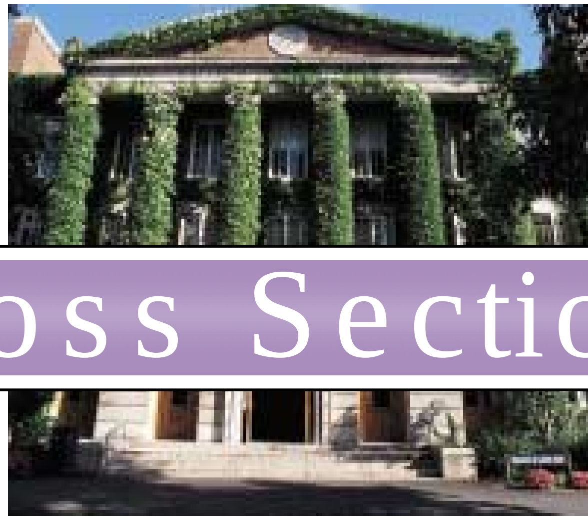


Cross Sections

DEPARTMENT OF PHYSICS AND ASTRONOMY
UNIVERSITY OF ROCHESTER
WINTER 2002

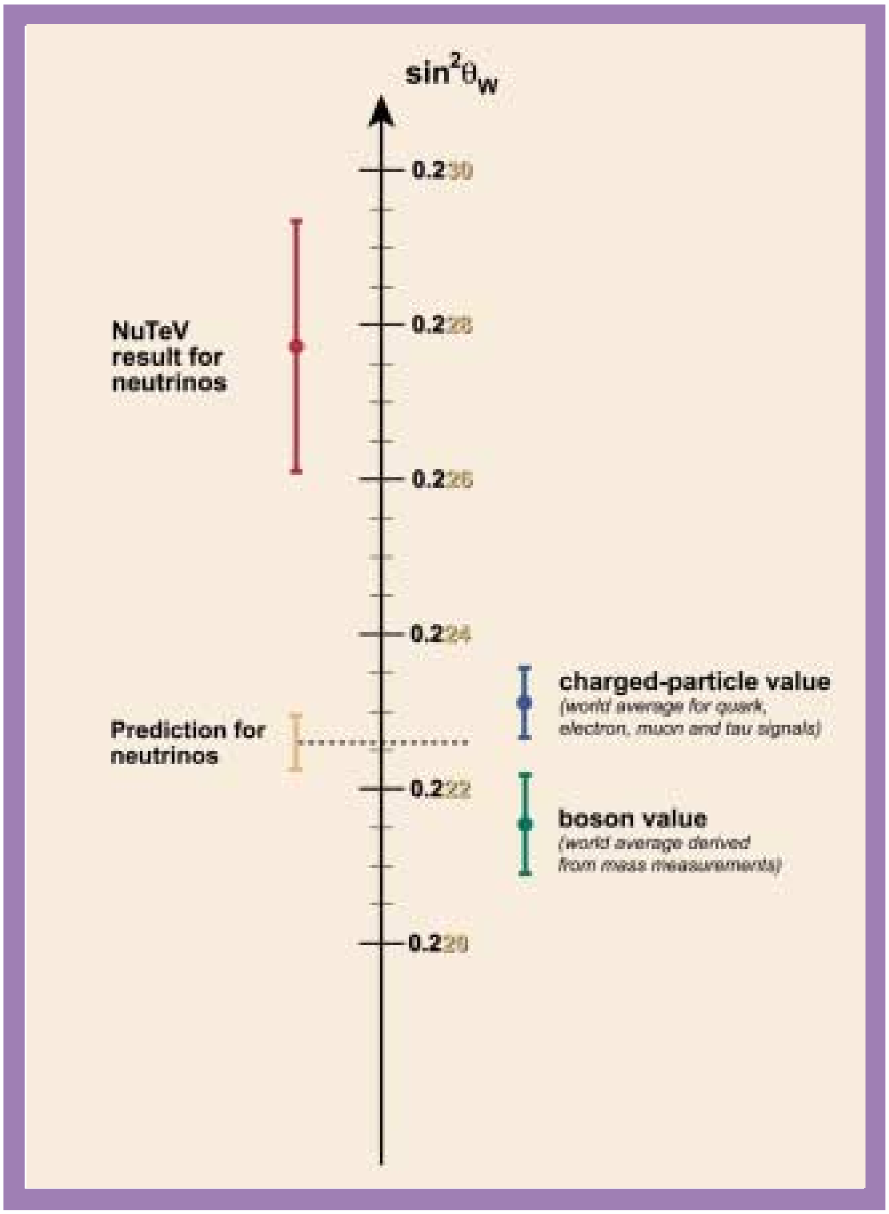
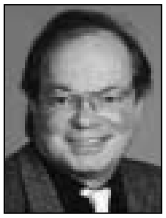


Diagram credit: Fermilab

Message from the Chair

—Arie Bodek

Because of the great success of last year's sesquicentennial celebration, the University has initiated a new tradition



of hosting a Meliora Weekend reunion every year. The theme this past fall was Freedom. Several of our alumni attended and visited the department during our open-house festivities. We encourage all our alumni and friends to continue this tradition, come for the weekend, and visit us during Meliora Weekend (or anytime!).

Several of our faculty and students have received awards during this past academic year. Among the faculty, Kevin McFarland was named a Cottrell Scholar by the Research Corporation of America, and five faculty were elected Fellows of the American Physical Society. Among our students, graduate student Un Ki Yang received an award from the American Korean Physics Association, Michael Fitch was awarded the 2001 URA/Fermilab award for best Ph.D. thesis, and undergraduate Albert Wang was named a finalist for the APS 2001 Apker award.

