BRIN MATHEMATICS RESEARCH CENTER

Geometry and Representation Theory Associated to G-Torsors on Curves

April 21-25, 2025

ABOUT THE WORKSHOP

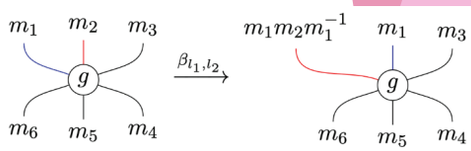
In the past decades, the theory of moduli spaces of bundles over algebraic curves has played a central role in various branches of mathematics, with deep ties to very active areas of research such as topological field theories, the Langlands program, and representation theory of affine Lie algebras. A crucial ingredient that unifies several refinements of the theory came into focus recently: torsors for parahoric Bruhat-Tits group schemes. This gives a uniform approach to level structures, parabolic bundles, Prym varieties, and the structures underlying twisted conformal blocks from conformal field theory.

ORGANIZERS

Johan Martens, University of Edinburgh

Swarnava Mukhopadhyay, TIFR Mumbai

Richard Wentworth, University of Maryland



$$\overline{\mathcal{M}}^{\Gamma}_{X,\mathbf{m},\mathbf{b}} := \prod_{v \in V(X)} \overline{\mathcal{M}}^{\Gamma}_{w(v),L_v}(\mathbf{m}|_{L_v}),$$

PARTICIPANTS

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Shrawan Kumar, University of North Carolina, Chapel Hill

Georgios Kydonakis, University of Patras

Chris Manon, University of Kentucky

Andy Neitzke, Yale University

Christian Pauly, University of Nice

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Christoph Schweigert, Hamburg University

Nicola Tarasca, Virginia Commonwealth University

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Katrin Wendland, Trinity College Dublin

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DEPARTMENT OF MATHEMATICS

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Schedule at a Glance

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12:00	Free Discussion	Schweigert	Pauly	Belkale	Andersen
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Workshop Overview

In the past decades, the theory of moduli spaces of bundles over algebraic curves has played a central role in various branches of mathematics, with deep ties to very active areas of research such as topological field theories, the Langlands program, and representation theory of affine Lie algebras. A crucial ingredient that unifies several refinements of the theory came into focus recently: torsors for parahoric Bruhat-Tits group schemes. This gives a uniform approach to level structures, parabolic bundles, Prym varieties, and the structures underlying twisted conformal blocks from conformal field theory.

The last few years have seen the start of a systematic study of these matters, involving different communities of researchers and areas of interest. This workshop will follow up on the successful conference at ICMS Edinburgh in June 2022 that was devoted to these topics.

Organizing committee

Johan Martens, University of Edinburgh

Swarnava Mukhopadhyay, TIFR Mumbai

Richard Wentworth, University of Maryland

Workshop Schedule

Monday, April 21, 2025

8:50 - 9:20	Breakfast
9:20 - 9:30	Doron Levy (University of Maryland/Director, Brin MRC) *Opening*
9:30 - 10:20	Giovanni Felder (ETH Zurich) *Hecke Modifications at Non-Critical Level*
10:20 - 11:00	Coffee Break
11:00 - 11:50	Ajneet Dhillon (Western University) *Strong Approximation for Classifying Stacks*
12:10 - 1:00	Free Discussion
1:00 - 2:30	Lunch
2:30 - 3:10	Andy Neitzke (Yale University) *A New Construction of c=1 Virasoro Conformal Blocks*
3:10 - 4:00	Coffee Break
4:00 - 4:50	Katrin Wendland (Trinity College Dublin) *Representing the Symmetries of Z3-Orbifold K3s as Subgroups of the Mathieu Groups*

Tuesday, April 22, 2025

9:00 - 9:30 Breakfast

9:30 - 10:20 Karim Rega (University of Edinburgh)
A Good Moduli Space for Parahoric Higgs Bundles

10:20 - 11:00 Coffee Break

11:00 - 11:50 Nicola Tarasca (Virginia Commonwealth University)
Root Puzzles and Plumbed 3-Manifolds

12:10 - 1:00 Christoph Schweigert (Hamburg University)
On Some Representation Theoretic Structures Related to Conformal Field Theory

