Fall 2022

EMISSARY

Mathematical Sciences Research Institute

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A New Name for MSRI as our 40th Anniversary Begins!

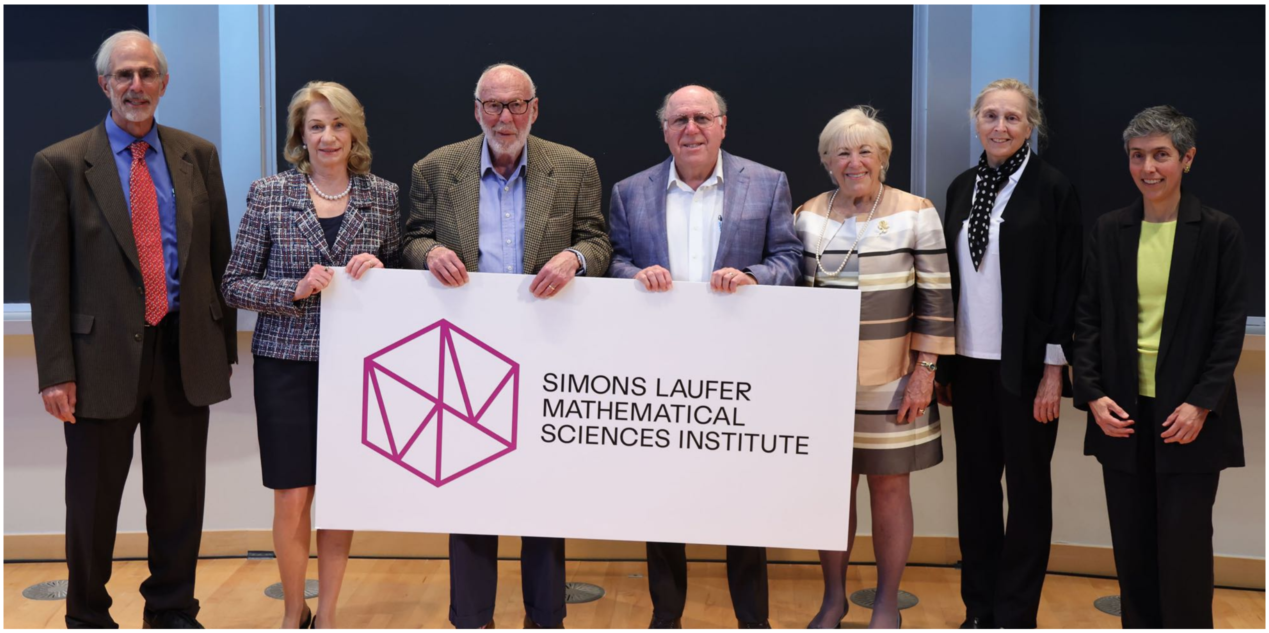

Photo by Jason Maze

David Eisenbud, Marilyn Simons, Jim Simons, Henry Laufer, Marsha Laufer, Hélène Barcelo, and Tatiana Toro celebrate at the Endowment Campaign Launch & Luncheon on May 18, 2022.

At the May 18, 2022, Committee for Academic Sponsors annual meeting, former director David Eisenbud announced that two families have joined together to bestow a transformational and unrestricted $70 million gift as part of MSRI's ongoing $100M endowment campaign.

James and Marilyn Simons and **Henry and Marsha Laufer**, each longtime supporters of MSRI, believe deeply in the mission and strategic vision of MSRI and have each committed $35 million to support the institute's community-driven programs and initiatives both in Berkeley and worldwide.

Inspired by the generosity of these families and their commitment to safeguarding our mission, MSRI is renaming the institute to the **Simons Laufer Mathematical Sciences Institute (SLMath)** in honor of the joint gift. The name change was effective as of August 1, 2022, with changes rolling out through the entire 2022–23 academic year.

Dr. James Simons is a renowned mathematician, philanthropist, and investor, and

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There's still time to join the endowment campaign — see page 16 for more on how you can contribute.

A New Era

SLMath Director Tatiana Toro reflects on the generosity that makes possible MSRI/SLMath's wonderful growth, kicks off our 40th Anniversary celebrations, and welcomes everyone to join in making the path that will lead SLMath into its next era in the **View column** on page 2.

Also in the Fall Emissary:

- As always, catch up with this semester's world class mathematics programs: **Floer Homotopy Theory** (page 10) and **Analytic and Geometric Aspects of Gauge Theory** (page 4).
- Thirteen summer graduate schools plus ADJOINT, MSRI-UP, and SRiM made for a **summer to remember** (page 13).
- Mint some coins and bring your goats as Joe and Tanya welcome a special guest contributor to the **Puzzles column** (page 15).

The View from MSRI

Tatiana Toro, Director

Generosity & Growth

On August 1, MSRI became the Simons Laufer Mathematical Sciences Institute (SLMath) and I became its Director. I feel honored to have been selected and excited to be taking the helm at a time filled with potential. As I begin my term as Director, I would like to express my gratitude for David Eisenbud's devoted service to MSRI as the former Director.

Looking to the future, I am thrilled to report that we have now reached 97% of our goal of $100 million in new pledges and gifts for our endowment campaign as of the time of writing. Thanks to our generous donors, this endowment will provide the necessary funding for new initiatives, as well as the expansion of our programming for both research and public understanding of mathematics. I invite the mathematical community to join me in giving to the campaign, and I am certain that together, we will successfully achieve our campaign goal.

We're Turning 40!

In August 1982, MSRI opened its doors in the UC Extension Building with a program in Nonlinear Partial Differential Equations. Forty years later, in August 2022, we opened our doors at 17 Gauss Way to two programs: Floer Homotopy Theory and Analytic and Geometric Aspects of Gauge Theory. The latter is a natural evolution of the 1982 program, and thus it is not surprising that the intersection between the participants in this semester's gauge theory program and our first-ever program is non-empty.

To kick off our 40th anniversary celebration, I was interviewed in front of a live and virtual audience by Trustee Dario Villani, followed by a Q&A with the attendees. Of the many wonderful questions I was asked, I would like to share the answers to a couple of them. (You can view the full interview online.)

"How do you plan to get a much broader audience to contribute to MSRI/SLMath?"

Past program participants often share that their time at MSRI changed the trajectories of their academic careers and was key to their current successes. This is certainly true for me. I invite all whose lives have intersected with MSRI to consider the institute's impact and how they might support others to have a similar experience.

"Why did you take the job?"

When I was first asked whether I would be interested in applying, I took time to reflect on my life and future. My involvement with MSRI began in Fall 1997, when I was a research member in the Harmonic Analysis program. Years later, I served a five-year term as a member, then co-chair, of the Scientific Advisory Committee (SAC). As co-chair, I was an ex-officio Board member, representing the SAC's interests on the Board and participating in the Institute's governance, attending Board and Steering Committee meetings.

In my varied roles at MSRI, which have spanned my academic career, it became clear to me that MSRI was an excellent vehicle to meaningfully contribute to and impact the mathematical sciences community. MSRI/SLMath is a place where new ideas come to life, and this made the job very appealing.

Photo by Aaron Fagerstrom

Trustee Dario Villani with Tatiana Toro

Breakthrough Prizes

Congratulations to all the 2023 Breakthrough Prize Foundation awardees! It is exciting to see that five of the prizewinners are former MSRI postdocs, organizers, or research members, and one a participant in the Summer Research in Mathematics (SRiM) program. David Deutsch was an organizer of the Quantum Computation program in the fall of 2002. Peter Shor was a postdoc at MSRI in 1985–86 and participated in the 2002 Quantum Computation program. Ana Caraiani attended Hot Topics workshops in 2018 and 2019. Ronen Eldan and James Maynard were research members in two different programs in the fall of 2017. Jinyoung Park was a 2022 SRiM participant.

Making Our Own Path Together

I finish this note with a 1912 poem by Antonio Machado that my parents quoted whenever I found myself at a crossroads. A possible translation of the second sentence of that poem is: Traveler, there is no road; you make your own path as you walk.

I see SLMath, the mathematical community and the participants in our programs as travelers. SLMath is making its path by walking hand-in-hand with the mathematical community to foster math-

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ematical research, develop talent in future generations, create a welcoming environment, and cultivate an appreciation of the power, beauty, and enjoyment of mathematics for all.

We value each individual path walked by our participants, and their lived experiences enrich everyone's experiences at SLMath.

40th Anniversary Celebration Events

Sep 29, 2022: *MSRI/SLMath 40th Anniversary Kickoff Event.* Even if you missed it, a video of the kickoff event is available online.

Oct 20, 2022: *Art Reception* featuring the works of painter Wosene Worke Kosrof. (See the PUM Update on page 9.)

Apr 13-15, 2023: *MSRI/SLMath 40th Anniversary Symposium (Berkeley, CA)* — Save the date!

Additional anniversary events will be announced through the year.

