MSRI
Mathematical Sciences Research Institute

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Annual Report
on the
Mathematical Sciences Research Institute
2009-2010 Activities
supported by
NSA Practical & Intellectual Grant
H98230-09-1-0095
June 30, 2010

Mathematical Sciences Research Institute
NSA Annual Report for 2009-2010

I. INTRODUCTION

The main scientific activities of MSRI are its Programs and Workshops. Typically, MSRI will host one year-long program and two semester-long programs or four semester-long programs each year. MSRI usually runs two programs simultaneously, each with about forty mathematicians in residence at any given time, with an additional eight to ten graduate students per program. Each year, MSRI also runs a one-year Complementary Program, with five to ten researchers. The purpose of the Complementary Program is to host mathematicians whose research expertise, while not directly in the area of the main programs held at MSRI that year, remains sufficiently close to it so as to promote interdisciplinary interactions among researchers.

During the 2009-10 academic year, aside from the Complementary Program, MSRI hosted a total of three programs. The year-long program *Symplectic and Contact Geometry and Topology* was paired with the *Tropical Geometry* program in the Fall and with the *Homology Theories of Knots and Links* program in the Spring.

Approximately 250 researchers participated in these programs for period of one month or longer. Of those, 14 were funded either entirely or partially by NSA Practical & Intellectual (P&I) Grant # H98230-09-1-0095. Among those 14 members, three of them were postdoctoral fellows: Lauren Williams was a postdoctoral fellow in the Tropical Geometry program, while both Christopher Hillar and Christopher Severs were in the Complementary program. More information about these three postdocs can be found in Chapter II.

Generally, each semester-long program features three workshops that are held at MSRI during the program. The program begins with a Connections for Women Workshop, which is designed to attract women participants. If the area of mathematics is one that traditionally has a large number of women, then the workshop can be used to highlight and to showcase their individual work. However, if the number of women in the field is low, then the workshop attempts to attract a wider audience among women in an effort to stimulate interest in the area as well as to encourage new connections early among the women in the program as a catalyst for eventual collaborations. This workshop is then followed by an Introductory Workshop, the purpose of which is to introduce the subject to the broader mathematical community. Later during the program, there is a Topical Workshop, which is designed to explore some of the themes of the program in depth.

A total of 12 of these programmatic workshops took place at MSRI during the 2009-10 academic year. The Tropical Geometry Program had four workshops. One workshop, *Tropical Structures in Geometry and Physics*, was partially funded by a separate NSA grant (H98230-09-1-0069). The report for that particular workshop has been filed with NSA. The program on Homology Theories of Knots and Links had the usual three workshops (as described above). Since the Symplectic and Contact Geometry and Topology program was a year-long program, it had five workshops. One workshop,

Symplectic Geometry, Noncummutative Geometry and Physics was a joint venture between MSRI and the Hayashibara Foundation from Japan. It is interesting to note that the Hayashibara Foundation is a pharmaceutical company that regularly supports various scientific workshops.

In addition to the programmatic workshops that run parallel with the programs, MSRI funded five other scientific workshops. One of them, *Black Holes in Relativity*, was a Hot Topics workshop. (Every year MSRI holds a Hot Topics workshop in an area of intense mathematical activity.) This year's topic was the understanding of the dynamics of the Einstein equations, which is intimately related to our current physical understanding of gravitational collapse. These workshops are briefly summarized in Chapter II, section B.

MSRI also hosts Educational & Outreach Workshops. These workshops focus on improving the skills of K-12 math teachers. Three Educational & Outreach Workshops took place during the 2009-10 academic year. Their descriptions, as well as lists of speakers, talks and participants, can be found on MSRI website, https://secure.msri.org/calendar/index_workshops. They are also briefly summarized in Chapter II, section C.

Another essential activity at MSRI is its series of Summer Graduate Workshops which target advanced graduate students in mathematics. During the summer of 2009, MSRI hosted six Summer Graduate Workshops, with themes ranging from Toric Varieties to Random Matrix Theory to Inverse Problems. A complete description can be found at the URL, https://secure.msri.org/calendar/index_sgw, with a summary in Chapter II, section D.

Last but not least, each summer since 2007, MSRI has hosted a summer school (MSRI-UP) for undergraduates students with the aim of increasing the number of PhDs among members of under-represented groups. These summer schools are co-funded by the NSA (H98230-09-0103) and the NSF. The 2009 MSRI-UP workshop in Coding Theory was a successful and popular workshop, with 17 undergraduate participants. (See Chapter II, section E, for a brief summary). Since MSRI-UP was funded by an NSA grant independent of the Practical and Intellectual Training one, its report has been filed separately.

II. OVERVIEW OF ACTIVITIES

In the lists of organizers of each activity, an asterisk (*) denotes lead organizer(s).

A. Major Programs and their Associated Workshops

Program 1: Symplectic and Contact Geometry and Topology

August 17, 2009 to May 21, 2010

Organized By: Yakov Eliashberg (Stanford University), John Etnyre (Georgia Institute of Technology), Eleny-Nicoleta Ionel (Stanford University), Dusa McDuff (Barnard College, Columbia University), and Paul Seidel (Massachusetts Institute of Technology)*

In the slightly more than two decades that have elapsed since the fields of Symplectic and Contact Topology were created, the field has grown enormously, and unforeseen new connections within Mathematics and Physics have been found. The goals of the program at MSRI were to:

I. Promote the cross-pollination of ideas between different areas of symplectic and contact geometry;

II. Help assess and formulate the main outstanding fundamental problems and directions in the field;

III. Lead to new breakthroughs and solutions of some of the main problems in the area;

IV. Discover new applications of symplectic and contact geometry in mathematics and physics; and

V. Educate a new generation of young mathematicians, giving them a broader view of the subject and the capability to employ techniques from different areas in their research.

To achieve these goals, the program concentrated on three broad, interrelated themes that encompass many of the modern trends in symplectic geometry: algebraic structures associated to holomorphic curves, symplectic and contact geometry in low dimensional topology, and symplectic topology and dynamics.

Workshops associated with the Symplectic and Contact Geometry and Topology Program:

Workshop 1: Connections for Women: Symplectic and Contact Geometry and Topology

August 14, 2009 to August 15, 2009

Organized By: Eleny-Nicoleta Ionel (Stanford University) and Dusa McDuff (Barnard College, Columbia University)*

The goal of this workshop was to establish a bridge between the graduate student workshop that ended on August 14, 2009 and the Introductory workshop scheduled for August 17, 2009. After some elementary talks describing some of the main questions in the field, there was an extended discussion session intended to explain basic concepts to those unfamiliar with the area. It was also an opportunity for young researchers in the field to present their work. To facilitate networking among women and members of

underrepresented minorities, MSRI hosted a dinner at a nearby restaurant that Friday evening.

