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Building 40



Book of Abstracts

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Poster Session / 1**Transformative Wave Attenuation Techniques for 1D Composite Structures with Inerter****Author:** Saeed Althamer¹¹ *Professor*

This article introduces a novel technique for mitigating longitudinal elastic waves in one-dimensional (1D) composite structures by utilizing inerter-based vibration absorbers paired with multifrequency resonators (MFRs). The proposed 1D resonant structure features an array of regularly spaced inerter-based absorbers embedded along an isotropic 1D framework. Each absorber is equipped with a system of spring-mass resonators connected at two critical points, significantly enhancing the ability to suppress wave propagation. Through an analytical approach leveraging Finite Element Modeling (FEM) and Bloch's theorem, the study reveals the presence of multiple stopbands, creating wide and tunable frequency ranges where wave transmission is effectively suppressed. The design and modeling of this resonant structure demonstrate that wave attenuation is grounded in well-established mechanical vibration absorption principles. The inerter-based absorbers generate two opposing internal forces that neutralize incoming longitudinal waves within the stopband frequencies. By adjusting key properties such as inerter, stiffness, and mass, these absorbers can be finely tuned to optimize their wave-blocking performance. A detailed parametric study explores how variations in the MFRs' characteristics, including inerter, mass, and stiffness, influence the location and size of the stopbands. The results from FEM simulations align closely with theoretical dispersion curves across various configurations, providing strong validation of the design. This approach, which leverages inerter-based vibration absorbers for efficient wave control, holds significant promise for applications where precise manipulation and attenuation of wave propagation are crucial.

Poster Session / 2**BEYOND $F=ma$: EMPIRICAL CHALLENGES TO NEWTON'S SECOND LAW IN REAL-WORLD PHYSICS EDUCATION****Author:** Amritpal Singh Nafria¹**Co-author:** Sugandhi Sharma ¹¹ *Lovely Professional University*

This study examines the practical application of Newton's second law ($F=ma$) by systematically analyzing the effects of resistance forces in real-world systems. Through controlled experiments using calibrated weighing scales, we measure frictional variations (1.44-1.80N across surfaces with $\mu=0.1-0.7$) and air resistance (0.24-0.37N) to develop an enhanced force equation ($F=ma+r$) that incorporates cumulative resistances. Our celestial mechanics models demonstrate how a 10N force on a 5kg mass produces environment-dependent accelerations (1.876 m/s² on Pluto vs. 0.0408 m/s² on Earth), highlighting the importance of contextual factors in force calculations. These findings provide physics educators with empirically validated teaching tools, including practical measurement techniques using standard laboratory equipment and ready-to-implement celestial mechanics examples that bridge theoretical principles with experimental observations.

Medical Physics / 6**Computed Tomography Dose Level in Selected Five Principal Hospitals in Ethiopia****Author:** Gebremedhin Kide Kinfe¹

Co-author: Birhanu Tsegaye Wores ²

¹ *ICTP, Univerdity of Trieste*

² *Nuclear Physicist (Aksum University Ethiopia)*

BACKGROUND: X-ray Computed Tomography dose levels have been varying among modalities and scanning body regions due to the absence of an incessant routine follow-up. Thus, the study aimed to compute the dose index discrepancies in Ethiopia for the most recurring scan protocols (head, chest, abdomen, and pelvis).

METHODS: Due to the rare existence of functional CT scanners in Ethiopia, a purposive sampling method was employed to select the hospitals. From the selected hospitals, 1,385 (249 heads, 804 chests, 132 abdomens, and 200 pelvis) standard dose metric values were collected from December 2019 to March 2020. Patients' DLP was computed into a mean value using IBM SPSS Statistics 20 software. From the mean DLP, we can compute the effective dose.

RESULTS: Patients' dose level disparity was observed in this study though it is below the ICRP standard level for all body regions except for pelvis DLP (593.37 mGy-cm) at Black Lion. The dose level for the head and chest are computed within the recommended level at all hospitals. Effective doses for the pelvis at four hospitals (Teklehaimanot, Black Lion, ALERT, Paul's, and Ayder hospitals) were computed as 6.45, 8.90, 5.08, 6.54, and 6.84 mSv respectively, and the effective doses for abdomen at Ayder Hospital was obtained to be 8.90 mSv, which is above the recommended value.

CONCLUSION: X-ray CT scanners are somewhat properly functioning although some sort of justification and optimization for pelvis and abdomen examinations are strongly recommended to implement as low as reasonably achievable principle.

Poster Session / 7

Cryogenic endoscopic iSCAT microscopy of quantum-vortices

Author: Luke Kelly¹

Co-authors: Christopher Baker ¹; Daniel Foshee ¹; Jesse Slim ¹; Nicole Luu ²; Warwick Bowen ¹

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Turbulence is one of the most elusive topics in physics that remains to be solved. Superfluid helium is a strongly interacting quantum fluid—characterised 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 quantised 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 quantised 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 femto-litre 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 realised 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 places historically tantalising investigations of elusive out-of-equilibrium superfluid phenomena—like vortex generation and annihilation, vortex matter, and long-time dynamics—within reach in the lab.

[1] Y. P. Sachkou et al., *Science* 366, 1480 (2019).

[2] A. Sawadsky et al, *Science Advances* 9, eade3591 (2023); X. He et al., *Nature Physics* 16, 4 (2020); A. Kashkanova et al., *Nat. Phys.* 13(1), 74–79 (2017).

[3] A. J. R. MacDonald et al., *Rev. Sci. Instrum.* 86, 013107 (2015); K. Lindfors et al., *Phys. Rev. Lett.* 93, 037401 (2004).

Theoretical Physics / 8**Expanding the class of Free Fermions****Authors:** Jannis Ruh^{None}; Ryan Mann^{None}; Samuel Elman^{None}

We present a novel graph-theoretic approach to simplifying generic many-body Hamiltonians. Our primary result introduces a recursive twin-collapse algorithm, leveraging the identification and elimination of symmetric vertex pairs (twins) within the frustration graph of the Hamiltonian. This method systematically block-diagonalizes Hamiltonians, reducing complexity while preserving the energetic spectrum. Importantly, our approach expands the class of models that can be mapped to non-interacting fermionic Hamiltonians (free-fermion solutions), thereby broadening the applicability of classical solvability methods. Through numerical experiments on spin Hamiltonians arranged in periodic lattice configurations and Majorana Hamiltonians, we demonstrate that the twin-collapse substantially increases the identification of simplicial and claw-free graph structures, which characterize free-fermion solvability. Finally, we extend our framework by presenting a generalized discrete Stone-von Neumann theorem. This comprehensive framework provides new insights into Hamiltonian simplification techniques, free-fermion solutions, and group-theoretical characterizations relevant for quantum chemistry, condensed matter physics, and quantum computation.

Poster Session / 9**A Fresh Geometric Perspective of an Electron and its Waves Appear to Provide A More Comprehensive Description of Matter****Author:** Fong Yang¹¹ *No Affiliation*

Matter consists of particles and waves. Every day we interact with particles while essentially disregarding waves. Quantum mechanics mathematically describe matter from the waves' perspective while disregarding particles. This description does not reflect our everyday experience with matter.

The double slit experiment shows that electrons inherently have wave properties. Quantum mechanics can predict time-elapsing double slit experiment results using wave mechanics. But it is unable to explain how electrons interact with the macroscopic environment within this experiment.

My theoretical research illustrates how electrons interact with its macroscopic environment using basic geometry and algebra, and the conservation of energy concept.

Theoretical research begins with a suggested first-person perspective of a traveling electron and its waves. The physical restrictions of the double slit experiment setup, the mathematical geometrics of the electron's waves, and the conservation of energy concept, together constrains the electron to certain locations in space until its interaction with the macroscopic environment. Basic algebra is then used to translate the geometric perspective into two distinctive wave properties. These properties are at a minimum a 99% match compared to double slit experiment calculations derived from conventional trigonometric perspective of the electrons' waves.

The electron's confined locations in space adds a particle complement to quantum mechanics' wave description. Together, these two independent descriptions appear to more closely reflect our everyday experience with matter.

Solar Terrestrial and Space Physics / 10

Unveiling the Solar Nexus: An Interdisciplinary Inquiry into the Dynamics of Our Star

Author: Amritpal Singh Nafria¹

¹ *Lovely Professional University*

The Sun exists at the intersection of many scientific frontiers, where classical and modern physics converge with environmental science, engineering, and data analytics. This paper presents a novel interdisciplinary approach to solar physics, emphasizing how understanding the Sun requires crossing traditional disciplinary boundaries. We explore the fusion-driven processes at the core, the fluid-like behavior of plasma in its outer layers, the emergence of magnetic structures, and their far-reaching influence through solar wind and radiation. Integrating methods from thermodynamics, electromagnetism, computational modeling, and Earth system science, we construct a unified perspective of the Sun not only as a stellar object, but as a dynamic agent shaping physical, ecological, and technological systems. This approach opens pathways for collaborative research that connects astrophysics with real-world applications in climate science, space weather prediction, and renewable energy.

