Carl Hagen of the University of Rochester and his collaborators. Weinberg's comments were part of his invited presentation at a conference celebrating the fiftieth anniversary of John Bardeen, Leon Cooper, and J. Robert Schrieffer's (BCS) theory of superconductivity.

The method suggested by Professor Hagen and others gives mass to vector bosons and is an essential ingredient in the unified electroweak theory for which Sheldon Lee Glashow, Abdus Salam, and Weinberg shared the 1979 Nobel Prize in Physics. In their acceptance speeches, they all gave equal prominence to the contributions of three independent teams who had predicted the existence of the Higgs boson, as it is now commonly called.

Three independently formulated papers describing the theoretical mechanism appeared in Volume 13 of Physical Review Letters in 1964. They were by Gerald Guralnik, Carl Hagen, and Tom Kibble; by Peter Higgs; and by Francois Englert and Robert Brout. All three papers were written from different perspectives, and each made a distinct contribution.

The Higgs boson is a hypothetical particle and the only fundamental piece of the Standard Model that has not yet been validated experimentally. It is massive and has no spin. To create the particle requires huge amounts of energy on the scale of that produced by the much anticipated Large Hadron Collider that is expected to be operational this year in Geneva, Switzerland.

It is this particle that many physicists believe will explain the origin of mass in other particles. If discovered, it will explain why the photon is massless and why the W and Z bosons are so heavy. In Glashow-Salam-Weinberg electroweak theory, this theoretical mechanism is also responsible for the heavy masses of the quarks, as well as of leptons: electrons, muons, and taus

Background

Of the four known fundamental forces, The Standard Model of matter includes three: electromagnetism and the strong and weak interactions. At present, gravity does not play an integral role in our theories about fundamental particles. The current model also has two categories of particles, quarks and leptons. The quarks are affected by all three forces and are the components that make up all protons and neutrons. Leptons generate and are affected by electromagnetism and weak interactions, and include the electron. The main difference between the quarks and leptons is something called color, and has nothing to do with colors that we see such as orange, yellow, or green. Rather, color in this case refers to a property that is somewhat like an electric charge. Leptons don't have color, while quarks have three colors. The color force leads to the strong interaction that is responsible for holding the proton and neutron bound in the nuclei.

In the Standard Model, the equations remain symmetric no matter how perspective shifts in space and time. Particles known as bosons transmit forces and ensure that the symmetries are maintained. Eight bosons called gluons carry the strong force.

Both the weak nuclear force and electromagnetism are thought of broadly as electroweak forces, and they have a different symmetry from the strong nuclear force. In the electroweak case, the forces are carried by four particles: the photon, the W+ boson, the W- boson, and the Z boson.

This unified electroweak theory is, in essence, the basis of Glashow, Salam, and Weinberg's Nobel Prize. Before the landmark Nobel work, theorists predicted four long-range mediators of force called the gauge bosons. In actuality, there is one long-range force particle, the photon, and the other three gauge bosons have short ranges that are less than one percent of the proton's radius, leading to the conclusion that the gauge bosons each have a mass of approximately 100 billion electron volts (GeV). And prior to Weinberg's work, it was not known why quarks and leptons have masses.

In Weinberg's 1979 Nobel Lecture, he described the impasse faced by scientists who were seriously thinking about developing a gauge theory of fundamental particles. To avoid the appearance of massless particles other than the photon, he sought to invoke the broken symmetry ideas in the BCS work.

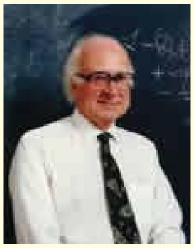
Professor Steven Weinberg

Professor Gerald Guralnik

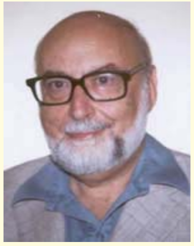
Professor Carl Hagen

Professor Tom Kibble

Professor Peter Higgs



Professor Francois Englert



Professor Robert Brout

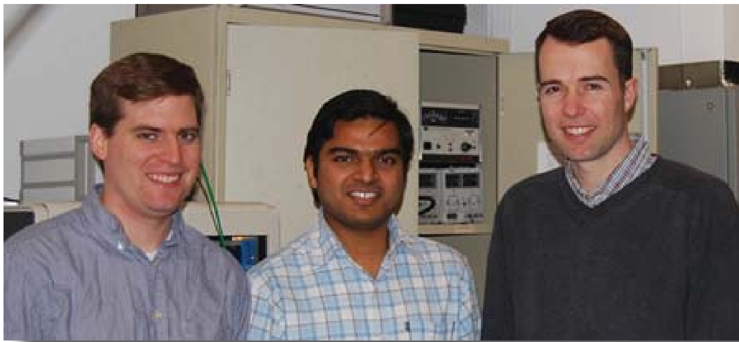
References

G.S. Guralnik, C.R. Hagen, and T.W.B. Kibble, "Global Conservation Laws and Massless Particles," Physical Review Letters, Volume 13, p. 585, 1964.
See: http://link.aps.org/abstract/PRL/v13/p585

Peter W. Higgs, "Broken Symmetries and the Masses of Gauge Bosons," Physical Review Letters, Volume 13, p. 508, 1964.
See: http://link.aps.org/abstract/PRL/v13/p508

F. Englert and R. Brout, "Broken Symmetry and the Mass of Gauge Vector Mesons," Physical Review Letters, Volume 13, p. 321, 1964.
See: http://link.aps.org/abstract/PRL/v13/p321

Slowing and Stopping Images



(*Hagen*, continued from last page)

In simple terms, broken symmetry refers to the notion that, while the laws of nature may be symmetric, the outcome of those laws need not be symmetric. In superconductivity, electromagnetism has symmetric laws, yet in superconductive materials, the behavior of electromagnetism is not symmetric. Put another way, while the field equations are all covariant with respect to the underlying symmetry, the sole agent of symmetry breaking was the vacuum of space. Given the choice of completely equivalent or symmetric vacuum states, nature picked one, thus breaking the symmetry.

This intuitively appealing answer immediately seemed incorrect when confronted with the problem presented by the appearance of massless bosons. A theorem associated with Jeffrey Goldstone asserts that, any time a continuous symmetry group is broken, there is an accompanying effect that requires the appearance of massless particles. There is no room in the particle zoo for massless bosons in addition to the photon, and Weinberg in his Nobel Lecture describes his state of utter discouragement at the time of his 1962 paper.

Three Independent Teams Discover the Answer

As noted, it was in 1964 that the problem was resolved by three separate papers, all of which were in Volume 13 of Physical Review Letters. Each paper independently solved the problem of a physically sensible broken symmetry theory of elementary particles by noting that the Goldstone theorem includes relativistic invariance in its core of underlying assumptions. Since particle physics experimentalists have yet to detect the slightest breakdown of relativistic invariance, this hardly seemed to offer escape from the deadening hand of the Goldstone theorem. However, the three papers observed that, in dealing with gauge theories, there was an exception.

When symmetry is broken by a two-component scalar field, the photon-like gauge field, which has two transverse modes, combines with one of the scalar field components, hence providing the missing longitudinal mode required for a gauge field with mass. The leftover scalar field is a particle, and it is this particle that was first called the "Higgs" by Ben Lee in his talk at the 1966 Rochester Conference held at Berkeley.

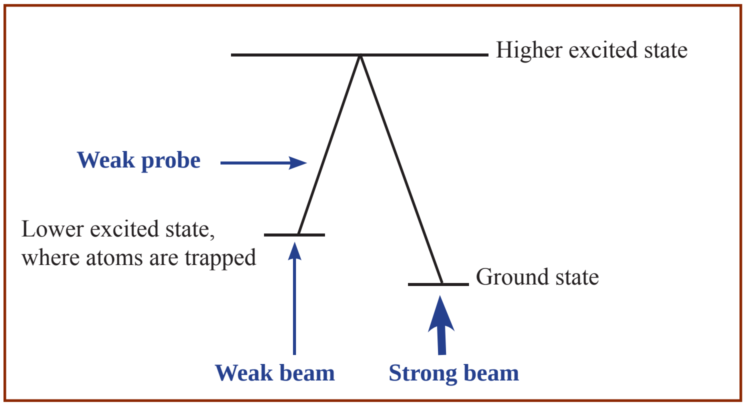
Many physicists believe that the W and Z bosons, as well as quarks and leptons, all obtain their masses because they interact with the Higgs field. Rather than having mass to begin with, they obtain it, and thus the particles conform to the symmetry that the weak force requires.

The unification of vector gauge fields with scalar fields to form vector particles led to the detection of the W and Z vector bosons, and it also led to the 1979 Nobel Prize. The contributions made by all three papers -- Gerald Guralnik, Carl Hagen, and Tom Kibble; by Peter Higgs; and by Francois Englert and Robert Brout -- cannot be underestimated. They formed the basis of unified electroweak theory, and they predicted what scientists believe is the origin of mass.

Associate Professor John Howell reported in January of 2007 that his group showed how to slow images down to "300 times lower than the speed of light" and preserve the amplitude and phase of the image. He also stated that, "we're working on systems that slow images down to 10 million times lower than the speed of light." Howell and his Quantum Optics team of Ryan Camacho, Curtis Broadbent, and Irfan Ali Khan used a technique known as slow light. When close to a narrow resonance feature, the group velocity of the light can be very slow. His team used naturally-occurring resonances in a cesium vapor to precisely slow images and delayed them for about 10 nanoseconds while retaining their properties.

Now the group *(photo, left to right: Ryan Camacho, Praveen VudyaSetu, and John Howell)* has stopped images in a hot gas of Rubidium atoms for about 10 microseconds and is working toward a goal of a millisecond (Physical Review Letters 100, 123903). The new process changes the light field into an atomic excitation, then reads out that atomic excitation and converts it back into a light field. This differs from the method used in January of 2007, in which the light propagated slowly through a dilute vapor. In the stored light technique, the light field is interconverted into a coherence in the atoms and then read out at a later time. Remarkably, the storage process remains robust even given the diffusion of the rapidly moving atoms.

Rubidium 85, one of the two most common isotopes of the element, has two hyperfine ground states that are shifted slightly in energy from one to another. A relatively strong laser beam of a few mW of light prepares the hot vapor so that atoms are in a single ground state. A weak pulse of light carrying the image then puts the atoms into a superposition of both ground states. The strong pump beam is then turned off, which causes the coherence setup by the two lasers to be "frozen" or stored in the medium. Each atom carries the local image phase and amplitude.



At some later time, the strong pump beam is turned on in the reverse fashion in which it was turned off. The strong pump beam reads out the coherence in the atoms. The weak pulse is then regenerated with the phase and amplitude of the image in tact. Howell and his students, Praveen VudyaSetu and Ryan Camacho, then read out the image with varying time delays. The greater the time between turning off the pump beam and turning it on again, the more the image was attenuated. However, the contrast in the image is not corrupted as might be expected with atoms moving very rapidly in a hot gas.

The surprising aspect of the work is that the image remains robust to strong diffusion. The Fourier transform of the image is stored in the atoms and has phase oscillations in a 2-dimensional cross section. The robustness occurs because the atoms store the local phase of the light field. As atoms move, they cancel their effect with atoms of different phase as they pass through zero phase points in the Fourier transform plane. The preservation of the zero phase points result in high contrast image readout long after the image would have washed out.

