MILLER INSTITUTE NEWSLETTER

Spring 2011

Miller Fellow Focus: Scott Morrison

Second year Miller Fellow Scott Morrison studies topological quantum field theories, and the algebraic data underlying them. One focus of his research is on the algebraic objects called 'subfactors' and 'fusion categories'. These objects are important in understanding topological quantum field theories in 3 dimensions, and are relevant in the study of topological phases of matter and also a certain approach to building quantum computers. His other focus is on the relationship between field theories and category theory in arbitrary dimension. This work has recently resulted in the introduction of the 'blob complex', which provides a homological extension of field theories. Scott Morrison is hosted by Prof. Vaughan Jones in the Department of Mathematics.

Topological quantum field theory is an important field of modern mathematics. Quantum Field

Theory (QFT) attempts to describe the quantum mechanical evolution of fields (e.g. the electromagnetic field) on spacetime. The mathematics of QFT is extremely difficult, and there are significant untamed problems. Topological quantum field theory (TQFT) was originally introduced as a 'toy model' of a full quantum field theory. In TQFT, we assume that the evolution of fields does not depend on any geometric properties of spacetime (e.g. lengths, areas, durations and so on), but only on the topological shape of space-time. While this does not appear physically reasonable, the hope was that understanding the topological case would be easier, and eventually lead to insights towards a satisfactory mathematical formulation of QFT. While this program is still underway, significant progress has been made by mathematicians in understanding TQFT, and this understanding is now contributing to work on QFT. Furthermore, in the meantime physicists have discovered that the mathematicians' 'toy model' is physically relevant! The fractional quantum hall effect, one of the great discoveries of condensed matter physics in recent decades, has a (partial) mathematical description given by certain TQFTs in 3 dimensions. Moreover, materials exhibiting this behavior have been proposed as the hardware substrate for a quantum computer. This idea

continued on page 2

CALL FOR NOMINATIONS

Miller Fellowship nominations
due Thursday, September 8, 2011

Miller Professor applications
due Thursday, September 15, 2011

Visiting Miller Professor Departmental nominations
due Monday, September 19, 2011

Please see page 3 for details on making nominations for the Miller Fellowship program. For complete information on all our programs, visit: http://millerinstitute.berkeley.edu

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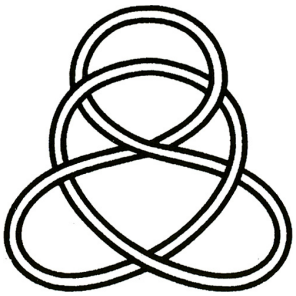
is being developed at Microsoft Station Q, where Scott worked prior to coming to the Miller Institute.

A topological quantum field theory in dimension $n + 1$ assigns a vector space to each "space", that is, a manifold of dimension n, and a number to each "spacetime", that is, a manifold of dimension $n + 1$. Essentially, this number is the quantum mechanical amplitude for the evolution of a space through a certain sequence of topological changes. An important property of TQFTs is that they are 'local': we can compute the number for a spacetime by decomposing it into smaller pieces, computing a certain invariant of each piece, and then assembling these answers by algebraic operations determined by the decomposition. In the end, everything is determined by a certain piece of algebraic data called an n-category. Conversely, given an n-category satisfying appropriate conditions, we can construct a TQFT in dimension $n + 1$.



When $n = 2$ (space is 2-dimensional while spacetime is 3), the algebraic data that determines a TQFT is called a fusion category. Recently Scott has been working on the classification of these objects. A complete classification is not feasible; indeed any finite group provides an example (its representation category). Instead he has been looking for a classification of small fusion categories. There are several good candidate notions of size for a fusion category. Each fusion category has a finite set of particle types (called simple objects by mathematicians), and the rank of a fusion category is the size of this set. Alternatively, there is a real number called the 'global dimension' associated to each fusion category. Recent progress by Etingof, Nikshych and Ostrik shows that when the global dimension is an integer and less than 84 the fusion category is 'weakly group theoretical' and essentially understood. When the global dimension is not an integer there are no strong results. Finally, each individual particle type has its own dimension, which is a real number. In quantum mechanics, a spin-½ particle has two states, and a quark has three 'colors', but in the wilder world of fusion categories the corresponding number need not be an integer. Scott's work recently has been on the classification of fusion categories containing an object with a small dimension. Dimensions up to 2 are well understood; there are particle types in fusion categories with dimensions of the form $2\cos(\pi/n)$, as well as a variety of particle types with dimension exactly 2. One surprising consequence of Scott's new results is that the spectrum of possible dimensions remains discrete above 2. The next possible value is $(\sqrt{3} + \sqrt{7}) / 2$ and after that $\sqrt{5}$. Although examples are known at these dimensions, a complete description of particle types with these dimensions is not yet available.