Poster Session / 11

Bridging Theory and Experiment: Quantum Gravity Phenomenology

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Quantum gravity seeks to unify quantum mechanics and general relativity into a coherent framework, addressing fundamental questions about space-time at the Planck scale. This pursuit has inspired diverse theoretical approaches, including string theory, loop quantum gravity, causal dynamical triangulations, and emergent space-time models, each predicting distinct phenomenological signatures. On the experimental front, advancements in astrophysical observations and high-precision laboratory techniques offer opportunities to test these predictions. Potential signals include violations of Lorentz invariance, quantum space-time fluctuations, modified dispersion relations for high-energy particles, and deviations in gravitational wave propagation. This review synthesizes the current state of quantum gravity phenomenology, highlighting how theoretical insights and experimental innovations converge to constrain or reveal new physics. By integrating diverse methodologies, we aim to bridge the gap between abstract models and observable phenomena, advancing our understanding of the quantum nature of gravity.

Condensed Matter & Materials / 12

Spin Texture Control and Magnetic Gap Engineering in a Ferromagnetic Insulator-Topological Insulator Sandwiched Heterostructure.

Authors: Md Tofajjol Hossen Bhuiyan¹; Qile Li¹

Co-authors: James Blyth¹; Jieun Lee²; Jonathan Denlinger²; Jaime Sánchez-barriga³; Alexander Fedorov³; Anton Tadic⁴; Emile Reinks³; Sung-Kwan Mo²; Alexei Fedorov²; Oliver J. Clark¹; Mark T. Edmonds¹

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The interplay between topology and magnetism in quantum materials gives rise to novel quantum phases, characterized by topologically protected surface states with non-trivial electronic band structures and complex spin textures. One of the most compelling outcomes of this interplay is the quantum anomalous Hall effect (QAHE)¹, where a single chiral edge mode enables dissipationless electron transport. Realizing QAHE requires a magnetic exchange gap to open at the Dirac point (DP) of a topological insulator's surface states.

The ferromagnetic insulator –topological insulator sandwich heterostructure composed of four-quintuple layer Bi₂Te₃ between two single-septuple layers of MnBi₂Te₄ (MBT/4BT/MBT), has recently been proposed as a magnetic topological insulator (MTI) through proximity-induced magnetization.² A gap of 75 meV and relatively high Curie temperature make it a candidate for realizing the QAHE at elevated temperatures. Despite the prior characterisation of the gap², the spin texture of the exchange-split surface state remains an open, but crucial, question. Additionally, reports exist regarding gap opening in Bi₂Se₃-family TIs via non-magnetic means,³ and therefore the direct characterization of the MTI spin texture- and the ability to manipulate it with an external magnetic field- would provide an unambiguous origin for the observed gap.

We report characterization of the surface-state spin texture of the MBT/4BT/MBT heterostructure using spin- and angle-resolved photoemission spectroscopy to directly verify that the band gap arises from broken time-reversal symmetry via proximity-driven magnetization. This study reveals a clear spin splitting at the Γ -point and demonstrates direct control of spin state via external magnetic fields, providing an unambiguous verification that the gap arises from exchange splitting rather than non-magnetic origins. The robust magnetic gap and controllable spin texture make this heterostructure a suitable candidate for spintronic applications and magnetic topological quantum phases.

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Poster Session / 13

Shaping the Cosmos: Mergers, Black Hole Dynamics, and the Transformation of Spiral Galaxies

Author: Anmol Gandhi¹

¹ *Independent Researcher*

Galaxy mergers play a pivotal role in shaping the structure and evolution of galaxies. This study investigates how spiral galaxies morphologically transform after merging with companion galaxies, focusing on the relationship between initial merger conditions and the resulting structures. Observational data from SDSS and HST archives will be integrated with high-resolution simulations like IllustrisTNG, EAGLE, GADGET, and RAMSES. Universe Sandbox will be used to illustrate merger dynamics.

Key factors such as mass ratios, angular momentum, gas content, and collision geometry will be correlated with final galaxy morphologies: elliptical, lenticular, irregular, or transitional. The study also examines the behavior of central black holes during mergers. As galaxies collide, their supermassive black holes are expected to interact and merge, pulling in matter and generating gravitational waves critical for detectors like LISA. This process also helps assess black hole mass, spin, and effects on the remnant core.

To quantify morphological evolution, Python tools like AstroPy, NumPy, Pandas, and Matplotlib will be used, along with indices like Gini-M20 and CAS metrics. This research aims to improve understanding of how mergers influence both visible and dark matter, contributing to broader insights in galaxy formation and cosmic structure evolution.

Keywords: Galaxy Mergers, Spiral Galaxies, Galaxy Morphology, Astrophysical Simulations, Cosmic Structure, Dark Matter Dynamics, Supermassive Black Hole Mergers.

Poster Session / 14

The Complex Morphology of The Medusae Fossae Formation on Mars

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¹ *University of Wollongong, School of Physics*

The Medusae Fossae Formation [MFF] is a significant and complex geological feature on Mars that extends for more than 5,000 km along the equator of Mars. The soft, easily eroded deposits rise 4km from the Northern Plains of Elysium Planitia to the Southern Highlands. It has been suggested that the MMF was emplaced during the Hesperian epoch (3.8-3.0 billion years ago) and has been physically reworked up to the present day.

There is a clear separation of the Southern Highlands from the MMF which can be seen to be eroding into the at the Martian Dichotomy.

The major structural features within the Central MFF region include

1 A low lying, fractured foreland that abuts the thin lava flows of Elysium Planitia.

2.A smooth, featureless ridge system, which is rising from 250m to 500m above the Plain. This is eroding at its the SE edge.

3.A moderately cratered dome rising from 1000m to 1500m.

4.A heavily eroded sloping and stratified feature rising from 1500m to 2250m before dropping steeply into the Martian Dichotomy.

The relationship between features and the evolution of the MFF are discussed in terms of

- Impact cratering and the resulting basal surges.
- Sublimation of ice layers and the formation of collapse features.
- Folding mechanisms.
- Volcanic interactions with Apollinaris Mons.

Poster Session / 15

Physically-Motivated Guiding States for Local Hamiltonians

Authors: Gabriel Waite¹; Karl Lin¹; Michael Bremner¹; Samuel Elman¹

¹ *University of Technology Sydney*

This work characterises families of guiding states for the *Guided Local Hamiltonian* problem, revealing new connections between physical constraints and computational complexity.

Focusing on states motivated by Quantum Chemistry and Hamiltonian Complexity, we extend prior **BQP**-hardness results beyond semi-classical subset states by demonstrating that broader state families preserve hardness while maintaining classical tractability under practical parameter regimes.

Crucially, we provide a constructive proof of **BQP** containment for the canonical problem, proving the problem is **BQP**-complete when provided with a polynomial-size classical description of the guiding state.

Our results show quantum advantage persists for physically meaningful state classes, and classical methods remain viable when guiding states admit appropriate descriptions.

We identify a *Goldilocks zone* of guiding states that are efficiently preparable, succinctly described, and sample-query accessible, allowing for a meaningful comparison between quantum and classical approaches.

Our work furthers the complexity landscape for ground state estimation problems, presenting steps toward experimentally relevant settings while clarifying the boundaries of quantum advantage.

Focus Session: Ultra-cold atoms and quantum technology / 16

Some Exact Solutions in Polaron Physics and Polaron Interactions: A Few-Body Perspective

Authors: Jia Wang¹; Xia-Ji Liu^{None}; Hui Hu^{None}

¹ *Swinburne University of Technology*

Polaron quasiparticles—impurities interacting with a quantum medium—represent one of the earliest and most fundamental topics in condensed matter physics. A key feature of polaron physics is the interplay between few-body and many-body effects. In strongly interacting regimes where mean-field and perturbative methods often fail, polaron systems offer a unique opportunity for exact treatment: due to the negligible back-action of a single impurity on the background medium, polarons can often be described from a few-body perspective, sometimes allowing for exact solutions.

We begin by examining the exact solution of a heavy Fermi polaron, modelled as an infinitely massive impurity immersed in a non-interacting Fermi gas. We demonstrate how Ramsey spectroscopy—closely related to nuclear magnetic resonance (NMR)—can be used to probe the polaron dynamics. By extending this technique to the multidimensional regime, in analogy with multidimensional NMR, we uncover nonlinear nonequilibrium features in polaron dynamics.

We then generalize the exact solution to a heavy impurity immersed in a paired two-component Fermi gas across the BEC–BCS crossover. This system admits an exact description of polaron physics in the presence of superfluid correlations.

Finally, we consider heavy polarons in a quantum Hall fluid. Remarkably, exact solutions are obtained not only for single polarons, but also for systems with multiple interacting polarons, allowing the polaron-polaron interactions to be determined analytically.

Poster Session / 17

Tracing the Impact of Dark Matter Halo Environment on Galaxy Quenching

Author: Sama Baloch^{None}

Understanding the processes which shut down star formation in galaxies, commonly known as galaxy quenching, is a central question in astrophysics. In this project, I investigate how a galaxy's location and motion within its group environment influence its star-forming activity, using data from the Deep Extragalactic Visible Legacy Survey (DEVILS).

