Department of Mathematics

The Department of Mathematics seeks to sustain its top ranking in research and education by hiring the very best faculty, with special attention to the recruitment of women and candidates from underrepresented minorities, and by continuing to serve the varied needs of the department's graduate students, mathematics majors, and the broader MIT community.

New Faculty

The Mathematics Department had another successful year in faculty hires for FY2012. Igor Rodnianski is an analyst from Princeton University, a leading specialist in nonlinear hyperbolic partial differential equations (PDEs), particularly of Einstein's equations for space-time in general relativity. He will join the department's faculty as professor in fall 2011.

Sug Woo Shin, a leading number theorist in the global Langlands program, will join the faculty as assistant professor of mathematics. Dr. Shin received his PhD at Harvard University under Richard Taylor in 2007. He was appointed Dickson instructor at the University of Chicago and, more recently, a member at the Institute for Advanced Study.

Jared Speck is an analyst of nonlinear PDEs of mathematical physics, which are linked to problems in relativistic fluid mechanics, nonlinear electrodynamics, and general relativity. He will join the faculty as assistant professor of mathematics. Dr. Speck received his PhD from Rutgers University in 2008 under Michael Kiessling and Shadi Tahvildar-Zadeh. He served as a lecturer at Princeton for a year before going to the University of Cambridge on a research appointment. He returned to Princeton last year as a National Science Foundation Fellow working with Igor Rodnianski and Sergiu Klainerman.

Gonçalo Tabuada is an algebraic topologist whose research program covers a broad and deep area of algebraic geometry, linking modern homotopical algebra to noncommutative derived algebraic geometry and K-theory. He completed his PhD at the University of Paris 7 in 2007 under Bernhard Keller and has had visiting appointments at the Paul Sabatier University, UCLA, the University of Bonn, the University of Göttingen, and MIT. He will join the faculty as an assistant professor of mathematics.

Faculty Promotion

Associate professor Steven Johnson, an applied mathematician in nanophotonics and high-performance computation, received tenure.

Assistant professors Mark Behrens (algebraic topology) and Benjamin Brubaker (number theory) were promoted to associate professor.

Administration

Michael Sipser will continue as department head.

Haynes Miller will become associate head of the department and will continue as undergraduate officer.

Tomasz Mrowka will follow David Jerison as chair of the pure mathematics committee. Michel Goemans will continue as chair of the applied mathematics committee. Bjorn Poonen and Gigliola Staffilani will continue as cochairs of the graduate student committee in pure mathematics, and Peter Shor as chair of the committee in applied mathematics graduate admissions. Steven Johnson will replace John Bush as cochair of the committee of undergraduate advisors, joining Ju-Lee Kim, who will continue as cochair.

Faculty Honors and Awards

Faculty Chairs

Gilbert Strang will be the first holder of the MathWorks professorship. The MathWorks professorship was recently endowed through the assistance of John N. (Jack) Little, president and cofounder of MathWorks and a member of the department's visiting committee since 2005. Strang is a leading numerical analyst, author, and instructor, and an important figure in the analysis of finite elements, wavelets, and all aspects of linear algebra and matrix computations. He served as the president of the Society for Industrial and Applied Mathematics (SIAM) during 1999 and 2000 and has received such distinctions as the Henrici Prize and the von Neumann Medal for research, as well as the Su Buchin Prize for educational outreach and MIT's Graduate Student Council Teaching Award. Professor Strang is an honorary fellow of Balliol College, a fellow of the American Academy of Arts and Sciences, and a member of the National Academy of Sciences.

Assistant professor Mark Behrens will be appointed the Cecil and Ida Green career development associate professor of mathematics. Behrens is an algebraic topologist whose research focuses on computational aspects of the homotopy groups of spheres and their connection to algebraic geometry.

Faculty Awards

Scott Sheffield received the Line and Michel Loeve International Prize in probability, awarded by the University of California, Berkeley, every two years "to recognize outstanding contributions by researchers in probability who are under 45 years old."

