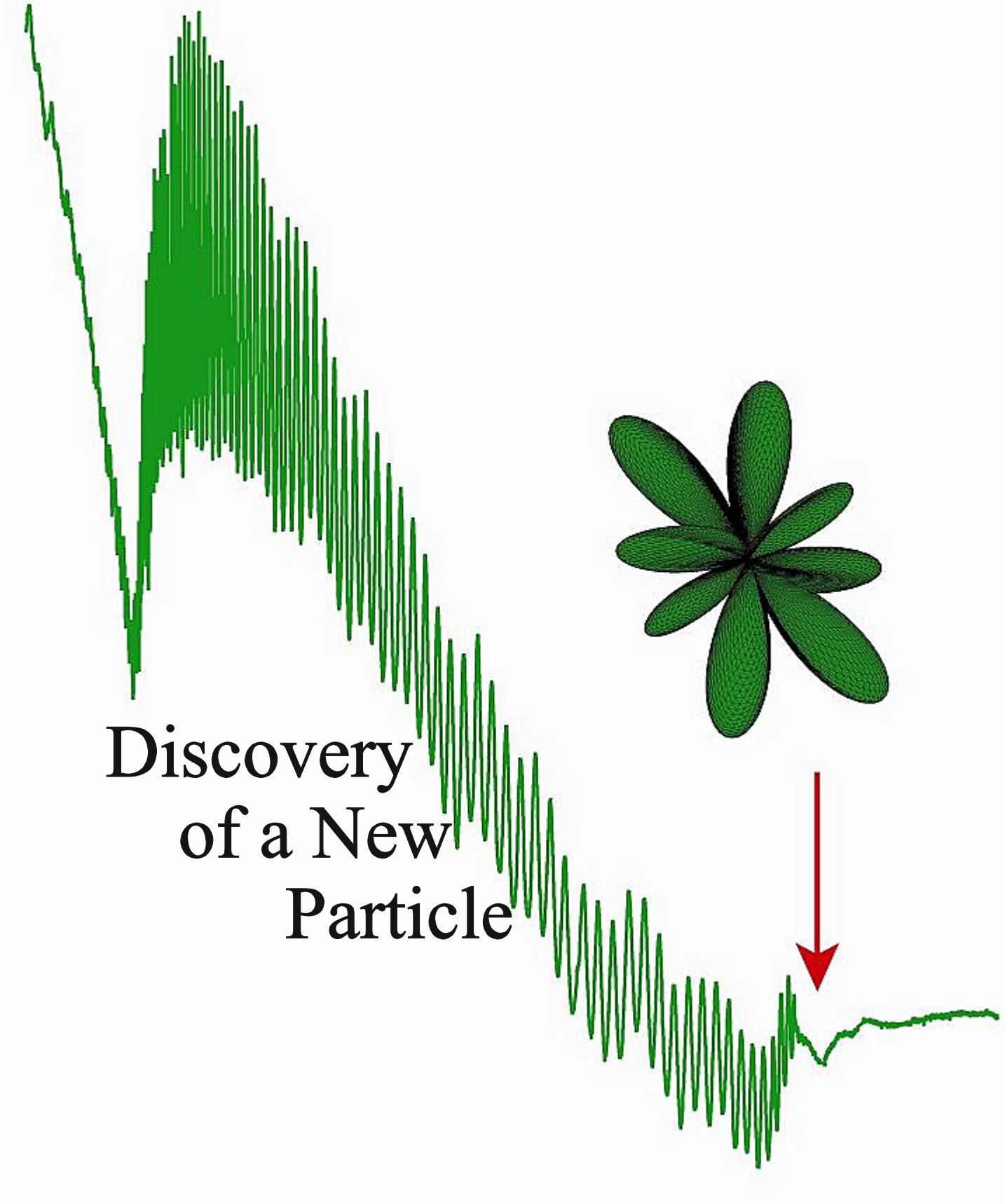
Dimensions

Summer 2008

Northwestern University's Department of Physics and Astronomy



Discovery of a New Particle

Discovery of a New Particle

William Halperin
John Evans Professor of Physics

Research

Physicists at Northwestern University have discovered a new particle. In the past, such announcements have marked a breakthrough in our understanding of the interactions between the fundamental particles of matter that can only be uncovered at particle accelerators at the highest energies created by man. However, the recent Northwestern work is at the extreme opposite end of the energy spectrum; the discovery was made at very low temperatures in superfluid helium. The reported exotic particle appeared in experiments conducted at temperatures a million times *lower* than would be comfortable for human beings. Nonetheless, the new particle can be classified in a manner strictly analogous to the particles of high energy physics, that is to say according to their total angular momentum. The unique characteristic of this new particle is that it must have an unusually high angular momentum according to the measurements by graduate students John P. Davis, Johannes Pollanen and Hyoungsoon Choi in collaboration with Professors James A. Sauls and William P. Halperin, as described in the journal *Nature Physics*. (Published online: 27 April 2008; DOI 10.1038/nphys969)