Caminante, no hay camino
(Traveler, there is no road)
By Antonio Machado

Caminante, son tus huellas el camino y nada más:
Caminante, no hay camino, se hace camino al andar.
Al andar se hace el camino, y al volver la vista atrás se ve la senda que nunca se ha de volver a pisar.
Caminante, no hay camino sino estelas en el mar.

Traveler, your footprints are the only road, nothing else.
Traveler, there is no road; you make your own path as you walk.
As you walk, you make your own road, and when you look back you see the path you will never travel again.
Traveler, there is no road; only a ship's wake on the sea.

A New Name for MSRI*!*

(continued from page 1)

former chair of the Simons Foundation. He and his wife, Dr. Marilyn Simons, an economist and philanthropist, were among the institute's first donors upon its creation in 1982. The family has remained supportive of the institute's programs and public outreach initiatives over its history. In 2007, the family made a $10 million gift to endow a professorship to support distinguished mathematicians visiting MSRI and an additional gift several years later to help launch the National Math Festival, the Mathical Book Prize for youth literature, and other programs that serve to raise the public profile of mathematics and to advance basic research.

Dr. Henry Laufer is a fellow mathematician and former Vice President of Research at Simons' Renaissance Technologies. He and his wife, Dr. Marsha Laufer — renowned philanthropist, political activist, and speech-language pathologist — have supported MSRI for more than 20 years. The Laufers' $35 million pledge is their largest gift to MSRI.

Their donations will be coupled with an additional $27 million in gifts from other donors, providing endowed funding that will support the institute's research and programs.

MSRI extends our deepest gratitude to all of our supporters and advisors who have contributed to our 40th Anniversary Endowment Campaign. **A complete list of donors will be shared in the Spring 2023 newsletter.**

We are 97% of the way to our campaign goal. If you would like to help us reach that goal and support mathematical research and outreach at SLMath, there is still time to do so by contacting Annie Averitt, Director of Advancement and External Relations, at development@msri.org.

Donoho Postdoctoral Fellowship

We're excited to announce that the Donoho poststdoctoral fellowship has been established by Dr. David Donoho and Dr. Miriam (Miki) Gasko Donoho; the first fellowship was awarded this semester. David Donoho is best known for coining the term "compressed sensing" while proposing a method for speeding up signals acquisition and reconstruction that today is used in MRI scanners by GE, Siemens, and Philips. He received an A.B. in statistics from Princeton and a Ph.D. in statistics from Harvard University. He has served on the faculties at UC Berkeley and Stanford University, and has also worked in industry in oil exploration, information technology, and quantitative finance.

David Donoho

Dr. Donoho is a member of the American Academy of Arts and Sciences and the National Academy of Sciences, and is a Foreign Associate of the French Académie des Sciences. He has received a MacArthur Fellowship, the Committee of Presidents of Statistical Societies Presidents' award, and the Norbert Wiener Prize of the American Mathematical Society. In 2013, he received the Shaw Prize in Mathematical Sciences and was awarded the Gauss Prize at the 2018 International Congress of Mathematicians. Dr. Donoho has served as a Trustee of MSRI/SLMath since 2016 and is a former MSRI postdoc as well as a program organizer in 2005.

Analytic and Geometric Aspects of Gauge Theory

Aleksander Doan

Modern physics paints a picture of reality radically different from our everyday experience. In that picture, all physical interactions propagate through certain fields, which permeate space and time, and it is those fields, and not particles or forces, that are the most fundamental building blocks of nature. At the core of this theory lie two facts, which connect the physics of fields to the problems of pure mathematics. First, the dynamics of fields is governed by systems of partial differential equations. Second, these equations exhibit special symmetries which do not come from the symmetries of space-time. Rather, they reflect the freedom in the choice of a mathematical description of fields, which physicists refer to as a *gauge*. Thus, *gauge theory* is the study of fields with such symmetries. While physics is interested chiefly in the *quantum* theory of fields, it turns out that already the classical, non-quantum theory has an immensely rich mathematical structure, whose study over the last forty years has led to many discoveries at the intersection of analysis, geometry, and topology.

Maxwell's Equations and Topology

The prototypical example of a theory with gauge symmetry is Maxwell's theory of electromagnetism. If we think of space-time as a four-dimensional manifold M, then the electric and magnetic fields are represented by vector fields on M. There is a convenient way of combining them into a single mathematical entity: the electromagnetic field F, which is a differential two-form on M, that is, an expression of the form $F = \sum_{ij} F_{ij} dx_i dx_j$, where x_i are coordinates and F_{ij} functions on M. There are two linear differential operators acting on the spaces of forms, the exterior derivative d and its adjoint d^*, corresponding to the curl and div operators known from vector calculus. According to Maxwell's theory, F obeys a system of partial differential equations, which in the simplest case is

$$dF = 0 \quad \text{and} \quad d^*F = 0.$$

These equations make sense on any manifold M equipped with a metric (which in physics would have indefinite signature, meaning that distances can be negative, but here we take it to be positive, like in Euclidean geometry). Given such M, we can ask whether there are any solutions to Maxwell's equations and if they tell us something about the geometry of M.

The first observation is that these two first order equations can be a reduced to a single second order equation. The exterior derivative satisfies $dd = 0$, so if we find a differential one-form A satisfying $F = dA$ (which we can always do, at least in a neighborhood of every point of M, by the fundamental theorem of calculus), then the first equation is automatically satisfied and we are left with

$$d^*dA = 0. \tag{†}$$

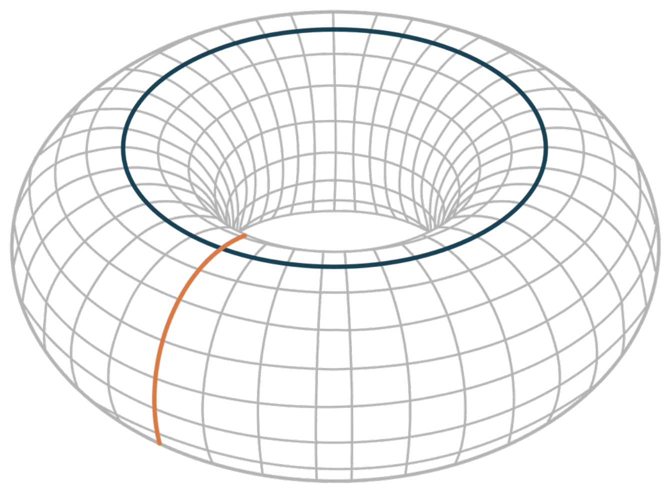
This simplification, however, comes at the price of ambiguity, as there are infinitely many choices of A satisfying $F = dA$, and it is F, not A, that has a physical meaning. For example, for any function $f\colon M \to \mathbb{R}$ we can replace

$$A \mapsto A + df, \tag{‡}$$

which does not change dA since $ddf = 0$. Thus, we are interested in the space of all A's solving (†) up to transformation (‡), which we call a gauge symmetry. In practice, it is hard to directly study system (†), as it is underdetermined: it has more unknown functions than equations. One way to fix this issue is to get rid of gauge symmetries by finding A which obeys the additional *gauge fixing* condition $d^*A = 0$, so that (†) becomes equivalent to the Laplace equation

$$\Delta A = (d^*d + dd^*)A = 0,$$

which has much better analytical properties. In particular, if M is compact, an old theorem of Hodge tells us that the space of solutions can be identified with the cohomology group $H^1(M)$, a classical topological invariant of M. We have reached a surprising conclusion that Maxwell's theory encodes some topological information about the underlying manifold. For example, if M is a torus, $H^1(M)$ is two-dimensional, corresponding to the fact that the electromagnetic field on M can wind around the torus in two different directions.



Horizontal and vertical lines represent two different ways in which the electromagnetic field can wrap around a torus.

It is exactly the winding behavior of fields that allows us to interpret (‡) as a symmetry. From a rather abstract point of view, the one-form A can be interpreted as a geometric structure called *connection* on the manifold $M \times \mathbb{R}^2$. Here we think of $M \times \mathbb{R}^2$ as having a copy of the plane $\mathbb{R}^2$ for every point of M, and A tells us how these planes rotate as we travel in M. In this framework, F is the *curvature* of the connection, while transformation (‡) corresponds to changing coordinates on $M \times \mathbb{R}^2$ by rotating the plane over $x \in M$ by the angle $f(x)$ modulo 2π, for each x. While A changes under this transformation, the geometry of the entire setup remains the same, and the invariance of (†) under (‡) is a manifestation of this fact. In other words, gauge symmetries of Maxwell's theory are related to $SO(2)$, the group of rotations of the plane. An important generalization of this idea is to replace $M \times \mathbb{R}^2$ by an arbitrary *bundle* of planes over M, for which the copies of $\mathbb{R}^2$ can twist in a topologically nontrivial way, similarly to how the Möbius band twists when we travel around it.