How to Save Schrodinger's Cat

The feature story of the May 14, 2007 issue of New Scientist features Assistant Professor Andrew Jordan's work on reversing quantum measurements, published with co-author Alexander Korotkov in Physical Review Letters 97, October 2006. Jordan defines experiments to physically undo a measurement of an unknown quantum state. In the case of Schrodinger's cat, this means that he has figured out how to monitor the state (dead or alive) of the classic "cat in a box," then undo any damage caused by the monitoring.

"Quantum measurement is usually taught in textbooks as an instantaneous process," Jordan explains in New Scientist. "What we've learned in the last few years is that real measurements don't work that way. In nature, all processes take a finite time."

According to textbook quantum measurements, wavefunction collapse is essentially an irreversible process; the measurement record is indelible. Contrary to this conventional wisdom, the authors show that continuous quantum measurements are written in pencil, not in pen.

The authors give explicit experimental procedures to undo quantum measurement. Step one is to fire a microwave pulse at a loop of superconducting wire known as a phase qubit. This puts the qubit into an equal superposition of both of its possible energy states, and essentially, makes the qubit "behave" like Schrodinger's cat. At this point, the scientists start to measure the state, and the superposition moves either towards "dead" or "alive." To avoid killing the cat, or in this case, the qubit, the next step is to test whether the qubit has undergone quantum tunneling. The key is to catch the qubit before it tunnels and collapses to a higher energy state. This is done by making a second continuous measurement and waiting until the combined detector output gives no information about the initial quantum state.

The information obtained from the first measurement is erased by the second, fully restoring the initial quantum state. The catch is that the undoing procedure is not always successful, so that as the strength of the first measurement grows (giving a particular answer with increasing certainty), the probability of undoing it decreases, finally reaching zero for a textbook quantum measurement. Continuous wavefunction collapse has recently been experimentally observed [Katz, et al., Science 312 in 2006], providing a promising candidate for verification of this prediction in the near future. The overall process is illustrated in a picture on the following web page: http://web1.pas.rochester.edu/~jordan/undo.html. The New Scientist article is at http://web1.pas.rochester.edu/~jordan/Quantum%20Undemolition.pdf.

Building Super-Amplifiers in Nano-Electric Systems using Strange Weak Values

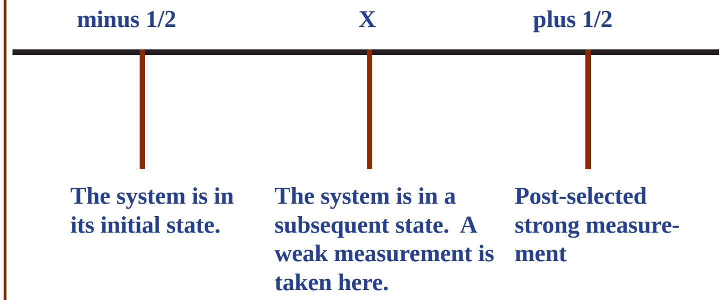
In a recent Physical Review Letters (PRL 100, 026804) article, Assistant Professor Andrew Jordan and third-year PhD student Nathan Williams *(photo, right)* describe how to implement one of the most bizarre predictions in quantum mechanics: a strange weak value in a nano-electric system. For a quantum system, their proposed method could provide an electrical current that exceeds the current supplied by the analogous classical system by factors of hundreds or thousands; that is, their device could boost a nano-amp to one amp or even to ten amps. This new method could also be used to determine whether an experimental system is a quantum mechanical device.

So what is a strange weak value, and why does it correspond to such a dramatic boost in current? The answers are key to understanding just how remarkable their nano-electric system is and just how peculiar strange weak values are.

When a strong measurement is made on a spin 1/2 system, the outcome is always one of two things: either the spin is plus 1/2 (pointing up) or minus 1/2 (pointing down).

However, with a weak measurement in the same system, the outcome becomes continuous and the average is somewhere between plus 1/2 (pointing up) or minus 1/2 (pointing down). So in a very simple system, we might see something like this:

Figure 1

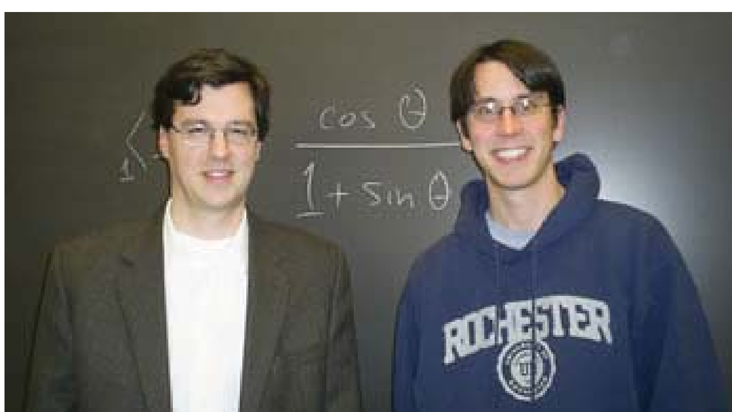


Here X is the average of the weak measurements. A subsequent strong measurement would force the spin into its up or down state. A weak value is the average of the weak measurement results, where the later measurement gives (only) spin up.

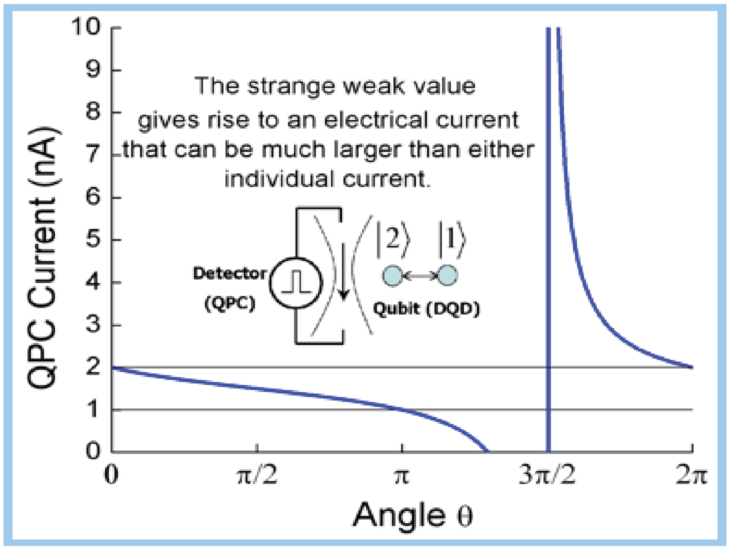
Notice that we've been discussing a weak value as opposed to a *strange* weak value. Jordan and Williams find that, after averaging a large sample of weak measurement results, the value of X is nowhere between minus 1/2 and plus 1/2. Nor is the value at minus 1/2 or plus 1/2. Indeed, the value of X -- the *strange weak value* -- can be a hundred or even a thousand times higher than plus 1/2 or minus 1/2. So if the spin is measured in units of Planck's constant, X might be 100 or 1,000 times Planck's constant.

The proposed device takes two measurements, the first being a weak measurement at X, the second being the post-selected strong measurement. "Using this method of pre-selection, weak measurement, and post-selection strong measurement," explains Jordan, "the resulting value of X is huge, and this phenomenon only exists quantum mechanically. Quantum mechanics can't possibly be explained using classical physics. If we perform the same procedure in classical physics, the value of X would always lie between plus 1/2 and minus 1/2."

The design of the nano-electric quantum device is shown on the next page. The detector consists of a double quantum dot, denoted by DQD, which functions as the spin 1/2 system. Next to the qubit is a detector, the quantum point contact (QPC), which is pulsed with a tiny amount of voltage through a wire width on the scale of the electron wavelength. One electron can pass through the QPC at any given time. The position of the electron in the DQD affects the transmission of electrons through the QPC, where the flow is translated into current. For example, if the electron is sitting at state 1, then 1 nano-amp flows through the QPC, and if the electron is at state 2, then 2 nano-amps are flowing: there are two distinct currents.



(*Jordan*, continued from last page)



The system is set to an initial state, a weak measurement is made at X, and then a post-selection is made with a strong measurement, as shown in Figure 1. After running a large sample, the mechanism produces an average amount of current for the total of all weak measurements. It is this value that exceeds anything within the classical system's normal range, which could be anywhere from 1 nano-amp to 2 nano-amps, denoted by the two horizontal lines in the figure. Rather than produce between 1 and 2 nano-amps, the device could produce current that lies in the range shown by the blue curve in the upper right corner of the graph. Any value above the two horizontal lines flies into non-classical regime. When asked how it is possible for a value measured between plus 1/2 and minus 1/2 can reach a thousand times past those spin values, Nathan Williams replies, "The math proves the possibility. Yet it confounds our intuition, doesn't it? And that's why we call these phenomena, strange weak values. Because they are incredibly strange."

A final point to note is that the Leggett-Garg criteria are actually a disguised form of the strange weak value criteria. The Leggett-Garg criteria, proposed in 1985, test a system to determine if it is classical or quantum mechanic. With Leggett-Garg, when a correlation function exceeds a classical bound the system, is shown to be quantum mechanical. When Jordan and Williams' detector produces an incredibly large current, it violates the Leggett-Garg criteria for classical systems. Hence, when the correlation function is written in terms of post-selection, the Leggett-Garg test is basically the same as that for the strange weak value. The Leggett-Garg criteria and the technique proposed by Jordan and Williams are different expressions of the same physics.

Controlling Electrical Properties of Organic Semiconductor Materials

University of Rochester physicists have learned why Pentacene, the leading candidate for developing organic semiconductors, conducts electricity in inconsistent ways rather than with predictable electrical properties. Specifically, Professors Yongli Gao and Yonathan Shapir, with Gao's PhD student Serkan Zorba (now an Assistant Professor at Whittier College), discovered that Pentacene is the first known substance with two basic growth mechanisms that combine to form thin films with unique fractal patterns. These fractal growths are why other researchers have found inconsistent electrical properties in layers of Pentacene.

Organic semiconductor materials have vast potential to transform electronic devices and save energy. For example, experts predict that organics will be used in the near future to create inexpensive, lightweight, flexible organic light-emitting diodes; organic thin film transistors; and organic photovoltaic cells that can power a wide variety of devices.

The processing of organic semiconductors can be done at low temperatures, whereas inorganic semiconductors require high temperatures. However, to create organic semiconductors inexpensively on large areas, fabricators must use evaporative deposition, a common method of placing a thin film on a substrate or on previously deposited layers. Another common method, called sputtering, takes a lot longer.

Pentacene is a compound of carbon and hydrogen ($C_{22}H_{14}$) with a crystal structure. Most organic materials considered as potential semiconductors are not crystals; rather, they are amorphous. Electricity can move more easily through crystalline materials because atoms are arranged in regular patterns.

As was the case with inorganic semiconductor devices in the twentieth century, the most important factor in developing twenty-first century organic semiconductors is being able to control their electrical properties in thin films. The process of controlling the electrical resistance (or its inverse, which is called mobility) of electrons in a substrate of Pentacene depends on how the material is grown in the laboratory.