1:00 - 2:30 Lunch

2:30 - 3:10 Bin Wang (Chinese University of Hong Kong)
Springer Correspondence and Mirror Symmetry for Hitchin Systems

3:10 - 4:00 Coffee Break

4:00 - 4:50 Georgios Kydonakis (University of Patras)
Level Structures on Parahoric G-Torsors

Wednesday, April 23, 2025

9:00 - 9:30 Breakfast

9:30 - 10:20 Chiara Damiolini (University of Texas at Austin)
Line Bundles on the Moduli of Parahoric Bundles

10:20 - 11:00 Coffee Break

11:00 - 11:50 Chongying Dong (University of California Santa Cruz)
Kac-Wakimoto Hypothesis and Coset Constructions

12:10 - 1:00 Christian Pauly (University of Nice)
The Prym-Hitchin Connection and Anti-Invariant Level-Rank Duality

6:30 - 8:30 Conference Dinner

Thursday, April 24, 2025

9:00 - 9:30 Breakfast

9:30 - 10:20 Iva Halacheva (Northeastern University)
Moduli Theory of the r-Braid Arrangement

10:20 - 11:00 Coffee Break

11:00 - 11:50 Tanmay Deshpande (TIFR Mumbai)
Crossed Extensions of Modular Categories and Twisted Conformal Blocks

12:10 - 1:00 Prakash Belkale (University of North Carolina at Chapel Hill)
Motivic Factorization of KZ Local Systems and Deformations of Representation and Fusion Rings

1:00 - 2:30 Lunch

2:30 - 3:10 Pierre Godfard (Sorbonne Universite)
Hodge Structures on Conformal Blocks

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4:00 - 4:50 Christopher Manon (University of Kentucky)
Classifying Bundles with a Torus Action

Friday, April 25, 2025

9:00 - 9:30 Breakfast

9:30 - 10:20 Philip Boalch (CNRS, IMJ-Paris)
Logarithmic Connections on Parahoric Bundles on Wild Riemann Surfaces

10:20 - 11:00 Coffee Break

11:00 - 11:50 Valerio Toledano Laredo (Northeastern University)

12:10 - 1:00 Joergen Andersen (University of Southern Denmark)
Gaussian Boson Sampling, Gaussian Weighted Integrals and their Generalization to Symplectic Manifolds

Abstracts of talks

Hecke Modifications at Non-Critical Level

Giovanni Felder

ETH Zurich

Monday, April 21, 2025 @ 9:30 AM

I will discuss a variant of Hecke modifications of conformal blocks of Wess-Zumino-Witten at non-critical level. The Hecke modification maps conformal blocks to conformal blocks with an insertion of a twisted vacuum module and is compatible with the twisted D-module structure. In particular it sends solutions of the Knizhnik-Zamolodchikov Bernard to solutions. Our result explains and extends recent results of Jeong, Lee and Nekrasov. The talk is based on work in progress with Raschid Abedin and Robert Windesheim, with input of Jorg Teschner.

Strong Approximation for Classifying Stacks

Ajneet Dhillon

Western University

Monday, April 21, 2025 @ 11:00 AM

Let G/k be a connected linear algebraic group over a number field k. Suppose that we are given G-torsors $P_1, \dots P_n$ over some completions of k at some non-Archimedean places. In this talk we consider the problem of when we can find a torsor over k that specialises to a torsor that is close to P_i with respect to the topology induced by the given non-Archimedean place. This is an analogue of the strong approximation theorem for the classifying stack. Following an idea of A. Christensen, we give the adelic points of the classifying stack BG the structure of a topological space. The question is answered by describing the closure of the rational points inside this topological space. If there is time, we will discuss the connectedness hypothesis and the modification needed in this setting.

A New Construction of c=1 Virasoro Conformal Blocks

Andy Neitzke

Yale University

Monday, April 21, 2025 @ 2:30 PM

I will describe a new method for constructing conformal blocks for the Virasoro vertex algebra with central charge c=1 by "nonabelianization", relating them to conformal blocks for the Heisenberg algebra on a branched double cover. The construction is joint work with Qianyu Hao. Special cases give rise to formulas for tau-functions and solutions of integrable systems of PDE, such as Painleve I and its higher analogues. The talk will be reasonably self-contained (in particular I will explain what a conformal block is).