James McKernan was elected a fellow of the Royal Society, "distinguished for his work in algebraic geometry, especially for his contributions to proving the existence of minimal models of complex algebraic varieties in all dimensions."

Jonathan Kelner received the Harold E. Edgerton Faculty Achievement Award, given to a junior member of the MIT faculty for exceptional distinction in teaching, in research, and in scholarship.

Tomasz Mrowka received the American Mathematical Society's Joseph Doob Prize, with Peter Kronheimer, for their book *Monoples and Three Manifolds* (Cambridge University Press, 2007).

Bjorn Poonen received the MAA Chauvenet Prize for his article "Undecidability in number theory," *Notices AMS*, vol. 55 (2008). Bjorn also received a Guggenheim Fellowship.

Peter Shor was elected a fellow of the American Academy of Arts and Sciences.

David Vogan received the AMS Levi L. Conant Prize for his article "The character table for E_8," *Notices AMS*, vol. 54 (2007).

Bonnie Berger was selected to give the Margaret Pittman Lecture, sponsored by the National Institutes of Health.

Alan Edelman was selected to be a SIAM Fellow "for his contributions in bringing together mathematics and industry in the areas of numerical linear algebra, random matrix theory, and parallel computing."

Laurent Demanet received a Sloan Research Fellowship.

Resource Development

The Department of Mathematics had another successful year in reaching out to and engaging alumni and friends of the department. We continued to do faculty presentations for alumni, parents, and friends. Professor Tom Leighton gave a School of Science breakfast talk titled "From Theory to Practice: The Akamai Story—Using Mathematics and Algorithms to Make the Internet Scale." This was a good opportunity to share the work that our faculty are doing and to highlight needs of the department. We have been hosting stewardship events on campus so our donors get to meet our students and faculty. This fall we will send out the 6th edition of our annual departmental newsletter, *Integral*.

Simons Lecture Series

Two lecturers presented the 2011 Simons Lectures: Steven Strogatz, the Jacob Gould Schurman professor of applied mathematics at Cornell University, and Manjul Bhargava, professor of mathematics at Princeton University. Professor Strogatz, renowned for his work in complex networks and a frequent guest on National Public Radio and other venues, presented a series of talks titled "Sync, Balance, and Blog." Professor Bhargava, recipient of the AMS Cole Prize in number theory and the SASTRA Ramanujan Prize, spoke in a series titled "Orbits of Group Representations and Arithmetic."

Women in Mathematics

The Women in Mathematics Lecture Series, begun in spring 2009, has been renamed the D. W. Weeks Lecture Series in honor Dorothy W. Weeks (1893–1990), the first woman awarded a PhD in Mathematics at MIT, in 1930. She subsequently had a substantial career as professor and department head of physics at Wilson College and as a

researcher in the spectroscopy lab at the Harvard Observatory in Cambridge.

The weekly lectures reach a wide audience, including graduate students from other departments and the general public. Aside from providing accessible mathematics talks of high quality, the series gives female researchers an occasion to visit MIT—to make connections or continue joint work.

The department has also seen the development of the Undergraduate Society for Women in Mathematics (USWIM) by MIT women undergraduates. As its web site describes, the USWIM "provides women with a chance to meet and learn more about the opportunities and research in mathematics as well as the future paths a student in mathematics might take." Events include Undergraduate Research Opportunities Program (UROP) dessert night, "math mixers" to assist new students in selecting math courses, and visits from industry representatives to speak about math applications and opportunities in the field.

Diversity Efforts

The department's Diversity Advisory Committee consists of professor Ruben Rosales (chair), professor David Vogan, associate professor Mark Behrens, CLE Moore instructor Stephen Kleene, and staff members Shirley Entzminger, Jeffrey Kinnamon, and Sarah Smith. The committee is charged with increasing engagement of underrepresented minorities (URM) at all levels in the department and in particular to recruit URM students. As explained by University of Arizona professor William Vélez in a talk on student diversity in mathematics last spring, URMs often mistakenly view mathematics as a non-lucrative or esoteric major in an undergraduate degree, so we must reach out to these students and explain the opportunities afforded by majoring in mathematics. Teaching assistants are now asked to encourage mathematically talented students to consider the major, not only to foster their talent but to augment their career prospects in any technical field. (Professor Vélez was scheduled to come to the department as a Martin Luther King visiting professor during spring 2011, but unfortunately had to cancel his arrangement for personal reasons.)