Over the years we have given high priority to the training of our undergraduate and graduate students. This attention has not gone unnoticed and has just been recognized in a nationwide survey of U.S. graduate students conducted in 2001. The Department of Physics and Astronomy at Rochester was ranked second nationwide in overall graduate-student satisfaction.

After an exhaustive search, it is a pleasure to report our success in the recent recruitment of Alice Quillen, our newest faculty member, who is an experimenter in astrophysics. She has just joined our astrophysics group as assistant professor of physics and astronomy and will be on campus starting January 2002.

The department suffered a major loss this past year with the passing of Len Mandel, one of the world's leading experts in the field of quantum optics. Len was an admired teacher and a brilliant experimenter, and was elected posthumously to the National Academy of Science. A search is currently under way for a new faculty member in experimental quantum optics to continue the strong tradition that Len established at Rochester in this area of physics.

We wish to take this opportunity to thank all our alumni who have contributed generously to the support of the department. By completing the form on the last page of our newsletter, or by responding to our recent appeal for assistance, you can continue (or begin) that tradition of giving that will assure the future excellence of the department.

Other ways to help our cause is to inform any promising students about our summer undergraduate research program (REU), and to encourage students interested in careers in physics to apply for graduate study at Rochester. All application material for these programs is available on our Web pages (www.pas.rochester.edu). If you know of any exceptional undergraduates whom we should consider either for our REU program or for graduate school, we would appreciate it if you would please send their names and e-mail addresses to Barbara Warren (barb@pas.rochester.edu), and we will contact them directly. Any help from our alumni along these lines would be welcomed.

Cross Sections

Editors: Eric Blackman and Ashok Das

Published by the Department of Physics and Astronomy of the University of Rochester, and distributed to alumni and friends free of charge. Copies may be obtained by writing to CROSS SECTIONS, Department of Physics and Astronomy, University of Rochester, P.O. Box 270171, Rochester, NY 14627-0171.

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On the Cover

The diagram on the cover illustrates a remarkable recent result in high-energy particle physics from Fermilab's NuTev collaboration. The analysis, led by Rochester's Kevin McFarland, suggests that Neutrinos simply do not behave as expected. The vertical axis gives the extent to which the combined electroweak force behaves as a mixture of the electromagnetic force (parity conserving) and the weak force (parity violating). The discrepancy between theory, results for other particles, and the NuTev neutrino findings has surprised many in the high-energy physics community and has received widespread public attention. The reason is that the Standard Model of particle physics has been so successful in so many ways that any such "apparent" disagreements are unusual. Is there a previously unrecognized problem with our understanding of the theory, or perhaps more likely, is there an as yet unseen particle? The story is discussed further on page 5.

The Department of Physics and Astronomy and its alumni continue to lead cutting-edge research efforts across a broad range of fields. Other examples of such endeavors are also presented in the science highlights section.

New Power from Fractal Mathematics: Predicting Extremes

Graduate student Subhadip Raychaudhuri, undergraduate Corry Przybyla, professor Yonathan Shapir, and mathematics professor Michael Cranston continue to demonstrate the power of fractal math for modeling physical systems. Most recently, the group has been able to formulate a prediction for when a single point on a surface will erode to a critical depth. [Raychaudhuri, Cranston, Przybyla, Shapir, *PRL* 87, 136101 (2001)]. Predicting when the lowest point in a surface will erode to a critical depth or when the highest point will build up to a critical height is challenging. The group has used "extreme-value statistics" to determine the probability of extreme events, such as to forecast severe weather conditions or predict floods. "This is the first time we've had a way to predict how these extreme points grow based on nothing more than the roughness of the surface they're on," says Yonathan. An extreme point could be the deepest point of rust in a steel girder or the highest point of metal accumulation inside a battery that leads to a short. Understanding such issues can lead to better designs of material and more reliable devices.

The process is akin to trying to find how tall the tallest person in the world is by measuring the height of a roomful of people. Although the tallest person in the world probably isn't in the room, extreme-value statistics offers a way to estimate how tall that tallest person is likely to be. Again the key is the idea of fractal scaling, across both space and time. A pattern that can be scaled is one that has the same shape no matter how close you may "zoom in" on it. The basic pattern repeats on any scale at which you view. Fractals display infinite scaling. Likewise, when a surface grows or is eroded, its overall pattern repeats with time. Consequently, a magnified piece of the surface will look just like the whole surface after a long period of erosion or accumulation.

The team visualized how the roughness of a surface changed as it wore away—by an acid, for instance—or accumulated, such as inside a battery. They concluded that the extreme point of a section changed in a nonlinear way with the roughness. The section could then be scaled to the whole of the surface affected by the corrosion or accumulation. In essence, the height of the tallest person in the world could be extrapolated by scaling up the relationship between the average and the tallest to account for the world's population.

The next step in the research was to model the growth or erosion process backward in time to determine what a small section of the surface originally looked like, by studying the way the whole surface wound up. With input from Michael Cranston, the team was able to generalize the way the extreme points wound up by solving a mathematical model that should work for other fractal surfaces.

Subhadip and Corry then ran computer simulations of different growth and erosion processes thousands of times to gather enough statistics for the extreme points. Their results confirmed the fractal-based predictions.

Yonathan emphasizes that the power of the widely applicable technique is its ability to determine when an extreme point will hit a critical height with much more accuracy than just trial and error.

