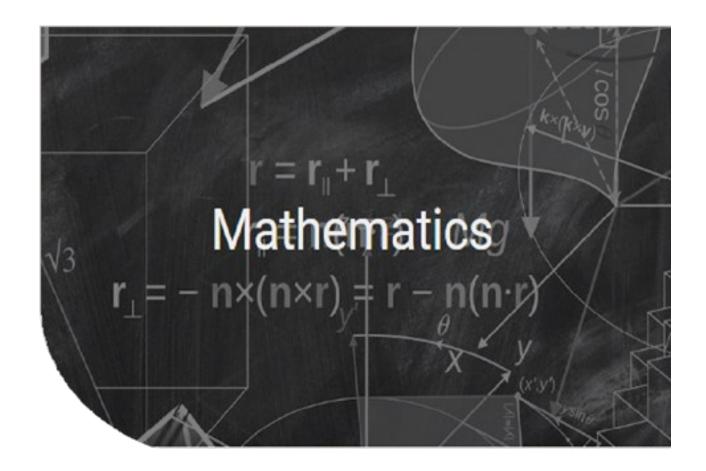# SMP Poster Day 2025 Abstract Booklet

CONTENTS

CONTENTS

1. A Data-Driven Neural Network Approach for Reward-Risk Decumulation

Candidate: *Chang Chen*

Advisor: Dr Duy-Minh Dang

Abstract: We study the portfolio optimisation problem for Defined Contribution (DC) pension plans in the decumulation phase. Our objective is to maximize expected total withdrawals while minimizing Conditional Value-at-Risk. With a data-driven neural network approach, we determine the optimal asset allocation and withdrawal amounts. We prove that the learned strategies converge to the theoretical optimal controls under mild assumptions satisfied in practice. Numerical experiments confirm the convergence and show that the neural network achieves accuracy comparable to PDE-based benchmark solutions.

2. 3D Invariants of Knots — Writhe and Ropelength

Candidate: *Finn Thompson*

Advisors: Prof Benjamin Burton

Abstract: The space writhe of a knot measures how 'coiled' a knot is in 3-space, and is taken as the average writhe of a configuration of a knot from all viewing points. By performing dynamical simulations, we can model a knot as a polymer to explore the relation between the space writhe and 'standard' writhe for various configurations. Additionally, we discuss a method for determining upper bounds on the rope length of torus links by optimising a superhelical 'building block' of helices.

3. Mean-CVaR optimizations via Neural network Fourier-learned transition kernels

Candidate: *Hao Zhou*

Advisor: Dr Duy-Minh Dang

Abstract: This work presents a provably convergent hybrid numerical method for solving multi-period mean-CVaR portfolio optimization problems. The approach centers on solving two-dimensional convolution integrals involving joint transition densities over each rebalancing interval. For such coupled two-dimensional systems, closed-form transition densities are typically analytically intractable. Leveraging known closed-form characteristic functions, we learn the transition-kernel in the Fourier domain via Four-Net—a Gaussian-activated single-layer neural network (Du and Dang, SIAM J Sci Computing 47(2):C529–C557, 2025). The resulting Fourier-learned densities are integrated into a numerical integration framework, enabling efficient approximation of the two-dimensional convolution integrals using standard composite quadrature rules. To further enhance computational efficiency, this hybrid integration scheme is implemented using 2D Fast Fourier Transforms (FFTs), exploiting the inherent Toeplitz structure of the convolution kernels. In addition, we rigorously study asymptotic boundary conditions for the truncated spatial domain and investigate the impact of artificial boundary conditions, effectively controlling truncation-induced error propagation. Numerical experiments utilizing long-term real market data demonstrate the robustness, accuracy, and practical relevance of the proposed scheme for portfolio risk management applications.

4. It's dangerous to go alone! Take this (massive degree of freedom): A scalar companion for a deformed supersymmetric theory

Candidate: *Joey Faller*

Advisor: Dr Gabriele Tartaglino Mazzucchelli

Abstract: This work introduces a novel mechanism for spontaneous supersymmetry (SUSY) breaking in 3D supergravity by deforming the field strength of a supersymmetric gauge theory on an arbitrary curved background. Normally, SUSY pairs bosons and fermions with equal masses, but unobserved superpartners imply symmetry breaking. We add a constant term to the Lagrangian, preserving gauge invariance while granting a nonzero vacuum expectation value (VEV) to the photino, thus breaking SUSY spontaneously via a Higgs-like process.

The deformed model yields a de Sitter vacuum with positive cosmological constant, aligning with observations. On-shell, it features a massive propagating scalar, a fermion with VEV, and mass acquisition by the gravitino through interactions, with the scalar "eating" the photon's degree of freedom.