Workshop 2: Introductory Workshop: Symplectic and Contact Geometry and Topology

August 17, 2009 to August 21, 2009

Organized By: John Etnyre (Georgia Institute of Technology), Dusa McDuff (Barnard College, Columbia University), and Lisa Traynor (Bryn Mawr)*

The aims of this workshop were to introduce people to a broad swath of the field and to frame its most important problems. Each day was organized around a basic topic, such as how to count holomorphic curves with boundary on a Lagrangian submanifold (which leads to various versions of Floer theory) or how to understand the general structure of symplectic and contact manifolds. There was also an introduction to the analytic and algebraic aspects of symplectic field theory and a discussion of some applications.

Workshop 3: Algebraic Structures in the Theory of Holomorphic Curves

November 16, 2009 to November 20, 2009

Organized By: Mohammed Abouzaid (Clay Mathematics Institute), Yakov Eliashberg (Stanford University), Kenji Fukaya (Kyoto University), Eleny-Nicoleta Ionel (Stanford University), Lenny Ng (Duke University), and Paul Seidel (MIT)*

The theory of holomorphic curves in symplectic manifolds leads to rich algebraic structures. The study of these structures is increasingly important both for understanding the theory itself and for actual computations and applications. The aim of the workshop was to survey ongoing developments in the area. Some of the topics of interest were

- cohomological field theories;
- relative and tropical Gromov-Witten invariants;
- Symplectic Field Theory (SFT) and connections with string topology; and
- theories of holomorphic curves with Lagrangian boundary conditions, such as relative SFT, open Gromov-Witten theory, and Fukaya categories.

Workshop 4: Symplectic and Contact Topology and Dynamics: Puzzles and Horizons

March 22, 2010 to March 26, 2010

Organized By: Paul Biran (Tel Aviv University), John Etnyre (Georgia Institute of Technology), Helmut Hofer (Courant Institute), Dusa McDuff (Barnard College, Columbia University) and Leonid Polterovich (Tel Aviv University)*

This workshop focused on recent progress in central problems in symplectic and contact topology and Hamiltonian dynamics, such as rigidity of Lagrangian submanifolds, algebra/topology/geometry of symplectomorphism and contactomorphism groups, exotic symplectic and contact structures, and existence of periodic orbits of Hamiltonian systems and Reeb flows. It explained applications of the 'large machines', such as Floer Theory, Symplectic Field Theory and Fukaya categories, showing where these machines do not yet provide satisfactory answers. Special attention was paid to articulating new problems and directions as well as to explaining interactions between symplectic and contact topology and other fields.

Workshop 5: Symplectic Geometry, Noncommutative Geometry, and Physics

***** Sponsor: Hayashibara Foundation**

May 10, 2010 to May 14, 2010

Organized By: Robbert Dijkgraaf (University of Amsterdam), Tohru Eguchi (Kyoto University), Yakov Eliashberg (Stanford University), Kenji Fukaya (Kyoto University), Yoshiaki Maeda (Keio University), Dusa McDuff (Barnard College, Columbia University), Paul Seidel (Massachusetts Institute of Technology), and Alan Weinstein (University of California, Berkeley)*

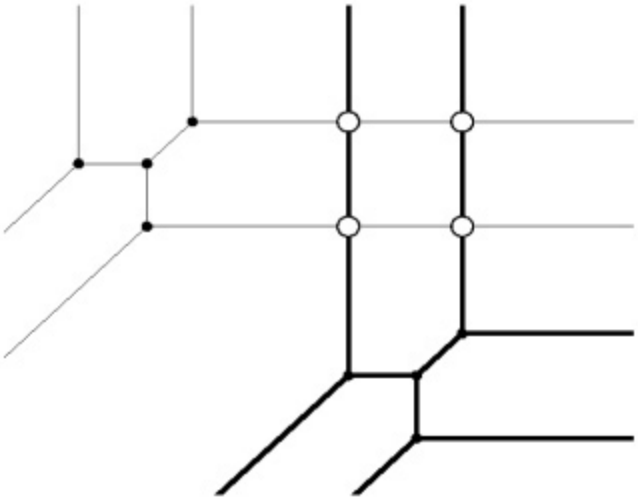
Symplectic geometry originated as a mathematical language for Hamiltonian mechanics, but during the last 3 decades it has witnessed both spectacular development of the mathematical theory and discovery of new connections and applications to Physics. Meanwhile, non-commutative geometry naturally entered into this picture.

The workshop aimed to highlight some of these connections and further boost interactions between mathematicians and physicists working in related areas. It consisted of 4 mini-courses given by Denis Auroux, Robbert Dijkgraaf, Yan Soibelman, and Katrin Wehrheim, as well as lectures given by physicists and mathematicians, such as Manabu Akaho, Michel Van den Bergh, Tohru Eguchi, Bertrand Eynard, Hiroshige Kajiura, Anton Kapustin, Yong-Geun Oh, Hiroshi Ooguri, Yongbin Ruan, Michael Sullivan, Dmitry Tamarkin, and Bruno Vallet.

Program 2: Tropical Geometry

August 17, 2009 to December 18, 2009

Organized By: Eva-Maria Feichtner (University of Bremen), Ilia Itenberg (Université de Strasbourg), Grigory Mikhalkin (Université de Genève), and Bernd Sturmfels (University of California, Berkeley)*



Bézout's Theroem: two tropical conics intersect in four points.*

Tropical Geometry is algebraic geometry over the min-plus algebra. It is a young subject that in recent years has both established itself as an area in its own right and unveiled its deep connections to numerous branches of pure and applied mathematics. From an algebro-geometric point of view, algebraic varieties over a field with non-archimedean valuation are replaced by polyhedral complexes, nevertheless retaining much of the information about the original varieties. From the point of view of complex geometry, the geometric combinatorial structure of tropical varieties is a maximal degeneration of a complex structure on a manifold.[1]

The tropical transition from objects of algebraic geometry to the polyhedral realm is an extension of the classical theory of toric varieties. It opens up problems about algebraic varieties to a completely new set of techniques and has already led to remarkable results in Enumerative Algebraic Geometry, Dynamical Systems, and Computational Algebra, among other fields, and to applications in Algebraic Statistics and Statistical Physics.

The goal of this program was, through its workshops and various other activities, to bring together researchers from the broad range of research areas involved and to provide an extended forum of interaction on Tropical Geometry while it is still in its formative phase.

