THE UNIVERSITY OF QUEENSLAND
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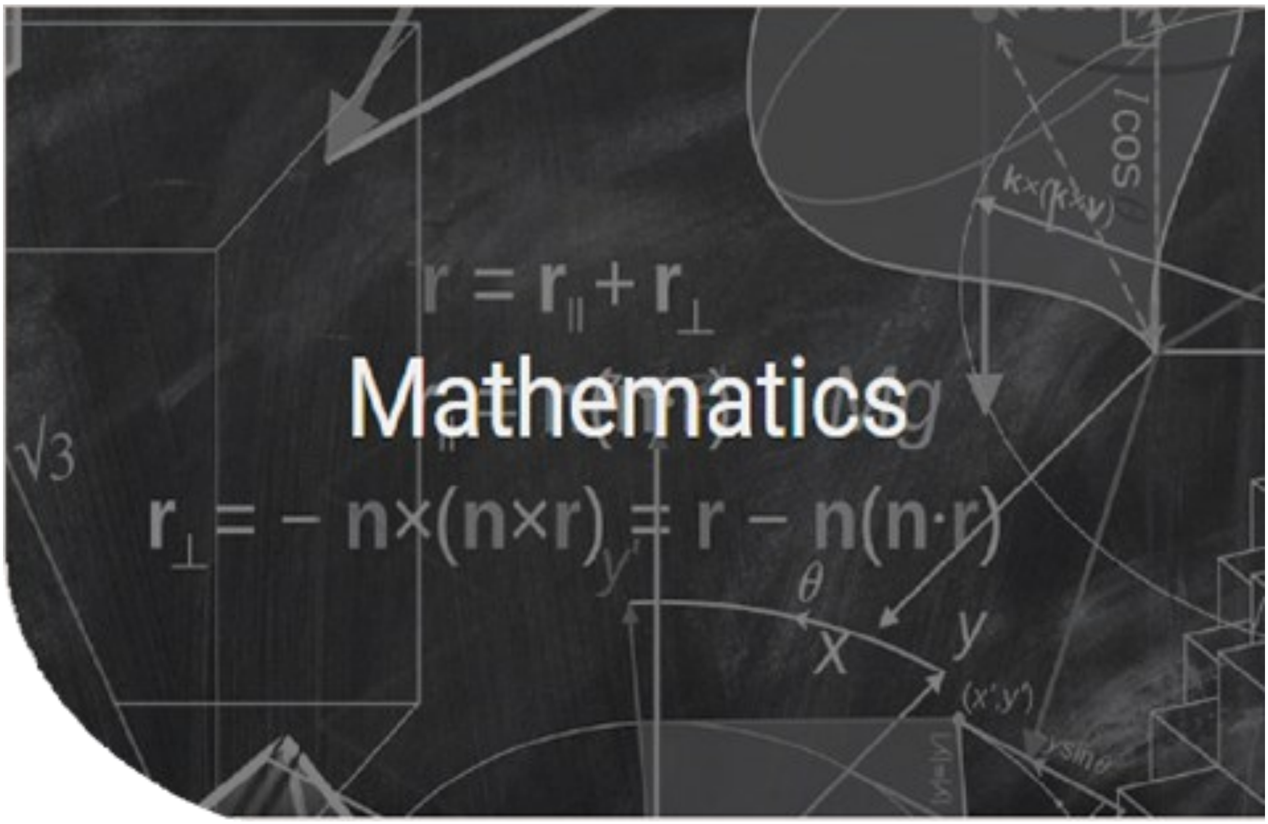
CREATE CHANGE

SMP Poster Day 2024
Abstract Booklet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Mathematics
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1. Hydrogen technology acceptance with Bayesian networks

Candidate: ***Daniel Herr***

Advisor: Radislav Vaisman

Abstract: There is trouble brewing in the world of technology acceptance research. On the one hand, social scientists contribute to this space by providing domain insights into human systems, but many lack the conceptual statistical knowledge required to develop quantitative models that describe human decision making processes. On the other hand, researchers from quantitative disciplines often lack the theory-based knowledge needed to explain the mechanisms that generate social data, and they consequently build associative models that emerge from patterns in data without considering the causal relationships between variables. Unfortunately, associative models are susceptible to bias and constrained to a far narrower scope of applicability than causal models, which integrate a relational understanding of system dynamics. These two camps are progressing along diverging paths and our research investigates ways they may be connected.

Using hydrogen technology acceptance as a case study, I introduce the concept of causal modelling and describe an approach we applied to connect domain insights with empirical data (n=1,682) through a statistical model called a Bayesian network. We demonstrate the practical benefits of causal models, such as out-of-sample counterfactual analyses, and compare our model's predictive performance against that of seven prevalent machine learning algorithms. Our findings show that models capable of causal inference, like the one we propose here, can outperform many purely predictive models, and assist in identifying the real factors affecting technology's social acceptance. Developing tools like these that are equipped to handle "what if" scenarios is highly relevant in addressing many of the challenges faced in scenarios like policy formulation or decision making, where the impacts of one's actions are uncertain. Naturally, the work is of particular interest to social scientists interested in estimating or understanding the effects of interventions, such as public messaging, and for those wishing to build predictive models that encompass domain-specific understanding.

