THE UNIVERSITY OF QUEENSLAND
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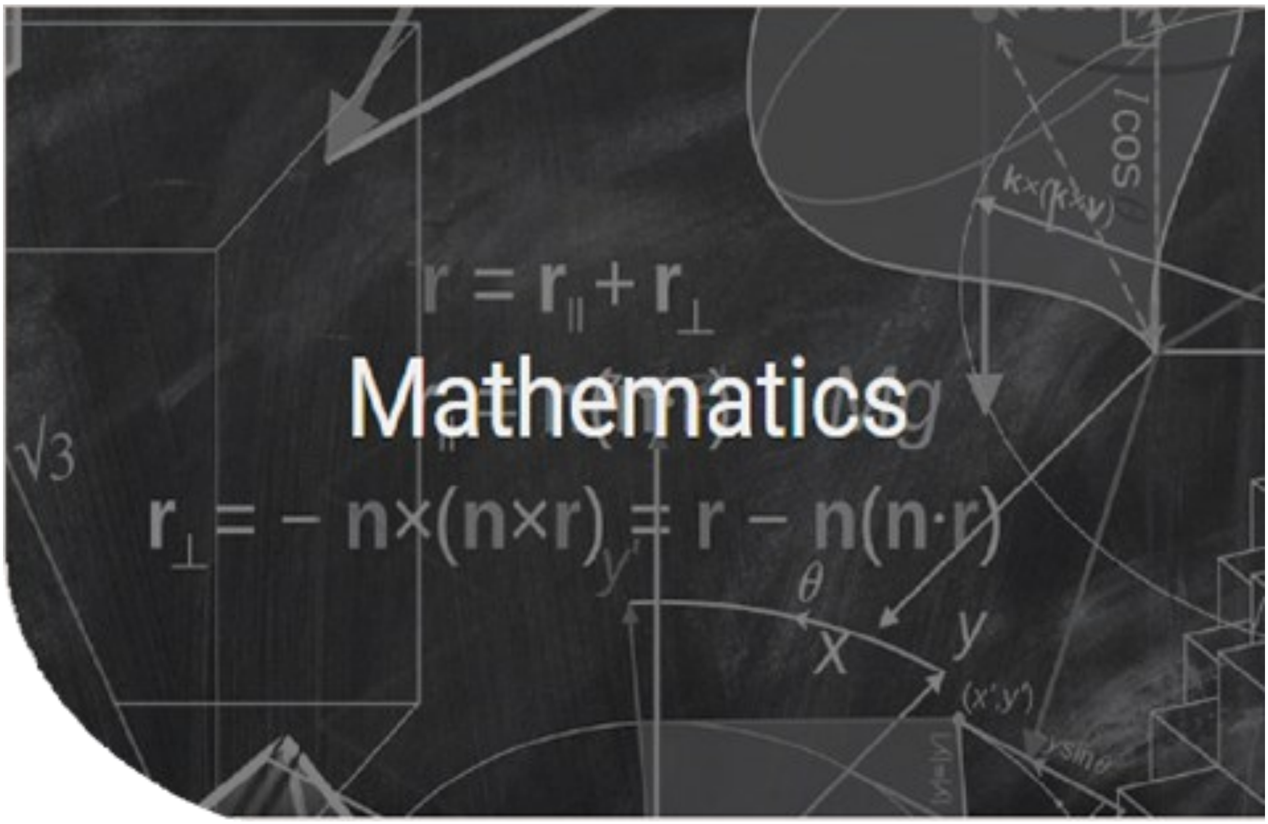
SMP Poster Day 2023
Abstract Booklet



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1. What is an Einstein metric?

Candidate: ***Adam Thompson***

Advisor: Dr Ramiro Augusto Lafuente

Abstract: Einstein manifolds are ubiquitous in geometry and physics. They inherit their names from Albert Einstein, one of the most well-known physicists in history. But what are they, and why should a mathematician care about them? In my poster I give an overview of Einstein manifolds from a mathematicians perspective. I also talk about how Einstein manifolds appear in my own research.

2. Nonconvex Newton-MR with Inexact Hessian

Candidate: ***Alexander Lim***

Advisor: Dr Farbod Roosta-Khorasani

Abstract: The celebrated Newton's method with conjugate gradient (CG) sub-problem solver, often referred to as Newton-CG, has historically held a special place among second-order optimization methods for unconstrained minimization of convex smooth objectives. Recent advances in nonconvex optimization have extended the application range of Newton-CG far beyond convex problems to nonconvex settings. We consider an alternative class of Newton-type methods where CG is replaced with the Minimal Residual (MINRES) method as the inner solver. This class of methods, generally termed Newton-MR, have been shown to also apply to non-convex settings and come equipped with several advantageous properties over the Newton-CG counterparts. However, their application to large-scale problems remains challenging. In this poster, I show the inexact variants of Newton-MR, which, by approximating the Hessian of the algo-

3. Using Super-integrability to solve the Schrödinger equation algebraically.

Candidate: ***Anthony Parr***

Advisors: Dr Ian Marquette

Abstract: We consider two-dimensional quantum systems on a space of constant curvature equipped with a singular oscillator potential with precession and reflection operators. This is a generalisation of a model that was first presented by Tremblay, Turbiner and Winternitz (2009) and a model discovered by Post, Vinet and Zhedanov (2011). The symmetries of these models have been incompletely classified in the literature and, in particular, their representations have not been studied. We will showcase the full symmetry algebra, which are polynomial Lie or Jordan type, as well as some of their representation theory. The representations are able to give us the physical spectrum of the Hamiltonian even when the underlying Schrödinger equation has not been solved analytically.

4. Topology of Representation Spaces via Arithmetic

Candidate: ***Bailey Whitbread***

Advisor: AsPr Masoud Kamgarpour

Abstract: Representation spaces are those whose points correspond to homomorphisms from the fundamental group of a surface to an algebraic group. These spaces are related to the Yang-Mills equations, Hitchin's equations, the geometric Langlands correspondence, the P=W conjecture and mirror symmetry. In general, representation spaces are not well-understood. The situation is best understood when the algebraic group is the general linear group of invertible matrices, thanks to the seminal work of Hausel--Rodriguez-Villegas and Hausel--Letellier--Rodriguez-Villegas.