Workshops associated with the Tropical Geometry Program:

Workshop 1: Connections for Women: Tropical Geometry

August 22, 2009 to August 23, 2009

Organized By: Alicia Dickenstein (University of Buenos Aires) and Eva Maria Feichtner* (University of Bremen)*

The aim of this workshop was to introduce advanced graduate students and postdoctoral fellows to tropical geometry. Various aspects of this multi-faceted field were highlighted in two short courses, comprising lectures and exercise/discussion sessions as well as research talks. The workshop thus provided the participants with an excellent introduction to the forthcoming events of the program.

[1] Illustration from Jürgen Richter-Gebert, Bernd Sturmfels and Thorsten Theobald: First Steps in Tropical Geometry; in: Idempotent mathematics and mathematical physics, Contemp. Math. 377, AMS, 2005, pp. 289–317.

There were two short courses, given by Hannah Markwig (University of Goettingen) and Federico Ardila (San Francisco State University).

Additional research lectures were given by:

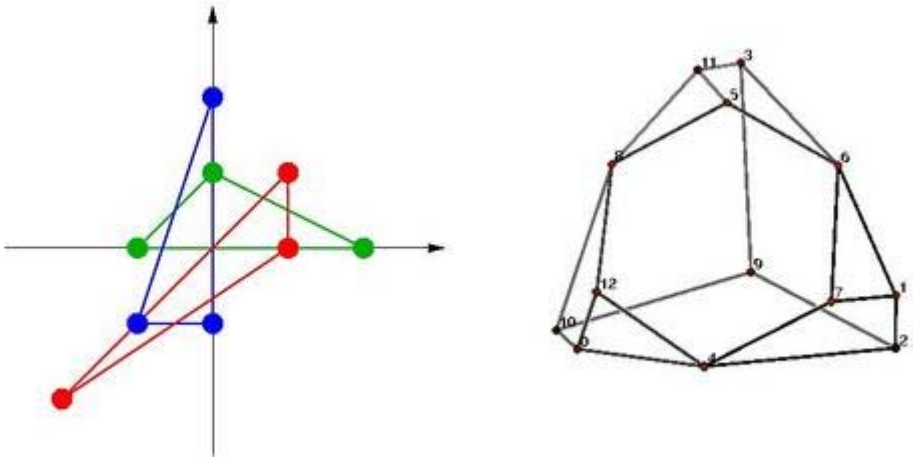
Marianne Akian (Institut National de Recherche en Informatique et en Automatique, Saclay - Ile de France),
Lucia Lopez de Medrano (Universidad Nacional Autonoma de Mexico),
Annette Werner (University of Frankfurt),
Lauren Williams (Harvard University, MSRI), and
Josephine Yu (Massachusetts Institute of Technology, MSRI),

among others.

A session of (very) short contributions, consisting of focused presentations of two to three slides each was also held. This was an important activity of the workshop, and participants of all levels were encouraged to send an abstract to the organizers by email in addition to completing the registration.

The scientific part was complemented by a round table discussion on career issues of female mathematicians. Panelists were: Hélène Barcelo (MSRI), Diane Maclagan (University of Warwick), Lauren Williams (University of California, Berkeley, and MSRI), Josephine Yu (Massachusetts Institute of Technology, and MSRI), and Angelica Cueto (University of California, Berkeley).

Female researchers were particularly encouraged to attend this workshop and were given priority for support of travel and lodging expenses.



An illustration for tropical implicitization from B. Sturmfels, J. Yu: "Tropical implicitization and mixed fiber polytopes", in Software for Algebraic Geometry (editors

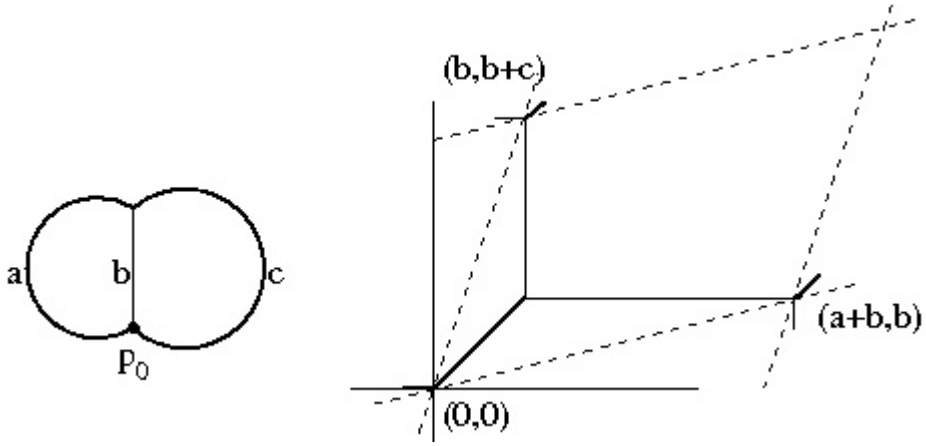
M. Stillman, N. Takayama, and J. Verschelde), I.M.A. Volumes in Mathematics and its Applications 148, Springer, New York, 2008, pp. 111–132.

Workshop 2: Introductory Workshop: Tropical Geometry

August 24, 2009 to August 28, 2009

Organized By: Eva Maria Feichtner (University of Bremen), Ilia Itenberg (University of Strasbourg), Grigory Mikhalkin (Université de Genève), and Bernd Sturmfels (University of California, Berkeley)*

This workshop laid the foundations for the program that followed. Mini-courses comprising lectures and exercise/discussion sessions covered the foundational aspects of tropical geometry as well as its connections with adjacent areas: symplectic geometry, several complex variables, algebraic geometry (in particular enumerative and computational aspects), and geometric combinatorics. The mini-courses were augmented by research talks on current tropical developments in order to open the scene and set up new goals in the beginning of the semester.



"An illustration of the tropical Abel-Jacobi map" from G. Milkhalkin, I. Zharkov: "Tropical curves, their Jacobians and Theta functions," arXiv: math/0612267.

Workshop 3: Tropical Geometry in Combinatorics and Algebra

October 12, 2009 to October 16, 2009

Organized By: Federico Ardila (San Francisco State University), David Speyer (Massachusetts Institute of Technology), Jenia Tevelev (University of Massachusetts, Amherst), and Lauren Williams (University of California, Berkeley)*

This workshop concentrated on tropical methods in Combinatorics and Algebra. Some of the topics explored were

- tropical ideas in combinatorial linear algebra, such as tropical convexity, tropical linear spaces and oriented matroids, tropical matrix algebra and its applications;
- tropical methods in combinatorial representation theory, including both discovery of new formulas and improved understanding of old ones;
- computational issues, including both how to compute tropical objects and how to use tropical tools in other computational settings; and
- applications of tropical methods in algebraic statistics.