2. (Extended) Yangian Truncations in Types B and D

Candidate: ***Gavrilo Sipka***

Advisors: Jon Links

Abstract: To each classical Lie algebra $\mathfrak{g}$, there exists an infinite-dimensional Hopf algebra known as the (extended) Yangian of $\mathfrak{g}$. One can further quotient out the (extended) Yangian by generators of ``certain orders" to obtain an algebra known as the truncated (extended) Yangian of order p. In type A, the truncation at the first order gives the enveloping algebra of the underlying Lie algebra. As a consequence, the finite-dimensional irreducible representations of the corresponding (extended) Yangian can be described relatively efficiently in terms of the underlying Lie algebra representations. In types B and D, this picture is more complicated: no longer is it sufficient to consider the truncation of the first order to describe the representation theory of the associated (extended) Yangian. This poster illustrates elements of this theory in types B and D.

3. A detection algorithm and evaluation framework for real-time fluorescence sensor detection

Candidate: ***Harrison Stitt***

Advisor: Paul Shaw

Abstract: Fluorescent sensors have been demonstrated to be effective tools for chemical detection. Unfortunately, training accurate, reliable algorithms for these sensors requires large datasets, which can be prohibitively time-consuming and expensive to collect. As such, there is a need for a general framework which enables the development of real-time detection algorithms which take full advantage of these sensors. In this work we propose a simulation pipeline for generating fluorescent sensor data and an evaluation method for obtaining optimal detection algorithms. We show that training detection algorithms on simulated datasets is sufficient for achieving accurate real-time detection.

4. What is the maximum number of mutually disjoint triples contained in the orbit of a triple of group elements?

Candidate: ***Jack Neubecker***

Advisor: Sara Davies

Abstract: Factor-criticality of graphs is a well studied topic in graph theory first introduced by Gallai in 1963. Our research has identified a generalisation for hypergraphs which has been somewhat overlooked, despite the variety of well-studied generalisations for graphs. Existence questions for factor-critical hypergraphs with given symmetries lead to the following group-theoretic question: ``What is the maximum number of mutually disjoint triples contained in the orbit of a triple of group elements?" We will explore this question in the poster with generous use of illustration.

5. An Integrable XY Central Spin Model

Candidate: **Jaco van Tonder**

Advisor: Jon Links

Abstract: Central spin models are an idealised model of spin particle interactions. They describe the dynamics of a central spin particle interacting with a bath of surrounding spins. In technological applications they in particular provide a good model for the interactions in quantum bits and nitrogen-vacancy (NV) centres in diamonds. The latter has found application in quantum metrology as a nanoscale magnetometer. The XY model is an integrable example of a central spin model and as such is analytically tractable. We describe some of the mathematical formalism based on the Lax matrix behind its diagonalisation and also how specific simplifications allow the spectrum to be deduced from relations satisfied by the charges.

6. Asymptotic Distribution of Error in Machine Learning

Candidate: ***Jacob Westerhout***

Advisor: Xin Guo

Abstract: One of the main problems in machine learning is the estimation of the error of a machine learning algorithm. We present a novel result for the calculating the limiting distribution of the error. This allows us to construct confidence intervals, and perform hypothesis test for a large class of machine learning algorithms.

7. Robust Loss Functions for Training Decision Trees with Noisy Labels

Candidate: ***Jonathan Wilton***

Advisor: Nan Ye

Abstract: We consider training decision trees using noisily labelled data, focusing on loss functions that can lead to robust learning algorithms. Our contributions are threefold. First, we offer novel theoretical insights on the robustness of many existing loss functions in the context of decision tree learning. We show that some of the losses belong to a class of what we call conservative losses, and the conservative losses lead to an early stopping behaviour during training and noise-tolerant predictions during testing. Second, we introduce a framework for constructing robust loss functions, called distribution losses. These losses apply percentile-based penalties based on an assumed margin distribution, and they naturally allow adapting to different noise rates via a robustness parameter. In particular, we introduce a new loss called the negative exponential loss, which leads to an efficient greedy impurity-reduction learning algorithm. Lastly, our experiments on multiple datasets and noise settings validate our theoretical insight and the effectiveness of our adaptive negative exponential loss.

8. Uncertainty Quantification in Machine Learning

Candidate: ***Joseph Wilson***

Advisor: Farbod Roosta-Khorasani

Abstract: Neural networks have shown impressive results on a wide array of tasks. However, correctly quantifying the uncertainty in the predictions of neural networks is necessary to guarantee trustworthy predictions and enable their widespread adoption in critical systems. Several uncertainty quantification (UQ) methods exist, both Bayesian and frequentist, each with strengths and drawbacks. We propose a novel method for uncertainty quantification of neural networks that employs the recent Neural Tangent Kernel (NTK), and wherein we can approximate a neural network as a Gaussian Process with an NTK kernel. This method is post-hoc, lightweight and performs as well or better than existing methods in uncertainty quantification metrics.

9. From Rogers—Ramanujan to Combinatorial Characters

Candidate: ***Lachlan McBeath***

Advisor: Ole Warnaar

Abstract: In the theory of affine Lie algebras, there are seven infinite families. In 2015 N. Bartlett and S. O. Warnaar obtained combinatorial expressions for characters of standard modules for $\mathrm{A}_{2n}^{(2)}$, $\mathrm{C}_{n}^{(1)}$, and $\mathrm{D}_{n+1}^{(2)}$. They did this by using Milne--Lilly's C_{n} Bailey lemma, and Hall--Littlewood polynomials.

In 2021 an alternative approach was undertaken by E. M. Rains and S. O. Warnaar that obtained several additional combinatorial expressions for characters of standard modules, including for $\mathrm{B}_{n}^{(1)}$ and $\mathrm{A}_{2n-1}^{(2)}$.