We seek to understand the situation for general algebraic groups. Our work includes new results regarding the geometry and topology of these representation spaces. In particular, we compute polynomials that describe the cohomology of these spaces, and extract topological data from them. This unifies and explains some results previously obtained in this area. A key feature of our approach is the utilisation of the representation theory of finite groups (of Lie type).

5. 6D N=(2,0) conformal supergravity

Candidate: ***Christian Kennedy***

Advisor: Dr Gabriele Tartaglino Mazzucchelli

Abstract: During the last four decades, supersymmetry has been at the forefront of theoretical and mathematical physics of fundamental interactions. It played a crucial role in constructing models aimed at the unification of all forces including quantum gravity, namely string theory. Supersymmetry has also led to several new developments in mathematical physics such as, for example, the study of conformal field theories (that play a fundamental role in string theory and in the description of phase transitions in statistical mechanics) and integrable systems. Moreover, supersymmetry has also led to the development of new mathematics, such as the extension of classical differential geometry to its super counterpart. A superconformal algebra extension of the conformal algebra does not exist in dimensions greater than six. This work will be focused on 6D N=(2,0) conformal supergravity, which gauges the N=(2,0) superconformal algebra and makes its symmetries local. Two lines of research are pursued: (1) the construction of the superspace geometry of 6D N=(2,0) conformal supergravity, (2) the analysis of the associated 6D N=(2,0)

6. An analogue of a conjecture of Saxl for GL_n(Fq)

Candidate: ***GyeongHyeon Nam***

Advisor: AsPr Masoud Kamgarpour

Abstract: The Kronecker coefficient is an intriguing number in the realm of character theory for symmetric groups. It represents the multiplicity of the trivial character in the tensor product of three irreducible characters of the symmetric group S_n. Remarkably, roughly a decade ago, Saxl introduced an intriguing conjecture regarding this number. Subsequently, we have enhanced and expanded upon this conjecture with unipotent characters of GL_n(Fq). Moreover, we can present more clear conjectures by extending the scope of our findings.

7. Covariance clustering: A linear mixed model solution for building covariance structures when experimental units are few and variables are many

Candidate: ***Clayton Forknall***

Advisor: AsPr Jonathan Nazarathy

Abstract: The size and complexity of datasets resulting from comparative research experiments in the agricultural domain are constantly increasing, due to the measurement of many variables on few experimental units. Repeated measurements on experimental units induces covariance between variables, and estimation difficulties can arise due to the resulting covariance structure being of reduced rank. We present a statistical method, based in a linear mixed model framework, for the analysis of such experiments. Incorporating k-means clustering, our covariance clustering method enables the estimation of covariance between variables through the introduction of clusters, as random effects with simple variance structures, into the modelling framework. In this way, the method allows for the estimation of more flexible covariance structures than those resulting from traditional variance component models, while also being applicable in cases where more complex covariance models can have estimation issues. We apply the method to the analysis of a mass spectrometry based barley malt proteomics experiment, demonstrating the method's use in the estimation of a parsimonious residual covariance structure. This structure approximates the known complex relationships that exist within the proteome and provides more accurate predictions of protein abundance than if such relationships had been ignored.

8. Automated Adaptive Multilevel Splitting

Candidate: ***Joseph Menesch***

Advisor: Dr Thomas Taimre

Abstract: Consider the small probability that a diffusion process parameterized by its noise level hits a particular set before another. For the estimation of this rare-event probability, adaptive multilevel splitting (AMS) is well-suited due to its practicality and desirable properties. However, it requires an importance function (IF), whose choice determines the algorithm's efficiency. The optimal IF for AMS is the committor function, which is generally not known nor easily guessed. We propose an iterative heuristic, called AutoIF, which is motivated by the observation that AMS efficiently generates an ensemble of points which can be utilized in solving the problem. For AutoIF, a sequence of modified, increasingly rare problems are solved via AMS, and the resulting ensemble is used to approximate a new IF for the next iteration via some function approximation method – in our case, a cell-based method and logistic regression. The final IF is used to estimate the target probability. A gradual approximation of IFs for rarer and rarer problems eventually leads to an IF for the target problem which may provide a better approximation of the committor function than one which is approximated outright.We compared AutoIF against ordinary AMS (using typical user-defined IF) on three problem-types – an Ornstein-Uhlenbeck spiral, three-wells potential, and rugged Mueller potential – across three rarity levels and up to dimension 10. AutoIF generally had lower relative error than AMS for rarer problems, but the function approximation method became a hinderance in higher dimensions. The cell method often outperformed logistic regression, but struggled with numerical issues. Furthermore, AutoIF performed best for the spiral and the three-wells problems. Overall, we found that AutoIF is strongest in rarer problems that have complex dynamics, making it a promising choice for rare-event problems which are out of reach for traditional algorithms. Possible improvements could include better function approximation methods.

9. Prevalence of stability for smooth Blaschke product cocycles fixing the origin

Candidate: ***Joshua Peters***

Advisor: AsPr Cecilia Isabel Gonzalez Tokman

Abstract: Formulating dynamical systems that model real world phenomena is an enormous, arguably impossible challenge facing applied mathematicians. Due to the number of uncontrollable degrees of freedom, one may question whether small modelling errors influence the long term predictions for such systems in a comparably small or drastic fashion. In recent years, significant progress has been made in exploring the robustness of autonomous and non-autonomous systems under perturbations, in both finite and infinite dimensional settings, but many problems remain entirely open. In this work, we address this question using the theory of prevalence and investigate the stability properties of Lyapunov exponents for transfer operator cocycles from a measure-theoretic perspective. Our results focus on so-called Blaschke product cocycles, a class of random dynamical systems amenable to rigorous analysis. We show that amongst smooth monic quadratic Blaschke product cocycles fixing the origin, those which are stable form a prevalent set. However, upon modifying the dimension of the probability space, we provide strong evidence that stability is not prevalent. Further, through a perturbative method we show that almost every smooth Blaschke product cocycle fixing the origin is stable.