Focusing on satellite galaxies, I explore two key environmental metrics: projected radial distance from the group centre (scaled by R100) and the galaxy's velocity offset (ΔV) relative to the group's systemic velocity. These parameters act as proxies for infall time and interaction history within the group. I compare these dynamical indicators with galaxy star formation classifications, either passive or star-forming, derived using the stellar mass–SFR plane.

My results show a clear trend. Galaxies at smaller R/R100 and lower ΔV are more likely to be quenched, consistent with environmental quenching mechanisms acting over time. In contrast, galaxies at larger radii and with high velocity offsets tend to be star-forming, suggesting they are recent in-fallers not yet affected by the dense group environment. These findings support the scenario that group preprocessing and environmental effects such as ram-pressure stripping and starvation play a significant role in galaxy evolution.

This work contributes to our understanding of how galaxies transition from star-forming to passive in dense environments, using the rich spectroscopic and group catalog data from DEVILS

Poster Session / 18

Synthesis, Structural, and Spectral Studies of Mn²⁺ doped LiSrVO₄ for Lighting Applications

Author: Parul Sharma¹

Co-author: Kamni Pathania

¹ Cluster University of Jammu

This study presents a simplistic way to synthesize LiSr(1-x)VO₄: xMn²⁺ nanophosphors with 0.25 ≤ x ≤ 3.0 mol% by using combustion method. The structural, spectral and optical properties were examined using XRD, UV-Vis spectroscopy, Scanning Electron Microscopy (SEM), Energy Dispersive Analysis of X-rays (EDAX), Transmission Electron Microscopy (TEM) and Photoluminescence (PL) spectroscopy. The XRD peaks confirmed that the synthesized nanophosphors were stabilized in monoclinic phase having space group P2/m. The grain size of around 34.92 nm was calculated from the Lorentz fitting of histogram, which is in agreement with the XRD data. By varying the amount of dopant, value of band gap initially decreases and then increases with the increase in concentration of Mn²⁺ due to mid gap absorption phenomenon. SEM supplies prodigious details about the microstructure of the nanophosphors. The particles are agglomerated and spherical in nature. The EDS image show the presence of all the elements except Li. TEM studies also confirm that the particle size lies in the nm range. Initially, a red shift is observed in the band gap for low amount of the transition metal ion Mn²⁺ in LiSrVO₄ host which is followed by an augment in the band gap values for higher concentrations. The co-relation of band gap, refractive index and metallization criterion is also investigated. Photoluminescence excitation ($\lambda_{em} = 380$ nm) and the emission spectra shows three sharp emission peaks located at 421 nm, 487 nm and 532 nm covering the violet - blue region. The optical studies showed that the peak excitation match quite well within the emission range (370 – 420 nm) of commercially available n-UV InGaN LEDs suggesting that this material can be employed in UV LEDs. The CIE coordinates and the dominant wavelength corresponds to the blue region.

Condensed Matter & Materials / 19

Fulde-Ferrell-Larkin-Ovchinnikov States and Topological Bogoliubov Fermi Surfaces in Altermagnets: an Analytical Study

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We present an analytical study of the ground-state phase diagram of dilute two-dimensional spin-1/2 Fermi gases exhibiting *d*-wave altermagnetic spin splitting under *s*-wave pairing. Within the Bogoliubov-de Gennes mean-field framework, four distinct phases are identified: a Bardeen-Schrieffer-Cooper-type superfluidity, a normal metallic phase, a nodal superfluidity with topological Bogoliubov Fermi surfaces (TBFSs), and Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) states with finite center-of-mass momentum. Notably, the FFLO states and TBFSs represent two unconventional forms of superconductivity. Considering the simplicity of this model, with only one band, zero net magnetization, and nodeless *s*-wave pairing, the emergence of both unconventional phases underscores the pivotal role of altermagnetic spin splitting in enabling exotic pairing phenomena. This analytical study not only offers a valuable benchmark for future numerical simulations, but also provides a concrete experimental roadmap for realizing FFLO states and TBFSs in altermagnets.

Condensed Matter & Materials / 20

Optimization of Ultrafast Singlet Fission in One-Dimensional Rings Towards Unit Efficiency

Authors: Alice Pagano¹; Daniel Jaschke¹; Francesco Campaioli²; Simone Montangero¹

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² *RMIT University*

Singlet fission (SF) is an electronic transition that in the last decade has been under the spotlight for its applications in optoelectronics, from photovoltaics to spintronics. Despite considerable experimental and theoretical advancements, optimizing SF in materials like multichromophoric systems and molecular crystals remains a challenge, due to the complexity of its analysis beyond perturbative methods. Here, we tackle the case of one-dimensional rings, aiming to promote singlet fission and prevent its backreaction. We study ultrafast SF nonperturbatively, by numerically solving a spin-boson model, via exact propagation and tensor network methods. By optimizing over a parameter space relevant to organic molecular materials, we identify two classes of solutions that can take SF efficiency beyond 85% in the nondissipative (coherent) regime, and to 99% when exciton-phonon interactions can be tuned. After discussing the experimental feasibility of the optimized solutions, we conclude by proposing that this approach can be extended to a wider class of optoelectronic optimization problems.

Condensed Matter & Materials / 21

Finite-temperature criticality through quantum annealing

Authors: Francesco Campaioli¹; Gianluca Teza²; Marco Avesani³; Oren Raz⁴

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Critical phenomena at finite temperature underpin a broad range of physical systems, yet their study remains challenging due to computational bottlenecks near phase transitions. Quantum annealers have attracted significant interest as a potential tool for accessing finite temperature criticality beyond classical reach, but their utility in precisely resolving criticality has remained limited by noise, hardware constraints, and thermal fluctuations. Here we overcome these challenges, showing that careful calibration and embedding allow quantum annealers to capture the full finite-temperature critical behavior of the paradigmatic two-dimensional Ising ferromagnet. By tuning the energy scale of the system and mitigating device asymmetries, we sample effective Boltzmann distributions and extract both the critical temperature and the associated critical exponents. Our approach opens the study of equilibrium and non-equilibrium critical phenomena in a broad class of systems at finite temperature.

Focus Session: Emerging Materials and Physics for Energy Conversion / 22

Trends and opportunities in composite thermoelectrics

Author: Meng Li¹

Co-authors: Xiao-Lei Shi¹; Zhi-Gang Chen¹

¹ *QUT*

Traditional thermoelectric research faces persistent challenges arising from inherent trade-offs among the Seebeck coefficient, electrical conductivity, and thermal conductivity. Despite extensive efforts through doping, alloying, and microstructural modifications, the figure-of-merit (ZT) of modified single-phase thermoelectric materials remains well below the theoretical Mahan–Sofo limit of 3.0, restricting device performance. This Report is to demonstrate how recent progress in composite thermoelectrics is reshaping the research landscape. I will first outline the mechanisms of composite effects that influence thermoelectric properties, which establish the foundation for diverse strategies to enhance ZT and facilitate materials design. Then, the feasibility and effectiveness of these strategies are examined, with particular emphasis on interfacial engineering and the transitions in minority phase. The growing roles of artificial intelligence and additive manufacturing in materials processing are also discussed. It is evident that except for the higher achievable ZT compared to single-phase materials, composite can offer superior mechanical robustness and properties favored by different applicational scenarios. Moreover, composite thermoelectric devices with desirable conversion efficiency can be applied in broadened fields. Given these advances, it is reasonable to anticipate that the development of composite thermoelectrics will remain strong and may lead to a paradigm shift in future.

Poster Session / 23

Nb Doping Strategy for Active Site Modification in Co₃O₄ to Enable Concurrent Hydrogen Production and Glycerol Valorization for Efficient Formate Production

Author: Sanni Kapatel¹

¹ *P D Patel Institute of Applied Sciences*

Electrocatalytic glycerol oxidation reaction (GOR) has emerged as a sustainable and energy-efficient alternative to the oxygen evolution reaction (OER), offering the dual benefit of hydrogen (H₂) generation and selective upgrading of biomass-derived glycerol into value-added chemicals like formate. However, the development of cost-effective, active, and stable electrocatalysts for GOR at low overpotentials remains a significant challenge. Herein, we report a niobium-doped cobalt oxide (Nb–Co₃O₄, designated as 3NCO) heterostructure directly grown on nickel foam (NF) via a hydrothermal strategy, serving as a high-performance, bifunctional electrocatalyst for HER, OER, and GOR. Nb incorporation introduces electronic modulation and lattice distortion within the Co₃O₄ framework, which enhances the density of active sites and optimizes charge transfer kinetics under alkaline conditions. As a result, the 3NCO/NF electrode exhibits excellent activity, requiring only 196 mV overpotential to achieve 10 mA cm⁻² for HER, and 1.50 V vs. RHE for OER. Notably, in 0.1 M glycerol + 1 M KOH, GOR proceeds at just 1.19 V vs. RHE, achieving a remarkable potential drop of 330 mV compared to OER, and enabling overall electrolysis at 1.46 V in a two-electrode system. This work highlights the role of lattice Nb doping in boosting active site availability and electron transfer, positioning 3NCO/NF as a robust platform for energy-saving H₂ production and electrochemical glycerol valorization.

