Miller Institute Newsletter

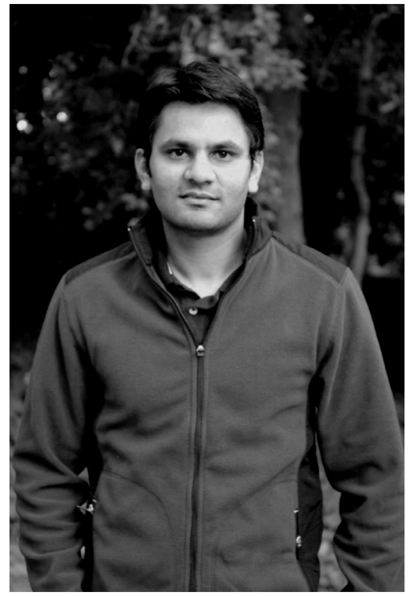
Spring 2010

Miller Fellow Focus: Prashant Jain

Lighting Up the Nanoscale World

'Chemistry'! The word typically conjures up an image of a bespectacled lab-coat wearing scientist mixing up colorful reagents in a test tube in anticipation of a new molecule's birth – a molecule that may serve as the next drug for cancer, or a wonder-material for the next-generation of solar cells. Chemistry, however, has long moved past this lay perception. Chemists have developed not only a comprehensive understanding of the structural makeup and properties of molecules, but also the ability to rationally control the synthesis of known molecules and their transformation into newer ones. But a longstanding dream that has remained elusive until recently is that of being able to watch molecules in "live action" as they form or transform.

Traditionally, we perform and study chemical transformations in the reaction flask, where an Avogadro's number ($\sim 10^{23}$) of molecules is allowed to react. Individual molecules in this flask stochastically switch, generally after being activated, from the reactant to product state, and sometimes even backwards, if it's a reversible transformation! But our current method of taking snapshots of our reaction flask, such as the color of the reacting solution, results in a statistically averaged picture of the $\sim 10^{23}$ molecules at any given time. The reactive molecules are not all in phase, so the snapshots do not give us a real-time trajectory of the molecule in the course of its transformation (dynamics); all we can know is the proportion of molecules in the flask that have transformed into the product. Furthermore, we cannot estimate how different one molecule's activity is from every other one (heterogeneity); we can only measure the average reactivity of the molecules in our flask. Thus, our reaction flask (Fig. 1) gives us no information about the dynamics and heterogeneity of molecular reactivity – two aspects that make chemistry rich and interesting. This is especially true in the case of complex chemical systems like the ones we encounter in the real world, covering the gamut from the biochemistry of life to the catalytic converter in our car. Prashant, a second-year Miller Fellow, believes that watching the transformation of one single reactant molecule can reveal hidden secrets about the complexity and stochasticity of the underlying chemistry.



Being trained as a laser spectroscopist by the best in the field (former Visiting Miller Professor M. A. El-Sayed at Georgia Tech and later Adam Cohen at Harvard) is an asset for Prashant. Spectroscopists have been skilled at interrogating molecules using laser light since the 1960s. However, around 1990, the community led by W. E. Moerner at Stanford and Michel Oritt learned how to image a single molecule by illuminating it with a laser beam and then using clever optics to detect the

continued on page 2

Call for Nominations
NEW ONLINE SYSTEM COMING SOON

Miller Fellow nominations are due on
Thursday, September 9, 2010

Miller Professor applications are due on
Thursday, September 16, 2010

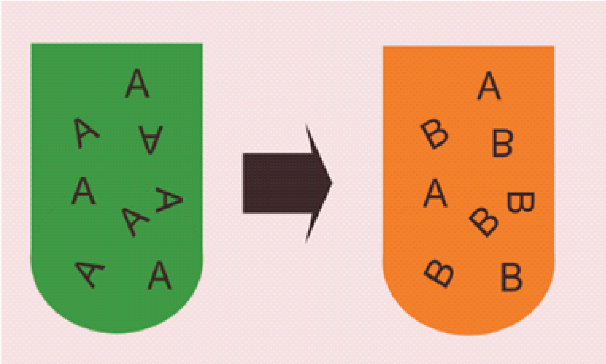
Visiting Miller Professor Departmental nominations are due on
Monday, September 20, 2010

Please see the enclosed insert for details on making nominations for the Miller Fellowship program. For complete information on all our programs, visit: http://millerinstitute.berkeley.edu