Evidence Found for Spinning Black Hole

University alumnus Todd Strohmayer (Ph.D. '92) has found that a blinking x-ray source near the center of the Milky Way has given the best evidence to date that black holes spin [Strohmayer, *ApJ* 552, L49 (2001)].

Theorists are almost certain that black holes of stellar mass rotate because they form during the collapse of a rotating heavy star and conserve angular momentum. But measuring the actual spin of a black hole is tricky.

Todd's evidence comes from a phenomenon observed during two blasts of x-rays from a binary system called GRO J1655-40. During x-ray flares in 1996, a small percentage of the x-ray light, within a narrow frequency range, turned on and off about 450 times per second. Given that the mass of the presumed black hole is known from properties of the binary system, the extremely rapid variability could only come from material orbiting very close to the black hole. A maximally spinning black hole provides the smallest radius for the last stable orbit of material, and this is the only consistent interpretation of the data. If confirmed, this would provide the first definitive detection of a spinning black hole.

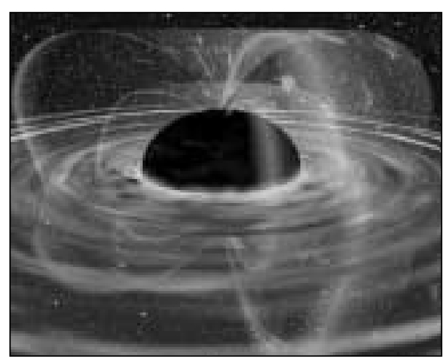


Image credit: NASA

Drawing of inner region of accretion disk around spinning black hole

Origin of Force That Shapes Planetary Nebulae

The cosmic "paintbrush" that creates some of the most dazzling images in the night sky may have been found by Rochester astrophysicists [Blackman, Frank, Markiel (Ph.D. '98), Thomas, and Van Horn, *Nature* 409, 485 (2001)]. The team realized that a magnetic dynamo, similar to the kind operating in the sun, also appears to operate in the stellar phases that immediately precede planetary nebulae—the colorful, wispy clouds of light that radiate from many dying stars. The forces of the magnetic fields can twist the radiating material into beautiful and distinctive shapes.

The model thrives on the properties of a typical low-mass star as it approaches the last years of its life. The core of such a star decouples from the outer shell of the star like a yolk spinning inside an egg. Since the magnetic fields act as elastic bands with endpoints on the shell and yolk, respectively, the differential rotation between the two strengthens the tension and energy in the magnetic field by stretching. The strong fields can then be used to propel and collimate material, as the fields uncoil like a spring.

The idea that magnetic fields play a role in shaping the material thrown off by dying stars has been considered before, but previous work looked only at the activity of the outer shell rather than the crucial interplay with the inner core, which leads to much stronger fields than previously realized.

The new model is supported by another well-known phenomenon. The typical leftover core of such stars, called a white dwarf, is known to spin more slowly than astrophysicists expect. The *Nature* article suggests that the core is slowed down by "magnetic braking"—a sort of drag produced by the magnetic fields that twist up like a wrung towel that gets harder and harder to twist. As this is happening, the material resting on the surface of the white dwarf is propelled into space along the magnetic lines, slowing the rotation further by carrying off angular momentum.

"The dynamo-generated magnetic field that we've proposed may explain many other phenomena of planetary nebulae, such as the launching of the stellar wind," says Jack Thomas. "This is the kind of unifying concept that one seeks in science." The implications of the research reach beyond nebulae. The same processes that generate the magnetic fields in dying stars are also at work in our own sun.

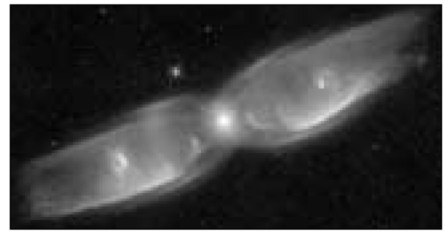


Image credit: NASA

Hubble Telescope image of planetary Nebula M2-9

Sunspots, solar storms, and coronal mass ejections that endanger power grids and satellites are all directly caused by magnetic fields generated in the present sun. But when our sun runs out of fuel in a scant four or five billion years, it too will become a planetary nebula. The role of magnetic fields will likely be as important then, as it is now, in powering the solar corona.

New Results on Superluminal Propagation of Light

Two graduates of the department's quantum optics group, Lijun Wang (Ph.D. '92, advisor L. Mandel) and Alexander Kuzmich (Ph.D. '99, advisors L. Mandel and N. Bigelow), have published important new experimental results [Wang, Kuzmich, Dogariu, *Nature* 406, 227, (2000)] on Gain-Assisted Superluminal Light Propagation.

The experiment involved the "superluminal" propagation of a light pulse through a cell of cesium gas: the group velocity (the velocity of a pulse undistorted in shape) is negative, a counter-intuitive situation, which means that the pulse peak arrives at the end of the cell in a time less than that of an equivalent pulse traveling through a vacuum. In fact, because the group velocity is negative, it exits the cell even before it enters. "This is not at odds with special relativity," maintains Lijun, now at the NEC Research Institute in Princeton, N.J. "In fact, we hope our experiment can clarify some subtle misunderstood implications of relativity."

Physicists agree that the speed of light does not provide an upper limit to the group velocity, contrary to what is stated in most textbooks. Instead it applies to a more idealized quantity called the "front velocity"—the speed of the edge of a light pulse that is abruptly and instantaneously switched on.