This toy model opens avenues for generalisations to higher supercharges, cosmological applications, and quantum analyses, providing insights into why SUSY remains hidden.

5. Clustering Accelerates Stabilization in Small-World Boolean Networks

Candidate: *Maram Alqarni*

Advisor: EmPr Diane Donovan

Abstract: Boolean networks (BNs) are models where each node is ON or OFF and updates according to a rule applied to its inputs. Introduced by Kauffman to study gene regulation, BNs reveal how systems stabilize into attractors—states or cycles that repeat over time. We investigate how network clustering affects the attractor period (the number of steps before repetition). Using Watts–Strogatz small-world networks, we simulate synchronous, signed-threshold dynamics across sizes $n = 10$–100 and mean degrees $\bar{k} = 2$–10. Higher clustering shortens mean attractor periods, suggesting that local feedback accelerates stabilization. A generalized additive model for log(mean period) shows that clustering is a significant predictor ($p < .01$; adjusted $R^2 = 0.93$), after adjusting for size, degree, and path-based graph properties. These results extend Kauffman's "edge of chaos" perspective by identifying clustering as a structural driver of stability. Although other network types (Erdős–Rényi and scale-free) were also examined, the poster focuses on the biologically relevant small-world structure. This work deepens our understanding of how real-world systems reach ordered behavior.

6. Generalised Linear Mixed Models for multi-experiment count data

Candidate: *Michael Mumford*

Advisor: Dr Alan Huang

Abstract: The analysis of response data from agricultural field experiments is typically performed using linear mixed models (LMMs). When the response variable is count data, the assumptions underpinning the LMM are violated, and it is necessary to extend to a generalised linear mixed model (GLMM). In this poster, a statistical methodology is proposed for the analysis of multi-experiment count data. The analysis approach uses a GLMM framework, assuming an underlying mean-parameterised Conway-Maxwell Poisson distribution, that can account for arbitrarily under and over-dispersed count data. This framework enables partitioning of residual variation from genetic and other extraneous sources of variation and adopts a factor-analytic model for the genotype by experiment interaction effects. The proposed methodology is applied to a series of common bean experiments. The analysis is implemented using the glmmTMB R-package, which uses automatic differentiation to enhance computational speed, the Laplace approximation estimation method to reduce estimation biases, and a residual maximum likelihood (REML)-like correction to further reduce estimation biases for variance components.

7. Deforming Quantum Field Theories using Auxiliary Fields

Candidate: *Nicola Baglioni*

Advisor: Dr Gabriele Tartaglino Mazzucchelli

Abstract: Quantum Field Theory is one of the most important tools in modern theoretical physics. It has found applications in the study of an incredible variety of systems, ranging from particle physics to condensed matter systems. These theories are however usually very difficult to study exactly. A recent approach to this subject has been to deform some solvable (integrable) models, usually defined in two spacetime dimensions, in such a way that the deformed theory can still be solved exactly. My research is currently focused on a specific deformation that can be implemented introducing in the theory some auxiliary fields chosen precisely so that the model is still integrable. I will discuss what is that we can describe with these auxiliary models and highlight some of the recent advances on this approach.

8. Towards higher-derivative 4D, N = 2 (conformal) supergravity via curvature-squared invariants in (conformal) superspace.

Candidate: *Parth Raina*

Advisor: Dr Gabriele Tartaglino Mazzucchelli

Abstract: General relativity provides a successful low energy description of gravity. However, as a quantum field theory it is non-renormalizable and breaks down at high energies. A natural extension is to include higher-derivative terms in the action. This is motivated by the fact that adding 4-derivative (curvature-squared) terms to the pure gravity action improves its renormalizability [Stelle, 1977]. Moreover, higher-derivative terms appear in the lower energy limit of (super)string theory, which is the best-known candidate for unifying gravity with quantum field theory. Supersymmetry further constrains the structure of these higher-derivative terms, by relating bosonic and fermionic degrees of freedom through supermultiplets. In this work, we use the conformal superspace formalism to construct three independent curvature-squared invariants from vector and tensor multiplets in 4D, N = 2 (conformal) supergravity. We derive their respective component actions and discuss future directions.