Because of Pentacene's importance to the future of the organic semiconductor industry, the University of Rochester team investigated the growth patterns of Pentacene substrates and thin films grown via evaporation. They used a device called an Atomic Force Microscope (AFM), which images surface layers at the level of observing single molecules. Then they created models of the process with numerical simulations and interpreted the results.

Much to their surprise, the researchers discovered that Pentacene has two basic growth mechanisms that together form films with unique fractal patterns.

Diffusion-Limited-Aggregation, or DLA, is one of the most famous fractal cluster structures. It occurs when particles diffuse toward and stick to a cluster of molecules on the surface of a substrate. Many substances exhibit DLA behaviors when used to grow a thin film surface layer. Due to random gaps introduced by the nature of the DLA structure, the fractal dimensions of a two-dimensional layer are 1.6; this means that, given a circle of radius r, the number of molecules inside the circle is proportional to the power of 1.6 rather than 2, which is the regular exponent for a circle.

Many substances grow thin film surface layers using a different mechanism, known as mounded growth, where material deposited grows in mounds, or tiny foot hills, on a substrate. This type of surface growth occurs due to the Schwoebel Effect, where a molecule that is deposited on the surface of a mound is prevented from going downward. As more material is deposited on the substrate, the mounds get higher, and as a result, the film is bumpy rather than smooth and uniform.

Pentacene simultaneously exhibits both Diffusion-Limited-Aggregation growth and mounded growth. The DLA occurs horizontally, while the mound growth occurs vertically.

As Professor Shapir says, "Not only has this never been seen before in any experiment, it has also never been predicted theoretically."

Professor Gao speculates that the manufacturing of the first monolayer of molecules is the key to making a uniform thin film. The random fractal structure in the evaporative deposition of the first layer causes surface gaps with large electrical resistance. The subsequent building of mounds on top of these fractal structures makes the resistance even worse.

The manufacturing of a smooth first monolayer of molecules can be done using Molecular Beam Epitaxy, but that technique is very expensive and can only be used to coat very small areas. Another technique to make a uniform first monolayer is called Self Assembly Monolayer, in which the substrate surface is dipped into a carefully prepared chemical mixture that includes Pentacene. A third technique involves shining linearly polarized light on the surface to organize molecules along straight lines during evaporative deposition. These and other ideas are currently being investigated by researchers worldwide.

High-Energy Particle and Nuclear Physics at the UR

In the next few issues of CROSS SECTIONS, we plan to offer you glimpses into the many areas of physics research in the Department. We figured we'd start with High-Energy Particle and Nuclear Physics, a domain that has enjoyed a long and distinguished history at the University of Rochester.

High-Energy Particle and Nuclear Physics deals with the nature of the fundamental constituents of matter and their interactions. The past fifty years have witnessed tremendous progress in our understanding of these issues, and a remarkably simple and elegant picture, the Standard Model, has emerged as a result of intensive experimental and theoretical investigations. This picture has been incredibly successful in describing the very tiny and energetic collisions at accelerators as well as helping us understand the large-scale structure and evolution of the universe.

Nevertheless, many basic questions remain such as:

Why does the universe contain so much more matter than antimatter? What is the origin of mass and electric charge? What is the purpose of the heavier "copies" of the quarks and the leptons that make up most of the normal matter in our universe? How did each of the four fundamental forces acquire their distinctive characteristics, and to what extent are these forces related? What is the nature of the dark matter that seems to constitute most of the mass in the universe?

Exploring these issues requires probing the structure of matter at extremely small distances, and therefore high energies. Consequently, experimental activity focuses on the use of high-energy accelerators to reach extreme conditions, and theoretical approaches lead to frontiers of modern mathematics in attempts to crystalize and unify understanding.

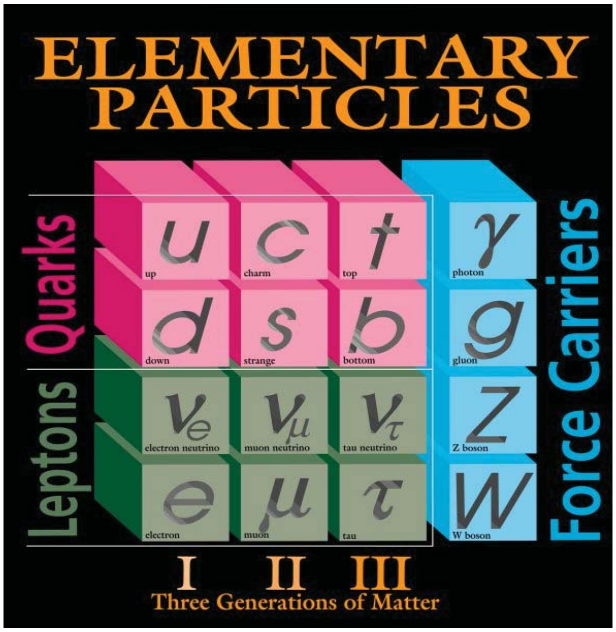
Some of the major accomplishments of the particle physics group at the University of Rochester are:

1. Important contributions to the Higgs boson theory, a critical component of the Standard Model, by Professor Carl Hagen and his collaborators.
2. The invention of the mass formula for hadrons, which led to the understanding that hadrons are made out of quarks, by Professor Susumu Okubo (1976 Nishima Prize, 2005 American Physical Society Sakurai Prize, and 2006 Wigner Medal).
3. The detailed study of the bottom quark and particles containing it by the CLEO collaboration at Cornell University led by Professor Edward Thorndike (1999 American Physical Society Panofsky Prize).
4. The discovery of the top quark by the CDF and DZero collaborations (Professors Arie Bodek, Kevin McFarland, as well as Paul Tipton, then at the University of Rochester) on the CDF project, and Professors Regina Demina, Thomas Ferbel, and Paul Slattery on DZero.
5. Precise and detailed studies of the structure of the nucleon by Professor Arie Bodek (2004 American Physical Society Panofsky Prize).
6. Helping to establish and study the quark-gluon plasma in heavy ion collisions at Brookhaven National Laboratory (Professors Steven Manly and Frank Wolfs, PHOBOS collaboration).
7. The development of tile fiber scintillation technology by Professor Arie Bodek's team on the CDF project at Fermilab, now a standard in particle physics and incorporated in the Large Hadron Collider (LHC) at CERN in Geneva.

Experimental High-Energy Particle and Nuclear Physics

On the experimental side, Department faculty currently participate in a broad range of major endeavors that address fundamental issues, including:

The search for the origins of symmetries (and their violations) in nature; the possible existence of new particles such as Higgs bosons and supersymmetric partners of the known fundamental particles; studies of the properties of the heaviest quarks and bosons (top, bottom, charm, W, and the Z); searches for dark matter; investigations of neutrino oscillations and neutrino mass; and the substructure of the nucleon.



The Standard Model, showing force carriers and fundamental particles, six quarks and six leptons. Credit: Fermilab 95-759

High-Energy Particle Physics has three frontiers:

1. The first is the energy frontier, where researchers are colliding the highest energy particles to produce new particles with high mass.
2. The second is the intensity frontier, where researchers are investigating rare processes by using very intense but lower energy beams of particles such as neutrinos and muons, and electron-positron collisions.
3. The third is the non-accelerator frontier, where researchers explore the nature of dark matter, dark energy, and search for proton decay.

Faculty and students are working in all three frontiers at several worldwide facilities.

Fermilab Tevatron: CDF and DZero Projects (proton-antiproton collisions)

Professors Arie Bodek, Regina Demina, Thomas Ferbel, Kevin McFarland, and Paul Slattery have been doing research at Fermilab's Tevatron Proton-Antiproton Collider for many years. The main Fermilab Tevatron projects are called CDF and DZero. Professors Bodek and McFarland work on CDF, and Professors Demina, Ferbel, and Slattery on DZero.

Both projects use similar techniques to measure the properties of the top quark, the W-boson and the Z-boson, as well as to search for the Standard Model Higgs particle and new physics beyond the Standard Model such as supersymmetry. Though the physics programs are similar, large portions of the two detectors are built using different technologies. For example, CDF uses scintillation counters for calorimetry while DZero uses liquid argon calorimetry.

Fermilab Main Injector: MINERvA Neutrino Project (neutrino-nucleon collisions)

The Fermilab Main Injector is the intensity frontier in High Energy Physics. This machine is used to generate a powerful neutrino beam. A new experiment, known as MINERvA and originated by Professors Arie

Bodek and Kevin McFarland at the University of Rochester, will begin taking data in this neutrino beam later this year. The goal of MINERvA is to improve dramatically our understanding of how neutrinos interact with matter. This information will prove invaluable in neutrino oscillation experiments.

Professor McFarland is the scientific co-spokesperson for MINERvA and its eighty physicists and twenty to twenty-five engineers and technicians. The University of Rochester plays a huge role on MINERvA, with the group being allocated $4.5 million of the overall $17 million construction budget.

MINERvA Scientific Co-Spokesperson Professor Kevin McFarland with high school teachers working in his PARTICLE program

In addition, Professors Arie Bodek and Steven Manly are heavily involved in the MINERvA neutrino experiments. Joining them from Rochester are Senior Research Scientist Howard Budd, Research Associate Robert Bradford, and Project Engineer Robert Flight. Fermilab Staff Scientist Debbie Harris, who serves as the MINERvA Project Manager, was previously a Research Associate at the University of Rochester (1994-1999) with Professor Arie Bodek's neutrino group.

Dr. Bradford, a Research Associate at Rochester for approximately three years now, is responsible for (among other things) the final assembly and quality control of the detector planes that make up the MINERvA detector. He built prototypes of the giant devices in the basement of the Rochester Bausch & Lomb building, home to the Department of Physics and Astronomy.

University of Rochester Project Engineer Robert Flight spends eighty percent of his time on the MINERvA project and recently built a huge computerized scanner, which moves a radioactive source over the entire surface of the detector plane before it is installed in MINERvA. The information recorded by this scanner will be used for quality control and as a position and sensitivity calibration for the data analysis.

The design of the MINERvA detector, says Professor McFarland, "is a function of having so many neutrinos to work with. We can choose to study in exquisite detail only the interactions that originate in its center. Then as we go outward, like a collider detector, we have an electromagnetic calorimeter, a hadron calorimeter, and a muon-catching device." MINERvA's tracker-target is made up of 25,000 strips of segmented scintillator arranged in roughly a hundred planes.

Neutrinos are nearly massless particles that are produced in interactions involving the weak nuclear force. They are produced prodigiously by fusion reactions at the center of stars and in many radioactive decays. Though the Standard Model says that neutrinos are massless, they were discovered to have mass in late 1998 by the Super-Kamiokande experiment in Japan. University of Rochester physics PhD (1955) Masatoshi Koshiba won the 2002 Nobel Prize in physics for this discovery.

Professor McFarland explains that there are "three types of neutrinos -- the electron neutrino, the muon neutrino, and the tau neutrino -- and all have different masses. The particle that is the lowest mass neutrino is actually a mixture of the electron, muon, and tau neutrinos." In fact, each type of neutrino is composed of mixtures of electron, muon, and tau neutrinos. As neutrinos propagate through space, the mixtures change through a quantum mechanical effect, leading the neutrino to oscillate from one type to another with time. This strange effect is known as neutrino oscillations. It is hoped that careful observations of these oscillations will help us understand the origin of neutrino mass and possibly give us the key to understanding the matter-antimatter asymmetry in the universe.