Much of this classification has been obtained indirectly by first classifying subfactors with small index. A subfactor is an inclusion of von Neumann algebras each with trivial centre. Although the subject has its origins in analysis, subfactors and fusion categories are intimately related. Obtaining the classification results requires techniques from across a broad range of mathematical disciplines: representation theory, combinatorics, analysis, number theory and topology! This project has involved collaboration with David Penneys and James Tener, graduate students at Berkeley, and with Masaki Izumi (Kyoto, and a former Miller Fellow), Vaughan Jones (Berkeley), Emily Peters (MIT) and Noah Snyder (Columbia). A series of papers **Subfactors with index less than 5, parts 1-4** describes these results.

In a somewhat different direction, Scott has been working on extending the TQFT framework via a construction which he calls the 'blob complex'. In work with Kevin Walker, he has defined the notion of a 'disklike n-category'. This object allows us to construct a TQFT in dimension $n + 1$, but also to construct higher order invariants containing more information. In technical terms, the blob complex associates a chain complex to each n-manifold, well defined up to homotopy, and the original TQFT vector space is just the 0-th homology of this chain complex. (This construction only generalizes the 'space' part of the TQFT, and has nothing to say about the 'spacetime' part.) This project incorporates ideas from the field of homotopy theory into the study of TQFTs. Using the blob complex, Scott has proved a higher dimensional generalization of Deligne's conjecture on the action of the little discs operad on Hochschild cohomology. A 90 page paper **The blob complex** submitted to *Geometry & Topology* introduces the blob complex and proves this generalization. There is also a companion paper **Higher categories, colimits, and the blob complex** to appear in the *Proceedings of the National Academy of Sciences*.

After completing his Miller Fellowship in 2012, Scott will be moving to Canberra, Australia, to take up a position at the Australian National University.

Obituary

Jerrold Marsden (Miller Professor 1981 - 1982), one of the original founders of reduction theory for mechanical systems with symmetry, passed away on September 21, 2010 at the age of 68.

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

CALL FOR MILLER RESEARCH FELLOWSHIP NOMINATIONS 2012-2015 TERM http://millerinstitute.berkeley.edu

Nomination Deadline: 8 September 2011

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 exceptional young scientists of great promise who have recently been awarded, or who are about to be awarded, the doctoral degree. Normally, Miller Fellows are expected to begin their Fellowship shortly after being awarded their Ph.D. A short period as a post-doctoral fellow elsewhere does not exclude eligibility. However, applicants who have already completed substantial postdoctoral training are unlikely to be successful except in unusual circumstances. 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. The Fellowship term must commence between July 1 and October 1, 2012. Eligible nominees will be invited by the Institute to apply for the fellowship. Direct applications and self-nominations are not accepted.

*All nominations must be submitted using the Online Nomination System at http://millerinstitute.berkeley.edu/

Nominators will need the following required information to complete the online nomination 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 a stipend of $60,000 with annual increases 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. Benefits, including medical, dental, vision and life insurance are provided with a modest contribution from the Miller Fellow. All University of California postdocs are represented by the UAW. Fellowships are awarded for three years, generally beginning August 1, 2012 and ending July 31, 2015. 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 2011-2014

The Miller Institute is pleased to announce the 2011-2014 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 2011 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.

Gregory Bowman

Ph.D. - Stanford University
Berkeley Departments: MCB and Chemistry
Faculty Host: Susan Marqusee

The role that a protein's dynamics play in its function is an unsolved mystery that is crucial to understanding many biochemical processes. For example, how do membrane proteins transmit extracellular signals into a cell? How do proteins fold into functional shapes? And how can a few mutations allow proteins involved in drug-resistance to degrade novel antibiotics? These questions are representative of the three topics Dr. Bowman would like to address as a Miller Fellow: protein allostery, folding, and evolution. By better understanding these fundamental questions, he hopes to greatly improve our ability to design small molecules and protein therapeutics.