9. An Inventory System with Two Supply Modes and Lévy Demand

Candidate: *Qingyuan Zhang*

Advisor: Dr Kazutoshi Yamazaki

Abstract: This study considers a continuous-review inventory model for a single item with two replenishment modes. Replenishments may occur continuously at any time with a higher unit cost, or at discrete times governed by Poisson arrivals with a lower cost. From a practical standpoint, the model represents an inventory system with random deal offerings. Demand is modeled by a spectrally positive Lévy process (i.e., a Lévy process with only positive jumps), which greatly generalizes existing studies. Replenishment quantities are continuous and backorders are allowed, while lead times, perishability, and lost sales are excluded. Using fluctuation theory for spectrally one-sided Lévy processes, the optimality of a hybrid barrier policy incorporating both kinds of replenishments is established, and a semi-explicit expression for the associated value function is computed. Numerical analysis is provided to support the optimality result.

10. Square integer relative Heffter arrays with primary transversals

Candidate: *Sarah Lawson*
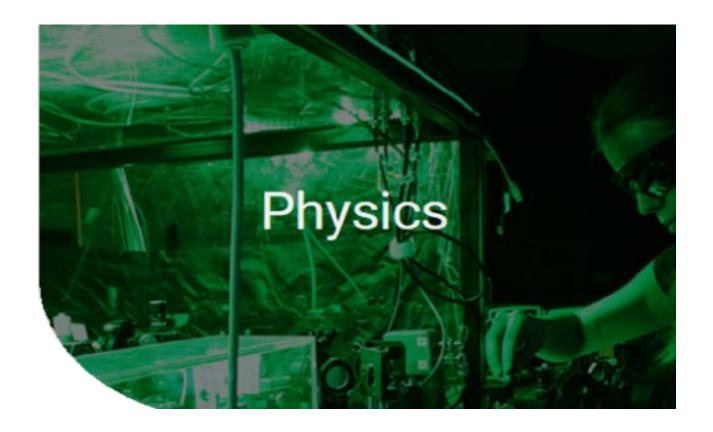
Advisor: Dr James Lefevre

Abstract: A Heffter array is an m x n partially filled array with entries arranged to satisfy three conditions: each row and each column contains h and k filled cells respectively; the sum of the entries in each row and each column is zero modulo 2nk+1; and for each x in the integers modulo 2nk+1\{0}, either x or -x appears in the array.

A relative Heffter array generalises this by replacing 2nk+1 with 2nk+t, where t is any positive integer, and replacing {0} with a subgroup of the integers modulo 2nk+t of order t. When m=n and the rows and columns sum to zero over the integers, we refer to these as square integer relative Heffter arrays. The existence of such arrays is only partially known. We consider the use of graphs and Skolem-type sequences to construct these arrays with the added property that they also contain a primary transversal, a transversal of the set {1,...,n} up to sign.

11. Sieves and almost primes

Candidate: *Simon Thomas*

Advisor: Dr Adrian Dudek

Abstract: Sieves are powerful and somewhat elementary tools designed to estimate the size of subsets of the primes. Many people have heard of the sieve of Eratosthenes but more sophisticated sieves are increasingly being used to prove impressive results in number theory, including significant steps towards resolving Goldbach's conjecture. My poster outlines two recent results on almost primes, or integers with a small number of prime factors, and demonstrates how we used sieve methods to prove them.

CONTENTS

CONTENTS

12. On the computation of minimal transversals in hypergraphs and applying them to applications in genetic theory

Candidate: *Maliheh Alaei*

Advisors: Dr James Lefevre

Abstract: A hypergraph H = (V(H), E(H)) is a finite set V(H) of elements, called vertices, together with a finite multiset E(H) of subsets of V(H), called hyperedges. A k-edge in H is an edge of size k. The rank of a hypergraph H is the maximum size of an edge on H. Thus, H is of rank k if $|e| \leq k$ holds for each edge e inE in H. The hypergraph H is k-uniform if every edge of H is a kedge. A subset $T \subset V$ of vertices in a hypergraph H is a transversal (also called vertex cover or hitting set in many papers) if for every $e \in E$, $T \cap e = \emptyset$, that is, every edge has a vertex in T. A transversal of cardinality τ (H) is called a τ-transversal of H. To study gene expression changes in Senecio lautus under mechanical stimuli, we used 600 F4 hybrid seedlings (dune and headland ecotypes) rotated 90° to induce gravitropism. Samples were collected at 30, 90, 180, 300, and 480 minutes post-treatment, with RNA extracted from shoot apices and analyzed via high-throughput transcriptome sequencing. Data analysis utilized Liquid Association (LA) to identify three-way gene interactions, validated with a permutation-based test and filtered at an FDR of 0.1. Significant triplets were clustered into co-expression modules based on similarity measures, visualized as a hypergraph to explore module interactions and identify core regulatory units influencing ecotype-specific responses. Initial analysis revealed a scalefree hypergraph with a median of 22 connections per node, highlighting key triplets like nodes 34, 35, and 75 (degrees 25, 23, 19) as potential regulatory hubs. The top weighted edge (nodes 80, 23, 7, weight 461.45) suggests strong interactions. Future work will apply the BergeOpt algorithm to compute minimal transversals, refining the identification of critical regulatory structures. This will enhance understanding of ecotype-specific gravitropic responses and inform genetic adaptation studies in Senecio lautus.