10. Quantum superintegrable systems in Darboux spaces

Candidate: ***Junze Zhang***

Advisor: AsPr Yao-zhong Zhang

Abstract: Superintegrable systems in 2D Darboux spaces were classified and it was found that there exist 12 distinct classes of superintegrable systems with quadratic symmetry algebras generated by the integrals in the Darboux spaces. Moreover, finite and Infinite-dimensional representations of symmetry algebras play a significant role in determining the spectral properties of physical Hamiltonians. Explicit construction of these representations is a non-trivial task due to the non-linearity of the polynomial algebras.

In this post, I will present the deformed oscillator realization and finite-dimensional irreducible representation of the underlying symmetry algebra on 2D Darboux spaces. This will lead to the energy spectrum of Hamiltonian. On the other hand, we introduce and apply a practical method to construct infinite dimensional representations of certain polynomial algebras which appear in the context of quantum superintegrable systems. Our method has similarities with the induced module construction approach in the context of Lie algebras and allows the construction of states of the superintegrable systems beyond the reach of the separation of variables. As a result, we are able to construct a large number of states in terms of complicated expressions of Airy, Bessel and Whittaker functions which would be difficult to obtain in other ways.

11. Quantum Integrable Bosonic Networks

Candidate: ***Lachlan Bennett***

Advisor: AsPr Jon Robert Links

Abstract: Bosons are elementary particles that can occupy the same local quantum state. To represent a many-body system of bosons we use a bosonic network, which associates a bosonic Hamiltonian with a weighted graph. The Hamiltonian is defined with hopping terms, assigned to the edges of the graph, and a global interaction term. We analyse a specific class of integrable bosonic networks, obtaining the eigenspectrum to investigate the quantum dynamics in certain tunnelling regimes. By examining the dynamics of these models, we find parity effects, measurement probabilities, and how the entanglement evolution depends on the structure of the graph. Emphasis is placed on an integrable four-site model which provides a framework for a NOON state generation protocol.

12. New Deformations of Quantum Field Theories

Candidate: ***Liam Smith***

Advisor: Dr Gabriele Tartaglino Mazzucchelli

Abstract: Quantum field theory (QFT) is one of the most successful frameworks to describe a wide array of physical phenomena from particle physics to condensed matter systems. It is also the core description of models of (quantum) gravity. Despite its success, the understanding of strongly coupled, interacting QFTs remains an outstanding mathematical problem. One route to make progress is to study exactly-solvable models and deformations thereof, together with symmetries, to move within the set of QFTs. The TTbar deformation is an exciting tool which aids in this exploration. Defined as the determinant of the stress-energy tensor for a two-dimensional QFT, it has proven to preserve integrability, (super-) symmetries, and it has shed new light on various areas of research including: non-local QFT, string theory, and holographic (AdS/CFT) dualities. TTbar-like deformations have been introduced also in D>2 dimensions finding surprising relations with non-local effective actions, such as the Born-Infeld theory of non-linear Electrodynamics, that describe universal sectors of string theory at low-energy. A $\sqrt{T\bar{T}}$ type of deformation have recently also been proven to lead to the ModMAX theory of non-linear Electrodynamics that has attracted substantial attention in the last couple of years. This poster will summarise some of the work done in finding theories in higher dimensions which obey a $T\bar{T}$ -like flow equation, as well as some pioneering work on understanding the new aforementioned $\sqrt{T\bar{T}}$ deformation. Supersymmetric extensions of all results will also be presented.

13. An isomorphism of diagram algebras

Candidate: ***Madeline Nurcombe***

Advisor: Prof Jorgen Rasmussen

Abstract: A diagram algebra is an algebra with a basis of diagrams, and multiplication based on concatenation of diagrams. The dilute Temperley-Lieb (dTL) algebra and the Motzkin algebra are diagram algebras; the dTL algebra is used in statistical mechanics to describe loosely-packed loop models, while the Motzkin algebra was introduced as the centraliser algebra of an action of a quantum group. These algebras are defined in terms of the same basis diagrams, but with different multiplication rules. We show that they are isomorphic, as long as a particular parameter of the Motzkin algebra is nonzero.

14. Balanced harvest in an age-structured fishery model

Candidate: ***Manuela Mendiolar***

Advisor: Dr Matthew Harrison Holden

Abstract: In Queensland, like in many other developed countries, sustainability targets for managed fisheries are usually expressed in terms of ratio rules such as maintaining a population size equal to 60% of carrying capacity. Despite the obvious appeal of such a simple quantitative target, it is clear that an unintended consequence may be a significant tilting of the proportions of biomass across different ages, from what they would have been under harvest free conditions. In this presentation, we focus on various notions of "Balanced Harvest" across age-cohorts of a single harvested species whose population can be well captured by an agestructured model. Fortunately, the generic age-structured model, widely used in Queensland, possesses some desirable mathematical properties. Despite being nonlinear, it can be shown to be asymptotically stable under weak conditions. This allows us to formulate a bi-objective optimization problem which captures the trade-offs between the desire to maximize sustainable yield and minimize a deviation function representing the degree to which the harvest is balanced. Since the latter function is non standard we consider several alternatives such as simple distance from the virgin biomass equilibrium, cross-entropy and an interior point barrier function.

