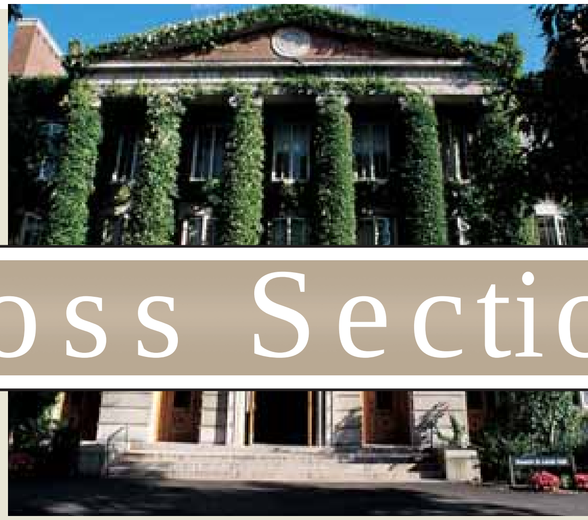
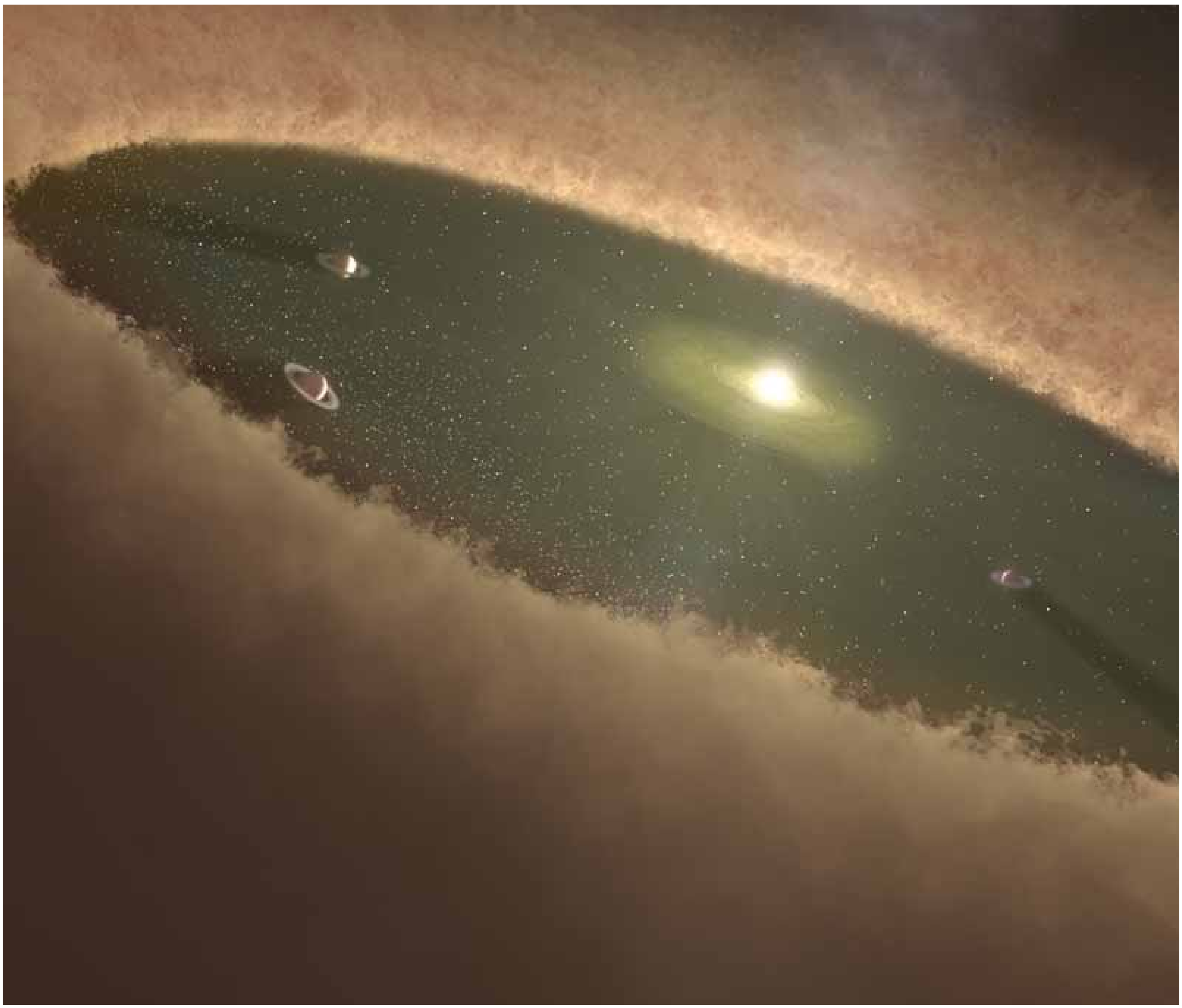


Cross Sections

DEPARTMENT OF PHYSICS AND ASTRONOMY
UNIVERSITY OF ROCHESTER
SPRING 2007



Message from the Chair

—Arie Bodek

After nine years, I am stepping down as chair and will resume my duties as a regular faculty member on July 1, 2007.