Yang–Mills Theory

In the 1950s, the physicists Yang and Mills proposed a theory of nuclear forces based on partial differential equations generalizing Maxwell's equations. In this theory, the group $SO(2)$ is replaced by a general matrix group, such as the group of n-dimensional isometries $SO(n)$ or the unitary groups $U(n)$, $SU(n)$. What seems like a merely technical generalization leads to many completely new features. Unlike $SO(2) = U(1)$, higher rank matrix groups are non-commutative. This results in nonlinear field equations, as A is now a connection represented by a matrix of one-forms, and, after gauge fixing, the Yang–Mills equations have the form

$$\Delta A + f(A, dA) = 0,$$

where $f(A, dA)$ consists of quadratic and cubic combinations of commutators of A and dA. In physics, these terms correspond to the interactions of the field with itself. Much is known about the analysis of these equations, largely due to the pioneering work of Uhlenbeck, who described a mechanism by which the energy of a sequence of solutions on a manifold M can become infinitely concentrated along a manifold of lower dimension contained in M.

Another new feature is that, unlike in the case of electromagnetism, the spaces of Yang–Mills connections up to gauge symmetry, so-called *moduli spaces*, can have very complicated geometry. The study of these spaces is particularly fruitful for manifolds of dimension four, which admit a special class of solutions to the Yang–Mills equations called *instantons*, characterized by having minimal energy. For instance, all instantons on $M = \mathbb{R}^4$ can be constructed by algebraic methods, and their moduli spaces provide examples of *hyperkähler manifolds*: rare objects studied in algebraic and differential geometry, whose structure is related to the algebra of quaternions.

Invariants of Manifolds

In the 1980s, Donaldson proved a number of astonishing theorems about four-dimensional manifolds by relating the geometry of the moduli spaces of instantons on a four-manifold M to the topology of M. One of these theorems states that there exist topological four-manifolds which carry infinitely many inequivalent smooth structures, in contrast with higher dimensions where this is known to be impossible. By a smooth structure we mean here a way of covering the manifold with coordinate charts such that all coordinate changes are differentiable to any order. Similar techniques show that infinitely many (in some sense, most) topological four-manifolds do not carry a smooth structure at all. It is striking that all known proofs of these topological results rely heavily on the analysis of the partial differential equations of gauge theory.

What is now known as Donaldson theory opened a new era in the study of four-manifolds. Shortly afterwards, these methods were extended to solve long-standing problems about three-manifolds, knots, and embeddings of surfaces. By now, gauge theory is one of the standard tools at the disposal of every low-dimensional topologist. However, a number of important questions remain open. For instance, it is not clear how much of low-dimensional topology is seen by gauge-theoretic methods. Instantons, as well as solutions to closely related equations introduced by the physicists Seiberg and Witten, lead to invariants of smooth four-manifolds, called Donaldson and Seiberg–Witten invariants, which can be used to tell apart inequivalent smooth structures. But it is still unknown whether we can find smooth structures whose invariants agree but which are nevertheless distinct. Complex geometry provides potential examples, but new tools will have to be introduced in order to actually distinguish them. There are similar questions for the corresponding invariants of three-manifolds and knots.

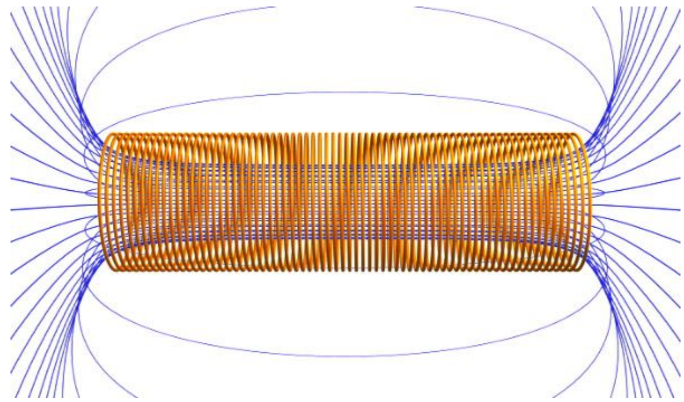


Figure by PerOX, Public domain, via Wikimedia Commons / Color modified

Electric current generating magnetic field, in agreement with Maxwell's equations.

A related question is whether Donaldson and Seiberg–Witten invariants can be refined, exploiting the rich structure of gauge-theoretic equations. Methods of homotopy theory provide one such refinement. This is familiar from algebraic topology: a map between topological spaces $f\colon X \to Y$ induces a map on the homology groups $f_*\colon H_*(X) \to H_*(Y)$, which is useful for studying the topology of X and Y. However, more detailed information is encoded in the homotopy class of f. Gauge-theoretic invariants are analogous to homological information; in this context, X and Y are infinite-dimensional spaces and f is given by the field equations. Bauer and Furuta introduced homotopical refinements of these invariants, which has proved incredibly useful. A recent application is Manolescu's resolution of a long-standing conjecture about triangulations of manifolds. For more on this topic, we refer to the article on the Floer Homotopy Theory program in this issue of the MSRI Emissary.

Other foundational open questions concern the structure of gauge-theoretic invariants. The most important of them is the simple type conjecture, which asserts that all information encoded in these invariants is, in some sense, finite. There is a related conjecture of Witten, now close to being proved, according to which Donaldson and Seiberg–Witten invariants are related by an intricate, but explicit formula predicted by string theory. An analogous problem for the invariants of three-manifolds is completely open, as their algebraic structure is much more complicated than that of the four-dimensional invariants. The situation is even less understood for the homotopical refinements of these invariants, as so far only Seiberg–Witten theory, and not Donaldson theory, has been generalized in this way. Constructing a homotopical refinement of Donaldson invariants remains a fascinating but technically challenging possibility.

Geometry of Moduli Spaces

Topological applications of Donaldson theory rely on detailed study of instanton moduli spaces. It turns out that the geometry and topology of these spaces is rather interesting in its own right. We have already mentioned that some of them carry a hyperkähler structure. In fact, all known compact hyperkähler manifolds can be built from some basic examples (tori, K3 surfaces) and instanton moduli spaces. Interesting non-compact examples can be constructed by studying the instanton equation on four-manifolds of the form $M = N \times \mathbb{R}^d$, where $d = 1, 2, 3$ and N is a manifold of dimension $4 - d$. By looking at solutions which are invariant in the $\mathbb{R}^d$ direction, we obtain a system of differential equations on N.

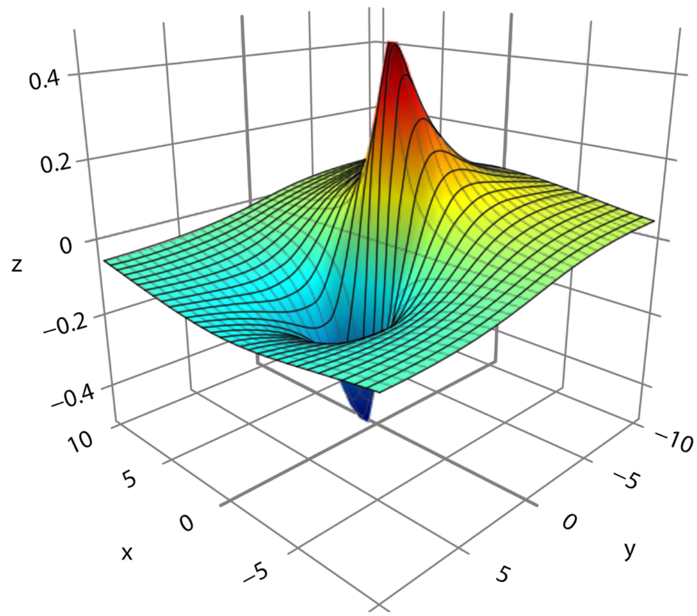
For $d = 1$ and N three-dimensional, these are the Bogomolny monopole equations. Their moduli spaces of solutions on $N = \mathbb{R}^3$ are non-compact hyperkähler manifolds, which appear naturally in the study of certain quantum field theories in physics. This has led to a number of interesting questions about their geometry. For example, the S-duality conjecture makes a precise prediction about the L^2 cohomology, a geometric invariant of non-compact manifolds, of these spaces. This conjecture is closely tied to the problem of understanding the asymptotic geometry of these spaces at infinity, a difficult task since the hyperkähler structure is given by an abstract construction and cannot be written explicitly.

A better understood case is $d = 2$, with N being a surface. The instanton equation in this case leads to the Hitchin equations, which turn out to be connected in a fascinating way to many areas of mathematics: representation theory, algebraic geometry, mirror symmetry, and the geometric Langlands program. These connections are discussed in the Fall 2019 issue of the Emissary. We only remark here that the moduli spaces of solutions are again hyperkähler and non-compact, and there is a tantalizing conjecture, originating from string theory, which provides a rather explicit description of the hyperkähler structure at infinity. If proved, it might lead to a geometric way of compactifying the Hitchin moduli spaces, and therefore to new examples of compact hyperkähler manifolds. The key step in proving this conjecture is to describe the limiting behavior of solutions to Hitchin's equations as we travel far in the moduli space, a problem which has already stimulated many exciting developments in geometric analysis.