15. Fighting Fires with Mathematics

Candidate: ***Mitch Harris***

Advisor: Dr Michael Alan Forbes

Abstract: The so-called Wildfire Suppression Problem is a network interdiction game played on a sparse directed graph that represents a landscape. The nodes in the graph represent regions of that landscape with arcs connecting adjacent regions. The weights on the arcs represent the expected travel times of the fire. Suppression resources become available at certain times, and we get to allocate them to nodes of our choice. If a node has a suppression resource, then the travel time of fire out of that region is delayed. Our goal is to calculate the allocation of suppression resources over time which maximizes the number of protected regions. Several approaches to this problem have been proposed in the literature, including a direct Mixed-Integer Programming formulation, and metaheuristics. We propose an alternative approach using Logic-Based Benders Decomposition. Ours is the first algorithm able to solve realistic instances to provable optimality. Although a coarse approximation of fire dynamics, models like this and the accompanying computational techniques are accurate and beneficial enough to be used by real fire analytics departments. Our paper has been published by Computers and Operations Research: https://doi.org/10.1016/j.cor.2023.106392

16. Inexact Newton's method for non-convex constrained optimization

Candidate: ***Oscar Smee***

Advisor: Dr Farbod Roosta-Khorasani

Abstract: Gradient methods lie at the heart of modern large scale, nonconvex machine learning. However, gradient methods can be sensitive to step size choice and ill conditioning. Classic Newton's method alleviates these issues but is computationally infeasible at scale and struggles to deal with nonconvexity. A recently developed inexact Newton method called Newton-MR significantly reduces computational cost and is capable of dealing with nonconvexity. We seek to extend the use of Newton-MR to simple constrained objectives by developing a Newton-MR based two metric projection algorithm.

17. Extreme Precipitation on the Eastern Coast of Australia

Candidate: ***Ruethaichanok Kardkasem***

Advisor: Dr Meagan Carney

Abstract: Severe flooding is an ongoing problem along the eastern coast of Australia, mainly attributable to multi-day extreme precipitation. Climate change has been identified as a significant contributor to these extreme weather events. However, conventional methods of estimating return levels using extreme value theory may not account for the impacts of non-stationary climate conditions. Moreover, these methods do not account for consecutive daily precipitation extremes. Our research aims to address these limitations by developing a comprehensive approach to extreme value analysis incorporating spatial-temporal and climate change variables, mainly focusing on consecutive extreme precipitation events.

18. The geometry of additive character varieties

Candidate: ***Stefano Giannini***

Advisor: AsPr Masoud Kamgarpour

Abstract: This project addresses a longstanding open problem in mathematics; namely, understanding the cohomology of representation spaces associated to surface groups. These representation spaces have deep connections to various fields of mathematics and physics, including non-abelian Hodge theory, mirror symmetry, Yang-Mills theory, and the Langlands program. Understanding their geometry is therefore a fundamental problem. This project aims to shed light on these spaces by studying the cohomology of their

19. Latin hypercubes realizing integer partitions

Candidate: ***Tara Kemp***

Advisor: Prof Diane Margaret Donovan

Abstract: A latin square of order n is a square array in which each of n symbols occurs exactly once in every row and column, similar to a Sudoku puzzle. L. Fuchs posed a question about the existence of quasigroups with disjoint subquasigroups and this problem is equivalent to the existence of latin squares with disjoint subsquares. The existence of these latin squares is a partially solved problem and it can be extended to a problem on latin cubes with disjoint subcubes. The problem can be extended further into latin hypercubes, and the higher dimensions create many new problems in determining existence.

20. Markov chains in periodic and random environments: long-term behavior of inhomogeneous chains

Candidate: ***Renee Oldfield***

Advisor: AsPr Cecilia Isabel Gonzalez Tokman

Abstract: Finite Markov chains have been extensively used to model different phenomena such as weather, transport networks and birth-death rates. Numerous models assume time-homogeneity, which may not accurately reflect reality, such as seasonal variation when modeling weather or random disruptions to a transport network. We incorporate inhomogeneity in the form of periodically and randomly (i.i.d.) occurring perturbations to the transition matrix, in the context of Markov chains in random environments (MCRE).

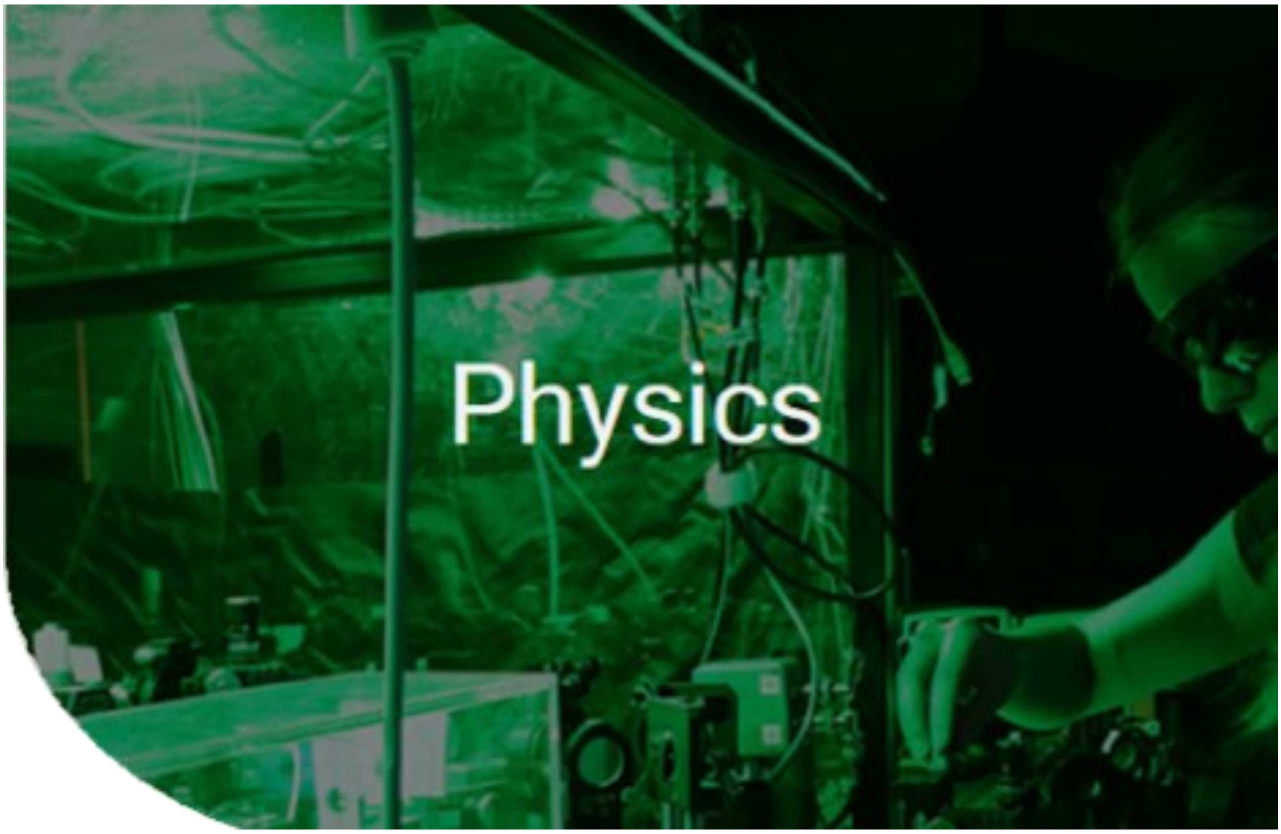
We investigate intrinsic properties of the system such as the annealed distribution, mean first passage times and Kemeny constant. These values describe some aspects of the long-term behavior of a discrete-time finite-state Markov chain such as the long-term probability of being in a particular state and the mean travel time of a random walker. In particular, we formulate mean first passage time and Kemeny constant equations for these two types of perturbations, extending results from the homogeneous case for these particular inhomogeneous cases. We also investigate the effect of perturbations on these properties for a