Dean Peter Lennie has asked Professor Nick Bigelow to become the next chair.

Several of our faculty, students, and alumni have received awards during this past academic year. I will mention only a few and refer you to news stories on our department Web page for the others. Professor Joe Eberly has been serving as vice president and president-elect of the Optical Society of America and will become president this year. Assistant Professor John Howell received the 2006 Adolph Lamb Medal from the Optical Society of America. Professor Okubo received the 2006 Wigner Medal for the Application of Group Theory in Physics. Professor Judy Pipher was inducted into the National Women's Hall of Fame in 2007, and Professor Nick Bigelow was elected fellow of the Optical Society of America in 2007. Among several teaching awards, I would like to mention that Professor Dan Watson received the 2006 Goergen Award for Distinguished Achievement and Artistry in Undergraduate Teaching, and Professor Ashok Das received the 2006 University Graduate Teaching Award.

Young Kee Kim (Ph.D. '90) was awarded the most prestigious Korean Science Prize in 2006 and assumed the post of deputy director of Fermi National Accelerator Laboratory in 2006. She has also been serving as co-spokesperson of the CDF collaboration at Fermilab, along with Robert Roser (Ph.D. '97).

We wish to take this opportunity to thank all our friends who have contributed so generously to the support of the department. By completing the form on the last page of our newsletter, you can continue (or begin) that tradition of giving that will assure the future excellence of the department. Other ways to help our cause are to inform any promising students about our summer undergraduate research program (REU) and to encourage students interested in careers in physics or astronomy to apply for graduate study at Rochester. Application material for all 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 studies, 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 greatly welcomed. Several years ago, the University initiated a tradition of hosting yearly Meliora Weekend reunions (see www.rochester.edu/alumni). I encourage all our alumni and friends to come and visit us October 19–21, 2007. For the latest news about the department, please visit our Web page, where you can also find the current and several recent issues of *Cross Sections* online.

Cross Sections

Editor: John Howell

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On the Cover

Artist's conception: Planets sweep away a clearing in a dusty disk surrounding a young, newly formed star. (NASA/JPL-Calech)

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The Search for Gravitational Waves

by Adrian Melissinos

The department has a long involvement in the search for Gravitational Waves (GW). In the 1970s Professor D. Douglass constructed a “Weber” type antenna (massive aluminum cylinder with very high q-factor) and with Professor W. Johnson and then graduate student M. Bocko carried out a search for GWs at the then prevailing sensitivity levels.

Presently, laser interferometers are the state-of-the-art gravity wave detectors. The LIGO (Laser Interferometer Gravitational Observatory) laboratory is funded by the NSF and operates three large interferometers at two widely separated sites. One site is at the Hanford reservation near Richland, Wash., and the other at Livingston Parish in Louisiana.

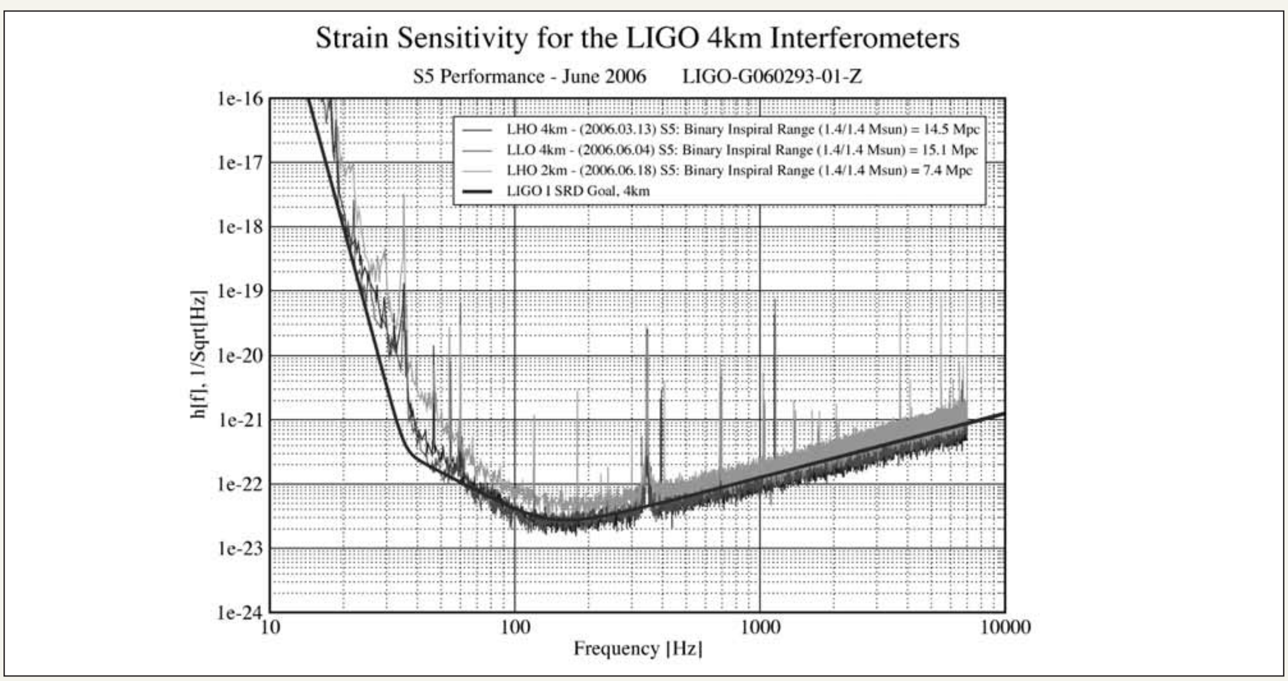
These instruments are Michelson interferometers with two orthogonal arms, each arm 4 km long. The arms are Fabry- Perot cavities such that the effective length of the arms reaches 600 km. The sensitivity to GW strain has reached ~10 ^ (-23)/sqrt(Hz). Namely, end-mirror displacements of Dx ~ 4x10 ^ (-20) m can be detected in 1 second of integration time. Fig. 1 shows aerial views of the interferometer enclosures at the two sites.