Past experiments of superluminal group velocity in an opaque material, including those in 1982 by Nobel laureate Steven Chu (B.S. '70) of Stanford University, have suggested the presence of the faster-than-light phenomenon, first predicted in 1970. The new work by Wang and his colleagues may be the most impressive so far: More than 40 percent of the pulse gets through the cesium gas medium, as opposed to previous experiments that largely involved quantum mechanical tunneling, in which very little incident light got through. The researchers used a combination of laser beams to create an unusual region of "anomalous dispersion" in the six centimeters of cesium gas, where the velocity of light is higher for higher frequencies of light. Raymond Chiao of the University of California at Berkeley describes the effect of a pulse reshaping akin to squeezing a long balloon filled with water. The cesium atoms amplify the front parts of the pulse by stimulated emission of radiation (the quantum process that creates laser beams), whereas later parts are deamplified by stimulated absorption. In other words, the system recreates the entire pulse based on the front part of the pulse.

Lijun plans to investigate several other aspects of superluminal group velocity, including the measurement of the velocity of energy transport (he suspects it will be bounded by the vacuum speed of light) by creating a pulse that allows the front velocity to be measured, and exploration of the few-photon case.

New Neutrino Measurement Surprises Particle Physicists

A team of scientists at the Department of Energy's Fermi National Accelerator Laboratory has found a surprising discrepancy between predictions for the behavior of neutrinos and the way they actually behave.

The NuTeV (Neutrinos at the Tevatron) collaboration, whose analysis team is led by Rochester's Kevin McFarland, measured the ratio of two types of particles—neutrinos and muons—emerging from high-energy collisions of neutrinos with target nuclei. The results of generations of particle experiments with other particles have yielded precise predictions for the value of this ratio, which characterizes the interactions of particles with the weak force, one of the four fundamental forces of nature. For other elementary particles, including the quarks and electrons of ordinary matter, the predictions seem to hold true. But, to the NuTeV experimenters' surprise, when they looked at neutrinos with comparable precision, neutrinos did not appear to fall into line with expectations.

"We measured a quantity called 'sine squared theta W,'" said NuTeV physicist Sam Zeller, a graduate student from Northwestern University. "It tells us the strength of the interaction of neutrinos with the Z boson, one of the carriers of the weak force. The predicted value was 0.2227. The value we found was 0.2277, a difference of 0.0050. It might not sound like much, but the room full of physicists fell silent when we first revealed the result."

The NuTeV result gets physicists' attention because it doesn't quite fit the Standard Model (see cover diagram), the very precise theoretical picture that physicists have developed to explain fundamental particles and forces and their interactions. In particle physics, such "misfit" results are often the harbinger of new particles, new forces and new ways of seeing nature. The experimenters reported a three-sigma discrepancy, which translates to a 99.75 percent probability that the neutrinos are not behaving like other particles.

"Our picture of matter has held true for 30 years of experimental results," said Fermilab Associate Director Michael Shaevitz, a NuTeV cospokesperson. "With the NuTeV result, it's possible we may have stumbled across a crack in the model. As yet, we don't know the explanation, but we believe it may foreshadow discoveries just ahead at accelerator laboratories."

Photo credit: Fermilab

Kevin McFarland (center) points out results to collaborators.

Kevin emphasized that the NuTeV measurement would not be so striking if the experiment had not achieved an extraordinary level of precision, unprecedented for a neutrino experiment of its kind. "Because we examined the interactions of millions of neutrinos and antineutrinos, their antimatter counterparts, we determined that there is only a one in four hundred chance that our measurement is consistent with the prediction. Unless this is a statistical fluke, it looks as if neutrinos may really behave differently from other fundamental particles. Further, experimenters using the Large Electron Positron at CERN, the European Particle Physics Laboratory, recently measured this same neutrino interaction in a different particle reaction. They saw the same discrepancy we found, although with less precision."

Neutrinos carry no electric charge and "feel" only the weak force, which is a hundred times weaker than the electromagnetic force. As a result, neutrinos rarely interact with each other or with other particles, making them extremely hard to detect. Physicists designed the NuTeV experiment in order to observe interactions of millions of the highest-energy, highest-intensity neutrinos ever produced. Starting with a proton beam from Fermilab's Tevatron, the world's highest-energy particle accelerator, experimenters created a beam of neutrinos directed at a giant particle detector. The detector itself was a 700-ton sandwich of alternating slices of steel and detector. As the beam passed from the first to the last slice, one in a billion neutrinos collided with a target nucleus, breaking it apart.

After the collision with a nucleus, the neutrino could either remain a neutrino or turn into a muon, a particle that is a heavier cousin of the electron. When NuTeV experimenters saw a nucleus break up, they knew a neutrino had interacted. If they saw a particle leaving the scene of the collision, they knew it was a muon. If they saw nothing leaving, they knew a neutrino (invisible to the detector's "eye") had come and gone. The NuTeV scientists measured the ratio of muons to neutrinos and compared it with the predicted values, which other experiments have verified to a part per thousand accuracy for other particles. A painstaking yearlong analysis of the NuTeV data revealed the unexpected discrepancy.

The 45-member, multi-institutional NuTeV collaboration (which is small on the scale of today's particle physics experiments) collected data for 15 months in 1996 and 1997. Kevin presented the analyzed results at an October 26 seminar at Fermilab. The collaboration has submitted the results to *Physical Review Letters*.

The collaboration included physicists from the University of Cincinnati, Columbia University, Fermilab, Kansas State University, Northwestern University, the University of Oregon, the University of Pittsburgh, and the University of Rochester. The Rochester group included faculty members Arie Bodek and Kevin McFarland; senior research associates Howard Budd, Pawel de Barbaro, and Willis Sakumoto; postdoctoral researcher Deborah Harris, and students Sergey Avvakumov and Un Ki Yang.