21. On the gl(m|n) Gaudin superalgebras

Candidate: **Mitchell Jones**

Advisor: Dr Phillip Isaac

Abstract: Lie superalgebras attract substantial research for applications in modelling systems of fermions. For integrable systems, previous research has shown a novel method for constructing r-matrices with non-additive spectral parameters associated with the general linear Lie superalgebras gl(m|n). Discussed here is the process of constructing thes Gaudin superalgebras of gl(m|n), a few examples of the resulting algebras, and a summary of the main results found in this project.



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1. Is our Milky Way galaxy being pulled towards the Great Attractor?

Candidate: ***Abbe Whitford***

Advisor: Prof Tamara Davis

Abstract: For over a decade there have been contradictory claims in the literature about whether the local bulk flow motion of galaxies, which can be thought of as an average of the galaxy motions sourced by gravity, is consistent or in tension with the currently accepted model of cosmology, Lambda-CDM. However, systematics in popular bulk flow estimators, that are associated with the bulk flow measurements that are in tension with the model, have not been widely investigated. My poster illustrates the research I have done to investigate how accurate and precise these estimators are. I also present my bulk flow measurement using the largest catalogue of peculiar velocities to date, which is consistent with the direction of previous bulk flow measurements but has a larger amplitude than predicted by Lambda-CDM. The bulk flow indicates a strong pull towards the hypothesised 'Great Attractor' which lies out of sight, behind the plane of the Milky Way.

2. Dark matter detection via atomic interactions

Candidate: ***Ashlee Caddell***

Advisor: Dr Benjamin Matthew Roberts

Abstract: The mystery of dark matter (DM) is a long-standing issue in physics, with numerous dedicated experiments returning no confirmed detections. As many direct detection experiments rely on catching a signal of nuclear recoil, these types of experiments are not applicable to many DM models. Instead, we can utilise the precision that atomic physics allows to search for potential interactions between atomic systems and DM, with possibilities spanning a large mass range. If we have a DM particle with masses just above electrons, then we can search for signals of atomic ionisation. If we move to masses just below electrons, then we look to absorption of DM on atomic electrons. Moving much further down to where DM begins to behave like a classical field, then we can measure the effects with atomic systems, such as those in atomic clocks and variations in fundamental constants. Additionally, interactions such as these many be possible to detect with current and upcoming detection experiments. In this work, I will discuss the prospect for DM detection with atomic systems, the tools needed to accurately assess the possibility, and potential implications for experimental searches.

3. Relativistic Particle Sources and Detectors

Candidate: ***Cassandra Bowie***

Advisor: Prof Gerard Milburn

Abstract: The Unruh-DeWitt detector is a popular application of the principles of Quantum Field Theory, acting as a simple model with large capacity to probe the fundamentals of field theory, spacetime and quantum phenomena. In simple terms, the detector is a two level system, which when subject to a background field or non-inertial worldline returns interesting results which can be monitored as excitations and de-excitations of the detector. We propose an extension of the traditional detector model to a source/detector paired model, and discuss the possible applications and benefits of this model.

4. Enhancing multimode silicon photonic devices for high-dimensional quantum computing using EME-based optimization and polymer-hybrid platforms

Candidate: ***Airin Antony***

Advisor: AsPr Mary Romero

Abstract: Multimode silicon photonics involves the integration of photonic components that support higher order modes on a silicon platform. The field shows great promise due to its varied applications (optical computing, data centres, artificial intelligence) and CMOS compatibility [1]. Lately, it is also becoming a popular platform for high-dimensional quantum computing [2]. A major hindrance, however, is that the conventional single-mode design approaches don't always translate to multimode components [1]. For instance, while designing our chip, optimizing a multimode broadband directional coupler (DC) proved computationally quite expensive compared to its single-mode counterpart. Another limitation is that a purely silicon platform is greatly limited in efficiency [3]. This renders components like the mode-sensitive thermo-optic phase shifters (MS-TOPS) highly inefficient [4] and in need of costly sub-wavelength (SW) fabrication [5]. Our approach makes use of efficient optimization techniques and silicon-polymer-hybrid platforms. We present two of our recent results: First, our technique optimizing the multimode DC about 100x faster than conventional FDTD methods utilizing eigenmode expansion (EME). Next, our PMMA cladding based MS-TOPS which is as efficient as the SW design without any costly SW fabrication. It can be further improved with new polymers, demonstrating the versatility of our hybrid platforms. Finally, we touch on implementing these devices on large-scale multimode circuits for quantum information processing.