Since November 2005, the LIGO interferometers have been accumulating data continuously operating at design sensitivity. Fig. 2 shows the current sensitivity level as a function of frequency.

Figure 1

Courtesy of Ed Foster

Figure 2



The analysis of the data from the two interferometers is the responsibility of the LIGO Scientific Collaboration (LSC). Rochester has been a part of the LSC since 2003. The group is headed by Professor A. Melissinos and includes graduate students S. Giampanis and T. Fricke, and earlier, W. Butler (Ph.D. '04). The signals sought by the LSC can be grouped as follows:

(a) Coalescence of binary systems, be it neutron stars or black holes. When the two bodies in-spiral towards coalescence, the emitted GW has a characteristic frequency chirp, which can be recognized with confidence.

(b) Short bursts of gravitational radiation from supernova collapse and similar catastrophic events (for instance gamma ray burst events). Such events are identified by their simultaneous (time coincident) detection in several detectors.

(c) GWs emitted at discrete frequencies as expected from rotating stars (possibly pulsars) with significant quadrupole mass distribution. These extremely narrow lines will exhibit a well-defined Doppler shift due to the motion of the earth through the galaxy, a unique signature.

(d) Finally, a stochastic signal of GWs left over from the big-bang or from the previous evolution of the universe should be present.

So far, the LSC has placed significant limits on all of the above mentioned phenomena. Following the present data run, which should end this fall, the interferometers will be upgraded, and the collaboration will be expanded to include a large interferometer in Pisa, Italy. A proposal has also been submitted to the NSF for the construction of "advanced LIGO" aimed at improving the sensitivity of the present instruments by a factor of 10. Thus the rate of gravitational events will increase by a factor of 1000, since the rate is proportional to the volume reached by the detectors. This will certainly lead to the detection of GWs and to the birth of Gravitational Wave Astronomy.

Light Propagates Backwards

Professor Boyd, who holds a joint appointment with the Department of Physics and Astronomy, and his group recently demonstrated that they could make light pulses propagate very slowly, superluminally, or even backwards.

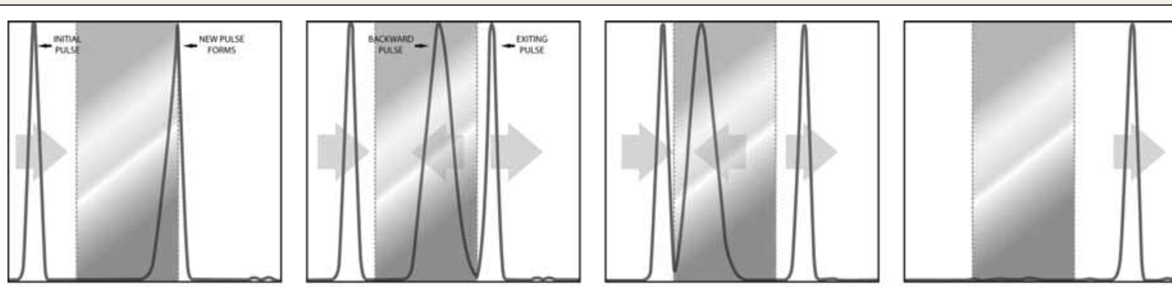
There is a well-known result in special relativity which says that if person A sends a superluminal signal to person B in another inertial reference frame and then person B sends it back to person A, it is possible for person A to receive the signal before it was originally sent. So, how is it possible to send superluminal or backward propagating signals without violating causality? We can reconcile our intuition of a causal universe and Professor Boyd's work, by realizing that Gaussian pulses, the kind used in the experiment, actually extend well beyond the peak of the pulse. The pulses in their experiment were several hundred kilometers full width at half maximum in length. The front edge of the pulse propagates far in advance of the center of the pulse and contains all of the information about the pulse.