This recent work can be best illustrated by comparison with a key high energy particle experiment 34 years ago that helped establish the quark nature of the basic constituents of matter. This was the discovery of a new excited state (the J/Ψ) of a pair of bound quarks called charmonium. Their observation required the most energetic particle accelerators of the day at the Brookhaven National Laboratory and at Stanford University and resulted in two Nobel prizes. Bound pairs of quark and anti-quark particles, called mesons, have only a short lifetime, but they have been shown to have a spectrum of excited states, also called particles, which are classified by their angular momentum. After the first observations of excited states of quark pairs, similar discoveries were made of other mesons formed from different quarks, completely consistent with the theory that is now known as the standard model of particle physics.

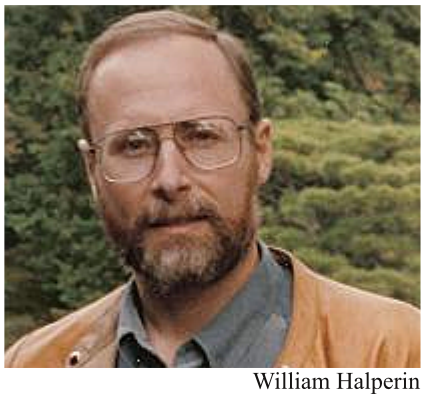
In the parallel universe of extremely low temperatures, helium atoms of the rare, light isotope called ^{3}He condense into bound pairs, called Cooper pairs, to form an unusual superfluid first observed by Douglas Osheroff, Robert Richardson, and David Lee at Cornell in 1971, who were awarded the Nobel prize for their work in 1996. Similar to quark pairs that have been excited in a high-energy particle accelerator, the Cooper pairs have extremely well-defined excited states that can be produced by sound waves. The experiments of Davis and co-workers at Northwestern University have a number of remarkable aspects. First the sound waves that they have used are of the type called transverse sound which cannot be found in any common fluid. Normally the medium for this type of sound must be a solid material. However, the Russian physicist Lev Landau, in his seminal publications in 1957, showed that at sufficiently low temperatures, transverse sound might exist in liquid helium. This fact was confirmed in 1999 for the superfluid phases of helium by Y. Lee (*Nature* **400**, 431 (1999)) and co-workers at Northwestern University. This work was stimulated by predictions made in 1993 by Geneva Moores and James Sauls, also at Northwestern University, based on the Landau theory.

The Northwestern group has now discovered that they can excite the Cooper pairs of helium atoms into a new unusual state using the transverse sound techniques developed in their earlier experiments. The theory says that to generate excited states of the Cooper pair, first the particle-like excitations must exist at the frequency or energy of the sound wave, and secondly there are specific values for the angular momentum of any particles that can be observed. These facts were used by the authors to identify the particles that are created by the sound waves. They concluded that the total angular momentum of the newly discovered particle must consist of 4 or more fundamental quanta of angular momentum. These quanta are measured in units of the most important parameter of quantum mechanics, the Planck constant. In fact Joseph Serene and James Sauls, then at Stony Brook University, predicted in 1981 the possibility for such high angular momentum states in helium. Since then, unusually high angular momentum states have been found in experiments at high energy at CERN in

Research

Switzerland. The significance of the recent Northwestern discovery of a new particle with high angular momentum affirms the broad generality and applicability of basic principles in physics from the most elementary of particles at the highest energies, to the particle-like excitations of superfluid helium at extremely low temperatures.

About the Author:


William Halperin

William Halperin is the John Evans Professor of Physics at Northwestern University. He also is an Alfred P. Sloan fellow, Yamada Science Foundation Fellow and an American Physical Society Fellow. Additionally, he is the editor of Progress in Low-Temperature Physics and regional editor of the New Journal of Physics.