Representing the Symmetries of Z3-Orbifold K3s as Subgroups of the Mathieu Groups

Katrin Wendland

Trinity College Dublin

Monday, April 21, 2025 @ 4:00 PM

For each K3 surface, Mukai showed that the group of holomorphic symplectic automorphisms (here referred to as symmetries) is a subgroup of the Mathieu group M24. These symmetries are conveniently described by their action on appropriate lattices - on the lattice of integral cohomology, but also on some Niemeier lattice, depending on the details of the K3 surface. For Kummer surfaces, whose geometry has been investigated in detail by Nikulin, we showed more than a decade ago that this leads to a concrete realization of all symmetries as elements of the Mathieu group M24. We now provide an analogue of Nikulin's studies of Kummer surfaces for Z3-orbifold K3s. We obtain a classification of all symmetries of these special K3 surfaces, and we realize the resulting symmetry group concretely as subgroups of the Mathieu groups M12 and M24.

A Good Moduli Space for Parahoric Higgs Bundles

Karim Rega

University of Edinburgh

Tuesday, April 22, 2025 @ 9:30 AM

We start off by reviewing criteria by Halpern-Leistner for the existence of a Theta-stratification on a stack such that the semistable locus admits a good moduli space. These were applied by Halpern-Leistner and Herrero to the moduli of gauged maps. After reviewing this, we show how they can be applied to the moduli of parahoric Higgs bundles.

Root Puzzles and Plumbed 3-Manifolds

Nicola Tarasca

Virginia Commonwealth University

Tuesday, April 22, 2025 @ 11:00 AM

The Witten-Reshetikhin-Turaev (WRT) invariants provide a powerful framework for constructing a family of invariants for framed links and 3-manifolds. An ongoing pursuit in quantum topology revolves around the categorification of these invariants. Recent progress has been made in this direction, particularly through a physical definition of a new series invariant for plumbed 3-manifolds. These invariants exhibit a convergence towards the WRT invariants in their limits. In this talk, I will present a refinement of such series invariants and show how one can obtain infinitely many new series invariants starting from the data of a root lattice of rank at least 2 and a solution to a combinatorial puzzle defined on that lattice. I will also introduce analogous invariant series for plumbed knot complements and establish a corresponding gluing formula. This is joint work with Allison Moore.

On Some Representation Theoretic Structures Related to Conformal Field Theory

Christoph Schweigert

Hamburg University

Tuesday, April 22, 2025 @ 12:10 PM

We explain that the representation categories of vertex algebras typically exhibit duality structures that are more general than rigid duality. Specifically, these categories have the structure of (ribbon) Grothendieck-Verdier categories, also known as *-autonomous categories. The construction of local conformal field theories (CFTs) necessitates a thorough understanding of Frobenius algebras internal to these representation categories. We explain how these algebras are connected to relative Serre functors.

Springer Correspondence and Mirror Symmetry for Hitchin Systems

Bin Wang

Chinese University of Hong Kong

Tuesday, April 22, 2025 @ 2:30 PM

In this talk, we will talk about mirror symmetry for parabolic Sp/SO Hitchin Systems. We will first talk about parabolic SL Hitchin systems as an example to show that singularities of generic spectral curves are determined by the Kazhdan-Lusztig map and construct a rational section of the Hitchin map. We will then talk about the relation of Lusztig's canonical quotient group with the failure of the mirror symmetry for residually nilpotent Sp/SO Hitchin systems and the mirror symmetry for parabolic Sp/SO Hitchin systems. This is based on joint works with Xiaoyu Su, Xueqing Wen and Yaoxiong Wen.

Level Structures on Parahoric G-Torsors

Georgios Kydonakis

University of Patras

Tuesday, April 22, 2025 @ 4:00 PM

For a reduced effective divisor of finitely many distinct points of a smooth complex algebraic curve, Seshadri introduced the notion of a level structure on a vector bundle over the curve as a local decoration given by a complete homomorphism on the fibers over the points of the divisor. A moduli space $\mathcal{U}$ of vector bundles with a level structure was constructured, and Markman showed that the moduli space $\mathcal{M}^s_{Higgs}$ of stable Higgs pairs is birationally isomorphic to the orbit space of a group action on the cotangent bundle of this moduli space $\mathcal{U}$. The space $\mathcal{M}^s_{Higgs}$ is thus equipped with a Poisson structure and algebraically completely integrable Hamiltonian systems appear in the symplectic leaves of this Poisson space. In this talk, we extend the notion of level structure on parahoric torsors for a general complex reductive group and show how one can similarly obtain a Poisson structure on the moduli space of logahoric Higgs torsors in this case. This is joint ongoing work with Lutian Zhao (Kavli IPMU).