In the backward propagating scheme, the fiber assembles a pulse at the far end of the medium; one component of the pulse propagates away from the fiber, and the other propagates backward in the fiber. A pictorial representation is shown in the figure. To demonstrate that the light was actually propagating backwards, they cut the fiber to shorter and shorter lengths and showed that the exit pulse left at later and later times.

The fields of slow, fast, and backward propagating light are based on manipulating a medium's index of refraction. A frequency dependent index of refraction (dispersion) occurs in any system which has a frequency dependent absorption. The group velocity, the speed at which the energy travels, is determined by the first derivative of the index of refraction (or the slope of the dispersion for a given frequency). In regions of anomalous dispersion, the slope of the index of refraction is negative. It is possible to have negative group velocities, which leads to the backward propagating pulses in Boyd's experiment.

"I know this all sounds weird, but this is the way the world works," says Boyd.

How Does Light Go Backward?



As the initial pulse of light approaches the glass, a new pulse forms at the far end.

The new pulse splits in two, one traveling backward in the glass, the other already exiting.

The backward pulse meets and cancels out the initial pulse.

Only the final pulse remains.

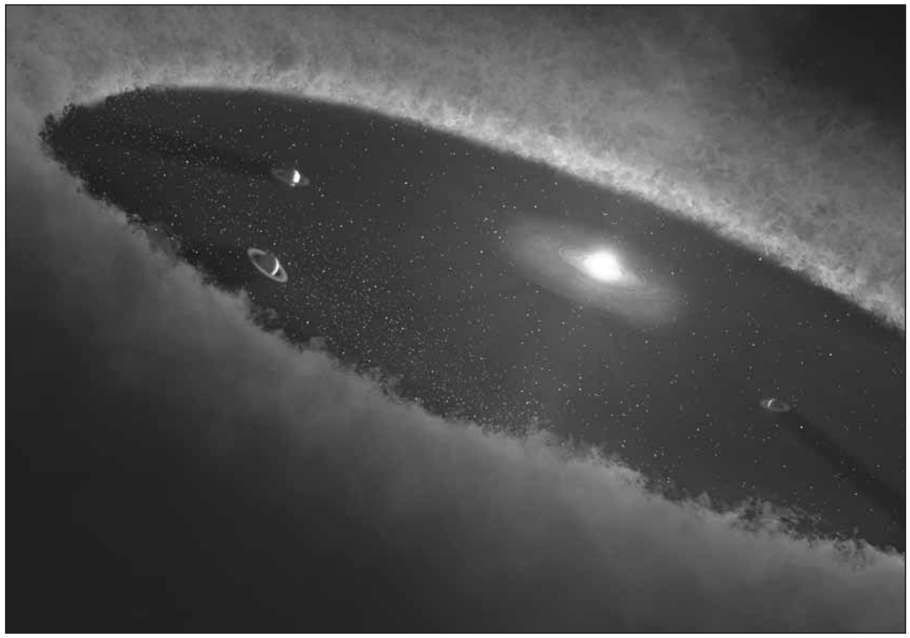
Rochester Astronomers Discover the Youngest Planets

By Eric Blackman

Using NASA's Spitzer Space Telescope, University astronomers led by Dan Watson and Bill Forrest in collaboration with an international team have been studying dusty disks surrounding very young stars. These dusty disks are similar to what our own solar system would have looked like when it was 1,000 times younger than it is now. The study of these "protoplanetary disks" probes the earliest stages of star and planet formation. A major result that has emerged from this ongoing research program is the indirect detection of the youngest planets yet discovered in the Universe.

To explain the result, note that dust in a protoplanetary disk is hotter in the center near the star and so radiates most of its light at shorter wavelengths than the cooler outer reaches of the disk. From spectra taken with Spitzer's Infrared Spectrograph (IRS), the IRS team identified abrupt deficits in emission radiating within a certain infrared wavelength range, thereby pinpointing that part of the disk that is cleared out. In some cases, such as around the star CoKu Tau 4, it appears that the central part of the disk is absent entirely. In other cases, such as around the stars DM Tauri and GM Aurigae, gaps within the disks are inferred. DM Tauri and GM Aurigae are 420 light years away in the Taurus constellation. While disks have been suspected to have gaps in these objects from previous data, the new high-resolution spectra leave no doubt.

The emptiness and sharpness of the observed gaps and holes in these protoplanetary disk systems are most naturally explained by the presence of a massive gas-giant planet therein. A massive planet will gravitationally clear out disk material from an annulus within which it orbits the star. Rochester theorists Alice Quillen, Peggy Vaniere, Eric Blackman, and Adam Frank constrained the mass of the planet orbiting CoKu Tau 4 from theoretical arguments, also finding that the required mass is consistent with a Jupiter-like mass range.



Courtesy NASA/JPL-Caltech

Artist's conception: Planets sweep away a clearing in mass of dust surrounding a fledgling star.