Most of the Rochester MINERvA group is also involved in a new neutrino oscillation experiment called the T2K (Tokai to Kamioka) project. This experiment will measure how neutrinos change as they propagate from a source in the eastern part of Japan to the Super-Kamiokande detector in the mountains of western Japan. The neutrino detector placed near the beam origin in eastern Japan has large components that are very similar to the MINERvA detector. So, there is a great deal of synergy between the Rochester MINERvA and T2K efforts.

Large Hadron Collider (LHC): CMS Project (proton-proton collisions)

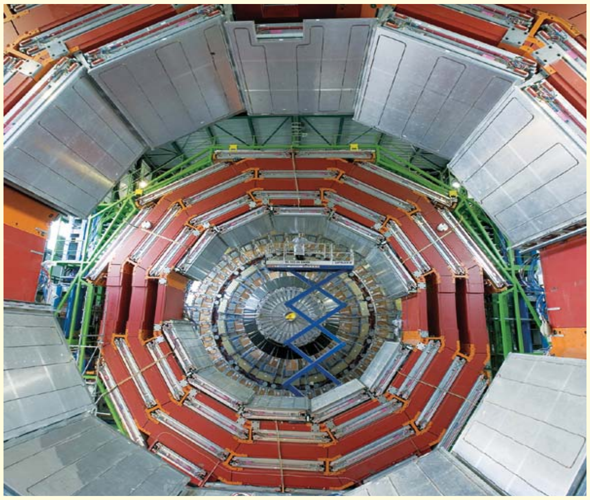
The LHC at CERN is sited in a 17-mile underground loop straddling the Franco-Swiss border near Geneva. It is destined to become the world's largest and most energetic particle accelerator and will host the research of more than 2,000 scientists from 38 countries and 174 institutions. At the LHC, Professors Arie Bodek, Regina Demina, and Paul Slattery are heavily involved with the Compact Muon Solenoid, commonly known as CMS. Professor Bodek played a major part in building the LHC calorimeter, and Professor Demina played a major role in building the silicon tracking detector.

The last piece of the CMS detector was recently lowered into place. There is great excitement in scientific circles about this project as it is expected to shed light on the origins of mass. "Because," Professor Bodek explains, "we're ignorant about the origins of mass, people have lumped it into one single particle, and in a sense, this particle encompasses all that we don't know about the origin of mass." It is the so-called Higgs boson about which Professor Bodek speaks, and as he adds, "In the Standard Model, this particle needs to exist." What we know is that something does what the Higgs does, and the primary goal of the LHC program is to discover what that is.

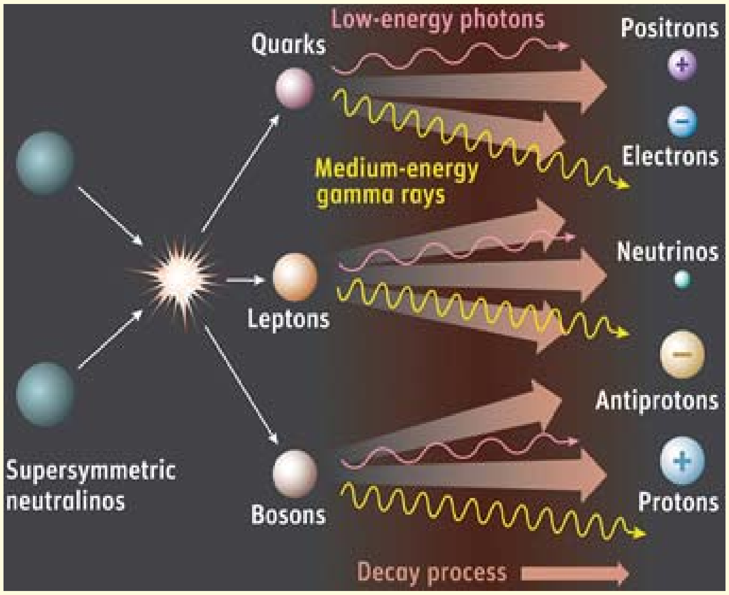
Various theories exist that might explain the so-called Higgs mechanism of the Standard Model. The most popular of these theories is known as supersymmetry. At its core, supersymmetry postulates a deep symmetry between particles with different spins. For every particle we know to exist, there is a mirror supersymmetric particle with a flipped spin. Though this multiplication of the elementary particles by a factor of two sounds like a complication, the idea is rather elegant and falls naturally out of some theories, such as string theory, favored by many physicists today.

Another theory of what might drive the Higgs mechanism is called technicolor. As the name suggests, technicolor hypothesizes a new kind of color force, similar to the one that holds the quarks together. It is this new color force that produces new particles, such as different types of very heavy quarks called techniquarks.

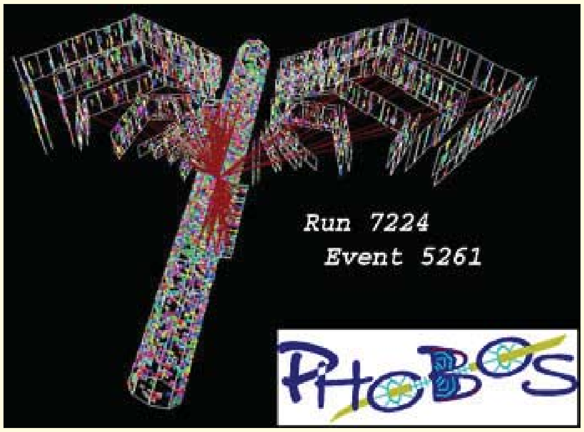
Basically, in most theories describing the Higgs mechanism, new particles are likely to be found in the range between 100 GeV, which is 100 times the mass of a proton, and about 1,000 GeV, or 1 TeV. At the LHC, two particles will collide at 7 TeV and 7 TeV, totaling a collision of 14 TeV at the center of mass. This high energy is the reason for all the excitement about the LHC program. At Fermilab, the energy is roughly a factor of seven lower. "Producing all of these particles is just out of the reach of Fermilab," says Professor Demina, "where the energy is lower, and therefore, these particles are more rarely produced."



The CMS detector. Credit: Photo, Fred Ullrich, Fermilab



"According to supersymmetry, dark-matter particles known as neutralinos (which are often called WIMPs) annihilate each other, creating a cascade of particles and radiation that includes medium-energy gamma rays. Credit: Sky & Telescope / Gregg Dinderman."
--Marcus Woo, "Dark Matter," 082307, http://www.nasa.gov/mission_pages/GLAST/science/dark_matter.html



Gold-gold collision at the maximum RHIC energy as seen by the Phobos detector. Credit: Brookhaven National Laboratory, http://www.bnl.gov/RHIC/full_en_images.htm

The LHC was built to look for the Higgs, supersymmetry, or technicolor. These are very heavy particles that don't exist in nature now. It's possible, however, that they existed at the time of the Big Bang. So to recreate these particles requires conditions that are close to those of the Big Bang: in essence, what's needed is an enormous amount of energy to convert energy into mass.

But the science of the LHC is about more than just elucidating the Higgs mechanism. There is growing evidence that the particles we have seen so far, such as protons, electrons, neutrons, and neutrinos, make up only around five percent of the mass and energy in the universe. To understand the observed motion of galaxies and clusters of galaxies, as well as the structure observed in the cosmic microwave background, many physicists believe that approximately twenty-five percent of the mass and energy in the universe must be in the form of dark matter, which interacts gravitationally but does not interact with light or with the strong force in nuclei. The remainder of the energy in the universe is said to be in the form of dark energy, which through some yet-to-be-determined mechanism, creates a force that is accelerating the expansion of the universe. It is quite possible that the LHC may discover particles that constitute dark matter and/or provide clues as to the true nature of dark energy.

It is conjectured that if supersymmetry is real, many supersymmetric particles were produced in the Big Bang and then decayed to the lowest mass supersymmetric particle possible. These lowest mass particles are neutral and stable, and only interact weakly with other particles. As these particles cooled down with the expansion of the universe, so the idea goes, they formed what we call dark matter.

When massive new particles are produced at the LHC, they will decay to quarks and leptons, which are point-like particles. While scientists can detect electrons and muons, the quarks become jets of particles called hadrons. So to detect an up, down, strange, charm, bottom, or top quark, it's necessary to look at jets of hadrons.

To measure the energy and direction of a jet of hadrons requires that the particles are stopped in a massive detector called a calorimeter. The University of Rochester team, headed by Professor Arie Bodek, was a major player in the construction of the CMS hadron calorimeter, which is made out copper plates interspersed with tiles of scintillator that make a projective tower. Inside the tower, light is collected and converted from blue to green using a wavelength shifting optical fiber and then piped out using clear optical fibers. This new technology was developed by Professor Bodek's group with the collaboration of Fermilab for use on the CDF project, and now it is a standard technology incorporated into LHC detectors.

To measure the energy and directions of charged particles, it is necessary to use a different type of detector, known as a tracking detector. For the CMS project, the tracking detector is made out of many high-resolution layers of silicon strips read out with silicon integrated circuits. Charged particles are bent by a very high magnetic field in the CMS detector. Their trajectory is determined by measuring their positions at various locations with silicon strips with a resolution of tens of microns. Using this information, the tracking detector determines the energy (momentum) and sign of charged particles. The tracking effort in the United States is led by Professor Regina Demina, Deputy Project Leader, and Professor Joseph Incandela from the University of California at Santa Barbara, as Project Leader.

Quark-Gluon Plasma: PHOBOS (relativistic heavy ion collisions)

A University of Rochester collaboration led by Professors Steven Manly and Frank Wolfs has been focused on the PHOBOS experiment at Brookhaven National Laboratory's Relativistic Heavy Ion Collider (RHIC), where beams of heavy ions, such as gold, collide with a center-of-mass energy as high as 200 GeV per nucleon pair. As the heavy ions pass through each other, they deposit a lot of energy in the space at the collision point due to strong nuclear interactions between nucleons in the heavy ions. The energy density is roughly the same as that of the expanding universe at an age of one microsecond. In these extreme conditions, the quarks and gluons that are normally confined into particles like protons and pions by the strong nuclear interaction tend to interact more weakly. Thus, ordinary particles are thought not to exist in this region. This new form of matter is known as the quark-gluon plasma (QGP).

Professors Manly and Wolfs and their collaborators have helped establish the existence of the QGP and have explored its characteristics. The idea is that in the QGP the quarks and gluons move relatively freely, and the characteristics of the plasma can be described by statistical thermodynamics. By characterizing this plasma and watching it undergo a phase transition back into normal matter as it cools, the PHOBOS team has investigated the nature of the strong nuclear force in a new regime.

Dark Matter: Large Underground Xenon (LUX) Detector and ZEPLIN II Detector

Professor Frank Wolfs spearheads the Department's efforts to detect dark matter directly. His latest collaborative experiment, known as LUX, is at the proposal stage and just getting started at the Sanford Underground Science and Engineering Lab (SUSEL) at the Homestake Mine in South Dakota. This facility is 4,850 feet beneath the ground. Working with Professor Wolfs are Professors Thomas Ferbel and Udo Shroeder, along with Senior Scientist Wojtek Skulski (University of Rochester Laboratory for Laser Energetics).