Condensed Matter & Materials / 24

Revealing the Antiferromagnetic-to-Ferromagnetic Interlayer Exchange Coupling Transition in Magnetic Insulator–Topological Insulator–Magnetic Insulator Heterostructures

Author: Enayet Hossain¹

Co-authors: Grace L. Causer¹; Qile Li¹; Kaijian Xing²; James Blyth¹; Mohammad T. H. Bhuiyan²; Michael S. Fuhrer¹; Mark T. Edmonds¹

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Topological insulators (TIs) are a class of materials that hosts insulating bulk states and topologically protected metallic surface states, arising from strong spin-orbit coupling and time-reversal symmetry^{1,2}. When time-reversal symmetry is broken—such as by introducing magnetism—these surface states can become gapped, giving rise to novel quantum phases like quantum anomalous Hall effect (QAHE)³. While early approaches relied on magnetic doping to induce such phases, they often suffered from disorder—such as dopant inhomogeneity and magnetic fluctuations—that ultimately reduced the quantization temperature of the QAHE¹.

To overcome these challenges, inducing magnetism in a topological insulator via magnetic proximity coupling is a compelling alternative². A single septuple layer (SL) of MnBi₂Te₄ is a promising two-dimensional ferromagnetic insulator that enables such proximity coupling with TIs like nearly lattice matched Bi₂Te₃ with quintuple layer (QL) unit. Here, we conducted electrical transport on 1 SL MnBi₂Te₄/n QL Bi₂Te₃/1 SL MnBi₂Te₄ sandwich heterostructures (n = 0 to 4) to investigate the role of Bi₂Te₃ spacer thickness in tuning interlayer magnetic interactions. Magnetotransport reveals that even a single QL of Bi₂Te₃ is sufficient to switch the intrinsic interlayer antiferromagnetic coupling in two septuple layer (2 SL) MnBi₂Te₄ to ferromagnetic interlayer order, evidenced by Hall hysteresis and the absence of spin-flop transitions. Increasing n leads to a monotonic decrease in coercivity and Curie temperature, reflecting progressively weaker interlayer coupling, with a simultaneous enhancement in anomalous Hall response at n = 4. These findings reveal magnetic-field-driven spin reconfiguration governed by exchange interactions, highlighting this atomic-scale spacer engineered heterostructure as a compelling platform for spintronic applications and tunable symmetry-broken topological quantum phases.

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Poster Session / 25

Rietveld-refined structural and optical properties of Dy³⁺ doped Li₂NaPO₄ nanophosphors as an efficient photoluminescent material

Author: Neha Lalotra¹

Co-author: Kamni Pathania²

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² Central University of Jammu

Rare-earth (RE) doped materials have emerged as promising candidates for photonic and optoelectronic applications due to their outstanding luminescent properties. Among these, lanthanide-activated phosphate-based phosphors stand out for their unique combination of mechanical, optical, electrical, magnetic and chemical characteristics, alongside their eco-friendliness, cost-effectiveness and chemical stability. In the present study, Dy³⁺ doped nalipoite –Li₂NaPO₄ nanophosphors were successfully synthesized using a low-cost combustion technique at 650 °C, with dopant concentrations ranging from 0 to 5 mol.%. X-ray diffraction (XRD) confirmed the formation of a pure orthorhombic phase with P m n b space group, and the crystallite size was estimated using the Debye Scherrer equation. Surface morphology and elemental composition were analyzed via scanning electron microscopy (SEM) and energy-dispersive X-ray spectroscopy (EDAX), while the oxidation states of the elements were investigated using X-ray photoelectron spectroscopy (XPS). The nanophosphors exhibited a wide band gap ranging from 3.64 to 3.84 eV, making them suitable for optoelectronic applications such as LEDs and laser diodes. Upon 390 nm excitation, Dy³⁺ ions exhibited characteristic emissions at 483 nm (blue), 574 nm (yellow), and 668 nm (red), with the most intense luminescence observed at 2 mol.% Dy³⁺ doping. A concentration quenching effect was noted at higher dopant levels, attributed to quadrupole-quadrupole interactions between Dy³⁺ ions. The chromaticity coordinates, derived from the CIE 1931 diagram, support the applicability of these phosphors in display technologies. Overall, the results highlight the potential of Dy³⁺ doped Li₂NaPO₄ nanophosphors for future advancements in solid-state lighting and display systems.

Focus Session: Combining astronomy and particle physics in the hunt for dark matter / 26**Blazar-boosted dark matter: a cosmic accelerator for terrestrial dark matter detection****Author:** Laura Manenti^{None}

After decades of not finding dark matter, we've gotten creative.

While liquid xenon detectors lead the direct search for 10-1000 GeV dark matter, sub-GeV dark matter particles from the local halo cannot transfer enough energy through nuclear scattering to be detected.

Blazars offer a solution. These supermassive black holes emit powerful particle jets directly toward Earth, and when dark matter from the blazar's host galaxy interacts with material in these relativistic jets, it gains sufficient kinetic energy to produce detectable recoils in xenon nuclei.

I will present the theoretical framework for blazar-boosted dark matter (BBDM) and report the first experimental constraints using XENONnT and LZ data.

We join the long tradition of not finding dark matter, but show that existing detectors can probe this new channel and constrain previously unexplored parameter space.

Poster Session / 27**Symmetry-Checking in Band Structure Calculations on a Noisy Quantum Computer****Author:** Shaobo Zhang¹**Co-authors:** Akib Karim²; Harry Quiney¹; Muhammad Usman³¹ *The University of Melbourne*² *CSIRO*³ *CRISO/The University of Melbourne*

Band crossings in electronic band structures play an important role in determining the electronic, topological, and transport properties in solid-state systems, making them central to both condensed matter physics and materials science. The emergence of noisy intermediate-scale quantum (NISQ) processors has sparked great interest in developing quantum algorithms to compute band structure properties of materials. While significant research has been reported on computing ground state and excited state energy bands in the presence of noise that breaks the degeneracy, identifying the symmetry at crossing points using quantum computers is still an open question. In this work, we propose a method for identifying the symmetry of bands around crossings and anti-crossings in the band structure of bilayer graphene with two distinct configurations on a NISQ device. The method utilizes eigenstates at neighbouring $\mathbf{k}$ points on either side of the touching point to recover the local symmetry by implementing a character-checking quantum circuit that uses ancilla qubit measurements for a probabilistic test. We then evaluate the performance of our method under a depolarizing noise model, using four distinct matrix representations of symmetry operations to assess its robustness. Finally, we demonstrate the reliability of our method by correctly identifying the correct band crossings of AA-stacked bilayer graphene around K point, using the character-checking circuit implemented on a noisy IBM quantum processor *ibm_marrakesh*.

Bragg medal session / 28**A New Sensing Dimension or Carbon Copy? Widefield Defect Microscopy Beyond Diamond**

Author: Sam Scholten¹

¹ *School of Mathematics and Physics, The University of Queensland*

Widefield defect microscopy is an emerging technology that provides spatially resolved quantitative maps of useful quantities, foremost of magnetic fields. These microscopes use color center spins in a crystalline host, which are controlled and measured optically to detect perturbations caused by fields in a proximal sample. Initial excitement around the nitrogen-vacancy (NV) defect in diamond led to a range of proof-of-concept demonstrations across diverse applications—from condensed matter to biology—using a rudimentary yet versatile setup. More recently, the field has shifted toward advanced, application-specific configurations, alongside emerging commercial solutions.

In this talk, I will briefly review the state of the art in the established widefield NV microscopy platform and broadly address its challenges and opportunities. I will then discuss results highlighting inaccuracies caused by optical aberrations and demonstrate magnetic current imaging of photovoltaic devices as examples of these two categories.

Researchers are now investigating alternative defects and material hosts to overcome some of NV-diamond's limitations. Of foremost interest are novel defects in two-dimensional materials, where the ability to exfoliate a sensor down to an atomically thin sheet allows for simple control over sample-sensor standoffs. The final portion of this talk discusses two such defects in hexagonal boron nitride: the boron vacancy centre and an unidentified visible emitter. The first widefield imaging demonstrations using these systems, as well as their comparative advantages and disadvantages relative to NV-diamond, are presented. We then analyze results identifying the spin multiplicity of the visible defect and tentatively classify it as a weakly coupled pair of carbon substitutions.

Plenary / 29

2D Quantum Materials for Next-generation Quantum Photonic Devices

Author: Yuerui (Larry) Lu^{None}

Two-dimensional (2D) van der Waals quantum materials have become important building blocks for future electronic, photonic, phononic and quantum devices. The highly enhanced Coulomb interactions in the atomically thin quantum 2D materials, arising from the reduced dimensionality and weak dielectric screening, allows the formation of tightly bound excitons, biexcitons and interlayer biexcitons. These tightly bound quasi-particles have been of keen interest for both fundamental studies and novel device applications, such as entangled photon sources, quantum logic gates, etc. The recently discovered single photon emitters at room temperature from the defects in 2D hexagonal boron nitride could find promising applications for quantum sensing and quantum communications. Because of their ultra-light weight, defect-less surface and low intrinsic losses, atomically thin 2D materials are also perfect candidate materials for ultra-sensitive transducers for sensing and communication applications. In this talk, I would like to talk about how to tailor the van der Waals interactions and engineer the light-matter interactions in ultrathin quantum materials, for next-generation nano-photonic and quantum devices. I will highlight our recent work on the discovery of new quantum phases from freestanding hetero bilayers, as well as the generation of entangled quantum light sources using ultra-thin nonlinear quantum materials. Finally, I will talk about my vision and discuss some possible future directions regarding the photonic and quantum applications of novel 2D materials and their heterostructures.