Because the aforementioned protoplanetary disk systems are known to be only of an order a million years old (via stellar cluster aging), the IRS team has indirectly detected the youngest planets yet identified in the universe. The youth of these planets has shocked the astronomy community because it requires that they form on a time scale 10 times faster than some leading conventional planet formation models can explain.

The new findings not only reinforce the idea that giant planets like Jupiter form much faster than scientists have traditionally expected, but one of the systems—called GM Aurigae—is likely particularly similar to our own solar system. GM Aurigae has 1.05 times the mass of our Sun—a near twin—so it will develop into a star very similar to the Sun. If it were overlaid onto our own Solar System, the discovered gap would extend roughly from the orbit of Jupiter (460 million miles) to the orbit of Uranus (1.7 billion miles). This is the same range in which the gas-giant planets in our own system appear. Small non-gas-giant planets, rocky worlds like Earth, would not sweep up as much material, and so would not be detectable from an absence of dust.

The Spitzer Space Telescope was launched into orbit on August 25, 2003. The IRS Disks research team is led by members that built Spitzer's Infrared Spectrograph and includes astronomers at the University of Rochester, Cornell University, the University of Michigan, the Autonomous National University of Mexico, the University of Virginia, Ithaca College, the University of Arizona, and UCLA. NASA's Jet Propulsion Laboratory in Pasadena, Calif., manages the Spitzer Space Telescope mission for NASA's Science Mission Directorate in Washington. Science operations are conducted at the Spitzer Science Center at the California Institute of Technology, also in Pasadena.

Beyond Qubits

John Howell, assistant professor of physics, and his group recently showed that it was possible to have over 1000 physically measurable states in a pair of entangled photons. His group showed that a single pair of time-energy entangled photons could carry the same amount of information as 10 entangled two-state quantum particles (quantum bits or qubits). These high-dimensional entangled photons were then used to enlarge the alphabets in a novel quantum key distribution scheme. Their work was reported in the February 9 *Physical Review Letters.*

Key distribution is the process of sharing random, but correlated, strings of numbers (the keys) between two intended users (usually known as Alice and Bob). Alice and Bob use the strings of numbers to encrypt plaintext messages. Since only Alice and Bob know the strings of numbers, they are the only users that can properly decrypt the message. An example is that Alice and Bob both have random bit strings of 11001. Alice wants to send plaintext message 10,010 to Bob. She must first add (addition modulo two) each term in the plaintext message to her random string. Alice then has a ciphertext 01011, which she sends to Bob over a public communication channel, such as a public announcement system at a football game. Bob then performs addition modulo two to the ciphertext with his key and decrypts the ciphertext to reveal plaintext message 10010. The technique is called the Vernam cipher or one-time pad. It can be seen that as long as the keys are secure, then the ciphertext is secure. Quantum key distribution is a means of sending secure keys between two intended users using the laws of quantum mechanics.

Since the Bennett Brassard 1984 protocol, most of the quantum key distribution schemes have used two-level systems, such as transverse polarization states. There has been significant interest in trying to obtain higher dimensional alphabets (strings with numbers 0,1,2,…d), instead of just bit strings. The interest is twofold. First, the information throughput can be increased without increasing the transmission rates. Second, the security of the key transmission, in many cases, is improved.

There had been incremental progress in increasing the dimensionality of the alphabet of cryptosystems. The largest alphabet had been 36 characters but used a multimode free space transmission. The interesting thing about Howell's group's work is that the system employed fiber transmission and had in excess of 1024 characters (equivalent of 10 bits of information).

The scheme is based on time-energy correlations which naturally exist in the process of spontaneous parametric downconversion (SPDC). In spontaneous parametric downconversion one photon is destroyed, and two photons are created with large single photon energy uncertainty but very small two-photon energy uncertainty. Owing to energy conservation the sum of the energies of the two downconverted photons has to be equal to the energy uncertainty of the destroyed photon. If a narrow band pump photon is destroyed, there is very small energy uncertainty. However, the individual energies of the photons can be very large. On the other hand, the photons are created at nearly the same time. Hence, if one measures the times of arrival of the two photons they arrive at times too correlated even to measure, except through interference techniques. If one measures the energy correlations they are also extremely good.

The quantum key distribution scheme is then made by measuring the random arrival of photons in correlated time bins. Since the photons will arrive at the same but random time then correlated strings of numbers set by the bins can be generated. The security of the system is tested by looking at the spectral correlations between the two photons. An interferometer which measures fourth-order fringes was used to measure the correlations between the photons. If an eavesdropper tries to determine the time of arrival of the photons, the spectral correlations will be destroyed. It can then be determined that an eavesdropper was present during the transmission.