INSIDE THIS EDITION

Miller Fellow Focus	1
Call for Nominations	3
2010-13 Miller Fellows	4-5
Chancellor's Outstanding Staff Award	6
Awards & Honors	7
Publications	7
Birth Announcements	7
Spring Dinner Photos	8

continued from page 1



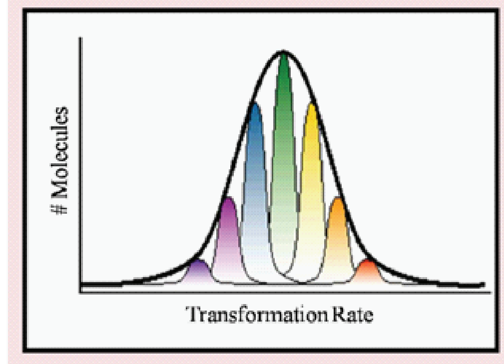


Figure 1: (left) Traditional "flask approach" for studying a chemical transformation (A → B) where we can only estimate the proportion of species A converted to species B at any given time. (right) We can measure an average rate of transformation for the entire flask of molecules; however, individual molecules can have significantly different rates from one another.

tiny amount of light emitted by the molecule. Inspired by the development of single-molecule spectroscopy, Prashant is carrying out chemical reactions inside a microfluidic "reaction flask" mounted inside an optical microscope, designed to sensitively and selectively light up the reacting molecules anchored to the base of the reaction chamber. Prashant selects chemical reactions where the transformation from reactant to product results in a dramatic change in the light emission, either its intensity or spectrum. By following changes in the emission, he is able to observe the transformation of individual molecules. Currently, his experiment relies on light emission, but in the future, he hopes to generalize his approach by using a spectral signature that is a finger-print of the structure of the molecule.

The kind of 'molecules' that fascinate Prashant are quite unique: tiny crystals of metals and semiconductors with sizes of a few nanometers (a nanometer = 10^{-9} m). 'Nanocrystals' represent the missing size-scale between small molecules and macroscopic materials, made accessible by the relatively newfound ability of chemists and physicists to engineer such tiny structures. At this intermediate size-scale, the behavior of electrons in the crystal is highly dependent on the size and geometry of the boundaries within which they are confined. As a result, nanocrystals manifest attributes (e.g. color, conductivity, or reactivity) that are highly size-dependent. In addition, a significant part of the nanocrystal constitutes a surface or interface to the external environment. This large surface/volume ratio makes nanocrystals remarkably more reactive and responsive to the outside world, compared to their macroscopic counterparts. It's no wonder that catalytic converters nowadays use nanoparticles of platinum for enhanced catalysis of carbon monoxide detoxification. Furthermore, the nature of the nanocrystal surface (its geometry, crystalline arrangement, and labile nature) strongly influences its chemistry. Each nanocrystal is unique from every other one of its seemingly identical counterparts making heterogeneity one of the salient features of nanoscale chemistry.

Prashant's interest in nanoscale chemistry directly results from being in the midst of one of the pioneering groups in nanoscience, led by LBNL Director and former Miller Professor A. Paul Alivisatos. One particular phenomenon discovered in this lab caught Prashant's attention – when a nanocrystal of cadmium sulfide is exposed to silver ions, the silver replaces the cadmium in the nanocrystal almost instantaneously, orders of magnitude faster than a macroscopic crystal. The nanocrystal transforms into silver sulfide and cadmium ions are released into solution. A flask full of these transforming nanocrystals exhibits a fast color change, which is mostly uninformative. So, Prashant watched the transformation of individual nanocrystals in his optical microscope by tracking the cadmium released from the nanocrystal (Fig. 2). He used an indicator dye which emits light when it "sees" the released cadmium ions. To his amazement, he was able to actually see a plume of cadmium ions being released from individual nanocrystals. He found that nanocrystals seem to "wait", presumably for a nucleation or activation event, for a random amount of time, before they start exchanging. Once nucleated, the nanocrystal seems to rapidly exchange in a single shot. A nucleation process prior to an actual transformation, one of the hallmarks of nanoscale chemistry, may have been directly imaged for the first time. The "waiting time" before nucleation seems to be uniquely defined for each nanocrystal – they don't all start exchanging at the same time, a classic example of nanoscale heterogeneity.