1. What's shaking in spin-crossover?: Machine-learned force fields from a DFT method tuned to lattice vibrations

Candidate: **Anna Carpenter**

Advisor: *Dr Carla Verdi*

Abstract: Spin-crossover (SCO) materials can switch between two spin ground-states, given changes in temperature, pressure, applied magnetic fields or light irradiation. Achieving room-temperature bistability of these states would enable many promising applications – as durable molecular switches, high-density memory devices, or vessels for the storage and retrieval of hydrogen. However, advancing the viability of any of these applications requires a deeper understanding of the collective phenomena present in SCO frameworks.

In this work, we use first-principles quantum mechanical calculations based on density functional theory (DFT) to predict structures and energies for [Fe(ptz)6](BF4)2 (ptz = 1-propyltetrazole), a prototypical SCO material, in both its spin states. This project combines selection of a reliable ab initio method with the training of machine-learned force fields to move beyond static calculations and simulate the dynamics of SCO lattices at finite temperature. Findings indicate that including the effect of lattice vibration is crucial to accurately evaluate the stability of the two spin states.

2. Understanding the Formation and Evolution of Intermediate Mass Black Holes

Candidate: **Arshia Anjum**

Advisor: *AsPr Holger Baumgardt*

Abstract: Intermediate-mass black holes (IMBHs) are the long-sought bridge between stellar-mass and supermassive black holes, with outsized influence on star-cluster structure and a potential role in seeding galactic nuclei, yet direct detections remain rare and debated. Omega Centauri, the nearest ultra-massive cluster/nuclear-remnant candidate, offers a decisive laboratory. We run million-body MOCCA models to a Hubble time and forward-model observables for comparison with HST/Gaia kinematics and photometry. IMBH-seeded models exhibit a two-phase growth comprising of early runaway plus BH–BH–dominated mergers, which inject heat that expands the half-mass radius and sustains a shallow central cusp, and reproduce the broad shape of the observed surface-brightness and velocity-dispersion profiles; residuals constrain the initial half-mass radius, binary fraction, and seed mass. Impact of this, our end-to-end pipeline narrows viable IMBH occupation in massive clusters, studies the conditions for SMBH seeding, and constrains the galaxy-black hole co-evolution.

3. Superfluidity with Penetrable Obstacles

Candidate: **Charlotte Thomson**

Advisor: *Prof Matthew Davis*

Abstract: Superfluids exhibit dissipationless flow and can only acquire rotation through the formation of quantised vortices. In my project, I study the two-dimensional flow of an ultracold atomic superfluid past a penetrable circular obstacle. By numerically modelling the stationary states of the system using the Gross-Pitaevskii equation, we observe that the system has multiple excitation states. Each state contains different numbers of vortex-antivortex pairs which are pinned to the obstacle. We characterise the existence of these states as a function of flow velocity and model their dynamical stability. Secondly, we aim to develop a realistic system for which we can study vortex pair formation for a flow past a penetrable obstacle for a superfluid of exciton-polaritons. Exciton-polaritons are hybrid quasiparticles which result from the strong-coupling between a cavity photon and an exciton (electron-hole pair). Their short lifetime prevents thermalisation and consequently, they exhibit non-equilibrium flow. I will outline a protocol which I will use to study this system numerically using a generalised form of the Gross-Pitaevskii equation.

4. Illuminating the structure of single photon emitters in layered 2D materials

Candidate: **Connor Tweedie & Mridul Singh**

Advisor: *Dr Carla Verdi*

Abstract: Robust engineering of optically-active defects in solid-state systems relies on knowledge of their structure, and is crucial for producing high quality single photon emitters (SPEs) for use in quantum computing and communication technologies. Blue-wavelength emitting SPEs in layered 2D boron nitride (BN) have recently been discovered and probed experimentally for these applications, however the atomic structure of the underlying defect is still a mystery even to the most sensitive microscopy techniques. A first-principles numerical modelling approach was developed to determine the most likely defect identity from a number of candidates, based on density functional theory calculations of their electronic, atomic, and vibronic structures. These defects were placed in hexagonal (hBN) and rhombohedral (rBN) stacking configurations, with photoluminescence (PL) spectra simulated for direct comparison to experimental measurements. The differences in out-of-plane phonon modes of these stackings helped determine unique PL signatures for differentiating otherwise similar polytypes. Our calculations, along with experimental data, determined that an in-plane carbon tetramer defect is the most likely candidate for this blue SPE.