Uncharted Territories in Low Dimensions

We have so far discussed various applications of the instanton and Seiberg–Witten equations to the study of manifolds of dimensions four, three, and two. Recent years have witnessed a growing interest in a multitude of other, less understood gauge theories.

On the one hand, there are numerous generalizations of the Seiberg–Witten equations. In fact, there is one for every compact Lie group G and a representation of G on a quaternionic vector space V. As before, the group corresponds to gauge symmetries, while V is the space of values of an additional field, called the *Higgs field* by virtue of its relation to the famous Higgs particle. This is familiar from physics, where fields carrying different interactions transform differently under gauge symmetries. Donaldson theory corresponds to $G = SU(2)$ and $V = \{0\}$, while Seiberg–Witten theory to $G = U(1)$ and $V = \mathbb{C}^2$. Other examples include the Kapustin–Witten equations, which conjecturally lead to new topological invariants of three–manifolds and knots, and the Vafa–Witten equations, which have links to algebraic geometry and modular forms. There has been recently a surge in the study of these and related equations, initiated by deep work of Taubes, who showed that their solutions can degenerate in a way unknown from other problems in analysis and geometry. Understanding such degenerations will require developing completely new analytic tools, but it is likely to lead to further applications of gauge theory to topology.



Instanton with energy highly concentrated at a point.

Towards Higher Dimensions

On the other hand, many attractive features of Yang–Mills theory on four-manifolds generalize to certain manifolds of higher dimensions. Here we are not interested in the classification of manifolds up to smooth equivalence, a problem which can be solved using classical tools of algebraic topology, but rather in understanding a particular class of geometric structures, called *special holonomy metrics*. These structures arise naturally from string theory, where they are related to supersymmetry, but they are also of independent interest to geometers, as they are examples of solutions to Einstein's equations.

From the viewpoint of gauge theory, manifolds with such metrics are interesting because they admit special solutions of the Yang–Mills equations, similar to instantons in dimension four. It is natural to ask whether we can extract invariants of special holonomy manifolds from instanton moduli spaces, mimicking the four-dimensional story. Such invariants would be helpful in classifying the existing millions of examples of special holonomy manifolds, whose geometry is not well understood. This is a fascinating proposal, which in recent years has been the subject of intense research. Like in the low-dimensional situation, here as well the main difficulty lies in understanding degenerations of solutions of the equations. Rather surprisingly, the low- and high-dimensional theories seem to be intimately connected. Based on Uhlenbeck's work, mentioned earlier, it has been conjectured that a sequence of higher-dimensional instantons on a special holonomy manifold X can concentrate along a lower-dimensional manifold M inside X, where it continues its existence as a solution to the generalized Seiberg–Witten equations. Proving that this indeed happens would tie together two strands of modern gauge theory in an unexpected way.

Focus on the Scientist: Rafe Mazzeo

Looking back at the programs that MSRI/SLMath has hosted over these 40 years, one discovers that Rafe Mazzeo is among the researchers who have most often visited the institute. In 1983, Rafe attended MSRI's very first program, Nonlinear Partial Differential Equations. At the time, he was a first-year graduate student accompanying his advisor, Richard Melrose. Since his first visit, Rafe has been a part of — in one form or another — over sixteen programs.

Rafe Mazzeo

A Northern California native, Rafe has been at Stanford University since 1986, first as a postdoctoral researcher and then as a professor. Rafe's research is broadly concerned with the development of new techniques to study geometric and analytic problems with singularities. He then applies those powerful techniques to specific problems of interest in various disciplines. As a result, he has participated in a diverse set of MSRI programs: Algebraic Topology, Differential Geometry, Inverse Programs, Spectral Invariants, Minimal Surfaces, Strings in Math and Physics, Analysis on Singular Space, and most recently Holomorphic Differentials in Math and Physics (2019), Microlocal Analysis (2019), and now this semester's Analytic and Geometric Aspects of Gauge Theory.

Rafe's research directions and subsequent collaborations have been shaped by his times at MSRI. In his own words, "the people I met, interacted with here, etc., have been enormously influential in my mathematical development — I have been extremely lucky that MSRI has been willing to let me spend this time here."

While a prolific researcher, Rafe has also been highly involved in mentorship and outreach. He cofounded Stanford's residential summer program for mathematically-talented high school students, and is faculty director of the Stanford Online High School. He is also the director of the Park City Mathematics Institute, which has parallel programs for high school teachers, undergraduates, graduate students, and a topical program for math researchers. About 300 people attend each year! He has also been a Ph.D. advisor to many graduate students and a faculty mentor to many postdocs.

— Laura Fredrickson and Laura Schaposnik

Forthcoming Workshops

Oct 24–28, 2022: *New Four-Dimensional Gauge Theories*

Nov 14–18, 2022: *Floer Homotopical Methods in Low Dimensional and Symplectic Topology*

Jan 19–20, 2023: *Connections Workshop: Algebraic Cycles,* L*-Values, and Euler Systems*

Jan 23–Jan 27, 2023: *Introductory Workshop: Algebraic Cycles,* L*-Values, and Euler Systems*

Feb 2–3, 2023: *Connections Workshop: Diophantine Geometry*

Feb 6–Feb 10, 2023: *Introductory Workshop: Diophantine Geometry*

Mar 13–17, 2023: *Shimura Varieties and* L*-Functions*

Mar 22–24, 2023: *Critical Issues in Mathematics Education 2023: Mentoring for Equity*

Apr 17–21, 2023: *Degeneracy of algebraic points*

May 8–12, 2023: *Hot Topics Workshop:* MIP* = RE *and the Connes' Embedding Problem*

Summer Graduate Schools

May 22–June 2, 2023: *Commutative Algebra and its Interaction with Algebraic Geometry (Notre Dame)*

Jun 5–16, 2023: *Formalization of Mathematics (MSRI/SLMath)*

Jun 12–23, 2023: *Algebraic Geometry for Molecular Biology (Leipzig, Germany)*

Jun 19–30, 2023: *Séminaire de Mathématiques Supérieures 2023: Periodic and Ergodic Spectral Problems (University of Montreal)*

Jun 20–30, 2023: *Topics in Geometric Flows and Minimal Surfaces (St. Mary's College, Moraga, CA)*

Jun 20–20, 2023: *Mathematics and Computer Science of Market and Mechanism Design (MSRI/SLMath)*

Jun 26–Jul 7, 2023: *Introduction to Derived Algebraic Geometry (UC Berkeley)*

Jul 3–14, 2023: *Concentration inequalities and localization techniques in high dimensional probability and geometry (MSRI/SLMath)*

Jul 10–21, 2023: *Mathematics of Big Data: Sketching and (Multi-) Linear Algebra (IBM Almaden, San Jose, CA)*

Jul 17–28, 2023: *Foundations and Frontiers of Probabilistic Proofs (Zurich)*

TBA: *Machine Learning (UC San Diego)*

Summer Activities

Jun 10–Jul 23, 2023: *MSRI-UP 2023: Topological Data Analysis*

Jun 5–Jul 14, 2023: *Summer Research in Mathematics*

Jun 19–Jun 20, 2023: *African Diaspora Joint Mathematics Workshop (ADJOINT)*

For more information about any of MSRI's scientific activities, please see msri.org/scientific.

Named Program Associates — Fall 2022

From left: Izar Alonso, Marcello Atallah, Gorapada Bera, Panagiotis Dimakis, Shaozong Wang

S. Della Pietra

Izar Alonso is a Stephen Della Pietra program associate in the Analytic and Geometric Aspects of Gauge Theory program. She is a fourth year Ph.D. student at the University of Oxford under the supervision of Andrew Dancer and Jason Lotay. Izar earned a double bachelor's degree in Mathematics and Physics at Universidad Complutense de Madrid, and a MASt in Pure Mathematics (Part III) at the University of Cambridge. Her research is in differential geometry and its connections with heterotic string theory, and in particular special geometric structures appearing in heterotic systems using cohomogeneity one techniques.

SLMath

Marcelo S. Atallah is an SLMath program associate in the Floer Homotopy Theory program. He received his B.A. from the University of Chicago and his M.S. from the Instituto de Matemática Pura e Aplicada (IMPA) in Rio de Janeiro, Brazil. He is currently a third-year graduate student at the Université de Montréal under the supervision of Egor Shelukhin. His research is in the field of symplectic topology, with a particular interest in using Floer theoretic persistence modules to study problems in Hamiltonian dynamics, C^0-symplectic topology, and symplectic group actions.

SLMath

Gorapada Bera is an SLMath program associate in the Analytic and Geometric Aspects of Gauge Theory program. His research interest is in the subject of differential geometry, mainly on gauge theory and calibrated geometry in Riemannian manifolds with special holonomy which are parts of two broad mathematical disciplines, geometric analysis and complex (or algebraic) geometry. He received his M.S. from Michigan State University and is currently a Ph.D. candidate at the Humboldt-Universität of Berlin working on gluing and desingularization of associatives in G_2-manifolds and generalized Seiberg–Witten equations under the supervision of Thomas Walpuski.