Halperin's research is focused on low-temperature physics (mainly liquid ^{3}He and superconductivity), NMR studies of high-temperature superconductors, and fluid transport in porous media. In an exciting recent development, his research group has discovered how to produce impurity suppression of the thermodynamic transition of superfluid ^{3}He, thus bringing together the practical aspects of fluid confinement in porous media and the basic science of superfluidity. Much of this research involves close cooperation and collaboration with Professor Sauls' theoretical group at Northwestern.

Halperin has been developing ^{17}O NMR as a probe of the magnetic fluctuations associated with magnetic vortices in novel high-T_c superconductors. His research group was the first to take these methods to extremely high magnetic fields, above 40 Tesla, using special facilities at the National High Magnetic Field Laboratory in Tallahassee, Florida.

Halperin is developing acoustic cavity techniques to investigate collective excitations of the ^{3}He superfluid order parameter and he is investigating gapless superfluidity using high-resolution heat capacity methods applied at very low temperatures. He is also studying heavy-fermion superconductivity using NMR on crystals of UPt_3. Together with David Seidman of Northwestern's Department of Materials Science and Engineering, Halperin has constructed a facility for crystal growth of heavy-fermion compounds. Their crystals of UPt_3 are of the highest quality ever produced. In the area of porous media and molecular diffusion, Halperin is using NMR in conjunction with extremely high-gradient magnetic fields to characterize pore structure and heterogeneous diffusion.


Ultra low temperature cryostat used in the discovery of the new excited pair state

Faculty News

John Ketterson receives an IGERT Grant

The NSF has approved a proposal submitted by a team of faculty from the Physics, Electrical Engineering, Chemistry, and Materials Science departments for the training of graduate students at both the MS and PhD levels. Initial participants include: Bob Chang (Mat Sci), Anupam Garg (Physics), Seng-Tiong Ho (EECS), John Ketterson (Physics & EECS), Prem Kumar (EECS & Physics), Selim Shahriar (EECS), Tamar Seidman (Chemistry & Physics) and Horace Yuen (EECS & Physics). The focus will be on the science and technology surrounding quantum coherent optical and matter systems and related photonic structures and sources. Such studies intimately relate to the emerging field of quantum information processing including quantum encrypted communications. Objectives include training a different kind professional who is cross-trained, flexible, and better prepared for the evolving needs of information technology, with an eye toward increasing underrepresented and female students. The former will be enhanced through vigorous recruiting and partnering with two universities with large minority populations.

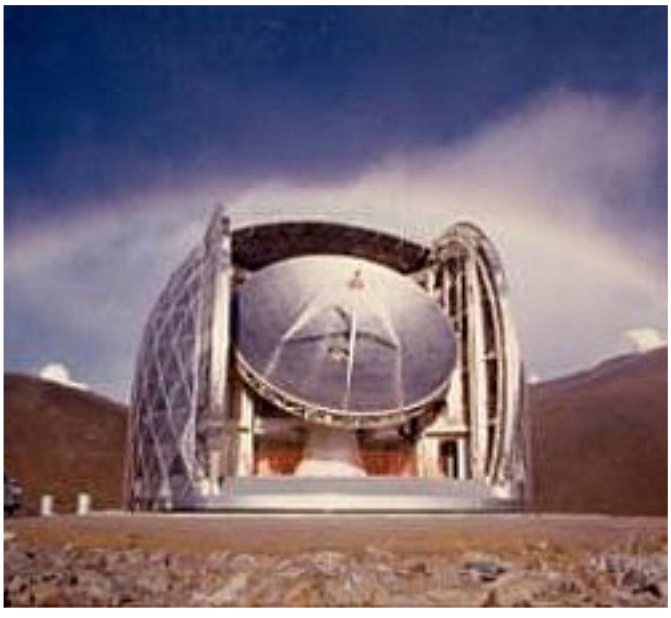
A central educational feature is that the participating students take courses in at least three of the four participating departments. Due to the advanced nature of the targeted research topics, much of the required theory and practice are not presently taught and the Faculty Advisors will create new courses that fill the gaps. A very important component of the plan is establishing a new laboratory course aimed at giving students hands on experience with modern optical phenomena and instrumentation, which the faculty will start assembling in the Fall quarter.