Justin Brown

Ph.D. - Princeton University
Berkeley Department: Physics
Faculty Host: Holger Mueller

General Relativity has been enormously successful at describing space and time on astronomical distance scales, but remains difficult to observe in the laboratory. Dr. Brown is interested in studying gravitational effects that deviate from simple Newtonian mechanics, Post-Newtonian effects, that are difficult to observe even within our solar system. The interference of cold atomic clouds in an atom interferometer provides a powerful tool for such precision tests of gravity on the laboratory scale.

Adam Day

Ph.D. - Victoria University of Wellington
Berkeley Department: Mathematics
Faculty Host: Theodore Slaman

Dr. Day's research is motivated by a desire to understand the mathematical properties of a random outcome. These properties can be investigated by combining the theory of computable functions with probability theory. He is particularly interested in considering the case when the underlying probability distribution cannot be computed.

Alexander Hayes

Ph.D. - California Institute of Technology
Berkeley Departments: Earth & Planetary Science and Astronomy
Faculty Host: Imke de Pater

How ubiquitous are the processes which shape planetary surfaces? Are the fluvial processes that carve channels into Titan's icy crust the same as those which have sculpted the Mississippi River? Are the eolian and diagenetic processes which have created and lithified cross-bedded sandstone on Mars the same as those responsible for the beautiful vistas of Zion National Park? Dr. Hayes addresses such questions using spacecraft-based remote sensing to quantitatively study the properties of planetary surfaces. To date, Dr. Hayes has focused on studying the coupling of surface, subsurface, and atmospheric processes on Titan and Mars. Saturn's moon Titan is the only extraterrestrial body currently known to support standing bodies of liquid on its surface and, along with Earth and Mars, is one of only three places in our solar system which we know to support an active hydrologic cycle. Understanding the nature of these hydrologic systems will teach us about the history of volatile compounds across the solar system and help define Earth's place within it.

Eric Neuscamman

Ph.D. - Cornell University
Berkeley Department: Chemistry
Faculty Host: Martin Head-Gordon

Dr. Neuscamman's research focuses on the theoretical treatment and computer modeling of strong electron interactions in molecular and solid state environments. In a typical molecule or solid at equilibrium, the formation of bonding and anti-bonding orbitals usually prevents strong interactions between electrons, making the electronic structure relatively easy to describe. Unfortunately, many important systems such as catalytic protein cores, high temperature superconductors, and chemical reaction transition states lack this simplifying structure and contain large numbers of strongly interacting electrons. This research seeks to create accurate models of these systems by combining the strengths of advanced theoretical models and massively parallel computation.

Rachel Pepper
Ph.D. - Harvard University
Berkeley Departments: Integrative Biology and Civil & Environmental Engineering
Faculty Host: Mimi Koehl / Mark Stacey

Dr. Pepper is interested in problems at the intersection of fluid mechanics and biology and in exploring research that lends insight both to underlying physical mechanisms and to biological functions, strategies, and evolution. In particular, she studies the fluid flows that microscopic organisms create and inhabit using experiments, theory, and simulations.

Adam Retchless
Ph.D. - University of Pittsburgh
Berkeley Department: ESPM
Faculty Host: Rodrigo Almeida

Many organisms can grow in a diverse range of environmental conditions, even when some of those conditions would kill closely related organisms. Dr. Retchless investigates the genetic basis of this phenomenon in the bacterial plant pathogen Xylella fastidiosa, which not only grows within multiple host species (causing disease in several crops), but also colonizes the foreguts of insects so that it can be transmitted to uninfected plants. To understand the genetic basis of adaptation to multiple environments, Dr. Retchless is comparing strains of X. fastidiosa that grow in different plants and modeling evolutionary processes that could cause bacteria to gain or lose the ability to grow on a host species of plant.