Salgo-Noren

Panagiotis Dimakis is a Salgo Noren program associate in the Analytic and Geometric Aspects of Gauge Theory program. He is currently a fifth year Ph.D. student at Stanford university, advised by Rafe Mazzeo. He received his bachelor's degree from MIT. His work focuses on the analysis and geometry of partial differential equations arising in particle physics. Specifically, he works on the Kapustin–Witten equations and their dimensional reductions with an eye towards low dimensional topology and geometry.

Salgo-Noren

Shaozong Wang is a Salgo-Noren program associate in the Analytic and Geometric Aspects of Gauge Theory program. He is currently a fourth-year graduate student at Rutgers University, advised by Paul Feehan and Daniel Ketover. Before that, he received a bachelor's degree in math and applied math at University of Science and Technology of China. He is working on the gluing construction of harmonic maps.

Named Positions, Fall 2022

Chern, Della Pietra, and Simons Professors

Andrew Blumberg, Columbia University
Daniel Freed, University of Texas at Austin
Jennifer Hom, Georgia Tech
Michael Mandell, Indiana University
Ciprian Manolescu, Stanford University
Thomas Walpuski, Humboldt-Universität

Named Postdoctoral Fellows

Berlekamp: Saman Habibi Esfahani, MSRI
Donoho: Inbar Klang, Columbia University
Huneke: Maxwell Zimet, Stanford University
McDuff: Shaoyun Bai, MSRI
Viterbi: Melissa Zhang, University of California, Davis

Named Program Associates

MSRI: Gorapada Bera, Humboldt-Universität
MSRI: Marcelo Sarkis Atallah, Université de Montréal
S. Della Pietra: Izar Alonso Lorenzo, University of Oxford
Salgo-Noren: Panagiotis Dimakis, Stanford University
Salgo-Noren: Shaozong Wang, Rutgers University

Clay Senior Scholars

Tomasz Mrowka, Massachusetts Institute of Technology
Ivan Smith, University of Cambridge

MSRI is grateful for the generous support that comes from endowments and annual gifts that support members of its programs each semester. The Clay Mathematics Institute awards its Senior Scholar awards to support established mathematicians to play a leading role in a topical program at an institute or university away from their home institution.

Public Understanding of Mathematics Updates

Math-Inspiring Books for Title I Schools

The **Mathical Book Prize** is teaming up with **Bring Me a Book**, a national nonprofit, and the **Oakland Literacy Coalition**, to deliver 1300 award-winning children's books inspiring a love of math to kids of all ages in Title I schools in Oakland, CA.

The books — along with book cubbies for classroom use — are being distributed in November 2022. The effort is funded thanks to the generosity of the **Firedoll Foundation**.

The Mathical Book Prize spans ages 2–18 and every genre of kids' literature, from novels to poetry to biography, picture books, chapter books, graphic novels, and more. Books are chosen by a national committee of educators, librarians, mathematicians, and others. Committee members' expertise spans the language arts, early childhood, and math.

The Mathical Book Prize is awarded by the Simons Laufer Mathematical Sciences Institute (**SLMath**) in cooperation with the Institute for Advanced Study (**IAS**). The award is presented in partnership with the National Council of Teachers of English (**NCTE**) and the National Council of Teachers of Mathematics (**NCTM**), and in coordination with the Children's Book Council (**CBC**). Explore the Mathical List at mathicalbooks.org/books.

National Math Festival + QSIDE: High School Datathon4Justice Curriculum

Student teams from five U.S. schools came together to learn through hands-on practice how to ask and answer questions related to math and social justice in the inaugural **High School Datathon4Justice** in April 2022. The event was coordinated by the Institute for the Quantitative Study of Inclusion, Diversity, and Equity (QSIDE Institute) in partnership with the National Math Festival. To learn more, visit qsideinstitute.org/high-school-datathon4justice/.

Available for download: A dataset and other curriculum resources prepared for high school use to examine inequities in displaying works of art through the lenses of race/ethnicity, gender, date of birth, and region of origin. See the QSIDE web site at qsideinstitute.org/data4justice-curriculum/.

Art at MSRI/SLMath

The institute hosted a number of art exhibitions curated by architect William Glass in the summer and fall of 2022, including the photographs of **Beverly Conley** and **Jon Kotinger**; an encore of **Kevin Walker**'s mathematical artworks; *Wave Motion*, a gallery of still images taken from **Candace Gaudiani**'s videos of bodies of water that highlight the abstract play of light, wind, and waveforms (see page 12 for an example); and the paintings of Ethiopian-born Berkeley artist **Wosene Worke Kosrof**.

Featured exhibit: Wosene. Born in 1950 in Addis Ababa, Wosene Worke Kosrof is a contemporary artist who has achieved international acclaim. Over the past five decades, Wosene has created an internationally recognized artistic signature in his work by being the first contemporary Ethiopian-born artist to use the script forms — fiedel — of his native Amharic as a core element in his paintings and sculptures. This recognizable "signature" emerges from the way he elongates, distorts, dissects and reassembles Amharic symbols — not as literal words — but as images that speak for themselves in a visual language accessible to international audiences. Jazz improvisations underlie his compositions, animating them with rhythmic movements and emboldening his masterful use of color.

Call for Proposals

All proposals can be submitted to the Director or Deputy Director or any member of the Scientific Advisory Committee with a copy to proposals@msri.org. For detailed information, please see the website msri.org.

Thematic Programs

The Scientific Advisory Committee (SAC) of the institute meets in January, May, and November each year to consider letters of intent, pre-proposals, and proposals for programs. The deadlines to submit proposals of any kind for review by the SAC are **March 1**, **October 1**, and **December 1**. Successful proposals are usually developed from the pre-proposal in a collaborative process between the proposers, the Directorate, and the SAC, and may be considered at more than one meeting of the SAC before selection. For complete details, see tinyurl.com/msri-progprop.

Hot Topics Workshops

Each year MSRI runs a week-long workshop on some area of intense mathematical activity chosen the previous fall. Proposals should be received by **March 1**, **October 1**, and **December 1** for review at the upcoming SAC meeting. See tinyurl.com/msri-htw.

Summer Graduate Schools

Every summer MSRI organizes several two-week long summer graduate workshops, most of which are held at MSRI. Proposals must be submitted by **September 1** for review at the upcoming SAC meeting. See tinyurl.com/msri-sgs.

Floer Homotopy Theory

Andrew J. Blumberg

The aim of this semester's program on Floer Homotopy Theory is to accelerate the cross-pollination of modern homotopy theory and Floer homology, broadly construed. There are outstanding problems in symplectic topology and the geometry of low-dimensional manifolds that require Floer homotopy theory, and new directions in homotopy theory that are motivated by new classes of examples provided by Floer homology.

Morse and Floer Homology

Starting with work of Morse from nearly 100 years ago, the basic result of Morse theory is that given a smooth function $f\colon M \to \mathbb{R}$, where M is a compact smooth manifold and f satisfies the second derivative test, we can recover the topology of M by studying the critical points of f. Most concretely, there is a chain complex computing the singular homology groups $H_*(M)$ that is built from the moduli spaces of *flow lines* between critical points of f. The flows are controlled by the gradient ∇f, and the complex has differential defined in terms of counts of flow lines. Palais and Smale extended this to certain functionals on manifolds which are infinite-dimensional.

In the 1980s, seminal work of Floer extended the techniques of Palais and Smale to construct analogues of Morse theory in the setting of suitable gradient flows on infinite-dimensional spaces associated to symplectic manifolds and low-dimensional smooth manifolds. Specifically, he constructed theories for the symplectic action functional for periodic orbits of a Hamiltonian diffeomorphism (Hamiltonian Floer homology), the symplectic action functional for paths between Lagrangian submanifolds (Lagrangian Floer homology), and the Cherns–Simons functional on connections on three manifolds (instanton Floer homology). Subsequent work extended these techniques to variants including monopole Floer homology, Seiberg–Witten Floer homology, and Heegaard Floer homology. These theories led to striking and radical progress on a wide variety of problems of central interest in low-dimensional topology, symplectic topology, and knot theory. For example, a version of the Arnold conjecture on the fixed-points of Hamiltonian diffeomorphisms, the Weinstein conjecture on 3-manifolds, and surgery characterizations of knots.