Physicists Elected APS Fellows

Five University of Rochester physicists were honored in early 2001 by the American Physical Society (APS) for their accomplishments. Less than 1/2 of 1 percent of the membership of the society is elected to fellowship.

Priscilla Auchincloss, senior lecturer in physics, was recognized for her exemplary record of service to the APS and for her ongoing effective work to improve the climate for women physicists and to ensure gender equity.

Stephen Craxton, senior scientist at the Laboratory for Laser Energetics, was recognized for original contributions to laser-driven inertial confinement fusion (ICF) including two-dimensional hydrodynamic simulations, uniformity modeling in tetrahedral hohlraums, and the ubiquitously used third harmonic conversion of ICF glass laser systems.

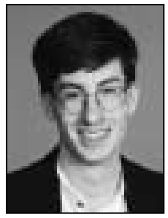
Stephen Teitel, professor of physics, was recognized for contributions toward the understanding and numerical modeling of critical phenomena in Josephson junction arrays and high-temperature superconductors.

Jack Thomas, professor of mechanical and aerospace sciences and of astronomy, was cited for contributions to solar magnetohydrodynamics, the study of the interaction between gas motions and magnetic fields in the sun.

Ian Walmsley, professor of optics, was recognized for developing methods of measuring quantum states of matter, and for the characterization of wave fields.

McFarland Recognized by Research Corporation and by Peers

In May of 2001, Kevin McFarland received a $75,000 Cottrell Scholars Award. McFarland is the first faculty member



from Rochester to receive this award since its inception in 1994. About 15 awards are given yearly (to faculty in astronomy, chemistry, or physics) nationwide. The Cottrell Scholars Awards are given by the Research Corporation to junior tenure-track faculty in the third calendar year of their first appointment. Designed to recognize teaching and research, the awards aim to help the holders become outstanding scientists and educators. Kevin's area of research is high-energy experimental particle physics.

Kevin was also recently "given the nod" by his peers, being appointed to a DOE/NSF panel to chart a 20-Year Future for High-Energy Physics. The appointments to the panel were made after a request for nominations was sent to the high-energy physics community.

Albert Wang Named Apker Award Finalist

Albert Wang, University of Rochester undergraduate physics and mathematics double major from the class of 2001, was one of three finalists for the 2001 Apker Award. This award is given by the American Physical Society to an undergraduate who has demonstrated exceptional potential for scientific research through an original contribution to physics.

Albert's nomination was based on his senior thesis in condensed matter theory, "Simulation of the Driven Lattice Two Dimensional Coulomb Gas," which was supervised by Steve Teitel. As a finalist, Wang traveled to Washington, D.C., to speak at the September 2001 APS meeting. He also received a $2,000 award.

Wang is the third student from the University to be named as a finalist for the Apker Award, which coincidentally is named for a University of Rochester physics and astronomy 1941 alumnus. In 1999, Govind Krishnaswami (B.S. '99), now a graduate student with Sarada Rajeev, went on to win the award for his undergraduate research also with Rajeev. In 1983, Bob Kowalewski, currently a professor at the University of Victoria in Canada, was an Apker finalist, and was supervised by Tom Ferbel.

David Birnbaum Honored at Xerox

David Birnbaum (Ph.D. '69) was recently named the first Xerox Fellow from the company's Office Systems Group, and the first Xerox Fellow from the engineering groups in over 20 years. This is outstanding considering there are only about 15 fellows in the corporation of nearly 90,000 employees. David was recognized for leadership in establishing color digital reproduction devices.

Un Ki Yang Honored by American Korean Physics Association

Un Ki Yang (Ph.D. '00), who received his Ph.D. in experimental high-energy physics from Rochester in 2000 (advisor A. Bodek), won honorable mention by the committee to select the Outstanding Young Researcher Award (ORYA) of the AKPA (American Korean Physics Association) in 2001. He was cited for ". . . his truly outstanding scholarly and pioneering research on high-energy physics" by the Awards Committee on March 14, 2001, in Seattle, Washington.

Talat Rahman Honored at KSU

Talat Rahman (Ph.D. '77, advisor Bob Knox) is one of five faculty honored as University Distinguished Professors at Kansas State University in 2001 in recognition of outstanding contributions to teaching, research, and service.

Talat is a solid-state theorist who investigates the physics of metal surfaces, which is important for solving technological issues such as thin-film growth, new materials development, catalysis, and corrosion. Before joining the K-State faculty, she was a postdoctoral physicist at the University of California at Irvine. Her awards include the UNDP Fellowship and the CNR-Italy Research Fellowship, the William L. Stamey Teaching Award, the K-State University Distinguished Graduate Faculty Member Award, and the Alexander von Humboldt prize in 2000. She is also a Fellow of the American Physical Society.

Michael Fitch Receives Award for Best Ph.D. Thesis at Fermilab

Michael J. Fitch (Ph.D. '00) was awarded the Universities Research Association (URA) thesis prize for the best Ph.D. thesis done on work at Fermilab. The award was presented by Fred Bernthal, president of the URA, at the Fermilab User's Meeting, June 12, 2001.