Joshua Ruderman
Ph.D. - Princeton University
Berkeley Department: Physics
Faculty Host: Yasunori Nomura

The Large Hadron Collider, that is now running at CERN, may soon discover new dynamics and uncover new symmetries of our Universe. Dr. Ruderman is interested in developing new theories of particle physics that can be tested at the Large Hadron Collider. More generally, he would like to understand how experiments can teach us about solutions to long-standing problems of particle physics, such as the origin of mass and the particle nature of dark matter.

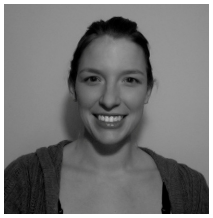
Mikhail Shapiro
Ph.D. - Massachusetts Institute of Technology
Berkeley Departments: MCB and Bioengineering
Faculty Host: David Schaffer

The brain is a complex system comprising billions of interconnected, specialized cells whose collective function gives rise to human consciousness, while malfunction leads to neurological and psychiatric disease. Understanding how this system works requires the ability to precisely sense and manipulate its activity. Dr. Shapiro is developing new technologies that will provide non-invasive access to the brain at a molecular level, and plans to apply such technologies to basic neuroscience and treatment of disease.

Yogesh Surendranath
Ph.D. - Massachusetts Institute of Technology
Berkeley Department: Chemistry
Faculty Host: Paul Alivisatos

The development of a new generation of technologies for the capture and conversion of sunlight and its storage in the form of chemical fuels relies on the ability to control the transfer of charge at nanostructured interfaces. Dr. Surendranath's work will focus on the synthesis of novel nano-sized catalyst-functionalized semiconductor heterostructures to uncover the key principles governing unidirectional charge flow at interfaces. In particular, the work will target multi-component architectures capable of generating H2 and O2 from sunlight.

Melissa Wilson Sayres
Ph.D. - The Pennsylvania State University
Berkeley Departments: Statistics and Integrative Biology
Faculty Host: Rasmus Nielson



Dr. Wilson Sayres is actively working to understand the evolution of sex chromosomes (X and Y in mammals), and also interested in using the unique properties of these chromosomes (e.g., that they spend different amounts of time in the male and female germlines, and are subject to different selective pressures) to address how mutations accumulate. To address the first area of interest, she is cataloging and interpreting variation among multi-copy gene families on the Y chromosomes from populations around the world. She is also comparing diversity on the sex chromosomes and non-sex chromosomes across hundreds of individuals to determine how population demography, selection, and sex-specific mutation processes combine to contribute to the accumulation of mutations in the human genome.

Awards and Honors

April 4, 2011: **Oliver Chadwick** (Visiting Miller Professor Fall 1994), **Liu Chen** (Visiting Miller Professor Fall 1987), and **Allen Goldstein** (Miller Professor Spring 2011) have been elected fellows of the American Geophysical Union.

March 29, 2011: **Saul Perlmutter** (Miller Senior Fellow 2010 - 2015) is one of this year's two speakers at the annual UC Berkeley Faculty Research Lectures.

March 15, 2011: **Jillian Banfield** (Miller Professor 2006 - 2007) has been awarded a 2011 L'Oréal-UNESCO For Women in Science Award.

February 27, 2011: **David Milstein** (Visiting Miller Professor Spring 2006) has been awarded a Meitner Humboldt Research Award.

February 24, 2011: **Sandra Faber** (Visiting Miller Professor Spring 2005) has been named as one of the 2011 "Women of Influence" in the Silicon Valley/San Jose Business Journal.

February 22, 2011: **Connie Chang-Hasnain** (Miller Professor 2003 - 2004) has been awarded the 2011 David Sarnoff Award from the Institute for Electrical and Electronics Engineers (IEEE).

February 20, 2011: **Michael Marletta** (Visiting Miller Professor Fall 2000) has been named president of The Scripps Research Institute, effective January 1, 2012.

February 19, 2011: **Saul Perlmutter** (Miller Senior Fellow 2010 - 2015) and **Adam Reiss** (Miller Fellow 1996 - 1998) share this year's Albert Einstein Medal.

February 15, 2011: **Joshua Eisner** (Miller Fellow 2005 - 2008) and **Jiaxing Huang** (Miller Fellow 2004 - 2007) have both been awarded Sloan Fellowships.

February 10, 2011: **Laurence Barron** (Visiting Miller Professor Spring 1995) has been awarded the 2011 Chirality Medal, instituted by the Societa Chimica Italiana.