Workshop 4: Tropical Structures in Geometry and Physics

November 30, 2009 to December 04, 2009

Organized By: Mark Gross (University of California, San Diego), Kentaro Hori (University of Toronto), Viatcheslav Kharlamov (Université de Strasbourg), and Richard Kenyon (Brown University)*

One of the successes of tropical geometry is its applications to a number of different areas of recently developing mathematics. Among these are enumerative geometry, symplectic field theory, mirror symmetry, dimer models/random surfaces, amoebas and algae, instantons, cluster varieties, and tropical compactifications. While these fields appear quite diverse, the common meeting ground of tropical geometry provided a basis for fruitful interactions between participants.

Program 3: Homology Theories of Knots and Links

January 11, 2010 to May 21, 2010

Organized By: Mikhail Khovanov (Columbia University), Dusa McDuff (Barnard College, Columbia University), Peter Ozsváth (Columbia University), Lev Rozansky (University of North Carolina), Peter Teichner (University of California, Berkeley), Dylan Thurston (Barnard College, Columbia University), and Zoltan Szabó (Princeton University)*

The goals of this program were to:

1. promote communication with related disciplines, including the symplectic geometry program in 2009-2010;
2. lead to new breakthroughs in the subject and find new applications to low dimensional topology (knot theory, three-manifold topology, and smooth four-manifold topology); and
3. educate a new generation of graduate students and PhD students in this exciting and rapidly-changing subject.

The program focused on algebraic link homology and Heegaard Floer homology.

Khovanov's theory of links is a very young and rapidly-developing area drawing on many branches of mathematics. The subject has its roots in representation theory, and it has benefited from its interactions with low dimensional classical and quantum topology and symplectic geometry. In the short period since its birth, link homology has already exhibited the remarkable feature of fusing together many distinct areas of mathematics. We anticipate further connections with hyperbolic geometry, combinatorics, smooth four-manifold topology, string theory, geometric representation theory, and the Langlands program.

From a different direction, Heegaard Floer homology is an invariant for low-dimensional manifolds whose discovery was inspired by gauge theory and its conjectural connections with symplectic geometry. Although this subject grew out of a different mathematical background from Khovanov's theory, the two subjects are clearly coalescing to give a picture of topological quantum field theories in low-dimensional topology.

Workshops associated with the Homology Theories of Knots and Links Program:

Workshop 1: Connections for Women: Homology Theories of Knots and Links

January 21, 2010 to January 22, 2010

Organized By: Elisenda Grigsby (Columbia University), Olga Plamenevskaya (SUNY/Stonybrook University), and Katrin Wehrheim (Massachusetts Institute of Technology)*

This 2-day workshop served as a prelude to the introductory workshop for the semester-long program on homology theories of knots and links. Survey talks in the mornings positioned the work in Khovanov and Heegaard Floer homology in a broader context, focusing on

1) applications to classical questions in low-dimensional topology, and
2) connections to contact and symplectic topology.

Research talks in the afternoons highlighted the range of current activity in the field. We planned a format of no more than four talks each day to allow ample time for presentation opportunities for younger researchers and formal and informal discussions.

Workshop 2: Introductory Workshop: Homology Theories of Knots and Links

January 25, 2010 to January 29, 2010

Organized By: Aaron Lauda (Columbia University), Robert Lipshitz (Columbia University), and Dylan Thurston (Barnard College, Columbia University)*

This workshop introduced the main branches in the study of knot homology theories. It consisted of three mini-courses, one on knot Floer homology and related topics, one on the various approaches to Khovanov and Khovanov-Rozansky homology, and one on categorification on quantum groups. (There were also several stand-alone lectures.) The techniques involved in the three branches are quite different; in particular, Heegaard Floer theory is analytic in nature, with its origin in gauge theory and symplectic geometry, while both Khovanov homology and categorification are more algebraic in nature, with origins in representation theory and algebraic geometry. The workshop provided an opportunity for graduate students and researchers outside the field to gain entry, as well as for researchers working in one part of the field to learn about techniques and developments in other parts.

Workshop 3: Research Workshop: Homology Theories of Knots and Links

March 15, 2010 to March 19, 2010

Organized By: Peter S. Ozsváth (Columbia University), Mikhail Khovanov (Columbia University), and Peter Teichner (University of California, Berkeley)*

Several recent developments have underscored the close parallels between link homology and Floer homological invariants for low-dimensional manifolds.

The aim of this conference was to study recent advances in categorification, link homology, Heegaard Floer homology, and gauge theory. We also focused on the interactions of these tools with low-dimensional topology, including knot theory and contact geometry.

Program 4: Complementary Program 2009–10

Academic year 2009–2010 (August 17, 2009 to May 21, 2010)

MSRI had a small Complementary Program comprised of two postdoctoral fellows, Christopher Hillar and Christopher Severs; one research professor, Burglind Juhl-Joricke; one research member, John Shareshian; and one guest, Stephen Kaliszewski.

Christopher Hillar had just completed a postdoctoral fellowship at Texas A&M University and was contemplating leaving academia. Bernd Sturmfels alerted us to the fact that Hillar was awarded a Young Investigator grant from the NSA and that, given his exceptional talent, it would be a loss to the mathematical community if he were to leave mathematics. We took him as a research member in the Complementary program while we administered his grant. It turned out to be one of MSRI's success stories. In Hillar's own words "…The chance to work at MSRI was life-changing and especially important given my research aspirations in mathematical neuroscience. It is challenging to work at the intersection of these two fields, and I attribute much of my ongoing success to the opportunities, encouragement, and support that MSRI has offered me." Hillar went on to obtain a joint postdoctoral fellowship with MSRI and the Redwood Center for

Theoretical Neuroscience at UCB. His mentor, Dr. Bruno Olshausen, is the Redwood Center's director. The Center's goal is to develop mathematical and computational models of the underlying neurobiological mechanisms involved in perception, cognition, learning, and motor function. The scientists collaborate with experimental neuroscience labs in the design of experiments and in the analysis of neural data. It has been a rewarding experience for MSRI to see one of its members branch out so successfully.

Christopher Severs was at MSRI for the academic year 2009-10 working with Deputy Director Hélène Barcelo, his mentor. His work on k-equal arrangements, in collaboration with Arizona State University graduate student Jacob White was accepted for publication in the Transactions of the American Mathematical Society. In addition, Dr. Severs' time at MSRI opened doors to other joint works, for example with John Shareshian of Washington University at St. Louis. He continues his career with a postdoctoral research position at Reykjavik University in Iceland for the academic year 2010-11. According to Dr. Severs, his "time at MSRI has greatly shaped his future research career…. He feels very fortunate to have had this chance to work at MSRI and is looking forward to coming back for another program in the future."