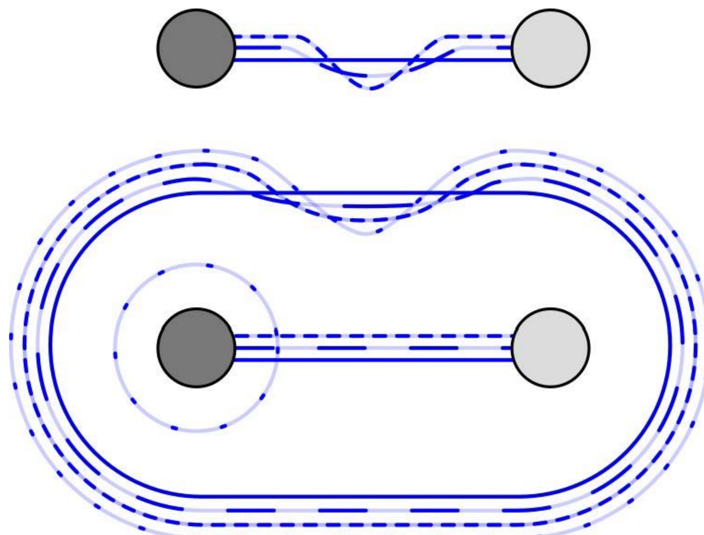
One key point to note is that Morse theory recovers the homology of M and is hence an invariant of the *stable homotopy type* of M. On the other hand, the various Floer homologies are evidently *not* invariants of the stable homotopy type of the underlying manifold. This leads to a very natural question:

Question. Can the various Floer homology theories be interpreted as the homology of some space, or more generally the invariants of the stable homotopy type of some space?

Attempting to answer this question is the point of departure for *Floer homotopy theory*.

The Stable Category and Brave New Algebra

One of the insights of the last 50 years in algebraic topology is that the algebraic structure of the homology of a space captures only shadows of the rich structure available. For example, Poincaré duality for compact oriented manifolds provides an isomorphism $H^k(M) \cong H_{n-k}(M)$. But interpreting the cohomology M in terms of the *Spanier–Whitehead dual* of M, we have a statement that is true for arbitrary cohomology theories, and holds without any orientation assumption.



Extensions of Floer's techniques have led to variants like Heegaard Floer homolgy. An illustration of a generic Heegaard quadruple by K. Hendricks, J. Hom, M. Stoffregen, and I. Zemke.

The basic idea of the stable homotopy type of a space is to produce a category (the *stable category*, typically referred to as the category of spectra) which has the formal structure of the category of complexes and quasi-isomorphisms (that is, has a triangulated homotopy category with a symmetric monoidal tensor product and shift functors). Every space gives rise to an object of the stable category. The existence of the symmetric monoidal structure gives rise to a theory of formal duality; the formal dual of a space in the stable category is precisely the Spanier–Whitehead dual.

The stable category provides a home for algebra and topology simultaneously: the objects of the stable category can be interpreted to represent (co)homology theories, and ordinary rings embed in spectra via the ordinary homology theories. The tensor product of spectra is set up to encode the cup product on cohomology theories; multiplicative cohomology theories give rise to ring objects in the category of spectra. In algebra, the initial commutative ring is the ring of integers $\mathbb{Z}$; in the category of spectra, the initial commutative ring is the sphere spectrum $\mathbb{S}$ and there is a canonical unit map $\mathbb{S} \to \mathbb{Z}$ — thus, even when studying purely algebraic objects there is a more refined viewpoint that comes from working over the sphere spectrum. This perspective is often referred to as "brave new algebra" following Waldhausen, as the algebra of spectra encompasses classical homological algebra but includes new ring objects. Lifting algebraic problems to brave new algebra over the sphere spectrum has turned out to be an immensely successful approach.

Stable Homotopy Types from Flow Categories

In the 1990s, Cohen–Jones–Segal proposed a strategy for building a Floer stable homotopy type from a "flow category," which in Morse theory is a category $\mathcal{C}$ with objects the critical points and morphisms $\mathcal{C}(p, q)$ the moduli space of gradient flows between p and q. Whereas Morse and Floer homology use the zero-dimensional moduli spaces of flow lines, that is, counts, to define the differentials in the respective complexes, the CJS construction proposes to use moduli spaces of arbitrary dimensions and suitable framings to glue them together using the Pontryagin–Thom construction. This idea has been massively influential, but it has only been quite recently that some of the ferocious technical issues that stymied the direct application of the CJS approach have been resolved.

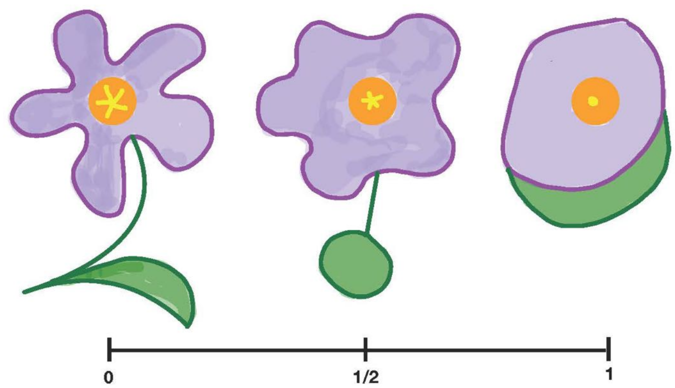
Using flow categories, Lipshitz–Sarkar (and subsequently Lawson–Lipshitz–Sarkar and Hu–Kriz–Kriz) constructed a Khovanov homotopy type, that is, a spectrum whose homology computes the Khovanov homology of a knot. There has subsequently been a flurry of work extending this (for example, an odd Khovanov homotopy type by Sarkar–Scaduto–Stoffregen and Khovanov–Rozansky homotopy types by Jones–Lobb–Schütz) and studying enhanced algebraic structures on it (for example, cup products). More recently, Abouzaid–Blumberg introduced a new approach to the Cohen–Jones–Segal construction and built a homotopy type in Hamiltonian Floer homology over a cohomology theory called Morava K-theory. Abouzaid–McLean–Smith considered a closely related construction that introduces a novel and radical simplification of our understanding of moduli spaces of pseudo-holomorphic spheres in terms of *global charts*. Building on this, Rezchikov and Bai–Xu have shown the existence of such global charts and flow categories for Hamiltonian Floer homology very generally.

Seiberg–Witten Homotopy Types

Another approach to a Floer homotopy type that has seen tremendous progress was initiated by Manolescu in 2001; the construction of a Seiberg–Witten Floer homotopy type using finite-dimensional approximations, following ideas of Bauer–Furuta. The idea here is to construct an S^1-equivariant homotopy type by filtering the eigenspaces of the Seiberg–Witten operator by finite-dimensional subspaces. The original construction required that the input be a homology three-sphere, but subsequent work of Khandawit–Lin–Sasahira generalized this to arbitrary manifolds. These homotopy types have been applied to prove gluing formulas that allow computation of Seiberg–Witten invariants via cut-and-paste of manifolds. A spectacular application of this construction has been the proof of the triangulation conjecture by Manolescu using a Pin(2)-equivariant version of the Seiberg–Witten invariants. In a different direction, Hopkins–Lin–Shi–Xu carried out Furuta's computational approach to the $11/8$-conjecture.

Parametrized Spectra and String Topology

Work of Kragh has constructed parametrized spectra that represent the symplectic cohomology of the cotangent bundle. The nearby Lagrangian conjecture predicts that a closed exact Lagrangian submanifold in a cotangent bundle must be Hamiltonian isotopic to the zero-section. Steady progress has been made on the nearby Lagrangian conjecture and related questions using increasingly sophisticated homotopy-theoretic constructions. Most recently, Abouzaid–Courte–Guillermou–Kragh introduced the homotopical notion of twisting to Morse theory, and showed that every exact Lagrangian in a cotangent bundles arises from a twisted stable Morse function. These Floer homotopy types are closed related to the *string topology* structures on the free loop space of a manifold, originally constructed by Chas–Sullivan and the inspiration for a huge amount of work both in homotopy theory and also in symplectic topology.



A fleur homotopy! Image by Nathalie Wahl.

Where Are We Going?

Despite the progress described above, we are just at the beginning of the flowering of Floer homotopy theory. We broadly anticipate that many modern directions in homotopy theory will find applications to phenomena in Floer theory.

Chromatic homotopy theory. Following Quillen's seminal work identifying the coefficients of complex cobordism as the Lazard ring, Morava conjectured that there is a tight connection between the fine structure of the stable homotopy category and the geometry of the moduli stack of formal groups. Morava K-theory, a cohomology theory arising from this perspective, has the key property it satisfies Poincaré duality for orbifolds and hence saw important application in the work of Abouzaid-Blumberg and Abouzaid–McLean–Smith. But there are many further things to explore here.

Homotopy coherence via ∞-categories. One of the most important developments in homotopy theory in the last 15 years has been the introduction of the theory of ∞-categories, which is a new technology for handling problems of homotopy coherence (for example, operadic multiplications). Already this has started to penetrate Floer homology in the work on equivariant Floer theory due to Hendricks–Lipshitz–Sarkar and work of Lazarev–Sylvan–Tanaka on functoriality via Liouville sectors. But we expect much broader applications, specifically to the key problem of how to construct *Fukaya categories* that are enriched over the category of spectra.

Equivariant stable homotopy theory. The subject has been reinvigorated by the theory of multiplicative transfers and the associated computational techniques introduced by Hill–Hopkins–Ravenel in

Focus on the Scientist: Jennifer Hom

Jennifer Hom is a Chern Professor in the MSRI program on Floer Homotopy Theory. She has made remarkable contributions to low dimensional topology, and particularly to the study of concordance and homology cobordism.