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5. QED radiative corrections to E1 amplitudes in heavy atoms

Candidate: Carter Fairhall

Advisor: Dr Jacinda Sophia Morris Ginges

Abstract: In the last years, increasing attention has been given to the role of quantum electrodynamic (QED) radiative corrections in high-precision studies of heavy many-electron atoms and ions. The ability to theoretically describe electric dipole (E1) transition matrix elements with high precision is important in a number of different areas, both fundamental and applied, including atomic parity violation studies, atomic clocks, and quantum information. The account of QED corrections was critical in the interpretation of the atomic parity violation measurement in cesium [1].

We report on the first detailed study of the interplay between QED and many-body effects in heavy atoms for E1 transition amplitudes. We use the radiative potential method and check its validity by comparing against the results of rigorous QED. We study the effects of core relaxation, polarization of the core by the E1 field, and valence-core correlations for the heavy alkali-metal atoms Rb, Cs, Fr, and alkali-metal-like ions Sr+, Ba+, and Ra+. We identify several transitions in Cs for which the QED contribution exceeds the deviation between atomic theory and experiment.

[1] C. S. Wood, S. C. Bennett, D. Cho, B. P. Masterson, J. L. Roberts, C. E. Tanner, and C. E. Wieman. *Measurement of parity nonconservation and an anapole moment in cesium.* Science **275**, 1759 (1997).

6. Fabrication of highly coherent superconducting quantum devices

Candidate: ***ChunChing Chiu***

Advisor: Associate Professor Arkady Fedorov

Abstract: The superconducting circuit has become the most widely used platform for implementing a quantum computer and investigating circuit quantum electrodynamics. The performances of a quantum computer and the experiments are determined by the quality of individual superconducting qubit. The coherence time of a superconducting qubit can be correlated with the quality of the superconducting resonators made from the same recipe. The quality of resonators is determined by the material and fabrication procedures. We investigated and optimized the fabrication procedure of a superconducting resonator based on aluminium and silicon. Notably, we had more than five-fold increase in quality factors after the optimization. Furthermore, we show effects of post-treatment on the quality of resonators.

7. Black hole volumes

Candidate: ***Colin MacLaurin***

Advisor: Prof Timothy Cameron Ralph

Abstract: I investigate the spatial volume of a Schwarzschild black hole, relative to various different families of observers. Recall that in special relativity, lengths and volumes are relative to the velocity of the observer. We can extend this concept to curved spacetime by choosing an observer velocity at every point. Then the total volume of a region is the sum of local measurements by the individual observers. The question then becomes, "What are the most natural observer families?" This approach contrasts with most of the literature, which picks a hypersurface with little physical justification, then computes its volume in the standard way.

8. Quantum Blockchains: an energy efficient alternative

Candidate: ***Deepesh Singh***

Advisor: Dr Austin Peter Lund

Abstract: Since its advent in 2011, boson-sampling has been a preferred candidate for demonstrating quantum advantage because of its simplicity and near-term requirements compared to other quantum algorithms. We propose to use a variant, called coarse-grained boson-sampling (CGBS), as a quantum Proof-of-Work (PoW) scheme for blockchain consensus. The users perform boson-sampling using input states that depend on the current block information, and commit their samples to the network. Afterward, CGBS strategies are determined which can be used to both validate samples and to reward successful miners. By combining rewards to miners committing honest samples together with penalties to miners committing dishonest samples, a Nash equilibrium is found that incentivizes honest nodes. The scheme works for both Fock state boson sampling and Gaussian boson sampling and provides dramatic speedup and energy savings relative to computation by classical hardware.

9. Revisiting K2 Bright Star Halo Photometry with TESS

Candidate: ***Irina Troitskaya***

Advisor: Dr Benjamin Pope

Abstract: The brightest stars in the sky not only have deep cultural histories, but are ideal targets for individual study with photon-hungry instruments. They are nevertheless often missed in wide-field surveys of faint objects, as they can saturate the detector and necessitate specialized approaches to data analysis. 'Halo' photometry constructs a signal as a linear sum of pixel time series of scattered light, and has been applied widely to data from the K2 mission. Now that 5 years have passed since Kepler/K2, TESS has begun to revisit the K2 fields. As TESS saturates only on much brighter stars, this offers an opportunity to validate the method, and follow up targets of interest. We show that the halo approach to K2 was largely successful, although some sources were contaminated. Revisiting the K2 fields offers extremely precise characterization of eclipsing binaries and pulsating stars, and we illustrate this with a special focus on the hot star system 98 Tau.

10. Quantum Simulators for Lattice Gauge Theories

Candidate: ***Jesse Osborne***

Advisor: AsPr Ian McCulloch

Abstract: Gauge theories are a fundamental part of modern physics, relevant in wide range of fields, from high-energy to condensed matter physics. The U(1) quantum link model (QLM) is a lattice formulation of a U(1) gauge theory, where the gauge and electric field operators are represented by finite dimensional spin-S operators. These have been experimentally realised using analogue quantum simulators. While most previous large-scale proposals and experiments have been limited to the spin-1/2 case, where the phenomenology is somewhat limited, we propose a scheme to simulate higher-spin QLMs in 1+1D using spinless bosons in an optical superlattice, and show the explicit mapping for the spin-1 case. We benchmark the accuracy of the simulator by using matrix product state based numerical simulations of the time evolution of the system under a global quench, as well as (de)confinement of a pair of particles as the parameters of the model are tuned. This opens the door to simulating more exotic gauge theory phenomena, such as confinement.