5. Atomic Parity Violation and the Caesium Polarisability Puzzle

Candidate: *Jack Easton*

Advisor: Prof Ben Roberts

Abstract: : The measurement of atomic parity violation in Cs currently provides the most precise test of electroweak theory at low energies [1]. High precision calculations of the Stark-induced 6S-7S vector transition polarizability () are required to interpret this measurement and determine the level of agreement with the Standard Model prediction. However, there is currently a >2.5 discrepancy between values obtained for this quantity using two different semi-empirical approaches and the subsequent "polarisability puzzle" is a major source of uncertainty [2-4]. In this work, we propose that the disagreement may be explained by a subset of contributions to the many-body perturbative expansion that have been neglected in calculations relevant to one of these approaches. We present preliminary results showing that the inclusion of these missing terms resolves much of the disagreement between the two methods of computing.

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G. Toh, A. Damitz, C. E. Tanner, W. R. Johnson, and D. S. Elliott, Phys. Rev. Lett. 123, 073002 (2019).

B. K. Sahoo and B. P. Das, (2020), arXiv:2008.08941 [hep-ph].

V. A. Dzuba and V. V. Flambaum, Phys. Rev. A 62, 052101 (2000).

6. Probing nuclear structure via hyperfine splitting in Yb-173

Candidate: *Jayden Hasted*

Advisor: AsPr Jacinda Ginges

Abstract: : Atomic hyperfine structure provides a window into the structure of nuclei. High-precision atomic theory is essential for extracting model-independent nuclear observables from hyperfine measurements — permitting the interrogation of nuclear models. Such studies also allow the testing of atomic structure theory in the nuclear vicinity, which is needed for low-energy searches for new physics beyond the Standard Model.

I will present the results of a collaboration with atomic clock experimentalists at the German national metrology institute, Physikalisch-Technische Bundesanstalt (PTB), where unparalleled experimental precision, in conjunction with state-of-the-art atomic theory, allows the extraction of higher-order nuclear moments of Yb-173 for the first time.

7. Is the stellar mass function universal? Clues from combining machine learning and Gaia DR3 on nearby open clusters

Candidate: *Lachlan Hobart*

Advisor: AsPr Holger Baumgardt

Abstract: The initial mass function (IMF) is a key concept in stellar astrophysics, describing how stellar masses are distributed at birth. The IMF is crucial in understanding a wide variety of astronomical phenomena like the chemical enrichment of galaxies, the rate of supernovae Type Ia explosions and the formation of exotic stars. We determined the IMF of three open clusters: Alpha Persei, Pleiades and Praesepe using Gaia DR3 proper motions and parallaxes. Corrections were applied for unresolved binaries, dynamical evolution, and mass segregation using a combination of N-body simulations and machine learning in a Bayesian framework. This approach allowed us to constrain the most probable initial conditions, including stellar number, binary fraction, radius and mass function. We find that the average IMF of the three clusters is consistent with the bottom-light form observed in globular clusters, though with cluster-to-cluster variation. These results provide new constraints on the universality of the IMF and on models of early cluster evolution.

8. Shining a light on dark sirens

Candidate: *Madeline Cross-Parkin*

Advisor: Prof Tamara Davis

Abstract: The `Hubble tension' refers to the persistent mismatch between early- and late-time measurements of the Universe's expansion rate, quantified by the Hubble constant. Gravitational wave dark sirens provide an independent means of measuring the Hubble constant and thus have the potential to shed light on the origin of the tension. In this work, we investigate biases inherent to the dark siren method and demonstrate their impact on a measurement of this expansion rate.

9. Unlabelled imaging of the living activity of cells.

Candidate: *Marino Lara*

Advisor: Prof Warwick Bowen

Abstract: Cell functionality is an active area of research, but many challenges arise due to the complexity of the processes involved. While techniques that provide information about the mechanical properties and/or dynamics of cells exist, they often rely on single point measurements or have limited acquisition speed. To overcome these limitations, I introduce the LIFE microscope. This system uses random motion of cells to extract information about intracellular dynamics by illuminating the cell with a 780 nm laser and analysing the fluctuations in the scattering signal. The system was successful in detecting motion reduction in cells treated with PFA compared to healthy cells.

