Since 2009, the String Group at the University of the Witwatersrand has hosted an annual workshop in formal theory. This year's meeting is held at the Wits Rural Facility from 3–8 September 2023. The theme of the workshop is "Mathematical Aspects of String Theory."

Schedule

Talk 1:	**Magdalena Larfors** (Uppsala University)
Talk 2:	**Fabian Ruehle** (Northeastern University)
Talk 3:	**Yannick Mvondo-She** (University of the Witwatersrand)
Talk 4:	**Mark Hughes** (Brigham Young University)
Talk 5:	**Piotr Sułkowski** (Warsaw University)
Talk 6:	**Garry Kemp** (University of Johannesburg)
Talk 7:	**Masahito Yamazaki** (Kavli Institute for the Physics and Mathematics of the Universe)
Talk 8:	**Yang Lei** (Soochow University)
Talk 9:	**Challenger Mishra** (University of Cambridge)
Talk 10:	**Sam van Leuven** (University of the Witwatersrand)
Talk 11:	**Shota Fujiwara** (University of the Witwatersrand)
Talk 12:	**Per Berglund** (University of New Hampshire)

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Per Berglund: "New Calabi–Yau manifolds from genetic algorithms"

Abstract: Calabi–Yau manifolds can be obtained as hypersurfaces in toric varieties built from reflexive polytopes. We generate reflexive polytopes in various dimensions using a genetic algorithm. As a proof of principle, we demonstrate that our algorithm reproduces the full set of reflexive polytopes in two and three dimensions, and in four dimensions with a small number of vertices and points. Motivated by this result, we construct five-dimensional reflexive polytopes with the lowest number of vertices and points. By calculating the normal form of the polytopes, we establish that many of these are not in existing datasets and therefore give rise to new Calabi–Yau four-folds. In some instances, the Hodge numbers we compute are new as well.

Shota Fujiwara: "Recent developments on the giant-graviton expansion"

Abstract: Recently, a new method for calculating the superconformal index, called the giant-graviton expansion, has been established. This method calculates superconformal indices of SCFTs from the holographic dual string theory on AdS spacetime. Specifically, the giant-graviton expansion adds the contribution of wrapped branes (giant-gravitons) as a finite-N correction to the large-N indices, and indices of SCFTs of any rank N can be calculated exactly. In this talk we will discuss recent developments on the giant-graviton expansion mostly focusing on "the duality" aspect associated to it.

Mark Hughes: "Computational bounds on the band rank of braids"

Abstract: Braid closures provide a way to study knots and links in 3-space via group-theoretic techniques. Important open problems in low-dimensional topology, such as the slice-ribbon conjecture, can be reformulated as problems in combinatorial group theory via a particular braid invariant called the band rank. In this talk I will describe the band rank and its connection to the slice and ribbon genera of its closure. I will also describe techniques for computing this quantity which draw on tools from combinatorial group theory, dynamic programming, and deep reinforcement learning.

Garry Kemp: "A generalized dominance ordering for 1/2-BPS states"

Abstract: We discuss a generalized dominance ordering for irreducible representations of the symmetric group S_n with the aim of distinguishing the corresponding states in the 1/2-BPS sector of $U(N)$ Super Yang-Mills theory when a certain finite number of Casimir operators are known. Having knowledge of a restricted set of Casimir operators was proposed as a mechanism for information loss in this sector and its dual gravity theory in $\mathrm{AdS}_5 \times S^5$. It is well-known that the states in this sector are labelled by Young diagrams with n boxes. We propose a generalization of the well-known dominance ordering of Young diagrams. Using this generalization, we posit a conjecture to determine an upper bound for the number of Casimir operators needed to distinguish between the 1/2-BPS states and thus also between their duals in the gravity theory. We offer numerical and analytic evidence for the conjecture. Lastly, we discuss implications of this conjecture when the energy n of the states is asymptotically large.

Magdalena Larfors: "CY metrics from NNs"

Abstract: Calabi Yau (CY) manifolds are used ubiquitously in research on string theory. Since decades, these spaces have provided the main avenue to connect string theory with observable physics. A stumbling block in these constructions is the lack of an analytical expression for the CY metrics. In this talk I will review recent work on obtaining numerical approximations of CY metrics using machine learning, and point towards improvements that will allow these methods to promote string theory research.