B. Other Scientific Workshop

Workshop 1: Hot Topics: Black Holes in Relativity

September 14, 2009 to September 18, 2009

Organized By: Mihalis Dafermos (University of Cambridge) and Igor Rodnianski (Princeton University)*

The mathematical study of the dynamics of the Einstein equations forms a central part of both partial differential equations and geometry and is intimately related to our current physical understanding of gravitational collapse. The celebrated singularity theorems of Penrose, proven in the 1960s, showed that geodesic incompleteness is inevitable provided that initial data contain what is known as a closed trapped surface. Trapped surfaces are also related to the presence of black holes. A breakthrough in the understanding of trapped surface formation has recently been achieved by Christodoulou in his 600-page monograph, "The formation of black holes in General Relativity", Publications of the EMS, January 2009, where it is shown that trapped surfaces can form in evolution for the Einstein vacuum equations from completely dispersed initial configurations, a phenomenon caused purely by the focusing of gravitational waves. The proof brings together ideas from geometric analysis and non-linear hyperbolic equations and, at the same time, introduces new techniques adapted to large data problems. The methods will undoubtedly have many future applications in both general relativity and other equations of mathematical physics. In particular, the work provides the first global 'large data' result in general relativity (without symmetry assumptions) and opens the possibility for many new developments on dynamical problems relating to black holes.

Workshop 2: Bay Area Differential Geometry Seminar (November 2009)

November 21, 2009

Organized By: Robert Bryant (MSRI), Joel Hass (University of California, Davis), David Hoffman (Stanford University), Rafe Mazzeo (Stanford University), and Richard Montgomery (University of California, Santa Cruz)*

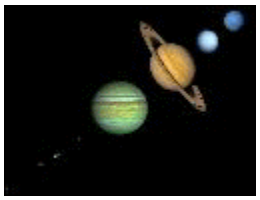
The Bay Area Differential Geometry Seminar meets around 3 times each year and is a 1-day seminar on recent developments in differential geometry and global analysis, broadly interpreted. Typically, it runs from mid-morning until late afternoon, with 3-4 speakers.

This instance of the seminar featured three speakers: Jacob Bernstein, *The asymptotic geometry of genus-g helicoids*; Clifford Taubes, *The Seiberg-Witten equations and the dynamics of vector fields in dimension 3*; and Hyam Rubinstein, *Generic spines and cut loci of Riemannian manifolds*.

Workshop 3: Macaulay2 Workgroup

January 4, 2010 to January 8, 2010

Organized By: David Eisenbud (University of California, Berkeley), Amelia Taylor (Colorado College), Hirotachi Abo (University of Idaho), Mike Stillman (Cornell University) and Dan Grayson (University of Illinois, Urbana-Champaign)*



Macaulay2 is a software system devoted to supporting research in algebraic geometry and commutative algebra. Its creation and development have been funded by the National Science Foundation since 1992.

Macaulay2 includes core algorithms for computing Gröbner bases and graded or multi-graded free resolutions of modules over quotient rings of graded or multi-graded polynomial rings with a monomial ordering. The core algorithms are accessible through a versatile high level interpreted user language with a powerful debugger supporting the creation of new classes of mathematical objects and the installation of methods for computing specifically with them. *Macaulay2* can compute Betti numbers, Ext, cohomology of coherent sheaves on projective varieties, primary decomposition of ideals, integral closure of rings, and more.

The goal of the workshop was to work at improving and augmenting the functionality of some of the existing packages. Likely projects included computing sheaf cohomology, intersection theory, and enumerative geometry.

Workshop 4: Bay Area Differential Geometry Seminar (April 2010)

April 17, 2010

Organized By: Robert Bryant (MSRI), Joel Hass (University of California, Davis), David Hoffman (Stanford University), Rafe Mazzeo (Stanford University), and Richard Montgomery (University of California, Santa Cruz)*

The Bay Area Differential Geometry Seminar meets around 3 times each year and is a 1-day seminar on recent developments in differential geometry and global analysis, broadly interpreted. Typically, it runs from mid-morning until late afternoon, with 3-4 speakers.

This instance of the seminar featured three speakers: Robert Bryant, *Classification of locally conformally flat Ricci solitons*; Xianshe Dai, *Intersection R-torsion and analytic torsion for manifolds with conical singularity*; Masood Ul-Alam, *Proof that static stellar models are spherical*.

Workshop 5: Symplectic and Poisson Geometry in interaction with Algebra, Analysis, and Topology

May 04, 2010 to May 07, 2010

Organized By: Yakov Eliashberg (Stanford University), Alvaro Pelayo (University of California, Berkeley), Steve Zelditch (Northwestern University), and Maciej Zworski (University of California, Berkeley)*

The first week of May 2010 coincided with the one-year anniversary of Alan Weinstein's retirement from UC Berkeley. Weinstein has been one of the most influential figures in symplectic geometry, Poisson geometry and analysis in the past forty years. Weinstein's fundamental work inspired many others and led to the development of central concepts in symplectic and Poisson geometry, as well as to the establishment of symplectic geometry as an independent discipline within mathematics. This conference was a forum to celebrate Weinstein's fundamental contributions to geometry and mathematics at large.

C. Educational & Outreach Activities

Workshop 1: Bay Area Circle For Teachers Summer Workshop

June 28, 2009 to July 02, 2009

Organized By: Brandy Wiegers (MSRI)

The aim of the Circle for Teachers is to equip educators with an effective problem-solving approach to teaching mathematics. This style of learning is based on the math circle environment that has proven to be successful for students around the world. The

workshop immersed a group of interested middle and high school math teachers in engaging mathematics and exposed them to a dynamic style of classroom presentation. Participants come away with a variety of resources, lesson modules, and a renewed sense of appreciation for the fascinating world of mathematics. Teachers were also eligible for continuing education credit, professional development units, or college course credits.

A major theme throughout the workshop was creatively answering the question of how to incorporate a problem-solving approach to math education into the existing curriculum. To this end, leaders supplied participants with handouts or short modules based on the material covered during their sessions. They also worked with teachers to share ideas for enlivening any math class and to develop lesson plans. Focused discussions were held regularly to determine what obstacles exist to incorporating this style of teaching into the present curriculum, what resources would be most helpful to teachers, and other related topics.

For more information about the BACT series, see the Bay Area Circle for Teachers website at http://bact.mathcircles.org.