Jennifer Hom

Jen likes to say that she grew up "outside Boston," but one of her mathematician colleagues observed that "that's most places," so the more accurate answer is that she grew up in Acton, Massachusetts. She first became interested in math while watching the program *Square One Television*. Later, in college, she started out as an applied physics major but had a second conversion to math in her junior year, after taking an abstract algebra class. She went to the University of Pennsylvania for her Ph.D. and then back to Columbia on a postdoctoral position. Since 2015 she has been on the faculty at Georgia Tech.

Two knots in three-dimensional space are called concordant if they can be the two boundaries of an annulus in four dimensions. Knots up to concordance form an abelian group, whose structure is still unknown. As a graduate student, while being a program associate in the 2010 MSRI program on Homology Theories of Knots and Links, Jen developed a new invariant of knot concordance, called epsilon. This became the topic of her Ph.D. thesis and is now a standard tool of the trade.

Since then, among Jen's many mathematical accomplishments are the finding of new obstructions for a 3-manifold to be surgery on a knot (jointly with Karakurt and Lidman) and a proof that the 3-dimensional homology cobordism group has an infinite rank summand (jointly with Dai, Stoffregen, and Truong). Jen's work was recently recognized with an invitation to speak at the 2022 International Congress of Mathematicians.

Apart from research, Jen is passionate about communication in mathematics. She endeavors to make talks and papers accessible to her audience and has written several expository lecture notes and articles. In her free time, she enjoys running. She is excited to be back at MSRI/SLMath as a faculty member, and she brings here two of her graduate students as program associates.

— Ciprian Manolescu

their approach to the Kervaire invariant one problem. These structures have not yet appeared in Floer theory, but we anticipate that they will have natural applications, especially in the study of periodic orbits of Hamiltonian systems, where group actions naturally arise.

Twisted parametrized spectra. The thesis of Douglas introduced the idea of considering sections of a bundle of categories with fibers equivalent to the stable category. These objects turn out to be relevant both in symplectic geometry (appearing in work of Xin–Treumann) and to Seiberg–Witten Floer homotopy types; when the polarization class is nonzero, such objects (where now the fibers are the S^1-equivariant stable category) are under active study by Behrens–Hedenlund–Kragh. An analogous construction is expected for Heegard Floer theory.

Call for Membership

MSRI invites membership applications for the 2023–24 academic year in these positions:

Research Members	by December 1, 2022
Postdoctoral Fellows	by December 1, 2022

In the academic year 2023–24, the research programs are:

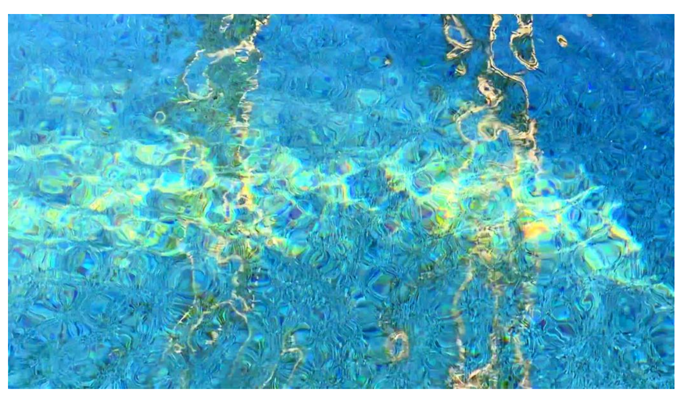
Mathematics and Computer Science of Market and Mechanism Design
Aug 21–Dec 20, 2023
Organized by Michal Feldman, Nicole Immorlica, Scott Kominers, Shengwu Li, Paul Milgrom, Alvin Roth, Tim Roughgarden, Eva Tardos

Algorithms, Fairness, and Equity
Aug 21–Dec 20, 2023
Organized by Vincent Conitzer, Moon Duchin, Bettina Klaus, Jonathan Mattingly, Wesley Pegden

Commutative Algebra
Jan 16–May 24, 2024
Organized by Aldo Conca, Steven Cutkosky, Claudia Polini, Claudiu Raicu, Steven Sam, Kevin Tucker, Claire Voisin

Noncommutative Algebraic Geometry
Jan 16–May 24, 2024
Organized by Wendy Lowen, Alexander Perry, Alexander Polishchuk, Susan Sierra, Spela Spenko, Michel Van den Bergh

MSRI uses **MathJobs** to process applications for its positions. Interested candidates must apply online at mathjobs.org. For more information about any of the programs, please see msri.org/scientific/programs.



From Candace Gaudiani's *Wave Motion* (PUM Update, p 9.)

Collaborations Underpin Record Summer of Activities

Hélène Barcelo, Deputy Director

The Geometric Flows summer graduate school in Crete, and the SRiM group on "Subcritical Superlinear Elliptic Problems" (from L to R): Rosa Pardo, Shalmali Bandyopadhyay, Briceyda Delgado López, Nsoki Mamie Mavinga, and Maya Chhetri.

Graduate students are the future leaders of mathematics, and providing opportunities for international networking and collaboration early in their careers is critical to the vitality of the profession. In summer 2022, MSRI received an unprecedented 680 summer graduate school student nominations, of which 70% (480) were invited and nearly 60% (393) were able to participate. We gratefully acknowledge MSRI's **academic sponsoring institutions** and **national and international partners** for making a record thirteen summer graduate schools possible in 2022!

Summer Graduate Schools

Due to the high volume of activities at MSRI, we established a partnership with **Roy Wensley**, Dean of the School of Science at **Saint Mary's College of California** to host three of the five Bay Area summer graduate schools. The bucolic setting of Saint Mary's campus enabled tightly-knit collaborations between lecturers, TAs, and students, and made their experiences especially successful (despite the extra firm mattresses!).

Eight further joint schools took place in collaboration with the Australian Mathematical Sciences Institute (**AMSI**); the Banff International Research Station–UBC Okanagan (**BIRS**, Canada); the Institute of Applied and Computational Mathematics (**IACM-FORTH**, Greece); Istituto Nazionale di Alta Matematica (**INdAM**, Italy); the National Center for Theoretical Sciences (**NCTS**, Taiwan); the **University of Oxford** (UK); the Park City Mathematics Institute (**PCMI**, Utah); and the Séminaire de Mathématiques Supérieures (**SMS**, Canada).

The BIRS–UBC Okanagan and University of Oxford schools took place in person and were extraordinarily productive; students rejoiced at the opportunity to collaborate in 3-D! We are grateful to both BIRS and Oxford for their financial and logistical contributions to the success of these schools. Thanks to **Cornelia Drutu**'s steadfast dedication, the collaboration with Oxford was able to see the light of day. We are also pleased to report that MSRI's longstanding partnerships with PCMI and SMS were their usual successes.

The newly developed collaboration with IACM-FORTH, funded by the Stavros Niarchos Foundation and MSRI and spearheaded by **Toti Daskalopoulos** (Columbia University) and **Nicholas Alikakos** (University of Athens), was an astounding success. We are thankful to Director **Charalambos Makridakis** and the entire IACM-FORTH staff, who warmly welcomed the Greek students and faculty and their US counterparts.

COVID-19-related travel restrictions prevented the schools with AMSI, INdAM, and NCTS from taking place in a single location. As such, MSRI implemented a satellite model for those schools: US-based students participated from one location in the US as close as possible to the time zone of the partner country, while the students of the partnering institution participated from their home countries.

Thanks to **Brian Wissman**, Chair of the Department of Mathematics, MSRI partnered with the **University of Hawai'i at Hilo** to host the AMSI and NCTS schools. For the joint school with INdAM, we partnered with the **Courant Institute**, New York, via **Russ Caflisch**, its director. These bicontinental summer school experiments proved worthwhile and allowed all students to attend lectures synchronously online; problem sessions were held in person at the various locations. While this configuration did not provide all of the advantages of in-person research sessions, it was undoubtedly an improvement over the experience of being entirely online.

Further Activities & Reunions

In addition to the summer schools, MSRI hosted its six-week **MSRI-UP** program for undergraduates; a two-week intensive research session for the 2022 African Diaspora Joint Mathematics Workshop (**ADJOINT**) for tenured and tenure-track mathematicians; as well as a week-long **reunion of cohorts** from ADJOINT 2020 and 2021. A further 37 participants from the Summer Research in Mathematics (**SRiM**) program, mostly women and gender-expansive individuals, visited MSRI and BIRS for 2-week research collaborations between June and August. The new BIRS–MSRI collaborations for both SRiM and summer graduate schools were established thanks to MSRI's long relationship with Director **Malabika Pramanik**.

For the first time, MSRI also held two one-month-long **program reunions** (one at MSRI and one at the Universidad Nacional Autónoma de México, Cuernavaca). These unqualified successes enabled mathematicians whose collaborations were paused due to the pandemic to reconvene — at last — face-to-face. **José Seade**, Director of the Instituto de Matemáticas at **UNAM**, was instrumental in ensuring a fruitful and rewarding experience for the participants in Cuernavaca.