Our focus is on $\mathrm{A}_{n-1}^{(1)}$, and the approach is a modification of the methods of Bartlett and Warnaar. However, we are utilising Milne--Lilly's A_{n-1} Bailey lemma, and Hall--Littlewood polynomials with the expectation of identifying combinatorial character formulas.

10. Ideal Fluid Flows Admitting Symmetries

Candidate: ***Max Orchard***

Advisor: Artem Pulemotov

Abstract: An ideal fluid in a domain in R^3 flows according to the Euler fluid equations, a restatement of Newton's second law of motion. Due to Arnold in 1966, there is a striking geometric interpretation of ideal fluid flows. In particular, an ideal fluid flow can be thought of as a geodesic (a locally distance-minimising curve) in some infinite-dimensional space. This allows us to generalise the notion of a fluid flow to higher dimensions and more general spaces. To simplify the equations, fluid flows have been studied under symmetry assumptions. In the literature, only specific symmetries in low dimensions have been studied. We are interested in analysing fluid flows that exhibit more general symmetries in more general spaces.

11. Integer Programming For Queenly Peace

Candidate: ***Natalie DiMichele***

Advisor: Michael Forbes

Abstract: On the way to showing that operations research can be a helpful tool in pure mathematics, we look at chessboard problems. In particular, we have formulated the first queens and peaceable queens problems with mixed integer programming and other techniques. We found some new solutions for the first queens problem, for n ranging from 62 to 100, and showed that a known solution for n=16 for the peaceable queens problem is in fact the optimal solution.

12. Measure theoretic entropy for a class of random expanding Blaschke products

Candidate: ***Renee Oldfield***

Advisor: Cecilia Gonzalez Tokman

Abstract: Measure-theoretic entropy, a measure-theoretic invariant of a dynamical system, measures the rate of increase in dynamical complexity over time. We consider a class of expanding Blaschke product cocycles, inner functions formed by taking products of Möbius transforms. The measure-theoretic entropy of a class of expanding Blaschke product cocycles acting on the complex unit circle will be explicitly described. We also obtain a computable formula for the average metric entropy for a class of one parameter families of expanding Blaschke product cocycles, extending the work by E. Pujals, L. Robert and M. Shub (Ergod. Th. & Dynam. Sys. (2006), 26, 1931–1937) to a random setting.

13. Tumor Cell Transmigration Through Endothelial Cells Using Material Point Method

Candidate: ***Sanchita Malla***

Advisor: Dietmar Oelz

Abstract: Tumor cell invasion and metastasis involve the migration of single or collective cells that break away from the primary tumor, intravasate the circulatory system, and eventually seed to distant parts of the body. Computational models can be utilized to adjust and modify several interacting variables, including geometry, confinement size, cell stiffness, and deformation. These are difficult to achieve through experiments and are necessary to understand how cell migration in confinement acts as a unified system. Here, we developed a continuum model that characterizes the cell as a deformable body passing through a fixed narrow slit. The material point method, a mess-free approach, is used to simulate the model and analyze the successful transmigration and deformation of cell. The simulation findings show how altering cell stiffness and model parameters influences distinct cell geometry and transmigration time. In conclusion, the particle-based simulation approach holds potential for the exploration of cancer cell transmigration, where fluid-structure interactions play a pivotal role.

14. Latin squares with five disjoint subsquares

Candidate: ***Tara Kemp***

Advisor: James Lefevre

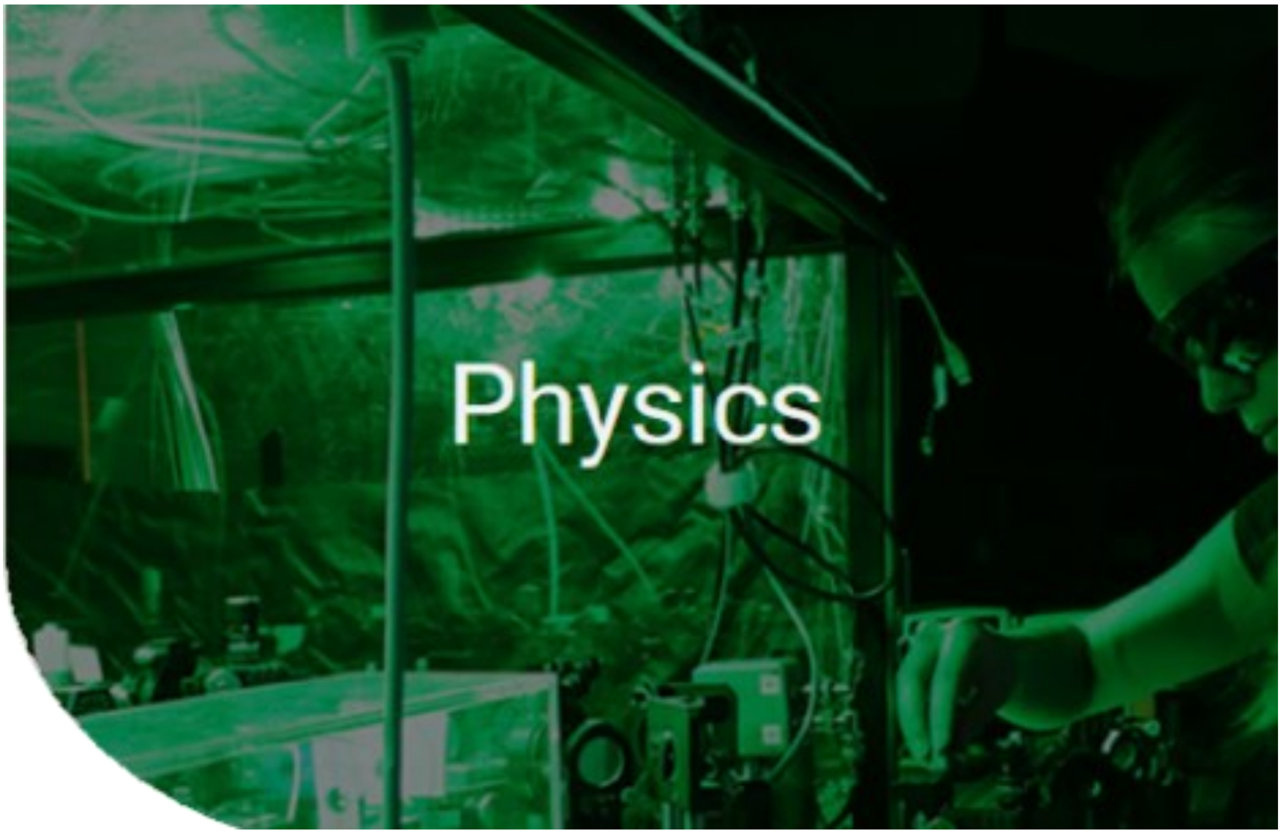
Abstract: A latin square of order n is a square array in which each of n symbols occurs exactly once in every row and column, similar to a Sudoku puzzle. L. Fuchs posed a question about the existence of quasigroups with disjoint subquasigroups and this problem is equivalent to the existence of latin squares with disjoint subsquares. The existence of these latin squares is a partially solved problem, and most known results are for latin squares with at most four subsquares. The case where there are five subsquares is significantly more complex, and we have completed this case.