This year the Mathematics Department increased its participation in the MIT Summer Research Program (MSRP). The program hosts outside undergraduates, particularly underrepresented minorities, to be mentored by a graduate student or recent PhD and overseen by a faculty member over a 10-week period, culminating in a poster session and luncheon in early August. In summer 2011 we will have two undergraduates: juniors Alejandro Ginory from Florida International University and Dominique Rice from Howard University.

In January 2011, Professor Behrens attended the MathFEST conference of the National Association of Mathematicians, an association dedicated to "the mathematical development of African Americans and other underrepresented American minorities." As a joint conference with many other math societies, the conference brought together faculty and math undergraduates from a large number of institutions. Behrens' goals in attending were to foster connection with historically black colleges and universities, to show MIT's support of MathFEST, and to recruit undergraduates to MIT's MSRP program. During the

conference he served on panels and as a judge of undergraduate projects.

Another departmental effort underway is the Direct Reading Program (DRP) during Independent Activities Period, in which a graduate student mentors an undergraduate in the reading of a mathematics text. Professors Behrens and Paul Seidel emphasized URM students in the advertising of this program and succeeded in ensuring a diverse student population in the 14 participants.

The Mathematics Department also hosted staff member Dennis Porche to attend the national conference of the Society for Advancement of Chicanos and Native Americans in Science (SACNAS). Dennis joined Susan Brighton of Chemistry and other School of Science staff and faculty to talk to interested students and parents about MIT. The conference was extremely rewarding, and the department will ask him to attend the next SACNAS conference in October 2011.

Education

The Mathematics Academic Services Office

This year the Mathematics Academic Services office (MAS) has transitioned from two separate undergraduate and graduate offices to one combined office serving students and faculty as a whole. This administrative transition represented major change in physical space, leadership, staffing duties, and the culture of the office. Simultaneously, with the retirement of Joanne Jonsson and Linda Okun, MAS lost over fifty years of collective experience and institutional memory. Under the new leadership of academic administrator Jeffrey Kinnamon, MAS has improved and consolidated its electronic database system to administer the graduate program and graduate admissions, provided new accounting tools for TA duties and faculty hours, created a new recruitment brochure for the PhD program, redesigned online forms for teaching preferences, and helped redesign the undergraduate web pages.

Graduate Students

There were 120 graduate students in mathematics in 2010–11, all in the PhD program. During 2010–11, a total of 34 students received a doctoral degree.

The 2011 doctoral candidates are highly distinguished. Six of the candidates were National Science Foundation graduate fellowship recipients, five had been awarded Department of Defense National Defense Science and Engineering graduate fellowships (NDSEG/DOD), one had been selected as a joint Hertz and NDSEG/DOD fellow, and 12 received the Institute's prestigious School of Science Presidential Fellowships.

All of the 34 have secured employment for the coming year: 29 will have postdoctoral positions in either mathematics or related departments at UCLA, the University of Texas at Austin, the Broad Institute, the University of Toronto, Boston College, the University of Pennsylvania, the University of Massachusetts Amherst, the Mathematical Sciences Research Institute, Stanford University, Harvard University, North Carolina State University, McGill University, MIT, Louisiana State University, the University of Alberta, McMaster University, SUNY Stony Brook, the Georgia Institute of Technology,

the University of Chile Santiago, the University of Geneva, and the Korea Institute for Advanced Study. One will work as a technical staff member at MIT Lincoln Laboratory, one is working at Pfizer, one at Goldman Sachs, and two others are entering careers in engineering and finance.