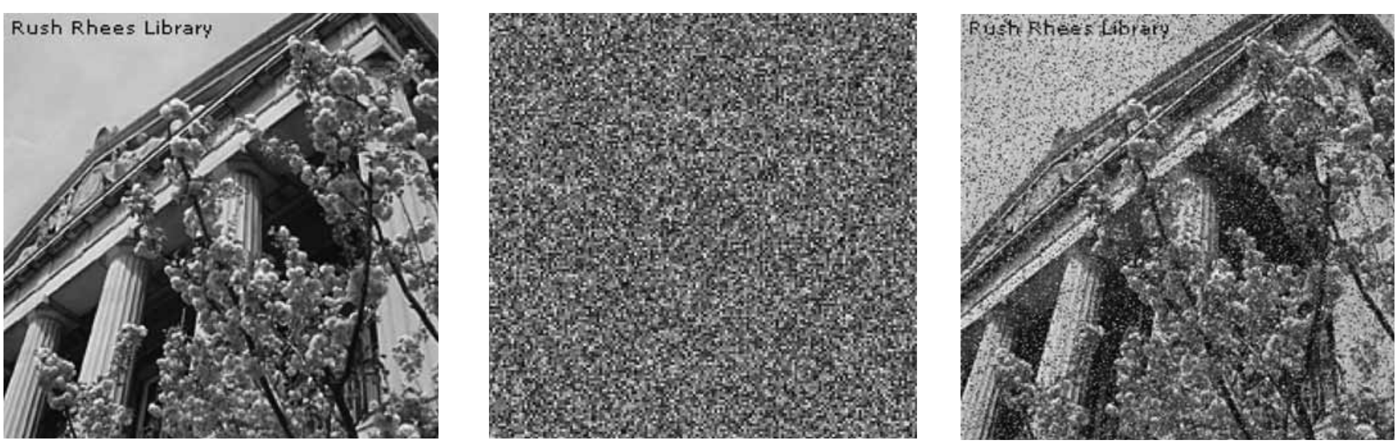


Fig 1. The figure shows an image of the Rush Rhees Library that Alice wishes to send to Bob. The image was encrypted using data from the cryptoscheme and decrypted with Bob's key. The discrepancies are due to errors in the transmission.

New Degree Program Announced

The Department of Physics and Astronomy announces a new professional master's degree program in physics with individualized course plans selected from physics, astrophysics, applied physics, physics education, or engineering to begin in the fall of 2007.

The individualized professional master's program, designed for students with a B.A. or B.S. in physics, takes one full academic year. Students who complete the individualized M.S. program may enter the workforce directly for practical training or may choose to apply to a Ph.D. program in physics or in an allied field or other related interdisciplinary programs in science and engineering.

Practical Training: For foreign students who come with an F1 student visa, the length of time allowed for practical training is 12 months following completion of the M.S. degree. Foreign students must apply for practical training and obtain approval before they complete the M.S. degree. M.S. students who have completed their 12 months of practical training may enter a Ph.D. program and later apply for an additional 12 months of practical training to follow their Ph.D. degree.

Examples of M.S. programs in traditional specialty subfields in physics include astrophysics, biological/medical physics, condensed matter physics, nuclear physics, optical physics, particle physics, physics education, and plasma physics. Examples of M.S. programs with individualized course plans selected from applied physics and engineering include (but are not limited to): physics in medicine, physics and computation, physics and engineering (e.g., electrical and computer engineering, chemical engineering, mechanical engineering), chemical physics, etc. Students may individualize their programs more narrowly according to their own specific interests (e.g., nanotechnology, geophysics/environmental science, energy, materials, etc.) in consultation with the graduate student advisor. Examples are shown on the department's Web page.

Every individualized M.S. degree candidate must declare an area of specialty in physics or an allied field in applied physics or engineering. Specialties (or allied fields) are organized as two-, three-, or four-course sequences. The goal is to provide a degree of depth in the M.S. education, rather than a random sampling of courses. Students choose their own specialty in consultation with the graduate student advisor.

The standard program of study (Plan B) for the M.S. degree in this program requires at least 30 credit hours of coursework and a master's examination. University rules for the M.S. degree require at least 18 hours of the coursework to be in physics and astronomy, and at least 12 of the 18 hours must be in courses numbered 400 or higher. The other courses may be at the 200-level or higher. To be successful, the student must have a strong background in physics and mathematics.

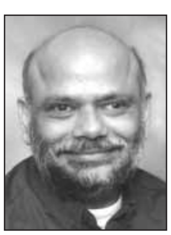
The M.S. exam: All Plan B (non-thesis option) full-time, part-time, 3-2, or 4-1 M.S. students must pass an M.S. exam, which can be a term project, an essay, or an oral exam. The M.S. exam is an exit exam; students should plan to take it toward the end of their study. Students admitted to the individualized M.S. program are eligible for financial aid in the form of a partial-tuition scholarship.

HONORS AND AWARDS

John Howell Wins Adolph Lomb Medal

Professor Howell received the 2006 Adolph Lomb Medal from the Optical Society of America at the annual OSA meeting in Rochester. He was selected "For innovative contributions in quantum optics, particularly aspects of quantum cloning, violations of Bell's inequalities and maximal photonic entanglement."

Ashok Das Has Received Fulbright Award (Brazil)



Ashok Das, professor of physics, has received a Fulbright Scholar Award to do research in Brazil in 2006–2007. This is the second Fulbright Scholarship awarded to Das.