Workshop 2: Summer Institute for the Professional Development of Middle School Teachers on Pre-Algebra (Wu Summer Institute)

July 06, 2009 to July 24, 2009

Organized By: Hung-Hsi Wu (University of California, Berkeley), Stefanie Hassan (Little Lake City School District), Winnie Gilbert (Hacienda La Puente Unified School District), and Sunil Koswatta (Harper College)

This was a 21-day workshop (July 6 to July 24, 2009) on pre-algebra followed by 5 Saturday sessions spread over the 2009-2010 school year. The targeted audience was middle school teachers.

Workshop 3: Bay Area Circle for Teachers Winter Workshop

January 30, 2010

Organized By: Brandy Wiegers (MSRI)

This was a continuation of the BACT series of workshops (for more information, see the description under Workshop 1 in this section).

For more information about this particular workshop, see the Bay Area Circle for Teachers Winter Workshop page at http://bact.mathcircles.org/winter.

D. 2009 Summer Graduate Workshops

Workshop 1: Toric Varieties

June 15, 2009 to June 26, 2009

Organized By: David Cox (Amherst College) and Hal Schenck (University of Illinois)

Toric varieties are algebraic varieties defined by combinatorial data, and there is a wonderful interplay between algebra, combinatorics and geometry involved in their study. Many of the key concepts of abstract algebraic geometry (for example, constructing a variety by gluing affine pieces) have very concrete interpretations in the toric case, making toric varieties an ideal tool for introducing students to abstruse concepts.

Workshop 2: IAS/PCMI Summer Program: The Arithmetic of L-functions

June 28, 2009 to July 18, 2009

Location: IAS/Park City Mathematics Institute, Salt Lake City, UT

Organized By: Cristian Popescu (UCSD), Karl Rubin (UC Irvine), and Alice Silverberg (UC Irvine)

For information, please visit IAS/PCMI application homepage

Workshop 3: Random Matrix theory

July 06, 2009 to July 17, 2009

Organized By: Jinho Baik (University of Michigan), Percy Deift (New York University), Toufic Suidan (University of Arizona), and Brian Rider (University of Colorado)*

The goal of this workshop was two-fold: (1) to describe many of the recent advances that have been made in the application of random matrix theory to problems in mathematics and physics and (2) to develop some of the mathematical tools that are needed to enter the field. Applications of random matrix theory are now being made to number theory, combinatorics, statistical physics, and statistics, amongst other fields. The techniques employed in the field include methods from integrable systems, combinatorics, complex analysis, orthogonal polynomials, and, of course, random matrix theory, *per se*.

Workshop 4: Inverse Problems

July 20, 2009 to July 31, 2009

Organized By: Gunther Uhlmann (University of Washington)*

Inverse Problems are problems where causes for a desired or an observed effect are to be determined. They lie at the heart of scientific inquiry and technological development.

Applications include a number of medical as well as other imaging techniques, location of oil and mineral deposits in the earth's substructure, creation of astrophysical images from telescope data, finding cracks and interfaces within materials, shape optimization, model identification in growth processes and, more recently, modeling in the life sciences.

The workshop consisted of several mini-courses addressing several of the theoretical and practical issues arising in inverse problems including boundary rigidity and travel-time tomography, cloaking and invisibility, electrical impedance imaging, statistical methods and biological applications, thermo-acoustic and x-ray tomography, and resonances.

Workshop 5: Computational Theory of Real Reductive Groups (Salt Lake City)

July 20, 2009 to July 24, 2009

Location: Salt Lake City -- University of Utah

Organized By: Jeffrey Adams (University of Maryland), Peter Trapa (University of Utah), Susana Salamanca (New Mexico State University), John Stembridge (University of Michigan), and David Vogan (Massachusetts Institute of Technology)*

The structure of real reductive algebraic groups is controlled by a remarkably simple combinatorial framework, generalizing the presentation of Coxeter groups by generators and relations. This framework in turn makes much of the infinite-dimensional representation theory of such groups amenable to computation. The Atlas of Lie Groups and Representations project is devoted to looking at representation theory from this computationally informed perspective. The group (particularly Fokko du Cloux and Marc van Leeuwen) has written computer software aimed at supporting research in the field and at helping those who want to learn the subject. The workshop explored this point of view in lecture series aimed especially at graduate students and postdocs with only a modest background (such as the representation theory of compact Lie groups).

Workshop 6: Symplectic and Contact Geometry and Topology

August 03, 2009 to August 14, 2009

Organized By: John Etnyre (Georgia Institute of Technology), Dusa McDuff (Barnard College, Columbia University), and Lisa Traynor (Bryn Mawr College)*

Symplectic and Contact Topology has undergone rapid and exciting growth in the past few decades and is currently a rich subject, employing a variety of diverse techniques and touching on many areas of mathematics, such as algebraic and differential geometry, dynamical systems, and low dimensional topology.

This workshop was intended both for graduate students new to the area and for those working in the field. Lectures in the first week introduced participants to basic

topological, geometric and analytic techniques, including J-holomorphic curves. The second week discussed applications to symplectic geometry and to 3-dimensional topology and knot theory. A variety of discussion sessions in the afternoon catered to the differing interests of the students.

Participants could stay for the Connections for Women and/or the Introductory workshop to the year-long program *Symplectic and Contact Geometry and Topology*, which started just after this workshop.

E. MSRI-UP 2009: Coding Theory

June 15, 2009 to July 24, 2009

Organized By: Duane Cooper (Morehouse College), Suzanne Weekes (Worcester Polytechnic Insitute), Ricardo Cortez (Tulane University), Ivelisse Rubio (University of Puerto Rico, Río Piedras), and Herbert Medina (Loyola Marymount University)

The MSRI-UP summer program is designed for undergraduate students who have completed two years of university-level mathematics courses and would like to conduct research in the mathematical sciences. The academic portion of the program was led by John B. Little, Professor of Mathematics at College of the Holy Cross. Dr. Little has done research in many mathematical fields including computational algebra and coding theory and has extensive experience with directing undergraduate research. Indeed, he has worked in Research Experience for Undergraduates (REUs) in both the U.S. and Puerto Rico.

During the summer, each of the 18 student participants

- participated in the mathematics research program under the direction of Dr. Little,
- completed a research project done in collaboration with other MSRI-UP students,
- gave a presentation and wrote a technical report on his/her research project,
- attended a series of colloquium talks given by leading researches in their fields,
- attended workshops aimed at developing skills and techniques needed for research careers in the mathematical sciences,
- learned techniques that will maximize a student's likelihood of admissions to graduate programs as well as the likelihood of winning fellowships, and
- received a $3000 stipend, lodging, meals and roundtrip travel to Berkeley, CA.

After the summer, each student

- had an opportunity to attend a national mathematics or science conference where students presented their research,
- became part of a network of mentors that will provide continuous advice in the long term as the student makes progress in his/her studies, and
- was contacted regarding future research opportunities.