There will be 26 new graduate students in our doctoral program in 2011–2012, including five women. We continue the policy of offering all first-year students fellowship support; as usual, many incoming students come with support from external sources.

Graduate Student Awards

Linan Chen and Joel Lewis received the Housman Graduate Student Teaching Award for their exceptional skill in and dedication to undergraduate teaching.

Steven Sivek and Vedran Sohinger were each awarded the Charles W. and Jennifer C. Johnson Prize for an outstanding research paper accepted in a major journal.

Majors

During 2011, more than 380 students listed mathematics as their major, making this the largest undergraduate program in the School of Science. Some 72 students graduated with a first degree in mathematics and 49 more finished with a second degree in the department. Eight of our seniors are continuing in graduate school in mathematics and 17 in other disciplines.

Undergraduate Awards

The MIT team placed second in the William Lowell Putnam Mathematical Competition. The winning team consisted of sophomores Sergei S. Bernstein and Whan Ghang and junior Jacob N. Steinhardt. Two other MIT participants, juniors Yu Deng and Colin Sandon, were among the Putnam Fellows—the five highest-ranking individuals. Five MIT students ranked in the next group of 19, and 16 received honorable mention among 60 honorees. Overall, MIT students once again dominated the competition. Students benefited from excellent coaching by professors Richard Stanley and Abhinav Kumar.

The Jon A. Bucsela Prize in Mathematics, given in recognition of distinguished scholastic achievement, professional promise, and enthusiasm for mathematics, was awarded to senior Alexandr Zamorzaev.

Senior Yinghui Wang and junior Fan Wei each received honorable mention in the Alice T. Schafer Prize for excellence in mathematics by an undergraduate woman, given by the Association for Women in Mathematics. Yinghui also received the Elizabeth Lowell Putnam Prize for outstanding performance by a woman in the Putnam Competition.

Senior Melissa Gymrek, a double major with electrical engineering and computer science, received the Association of MIT Alumnae Senior Academic Award.

Senior Raghu Mahajan, a double major with physics, received the Gates Cambridge Scholarship to study at the University of Cambridge.

Junior Paul Christiano received the Anna Pogosyants Award for his UROP project in the Computer Science and Artificial Intelligence Laboratory, under the supervision of assistant professor Jonathan Kelner.

Junior Shaunak Kishore received the Barry M. Goldwater Scholarship, given to students who exhibit outstanding potential and who intend to pursue careers in mathematics, the natural sciences, or engineering disciplines.

Former undergraduate Maria Monks '10 was awarded the 2011 Frank and Brennie Morgan Prize for outstanding research in mathematics while an undergraduate. Yufei Zhao '10 also received honorable mention for this prize.

Undergraduate and High School Summer Research Programs

In summer 2010 the department hosted its 14th Summer Program in Undergraduate Research (SPUR), a six-week intensive mathematical research experience for MIT undergraduates in which each undergraduate pursues an individual project with a graduate student mentor. Ten MIT undergraduates participated, supervised by six graduate students. The program culminates in written papers and lectures. A jury of faculty members selects winners of the Hartley Rogers Jr. Family Prize, which is awarded jointly to a student-mentor team. The 2010 Rogers Prize was awarded to senior Harrison Chen, who graduated in 2011, and mentor Martina Balagovic.

Summer 2010 was the 18th year of the Mathematics Department's participation in the Research Science Institute program (RSI) for gifted high school students. Thirteen students carried out mathematics projects in RSI. Several went on to great success with their RSI projects in the Intel Science Talent Search (Intel STS 2011) and the Siemens Competition in Math, Science, and Technology (Siemens 2010). Of the 11 who were US residents and hence eligible for these competitions, six reached the semifinal stage (top 300) in one or both competitions. Of those six, one student, Wenyu Cao (supervised by mentor Rosalie Beranger-Rioux) was a finalist (top 40) in the Intel STS; another, Randy Jia (supervised by mentor John Lesieutre) was a finalist in the Siemens Competition (top 25 in the individual category).