Line Bundles on the Moduli of Parahoric Bundles

Chiara Damiolini

University of Texas at Austin

Wednesday, April 23, 2025 @ 9:30 AM

Moduli spaces of vector bundles over a curve X have been a central focus in algebraic geometry and adjacent fields. A natural generalization of these spaces can be obtained by replacing vector bundles with G-bundles, for G an algebraic group. In this talk I focus on the case when G takes the form of a parahoric Bruhat–Tits group and discuss how, using representation-theoretical methods, one can describe line bundles (and their sections) on Bun_G and sections, the moduli space of G-bundles. Specifically, I show how twisted conformal blocks can be used to detect when line bundles on an appropriate flag variety descend to Bun_G. This is based on joint work with J. Hong.

Kac-Wakimoto Hypothesis and Coset Constructions

Chongying Dong

University of California Santa Cruz

Wednesday, April 23, 2025 @ 11:00 AM

Motivated by the coset construction in the theory of vertex operator algebra, we investigate the coset constructions in the categorical setting. In particular, we establish the Kac-Wakimoto Hypothesis associated with pseudo-unitary modular tensor categories. This is a joint work with Li Ren and Feng Xu.

The Prym-Hitchin Connection and Anti-Invariant Level-Rank Duality

Christian Pauly

University of Nice

Wednesday, April 23, 2025 @ 12:10 PM

In this talk I will outline a construction of a "Hitchin-type" connection on the bundle of non-abelian theta functions over the so-called higher-rank Prym varieties, i.e., the moduli spaces parameterizing anti-invariant vector bundles over curves equipped with an involution. In this Prym setting I formulate a version of level-rank duality and I will show that the duality is projectively flat with respect to the Prym-Hitchin connection, which parallels the result obtained for the classical level-rank duality. As an application I will deduce that the monodromy of the Hitchin connection for classical SL(2) non-abelian theta functions at level 4 is finite. This finiteness result contrasts with a fact coming from TQFT saying that this monodromy is infinite for almost all levels.

Moduli Theory of the r-Braid Arrangement

Iva Halacheva

Northeastern University

Thursday, April 24, 2025 @ 9:30 AM

I will discuss the moduli problem for the wonderful compactification of a family of hyperplane arrangements depending on a positive integer parameter r, which we refer to as the r-braid arrangements and which can be viewed as a generalization of the classical type A braid arrangement. The wonderful compactification of the type A braid arrangement (with respect to its minimal building set) is well-known to yield the Deligne-Mumford moduli space M(0,n). We construct a moduli space M(r,0,n) of certain genus-zero curves with an order-r involution that we identify with the corresponding wonderful compactification of the r-braid arrangement. Just as M(0,n) relates to the Losev-Manin space L(0,n), the resulting space M(r,0,n) relates to a previously studied moduli space L(r,0,n), related via a change of weights on the markings. This is joint work with E. Clader, H. Liu, and D. Ross.

Crossed Extensions of Modular Categories and Twisted Conformal Blocks

Tanmay Deshpande

TIFR Mumbai

Thursday, April 24, 2025 @ 11:00 AM

For a finite group G acting on a simple Lie algebra, I will describe an approach to compute the dimensions of the corresponding twisted conformal blocks using a categorical twisted Verlinde formula for G-crossed extensions of the modular categories corresponding to the well-known untwisted case. For this, I will describe the equivalence between G-crossed extensions of modular categories and G-crossed modular functors. In joint work with S. Mukhopadhyay, we proved that if the G-action on the Lie algebra preserves a Borel subalgebra, then the corresponding twisted conformal blocks define a G-crossed modular functor and hence define a G-crossed modular category. The categorical twisted Verlinde formula then gives us the dimensions of the twisted conformal blocks in terms of crossed S-matrices. Finally, I will describe ongoing joint work with S. Mukhopadhyay, where we consider the general case and its relationship with the classification of G-crossed extensions of modular categories due to Etingof-Nikshych-Ostrik.