10. Cryogenic endoscopic iSCAT microscopy of quantum-vortices

Candidate: *Luke Kelly*

Advisor: Dr Christopher Bake

Abstract: Turbulence is one of the most elusive topics in physics that remains to be solved. Superfluid helium is a strongly interacting quantum fluid—characterized by a vanishing viscosity—and has been a vastly successful platform in furthering our understanding of turbulent flows in recent years [1]. The dynamics of quantized vortices play an essential role in the classical-to-quantum transition of two-dimensional superfluids, and the quantum turbulence they exhibit. However, the study of these quantized vortices is complicated by their nanoscopic sizes, weak scattering, and the need for cryogenic conditions—leaving standard imaging techniques impractical. Recently, precision sensing of superfluid volumes down to the femtoliter scale has been achieved through several successful indirect techniques [1-2]. However, direct, real-time, non-destructive, and label-free optical sensing of singular vortices in a two-dimensional superfluid is yet to be realized in experiment [1]. Here I will present preliminary results towards overcoming these challenges. Through a novel application of `interferometric-scattering' (iSCAT) nano-particle sensing in a cryogenic endoscopic package, this work promises high-speed and real-time imaging of two-dimensional quantum vortices [3]. In combination with nanofabricated on-chip electrostatic `vortex traps', our sensing platform will place historically tantalizing investigations of elusive out-of-equilibrium superfluid phenomena—like vortex generation and annihilation, vortex matter, and long-time dynamics—within reach in the lab.

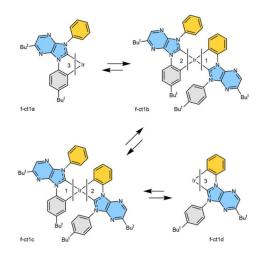References:

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11. Theoretical studies on electronic and photophysical properties of phosphorescent Ir(III) complexes as efficient blue OLED emitters

Candidate: *Martin Kuhn*

Advisor: Dr Xiuwen Zhou

Abstract: OLEDs are generally seen as the next generation technology for displays and lighting and are already widely applied industrially. However, the development of stable and efficient blue OLED emitters which are essential to achieving the technology's full potential is still a major bottleneck. Being able to model and explain photophysical properties of OLED emitters computationally allows for goal-oriented and streamlined design of blue emitters prior to extensive experimental work being conducted. In this research work, multiple blue phosphorescent OLED emitters made of Ir(III) carbene complexes were investigated computationally to understand how ligand modification and isomerization affect their photophysical properties. By computing the excited singlet and triplet states using time-dependent density functional theory (TD-DFT) and calculating excitation energies, their experimentally observed emission colour could be modelled. Further, theoretical explanations of differences in experimental emission efficiency within groups of Ir(III) complexes could be derived by analysing computed electronic orbitals and electron distribution involved in the excited states. Calculated orbital overlap and percentage of metal-to-ligand charge transfer (MLCT) were shown as important factors influencing efficiency of OLED emitters. Finally, it was shown that observed trends in radiative decay behaviour among Ir(III) complexes, which is an important indicator of voverall emitter efficiency, can be modelled computationally by calculation of the radiative rate. The obtained results confirm the potential of computational investigations for prediction of OLED emitter properties and provide direction for further development of efficient blue OLED emitters.[1,2]

Investigated blue phosphorescent Ir(III) carbene complexes f-ct1a-d.[1]

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[2] Yixin Wu, Kai-Ning Tong, Martin Kuhn, Chengcheng Wu, Wen-Yi Hung, Guodan Wei, Jie Yan*, Yun Chi* & Xiuwen Zhou*, *Journal of Materials Chemistry C*, **2025**, *13*, 3501-3510.

12. Constraining Black Hole Kicks Using Dense Star Clusters

Candidate: *Mitchell Hooymans*

Advisor: AsPr Holger Baumgardt

Abstract: Massive stars play a crucial role in the chemical enrichment history of galaxies. They are also the progenitors of compact remnants, such as neutron stars and black holes, and therefore play a key role in the formation of gravitational-wave-driven mergers like those detected by LIGO/Virgo/KAGRA. Although massive stars have been studied extensively, many aspects of their evolution remain uncertain, particularly the remnant masses and the magnitude of the initial velocity kicks they receive. Our project aims to constrain these properties by running a set of Monte Carlo simulations of dense star clusters. We specifically apply our models to NGC 3201, an extensively studied globular cluster with a confirmed population of black holes in its core. To reproduce the observed properties of this cluster, we find that its black holes must have received significant natal kicks at birth, with peak velocities ranging from at least 40 km/s up to magnitudes typical for neutron stars (~265 km/s). These strong kicks are essential to eject a large fraction of the initially formed black holes, a process required for our simulations to match the present-day structure of NGC 3201. Future research will expand this methodology to a broader selection of globular clusters to further constrain the natal kick distribution. By linking cluster dynamics with observational data, our work provides a valuable observational test of black hole formation, with broad implications for both stellar and gravitational-wave astrophysics.