The New PRIMES Program

In October 2010 the Department of Mathematics launched a new, year-long high school research program, the Program for Research in Mathematics, Engineering, and Science (PRIMES). Directed by Dr. Slava Gerovitch, with Dr. Tanya Khovanova as head mentor, PRIMES is designed to select highly talented students from greater Boston to work on research projects formulated by faculty under the mentorship of graduate students. Meeting during the academic year, PRIMES complements the RSI summer program but allows students more time to pursue their projects. Six graduate students serve as mentors and thereby have an opportunity to acquire teaching experience and to learn new fields. Professor Pavel Etingof serves as the chief research advisor of PRIMES. He explains that the program's goal is to "let mathematically talented high school students discover how it feels to be a research mathematician."

On May 21, 2011, PRIMES held its first annual conference at MIT, in which 21 students presented their projects. The widely attended event showed the tremendous success of

the program. Several projects will likely lead to publications in professional journals and will be strong contenders at national science competitions for high school students. As students' parents attested, "The program provides a truly transformative experience for bright kids—they got to learn what real research is like by actually doing real research." Several PRIMES students are entering MIT as undergraduates in fall 2011 and will continue their research under the UROP program.

Faculty Research Highlights

Clark Barwick is an algebraic topologist. With professor emeritus Daniel Kan, he constructed new models of higher categories, and with CLE Moore instructor Christoher Schommer-Pries, Barwick developed a minimal set of axioms that uniquely characterize "a theory of higher categories." In a related project, Barwick developed a new way of organizing homotopy coherent algebraic structures, culminating in a proof (joint with Schommer-Pries) of a powerful "strictification" theorem that gives conditions under which one may find "on-the-nose" models of "up-to-homotopy" structures. This has led to new proofs of a broad class of conjectures, generally known as the Deligne conjectures. With John Rognes, Barwick developed a K-theory of higher categories, solving a conjecture of Bob Thomason's on extensions of the classical devissage theorem to new contexts, and he is making progress toward a conjecture on the relationship between K-theory and chromatic theory. Barwick has also developed a new point of view on equivariant stable homotopy theory; and armed with this, he has proved a conjecture of G. Carlsson on the algebraic K-theory of field extensions.

Mark Behrens is also an algebraic topologist. Over the past five years, he has studied infinite families of elements in the stable homotopy groups of spheres using modular forms. Generalizing on research in that area with Tyler Lawson (former CLE Moore instructor), Behrens has shown that v_n-*periodic families* in the stable homotopy groups of spheres can be detected by automorphic forms. With professor Michael Hopkins at Harvard, Behrens is currently working to develop a genus, analogous to the *A hat* genus and the Witten genus, which produces automorphic form-valued invariants of manifolds with extra structure. These invariants involve Eisenstein series on the associated unitary groups. In a third strand involving the Goodwillie calculus, which provides a means of understanding unstable homotopy groups from stable homotopy groups, Behrens is studying its computational means of implementation, and he recently proved a conjecture that describes the outcome when its is applied to the circle.

David Jerison is an analyst who has been working on free boundary problems. In 1969, E. Bombieri, E. De Giorgi, and M. Miranda proved a theorem stating that minimal surfaces that are graphs necessarily have bounded slope, the fundamental step leading to the property that these surfaces are smooth. In joint work with his student Daniela de Silva, Jerison proved the analogue of this for free boundary problems. The methods should lead to a much more robust theory of phase transitions, especially in high dimensions. He has also been working on internal diffusion limited aggregation, a model proposed in 1986 by professor of chemistry John Deutch and chemist Paul Meakin (then at DuPont) to describe corrosion or electropolishing processes. The problem is also of considerable interest in probability and combinatorics and is related to continuum evolutions of free boundaries. With CLE Moore instructor Lionel Levine and professor

Scott Sheffield, Jerison resolved a 20-year-old conjecture about fluctuations of this model. Their approach confirms the Meakin-Deutch numerics and relates the fluctuations in an unexpected way to the Gaussian free field (a kind of higher dimensional random surface, just as Brownian motion is a one-dimensional random curve).