The main objective of MSRI-UP is to identify talented students, especially those from underrepresented groups, who are interested in mathematics and make available to them meaningful research opportunities, the necessary skills and knowledge to participate in successful collaborations, and a community of academic peers and mentors who can advise, encourage and support them through a successful graduate program.

The objective is designed to contribute significantly toward meeting the program goal of increasing the number of graduate degrees in the mathematical sciences, especially doctorates, earned by U.S. citizens and permanent residents by cultivating heretofore untapped mathematical talent within the U.S. Black, Hispanic/Latino and Native American communities.

III. PARTICIPATION SUMMARY

The table below indicates the number of participants for each activity that took place at MSRI during the 2009-10 academic year.

Table 1
Programs and Workshops Participation in 2009-10

Time	*Activity Type*	*Name*	*No. of Participants*	*MSRI Postdocs*	*PD/RMs*
Whole year 09-10	Scientific Program	Symplectic and Contact Geometry and Topology	97	Buhovsky, Lev Gadbled, Agnes Kutluhan, Cagatay Lekili, Yanki Ma'u, Sikimeti McLean, Mark Parker, Brett Vertesi, Vera Golovko, Roman He, Jian Savelyev, Yasha Fabert Oliver	Cotton-Clay, Andrew Maydansky, Maksim
08/14/09 to 08/15/09	Programatic Workshop	Connections for Women: Symplectic and Contact Geometry and Topology	33		
08/17/09 to 08/21/09	Programatic Workshop	Introductory Workshop: Symplectic and Contact Geometry and Topology	103		
11/16/09 to 11/20/09	Programatic Workshop	Algebraic Structures in the Theory of Holomorphic Curves	100		
03/22/10 to 03/26/10	Programatic Workshop	Symplectic and Contact Topology and Dynamics: Puzzles and Horizons	125		
05/10/10 to 05/14/10	Programatic Workshop funded by Hayashibara Foundation	Symplectic Geometry, Noncommutative Geometry and Physics	76		
Fall 2009	Scientific Program	Tropical Geometry	62	Bogart, Tristram Brugalle, Erwan Katz, Eric Lopez, de Medrano, Lucia Nill, Benjamin Stapledon, Alan Williams, Lauren (NSA Funded) Nisse, Mounir	Musiker, Gregg Parker, Brett Tabera, Luis Yu, Josephine Payne, Sam Manon, Christopher
08/22/09 to 08/23/09	Programatic Workshop	Connections for Women: Tropical Geometry	73		
08/24/09 to 08/28/09	Programatic Workshop	Introductory Workshop: Tropical Geometry	102		
10/12/09 to 10/16/09	Programatic Workshop	Tropical Geometry in Combinatorics and Algebra	87		
11/30/09 to 12/04/09	Programatic Workshop	Tropical Structures in Geometry and Physics	80		
Spring 2010	Scientific Program	Homology Theory of Knots & Links	64	Grigsby, Julia Elisenda Kutluhan, Cagatay (SCGT) Lekili, Yanki (SCGT) Vertesi, Vera (SCGT) Wehrli, Stephan Martin Krasner, Daniel Lobb, Andrew Jay Sazdanovic, Radmila	Morrison, Scott Sarkar, Sucharit Vela Vick, David Shea Horn, peter Douglas
01/21/10 to 01/22/10	Programatic Workshop	Connections for Women: Homology Theories of Knots and Links	58		
01/25/10 to 01/29/10	Programatic Workshop	Introductory Workshop: Homology Theories of Knots and Links	108		
03/15/10 to 03/19/10	Programatic Workshop	Research Workshop: Homology Theories of Knots and Links	137		

Time	Activity Type	Name	No. of Participants	MSRI Postdocs	PD/RMs
Whole year 09-10	Scientific Program	Complementary Program 2009-10	6	Christopher Hillar (NSA Funded) Christopher Severs (NSA Funded)	
09/14/09 to 09/18/09	Scientific Workshop	Hot Topics: Black Holes in Relativity	52		
11/21/09 to 11/21/09	Scientific Workshop	Bay Area Differential Geometry Seminar (November 2009)	25		
01/04/10 to 01/08/10	Scientific Workshop	Macaulay2 Workgroup	20		
04/17/10 to 04/17/10	Scientific Workshop	Bay Area Differential Geometry Seminar (April 2010)	27		
05/04/10 to 05/07/10	Scientific Workshop	Symplectic and Poisson Geometry in interaction with Algebra, Analysis and Topology	74		
06/28/09 to 07/02/09	Educational & Outreach Workshop	Bay Area Circle For Teachers 2009-2010	30		
07/06/09 to 07/24/09	Educational & Outreach Workshop	Summer Institute for the Professional Development of Middle School Teachers on Pre-Algebra (Wu Summer Institute)	25		
01/30/10 to 01/30/10	Educational & Outreach Workshop	Bay Area Circle For Teachers Winter Workshop	51		
				No. of Academic Sponsored student	*No. of Non-academic sponsored students*
06/15/09 to 06/26/09	Summer Graduate Workshop	Toric Varieties	49	41	8
06/28/09 to 07/18/09	Summer Graduate Workshop	IAS/PCMI Summer Program: The Arithmetic of L-Functions	5	N/A	N/A
07/06/09 to 07/17/09	Summer Graduate Workshop	Random Matrix Theory	39	32	7
07/20/09 to 07/31/09	Summer Graduate Workshop	Inverse Problems	46	34	12
07/20/09 to 07/24/09	Summer Graduate Workshop	Computational Theory of Real Reductive Groups (Salt Lake City)	10	N/A	N/A
08/03/09 to 08/14/09	Summer Graduate Workshop	Symplectic and Contact Geometry and Topology	49	35	14
06/15/09 to 07/24/09		MSRI-UP 2009	17		

MSRI allocated NSF, NSA and private funding to support 25 postdoctoral fellows during the 2009-10 academic year. Of those 25 postdoctoral fellows, 3 were financially supported by the NSA Practical & Intellectual H98230-09-1-0095 Grant.

NSA Practical & Intellectual H98230-09-1-0095 Grant supported Postdoctoral Fellow number one: Lauren Williams. Dr. Williams was given a stipend (plus fringe benefits) for 5 months for her participation in Tropical Geometry Program. Below is the information regarding her work during her stay at MSRI:

Lauren Williams

Lauren received her Ph.D from Massachusetts Institute of Technology in 2005 under the supervision of Richard Peter Stanley. Her dissertation was titled "Combinatorial Aspects of Total Positivity." While at MSRI Lauren continued thinking about total positivity and its connections to tropical geometry. She also investigated the connections between Teichmuller theory and tropical geometry, via cluster algebras associated to surfaces. But probably the most beneficial aspects of her postdoc at MSRI, according to Lauren, was establishing new contacts. She had several very interesting discussions with Mark Gross about mirror symmetry and possible connections to cluster algebras. She also met several time with her mentor Grisha Mikhalkin, who explained to her the Thurston compactification of Teichmuller space. In addition, she met Rick Kenyon and had several very interesting discussions with him, which may lead to a joint project. After her stay at MSRI, Lauren took on a position of assistant professor at the University of California, Berkeley.