13. Direct Detection of Dark Photons

Candidate: *Narise Williams*

Advisor: Dr Christopher Baker

Abstract: As dark matter continues to evade direct detection, new physics, such as theoretical particles, must be hypothesised to explain inconsistencies in astrophysical and cosmological observations. One of these proposed hypothetical particles, the dark photon, could be detected by liquid noble gas scintillators, such as the XENON experiment, through ionisation in an atom via the 'dark photoelectric effect'. In order to verify whether a dark photon signal has been detected in these experiments, the theoretical rate of these interactions must be calculated. However, calculations for this rate in the literature use the electric-dipole approximation, which is estimated to break down for dark photons with masses greater than 27 eV. Additionally, a statistical study using high-energy collider data suggests the existence of a dark photon with a mass of ~ 4 GeV [1]. In my Honours research project, I demonstrated that the electric-dipole approximation, as well as other approximations, are not suitable for modelling dark photons with masses beyond 27 eV. Additionally, scintillators using xenon cannot probe masses beyond ~0.1 GeV, making the detection of the dark photon predicted by Ref. [1] just out of reach. Continuing this project into my PhD, the next goal is to develop a general method to calculate absorption and scattering rates for other dark matter candidates as well as neutrinos, which contribute to significant background noise in these dark matter detectors.

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14. Morphology in Motion: Linking Angular Momentum to Galactic Structure

Candidate: *Pratyush Kumar Das*

Advisors: Dr Sarah Sweet

Abstract: This project aims to explore how angular momentum, a fundamental physical property, influences the morphological evolution of galaxies. These changes are influenced by both external forces, such as gas flow, mergers, tidal interactions, and ram pressure stripping, as well as internal forces, including feedback from stars and active galactic nuclei, viscosity, and biased collapse. A key part of our work involves the development of a computational model that accurately measures the stellar specific angular momentum of galaxies (j). Subsequently, we aim to analyze the correlation between the derived j values and stellar mass (M). j is computed by normalizing angular momentum J by the M, making it independent of M and allowing for a comparison between two theoretically uncorrelated parameters. We further plan to investigate this relation alongside the galaxy's morphological information. So, we plan to extend this correlation to a third dimension by adding the bulge-to-total light ratio (ß), a key morphology indicator, derived from state-of-the-art photometric fits. Our primary advantage over previous benchmarks comes from access to larger and more spatially resolved galaxy datasets from Integral Field Spectrograph (IFS) surveys, including the Sydney-Australian-Astronomical-Observatory Multi-object Integral field (SAMI), Hector, and Middle Ages Galaxy Properties with Integral Field Spectroscopy (MAGPI). The second major improvement comes from the computational technique of j, where we compute it by careful spatial integration in the two-dimensional map unlike previous works based on a one-dimensional approximate function or less accurate spatial integration. In addition to computing the total j, we will generate a two-dimensional map of the j distribution, which will help us better understand spatial changes influenced by internal and external factors.

15. UMa3/U1 — The Smallest Known Galaxy?

Candidate: *Scot Devlin*

Advisor: AsPr Holger Baumgardt

Abstract: Dark matter continues to elude us: while the motions of stars and galaxies clearly reveal its gravitational pull, no direct detection of the underlying particles has yet been achieved. The faintest and most compact Milky Way satellite, Ursa Major III / UNIONS 1 (UMa3/U1), discovered in 2024, was proposed as the most dark-matter–dominated galaxy and a prime site for a first detection — but its classification sits on the knife-edge between star cluster and galaxy. Our new high-resolution spectroscopy from the European Southern Observatory's Very Large Telescope (Paranal, Chile) reveals strong velocity variability in UMa3/U1's second-brightest star, direct evidence for binarity. This collapses the system's apparent velocity dispersion and demonstrates its true nature as a dark-matter–free star cluster.

16. Comparing Single-Mode and Pulse-Based Squeezing

Candidate: *Sepanta Moussavian*

Advisor: Dr Joel Corney

Abstract: Squeezing is the process by which the uncertainty of one aspect of a quantum state, such as momentum, is pushed below the uncertainty of vacuum, at the expense of the conjugate variable, typically position for the momentum. Properties of light, such as photon number, can also be squeezed. These squeezed light states are useful in quantum information processing, precision measurements, and so on.