James McKernan works in higher dimensional algebraic geometry, especially in the minimal model program. Together with Christopher Hacon he proved the existence of flips and together with C. Birkar, P. Cascini, and C. Hacon, he then proved existence of log terminal models and finite generation of the canonical ring. Recently with C. Hacon and CLE Moore instructor Chenyang Xu, McKernan found a general bound on the number of automorphisms of varieties of general type and proved a conjecture of V. V. Shokurov that the log canonical threshold satisfies the ascending chain condition.

Tomasz Mrowka, a differential geometer, works on connections between the gauge theories of high energy physics and explores their implications on the topology of three- and four-dimensional manifolds, potential mathematical models for exotic space-times. With Peter Kronheimer (Harvard) he wrote a prize-winning foundational book on these connections. This book also contains results that are fundamental in C. Taubes's proof of the Weinstein conjecture. Recently they also proved that Khovanov homology detects the unknot. Khovanov homology is a combinatorial invariant of knots with roots in representation theory. The proof connects Khovanov homology with gauge theory using sophisticated geometry and analysis.

Peter Ozsváth works in geometry and topology He has been developing an invariant for three-dimensional manifolds with boundary, called "bordered Heegaard Floer homology," jointly with Robert Lipshitz and Dylan Thurston. This associates to a (parameterized) surface a differential graded algebra and to a three-manifold whose boundary is that surface, a module over the algebra. This new structure gives insight into how to calculate an earlier-defined invariant (Heegaard Floer homology, discovered jointly with Zoltán Szabó), as well as to provide a conceptual framework into which that invariant fits. This research may point toward an axiomatization of some of the interesting new invariants for low-dimensional manifolds which come from gauge theory.

Alexander Postnikov, an algebraic combinatorialist, has investigated total positivity on the Grassmannian. This work involves beautiful combinatorial objects, and it has connections to many areas of mathematics, such as algebraic geometry (Schubert calculus), representation theory (Lie theory), and inverse boundary problems. Recently related combinatorial structures have appeared in statistical mechanics (PASEP model) and in mathematical physics (solitons and Kadomtsev-Petviashvili equation). In another project, he has studied generalized permutohedra. This class of convex polytopes includes many classical polytopes (e.g., permutohedra and Stasheff's associahedra) and it has links with matroid theory, de Concini-Procesi models, tropical geometry, etc. Another project is devoted to combinatorics of power ideals. These ideals in a polynomial ring are closely related to the theories of fat point ideals, Cox rings, and box splines (works of Dahmen-Micchelli, Holtz-Ron, De Concini-Procesi, and Sturmfels-Xu). With colleagues, Postnikov has developed foundations of new combinatorial theory

related to splines.

Paul Seidel works on symplectic topology and mirror symmetry. Symplectic topology is the modern incarnation of classical mechanics in its Hamiltonian formulation. The field has been significantly affected by inputs from other parts of mathematics and physics, notably enumerative geometry and string theory. Seidel's most recent work shows that there is structure in symplectic topology going beyond what is visible to enumerative geometry, answering a long-standing question about the structure of closed symplectic manifolds. With postdoctoral fellow Mohammed Abouzaid, he has also investigated the wealth of symplectic structures existing on open manifolds. Finally, work with PhD alumnus Jake Solomon aims to use symplectic topology and mirror symmetry to construct structures of interest in representation theory.

Gilbert Strang has seen success on two problems in linear algebra. Banded matrices with banded inverses form a useful and interesting group of matrices: all zero entries beyond diagonal w, as in wavelet matrices. The new result is that they have the form $A = BC$ where B and C are block-diagonal matrices (with blocks of size $2w$). This work was published in the *Proceedings of the National Academy of Sciences* and extended in 2010. The classical *LPU* factorization of a matrix is reached by elimination (lower triangular L times permutation P times upper triangular U). A recently answered question was how to extend this to doubly infinite matrices, for which the elimination algorithm has no place to start.

Michael Sipser
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