Michael's thesis, titled "Electro-Optic Sampling of Transient Electric Fields from Charged Particle Beams," was advised by Adrian Melissinos. In the thesis, a new technique was developed for measuring beam positions in accelerators. The technique will be used for future linear colliders, and may also be useful in other accelerators in which nonintercepting diagnostics are needed. During his stay at Fermilab, Fitch was supported by our Department of Energy (DOE) High-Energy Physics grant and by a Fermilab Graduate Fellowship in the Beams Division.

Michael has taken a one-year postdoctoral position with Ian Walmsley's group at The Institute of Optics.

APS Prize Named for Alumnus

The APS has established a new prize to recognize physicists under the age of 30. Named the George E. Valley, Jr. Prize in honor of a generous bequest from the estate of George E. Valley, Jr. (Ph.D. '39), the prize will be given every two years and will carry a cash award of $20,000, making it the largest single prize that the society gives. Recipients will be chosen by the president and two immediate past-presidents of the APS, as well as a chairperson to be elected by the APS Council. The prize is open to candidates in any field of physics.

George received his Ph.D. in physics from Rochester in 1939. He was named a National Research Fellow in nuclear physics in 1940 and was project supervisor and senior staff member of the Radiation Laboratory at MIT from 1941 to 1945. He was on the faculty at MIT from 1946 to 1974, was one of the founders of MIT Lincoln Laboratory, and was chief scientist of the Air Force in 1957–58. His areas of research included artificial radioactivity, mass spectroscopy, cosmic rays, design of radar systems, and invention of the SAGE Air Defense System.

George passed away in 1999.

Alumnus Receives Canadian National Teaching Medal

The Canadian Association of Physicists (CAP) awarded its 1999 National Teaching Medal to Professor Calvin Kalman (Ph.D. '71, advisor C. Hagen) of Concordia University for his dedication to the improvement of undergraduate physics teaching, which has been manifest in both the classroom, where he has been a pioneer in employing innovative cooperative teaching techniques, and in the educational community, where he has disseminated his expertise in numerous papers on student-centered learning.

Calvin has been a full professor of physics at Concordia since 1984 and was chair from 1983 to 1989. He specializes in high-energy particle research and physics education.

Herbert York Wins Fermi Award in 2000

Herbert F. York (B.S./M.S. '43) won the Enrico Fermi Award in 2000 "for his contributions to formulating and implementing arms control policy under four Presidents; for his founding direction of the Lawrence Livermore National Laboratory and his leadership in Research and Engineering at the Department of Defense; and for his publications analyzing and explaining these complex issues with clarity and simplicity."

Herbert was born in Rochester in 1921 and earned his B.S. and M.S. degrees in physics at Rochester in 1943 and his Ph.D. degree at the University of California in 1949. Among his awards are the Ernest Orlando Lawrence Award of the Department of Energy (1964), Guggenheim Fellowship (1972–73), Szilard Award (1994), the National Science Board's Vannevar Bush Award (2000), and the University of California at Berkeley's Clark Kerr Award (2000), and Honorary Doctorate degrees from Case Western Reserve University, Claremont Graduate University, and the University of San Diego.

The full text of the Enrico Fermi Award Citation can be found at www.pnl.gov/fermi/citations/york-cit.htm. Herbert was also awarded the University of Rochester Hutchison Medal, see www.rochester.edu/pr/Review/V60N1/alumni.html.

Rochester Leads Domestic Universities at Fermilab

The June 2001 survey of Fermilab users (www.fnal.gov/pub/ferminews/ferminews 01-06-08/p1.html) shows the Rochester group at Fermilab leads all U.S. institutions with 57 users, followed by Lawrence Berkeley National Laboratory with 56 users.

Selected Works of Emil Wolf Published

Selected works of Professor Emil Wolf, Wilson Professor of Physics and Optics, have been published as Vol. 29 of the *World Scientific Series in 20th Century Physics* (2001). The 661-page volume presents many of Emil's seminal papers over the past 50 years. Main topics include diffraction theory, the theory of direct and inverse scattering, phase-space methods in quantum mechanics, the foundation of radiometry, phase conjugation and coherence theory. Emil's classic papers on a rigorous formulation of the theory of partial coherence and partial polarization, the introduction of diffraction tomography, and his discovery of correlation-induced shifts of spectral lines (the "Wolf effect") are included, as are papers discussing the historical development of optics and review articles and commentary on the selections.

Rochester Physics and Astronomy Ranks 2nd Nationally in Graduate-Student Satisfaction

The National Association of Graduate-Professional Students (NAGPS) has announced the results of its 2000 survey of graduate students (http://survey.nagps.org/), funded by the Alfred P. Sloan Foundation. Our department did extremely well. The full list follows.

Overall Satisfaction: 2nd place; Information for Prospective Graduate Students: 1st place; Preparation for a Broad Range of Careers: 2nd place; Teaching and TA Preparation: 4th place; Professional Development: 3rd place; Career Guidance and Placement Services: 1st place; Controlling Time to Degree: 8th place; Mentoring: 3rd place; Program Climate: 2nd place.

Alice Quillen Joins the Department as Assistant Professor of Physics and Astronomy

In January 2002, the department will welcome Alice C. Quillen, its newest faculty member in observational astrophysics. Currently assistant astronomer at the University of Arizona's Steward Observatory, Alice earned her degrees from Harvard (A.B., Physics) and the California Institute of Technology (Ph.D., Physics). She was a Columbus postdoctoral fellow at Ohio State University before moving to Arizona.

Her research takes her to the forefront of a broad range of areas of astronomy, including the structure of active, barred, and star-forming galaxies, the nature of active galactic nuclei, and the dynamics and evolution of planet formation and protoplanetary systems. Alice's work is characterized by her ability to use both theoretical and observational techniques in her research. We look forward to her continued success.