15. Time-fractional cable equation on a metric star graph

Candidate: ***Yash Vats***

Advisor: Dietmar Oelz

Abstract: In this study we consider the pre-synaptic and its post-synaptic neurons together as a metric star graph. Electric currents in the neuron are driven by electrodiffusion of ions across trans-membrane channels. This research paper explores the time-fractional cable equation on a metric star graph representing the topology of a single pre-synaptic neuron cell and its post-synaptic neurons. The existence and uniqueness of solutions is established through the eigenfunction expansion method. Subsequently, a finite difference approximation for the time-fractional cable equation is proposed in which the L1 method is used for the approximation of the Caputo time-fractional derivative. The existence of a unique solution of the proposed numerical scheme is established, and its stability and convergence are analyzed through the discrete energy method, exhibiting convergence of order $2-\alpha$ in space and order 2 in time. Theoretical findings are validated through numerical results for two test problems.



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1. Measuring the neutrino-induced phase-shift in DESI BAOs

Candidate: ***Abbe Whitford***

Advisor: *Tamara Davis*

Abstract: Upcoming galaxy surveys aim to constrain the properties of neutrinos by constraining the effects of free-streaming particles in the early Universe, via a parameter known as the Effective Number of Neutrino species. This is possible, because the presence of fast-moving free-streaming particles during the epoch sound waves were able to propagate through the primordial plasma, known as the Baryon Acoustic Oscillations (BAOs), induced a phase-shift in the sound waves. The over and under-densities formed by the sound waves in the moment they ceased to propagate seeded the Large-Scale Structure that case be seen today as a peak in the correlation function of galaxies. It has been shown in the literature that it is possible to constrain the Effective number of neutrino species by a parameterisation of the phase-shift that is induced in the BAO signal. In this work, we measure this phase-shift in the BAOs measured by the DESI collaboration from the galaxy correlation function. This provides an improved and less model-independent constraint on the number of neutrinos in addition to any other radiation that contribute to the effective species in the early Universe.

2. Controlled closed timelike geodesics in a rotating Alcubierre spacetime

Candidate: ***Achintya Sajeendran***

Advisor: *Timothy Ralph*

Abstract: General relativity contains solutions that allow for closed timelike curves (CTCs), paths in spacetime that permit backwards time travel. Whether such a phenomenon occurs in our universe is currently unknown. To investigate this, multiple mathematically self-consistent models of CTCs have been developed in the literature, but they all abstract away the spacetime geometry giving rise to such paths. While this is a convenient simplification given the complicated nature of spacetimes that permit CTCs, valuable physical insights might be gained by investigating these models in a truly general relativistic setting. It has recently been shown that a rotating version of Alcubierre's 'warp drive' spacetime permits CTCs. Furthermore, this background allows for a simple model of a situation in which particles enter from a chronology-respecting past, interact with a CTC, and eventually exit into a chronology-respecting future. We propose two different modifications to this metric in which such paths are promoted to geodesics. These spacetimes may serve as useful playgrounds for future developments on quantum mechanics near CTCs.

3. Efficient Atomistic Modelling of Spin Crossover Materials

Candidate: ***Amirhossein Rezavand***

Advisor: *Benjamin Powell*

Abstract: Spin crossover (SCO) materials, particularly transition metal (TM) complexes, exhibit the ability to switch between high-spin (HS) and low-spin (LS) states in response to stimuli such as temperature, pressure, or light, making them valuable for applications in electronics, sensors, and data storage. Accurately predicting the electronic properties of these strongly correlated systems is a challenge due to their complex electronic transitions. In this work, we use the Angular Overlap Model (AOM) to provide quantitative predictions of electronic properties of these complexes, offering rapid solutions in less than a second for arbitrary atomic positions. To improve accuracy, we parameterize the AOM using ab initio methods. Additionally, by incorporating Molecular Dynamics (MD) simulations, we aim to account for the dynamic behaviour of SCO materials, providing a comprehensive understanding of spin crossover phenomena. This combined AOM-MD approach allows for efficient pre-synthesis screening of SCO materials, significantly reducing computational cost while maintaining high accuracy. Future improvements through more precise ab initio methods will enhance the predictive power of this model, offering better insights into the electronic properties of spin-crossover systems.