Conwell Receives Susan B. Anthony Lifetime Achievement Award

The department is pleased to announce that Esther M. Conwell, professor of chemistry and physics, has received the University of Rochester's 2006 Susan B. Anthony Lifetime Achievement Award. This award honors preeminent women scholars having a strong association with the University of Rochester who best exemplify the admirable characteristics of Susan B. Anthony.

HONORS AND AWARDS

Judith Pipher Inducted into National Women's Hall of Fame

Judith Pipher, professor of physics and astronomy at the University of Rochester, will be one of nine women inducted into the National Women's Hall of Fame in Seneca Falls, N.Y., in October 2007.

Her citation reads: Dr. Judith L. Pipher, a professor of observational and experimental astronomy at the University of Rochester who is known for her research and experiments in the field of infrared astronomy. "Pipher's achievements in science have really been groundbreaking," Hall of Fame Acting Director Christine Moulton said. "Very often scientists' work goes unnoticed outside their professional field. Her achievements have impact for all of us. It's time for her to be widely recognized."

Steve Manly to Receive 2007 American Association of Physics Teachers for Excellence in Undergraduate Teaching

Steve Manly, associate professor of physics at the University of Rochester, has been selected to receive the 2007 American Association for Physics Teachers (AAPT) Award for Excellence in Undergraduate Teaching. His award is given in recognition of contributions to undergraduate physics teaching.

The recipient, an AAPT member for whom undergraduate teaching is a primary responsibility, is invited to make a presentation at an AAPT summer meeting. The recipient receives a $3,000 monetary award, travel expenses to the meeting, and an Award Certificate.

Bigelow and Novotny Elected Fellows of the Optical Society of America in 2007

Nicholas N. Bigelow, Lee A. DuBridge Professor of Physics and professor of optics, was elected fellow of the Optical Society of America in 2007 for "Pioneering experimental leadership in both spin squeezing and two-species trapping of ultra-cold atoms and for service through meeting organization and journal editing."

Lukas Novotny, associate professor of optics and of physics, was elected fellow of the Optical Society of America in 2007 for "Pioneering contributions to the fields of nano-microscopy and nano-spectroscopy and for leadership in the community of near-field optics."

OTHER DEPARTMENT NEWS

Our Newest Faculty Member: Professor Andrew Jordan

Born in Garland, Texas, Professor Andrew N. Jordan was raised in Dallas and graduated from Texas A&M University, with degrees in mathematics and physics. He went on to take his Ph.D. at UC Santa Barbara, studying with Professor Mark Srednicki. His thesis was on quantum chaos and coherence.

Professor Jordan then married Marian, and together they moved to Geneva, Switzerland, where he worked in the group of Professor Markus Büttiker on mesoscopic physics at the University of Geneva. During their four years in Geneva, their son, Thomas (3), and daughter, Juliana (2), were born.

Before coming to Rochester, the Jordans briefly returned to Texas A&M for six months, where Andrew also worked with Professor Marlan Scully on statistical physics of Bose-Einstein condensation. The Jordans' third child, Catherine, was born in February. They are all very happy to be in Rochester, though being Yankees will take some getting used to.

Professor Jordan's research interests are in theoretical quantum optics, quantum physics, and condensed matter physics. His recent work has primarily focused on nanoscale electrical conductors, quantum information, and measurement theory.

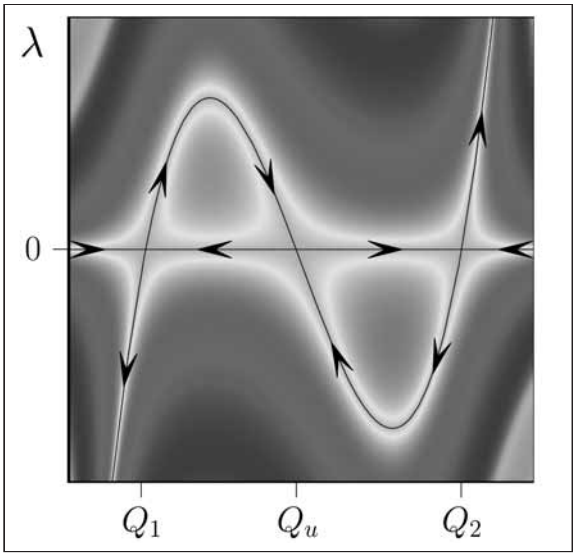
One main research theme is the stochastic path integral formalism, developed in Geneva to calculate statistical properties of noisy circuits and networks. This formalism has been applied to investigate electron counting statistics, bistability in mesoscopic conductors, and superconducting threshold detectors.

Another active area of research is the theory of continuous quantum measurement, particularly in a solid state context.