The assumption in dark matter research is that the particles react very weakly. Researchers hope to "see" (detect) dark matter particles, which are conjectured to be weakly interacting massive particles, or WIMPs, passing through the Earth. Direct detection of such particles would be a first step leading to our understanding of the nature of dark matter. Dark matter experiments require essentially no background noise. Therefore, they are performed deep underground to minimize the cosmic ray background and are constructed from extremely pure materials to minimize background from naturally occurring radioactive trace elements. The experiments aim to observe the few rare events when these very weakly interacting particles interact with atomic nuclei in the detector.

While the Large Hadron Collider may create dark matter particles in the laboratory and tell us about the nature of dark matter, an experiment such as LUX aims to detect the sea of dark matter particles around us that the Earth traverses as it moves in space. The two types of experiments are complementary.

At the South Dakota facility, low-background counting equipment will use radiation from radioactive sources to calibrate the LUX experiment. The 4,850 feet of hard rock over the laboratory will shield the experiment from cosmic rays, and to further remove stray noise, a cylindrical tank of 300 kilograms of cold liquid xenon will be suspended in a 20-foot-diameter tank filled with water. Photomultipliers will monitor the xenon tank for energy bursts indicating that a WIMP has collided with a xenon nucleus.

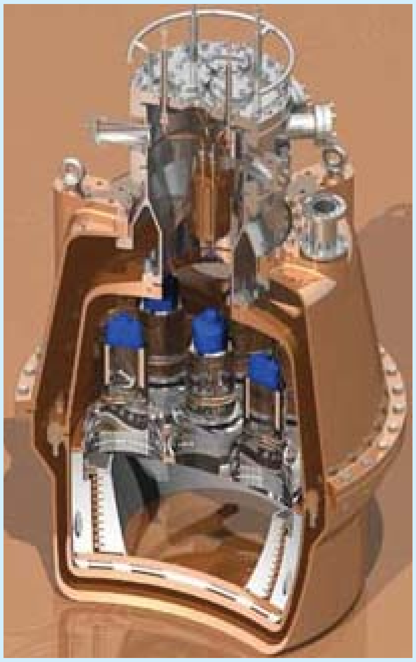
Professor Wolfs has been working for several years on the ZEPLIN II dark matter experiment, which was of the initial detectors. The first results of this project (http://arxiv.org/pdf/astro-ph/0701858) were published in January 2007.

CLEO (electron-positron collisions, study of bottom and charm quarks)

Professor Edward Thorndike has been working on the CLEO experiment at Cornell University for twenty-five or thirty years now. His earlier work on CLEO focused on the physics of B quarks and his more recent work is with charm quarks. For his work with B quarks on CLEO, Professor Thorndike received the 1999 American Physical Society (APS) Panofsky Prize, the highest honor given to a particle physicist in the United States. As CLEO winds down, Professor Thorndike is continuing his research at the new BES machine at Institute for High Energy Physics, in Beijing, China.

Theoretical High-Energy Particle and Nuclear Physics

On the theoretical side, active areas include investigation of the foundations of Quantum Field Theories (Professors Ashok Das, Carl Hagen, and Sarada Rajeev), nonlinear integrable models (Professor Das), and non-associative algebras (Professor Susumu Okubo). Professor Lynne Orr's research has focused on the phenomenological application of theory to experiment. Professor Carl Hagen was key to the theoretical description of the Higgs boson (see "Nobelist Steven Weinberg Praises Carl Hagen and Collaborators for Higgs Boson Theory" elsewhere in this newsletter).



ZEPLIN II Detector.
http://hepwww.rl.ac.uk/ukdmc/project/Zeplin-II/ZEPLIN-II.

Upgrade to the Advanced Lab (PHY 243): Positron Tomography Teaching Laboratory

By far, the course that our undergraduates like the most is the Advanced Lab (PHY 243), which they take in the fall of senior year. This course is a centerpiece of the curriculum leading to a BS in Physics, enabling students to perform sophisticated experiments, where they apply everything they've learned.

Thanks largely to Physics alumnus Dr. Chris Lirakis, a board member of the Donaldson Trust, the Department is adding an interdisciplinary experiment to the Advanced Lab in the emerging frontier of bio-medical physics. Because Dr. Lirakis enjoyed the Advanced Lab during his undergraduate years at the University of Rochester, he has enabled the Department to purchase a high-resolution germanium detector for use in the study of positron tomography. Future upgrades are also in the works.

The Advanced Lab has been heavily focused on optics experiments for years, having been run by quantum optics specialists Chair and Professor Nicholas Bigelow and Assistant Professor John Howell. Professor Frank Wolfs, who is in charge of our undergraduate program, has always wanted to give the Advanced Lab a medical twist because, as he says, "a lot of physics students want to do graduate work in medical applications. This is a burgeoning field." After talking with Dr. Lirakis during Meliora Weekend, Professor Wolfs devised a new experiment, one that focuses on nuclear radiation.

Positron emitters are radioactive nuclei that decay with the emission of a positron. The positron, the anti-particle of the electron, annihilates when it encounters an electron and creates a characteristic pair of 511 keV photons, emitted back to back. If the positron emitter is located in the human body, the positron annihilation will occur within a few µm from the position of the emitter. By detecting the intensity distribution of the 511 keV photons and/or using the back-to-back nature of coincident 511 keV photons, the location of the emitter can be determined accurately.

The first Positron Emission Tomography (PET) machine was developed in 1950, and since then PET scans have increased in importance in health care. The technique complements other imaging techniques such as Magnetic Resonance Imaging (MRI). An example of images of the brain of a patient with Huntington's disease, obtained with different imaging techniques, is shown in the following figure.

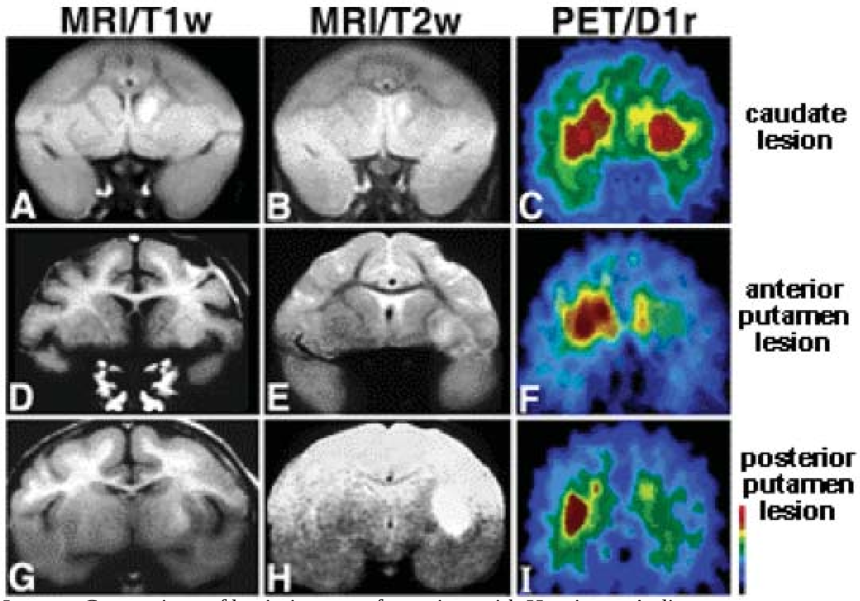


Image: Comparison of brain images of a patient with Huntington's disease obtained with MRI and PET techniques (from http://neurosurgery.mgh.harvard.edu/pet-hp.htm).

Patients who are scheduled for a PET scan are administered a substance that is labeled with a positron emitter. Usually, the positron emitter is attached to a compound that occurs naturally in the human body, for example, glucose. The type of compound can be adjusted based on the part of the body to be examined. The interpretation of the results of a PET scan relies on the fact that different tissue types collect the compound at different rates; for example, cancerous tissue has a much higher rate of glucose absorption than healthy tissue. Since the PET scan not only provides information about the location of the emitting source, but also about the intensity of the source, it is a very powerful tool to detect cancer. PET scans are also used to examine the health of the heart tissue. In this application, the difference in collection rates of glucose in healthy and unhealthy tissue is used to identify the areas of the heart that show decreased functionality, for example, as a result of a heart attack.

Modern PET scan imaging machines use hundreds of small scintillation crystals to detect the coincident 511 keV photons. Based on the detection location of many pairs of coincident photons, the location of the emitter can be determined very accurately.

In the Advanced Lab, we will focus on the principle of positron tomography using one or two gamma ray detectors. We plan to create an object that can hold one or more Na22 sources at different locations. The students will only see the outside of the object and not the location of the sources, but they will be able to move the gamma ray detectors to different locations around the object. By measuring the gamma ray intensity distribution around the object and/or the coincidence efficiency as a function of the angle between the gamma ray detectors, the students will try to determine the location of the source. Initially, the students will work with one source. When the position of the single source is accurately determined, we will increase the complexity of the analysis by adding more sources to the object. In essence, the new experiments will simulate what happens in the medical community on a daily basis.

The Advanced Lab currently uses sodium iodide (NaI) detectors. Ideally, we would like to use two germanium detectors in the new experiment; these detectors can measure the gamma ray energy with much higher resolution than, for example, NaI crystals, and their excellent signal-to-noise capabilities allows the use of low-intensity gamma ray sources. However, in the initial development, we will carry out the experiment with a single germanium detector, complemented by one of our NaI detectors to capture the second gamma ray. In this manner, the students will explore the differences in imaging accuracy between single and coincident photon detection techniques. In the future, we hope to upgrade the experiment with the addition of a second germanium detector.

It is critical, though expensive, to continually upgrade the Advanced Lab. It is the hope of Professor Frank Wolfs and Chair Nicholas Bigelow to bring PHY 243 fully into the future with at least four new sophisticated experiments. We thank Dr. Chris Lirakis and the Donaldson Trust for enabling us to offer the first of a series of new experiments, the Positron Tomography Teaching Laboratory.