4. Ultrafast charge carrier dynamics of methylammonium lead iodide from first principles

Candidate: ***Ariel Moises Cabrera Aguilar***

Advisor: *Carla Verdi*

Abstract: Methylammonium lead iodide (MAPbI3) has been a major focus of photovoltaic research for the last decade. The unique interplay between the structural and electronic properties of this material contributes to its exciting optical properties especially under the action of an ultrafast laser pulse. First-principles methods like real-time time-dependent density functional theory (RT-TDDFT) enable performing corresponding simulations without the aid of empirical parameters: the gained knowledge can be applied to future studies of other complex materials. In this work, we investigate the ultrafast charge-carrier dynamics and the nonlinear optical response of MAPbI3 excited by a resonant pulse above the gap. First, we examine the electronic and optical properties in the static regime. Next, we impinge the system with a femtosecond field of varying intensity and follow the evolution of the photoexcited carrier density. A pronounced intensity-dependent response is observed, manifested by high-harmonic generation and nonlinear trends in the number of excited electrons and excitation energy. Our results provide relevant indications about the behavior of MAPbI3 under strong and coherent radiation and confirm that RT-TDDFT is a viable tool to simulate the photo-induced dynamics of complex materials from first principles.

5. Black hole volumes

Candidate: ***Colin MacLaurin***

Advisor: Timothy Ralph

Abstract: I present the volume of a Schwarzschild black hole, relative to the energy and angular momentum of worldlines which fill the spacetime. This generalises and (further) resolves the vexing "Ehrenfest paradox" about the circumference of a relativistically rotating disc.

6. Vortex-Vortex Interactions in Superfluid Helium-II Thin Films

Candidate: ***Daniel Harvey***

Advisor: Warwick Bowen

Abstract: : The relationship regarding vortices and superfluidity in liquid helium originally proposed in the 1950s by Onsager and Feynman has been well established. Understanding vortices in 2D superfluids and their interactions can develop our understanding of quantum turbulence, quantum dissipation, and BKT phase transitions [1]. Despite this, observing these vortices is very difficult, due to the small core size, nanoscopic film thickness and small refractive index. Several approaches have already been used to investigate properties of superfluid helium, such as their coupling to confined acoustic third-sound modes [2].

Here, we explore the possibility of directly optically detecting the vortices directly via interferometric scattering microscopy (iSCAT). iSCAT utilises a relatively strong reference beam to significantly improve the weak scattering signal for nanoobjects and is not restricted by the small volume of the superfluid vortices. In addition, vortices produce a dimple on the free surface of helium film [3], due to the greater kinetic energy closer to the core. We aim to leverage this effect to greatly enhance the magnitude of the observable signal. However, the exact nature of this effect when several vortices interact, and the superposition of their flow fields is not well understood in the presence of surface tension. To resolve this, we have formulated a new approach which allows us to calculate the surface profile from any arbitrary arrangement of vortices. These calculations suggest the presence of an attractive force resulting from the mutual interaction of vortex dimples. These become prominent at sub-micron separations and intermediate film thicknesses.

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[2] Sachkou, Yauhen P., et al., 2019, “Coherent vortex dynamics in a strongly interacting superfluid on a silicon chip,” Science 366, 1480.

[3] E. Vittoratos, M. W. Cole, and P. P. M. Meincke,Can. J. Phys. 51, 2283 (1973).

7. Open-Source Parallel Electromagnetic Simulations for Superconducting Circuit Design

Candidate: ***David Sommers***

Advisor: Prasanna Pakkiam

Abstract: Superconducting quantum devices require careful design of device geometry for optimal performance. The ability to perform finite element method (FEM) electromagnetic simulations to determine device parameters from the geometry and structure of a design is a crucial part of an iterative design process. By simulating the behaviour of superconducting devices, we save time and cost during the fabrication process as device behaviours are characterized and fine-tuned before starting fabrication.

8. Energy-efficient Blockchains using Boson Sampling

Candidate: ***Deepesh Singh***

Advisor: Timothy Ralph

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. Afterwards, CGBS strategies are determined which can be used to both validate samples and reward successful miners. By combining rewards for miners committing honest samples together with penalties for miners committing dishonest samples, a Nash equilibrium is found that incentivises honest nodes. The scheme works for both Fock state and Gaussian boson sampling and provides dramatic speedup and energy savings relative to computation by classical hardware.

9. Designing and Fabricating Superconducting Qubits Resilient to Background Radiations

Candidate: ***Divita Gautam***

Advisor: Arkady Fedorov

Abstract: Given the vulnerability of superconducting qubits to various types of noise, particularly from background radiation, this project focuses on advancing fabrication and shielding techniques to develop superconducting qubits that are resilient to background radiation. By implementing a novel approach to isolate qubits using membranes, we aim to suppress phonons generated by background radiation, thereby reducing quasiparticle density and preserving qubit coherence. The ultimate goal is to develop robust and scalable methods to protect qubits from quasiparticle noise, ensuring their stability and reliability in practical applications.