Prashant hopes to extend his approach to learn more about semiconductor nanocrystals that mimic photosynthetic systems. Lilac Amirav in the Alivisatos lab has been designing a multi-component nanocrystal that is able to absorb sunlight and produce energetic charge carriers that can be used to split water into hydrogen and possibly oxygen – fuel that can be used as a "green" energy source. Prashant aims to measure the rate at which useful charge carriers are produced by a single nanocrystal in response to the light. This rate is an important determinant of the intrinsic

continued on page 6

The Adolph C. and Mary Sprague Miller Institute for Basic Research in Science
University of California, Berkeley

MILLER RESEARCH FELLOWSHIPS FOR 2011-2014 TERM

Please watch for the Miller Institute's new online nomination system at

http://millerinstitute.berkeley.edu

Nomination Deadline: 9 September 2010

The Miller Institute for Basic Research in Science invites department chairs, faculty advisors, professors and research scientists at institutions around the world to submit nominations for Miller Research Fellowships in the basic sciences. The Miller Institute seeks to discover and encourage individuals of outstanding talent, and to provide them with the opportunity to pursue their research on the Berkeley campus. Fellows are selected on the basis of their academic achievement and the promise of their scientific research. The Miller Institute is the administrative home department for each Miller Fellow who is hosted by an academic department on the Berkeley campus. All research is performed in the facilities provided by the UC Berkeley academic department. A list of current and former Miller Research Fellows can be found at: http://millerinstitute.berkeley.edu/all.php?nav=46

Miller Research Fellowships are intended for brilliant young women and men of great promise who have recently been awarded, or who are about to be awarded, the doctoral degree. The Fellowship term must commence between July 1 and October 1, 2011. Candidates should be within 5 years of their Ph.D. to be eligible. A nominee cannot hold a paid or unpaid position on the Berkeley campus at the time of nomination or throughout the competition and award cycle. Nominees who are non-US citizens must show eligibility for obtaining J-1 Scholar visa status for the duration of the Miller Fellowship. The Miller Institute does not support H1B visa status. Eligible nominees will be invited by the Institute to apply for the fellowship. Direct applications and self-nominations are not accepted.

To prepare for the online nomination, the following information will be necessary to complete the submission process:

- Nominee's complete full and legal name
- Nominee's current Institution
- Nominee's complete and current **active** E-mail address, current mailing address and telephone number
- Nominee's Ph.D. Institution and (expected) Date of Ph.D. (month & year required)
- Letter of recommendation and judgment of nominee's promise by the nominator. The Executive Committee finds it helpful in the recommendation letter to have the candidate compared with others at a similar stage in their development.
- Nominator's current **active** E-mail address, title, and professional mailing address (include zip code/campus mail code)

The Institute will provide an annual stipend of $60,000 and a research fund of $12,000 per annum. There is provision for travel to Berkeley for Miller Fellows and their immediate families and a maximum allowance of $3,000 for moving personal belongings. The Miller Institute also provides benefits including medical, dental, vision and life insurance. Fellowships are awarded for three years, generally beginning August 1, 2011 and ending July 31, 2014. Approximately eight to ten Fellowships are awarded each year. Candidates will be notified of the results of the competition starting in mid-December, and a general announcement of the awards will be made in the spring.

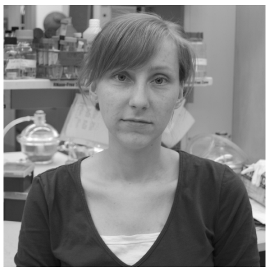
We are grateful for your thoughtful participation in this process and hope that you regard the time you may devote to this effort justified by the contribution you will be making to the careers of distinguished young scientists.

MILLER INSTITUTE FOR BASIC RESEARCH IN SCIENCE
2536 CHANNING WAY, BERKELEY, CA 94720-5190
510-642-4088 fax 510-643-7393
E-MAIL: millerinstitute@berkeley.edu
http://millerinstitute.berkeley.edu

Miller Research Fellowship Awards 2010-2013

The Miller Institute is pleased to announce the 2010-2013 Miller Research Fellows. Each year, the Miller Institute seeks to discover individuals of outstanding talent and to bring to Berkeley young scholars of great promise. Candidates are nominated for these awards and are selected on the basis of their academic achievement and the potential of their scientific research. The Fellows will be working with Berkeley faculty hosts for a three-year term beginning in the 2010 academic year. A full list of all past and present Miller Fellows is available on our website at http://millerinstitute.berkeley.edu/all.php?nav=46.