RECENT RECIPIENTS OF PHYSICS AND ASTRONOMY PHD DEGREES

Boersma, John, "Guage Boson Phenomenology of Little Higgs Models," Advisor: Lynne Orr
Chen, Hui, "Towards a Nanocrystalline Silicon Laser," Advisors: Philippe Fauchet and Yongli Gao
Cunningham, Andrew, "Star Formation Driven Mechanical Feedback in Molecular Clouds," Advisor: Adam Frank
Garcia, Carlos, "Precision Measurement of the Mass of the Top Quark in ppbar Collisions," Advisor: Tom Ferbel
Ho, Phay J., "e-e Correlated Intense-Field Multiple Ionization as a Completely Classical Photo-electric Effect," Advisor: Joe Eberly
Holmes, Michael, "Trapping Ultracold Atoms Close to Surfaces and Molecule Chips," Advisor: Nick Bigelow
Khafizov, Marat, "Photoresponse Mechanism of Superconducting MgB_2," Advisor: Nick Bigelow
Pack, Michael, "Dynamics of Electromagnetically Induced Transparency Optical Kerr Nonlinearities," Advisor: John Howell
Park, Su-Jung, "Search for Admixture of Scalar Top in the ttbar Lepton+Jets Final State at $\sqrt{s}$=1.96 TeV," Advisor: Regina Demina
Selkowitz, Robert, "Stochastic Fermi Acceleration and the Dissipation of Astrophysical Magnetic Turbulence," Advisor: Eric Blackman
Sublett, Stephanie, "Omega Laser-Driven Hydrodynamic Plasma Jet Experiments with Relevance to Astrophysics," Advisors: David Meyerhofer, J. Knauer
Wesely, Elizabeth Jane, "Decay Pathways for Excitations in a Conjugated Oligofluorene," Advisor: L. Rothberg
Wilson, Jeremy, "Measurements and Interpretations of Light Scattering From Intact Biological Cells," Advisor: T. Foster
Winey, Brian, "Use of Stationary Focused Ultrasound Fields for Characterization of Tissue and Localized Tissue Ablation," Advisor: Y. Yu, N. Bigelow
Wong, Chung Ki, "Theoretical Studies of the Properties of Magnetic Resonance Signal Formed Under the Influence of Distant Dipolar Field," Advisor: J. Zhong
Woo, Sungjong, "Dynamics of Rotating Bose-Einstein Condensate with Vortices," Advisor: N. Bigelow
Wu, Shuai, "Time-Resolved Characterization of Carrier and Phonon Dynamics in GaN Single Crystals," Advisor: R. Sobolewski
Yoon, Sung-Yong, "Error-Induced Beam Degradation in Fermilab's Accelerators," Advisors: A. Bodek, W. Chou

JOHN K. GOLDEN AND SAMUEL T. HARROLD WIN 2008 GOLDWATER SCHOLARSHIPS

University of Rochester Physics sophomore John K. Golden and junior Samuel T. Harrold have received 2008 Barry M. Goldwater Scholarships, one of the most prestigious awards for undergraduates in this country.

The Goldwater Scholarship, which is endowed by the U.S. Congress to honor the late Sen. Barry M. Goldwater, is designed to provide a continuing source of highly qualified scientists, mathematicians, and engineers by awarding scholarships to college students who intend to pursue careers in these fields.

Both recipients of the award have demonstrated an interest and commitment to research by participating in the Research Experience for Undergraduates (REU), which is funded by the National Science Foundation to support highly qualified students to undertake supervised research projects in the summer.

Sophomore John K. Golden (class of 2010) is earning a BS in Physics and a BA in Mathematics. John is the Social Coordinator and a member of the Society of Physics Students and won the 2007 Iota Book Award. Currently, he is doing research with Profs. Nicholas Bigelow and Sarada Rajeev.

Junior Samuel T. Harrold (class of 2009) is earning a BS in Physics and a BS in Mathematics. He is the Secretary and a member of the Society of Physics Students, and in 2007, he won a Department of Energy National Undergraduate Fellowship in Plasma Physics and Fusion Energy Sciences. Currently, he is doing research with Professor Dan Watson.

Since 2002, 17 University students have been named Goldwater Scholars. The scholarship is worth up to $7,500.

Applicants must rank in the top quartile of their class while demonstrating outstanding research skills and potential for advanced study in their fields as well as a strong commitment to pursuing research-oriented careers. The average grade point average of Goldwater Scholars is about 3.8 to 4.0 and most scholars go on to obtain doctorate degrees.

Daniel Richman and Samuel T. Harrold Win 2007 DOE National Undergraduate Fellowships

Undergraduate Physics students Daniel Richman and Samuel T. Harrold won U.S. Department of Energy 2007 National Undergraduate Fellowships in Plasma Physics and Fusion Energy Sciences.

Fellowship winners perform nine-week research projects at one of the many participating universities and national laboratories throughout the country. Daniel Richman spent the summer of 2007 at the MIT Plasma Science and Fusion Center, and Samuel Harrold was at the Los Alamos National Laboratory in New Mexico.

Kristin M. Beck Wins 2007 Physics Honor Prize

The Department of Physics congratulates Kristin M. Beck, the 2007 recipient of the Physics Honors Prize, which is awarded annually to the top-performing undergraduate in the freshman/sophomore Honors Physics sequence. Kristin's instructors in PHY 141, 142, 143, and 237 selected her from a pool of six qualified candidates.

Above, Kristin receives her award from Professor Frank Wolfs, Physics Undergraduate Advisor.

Ben Sargent Wins 2007 Messersmith Fellowship

Ben Sargent won the 2007 Agnes M. and George Messersmith Fellowship, which is awarded annually for graduate work in the preclinical departments of the School of Medicine and Dentistry or for graduate work in Biology, Chemistry, or Physics. Only one or two Fellowships are awarded each year.

Faculty Named APS Outstanding Referees

The American Physical Society (APS) has honored five University of Rochester Physics Professors as Outstanding Referees:

- R. W. Boyd
- Esther M. Conwell
- C. R. Hagen
- Y. R. Shapir
- C. R. Stroud

The APS chose only 534 Outstanding Referees from a list of 42,000 active referees. This is the first year of the Outstanding Referee Program, which will anually recognize approximately 130 additional Outstanding Referees.

According to the 2008 APS press release, "The highly selective award program recognizes scientists who have been exceptionally helpful in assessing manuscripts for publication in the APS journals." In addition, "Like Fellowship in the APS, this is a lifetime award."

Professor Judith Pipher Inducted into National Women's Hall of Fame

Professor Judith Pipher was inducted into the National Women's Hall of Fame on October 6, 2007 for her excellence as a teacher, her role as mentor to a new generation of young female scientists, and for the exceptional advances she's made in the field of infrared astronomy. (*Photo*: Judith Pipher, right, receives her award from National Women's Hall of Fame Board President Barbara DeBaptiste.)

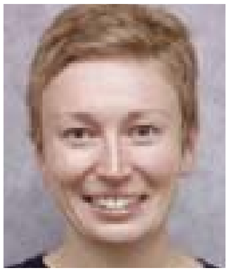
A 2002 recipient of the University's Susan B. Anthony Lifetime Achievement Award, Pipher has been a member of the University of Rochester faculty since 1971, just after earning her doctorate from Cornell University in the newly emerging field of infrared astronomy.

Professor Esther M. Conwell Wins Prestigious ACS Award for Encouraging Women into Careers in the Chemical Sciences

The American Chemical Society (ACS) announced on August 20, 2007 that Esther M. Conwell, Professor of Physics and Chemistry at the University of Rochester, is the winner of the 2008 ACS Award for Encouraging Women into Careers in the Chemical Sciences. The award recognizes one scientist each year who has significantly encouraged the education and professional development of women as chemists and chemical engineers. Funded by The Camille & Henry Dreyfus Foundation, Inc., it consists of $5,000 to the scientist and $10,000 to an academic institution of her choice. Professor Conwell received the award in New Orleans on April 8th.

APPOINTMENTS AND PROMOTIONS IN 2007

Professor Nicholas Bigelow (Experimental and Theoretical Quantum Optics) was elected to his first three-year term as Department Chair (July 1, 2007 - June 30, 2010).



Regina Demina (Experimental Particle Physics) was promoted to Professor of Physics in Fall 2007.

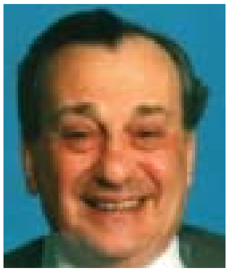
Professor Jianhui Zhong (Experimental Medical and Biological Physics) was re-appointed to his third 3-year joint appointment term as Professor of Radiology and Physics (July 1, 2007 - July 1, 2010).

Phillipe Fauchet (Experimental Condensed Matter Physics), Professor of Electrical and Computer Engineering and Optics, was re-appointed to his second joint appointment term as Professor of Physics (July 1, 2007 - July 1, 2010).

John Howell (Experimental Quantum Optics) was promoted to Associate Professor of Physics with unlimited tenure in Fall 2007.

PROFESSOR EMIL WOLF: TOP OPTICAL PHYSICIST PUBLISHES NEW BOOK

Wilson Professor of Optical Physics and Theoretical Physics Emil Wolf is one of the top 1,000 scientists of all time. Or so states British archaeologist Philip Barker and former President of the The British Society for the History of Science Ludmilla Jordanova in a 1999 book called Top 1000 Scientists: From the Beginning of Time to 2000 AD. It is a fitting tribute to Professor Wolf, who has long been considered a world authority in Optics.



His latest book is Introduction to the Theory of Coherence and Polarization of Light, which was published in September 2007 by Cambridge University Press. Among all of his many publications, Professor Wolf is perhaps most well known for his classic book Principles of Optics: Electromagnetic Theory of Propagation, Interference and Diffraction of Light, which he wrote with Nobel Laureate Max Born. This book was first published in 1959 and is now in its seventh edition, which was published by Cambridge University Press in 1999.

Carl Helmers (BS, Physics, 1970): Founder of Byte Magazine

"My physics education underlies everything else I did in life."
--Carl Helmers

Carl Helmers is best known for creating and launching Byte, the first commercial magazine devoted to the personal computer. Being the first magazine of its kind, Byte was famous in computer circles for many years. Helmers founded Byte in 1975, a mere five years after earning his BS in Physics with Distinction from the University of Rochester.

His class included another distinguished alumnus, Steve Chu, winner of the Nobel Prize, and according to Helmers, "Steve had the highest GPA and earned his BS in Physics with Highest Distinction, along with a BS in Math with Distinction." Helmers recalls that his GPA placed him third in the graduating class of twenty Physics majors that year.

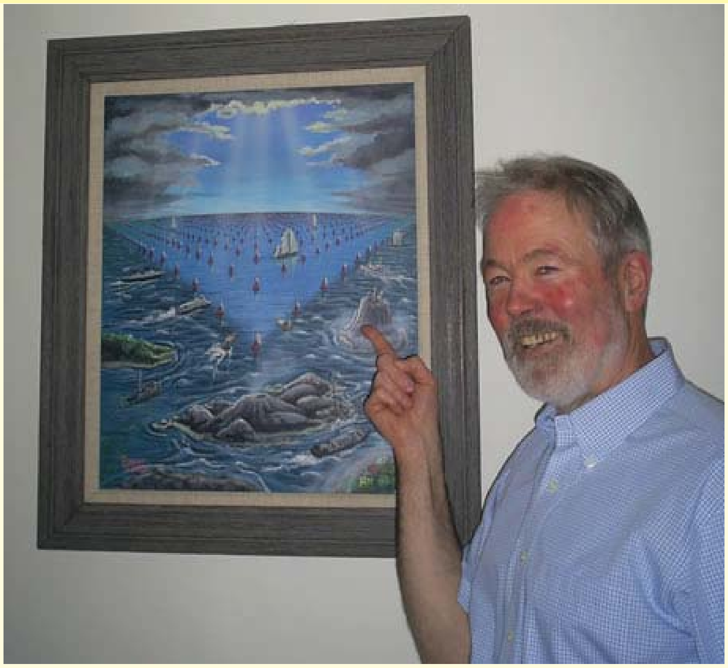
So how did such a successful Physics student become the founder of a major computer magazine? Read on, for it's a fascinating story.