Nuclear and Particle Physics / 30

The SABRE South Experiment at the Stawell Underground Physics Laboratory

Authors: Antoine Cools¹; Irene Bolognino²

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SABRE is an international collaboration that will operate similar particle detectors in the Northern (SABRE North) and Southern Hemispheres (SABRE South). This innovative approach aims to distinguish potential dark matter signals from seasonal backgrounds: a pioneering strategy only feasible with a Southern Hemisphere experiment. SABRE South is located at the Stawell Underground Physics Laboratory (SUPL), in regional Victoria, Australia.

SUPL is a newly constructed facility situated 1024 metres underground (~2900 metres water equivalent) within the Stawell Gold Mine. Its construction was completed in 2023.

SABRE South employs ultra-high purity NaI(Tl) crystals immersed in a linear alkyl benzene (LAB)-based liquid scintillator veto, surrounded by passive steel and polyethylene shielding, and topped with a plastic scintillator muon veto.

Significant progress has been made in the procurement, testing, and preparation of equipment for the installation of SABRE South. The assembly of the experiment at SUPL will take place throughout 2025. The SABRE South muon detector and data acquisition systems are already operational and actively collecting data at SUPL, and full commissioning of SABRE South is planned for the first quarter of 2026.

This presentation will provide an update on the overall progress of the SABRE South construction, its anticipated performance, and its potential physics reach.

Poster Session / 31

Assessing Quantum and Classical Approaches to Combinatorial Optimization: Testing Quadratic Speed-ups for Heuristic Algorithms

Authors: Dong An¹; Mauro E.S. Morales²; Pedro Contino da Silva Costa³; Yuval R. Sanders^{None}

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Many recent investigations conclude, based on asymptotic complexity analyses, that quantum computers could accelerate combinatorial optimization (CO) tasks relative to a purely classical computer. However, asymptotic analysis alone cannot support a credible claim of quantum advantage. Here, we highlight the challenges involved in benchmarking quantum and classical heuristics for

combinatorial optimization (CO), with a focus on the Sherrington-Kirkpatrick problem. Whereas hope remains that a quadratic quantum advantage is possible, our numerical analysis casts doubt on the idea that current methods exhibit any quantum advantage at all. This doubt arises because even a simple classical approach can match with quantum methods we investigated. We conclude that more careful numerical investigations are needed to evaluate the potential for quantum advantage in CO, and we give some possible future directions for such investigations.

Industrial Applied Physics / 32

Compact and Scalable Electronics for Sub-10 ps Timing in Particle Physics and Medical Imaging

Authors: Andrea Abba¹; Andrea Picchi²; Annalisa Mati²; Camilla Maggio²; Carlo Tintori³; Daniele Ninci²; Vincenzo Bottiglieri²; Yuri Venturini²

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High-precision time measurements are crucial for both high-energy physics experiments and advanced medical imaging applications, such as Positron Emission Tomography (PET). Future detector systems require readout electronics that combine sub-10 ps timing resolution with scalability, compactness, and efficient multi-channel integration.

The CAEN A5203 module, part of the FERS 5200 system, integrates the high-performance picoTDC ASIC from CERN, enabling precise Time of Arrival (ToA) and Time over Threshold (ToT) measurements. The unit features 3.125 ps LSB precision over 64 channels and can be coupled with a leading-edge discriminator stage. In this configuration, it achieves ~7 ps RMS timing resolution for constant-amplitude signals and ~20 ps RMS for variable-amplitude signals. The walk effect is corrected via ToT, which also enables signal amplitude reconstruction and background noise suppression.

Successfully deployed in a high-resolution PET imaging system, the A5203 has demonstrated its capability for large-scale applications, supporting continuous, dead-time-free acquisition from thousands of channels. In high-energy physics, the FERS architecture, combined with the picoTDC's performance, is well-suited for integration with advanced front-end electronics, such as Weeroc's Radioroc and Psiroc ASICs, enabling precise energy and time measurements with Silicon-based detectors. These features make the FERS system a powerful and flexible solution for next-generation applications in both fundamental research and applied physics.

Condensed Matter & Materials / 33

Experimental realization of qubit-state-controlled directional edge-states in waveguide QED

Author: Prasanna Pakkiam¹

Co-authors: N. Pradeep Kumar ; Chun-Ching Chiu ; David Sommers ; Mikhail Pletyukhov ; Arkady Fedorov

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We experimentally realise the theoretical proposal for in-situ tunable photonic edge states emerging from qubits coupled to a waveguide with a photonic bandgap. These edge-states are directional, exhibiting theoretically zero population in the opposite direction. Our experiment implements a tunable Rice-Mele waveguide configuration, where the directionality of edge states is controlled in-situ by varying the qubit energy. The Rice-Mele waveguide is constructed using lumped resonators coupled to an Xmon qubit. We demonstrate the existence of these edge states both actively, via waveguide transmission, and passively, through qubit emission via an edge state. We estimate a 99.4% directional fidelity, constrained by our measurement noise floor. These results hold significant promise for the development of long-range qubit couplers with effectively zero crosstalk.

Poster Session / 34

Quantum Cellular Automata for the Density Classification Problem via Evolutionary Search

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We investigate the density classification task DCT—determining the majority bit in a one-dimensional binary lattice—within the quantum cellular automata framework. While classical cellular automata constrained by locality, homogeneity, and irreversible rules, cannot solve the DCT perfectly, we explore whether a unitary quantum model can succeed. Specifically, we employ the Partitioned Unitary Quantum Cellular Automaton (PUQCA), a number-conserving QCA framework, and reformulate the consensus condition regarding measurement probabilities rather than convergence to fixed-point configurations. Additionally, we identify a classically simulable regime for PUQCA, where rules that solve the DCT for fixed sizes can still be found.

Quantum Science and Technology / 35

Collectively-pumped superradiant laser with coherence scaling beyond the standard quantum limit

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For more than half a century, the standard quantum limit (SQL) was thought to limit the laser coherence $\mathcal{C}$ —the number of photons emitted from the laser into the beam in one coherence time—to a scaling $\Theta(\mu^2)$, where μ is the mean number of optical-frequency excitations stored inside the laser. However, recently it has been shown [Baker et al., Nat. Phys. 17, 179 (2021)] that the Heisenberg limit—an achievable ultimate limit set by quantum mechanics for the task of producing a beam with the standard properties of a laser beam—is $\mathcal{C} = \Theta(\mu^4)$, a quadratic enhancement. So far, proposals to demonstrate beyond-SQL scaling of $\mathcal{C}$ have been limited to circuit QED, at microwave frequencies (i.e., a maser). Here, we propose an optical-frequency laser platform that can surpass the SQL scaling: a superradiant laser in the bad-cavity limit with feedback-controlled collective pumping. We show that the coherence can exhibit a scaling as large as $\mathcal{C} = \Theta(\mu^{8/3})$. Here, in the bad-cavity limit, $\mu \approx N/2$, where N is the number of superradiant atoms.

Quantum Science and Technology / 36

Tunable Λ -system to detect timelike Unruh effect

Author: Pravin Kumar Dahal¹

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The Unruh effect, resulting from the entanglement of modes across the right and left wedges of Rindler spacetime, predicts that a uniformly accelerating observer perceives the Minkowski vacuum as a thermal bath. Despite its theoretical significance, this effect remains undetected. The Unruh effect has a timelike counterpart due to the entanglement between past and future Rindler light cones. Similar to the conventional Unruh effect, the timelike Unruh effect also imparts an additional geometric phase to a detector confined to a spacetime trajectory within one of the future or past light cones. We employ quantum circuits—specifically flux qubits—to design a Λ -detector with two degenerate ground states and an excited state whose energy levels can be tuned to measure the geometric phase change induced by this effect. This detector, with a transition frequency scaled inversely with time in Minkowski coordinates, corresponds to a detector with a constant transition frequency in future/past Rindler coordinates. Simulations show that this system can effectively measure the geometric phase associated with the timelike Unruh effect, providing a feasible experimental

setup for its detection. This demonstrates an application of quantum computing to test the nature of spacetime.

Condensed Matter & Materials / 37

Super-Resolved Label-Free Plasmon-Enhanced Array Tomography

Author: Kristian Caracciolo¹

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Biological function is closely linked to cell morphology and subcellular structure, making 3D imaging techniques an essential tool for understanding complex biological processes. Typically, 3D imaging involves staining and labelling, which can be time-consuming, error-prone, and reliant on toxic reagents. Imaging based on the intrinsic biophysical properties of cells and tissues, such as refractive index (RI), offers a promising alternative. This approach avoids these challenges, offering the potential to complement or even surpass chemical sensitivity, acting as a non-invasive marker for disease (Wang et al., *J. Biomed. Opt.*, 16(11), p. 116017, 2011). Recently, plasmonic metamaterials, designed to the same dimensions and specifications as traditional microscope slides, have emerged as a means to visualise RI by converting variations in this property into striking colour contrast, offering sensitive, label-free biological imaging (Balaur et al., *Nature*, 598(7879), pp. 65–71, 2021). These metamaterials exploit the sensitivity of surface plasmon resonance (SPR) at metal-dielectric interfaces, allowing detection of refractive index changes in the near-surface region through a colorimetric response (Balaur et al., *Sci. Rep.*, 6(1), p. 28062, 2016).