Motivic Factorization of KZ Local Systems and Deformations of Representation and Fusion Rings

Prakash Belkale

University of North Carolina at Chapel Hill

Thursday, April 24, 2025 @ 12:10 PM

Let g be a simple Lie algebra over C. The KZ connection is a connection on the constant bundle associated to a set of n finite dimensional irreducible representations of g and a nonzero k, over the configuration space of n-distinct points on the affine line. Via the work of Schechtman–Varchenko and Looijenga, when k is rational the associated local systems can be seen to be realizations of naturally defined motivic local systems. We prove a basic factorization for the nearby cycles of these motivic local systems as some of the n points coalesce. This leads to the construction of a family of deformations of the representation ring of g— we call these enriched representation rings—which allows one to compute the ranks of the Hodge filtration of the associated variations of mixed Hodge structure; in turn, this has applications to both the local and global monodromy of the KZ connection, and of the associated quotient of conformal blocks. In the case of special linear groups we give an explicit algorithm for computing all products in the enriched representation rings. This is joint work with N. Fakhruddin and S. Mukhopadhyay. If time permits I will also mention ongoing joint work with Fakhruddin on properties of the weight filtrations of KZ motives.

Hodge Structures on Conformal Blocks

Pierre Godfard

Sorbonne Universite

Thursday, April 24, 2025 @ 2:30 PM

Modular functors are collections of vector bundles with flat connections on (twisted) moduli spaces of curves, individually known as conformal blocks, that satisfy strong compatibility conditions with respect to natural maps between these moduli spaces. Such structures arise naturally in the representation theory of affine Lie algebras and quantum groups, where the conformal blocks are known to be semisimple. Recently, Hodge structures on genus-0 conformal blocks arising from affine Lie algebras have been studied by Belkale, Fakhruddin, and Mukhopadhyay through a motivic construction. In particular, they computed genus-0 Hodge numbers for sl_n. The subject of this talk is an axiomatic proof of the existence and uniqueness of such Hodge structures and the semisimplicity of conformal blocks for any modular category. If the flat bundles of conformal blocks were rigid, a result of Simpson in non-Abelian Hodge theory would imply that they support Hodge structures. However, this is not the case in general. I will explain how a different form of rigidity for modular categories—Ocneanu rigidity—can be used, together with non-Abelian Hodge theory, to tackle these questions. Finally, I will discuss an application to the computation of Hodge numbers for sl_2 modular functors of odd level in higher genus and how these numbers are part of (mysterious) cohomological field theories (CohFTs).

Classifying Bundles with a Torus Action

Christopher Manon

University of Kentucky

Thursday, April 24, 2025 @ 4:00 PM

A toric vector bundle is a vector bundle over a toric variety which is equipped with a lift of the action action of the associated torus. Toric vector bundles were first classified by Kaneyama, and later by Klyachko using the data of decorated subspace arrangements. This description enables many interesting results, including the construction of moduli spaces by Sam Payne. In recent joint work with Kiumars Kaveh, we have shown how Klyachko's data can be repackaged in a way that is at once more combinatorial and geometric: a piecewise-linear map from the fan of the toric variety to a spherical building of type A. We have since used this perspective to give a classification of toric G-principal bundles (G a connected algebraic group) using more general spherical buildings, bundles over a toric scheme using the affine building (joint with Boris Tsevlikhovskiy), and introduce a notion of tropical vector bundles. The Chern-Weil map, reduction of structure group, and various notions of positivity can be phrased naturally in this language. After introducing some of this background, I will describe a recent result along these lines classifying torus equivariant vector bundles on normal varieties of equipped with the action of a codimension 1 torus. Such varieties are called complexity 1 T-varieties. After explaining this result and several applications, I'll give some tentative remarks on an ongoing project to construct moduli, and connections to vector bundles over stacky curves. This is joint work with Jyoti Dasgupta, Chandranandan Gangopadhyay, and Kiumars Kaveh.