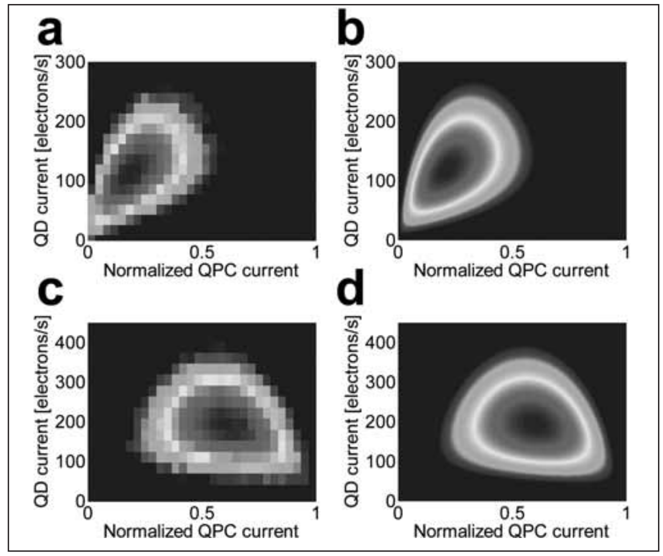
continued on next page

OTHER DEPARTMENT NEWS

Focusing on quantum dots and superconducting quantum systems, Professor Jordan has worked on "kicked" QND measurements, tests of quantum mechanics, entangling measurements, feedback control, and quantum logic gates and has recently developed the "quantum undemolition measurement," whereby the effect of weak quantum measurement can be undone by erasing information.



Phase-space plot of a noise-driven bistable system; the two stable points are on the left and right, and there is an unstable point at the center. The system moves on lines of constant color, with the black zero-energy lines the most probable. Noise can cause the system to transit from one stable point to the other, at a rate given by the negative exponential of the area between the black lines. [Cover image of Phys. Rev. Lett. *93, 260604 (2004).]*



Joint probability distributions. The logarithm of the joint probability distribution of detecting quantum point contact (QPC) current (x-axis) and quantum dot (QD) current (y-axis) is given as a color density plot, where red indicates high probability, and blue indicates low probability. (a), (c) Experimental construction for two data sets. (b), (d) Theoretical prediction for the two configurations respectively. [Taken from experiment by the K. Ensslin group at the ETH, Switzerland, to be published in Nature Physics.]

THANK YOU

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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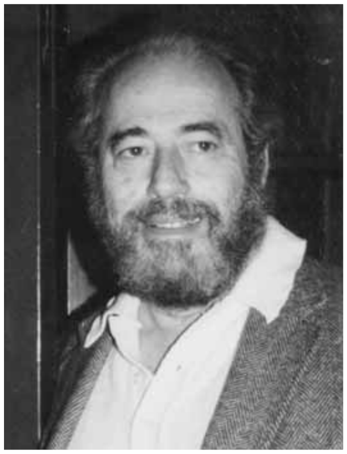
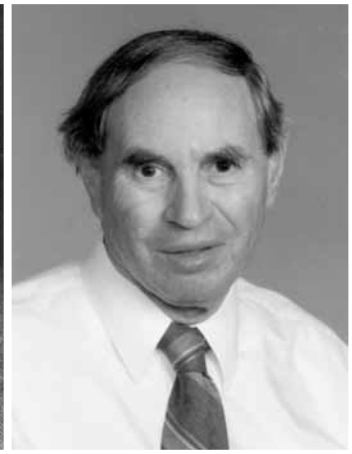

Elliott W. Montroll


Leonard Mandel


Robert E. Marshak

You Can Contribute . . .

. . . to promoting research and teaching in physics and astronomy at Rochester.

For those of you who receive this publication, there is a desire to promote the study and research in the areas of physics and astronomy. Within the department we are interested in establishing a firm financial base on which the future generation can build. A significant way this can be done is through outright gifts to an endowment like the Mandel Fund. Another way is by including the Department of Physics and Astronomy in your long-term financial plans. If you are interested in funding a gift to the University that would give you a lifelong income stream and upon your death would benefit the Department of Physics and Astronomy, please contact Shirley Brignall. Our assistant chair, Sondra Anderson, has experience in setting up gift annuities and charitable trusts and will work with you to establish one of these types of giving agreements.

Departmental Funds

The department has established several funds that greatly benefit departmental 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 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 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 to the facility.

The Physics and Astronomy Endowment Fund is for the discretionary use of the chair of the Department of Physics and Astronomy in support of department activities.

The Leonard Mandel Endowment Fund. This will fund the Leonard Mandel Faculty Scholar Award in Optical Science at the University of Rochester and be used to support one graduate student.

The Physics Education Award Endowment Fund supports undergraduate awards and graduate student fellowships.

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.

I wish to contribute to the following fund:

- ❑ *The David L. Dexter and Elliott W. Montroll Endowment Fund*
- ❑ *The Robert E. Marshak Memorial Endowment Fund*
- ❑ *The C. E. Kenneth Mees Observatory Fund*
- ❑ *The Physics and Astronomy Endowment Fund*
- ❑ *The Leonard Mandel Endowment Fund*
- ❑ *The Physics Education Award Endowment Fund*

My contribution: $____________________

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