Let's rewind for a moment to Carl Helmers' life before he came to the University of Rochester. He was a top student at Hanover Park High School, and when Sandoz Pharmaceuticals offered a Fortran II programming class to the advanced placement math and science students, Carl Helmers signed up. His life changed forever.

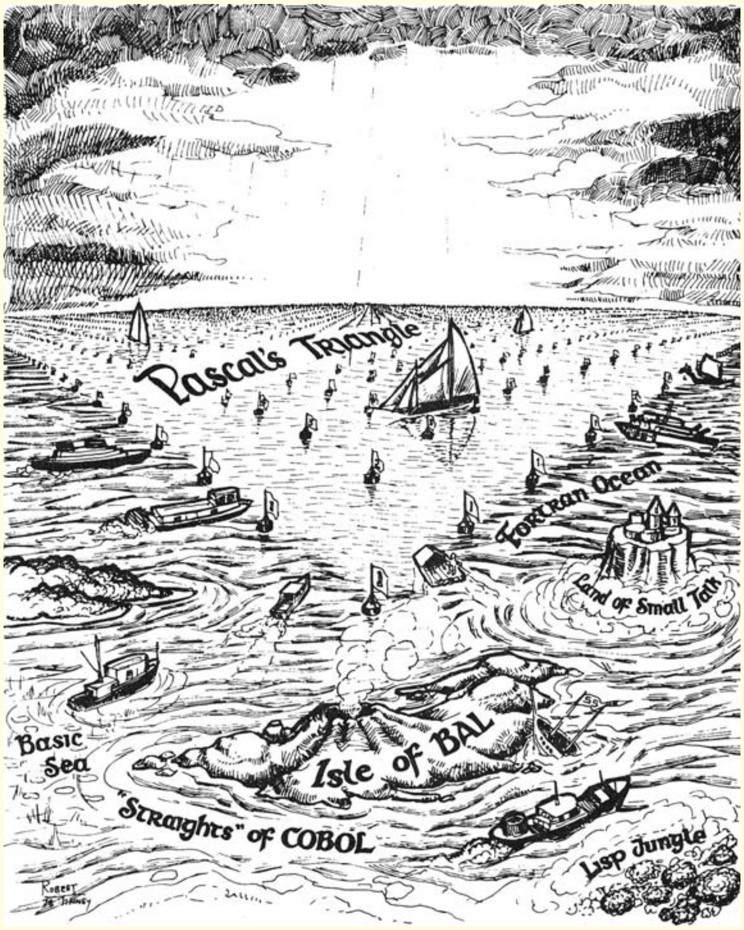
In the summer before college, Helmers started working as a programmer for Paul McGillicuddy at Sandoz. His job was to convert Fortran IV programs to Fortran II, so the code could run on an IBM 360 Model 30. Then starting in the summer of 1968 and continuing until his college graduation, he got a job as a programmer at Infodata Systems in Webster, New York, where he wrote Cobol and Assembly programs for IBM 360 and Univac machines. Throughout college, Helmers majored in Physics while working professionally as a programmer.

In his senior year, Helmers studied for his Physics final exam by launching what he calls a UFO. As he explains, "The world's third cyclotron had just been moved from the basement of Bausch & Lomb to India. I decided to study for the exam in the old cyclotron room with my friend, Peter Pearson, who aced the exam without even studying for it: Peter went to Caltech the next year. Instead of studying, I used a soldering iron to make a bag out of two large plastic sheets. Then Peter sprayed the inside of the bag with phosphorescent orange paint, and I built a hot air source for some charcoal briquettes made out of Tropicana juice cans. I made little holes in the cans, put wires through the holes to hold the cans together, then used a socket punch to make a big hole in the bottom." The two boys added charcoal briquettes and a small fan, hence concocting a UFO out of juice cans, charcoal, plastic sheets, and a fan. They took their UFO to the corner of what was the men's dormitory quad at that time, and they launched the balloon the night before the final exam.

Armed with a Physics degree and years of programming experience, Helmers took a job as a quality assurance and documentation specialist with Intermetrics, Inc. in Cambridge, Massachusetts, a NASA space shuttle contractor that created the flight software development tool set. Helmers' boss was Dan Lickly, who was responsible for much of the software in the Apollo Guidance and Control computers. Carl Helmers points out that, to write the software for the space shuttle and Apollo, required a thorough grounding in physics because the programmers had to calculate such things as the momentum and velocity of the rocket in three dimensions.



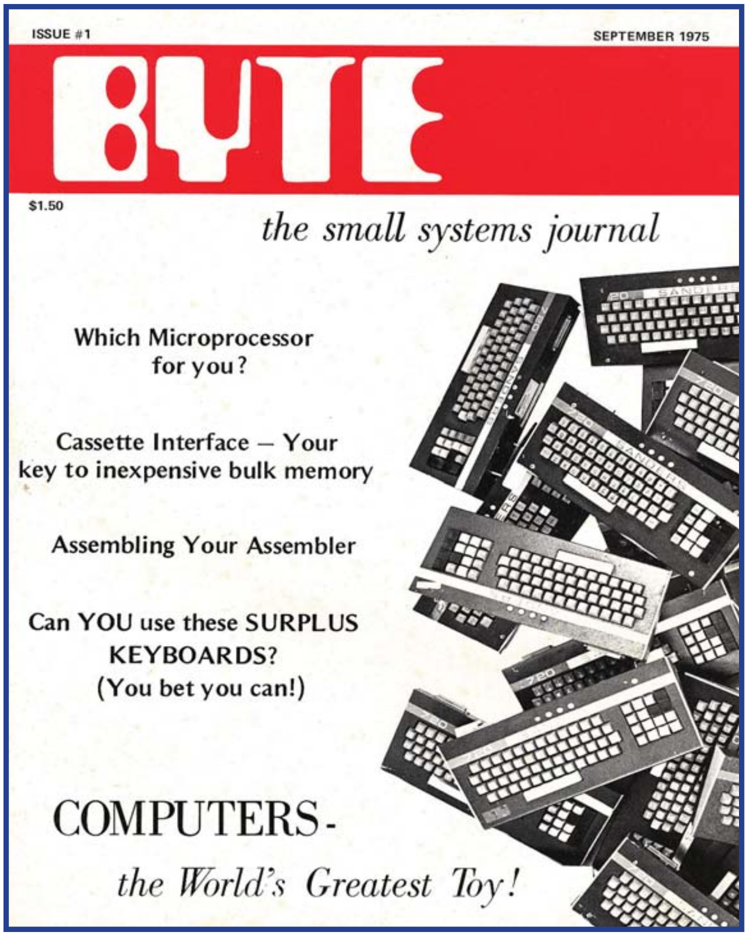
Carl Helmers with the Robert Tinney painting that graced the August 1978 issue of Byte. The cover is one of Carl's favorites and is called "Pascal's Triangle." As he wrote in the magazine, "The primary allegory of the cover is of course the inversion of the 'Bermuda Triangle' myth's theme to show smooth waters." The detailed illustration below appeared on page 16 of the issue.



While at Intermetrics, Helmers started tinkering with the idea of building his own home computer. As he figured out how to build components, he documented what he was doing and eventually self-published a 300-page booklet about how to use wire wrap. In 1974, he started the self-published Experimenter's Computer Systems Series, or ECS. By 1975, he was cranking out the "how to" pamphlets approximately once a month and had somewhere between two and three hundred subscribers.

A magazine publisher named Virginia Londner happened to see Helmers' ECS pamphlets and got in touch with him. With some friends, he drove to Peterborough, New Hampshire, to meet with Londner and her co-publisher Wayne Green. And in May 1975, Londner and Helmers decided to transform the self-published ECS pamphlets into Byte magazine.

September 1975 marked the first issue of Byte (*below*), which had a circulation of 50,000 in its first year. By the time Helmers left the magazine on December 31, 1980, the magazine had a circulation of more than two hundred thousand.

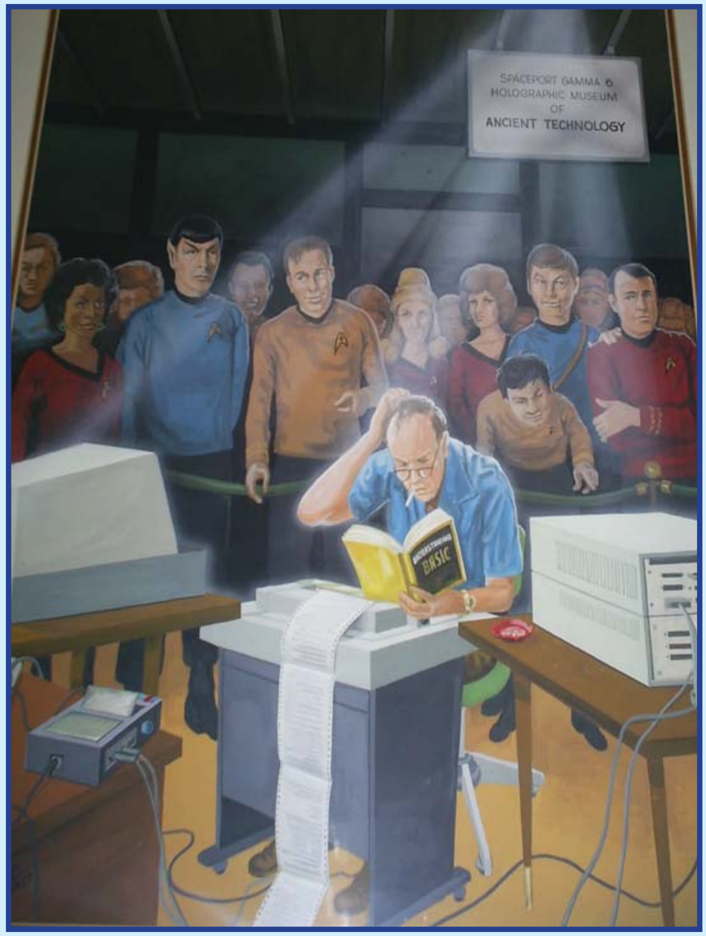


Helmers' Byte was known for its explicit "how to" articles, as well as for beautiful cover paintings by Robert Tinney, one of which is shown to the right.

While Helmers is most famous for starting Byte, he went on to launch other computer-oriented publications. Examples are Bar Code News magazine, which later was called Supply Chain Systems; Sensors; and Desktop Engineering. And because he remains fascinated with Physics and Astronomy, he also launched SETIQuest, a publication centered around the idea of bio-astronomy.

While attending an alumni event, Carl Helmers met his wife, Jean Bidlack, Professor Pharmacology and Physiology at the University of Rochester Medical School. Professor Bidlack obtained her PhD in Bio-Physics from the University in 1979. For ten years, Helmers had been participating in a Dean's advisory panel at the School of Engineering and Applied Science, and in 2000, he became a member of the Trustee's Alumni Council of the College (TACC). It was during a TACC event in 2002 that Helmers and his wife met, and at yet another TACC meeting, they dined at the Meliora Club, a shared meal that was to become the first of thousands more.