Franziska Bleichert
Ph.D. - Yale University
Berkeley Department: Molecular & Cell Biology
Faculty Host: James Berger



Before each cell division, the genetic content of cells is duplicated by DNA replication. Dr. Franziska is interested in understanding the initial steps of this process which involve the binding of numerous proteins to DNA to form replication initiation complexes. She will use a combination of X-ray crystallography and electron microscopy to study the architecture and structure of replication initiation complexes, seeking to understand how the structures of these macromolecules determine their functions.

Linyou Cao
Ph.D. - Stanford University
Berkeley Department: Chemistry
Faculty Host: Stephen Leone

Understanding the dynamics of basic particles (including electrons, photons and phonons) in nanostructures holds great promise for significantly advancing fundamental and applied research. Dr. Cao is particularly interested in pursuing exciton dynamics in semiconductor nanostructures using time-resolved optical spectroscopies.

Claude-André Faucher-Giguère
Ph.D. - Harvard University
Berkeley Department: Astronomy
Faculty Host: Chung-Pei Ma

Dr. Faucher-Giguère has broad interests in theoretical astrophysics and cosmology, with particular emphasis on cosmic structure formation. A problem of central importance is to understand how the low-density intergalactic medium evolves from Big Bang initial conditions into the galaxies that we observe today. To address this, he uses a combination of analytical modeling and numerical simulations, and develops ways to relate the theoretical models to observations that can test and inform them.

Matthew Good
Ph.D. - UC San Francisco
Berkeley Department: Molecular & Cell Biology
Faculty Host: Rebecca Heald

Dr. Good is generally interested in the principles that govern the spatiotemporal regulation of protein networks inside of living cells. As a Miller Fellow, Dr. Good will tackle an intriguing question fundamental to cell growth and division: how are intracellular structures modified to fit within a changing cell volume?

A. Meredith Hughes
Ph.D. - Harvard University
Berkeley Department: Astronomy
Faculty Host: James Graham

Planets form in disks of gas and dust orbiting their host stars. Dr. Hughes is interested in observing these circumstellar disks to understand both the physics of the planet formation process and the properties of the youngest planetary systems. Using millimeter-wavelength radio interferometers to observe the cool dust and molecular gas in sharp detail, it is possible to map out the characteristics and conditions of planet-forming regions. In addition, studying the dynamical interactions between young planets and their natal disks can indicate the presence of planets undetectable by other means and place crucial constraints on the masses of these young objects.

August Johansson

Ph.D. - Umea University, Sweden
Berkeley Department: Mathematics
Faculty Host: James Sethian

Partial differential equations are used for describing a vast number of various physical phenomena such as heat and fluid flow, elasticity, electromagnetism and acoustics to name a few. Dr. Johansson's research is on developing numerical methods for solving such equations, primarily using finite element methods. He is particularly interested in phenomena that are described by several partial differential equations coupled to each other that may involve different temporal and spatial scales. He is also interested in immersed methods for moving interfaces.

Eric King

Ph.D. - UCLA
Berkeley Department: Earth & Planetary Science
Faculty Host: Bruce Buffett

The magnetic fields of planets and stars (such as Earth and the Sun) are generated by turbulent motions occurring in the vast seas of electrically conducting fluids within them. Dr. King's research draws on theoretical, experimental, and computational analogs of geophysical and astrophysical flows to improve our fundamental understanding of this and other natural phenomena.

Mark Laidre

Ph.D. - Princeton University
Berkeley Departments: Integrative Biology/ Psychology
Faculty Host: Roy Caldwell/Lucia Jacobs

Without communication, organismal life as we know it would be difficult, if not impossible. How then did communication originate? What forces shaped its evolutionary and developmental trajectory? What cognitive and neural mechanisms enable it? And what Darwinian functions does it ultimately serve? As a biologist Dr. Laidre investigates these questions across a broad suite of organisms, spanning invertebrates to humans. His research examines both the underlying mechanisms and the ultimate function of communication, mixing experiments in the field and laboratory with theoretical modeling and computer simulations. He is especially interested in the evolutionary dynamics of information transmission; in how reliable signaling is maintained in the face of genetic conflicts-of-interest; and in how communication networks produce emergent, novel biological properties. While biology is essential for shedding light on how ecology and evolution have simultaneously shaped and constrained communication, other disciplines have much to contribute as well. Dr. Laidre therefore seeks to integrate into his research the rich insights of other fields, from neuroscience and anthropology to economics and mathematics.