11. Branches: when you can't tell pure states from mixed states

Candidate: ***Jordan Taylor***

Advisors: *AsPr Ian McCulloch*

Abstract: We introduce a criterion for finding effectively decohered superpositions, generalizing the basic ideas of decoherence to states without a clear partition into "system" and "environment". We define these effectively decohered superpositions when a quantum state can be written as a superposition of terms (sometimes called "branches") which are easy to distinguish, but hard to interfere: when it takes many more local quantum operations to swap terms in a superposition than to distinguish them. We show that attempts to get relative-phase information between branches will fail without frequent active error correction, that branches are effectively the opposite of good error-correcting codes, that branches effectively only grow further apart in time under natural evolution, and that branching is stronger in the presence of conserved quantities. Identifying these branch decompositions in many-body quantum states could shed light on the emergence of classicality, provide a metric for experimental tests at the quantum/ classical boundary, and allow for longer numerical time evolution simulations of quantum dynamics. https://arxiv.org/abs/2308.04494

12. Binary Black Hole Merger Rates and Model Selection with COMPAS

Candidate: ***Liana Rauf***

Advisors: Dr Cullan Howlett

Abstract: The evolution of compact object binaries that emit gravitational waves is subject to large uncertainties. Questions such as "What are their properties?", "Where and how to do they form?", and "How often do they merge in the Universe?" are yet to be confidently resolved. We show how to use a population modelling code, COMPAS, to efficiently calculate the number of gravitational wave events for various stellar evolution models. We then use Bayesian inferencing to determine which model best fits the current gravitational wave data from the LIGO-Virgo-KAGRA observing runs. The results of this work are a positive step in constraining stellar evolution models.

13. Sensing Rotational Inertia using Rotational Optical Tweezers

Candidate: ***MarkWatson***

Advisor: Prof Halina Rubinsztein-Dunlop

Abstract: The dissipation of inertia in microscopic systems is obscured by Brownian motion and sensing it enables orders-of-magnitude faster measurements of fluid viscosity and particle behaviour than typical measurements of position relaxation. In an optical trap, the behaviour of a particle depends on the bandwidth of the restraining optical forces and the drag from the surrounding fluid leading to characteristic timescales describing the rate of particle position relaxation, its velocity dissipation, and the fluid flow relaxation. The rotational regime has analogous time scales which we show can be observed using rotational optical tweezers. By measuring the dissipation of rotational inertia, this work enabled ultrafast viscosity measurements and studies of rotational hydrodynamic theory.

14. Elucidating Dark Matter in the Cosmic Web with AI

Candidate: ***Matt Craigie***

Advisor: Dr Rossana Ruggeri

Abstract: Galaxies are not scattered randomly throughout the universe – instead, they exhibit patterns that are highly-dependent on the variety of physics that they experience throughout their lifetimes, including the effects of dark matter. With new developments in neural network-based techniques, we can extract more information from the patterns in these galaxies. We use these new techniques to better compare modern simulation suites with observational data and learn about the elusive nature of dark matter.

15. Investigating exotic cosmological models using the state-of-art supernova sample from the Dark Energy Survey

Candidate: ***Ryan Camilleri***

Advisor: Prof Tamara Davis

Abstract: A significant challenge currently facing cosmology involves the discrepancy between the locally measured expansion rate of the universe using supernovae and the rate inferred from observations of the Cosmic Microwave Background. This has led to a wealth of exotic cosmological models being proposed to try and explain this discrepancy. In this work, we test some popular non-standard models using the DES 5-year sample of Type Ia Supernovae (SNe Ia) - the largest and deepest single sample of SNe Ia to date. We also provide a detailed discussion of cosmological assumptions that appear in modern supernova cosmology analyses and show the extent to which they are negligible. The most significant impact arises from the assumption of an assumed cosmological model required to perform selection bias corrections to the data. While we ultimately show that this bias is sub-dominant to statistical uncertainties, this may not be the case for future surveys. Therefore, we detail a methodology to reduce this bias.

16. Experimental demonstration of relativistic Bohmian trajectories of a single photon

Candidate: ***Sayantan Das***

Advisors: AsPr Mary Romero

Abstract: Standard quantum mechanics has achieved remarkable empirical success so far. Yet, it continues to have foundational issues. This resulted in the development of many theories which are the so called interpretations of quantum mechanics. One of them is Bohmian mechanics. It is a non-local hidden variable theory, allowing deterministic trajectories for a quantum particle as per the guiding equation and choreographed by the wave function which itself evolves under the Schrodinger equation. Bohmian trajectories in the non-relativistic regime had been successfully demonstrated in experiments ([1], [2]) following Wiseman's operational proposal [3]. However, its incompatibility with special relativity remained unresolved until recently, when an operational method, grounded in weak values, to obtain relativistic Bohmian trajectories of a single photon had been theoretically illustrated [4]. Thus far, there had been no experimental demonstration of it. Here, we are using a Michelson-Sagnac interferometer as our setup for demonstrating the Bohmian trajectories of a single photon obtained from an InGaAs quantum dot source. We will probe along the path of photon propagation which will ensure that we are in the relativistic regime. The Bohmian trajectories will be reconstructed from the photon counts obtained from the single photon detectors. A successful demonstration of the relativistic Bohmian trajectories, even for this simple case of a single particle, will be a crucial step towards reconciling Bohmian mechanics with special relativity and will pave the way to perform similar future experiments.

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17. Asymmetric vibrations and the excited state dynamics of spin-crossover molecules

Candidate: ***Shuang Yuan***

Advisor: Prof Benjamin James Powell

Abstract: The spin state of the spin-crossover (SCO) molecule can switch between the low spin (LS) state and the high spin (HS) state, simultaneously with the structure change due to an external stimulus, such as temperature, pressure and light. Conventional crystal field theory (CFT) and typically symmetry vibration modes calculate the energy terms of SCO molecule with perfect octahedral symmetry, which means the symmetry operations of the SCO molecule will form an Oh group. However, the symmetry breaking of SCO molecules, which means the angle distortion and unequal metal-ligand bond length, are observed mainly in SCO experiments. In this poster, we introduce an asymmetric vibration mode to the SCO molecule, which causes the symmetry operations of the SCO molecule to form a C4v group, and calculate its energy terms by applying the CFT. Further, a 2D double-well potential is established to describe the transition of SCO between LS and HS states. Transition state theory (TST) is used to determine the critical temperature of the thermal transition ($T_{1/2}$), and the highest temperature for which the trapped state is stable (T_{LIESST}) in light-induced spin-state trapping (LIESST). By applying some realistic parameters, our model can reproduce the linear relationship between $T_{1/2}$ and T_{LIESST} observed in the experiment. We also predict that increasing the stiffness of the vibration modes and coordination distances between LS and HS states when at equilibrium positions will increase the T_{LIESST}. Finally, we show that symmetry breaking of SCO molecule will increase the $T_{1/2}$ and have a minor influence on T_{LIESST}.