10. Relativistic Unruh-DeWitt Detectors and Position-Velocity Minimum Uncertainty States

Candidate: ***Evan Gale***

Advisor: Magdalena Zych

Abstract: Models of particle detectors, such as the Unruh-DeWitt (UDW) model, have traditionally assumed the detector follows a classical worldline. However, a full treatment should include a quantised description of the detector's centre-of-mass degrees of freedom, which has been previously studied in Ref. [1], and with accelerated centre-of-mass in Ref. [2]. These analyses have so far assumed a non-relativistic centre-of-mass, which is insufficient as it leads to spurious friction forces acting on the detector [3,4]. Therefore, in Ref. [5], we extend these models to include the full relativistic dispersion relation of the detector's quantised centre-of-mass, for a detector that is coupled to a scalar field in a medium. Our extension, beyond fundamental interest and its ability to demonstrate self-consistency across various regimes, is able to capture new relativistic effects, particularly those in the ultra-relativistic regime.

Our model has several possible applications, such as a phenomenological description of neutrinos or low-energy composite particles coupled to quantum fields. Free quantum composite particles (not interacting with fields) provide an idealisation of quantum clocks and can be described by a class of minimum uncertainty states, which are localised and are able to maintain spatial coherence [6]. These states minimise the Schrödinger-Robertson uncertainty between position and velocity, and transform covariantly under boosts, thus providing a suitable description for the relativistic regime. This work extends the treatment of ideal clocks to idealised detectors by describing the coupling of composite particles to quantum fields, providing the thus far missing model of a UDW detector with dynamical, relativistic centre-of-mass.

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11. The Measurement Problem in QFT meets the Measurement Problem in Quantum Theory

Candidate: ***Francisco Sa Ferreira Loureiro Pipa***

Advisor: Gerard Milburn

Abstract: Different models of measurements in Quantum Field Theory (QFT) were developed to provide a consistent local account of measurements in QFT, solving the so-called measurement problem of QFT. This problem was first identified by Sorkin. Its source comes from noticing that a plausible extension of quantum measurement theory from non-relativistic quantum theory to Quantum Field Theory (QFT) leads to the unacceptable consequence where the expectation values in one region become dependent on the choice of unitary operation applied in a spacelike separated region. However, these models still treat the system that prepares the probe and measures it as a black box. This limitation is a manifestation of the so-called measurement problem in quantum theory, which these models don't pertain to solving. The measurement problem arises from interactions in quantum theory, which, without introducing additional assumptions, lead to the quantum state of a macroscopic system being in a superposition. However, we know from classical physics and experimental evidence that this cannot be the case at macroscopic scales. In this poster, we will present a new approach to quantum theory that, contrary to all consistent approaches to quantum theory, has the benefit of being non-relationalist (i.e., measurement outcomes don't vary according to systems, worlds, or agents), does not modify the basic equation of quantum theory, while not adding superdeterministic, retrocausal, or non-local hidden variables. We will then outline how this approach may overcome the limitations of the above models of measurements in QFT.

12. Vacuum polarization corrections to hyperfine structure in many-electron atoms

Candidate: ***Jayden Hasted***

Advisor: Jacinda Ginges

Abstract: Accurate account of quantum electrodynamic (QED) radiative corrections are important in high-precision atomic calculations for low-energy searches for new physics [1, 2]. I will present my recent work on QED vacuum polarisation corrections in hyperfine structure for many-electron atoms and ions. This is the first such study that combines many-body and vacuum polarisation corrections, with previous works limited to simple atomic systems and potentials. I will discuss which many-body effects are the most important to consider, and how they may change the order of magnitude and even the sign of the vacuum polarisation correction for some states.

[1] V.V. Flambaum, J.S.M. Ginges. 'Radiative potential and calculations of QED radiative corrections to energy levels and electromagnetic amplitudes in many-electron atoms." Physical Review A 72, 5 (2005).

[2] J.S.M. Ginges, J.C. Berengut. 'Atomic many-body effects and Lamb shifts in alkali metals.' Physical Review A 93, 5 (2016).

13. Quantum-enabled super resolution imaging

Candidate: ***Kyle Clunies-Ross***

Advisors: Warwick Bowen

Abstract: Resolving the dynamical structure of biomolecules is fundamental to research in biology and medicine. However, standard optical microscopy is incapable of resolving features below 200 nm as these structures are sub-diffraction limited. Several super resolution methods exist that exceed the sub-diffraction limit, but these methods are limited when control of the illuminating beam is impossible. A super resolution method using Bayesian inference and point spread function (PSF) engineering can overcome these limitations, and we present the first experimental validation of visible light sub-wavelength imaging without illuminating beam control using this method.

Fluorescent molecules are attached to DNA nanorulers, and we model this system as two physically separated incoherent point sources. We then use Bayesian inference to estimate emitter separations below the Rayleigh criterion using approximated PSFs of the imaged photon distributions. We show—both theoretically and experimentally—that the precision of separation estimates is improved if the PSF is engineered with a specific arrangement of waveplates.

We detect separations as small as 50 nm using this method. The resulting root-mean square errors (RMSEs) are comparable to theoretically optimal bounds.

Comparing the RMSEs to theoretical bounds suggests further experimental refinement can yield increased precision. Other papers suggest experimental variations that leverage quantum effects to further improve precision. Experimental validation is therefore a key step in developing this super resolution method.