February 8, 2011: **Jitendra Malik** (Miller Professor Fall 2001) has been elected to the National Academy of Engineering.

February 2, 2011: **Alexander Levitzki** (Visiting Miller Professor Spring 2008) has been elected to the Academia Europaea (the Academy of Europe).

January 28, 2011: **Gabor Somorjai** (Miller Professor 1977 - 1978, Miller Senior Fellow 2009 - 2014) has been awarded the BBVA Foundation Frontiers of Knowledge Award "for his pioneering experimental and conceptual contributions to the understanding of surface chemistry and catalysis at a microscopic and molecular level."

January 18, 2011: **Sandra Faber** (Visiting Miller Professor Spring 2005) has been awarded the 2011 Henry Norris Russell Lectureship from the American Astronomical Society.

January 11, 2011: The following Miller members have been named fellows of the American Association for the Advancement of Science (AAAS):

- o **Tamara Doering** (Miller Fellow 1993 - 1995)
- o **Michael J. Frisch** (Miller Fellow 1983 - 1985)
- o **Gerald McClearn** (Miller Professor 1962 - 1963)
- o **Hongkun Park** (Visiting Miller Professor Fall 2003)
- o **Eugene Wong** (Miller Professor 1983 - 1984)
- o **Patricia Zambryski** (Miller Professor 2004 - 2005)

January 7, 2011: **Bjorn Poonen** (Miller Professor Fall 2005) was awarded the 2011 Chauvenet Prize (the mathematical analogue of the Pulitzer Prize).

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.

Antonio Castro-Neto
Visiting Miller Professor Spring 2010

Chung-Pei Ma
Miller Professor Fall 2010

Prashant Jain
Miller Fellow 2008 - 2011

Nick Piro
Miller Fellow 2009 - 2012

Next Steps

The Miller Institute congratulates the following Miller Fellows on their next endeavors.

Pascal Audet
Assistant Professor
Department of Earth Sciences
University of Ottawa

Linyou Cao
Assistant Professor
Department of Materials Science & Engineering
North Carolina State University

Candace Chan
Assistant Professor
Materials Science & Engineering
School for Engineering of Matter, Energy and Transport
Arizona State University

Greg Crutsinger
Assistant Professor
Department of Zoology
University of British Columbia

Isamu Matsuyama
Assistant Professor
Lunar and Planetary Laboratory and
Department of Planetary Sciences
University of Arizona

Dan Nicolau
Research Fellow
Computational Laboratory
Oxford University

Heather Knutson
Assistant Professor
Division of Geological and Planetary Sciences
California Institute of Technology

TaeJoo Park
Assistant Professor
Nano-biological Science and Chemical Engineering
Ulsan National Institute for Science and Technology, Korea

Raman Sanyal
Assistant Professor
Department of Mathematics
Freie Universität Berlin, Germany

Rebecca Schulman
Assistant Professor
Department of Chemical and Biomolecular Engineering
Johns Hopkins University

Visiting Miller Professorships

The Advisory Board of the Miller Institute for Basic Research in Science invites Berkeley faculty to submit online nominations for Visiting Miller Research Professorships. The purpose of the Visiting Miller Professorship is to bring promising or eminent scientists to the Berkeley campus on a short-term basis for collaborative research interactions. Faculty members or research scientists from any place in the world are eligible to be considered for sponsorship.

Online nominations will be accepted beginning in June 2011 and are due by Monday, September 19, 2011.

Miller Research Professorships

Applications from University of California faculty for Miller Research Professorship terms in the 2012-13 academic year will be accepted online beginning in June 2011. The purpose of the Professorship is to release members of the faculty from teaching and administrative duties and allow them to pursue research. Appointees are encouraged to follow promising leads that may develop in the course of their research effort whether or not they fall within the original research online.

Applications are judged competitively and are due by Thursday, September 15, 2011. It is anticipated that between five to ten awards will be made.

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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

Miller Snapshots

Miller Fellows Chang Liu and Raman Sanyal enjoying a Miller Happy Hour at the Faculty Club

Visiting Miller Professors Jotun Hein, Carl Brenninkmeijer, and Eric Agol at the Berkeley Faculty Club

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."