Kirk Lohmueller

Ph.D. - Cornell University
Berkeley Department: Integrative Biology
Faculty Host: Rasmus Nielsen

Dr. Lohmueller studies patterns of genetic variation in human populations. He is developing and implementing computational techniques to analyze large-scale genomic datasets with the goal of understanding how population history and natural selection have shaped genetic diversity. His work is important for understanding human history, medical genetics, and forensic science.

Jun Zhao

Ph.D. - University of Tennessee
Berkeley Department: Physics
Faculty Host: Robert J. Birgeneau

Dr. Zhao is interested in the magnetic properties of the strongly correlated systems, including Fe based and cuprate superconductors. In particular, he mainly focuses on using neutron scattering to study the magnetic phase transition and spin dynamics of the Fe based superconductors, as well as the spin dynamics in electron doped cuprates.

Miller Fellow Focus (continued)

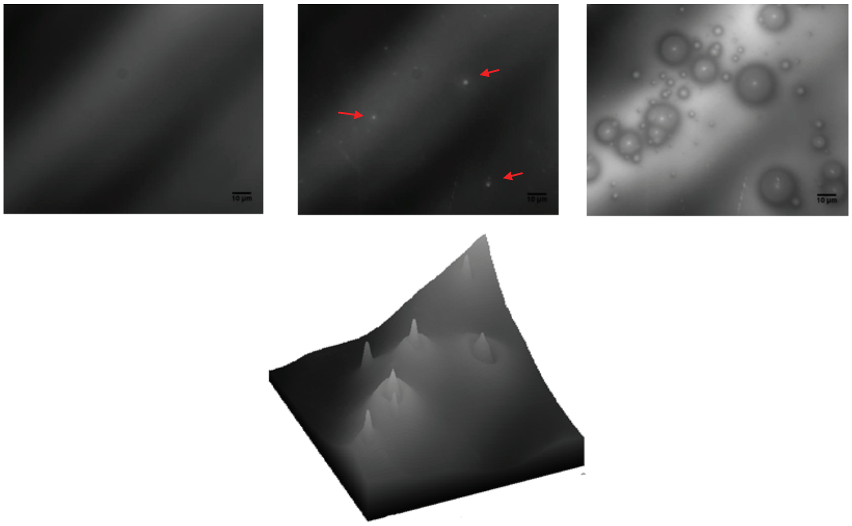


Figure 2: Watching individual nanocrystals transform in an optical microscope. (top) Snapshots of cadmium sulfide nanocrystals undergoing exchange with silver in a microfluidic "reaction flask", in the presence of a cadmium-sensitive light-emitting dye. At t= 0 sec, no evidence of nanocrystal exchange is seen. At t=8 sec, a few nanocrystals (indicated by red arrows) are seen to have begun to release a plume of cadmium, indicating exchange. At t=17 sec, most of the nanocrystals in the field of view are seen to be undergoing exchange. (bottom) An intensity map of a representative snapshot showing waves of cadmium being released from individual nanocrystals. (Courtesy: Jessy Baker for synthesizing cadmium sulfide nanocrystals).

continued from page 2

efficiency of this nanocrystal for fuel generation. By using his technique in combination with electron microscopy, he wishes to identify nanocrystal structures that are intrinsically more efficient than others.

In parallel, Prashant has also been interested in amplifying the tell-tale optical signature of a molecule that may be otherwise too weak to detect. During his doctoral work, he learned that nanostructures of metals can confine and enhance light at the nanoscale, sort of like having an intense localized source that can "light up" or alternatively "heat up" molecules in the vicinity. This has the potential for opening up novel forms of light-matter interaction, and also for practical applications, like chemical sensing with extremely low detection-limits and selective laser-based cancer therapy. Prashant has given several examples of how the nanoscale light-field can be tailored by playing with the geometry of a metallic nanostructure. At Berkeley, Prashant is furthering this work with Sassan Sheikholeslami, Young-Wook Jun, and Jessica Smith by attempting the design of structures that sculpt the light-field in a complex way, for instance, engineer a light-field with handedness at the nanoscale, or, one with different colors spatially filtered at the nanoscale. He hopes that with these nanostructures, a wide variety of molecules will SEE THE LIGHT!

When Prashant is not hanging out in the D-level of Hildebrand with his friends from the Alivisatos group, he enjoys playing badminton and catching up on Bollywood, things he enjoyed doing, growing up in Bombay.