Carl Helmers exemplifies what's best in University of Rochester Physics majors: a strong desire to learn, a keen interest in Physics and Mathematics coupled with a fascination in Engineering, and the drive to make things happen. A note to current Physics students: if you're caught in the old cyclotron room making UFO's the night before finals, just make sure you're as smart as Carl Helmers.



An early Robert Tinney Byte cover, in which the Star Trek Classic characters are visiting the "Spaceport Gamma Holographic Museum of Ancient Technology" and gawking at a programmer who is baffled by a Basic language textbook. The hardware is also ancient by today's standards: notice the old Spinwriter-type printer and the enormous hard drives. The lit cigarette dangling over the computer equipment is a humorous touch: in the old days, programmers often wore ties that got caught in the hardware, drank soda that dribbled into the equipment, and yes, could be caught from time to time flicking cigarette ashes where no ashes had gone before.

Kevin Short (BS, Physics, 1985) Wins Grammy Award

Kevin Short with the CD, *The Live Wire: Woody Guthrie in Performance 1949*, and the medallion he received as a Grammy nominee. (Credit: Douglas Prince, UNH Photo Services)

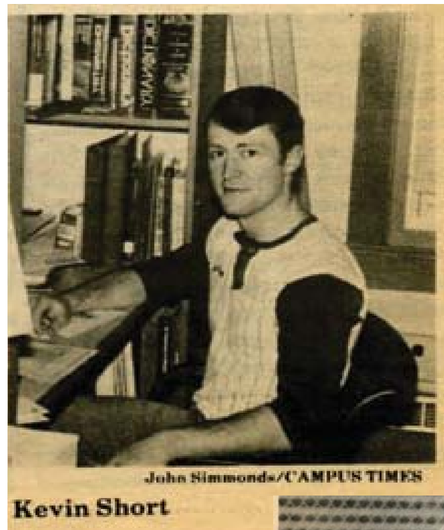
It's not often that a physicist wins a Grammy award. But Kevin Short, who earned his BS in Physics along with a BA in Geological Sciences from the University of Rochester in 1985, scored a Grammy on February 10, 2008.

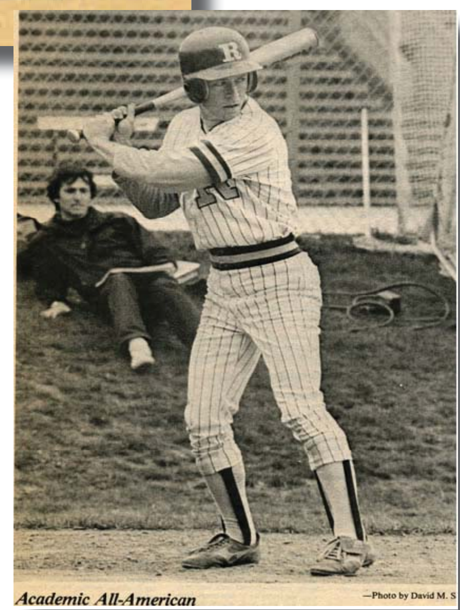
Kevin is currently a professor of mathematics at the University of New Hampshire and won his Grammy for being the master engineer on a team that restored a 1949 wire recording of a Woody Guthrie concert. He attended the ceremony, and with his wife Michelle, represented science in a lavish concert hall adorned with the singing stars of today.

During his undergraduate days at the University of Rochester, Kevin was elected to the 1984 College Division Academic All-American Baseball Team. In December of the same year, he won a Marshall Scholarship and came close to winning a Rhodes Scholarship. He later earned his PhD at Imperial College in London for research into general relativity and mathematical physics.

Until he won his Grammy Award, Kevin was most famous for discovering Chaotic Compression Technology, which uses mathematical chaos theory along with signal processing to analyze audio, video, and image data. His technology is used whenever someone downloads ring tones and songs to a cell phone.

Kevin as a student at the University of Rochester and as an Academic All-American Baseball Star:





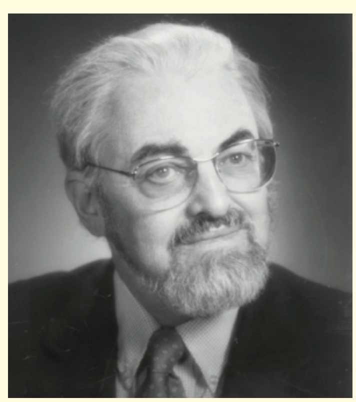
Ernest Courant (PhD, Physics, 1943) Receives UR 2007 Distinguished Scholar Award

Ernest Courant (PhD, Physics, 1943), emeritus distinguished scientist at Brookhaven National Laboratory and Adjunct Professor at the University of Michigan received the UR 2007 Distinguished Scholar Award in recognition of his significant career accomplishments. The honor is available only to PhD graduates of the University and is determined by the Provost.

Dr. Courant has won many academic honors for his work, including the 1986 Enrico Fermi Award from the Department of Energy:

"For his many contributions, for over three decades, to the physics of acceleration of charged particles; including his role in the invention of alternating gradient focusing, which is the essential mechanism of strong focusing now used in accelerators of the highest energies; and forh is many studies of beam interactions and instabilities that have been of critical importance in accelerator design."

In addition, Dr. Courant was the recipient of the First Annual Robert R. Wilson Prize of the American Physical Society in 1987, and he also was awarded the Boris Pregel Prize of the New York Academy of Sciences in 1979. He has been a member of the U.S. National Academy of Sciences since 1976.



Dr. Courant is known as the "Father of Modern Particle Accelerators." He was one of three scientists who originated the strong focusing accelerators that led to the Brookhaven AGS, the CERN PS, and just about all of the other big accelerators.

We gratefully acknowledge recent donations of alumni and friends to the Department of Physics and Astronomy at the University of Rochester. Every effort has been made to ensure the accuracy of this list. If you find an error or an omission, please let us know by calling Shirley Brignall at 585-275-4344 or by e-mail to shirl@pas.rochester.edu. If you have a postal or e-mail address change, please contact Bob Knox with your new whereabouts (rsk@pas.rochester.edu).

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Departmental Funds

The Department has established several funds that greatly benefit our activities. They are:

- *The David L. Dexter and Elliott W. Montroll Lecture Fund*. Established in the 1980s in memory of Professors Dexter and Montroll, these funds support an annual lecture by an outstanding scientist as part of either the Dexter Lecture or the Montroll Lecture series.
- *The Leonard Mandel Endowment Fund*. This fund supports one graduate student who earns the Leonard Mandel Faculty Scholar Award in Optical Science at the University of Rochester.
- *The Robert E. Marshak Memorial Endowment Fund*. This fund is used to support the postdoctoral Robert E. Marshak Research Fellowships, intended to attract the most talented young nuclear and particle physicists to continue their research in the Department.
- *The C.E. Kenneth Mees Observatory Fund*. Established in 1977, this fund is for the discretionary use of the director of the University's Mees Observatory in support of observatory activities, such as the upgrade of the facility.
- *The Physics Education Award Endowment Fund*. This fund supports undergraduate awards and graduate student fellowships.
- *The Physics and Astronomy Endowment Fund*. This fund is for the discretionary use of the Chair of the Department of Physics and Astronomy in support of departmental activities.

Contributions from alumni and friends are the dominant source of income to these funds. If you would like to support the Department, please mark the appropriate box on the form below and send it with your contribution. Donations may be tax deductible, and donations of appreciated securities may also carry tax advantages. The Department is grateful for any help you give.

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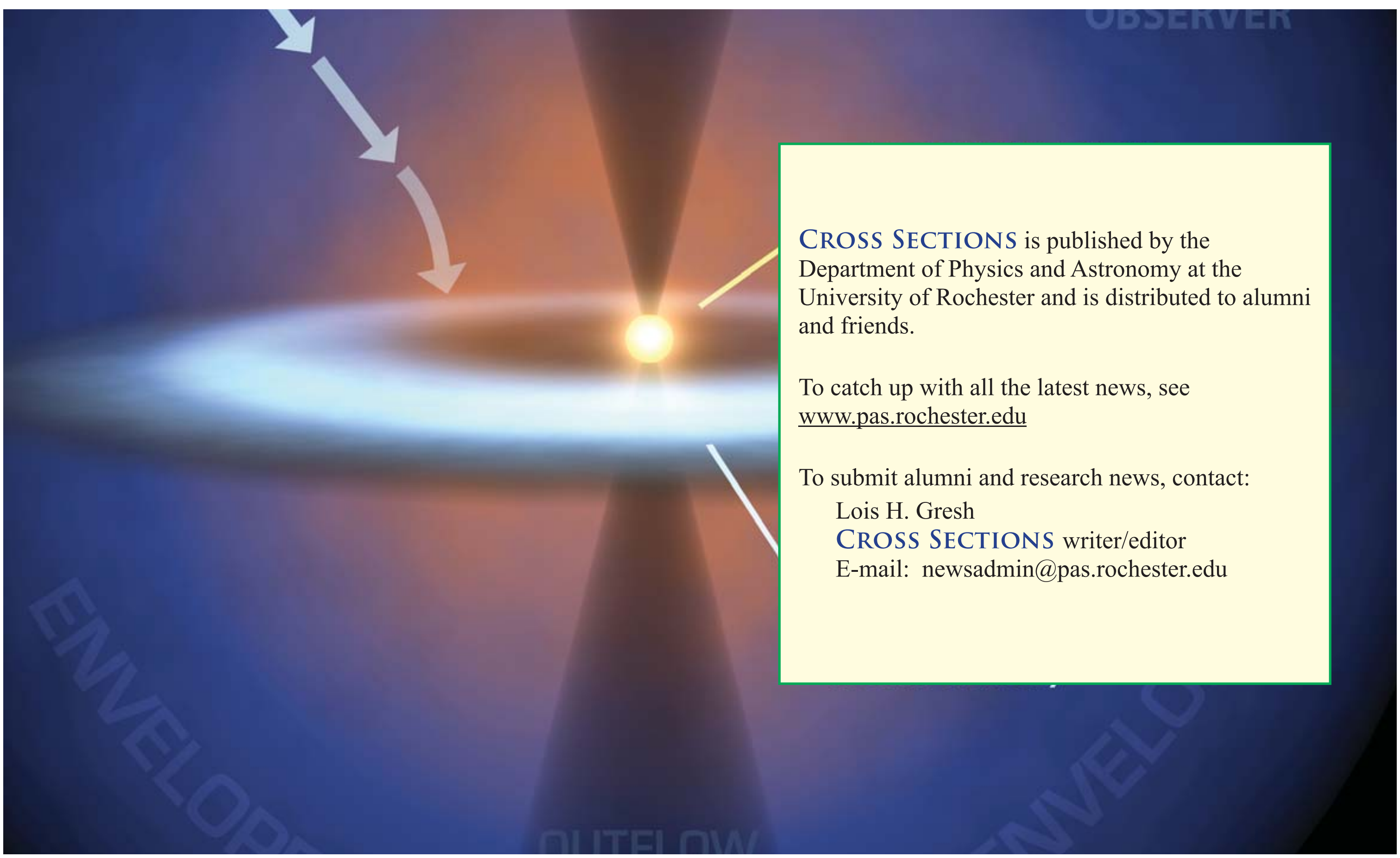

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