In this study, we demonstrate the integration of plasmonic metamaterials with array tomography imaging protocols to reconstruct 3D volumes from resin-embedded tissue sections, each 70–100 nm thick. We present high-resolution reconstructions of malaria-infected red blood cells and optic nerve tissue exhibiting multiple sclerosis-like disease features. In the malaria samples, by-products of cell parasitisation are clearly visible, while the optic nerve sections reveal various inflammatory cell types associated with disease. The tomograms generated through brightfield optical imaging achieve an experimentally determined resolution of 100 nm in the sectioning axis direction, demonstrating super-resolution capabilities. This approach holds significant potential for 3D histology at the sub-cellular level, paving the way for improved biological imaging and disease monitoring (Caracciolo et al., arXiv:2507.12786).

Condensed Matter & Materials / 38

Using applied magnetic fields to induce unconventional magnetic order in the frustrated quantum magnet, clinoatacamite, Cu₂Cl(OH)₃.

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The natural mineral clinoatacamite, $[\text{Cu}_2\text{Cl}(\text{OH})_3]$, exhibits low-temperature, frustrated magnetic behaviour where competing interactions are responsible for novel magnetic properties. Attempts to establish the magnetic phases in this material have been undertaken and an unconventional applied field ($H\parallel b$) phase diagram has been revealed [1]. Two critical transition temperatures at zero field have been identified with long range antiferromagnetic (AFM) order for $T_1 < 6\text{K}$, and paramagnetic behaviour for $T_2 > 18\text{K}$. In-field magnetisation data collected between 6-18K reveal three distinct phases for $H\parallel b$ which are not completely understood. Until now, the phase diagram of clinoatacamite has not been probed for $H\parallel a$ or $H\parallel c$. We will present neutron scattering measurements of single crystal clinoatacamite in applied fields up to 10T. With these measurements we have mapped out the phase diagram of the antiferromagnetic structure for $H\parallel a^*$.

Poster Session / 39

Floquet Control of Coulomb Drag and Dispersion Forces in Nonequilibrium Quantum Systems

Authors: Christine Little¹; Daniel Kosov¹

¹ *James Cook University*

Understanding interaction-driven phenomena in nanoscale quantum systems far from equilibrium is essential for describing how spatially separated quantum systems entangle and exchange energy, momentum, and information. In this work, we investigate Coulomb drag and nonequilibrium dispersion forces between two interacting quantum dots, each connected in parallel to its own macroscopic leads. Coulomb drag occurs when carrier flow in one subsystem induces a current in the other purely through long-range Coulomb interactions, while nonequilibrium dispersion forces originate from correlated quantum fluctuations under bias.

We develop a theoretical framework based on the nonequilibrium Green's function (NEGF) formalism, treating electron-electron correlations within the self-consistent second-order Born approximation. The resulting correlation self-energy contains both Hartree and exchange-correlation contributions, enabling us to capture static mean-field effects alongside dynamic nonequilibrium many-body processes.

Our study begins in the static regime, where we compute drag currents and interaction energies as functions of bias, temperature, and intersystem coupling strength. We then introduce periodic driving via an external time-dependent field and employ the Floquet-NEGF theory developed by our group to handle the explicit time dependence. This Floquet representation maps the continuous time domain into a discrete harmonic index, transforming the Keldysh-Kadanoff-Baym equations into a coupled algebraic form in Floquet space.

The resulting Floquet-NEGF method allows us to explore how coherent periodic driving modifies Coulomb drag and reshapes nonequilibrium dispersion interactions. We find that the driving field provides tuneable enhancement or suppression of drag currents and alters the effective interaction profile between the quantum subsystems. Our results demonstrate that Floquet control offers a powerful route for engineering long-range interaction effects in nonequilibrium quantum systems, opening possibilities for dynamically controlled quantum transport, long-range entanglement, and force manipulation at the nanoscale.

Focus Session: Frontiers of Medical Physics / 40

Non-Ionising Optical Tomography and Inverse Radon Reconstruction for Imaging Diffuse Environments

Author: Renee Goreham¹

Co-authors: Catherine Merx¹; Galiya Sharafutdinova¹; John Holdsworth¹

¹ *The University of Newcastle*

This study presents a novel approach to imaging diffuse environments using non-ionising optical tomography combined with inverse Radon reconstruction techniques. We developed and characterised gelatin-based phantom materials with distinct spectral properties, measured using a Cloud-Spec spectrophotometer across the 350–850 nm range. These materials simulate biological tissues and enable precise modelling of light propagation in scattering media. A custom Python-based pipeline was implemented for sinogram preprocessing and image reconstruction via filtered back-projection, facilitating the transformation of raw optical data into high-resolution 2D images. Control and experimental scans, including vials containing full cream milk, demonstrate the system's capability to resolve internal structures in highly scattering samples. This work lays the foundation for safe, cost-effective, and portable imaging systems suitable for biomedical and environmental applications.

Poster Session / 41

Expressive and Scalable Quantum Fusion for Multimodal Learning

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Multimodal learning, which integrates heterogeneous data modalities including text, vision, and sensor signals, has made remarkable progress. Yet, effectively capturing complex relationships across modalities remains a challenge, especially in settings with numerous input streams. Existing methods often restrict these interactions to remain computationally tractable: tensor-based models enforce low-rank constraints, while graph-based models rely on localized information flow, requiring deep networks to model long-range dependencies. In this work, we propose the Quantum Fusion Layer (QFL), a hybrid quantum-classical architecture that efficiently captures arbitrary-degree polynomial interactions across modalities with linear parameter scaling. We provide theoretical guarantees on QFL's expressivity, supported by a case study demonstrating a query complexity separation from classical tensor-based methods. Empirically, we benchmark QFL across a diverse set of multimodal tasks, ranging from low- to high-modality settings. In small-scale simulations, QFL consistently outperforms classical baselines, showing particularly strong improvements in high-modality scenarios. Specifically, in the best case, QFL achieves a 76% increase in ROC AUC while using only 5% of the parameters compared to a tensor-based method. Against graph-based approaches, QFL improves ROC AUC by 12%, while maintaining a comparable number of trainable parameters. These results provide both theoretical insight and empirical validation for the promise of hybrid quantum models as a scalable and expressive solution for complex multimodal learning tasks.

Solar Terrestrial and Space Physics / 42

Physics of impact events across terrestrial and planetary surfaces

Author: Katarina Miljkovic¹

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Impact cratering is a physical process causing geological changes on all planetary surfaces. It is one of common processes responsible for crustal structure and evolution over geological timescales.

High-fidelity shock physics simulations are made to track the fate of a planetary impactor and associated shock changes in the target material during a non-catastrophic impact event. The size of the impactor ranged from 10 to 250 km in diameter, moving at 15 to 60 km/s impact speed across a range of parent-body gravities. Impactors were considered spherical (chondritic-only, iron-only, and differentiated into iron core and rocky mantle). This work investigates delivery of extraterrestrial material to planetary surfaces, including but not limited to magnetic signatures associated with large impact craters that may result from impact-delivered localized iron enrichments. Shock physics calculations were applied to understand what portion of impactors melted and vapourized as well as where the remaining solid and melt inclusions were embedded in the planetary crust. Division of impact energy to kinetic energy of excavation and internal heating was mapped as a function of impactor and crust properties, with emphasis on porosity and composition effects in order to better understand the shock physics process planetary surfaces endure.

Focus Session: Ultra-cold atoms and quantum technology / 43

Quantum Many-Body Correlation from Controlled Dynamics

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I will discuss how to utilize highly controllable quantum dynamics to study correlations in quantum many-body systems, particularly the strong correlations of quantum critical states. I will discuss two theories of non-hermitian linear response and the finite-size scaling theory of the Kibble-Zurek dynamics, and I will talk about their recent experimental realizations in cold atom systems.

Condensed Matter & Materials / 44

High Harmonic Generation of quantum light via topologically nontrivial crystals

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High harmonic generation (HHG) is a physical effect which happens when a strong driving laser acts on atomic, molecular, or solid systems. As a result, a system emits at frequencies of integer multiples of the driving laser frequency [1]. It was also shown that including correlations between atoms can generate entangled and squeezed light or entangled photon pairs [2]. These can be an important resource in quantum technology and quantum metrology. Also, such radiation may have pulse durations about attosecond timescales. In 2023 the achievements in this area were awarded the Nobel in physics [3]. However, there is no particular theory that can describe the generation of quantum light from the topologically nontrivial systems as crystalline. It is important because the nontrivial geometric properties of the system can provide more efficient way of HHG. In this work we develop a formalism that describes the influence of topological properties of systems on HHG taking into account arbitrary crystalline structure as an example. As a result, the 1D and 2D crystals were considered as examples. Moreover, we pay extreme attention to self-correlation effects, namely dipole-dipole correlations that are always presented in solid systems and estimate their effect on outgoing generation. For example, as it can be seen, in the topological phase of the 1D Su-Schrieffer-Heeger model (SSH) these effects are stronger than in the trivial phase resulting in stronger squeezing. The main reason for that is the difference of geometric tensor for trivial and topological phases on winding number.