Students working in John Ketterson's laboratory

Giles Novak is promoted to Full Professor

Associate Professor Giles Novak has been promoted to Full Professor. Novak's research is in the area of observational astrophysics and astrophysical instrumentation. His research group developed a polarimetric imager for use at the South Pole. This instrument, called SPARO (Submillimeter Polarimeter for Antarctic Remote Observations), has been used to map large-scale Galactic magnetic fields. The goal is to study the role that these fields play in the process of star formation, and in the dynamics of the Galactic center region.

Novak is also leading a team that is developing a new submillimeter polarimeter for the ten-meter Caltech Submillimeter Observatory, located at the summit of Mauna Kea, Hawaii. This new instrument is called SHARP. The primary science goals are to map magnetic fields in the vicinity of low-mass protostars and to study the structure of magnetohydrodynamic turbulence in star-forming clouds. Another application of SHARP is the study of black hole accretion in the Sagittarius A* source.



Transitions

Senior Class Plans:

Sarah Braden has been accepted into the PhD program at the School of Earth and Space Exploration at Arizona State University. She will pursue her PhD in geological sciences.

Nicole Carlson has been accepted into the PhD program at the University of California-Berkeley. She will pursue her PhD in physics and do research in computational neuroscience.

Jeffrey Chilcote has been accepted into the PhD program at the University of California- Los Angeles. He will pursue his PhD in astronomy.

Jennifer Hobbs has been accepted into the PhD program at Northwestern University, and she will pursue her PhD in experimental particle physics.

Elissa Knoff will begin work as an analyst for Accenture in their System Integration and Technology division.

Timothy Linden has been accepted into the PhD program at the University of California-Santa Cruz. He will pursue his PhD in physics.

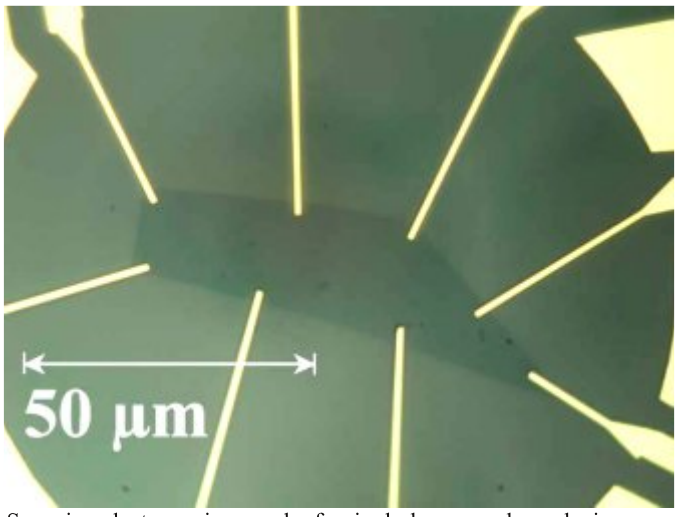
Brandon Lane will be doing research under Professor Ulrich Simon at RWTH Aachen University in Aachen, Germany. He will be working on a collaborative project entitled "Size Dependent Cytotoxicity of Metal Nanoparticles."

Leon Mayr will teach high school physics in high-needs schools and work with the Chicago Teaching Fellows program to improve teaching methods in physics education.

Seth Myers has been accepted into the PhD program at Stanford University. He will pursue his PhD in computational and mathematical engineering.

News from Alumni:

Zhigang Jiang, PhD 2005, will join the School of Physics at Georgia Institute of Technology in August 2008 as an assistant professor. Jiang was a member of Venkat Chandrasekhar's research group while at Northwestern. He completed his postdoctoral research at National High Magnetic Field Laboratory under the supervision of Prof. Horst Stormer of Columbia University and Prof. Daniel Tsui of Princeton University. He pursued several research interests during this period, primarily concerning the quantum Hall effect in graphene and infrared spectroscopy of graphene. His major achievements include: 1) discovery of the room temperature quantum Hall effect in graphene; 2) observation of new quantum Hall phases in graphene, corresponding to lifting of the spin and sublattice degeneracy of Landau levels of graphene; 3) the first experimental studies of cyclotron resonance in graphene monolayers and bilayers.



Scanning electron micrograph of a single-layer graphene device, courtesy of Dr. Zhigang Jiang

Graduate Student Milestones:

Timothy Andeen, working with Heidi Schellman, has successfully defended his dissertation, "Measurement of the W Boson Mass with the D-Zero Run II Detector using the Electron PT Spectrum."

Meghan Anzelc, working with Dave Buchholz, has successfully defended her dissertation, "Study of $B0_s$ Mixing at the D-Zero Detector at Fermilab Using the Semi-leptonic Decay $B0_s \rightarrow D_s \mu \nu X$."