Logarithmic Connections on Parahoric Bundles on Wild Riemann Surfaces

Philip Boalch

CNRS, IMJ-Paris

Friday, April 25, 2025 @ 9:30 AM

I'll have a go at describing some of the background and motivation leading up to the definition of "good" meromorphic connections on parahoric bundles [4] extending the tame case [2] (tame logahoric connections). In particular I'll try to emphasize that the parahoric weights are needed to define the enriched Riemann-Hilbert correspondence, not just to define stability and parameterise harmonic bundles. The corresponding notion of "nonabelian Hodge space" [4] generalises the definitions in the fantastic work of Simpson [7] in two ways (any pole order and any G), encompassing their hyperkahler upgrade (Biquard, Konno, Nakajima, ... that led to [1]). The (wild) nonabelian Hodge spaces may be viewed as the noncompact, infinite energy, analogues of the spaces considered by Hitchin [6] involving harmonic bundles on compact Riemann surfaces. The full story involves upgrading the topological notion of local system to the notion of Stokes $\mathcal{G}$ local system for a local system of groups $\mathcal{G}$ [5]. If time permits I'll discuss examples of the representation theory of genus zero nonabelian Hodge spaces, for example the G_2 representations of the symmetric Fricke-Klein-Vogt Betti spaces [3].

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[1] Olivier Biquard and P.B., Wild non-abelian Hodge theory on curves, Compositio Math. 140 (2004), no. 1, 179–204. arXiv:math/0111098

[2] P.B. Riemann–Hilbert for tame complex parahoric connections, Transform. Groups 16 (2011), no. 1, 27–50, arXiv:1003.3177.

[3] P.B. and Robert Paluba, Symmetric cubic surfaces as G_2 character varieties, J. Algebraic Geom. 25 (2016), 607–631. arXiv:1305.6594.

[4] P.B. Wild character varieties, meromorphic Hitchin systems and Dynkin diagrams, (2018), Geometry and Physics: A Festschrift in honour of Nigel Hitchin, pp.433–454, arXiv:1703.10376.

[5] P.B. and Daisuke Yamakawa, Twisted wild character varieties, arXiv:1512.08091

[6] Nigel Hitchin, The self-duality equations on a Riemann surface, Proc. London Math. Soc. 55 (1987), no. 3, 59–126.

[7] Carlos Simpson, Harmonic bundles on noncompact curves, J. Am. Math. Soc. 3 (1990), 713–770.

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TBD

Valerio Toledano Laredo

Northeastern University

Friday, April 25, 2025 @ 11:00 AM

Gaussian Boson Sampling, Gaussian Weighted Integrals and their Generalization to Symplectic Manifolds

Joergen Andersen

University of Southern Denmark

Friday, April 25, 2025 @ 12:10 PM

First the notion of Gaussian Boson Sampling in the context of general symplectic manifolds which admits Kahler structures will be introduced together with the corresponding Gaussian weighted Integral problem. The simplest possible, yet very interesting case, is the case of flat Euclidean space with its standard symplectic structure. This example describes the mathematics behind the Gaussian Boson Sampling Quantum computing platform which has been realized in a number of quantum physical labs and quantum computing companies around the world using quantum optics. We will demonstrate how these quantum computing platforms can be used to solve Gaussian weighted Integral problems, in fact some of them exponentially faster than using the traditionally Monte Carlo simulation techniques. We will then turn to the general setting and explore these techniques and problems in the context of 2+1 dimensional TQFT in terms of geometric quantization of moduli spaces and their relation to more standard quantum computing platforms. Finally, we will consider these techniques and problems in the context of general symplectic manifolds admitting Kahler structures.

The Brin Mathematics Research Center

The Brin Mathematics Research Center is a research center that sponsors activity in all areas of pure and applied mathematics and statistics. The Brin MRC was funded in 2022 through a generous gift from the Brin Family. The Brin MRC is part of the Department of Mathematics at the University of Maryland, College Park.

Activities sponsored by the Brin MRC include long programs, conferences and workshops, special lecture series, and summer schools. The Brin MRC provides ample opportunities for short-term and long-term visitors that are interested in interacting with the faculty at the University of Maryland and in experiencing the metropolitan Washington DC area.

The mission of the Brin MRC is to promote excellence in mathematical sciences. The Brin MRC is home to educational and research activities in all areas of mathematics. The Brin MRC provides opportunities to the global mathematical community to interact with researchers at the University of Maryland. The center allows the University of Maryland to expand and showcase its mathematics and statistics research excellence nationally and internationally.

List of Participants

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