Nuclear and Particle Physics / 45

Searching for triaxial deformation in highly exotic nuclei towards the neutron dripline

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A leading challenge in nuclear-structure research is to experimentally establish regions of oblate and triaxial deformation. Such a phenomenon is not only interesting from a fundamental structure perspective, but could also provide vital understanding and constraints of the flow of r-process nucleosynthesis in the vicinity of the $N = 82$ shell closure [1]. The very neutron-rich Mo-Ru-Pd nuclides, which exhibit filling of the neutron $\nu h_{11/2}$ and proton $\pi g_{9/2}$ orbitals and an abundance of low-energy 2_2^+ states, are expected to lie in a relatively rare region of triaxial-oblate deformation [2,3]. The opening of the Facility for Rare Isotope Beams (FRIB) enables the study of these highly exotic nuclei along the neutron drip line.

Using the world-class FRIB Decay Station initiator (FDSi), we performed discrete spectroscopy on over 100 nuclei, including the very-exotic ^{114}Mo , $^{116,118}\text{Ru}$, and $^{120,122}\text{Pd}$ isotopes, to probe their shape degrees of freedom. A determination of energies and transition strengths is expected to provide direct evidence of triaxial deformation. The FDSi coming online is an exciting development in the community as it is an assembly of cutting-edge clovers, particle detectors, an ultra fast-timing array and a neutron time-of-flight array. This work presents spectroscopy of several exotic nuclei between Rb ($Z = 37$) and Ag ($Z = 47$), which includes ground and excited-state lifetime measurements and several instances of first spectroscopy. We focus on a preliminary analysis and will discuss the likely direction of future work.

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Nuclear and Particle Physics / 46

Investigating two-phonon γ -vibrational states in ^{162}Dy through Coulomb excitation

Authors: Tom Perissinotto¹; A.J. Mitchell¹; B.J. Coombes¹; J.A. Woodside¹; G.J. Lane¹; A.E. Stuchbery¹

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The existence of two- γ -phonon excited states in rare-earth nuclei remains a contentious issue in nuclear structure. While examples of single-phonon γ -vibrational states are prevalent in even-even deformed nuclei, identifying two-phonon excitations is challenging due to strength fragmentation

and competing non-collective states. Although two-phonon states are predicted by the collective model [1], only six cases have been reported in rare-earth nuclei [2–5]. While these states are largely in agreement with predictions from collective models, their rarity has challenged the validity of a collective model in well-deformed nuclei [6].

Coulomb excitation populates excited states in both beam and target nuclei, while allowing other scattering process to be neglected. The well-established formalism of electromagnetic interactions then allows extraction of reduced matrix elements and branching ratios from experimental γ -ray yields numerically [7].

In this presentation, the results of Coulomb-excitation γ -ray spectroscopy on the rare-earth, even-even nucleus ^{162}Dy with an ^{16}O beam will be presented. Precise measurements of the transition strengths between low-lying (< 2 MeV) excited states of ^{162}Dy were made, building towards a more complete picture of the level scheme and identifying collective features.

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Nuclear and Particle Physics / 47

Searching for new Particles at 95 GeV

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Recent observations by the CMS and ATLAS experiments at the LHC have reported anomalies in the production of tau-lepton and photon pairs over expected background at an invariant mass of ~ 95 GeV. Taken with an older result from LEP data showing a similar anomaly in the production of b-quark pairs, these results raise the possibility of an as-yet unknown resonance at 95 GeV causing each of these anomalies. We investigate the possibility of the 2HDM+a/s - extensions of the SM containing an additional Higgs doublet as well as a singlet scalar (s) or pseudoscalar (a) - as an explanation for these anomalies. These models are well-motivated as minimal extensions of the Standard Model that can potentially resolve longstanding issues such as the baryon asymmetry problem and provide a portal to a hypothetical dark sector. We additionally analyse relevant constraints on these models such as those from collider searches and rare B-meson decays. We find that while both models are able to account for the CMS and ATLAS excesses in the diphoton and ditau channels, neither can explain the LEP anomaly while satisfying all required constraints. It remains to be seen if these anomalies are statistical artefacts, or true hints of physics beyond the Standard Model.

Poster Session / 48

Spin-Active Defects in Layered Hexagonal BeO: A Wide-Bandgap 2D Host for Quantum Technologies

Author: Aiden Thurlloe¹

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Precise control of quantum states is a key requirement for the development of quantum-based technologies. Engineering point defects in low-dimensional materials provides a promising approach to achieving this control, as strong in-plane coupling can accelerate quantum gate operations while mitigating decoherence. Hexagonally layered beryllium oxide (h-BeO) is a recently synthesised two-dimensional material with a wide bandgap, offering the potential to host highly localised defect states suitable for qubit implementation and quantum sensing.

In this study, we employ density functional theory to investigate the structural and electronic properties of ultra-thin and bulk h-BeO and to evaluate the feasibility of defect-based qubits. We identify several point defects exhibiting non-zero ground-state spins and optically addressable transitions. The calculated defect levels and transition energies indicate that h-BeO can provide stable, well-isolated spin states within its bandgap, enabling coherent control and optical readout.

Our results position h-BeO as an interesting platform for defect-based quantum technologies, expanding the range of viable two-dimensional hosts for qubits. This work advances the understanding of native defect physics in wide-bandgap oxide-based layered materials, bridging the gap between theoretical prediction and experimental realisation.

Theoretical Physics / 49

Gravitational waves from phase transitions in the early universe

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Gravitational waves from cosmological phase transitions offer a novel probe of particle physics. As the early universe cooled, it may have undergone a phase transition from a metastable vacuum to the true vacuum. While the Standard Model of particle physics predicts continuous phase transitions during electroweak and QCD symmetry breaking, many extensions of the Standard Model predict first-order (discontinuous) phase transitions. These can provide the conditions necessary for baryogenesis and produce stochastic gravitational waves that encode information about the fields that drive the transition. Furthermore, if such a transition occurs at the electroweak scale, the resulting gravitational waves are expected to be visible to future detectors, motivating accurate calculations of gravitational wave spectra across a range of particle physics models.

Recent calculations often adopt a simplified equation of state describing the relativistic hydrodynamics of the phase transition, which impacts the shape of the gravitational wave spectrum. This relies on the assumption that the universe is radiation dominated during the phase transition, which breaks down in the true vacuum phase. Furthermore, fitting formulas used to determine the gravitational wave spectrum from hydrodynamics are not easily generalised to a generic equation of state. We propose a self-consistent method for evaluating the gravitational wave spectrum from a particle physics model using the exact equation of state and without fitting formulas. We perform these calculations across select regions of parameter space for simple extensions of the Standard Model to demonstrate the difference in the shape of the resulting gravitational wave spectra.

Quantum Science and Technology / 50

Exact Spectral Properties of Fermi Polarons in One-Dimensional Lattices: Anomalous Fermi Singularities and Polaron Quasiparticles

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We calculate the exact spectral function of a single impurity repulsively interacting with a bath of fermions in one-dimensional lattices, by deriving the explicit expression of the form factor for both regular Bethe states and the irregular spin-flip state and η -pairing state, based on the exactly solvable one dimensional Hubbard model. While at low impurity momentum $Q \sim 0$ the spectral function is dominated by two power-law Fermi singularities, at large momentum we observe that the two singularities develop into two-sided distributions and eventually become anomalous Fermi singularities at the boundary of the Brillouin zone, with the power-law tails extending toward low energy. Near the quarter filling of the Fermi bath, we also find two broad polaron peaks at large impurity momentum, collectively contributed by many excited many-body states with non-negligible form factors. Our exact results of those distinct features in one-dimensional Fermi polarons, which have no correspondences in two and three dimensions, could be readily probed in cold-atom laboratories by trapping highly imbalanced twocomponent fermionic atoms into one-dimensional optical lattices.

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Nuclear and Particle Physics / 51

Impact of shell model interactions on nuclear responses to WIMP elastic scattering

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Experimentalists strive to better analyse signals of dark matter direct detection at detectors. Thus, improved theoretical models are being developed to describe WIMP-nucleus elastic scattering, with one particular interest area focusing on enhanced study of the nuclear response functions associated with various target detector isotopes. We build on this by investigating the sensitivity of said nuclear responses to nuclear structure, considering a complete list of non-relativistic effective field theory (EFT) nuclear operators. We employ nuclear shell model interactions which differ from those used in previous literature, to facilitate comparison between different nuclear structure results.