Based on the successes of summer 2022, MSRI/SLMath plans to continue to explore new opportunities for creative and responsive models for scientific activities in the "post"-pandemic era.

Named Postdocs — Fall 2022

Berlekamp

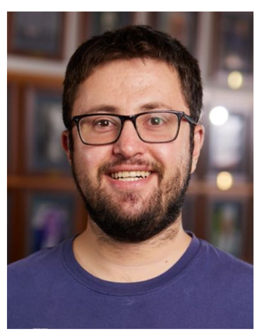
Saman Habibi Esfahani is the Berlekamp endowed postdoc on the Analytic and Geometric Aspects of Gauge Theory program. Saman obtained his Ph.D. this year from Stony Brook University under the supervision of Simon Donaldson, having previously taken both a B.S. and M.A. in Mathematics at Sharif University. He will be starting as a William W. Elliott Assistant Research Professor at Duke University at the end of the program. Saman's thesis concerns three distinct but related topics, with a focus on monopoles, which form a core part of gauge theory. His first result is the construction of monopoles with singularities on rational homology 3-spheres. Motivated by gauge theory in higher dimensions and the moduli space of monopoles, his second topic is the study of compactness of the space of Fueter sections on 3- and 4-dimensional manifolds. The third and final part of Saman's thesis concerns special 3-dimensional submanifolds (associative submanifolds) in certain 7-dimensional spaces (G_2-manifolds), specifically making progress towards a conjecture of Donaldson and Scaduto. Saman continues to pursue a range of topics in geometry and topology, primarily related to gauge theory, special holonomy, and the theory of invariants. *The Berlekamp fellowship was established in 2014 by a group of Elwyn Berlekamp's friends, colleagues, and former students whose lives he touched in many ways. He was well known for his algorithms in coding theory, important contributions to game theory, and his love of mathematical puzzles.*

Donoho

Inbar Klang is the Donoho Endowed postdoctoral fellow in Floer Homotopy Theory. She received her Ph.D. in 2018 from Stanford University under the supervision of Ralph Cohen. Her thesis studied duality phenomena in factorization homology and in string topology; she has written several papers on these and other topics since then. Before coming to SLMath, she had a postdoctoral position at EPFL and a Ritt Assistant Professorship at Columbia University, where she won the Departmental Teaching Award. Her research area is homotopy theory and her research interests include Hochschild homology and cohomology, fixed point theory, factorization homology, and applications of algebraic topology to manifold topology and symplectic topology. *The Donoho fellowship was established in 2022 by David Donoho and Miriam (Miki) Gasko Donoho. David Donoho has made fundamental contributions to theoretical and computational statistics throughout his career, as well as to signal processing and harmonic analysis. He has served as a Trustee of MSRI/SLMath since 2016.*

Huneke

Max Zimet is the Huneke postdoctoral fellow in the Analytic and Geometric Aspects of Gauge Theory program. Max received his Ph.D. in Physics from Stanford University in 2019 and arrives at MSRI/SLMath after a postdoctoral position at the Harvard Black Hole Initiative. The central objects of Max's research are K3 surfaces and the ubiquitous role that their hyperkähler geometry plays in mathematics and theoretical physics. His earlier work in theoretical physics revolves around umbral moonshine, and connects theoretical physics with enumerative geometry, group theory, and number theory. More recently, Max has been working on a series of exciting projects in pure mathematics on the realization of hyperkähler metrics on K3 surfaces (and related manifolds) as moduli spaces in gauge theory, connecting classical work in differential geometry from the 1980s and 90s with recent breakthroughs at the interface of geometry and theoretical physics, including mirror symmetry and enumerative geometry. *The Huneke postdoctoral fellowship is funded by a generous endowment from Professor Craig Huneke, who is internationally recognized for his work in commutative algebra and algebraic geometry.*



Viterbi

Melissa Zhang received her bachelor's degree at Caltech before moving to Boston College and completing her doctoral work under the supervision of Eli Grigsby and David Treumann in 2019. On completing her Ph.D., Melissa moved to the University of Georgia for a three-year postdoc before joining the 2022 program on Floer Homotopy Theory as the Viterbi postdoctoral fellow. Beginning in January she will be at UC Davis as a Krener Assistant Professor. Melissa's work is in low-dimensional topology, where her focus has been on the interplay between Khovanov homology and Heegaard Floer theory. Her doctoral work produces a refinement of annular Khovanov homology in the presence of a period-two involution on a link. This yields a rank inequality between the annular Khovanov homologies of the link and its quotient that splits along annular gradings. One result of Melissa's that is particularly close to the subject of the semester program comes in joint work with Matthew Stoffregen: here the authors build on Melissa's earlier work and construct equivariant Khovanov spectra for periodic links. This homotopy-theoretic extension allows for a generalization of Melissa's earlier work to links admitting a period-p involution for any prime p, and to other flavors of Khovanov homology. *The Viterbi postdoctoral fellowship is funded by a generous endowment from Dr. Andrew Viterbi, well known as the co-inventor of Code Division Multiple Access based digital cellular technology and the Viterbi decoding algorithm, used in many digital communication systems.*

McDuff

Shaoyun Bai is this semester's McDuff postdoctoral fellow in the Floer homotopy program. Bai received his Bachelor's degree from Tsinghua University in 2017, and his Ph.D. from Princeton University in 2022 under the direction of John Pardon. In the two-year period from September 2020 to September 2022, he released six preprints on gauge theory, Gromov–Witten theory, and Fukaya categories. The latest two of these preprints, written jointly with Gangbo Xu, develop a theory of integral virtual fundamental classes for stably complex derived orbifolds, yielding a construction of integral Gromov–Witten invariants, as well as a proof of an integral version of Arnold's conjecture on fixed points of non-degenerate Hamiltonian diffeomorphisms, resolving a question that has driven the development of symplectic topology since its origin in the second half of the 20th century. *The McDuff fellowship was established by an anonymous donor in honor of Dusa McDuff. She is an internationally renowned mathematician, a member of the National Academy of Sciences, and a recipient of the AMS Leroy P. Steele Prize (2017). She is also currently a trustee of MSRI.*

Puzzles Column

Joe P. Buhler and Tanya Khovanova

When the Emissary Puzzle Column first started appearing (23 years ago!), one of the ideas was to shine a spotlight on puzzles in the air in the building. To reinvigorate this notion (at the same time the institution has a new name), we will attempt to have a guest puzzlist for each issue. This fall's contributor is ***Melissa Zhang*** *(Viterbi postdoc in this semester's Floer Homotopy Theory program), who contributed the first and last puzzles.*

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1. Two very logical beings, Green and Brown, are playing a game where they take turns coloring points in the integer lattice on the plane. Whoever is first to color all four points of a 2×2 square with their color wins the game. Green goes first. What is the outcome of the game?

2. The Oracle at Delphi has in mind a certain polynomial p (in the variable x, say) with non-negative integer coefficients. You may query the Oracle with any integer n, and the Oracle will tell you the value of $p(n)$. How many queries do you have to make to determine p?

3. Eight glasses of wine are placed in a circle on a round table. Three sages are invited to take the following challenge: In the presence of the first sage, five glasses are filled with good wine and the other three with poisoned wine, indistinguishable from the good wine. After drinking the poisoned wine, a person will die immediately. Each sage has to drink one full glass. The first sage is not allowed to give any hints to the other sages, but they can see which glass she chooses before making their own selection. The three sages can agree on their strategy beforehand. What strategy will keep them all alive? *An extra question:* Does a strategy exist if fewer than eight glasses are placed around the table?

4. Once upon a time, in a faraway kingdom, two officials of the Treasury Department are minting coins. They decide to make it into a game, taking turns minting coins. On each turn, a treasurer ("player") chooses a particular integral denomination and mints an infinite supply of coins of this denomination. The rules of the game forbid choosing a new denomination that can be paid with the existing coins. The player who is forced to mint a coin of denomination 1 loses.

- Prove that if the first player starts with denomination 2 or 3, they lose.
- Is it profitable for the first player to start with denomination 4?
- Is it profitable for the first player to start with denomination 6?
- Suppose the first player mints coins of denomination 5, and the second player of denomination 6. What is the winning strategy for the first player after that?
- Suppose the first player mints coins of denomination 5, and the second player of denomination k. Prove that the largest denomination available for minting is $4k-5$.
- Prove that the first player can win by starting with denomination 5.

5. I own a 1000-ft-tall, rotationally symmetric mountain that is great for goat grazing. Each year, n goat herders come to me and I divide the land on my mountain based on altitude: the k-th herder is allotted the strip of land lying between $1000(k-1)/n$ ft and $1000k/n$ ft from the base of the mountain. This way, no matter how many herders come to me in a given year, every herder will have the same area of land to graze on. What shapes might my mountain be? (Nowhere on the surface of the mountain are goats forced to be upside down.)

Send your thoughts to the authors at puzzles@msri.org. Solutions will be posted online by April 2023.

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