Kathy Receives Chancellor's Outstanding Staff Award

Kathryn Day received the Chancellor's Outstanding Staff Award (COSA) for 2010. The COSA award is one of the highest campus-wide honors for staff employees at UC Berkeley and is "presented to staff and teams who in addition to performing all their normal job duties with excellence, also take initiative and go above and beyond in their contributions to the UC Berkeley campus community". Kathy previously received the COSA in 1996, 2000 and 2005. Kathy and the other 2010 COSA recipients were presented their awards by Chancellor Robert Birgeneau on April 22nd at a ceremony and reception attended by their nominators and supervisors.

Awards and Honors

March 30, 2010: **Grigori Perelman** (Miller Fellow 1993 - 1995) has won the Millenium Prize from the Clay Mathematics Institute of Cambridge, Massacusetts.

March 19, 2010: **Yue Wu** (Miller Fellow 2006 - 2009) has been awarded an Air Force Summer Faculty Fellowship.

February 22, 2010: **Hermann Grimmeiss** (Visiting Miller Professor Spring 1991) received the Czochralski Award in Sept. 2009 and an "Honorary European Award" in May 2009.

February 18, 2010: **Dustin Rubenstein** (Miller Fellow 2006 - 2009) was awarded the 2010 Ned K. Johnson Young Investigator Award by the American Ornithologists' Union.

February 17, 2010: **Eugene Haller** (Miller Professor Fall 1990, Fall 2001) and Michael Jordan (Miller Professor Fall 2008) have been selected as two of the 68 new members of the National Academy of Engineering (NAE).

February 16, 2010: **Yi Cui** (Miller Fellow 2003 - 2005) was awarded a 2010 Sloan Research Fellowship.

February 5, 2010: **Katherine Freese** (Visiting Miller Professor Fall 2006) has been named a Fellow of the American Physical Society and is now George Eugene Uhlenbeck Professor of Physics at the University of Michigan.

January 27, 2010: **Axel Meyer** (Visiting Miller Professor Spring 1996) was elected member of the Berlin-Brandenburg Academy of Sciences and member of the European Molecular Biology Organization (EMBO) this past year. He has also been awarded the Carus Medal of the Leopoldina (the German National Academy of Sciences) and the EMBO Prize for Communication in the Life Sciences.

January 25, 2010: **Stephen Leone** (Miller Professor Spring 2010) has been selected as a member of the 2010 class of the Department of Defense's National Security Science and Engineering Faculty Fellowship (NSSEFF) program.

January 21, 2010: **Chris Greene** (Visiting Miller Professor Spring 2007) has been awarded the 2010 Davisson-Germer Prize of the American Physical Society.

Publications

The following Miller Institute members have recently published works resulting from research during their Miller Institute terms. For more information about these publications, please visit the Miller Institute's website at: millerinstitute.berkeley.edu/publications.htm.

David Jenkins
Miller Fellow 2005 - 2008

Adi Livnat
Miller Fellow 2006 - 2009

Ashvin Vishwanath
Miller Professor Fall 2009

Prashant Jain
Miller Fellow 2008 - 2011

Corrie Moreau
Miller Fellow 2007 - 2010

Ken Wachter
Miller Fellow 1977 - 1979, Miller Professor Fall 2009

Birth Announcements

The Miller Institute would like to congratulate:

Hye-Jin Kim and **Tae Joo Park** (Miller Fellow 2009 - 2012) on the birth of their daughter Kayla on April 13, 2010.
Sera Young and **Julius Lucks** (Miller Fellow 2007 - 2010) on the birth of their daughter Stella on April 10, 2010.
Shaorong and **Jiaxing Huang** (Miller Fellow 2004 - 2007) on the birth of their son Evan in October 2009.

Miller Institute News
Spring 2010
2536 Channing Way, #5190
Berkeley, CA 94720-5190
Phone (510) 642-4088
Fax (510) 643-7393
http://millerinstitute.berkeley.edu

Please send address corrections to:
miller_adm@berkeley.edu

Spring Dinner Photos

The annual Miller Institute Spring Dinner was held on Monday, March 15 in the Alumni House on campus. Miller Senior Fellow Gabor Somorjai delivered the evening's lecture entitled, "The Frontiers of Molecular Surface Science: Dreams and Strategy."

Vanessa Kääb-Sanyal, Chang Liu, and Raman Sanyal

Lior Pachter and Michael Manga

The Miller Institute is "dedicated to the encouragement of creative thought and the conduct of research and investigation in the field of pure science and investigation in the field of applied science in so far as such research and investigation are deemed by the Advisory Board to offer a promising approach to fundamental problems."