Yang Lei: "The panorama of Spin Matrix theory"

Abstract: Spin Matrix theory describes near-BPS limits of $\mathcal{N} = 4$ SYM theory, which enables us to probe finite N effects like D-branes and black hole physics. In previous works, we have developed the spherical reduction and spin chain methods to construct Spin Matrix theory for various limits. In this paper, by considering a supercharge Q which is cubic in terms of the letters, we construct the Hamiltonian of the largest Spin Matrix theory of $\mathcal{N} = 4$ SYM, called the $PSU(1, 2|3)$ Spin Matrix theory, as $H = \{Q, Q^\dagger\}$. We show the resulting Hamiltonian is automatically positive definite and manifestly invariant under supersymmetry. The Hamiltonian is made of basic blocks which transform as supermultiplets. A novel feature of this Hamiltonian is its division into D-terms and F-terms that are separately invariant under $PSU(1, 2|3)$ symmetry and positive definite. As all the other Spin Matrix theories arising from $\mathcal{N} = 4$ SYM can be acquired by turning off certain letters in the theory, we consider our work as revealing the "Panorama" of Spin Matrix theory.

Sam van Leuven: "Modular factorization of superconformal indices"

Abstract: We argue for a genuinely new type of modular property obeyed by superconformal indices of a large class of $4d$ $\mathcal{N} = 1$ gauge theories. The modular property reflects ambiguities in the Heegaard splitting of a Hopf surface. It relies on a a factorization property of the superconformal index, known as holomorphic block factorization. We point out a connection with quantum modular properties and argue that this can be used to explain some observations in the literature concerning modular properties of $\mathcal{N} = 2$ Schur indices.

Challenger Mishra: "Mathematical conjecture generation and machine intelligence"

Abstract: Conjectures hold a special status in mathematics. Good conjectures epitomise milestones in mathematical discovery, and have historically inspired new mathematics and shaped progress in theoretical physics. Hilbert's list of 23 problems and André Weil's conjectures oversaw major developments in mathematics for decades. Crafting conjectures can often be understood as a problem in pattern recognition, for which Machine Learning (ML) is tailor-made. In this talk, I will propose a framework that allows a principled study of a space of mathematical conjectures. Using this framework and exploiting domain knowledge and machine learning, we generate a number of conjectures in number theory and group theory. I will present evidence in support of some of the resulting conjectures and present a new theorem. I will lay out a vision for this endeavour, and conclude by posing some general questions about the pipeline.

Yannick Mvondo-She: "The log partition function of critical topologically massive gravity: from Calabi–Yau manifolds to mathematical genetics"

Abstract: We review different aspects of the logarithmic contribution of the 1-loop partition function of critical cosmological topologically massive gravity, originally derived by Gaberdiel, Grumiller and Vassilevich, leading to several inferences concerning the logarithmic sector of the theory.

Fabian Ruehle: "Massive string towers, level crossing, and black hole attractors"

Abstract: Using numerical approximations to the Ricci-flat CY metric, it has become possible to compute higher eigenmodes of the scalar Laplacian, which correspond to massive towers of states. It has been observed that these towers become heavier or lighter as one traverses the CY moduli space, and that eigenmodes cross along codimension 1 loci. This begs the question whether there is something special about these crossing points. To shed light on this, we study simple one-parameter families of CYs in various dimensions. For tori, analytic solutions are possible, which shows an interesting relation between level crossings and number theory. We also use these toy models to assess the quality and the main

sources of error for of our numeric spectrum approximations. Armed with these results, we speculate about generalizations of our observations to more general CY manifolds.

Piotr Sułkowski: "Knots–quivers correspondence — status report"

Abstract: As the name indicates, the knots-quivers correspondence is a relation between quiver representation theory and knot theory. It follows from physical considerations and properties of brane systems in string theory. It was found a few years, and in the original formulation it enables to express various invariants of knots in terms of invariants of quivers. Since then the relation to quivers has been generalized to other systems, in particular 3-manifolds and toric Calabi–Yau manifolds. These developments also turn out to be related to (and also enable to solve) problems in combinatorics, number theory, conformal field theory, and other fields. In this talk I will review various results and open problems in this research area.

Masahito Yamazaki: "Quiver Yangians and crystal meltings"

Abstract: We discuss recent developments in BPS state counting problems for non-compact toric Calabi–Yau manifolds. In short, the counting is reformulated as a statistical model of crystal melting, which can be understood as the representation space for the quiver Yangian.

Other participants: Pallab Basu (University of the Witwatersrand), Kevin Goldstein (University of the Witwatersrand), Shajid Haque (University of Cape Town), Vishnu Jejjala (University of the Witwatersrand), Anosh Joseph (University of the Witwatersrand), Mbavhalelo Mulokwe (University of the Witwatersrand), Pratik Roy (University of the Witwatersrand), Laila Tribelhorn (University of Pretoria), and Costas Zoubos (University of Pretoria).