14. Viscous-free Drag in a Quantum Wind Tunnel

Candidate: ***Maarten Christenhusz***

Advisor: Tyler Neely

Abstract: Despite the fundamentally different dissipation mechanisms, many laws and phenomena of classical turbulence equivalently manifest in quantum turbulence. The Reynolds law of dynamical similarity states that two objects of same geometry across different length scales are hydrodynamically equivalent under the same Reynolds number, leading to a universal drag coefficient law. In this work we confirm the existence of a universal drag law in a superfluid wake, facilitated by the nucleation of quantized vortices. We numerically study superfluid flow across a range of Reynolds numbers for the paradigmatic classical hard-wall and the Gaussian obstacle, popular in experimental quantum hydrodynamics. In addition, we provide a feasible method for measuring superfluid drag forces in an experimental environment using control volumes.

15. An improved model of simultaneous quantum-classical communication under composable security

Candidate: ***Nicholas Zaunders***

Advisor: Timothy Ralph

Abstract: In this work we present the most sophisticated analysis of simultaneous quantum-classical communications in Gaussian-modulated continuous-variable quantum key distribution to date. We rectify security issues posed by previous formulations, present an updated model of the coupling between the classical and quantum channels, extend analysis into the finite-key regime using contemporary results, demonstrate superior quantum performance for equivalent classical quality-of-service, and lastly detail a proof-of-concept utilising virtual measurement-based noiseless amplification.

16. Optical Detection of Quantized Vortices in Superfluid Helium Thin Films.

Candidate: ***Nicole Luu***

Advisor: Warwick Bowen

Abstract: Quantized vortices are central to two-dimensional superfluidity and quantum turbulence. Though there is great interest in observing and understanding their behaviour, vortices in superfluid helium-4 are particularly challenging due to their Angstrom-sized cores and low refractive indices. I will present my work in the experimental exploration of vortex dynamics in thin films of superfluid helium by direct optical detection. This is achieved by cooling silicon photonic crystals to millikelvin temperatures, at which superfluid helium self-assembles into a nanometre-thick film along the surface of the crystal [1]. Advanced fabrication techniques enable the creation of high-quality silicon photonic crystals with small optical mode volumes that provide the ability to enhance interactions between light and quantized vortices. The presence of vortices creates a dimple in the superfluid film and shifts the resonance frequency of the optical cavity, providing a direct indication of the location of the vortices [2]. Going forward, we will be able to track the position of vortices with sub-nanometre resolution as well as employ optomechanical techniques to trap and control the vortices [3].

References

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17. Bacterial active matter tracking using neural networks

Candidate: ***Patrick Grant***

Advisors: Halina Rubinsztein-Dunlop

Abstract: Tracking is a crucial component in understanding active matter experiments and advancing the development of models. While current tracking methods can highlight the broader dynamics of active matter, more quantitative information is required to assess current models. This work uses recent advances in machine learning to track bacterial active matter. Using DeepTrack (Midvedt et al., 2021), we can analyse the individual and collective behaviours of bacteria in complex environments such as confinement in circular structures. Tracking with DeepTrack can provide the quantities necessary to compare active matter experiment and theory. Analysing bacterial active matter also has promising applications in engineering and medicine.

18. Organometal halide perovskite for high performance photodetector

Candidate: ***Prabal Dweep Khanikar***

Advisor: Ebinazar Namdas

Abstract: Organic-inorganic halide perovskites have been widely studied for optoelectronic applications such as photodetectors, solar cells, and LEDs due to their excellent electronic and optical properties. Formamidinium (FA)-based perovskites (FAPbI3) are reported to have good photodetector performance. However, their ability to detect light in the low-intensity region and to maintain photocurrent linearity in the high-intensity region has not yet been properly demonstrated. Herein, we employed different hole transporting layers (SpiroOMeTAD and C8-BTBT) in a FAPbI3-based photodetector device to study their effect on its photodetector performance, mainly noise equivalent power (NEP) and linear dynamic range (LDR). A high measured LDR of 170 dB was obtained for the device with doped SpiroOMeTAD as the HTL layer. Meanwhile, the undoped SpiroOMeTAD-based device showed the highest NEP of 0.16 pW. Additionally, all the devices also showed a fast carrier transport time of less than one microsecond. These results suggest that the FAPbI3 perovskite has great potential for high-performance photodetector applications.

19. Uncovering Cosmic Flows with Machine Learning

Candidate: ***Rianna Bell***

Advisors: Khaled Soliman

Abstract: The peculiar velocities of galaxies provide some of the most versatile measurements in cosmology. However, there is no straightforward way of obtaining peculiar velocity measurements from cosmological observations. For this reason, peculiar velocities are often obtained via theoretical reconstructions of the complete peculiar velocity field using observed redshifts. Standard reconstruction techniques generally rely on a process of smoothing the observed galaxy distribution, and then computing the peculiar velocity field from an approximated matter density field using linear perturbation theory. The smoothing process involved in these techniques, combined with the analytic approximations required to compute the velocity field result in a significant loss of information on small scales. For this reason, we are developing a new Machine Learning technique for reconstructing the peculiar velocity field directly from galaxy observations that does not require any smoothing of the data and does not contain any fundamental assumptions about the underlying field, or analytic approximations. This technique differs from previous Machine Learning reconstructions of the peculiar velocity field in that it is a two-step process that involves first compressing simulations of the peculiar velocity field via an implicit neural field. This has the benefit of allowing us to represent the peculiar velocity information at an arbitrarily high resolution, using a set of neural field parameters that is two orders of magnitude smaller than the size of a grid that would be able to contain the same information resolution. In the second step of the reconstruction, we will train a Probabilistic Diffusion model to reproduce the parameters of the neural fields that represent the underlying peculiar velocity fields from the simulations when conditioned on simulated galaxy observations.