New Opportunity for Rochester Undergraduates to Accelerate into Graduate Program

A new opportunity has been established for our undergraduates to continue on to graduate school in physics and astronomy at Rochester. Our students can apply in their junior year for early admission into graduate school. The program is designed for top undergraduates who have established strong research ties with one or more of our faculty members. Highlights of the program include additional financial compensation for students, and a significantly shortened completion time for the course and teaching requirements of graduate study. The program aims for the smoothest possible transition between undergraduate and graduate school and early completion of a Ph.D.

While the value of attending graduate school at a student's undergraduate institution is often debated, this program operates under the philosophy that there is no single answer that applies to every student. The program therefore provides an option for students to consider, and can also bring superb graduate students to the department.

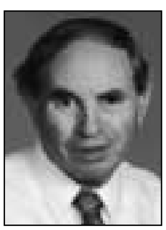
Florencia Canelli Wins Multiple Accolades

Florencia Canelli, a graduate student working with Tom Ferbel on the DZero antiproton-proton Tevatron Collider experiment at Fermilab, has over the years made many important contributions to her experiment and to the Laboratory. Last year, she represented the Laboratory in Dallas, Texas, at a Department of Energy exhibition promoting science and technology. She has also been involved with the Fermilab Users Organization, and has been a leader of the Young Physicists Association. Because of her accomplishments and hard work, this past August, Michael Witherell, the Director of Fermilab, offered Florencia the opportunity to attend the prestigious Erice Summer School in Sicily. Once again, she impressed the organizers, who awarded her a Chien Shiung Wu scholarship (named after legendary physicist Mme. Wu of Columbia University), and a "New Talents" Prize for Original Work. Both affidavits were signed by no lesser luminaries than Gerard't Hooft, Gabriele Veneziano, and the Director of the School, Nino Zichichi. Her presentation was based on a new approach to extracting parameters of the top quark, a method she has developed in collaboration with her colleague Juan Estrada (who just received his Ph.D. from Rochester) and Gaston Gutierrez from Fermilab. Florencia plans to apply the new ideas in her own Ph.D. analysis to check whether the top quark decays as expected in the Standard Model (V–A theory) of electroweak interactions.

Remembering Leonard Mandel

Professor Leonard Mandel died Friday, February 9, 2001, at the age of 73. The DuBridge Professor Emeritus of Physics and Optics, he was one of the founders of quantum optics—the study of the physics of light at its most fundamental level. He was known for his groundbreaking experiments on the nature of light and was first to observe a variety of remarkable phenomena predicted by quantum theory.

Len's career spanned an era when the influence of quantum theory, which describes the behavior of matter at the subatomic level, expanded to touch every area of physics. He was at the forefront, putting quantum theory through its paces, and demonstrating in the laboratory some of the bizarre outcomes predicted by quantum mechanics.



It was he who most elegantly demonstrated what Einstein once called "spooky action at a distance," the idea that any action can affect another seemingly unrelated action elsewhere—an idea physicists call "quantum entanglement." With a laboratory set-up as simple and disarming as his smile, Len showed that a change to one laser beam in his laboratory affected another, unrelated beam elsewhere in the laboratory. The experiment was one of the clearest demonstrations of the validity of quantum mechanics, whose many implications even the most experienced scientists have difficulty accepting. Nevertheless, the theory has held up whenever experimenters have been clever enough to find a way to test it.

"Len systematically tested the foundations of quantum theory with the finest experiments in the world," says Emil Wolf, longtime colleague and friend, who persuaded Len to join him in Rochester in 1964. "He was an excellent teacher and a first-class researcher, and he was truly one of the founders of quantum optics. He was also a kind and incredibly generous man."

Len laid claim to several achievements through a series of experiments from the 1950s through the 1990s. He and his students were the first to demonstrate the self-interference of single photons; first to demonstrate nonclassical interference between two photons; and first to design and carry out an experiment to observe "photon anti-bunching," demonstrating that a single atom illuminated by a laser beam emits photons uniformly spaced in time like soldiers marching past in a column. His measurements of the statistical properties of light gave rise to the "Mandel formula," which addresses the topic of photon detection. In one experiment, his team measured the time interval between the arrival of two photons more accurately than anyone had ever done before. The team worked constantly at the boundary between classical and quantum physics, says Ian Walmsley, professor and director of the University's Institute of Optics. "Len was always able to put his finger precisely where the boundary lay between classical and quantum physics. His experiments were models of simplicity and elegance. It was the way you would do the experiment if you were as smart as someone like Len Mandel."

Len's work helped form the basis for a growing field of knowledge that today includes quantum encryption, quantum computing, and quantum communications—radically new ways to process, transmit, and retrieve information that offer super-secure protocols and extraordinary powers of deciphering. Several research centers around the world owe their existence to initial work by Len, including the University's Center for Quantum Information.

Typically, his experiments employed laser beams and simple equipment to split the beams and bounce them in various directions in the laboratory, and sensitive equipment to measure the results. His experiments with photons even earned a nickname: "quantum pinball." Using such a set-up 10 years ago, Len showed that the Heisenberg Uncertainty Principle is more subtle than had previously been thought. By checking interference patterns of photons, he showed that just the possibility of making a measurement is enough to change the outcome of an experiment,

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whether or not anyone actually makes a measurement.