NSA Practical & Intellectual H98230-09-1-0095 Grant supported Postdoctoral Fellow number two: Christopher Hillar. Dr. Hillar was given a stipend (plus fringe benefits) for 6 months for his participation in Complementary Program. In addition to his MSRI stipend, Dr. Hillar had his own NSA Young Investigator Grant that supported him for 2 summer months. Below is the information regarding his work during his stay at MSRI:

Christopher Hillar

Christopher received his Ph.D. from Berkeley in 2005 under the supervision of Bernd Sturmfels. His dissertation was titled "Solving Polynomial Systems with Special Structure." In his time at MSRI Christopher worked on applications of compressed sensing to sparse coding with Fritz Sommer at the Redwood Institute for Theoretical Neuroscience. They have submitted their work to a NIPS conference and will be finishing up a journal article in the next month. He has also been collaborating with Lek-Heng Lim at Berkeley on the computational complexity of tensor decompositions. They should also have a paper out in the next few months. Finally, he has been working with Pentti Kanerva and Fritz Sommer on the mathematics underlying a new computational paradigm, "Hyperdimensional Computing." With it, they hope to understand and model complex systems that appear to be turing incompatible. After his stay at MSRI, Christopher went on to the Redwood Center for Theoretical Neuroscience.

NSA Practical & Intellectual H98230-09-1-0095 Grant supported Postdoctoral Fellow number three: Christopher Severs. Dr. Severs was given a stipend (plus fringe benefits) for 10 months of his participation in Complementary Program. Below is the information regarding his work during his stay at MSRI:

Christopher Severs

Christopher completed his Ph.D at Arizona State University in 2009 under the supervision of Hélène Barcelo. His dissertation was titled "On the Discrete Fundamental Groups of the Associahedron and Cyclohedron." During his time at MSRI, Christopher worked on some real subspace arrangements, called k-equal arrangements, with Hélène Barcelo and Jacob White. Their work was accepted for publication in the Transactions of the American Mathematical Society. Further work by Christopher and Jacob White on this subject was accepted for a presentation at the International Conference on Formal Power Series and Algebraic Combinatorics in San Francisco. While at MSRI, Christopher also started a collaboration with John Shareshian of Washington University at St. Louis. This work is in its early stages but has so far yielded results that have applications in computational group theory. After leaving MSRI, Christopher accepted a 2-year postdoctoral research position at Reykjavik University in Iceland.

IV. PUBLICATIONS SUMMARY

14 research members (including three postdoctoral fellows) were funded either entirely or partially by NSA Practical & Intellectual (P&I) Grant # H98230-09-1-0095. These members worked on a total of 48 papers during their stay at MSRI. The 48 papers are summarized as follow:

Manuscript Status	*Number of paper*
Accepted & Appeared	14
Submitted	3
Posted	2
Rough/Draft	18
Notes	11
Total	**48**

The table below provides complete details of the accepted & appeared, submitted and posted papers:

Table 2
List of Publications
from NSA funded scientists

Author	Title	Co-Author(s)	Manuscript Status	Comments
Lauren Williams	Staircase tableaux, the ASEP, and Askey-Wilson polynomials	Sylvie Corteel	Accepted and Appeared	
Chris Severs	Title: k-Parabolic Subspace Arrangments	Helene Barcelo, Jacob White	Accepted and Appeared	Trans. Amer. Math. Soc.
Mark Gross	Tropical geometry and mirror symmetry for P^2		Accepted and Appeared	I worked on a revision of this paper during my stay-it is now accepted and published.
Mark Gross	The Tropical Vertex	Rahul Pandharipande; Bernd Siebert	Accepted and Appeared	I worked on a revision of this paper during my stay-it is now accepted.
Mark Gross	Quivers, curves and the tropical vertex	Rahul Pandharipande	Accepted and Appeared	I wrote this paper while at MSRI.
Federico Ardila	Root polytopes and growth series of root lattices	M, Beck, S. Hosten, J. Pfeifle, and K. Seashore	Accepted and Appeared	Put the finishing touches on this.
Federico Ardila	Matroid polytopes and their volumes	C. Benedetti and J. Doker	Accepted and Appeared	Put the finishing touches on this.
Federico Ardila	Tilings	R. Stanley	Accepted and Appeared	Put the finishing touches on this. Also translated it to Spanish - that version was accepted also.
Satyan Devadoss	Particle Collisions on Graphs	Rahul Shah	Accepted and Appeared	
Satyan Devadoss	(BOOK) Discrete and Computational Geometry	Joe O'Rourke	Accepted and Appeared	Talks with Chris Manon and Bernd Sturmfels (both MSRI) were great.
Anton Leykin	Certified Numerical Homotopy Tracking	Carlos Beltran	Accepted and Appeared	
John Shareshian	Eulerian quasisymmetric functions	MIchelle Wachs	Accepted and Appeared	We made revisions in response to a referee's report on a paper that will appear in Advances in Mathematics.
John Shareshian	Eulerian quasisymmetric functions and cyclic sieving	Bruce Sagan, Michelle Wachs	Accepted and Appeared	We made revisions in response to a referee's report on a paper that will appear in a special issue of Advances in Applied Mathematics in honor of Dennis Stanton.
John Shareshian	Non-right orderable 3-manifold groups	Rachel Roberts	Accepted and Appeared	We made final revisions to a paper that will appear in the Canadian Mathematical Bulletin.
Lauren Williams	Tableaux combinatorics for the asymmetric exclusion process and Askey-Wilson polynomials	Sylvie Corteel	Submitted	
Mark Gross	Mirror symmetry via logarithmic degeneration data II	Bernd Siebert	Submitted	I worked on a revision of this paper during my stay-it is now pending a final decision.
Anton Leykin	Numerical Algebraic Geometry for Macaulay2		Submitted	
Chris Severs	Pentagonal Relations in the Type-A Cluster Algebra	Helene Barcelo, Jacob White	Posted	Extended Abstract accepted to FPSAC conference.
Lenhard Ng	Legendrian and transverse twist knots	John Etnyre, Vera Vertesi	Posted	Completed while at MSRI.