Here we use mathematical methods to model Kerr squeezing typically made in optical fibres, using a single-mode and a multi-mode pulse model. We identify two areas in the pulse: the central area, which acts as similarly to the single mode model, and the outer area which undergoes more complex dynamics.

17. Effect of the weak quadrupole moment in atomic systems

Candidate: *Shannon Ray*

Advisor: AsPr Jacinda Ginges

Abstract: Parity nonconservation (PNC) in atoms is a tiny weak interaction effect, arising largely from Z-boson exchange between atomic electrons and neutrons. This has been a rich area of study for the past few decades with the weak charge measured with up to a fraction of a percent precision, and the nuclear anapole moment experimentally observed once, with an uncertainty approaching 10%. Of recent interest, is the weak quadrupole moment (WQM), which leads to small changes in parity-violating amplitudes between hyperfine states in deformed nuclei.

In this poster I discuss the influence of the weak quadrupole moment on atoms. Due to weak mixing properties between atomic transitions and their dependence on the tensor rank of the operators. This has been studied in conjunction with the weak charge and the nuclear anapole moment. Nuclei with a quadrupole deformation have an enhanced WQM which induces the tensor weak electron-nucleus interaction in atoms and molecules, two such atoms are francium and triply-ionised thorium and are the focus of this poster.

18. Atomic-Scale Imaging of Tantalum Germanide Surfaces for Superconducting Quantum Devices

Candidate: *Suhani Singh*

Advisors: **Dr Peter Jacobson**

Abstract: Superconductor–semiconductor hybrid materials are emerging as key platforms in the development of scalable quantum technologies, particularly for superconducting qubits and quantum-dot-based devices. In this work, we explore the surface morphology and atomic-scale structure of Tantalum Germanide (TaGe) alloys grown on Germanium substrates as a candidate material system for next-generation quantum hardware. The robust superconducting properties of Ta with the surface tunability and compatibility of Ge offer a promising alternative to conventional Al-based materials which are limited in tunability, coherence times, and integration with scalable fabrication.

19. The truncated Wigner approxima3on as a tool for quantum sensing

Candidate: *Thakur Hiranandani*

Advisor: AsPr Jacinda Ginges

Abstract: The truncated Wigner approximation (TWA) is a semiclassical quantum phase-space tool that has proven to be useful in the simulation of optic, atom-optic systems and Bose-Einstein Condensates. In the TWA, the evolution of the quantum state is fully determined by the classical dynamics of phase-space variables which greatly simplifies the problem. This is particularly useful when exact methods become numerically intractable. We discuss applications of these results to quantum sensing. In particular, we present a novel method for computing quantum Fisher information that admits a simple interpretation in terms of stochastic samples. This method proves to be especially useful when applied to nontrivial sensing schemes, where other methods fail.

20. Brain-inspired computational hardware to tackle an AI energy crisis

Candidate: *Will Gunn*

Advisors: Dr Markus Rambach

Abstract: As global demand for AI continues to surge, energy usage while training these models doubles every nine months. Some of the most promising developments in improving energy efficiency are from the field of neuromorphic computing, a ground-up redesign of computational hardware that mimics the structure and efficiency of the human brain. Our research outlines the development of superconducting, artificial 'neurons' interconnected by 'spiking' on-chip light sources. Specifically, we detail a three-step design which includes superconducting nanowire single-photon detectors (SNSPDs) to detect and accumulate upstream signal, electrically-driven colour centre emitters doped into silicon to 'spike' after a threshold, and compact integrated photonics devices to fan-out and propagate these spikes to downstream nodes. Results are shown for the optimisation and fabrication of both the light sources and integrated photonics devices, along with preliminary development of the SNSPDs in collaboration with UNSW. We envisage a proof-of-concept network in hardware interconnected at speed-of-light latency with the robustness and energy efficiency of CMOS and superconducting electronics.

21. Nanomechanical Error Correction

Candidate: *Xiaoya (Tina) Jin*

Advisor: Prof Warwick Bowen

Abstract: Nanomechanical computers offer ultra-low power consumption and enhanced lifetimes in harsh environments, but remain vulnerable to errors from environmental perturbations. Here, we exploit the emergent collective dynamics in a network of three coupled nonlinear nanomechanical resonators to experimentally demonstrate a key computing functionality: error correction. We encode binary information in the vibrational modes of coupled nanomechanical resonators, and record their responses to external impulses. We show that our device autonomously restores perturbed memory states via the collective dynamics of the nonlinear network. Our work highlights how emergent nonlinear dynamics can be harnessed for practical applications, paving the way towards error-resilient nanomechanical computing.