Subsequently, Len demonstrated, unequivocally, a central tenet of quantum mechanics, that an event is not real until it has been measured. In other words, no matter how much is known, what will happen next can never be known with certainty. His experiment had its roots in a 1935 paper by Einstein, Podolsky, and Rosen, which implied that if an event can be predicted with certainty, the event is real, even if it is not specifically measured. Backers of quantum theory demurred, with Niels Bohr, Werner Heisenberg, and Max Born insisting that there is no reality until a measurement is made. Sixty years later, with careful study of photons in the laboratory, Mandel demonstrated with dramatic clarity that the quantum theory of Bohr, Heisenberg, and Born is correct.

"Len took what seemed like an intellectual exercise and demonstrated that it corresponded to physically observable consequences," says Nick Bigelow, who succeeded Len as the DuBridge Professor of Physics and Optics.

Len earned his doctorate in nuclear physics in 1951 from the University of London, where he also earned undergraduate degrees in mathematics and physics. As a graduate student, he studied cosmic rays, and as part of his work he climbed high into the Alps to make his measurements. It wasn't long before he began to wonder how his cosmic ray detectors actually worked; that curiosity led him to a career asking fundamental questions about photon detection and measurement. He was senior lecturer in physics at Imperial College of the University of London for nine years before joining the University of Rochester in 1964.

At the University, he was known as an outstanding teacher, training 39 doctoral students who permeate physics programs around the world. In 1992 Len was awarded the University's Faculty Award for Graduate Teaching.

In addition to his work at the highest level of physics, Len also had a special interest in neophyte science students. He developed the University's first physics course geared specifically for non-science majors and taught that course regularly for 20 years, and was known for his gift of explaining the most complex topics in the simplest terms.

Len wrote more than 300 scientific papers, including one with Emil on the coherence properties of optical fields that became one of the most-cited articles in physics. Emil, Len, and others also wrote the seminal textbook *Optical Coherence and Quantum Optics*, a 1,166-page volume on the nature of light. The pair and others also organized an ongoing series of Rochester Conferences on Coherence and Quantum Optics, considered one of the world's premier conferences in the field since the first one in 1960.

Len was recognized with many top honors, including the Frederic Ives Medal and Max Born Award of the Optical Society of America, the Italian National Research Council's Marconi Medal, and the Thomas Young Medal from the British Institute of Physics. He was a fellow of the American Physical Society, the Optical Society of America, and the American Academy of Arts and Sciences. In 2001 he was elected posthumously to the National Academy of Sciences.

ALUMNI NOTES

Vi-En Choong (Ph.D. '97) is currently working at BioChip Systems of Motorola Inc. He is involved in making high-density biochips. Biochips are thin wafers of glass or plastic with thousands of microscopic bits of DNA arrayed on their surfaces. Scientists are already using them to identify disease genes and to help speed drug discovery. They may ultimately do for biology what microprocessors did for computers. The biggest market for DNA chips is expected in the diagnosis of disease.

Sameer Datar (Ph.D. '94) is currently a development engineer with PDF Solutions, Inc., a semiconductor fabrication consulting company in San Jose, Ca., and works out of the Dallas office.

Jesse Ernst (Ph.D. '95) is to be congratulated. His thesis, "First Measurement of the Rate for the Inclusive Radiative Penguin Decay b -> s gamma" *PRL* 74, 2885 (1995) received its 500th citation this year. Very few experimental papers reach this magic number.

John Harvey (Ph.D. '78) finished serving with the Clinton administration Defense Department as Deputy Assistant Defense Secretary for Nuclear Forces and Missile Defense Policy. He was brought to Washington by Bill Perry, for whom he worked at the Stanford University Center for International Security and Arms Control, and who later became Secretary of Defense. Though planning to leave government in January 2001, Harvey was convinced to stay in government by General John Gordon, who heads the DOE National Nuclear Security Administration, a semi-autonomous organization responsible for stewardship of U.S. nuclear weapons capabilities and nonproliferation programs with the former Soviet Union.

Kay Koeningsmann (M.S. '73) has been serving as the Dean of the Physics Faculty at the University of Freiburg since 1999 and continues to work in nuclear and particle physics at the DESY and CERN accelerators.

Jim Scholl (B.S. '80) is currently a senior multi-disciplined engineer at Raytheon Missile Systems in Tucson. Before that he had spent 10 years at the Rockwell Science Center in Thousand Oaks, Ca. After being out of school over 12 years, he is now enrolled in the Ph.D. program at the Optical Sciences Center at the University of Arizona.

Tim Tredwell (Ph.D. '75) is still at Kodak, and was just appointed Executive Chairman of the IEEE International Solid State Circuits Conference (ISSCC). He has served on ISSCC for the past 12 years, including program chair in 1995, and has served on the ADCOM of the IEEE Solid-State Circuits Society for the past five years.

Departmental Funds

The department has established several funds that greatly benefit departmental activities. They are:

The David L. Dexter Memorial Fund. Established in 1981 to honor the memory of the late Professor Dexter, this fund supports an annual lecture by an outstanding scientist.

The Robert E. Marshak Memorial Fund. This fund will be used to support the newly created postdoctoral Robert E. Marshak Research Fellowships, intended to attract the most talented young nuclear and particle physicists to Rochester 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 recent upgrade to the facility.

The Elliott W. Montroll Memorial Fund. Established in 1984 in memory of the late Professor Montroll, this fund supports the Montroll Memorial Lectures in Physics.

The Physics and Astronomy Alumni Fund. Established in 1968, 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 of Physics and Astronomy, 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 significant tax advantages. The department is grateful for any help you may wish to give.

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Thank You!

We gratefully acknowledge the following for their donations to the department during this past year.

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