18. Conditional quantum states of a continuously monitored mechanical oscillator

Candidate: ***Soroush Khademi***

Advisor: Prof Warwick Paul Bowen

Abstract: A macroscopic solid structure has many vibrational modes, thermalized by the surrounding environment. When an optical cavity is placed close to this object, the resonance frequency of the cavity changes with the movement of the structure and a dispersive optomechanical system forms. In these types of systems, it is possible to perform a continuous-in-time quantum measurement of the object's canonical position. We present novel quantum frameworks for inferring the quantum state of the mechanical oscillator from the produced photocurrent in different scenarios and elaborate on how they are applied to a resonator in the laboratory.

19. Implementation of a coherent feedback quantum clock

Candidate: ***Stefan Zeppetzauer***

Advisors: AsPr Arkady Fedorov

Abstract: Clocks play an integral part in a variety of applications but have recently drawn interest in the context of fundamental questions such as the connection between time and thermodynamics and the limits of timekeeping. From a thermodynamic point of view, a clock is a nonlinear dissipative system that relies on the increase in entropy to keep track of time. It was recently shown that the resolution of a periodic clock is directly proportional to the energy dissipated per cycle. Therefore, a good clock, both classical and quantum, necessitates a high energy dissipation rate.

We realise a new type of periodic quantum clock based on coherent feedback between two coupled resonators. As the feedback is not done via readout, there is no measurement-induced noise, allowing for the characterisation of the system's inherent quantum noise and its effects on the clock's thermodynamical and metrological properties.

We implement the coherent feedback clock on a superconducting circuit consisting of two coupled high-Q coplanar resonators, where one is rendered nonlinear by a Josephson junction embedded in the centre conductor. This provides the nonlinearity necessary for a periodic clock. We show the existence of limit cycles in the quantum regime, where quantum fluctuations become the dominant noise source, and demonstrate the system's applicability as a new type of quantum clock. Specifically, we aim to show the relation between dissipated energy and clock resolution, and how quantum fluctuations in the feedback cycle affect the clock tick accuracy.

In addition, our clock is a candidate for the implementation of spiking neural networks, a novel deep learning model that mimics the behaviour of biological neurons and shows promising advantages in dynamic learning tasks compared to conventional perceptron models.

20. Directing energy in an on-chip acoustic waveguide

Candidate: ***Timothy Hirsch***

Advisor: Prof Warwick Paul Bowen

Abstract: On-chip acoustic waveguides are a promising platform for realising phononic integrated circuits, which are interesting for uses ranging from quantum state transfer, to compact optomechanical devices, to nanomechanical computing. To fully realise their potential they require a method for unidirectional acoustic wave emission. Here we demonstrate unidirectional emission, fully integrated into an on-chip membrane waveguide platform that can be used to construct phononic integrated circuits with purely mechanical coupling and access to nonlinearity.

Applying a technique widely used for RF radio antennas and surface acoustic wave transducers, we achieve a reconfigurable 99.9% directional suppression, with even better performance expected after optimisation. By eliminating -3 dB loss and allowing reconfigurable circuit designs, this is an important step towards on-chip and radiation-tolerant phononic integrated circuits for tasks like mechanical computing.

21. On-chip source of high-dimensional entangled photons

Candidate: ***Tavshabad Kaur***

Advisors: AsPr Mary Romero

Abstract: The fundamental unit of quantum information processing (QIP), qubit (a two-level state), when extended to highdimensional qudit states, exhibits dimensionality scaling d N with d and N being the number of dimensions and parties, respectively. The multi-level nature of qudit provides a larger state space to store and process information, thus offering an important role in reduction of circuit complexity, the simplification of the experimental setup and the enhancement of the algorithm efficiency. Photons act as carrier of high-dimensional quantum information, by encoding the qudit states in a variety of degrees of freedom (DoF) such as path, frequency, orbital angular momentum, spatial mode, and time-bins. To harness the full potential of high-dimensional quantum systems, it's essential to generate and manipulate high-dimensional entanglement efficiently. Therefore, in order to scale to larger devices we need efficient sources of high-dimensional entanglement.

Integrated high-dimensional entangled photon pair sources on a chip offer compact, miniaturized quantum devices for applications like quantum computing, quantum communication and efficient quantum information processing with high-dimensional states. Transverse- mode entanglement harnessed within on-chip silicon waveguides provide a platform for efficiently generating and manipulating transverse mode-entangled photon pairs in a compact and integrated manner. It arises through spontaneous four-wave mixing (SFWM), a process involving the interplay of two laser beams that give rise to the generation of photon pairs (i.e., signal and idler), exhibiting entanglement in their transverse spatial modes, in nonlinear optical medium like silicon waveguides. [1].

While designing, fabricating and testing integrated silicon photonic chip for intermodal FWM, phase matching and modal dispersion of different waveguide modes in a multimode waveguide provides increased flexibility for allowing broadband and tunable wavelength conversion [2]. By engineering the waveguide geometry, we can control the modal disperions, and can achieve the phase-matching condition [3]. The key feature of using a transverse mode source is that by having the pump photons in different modes it provides more control for engineering desirable source properties such as spectral purity.

In this poster, we study the phase matching bandwidth and nonlinear efficiencies for different combinations of transverse-modes in a multimode waveguide with different geometries.

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