Department Alumni Request:

The department newsletter is a means of reaching out to the alumni to keep them abreast of current research and developments in the Department of Physics and Astronomy. However, it is also a forum for alumni to keep the department abreast of their accomplishments. Therefore, the department welcomes submissions from alumni of newsworthy items for publication in the monthly newsletter. Please send your submissions to physics-astronomy@northwestern.edu or detach the last page of the newsletter and mail it to the department.

News and Notes

Honors:

Professors Andy Rivers, Bill Halperin and Vicky Kalogera received WCAS Teaching Awards for 2007-2008. Professor Rivers was awarded the Arts and Sciences Alumni Teaching Award, Professor Kalogera was awarded the Award for Excellence in Mentoring Undergraduate Research, and Professor Halperin was awarded the E. LeRoy Hall Award for Excellence in Teaching.

Undergraduate student James Kath (Advisor: John Marko) has received the "Outstanding Junior in Physics and Astronomy" award.

Undergraduate student Timothy Linden (Research Advisor: Vicky Kalogera) has received the "Outstanding Senior Thesis in Physics and Astronomy" award for his senior thesis entitled, "Young X-Ray Binary Populations: Metallicity Effects and a Diagnostic for Electron-Capture Supernovae."

Undergradute students Nicole Carlson (Advisor Adilson Motter), Yonatan Kahn (Advisor: Michael Schmitt), James Kath (Advisor: John Marko), Justin Lieber (Advisor: Adilson Motter) and Thomas Wytock (Advisor: André de Gouvêa) have all been elected to Phi Beta Kappa.

Undergraduate Students Nicole Carlson (Advisor: Adilson Motter), Jeffrey Chilcote (Advisor: Farhad Zadeh), Gaspard Clozel (Advisor: Fred Rasio), Jennifer Hobbs (Advisor: Heidi Schellman), Timothy Linden (Advisor: Vicky Kalogera), Erik Offerman (Advisor: Venkat Chandrasekhar) and Thomas Wytock (Advisor: André de Gouvêa) will graduate with departmental honors.

Dan Lascar has been selected to attend the meeting of graduate students and noble laureates held annually in Lindau, Germany. Dan is a student of Professor Ralph Segel and is doing his thesis at Argonne National Laboratory using a penning trap system to measure that masses of nuclei that play a significant role in the build up of elements through the r-process.

Graduate student SungWoo Youn's work using D_s meson decay to better understand charge-parity violations in B_s mesons was honored as the "Fermilab Result of the Week." To read more about his work, please go to http://www.fnal.gov/pub/today/archive_2008/today08-05-08.html.

Undergraduate student Vasiliy Kuzetsov, a math major working with Heidi Schellman was chosen as the the "On-Campus Work-Study Employee of the Year."

The Physics and Astronomy Department's Business Adminstrator Marsha Coffey was a finalist for Northwestern University's Employee of the Year Award.

Student Scholarships:

Undergraduate student James Kath (Research Advisor: John Marko) has been awarded a Katherine L. Kriegbaum Fellowship to support his research developing experimental techniques to study topoisomerases, which are enzymes essential to cell viability. Kath's research has many potential long-term benefits because a greater understanding of topoisomerases could help scientists design antibacterial and cancer chemotherapy drugs more effectively.

Undergraduate student Brandon Lane (Research Advisor: Chad Mirkin-Chemistry) has received a Fulbright Grant to do chemistry research in Germany.

Undergraduate student Yonatan Kahn (Research Advisor: Michael Schmitt) has been awarded a Josephine De Kármán Fellowship Trust. Kahn is the first Northwestern undergraduate student to receive this fellowship in over a decade. The $10,000 fellowship will fund Kahn's senior year of study at Northwestern. To read more about the Josephine De Kármán Fellowship Trust, please go to http://www.dekarman.org/ .

Undergraduate student Ryosuke Kita has been awarded a Goldwater Scholarship for 2008-09. Kita is a student in Northwestern's Integrated Sciences Program, majoring in Earth and Planetary Sciences, who has been conducting research in the area of extrasolar planet dynamics under the supervision of Professor Fred Rasio.

The ten-meter Caltech Submillimeter Observatory (CSO)

Compiled by Anne Colilla

Alumni Contribution Form

Name: _____

Degree: _____

Graduation Year: _____

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News:

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