20. UMa3/U1: The Smallest Galaxy Ever! …maybe?

Candidate: ***Scot Devlin***

Advisor: Holger Baumgardt

Abstract: Ursa Major III/UNIONS 1 (UMa3/U1), the smallest and faintest Milky Way satellite discovered to date, exhibits an absolute V-band magnitude of $+2.2 \pm 0.4$ and a half-light radius of 3 ± 1 pc. While its true nature remains uncertain pending multi-epoch spectroscopic data, Errani et al. (2024) suggest that UMa3/U1 is a dwarf galaxy. This conclusion is based on its large velocity dispersion and the improbability, as indicated by dynamical cluster simulations, of its long-term survival if it were a dark matter-free star cluster.

We model the evolution of UMa3/U1 as a star cluster using collisional N-body simulations to find that it would have a remaining lifetime of 2.4 Gyr $\pm$ 0.3 Gyr, thereby allowing for the possibility that UMa3/U1 is a star cluster. The findings show a significant difference in the observable mass functions between UMa3/U1 star cluster and galaxy models, with a p-value $\ll 1$, but no convincing difference in observable mass segregation. Therefore, it is suggested that future observations should target the mass function as a classifier for UMa3/U1 and other very small Milky Way satellites of uncertain nature.

21. Controllable spin splitting in 2D ferroelectric few-layer γ-GeSe

Candidate: ***Shuyi Shi***

Advisors: Carla Verdi

Abstract: -GeSe is a new type of layered bulk material that was recently successfully synthesized. By means of density functional theory first-principles calculations, we systematically studied the physical properties of two-dimensional (2D) few-layer -GeSe. It is found that few-layer -GeSe are semiconductors with band gaps decreasing with increasing layer number; and 2D -GeSe with layer number n = 2 are ferroelectric with rather low transition barriers, consistent with the sliding ferroelectric mechanism. Particularly, spin–orbit coupling induced spin splitting is observed at the top of valence band, which can be switched by the ferroelectric reversal; furthermore, their negative piezoelectricity also enables the regulation of spin splitting by strain. Finally, excellent optical absorption was also revealed. These intriguing properties make 2D few-layer -GeSe promising in spintronic and optoelectric applications.

22. Measuring the Nuclear Magnetic Distribution using Muonic Atoms

Candidate: ***Thakur Giriraj Hiranandani***

Advisor: Jacinda Ginges

Abstract: To date, little is known about the distribution of magnetisation inside the nucleus. Previous works have estimated root means square radius, assuming a model for the distribution. In this work, we attempt to estimate higher-order moments while remaining model-independent. Using the finite nuclear correction to hyperfine splitting we can determine the moments of the nuclear magnetic distribution using muonic atoms. This method uses the nuclear single-particle model and assumes that the nuclear charge distribution is known, however, minimal assumptions are made about the magnetisation distribution.

23. Quantum thermal machines in the transverse field Ising model

Candidate: ***Vishnu Muraleedharan Sajitha***

Advisor: Matthew Davis

Abstract: We identify and interpret the possible quantum thermal machine regimes with a transverse-field Ising model as the working substance. In general, understanding the emergence of such regimes in a many-body quantum system is challenging due to the dependence on the many energy levels in the system. By considering infinitesimal work strokes, we can understand the operation from equilibrium properties of the system. We find that infinitesimal work strokes enable both heat engine and accelerator operation, with efficiencies and boundaries of operation described by macroscopic properties of the system, in particular net transverse magnetization and energy. At low temperatures, the regimes of operation and performance can be understood from quasiparticles in the system, while at high temperatures an expansion of the free energy in powers of inverse temperature describes the operation. The understanding generalises to larger work strokes when the temperature difference between the hot and cold reservoirs is sufficiently large. For hot and cold reservoirs close in temperature, a sufficiently large work stroke can enable refrigerator and heater regimes. Our results and method of analysis will prove useful in understanding the possible regimes of operation of quantum many-body thermal machines more generally.

24. Circuit Quantisation from First Principles

Candidate: ***Yun-Chih Liao***

Advisors: Thomas Stace

Abstract: Superconducting circuit quantisation conventionally starts from classical Euler-Lagrange circuit equations-of-motion. Invoking the correspondence principle yields a canonically quantised circuit description of circuit dynamics over a bosonic Hilbert space. This process has been very successful for describing experiments, but implicitly starts from the classical Ginsberg-Landau (GL) mean field theory for the circuit. Here we employ a different approach which starts from a microscopic fermionic Hamiltonian for interacting electrons, whose ground space is described by the Bardeen-Cooper-Schrieffer (BCS) many-body wavefuction that underpins conventional superconductivity. We introduce the BCS ground-space as a subspace of the full fermionic Hilbert space, and show that projecting the electronic Hamiltonian onto this subspace yields the standard Hamiltonian terms for Josephson junctions, capacitors and inductors, from which standard quantised circuit models follow. Importantly, this approach does not assume a spontaneously broken symmetry, which is important for quantised circuits that support superpositions of phases, and the phase-charge canonical commutation relations are derived from the underlying fermionic commutation properties, rather than imposed. By expanding the projective subspace, this approach can be extended to describe phenomena outside the BCS ground space, including quasiparticle excitations.