We perform state-of-the-art nuclear shell model calculations for isotopes relevant to direct detection experiments: ^{19}F , ^{23}Na , $^{28-30}\text{Si}$, ^{40}Ar , ^{127}I , $^{70,72-74,76}\text{Ge}$ and $^{128-132,134,136}\text{Xe}$. Our integrated nuclear response values sometimes exhibit large (up to orders-of-magnitude) factor differences compared to those in previous works for certain WIMP-nucleus interaction channels and their associated isotopes. We highlight the potential uncertainties that may arise from the nuclear components of WIMP-nucleus scattering amplitudes due to nuclear structure theory and modeling. This enables us to deduce the effect of these uncertainties on the scattering cross-section. In particular, we investigate the effect of nuclear structure on the scattering cross-sections associated with several dark matter direct detection experiments.

Poster Session / 52

Rethinking Dose Point Kernels for Radionuclides in Cancer Treatment

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The advent of Radio-Pharmaceutical Therapy (RPT) marks an impactful advancement in radiation oncology, offering the potential to treat tumours with cellular precision while minimising adverse effects. Evaluating the efficacy of this treatment relies on accurate dosimetry, which is traditionally informed by absorbed dose, but absorbed dose alone overlooks the spatial complexity of radiation-induced damage and is likely an incomplete predictor of cell damage. Linear Energy Transfer (LET), which quantifies microscopic particle track structure, has been correlated with higher rates of complex and lethal DNA damage [1,2]. Therefore, this work moved to improve RPT treatment planning by generating a library of LET point kernels alongside standard dose point kernels.

A custom application was developed using the Geant4 particle simulation toolkit [3,4] to model monoenergetic alpha particles and electrons in a water phantom. Dose and LET point kernels were generated for energies from 2.5 keV to 10 MeV. The dose point kernels demonstrate that absorbed dose is deposited locally, within 0.02 times the particle's CSDA range. The corresponding LET point kernels show highest LET regions located significantly further, with LET peaking at 0.4-1.2 times each particle's CSDA range. For alpha particles, this is expressed as a characteristic high-LET Bragg peak at the end of the particle's track, illustrating a high incidence of DNA damage far from the maximum dose region.

These findings highlight that conventional dose-based planning may largely underestimate biologically significant cell damage. Instead, LET point kernels could be used generate 3D LET distributions alongside clinical dose maps, paving the way for more and biologically driven RPT treatment planning.

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Condensed Matter & Materials / 53

Subtraction of orbital self-interaction from the Kohn-Sham equations

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The effective design of new materials for sustainable energy conversion can be facilitated by the accurate prediction of electronic properties with moderate computational complexity and cost. The self-interaction error (SIE) of Kohn-Sham density functional theory (KS-DFT) is a non-physical, non-linear dependence of an orbital's energy on its own fractional occupation [Dabo et al., *Phys. Rev. B*, 82:115121, 2010]. The generalized Koopmans condition (GKC) ensures an atomic orbital's eigenenergy is invariant with its own fractional occupation, and is free of self-interaction. The constrained search of the Levy spin-density-functional theory yields orbital densities and delivers the ground-state energy in accordance with the Hohenberg-Kohn theorems. In this work, the electron density of the Kohn-Sham equations is thereby constrained to be orbital-density dependent, with a total energy functional linear with respect to variation of its orbital densities. That is, the KS multiplicative effective potential $v_s[n]$ for an orbital $\varphi_i[n]$ is constrained to a functional $v_{\text{eff}}[n - n_i]$. The result complies with the generalized Koopmans condition (GKC). Preliminary calculations show fundamental band gaps with an accuracy comparable to the G_0W_0 approximation of many-body perturbation theory (MBPT), with a level of complexity comparable to KS-DFT. In practice, software codes can be

combined to remove SIE and to model composite material properties. With the subtraction of non-physical electron self-interaction from the Kohn-Sham equations, GKC-DFT can possibly improve computational efficiency, reduce the complexity of highly accurate DFT simulations, and facilitate the development of new applications.

Poster Session / 54

Quantum Computing for Corrosion Simulation: Workflow and Resource Analysis

Author: Samuel Elman¹

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Corrosion is a pervasive issue that impacts the structural integrity and performance of materials across various industries, imposing a significant economic impact globally. In fields like aerospace and defense, developing corrosion-resistant materials is critical, but progress is often hindered by the complexities of material-environment interactions. While computational methods have advanced in designing corrosion inhibitors and corrosion-resistant materials, they fall short in understanding the fundamental corrosion mechanisms due to the highly correlated nature of the systems involved. This paper explores the potential of leveraging quantum computing to accelerate the design of corrosion inhibitors and corrosion-resistant materials, with a particular focus on magnesium and niobium alloys. We investigate the quantum computing resources required for high-fidelity electronic ground-state energy estimation (GSEE), which will be used in our hybrid classical-quantum workflow. Representative computational models for magnesium and niobium alloys show that 2292 to 38598 logical qubits and $(1.04 \text{ to } 1962) \times 10^{13}$ T-gates are required for simulating the ground-state energy of these systems under the first quantization encoding using plane waves basis.

Focus Session: Emerging Materials and Physics for Energy Conversion / 55

Organic ionic plastic crystals with colossal barocaloric effects for sustainable refrigeration

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Cooling technologies are essential for health and comfort worldwide, yet conventional vapour-compression systems are a major contributor to greenhouse gas emissions. These emissions arise from both the low energy efficiency of the cycle and the leakage of hydrofluorocarbon (HFC) refrigerants, which have very high global warming potentials. As demand for air-conditioning accelerates in a warming climate, emissions from both sources are set to rise sharply.

Solid-state refrigerants offer a promising route to eliminate the use of volatile greenhouse gases in cooling. In barocaloric materials, an order-disorder phase transition—and the associated thermal response—is driven by hydrostatic pressure, providing a solid-state alternative to liquid-vapour refrigerants.

Organic ionic plastic crystals (OIPCs) are a large but relatively underexplored class of organic salts that undergo one or more solid-solid phase transitions, producing a soft, dynamically disordered “plastic” phase before melting. Importantly for cooling applications, these thermal transitions often occur below room temperature.

Here we will report the barocaloric properties of four prototype BC-OIPCs using high-pressure differential thermal analysis, and the first measurement of the volume change across the phase transition using pycnometry. We will discuss our approach to decreasing the supercooling of the solid-solid

phase transition, leading to a substantial enhancement in predicted barocaloric performance. These findings position OIPCs as a promising new class of material for next-generation, environmentally sustainable cooling technologies.

Condensed Matter & Materials / 56

Fano-Like Resonances in Self-Coupled Waveguide Sagnac Interferometers

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We present Fano-like resonances in silicon-on-insulator (SOI) nanowire resonators composed of coupled Sagnac interferometers (SIs). By tuning the reflectivity of each SI and the inter-coupling strength, we precisely control coherent mode interference to realize high-performance optical analogues of Fano resonances. The device, designed and fabricated on an SOI platform, is analyzed theoretically and validated experimentally. Simulations predict periodic resonances with high extinction ratios and steep slopes, arising from strong coherent mode interference in a compact configuration. Experimental results closely match theoretical predictions, confirming the design's effectiveness and underscoring the potential of coupled SIs for compact, high-performance Fano-like resonance generation in integrated photonics.

Poster Session / 57

Quantum–classical reciprocity for photon-triplet modelling

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Non-Gaussian optical resources are central to scalable quantum networks, precision sensing and photonic computing. A direct route is generating correlated photon triplets, yet optical third-order spontaneous parametric down-conversion (TOSPD) is difficult because $\chi(3)$ nonlinearities are weak and dispersion and phase-matching are complex. We introduce a general modelling framework that predicts TOSPD emission by exploiting a quantum–classical reciprocity: we reconstruct the photon-triplet amplitude and rate from the classically accessible three-wave sum-frequency generation (TSFG) field.

Using Lorentz reciprocity and Green-function formalism, we derive a closed relation linking the triplet wavefunction to TSFG. This enables rapid evaluation of spectra, angular correlations and collection efficiencies with standard electromagnetic solvers, avoiding full quantum simulations. The approach is geometry- and material-agnostic and applies across bulk media, waveguides and resonant photonic structures. It yields clear design rules that connect pump configuration, modal overlaps and resonance linewidths to brightness and directionality.

As an example, we apply the method to resonant $\chi(3)$ metasurfaces supporting quasi-bound-state resonances. Reciprocity-based reconstruction maps tunable collinear and non-collinear triplet emission and identifies collection-friendly, low-NA configurations. The same workflow supports k-space

scanning, uncertainty analysis and inverse design, and can incorporate non-degenerate pumping and narrowband detection.

By reframing photon-triplet generation as a classical forward problem followed by reciprocity-based reconstruction, this work provides a broadly applicable, experimentally aligned toolkit to screen candidate platforms and interpret measurements, advancing prospects for optical triplet sources in both integrated and free-space systems.

Quantum Science and Technology / 58

Logical channel for heralded and pure loss with the Gottesman-Kitaev-Preskill code

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Photon loss is the dominant source of noise in optical quantum systems. The Gottesman-Kitaev-Preskill (GKP) bosonic code provides significant protection; however, even low levels of loss can generate uncorrectable errors that another concatenated code must handle. In this work, we characterize these errors by deriving analytic expressions for the logical channel that arises from pure loss acting on approximate GKP qubits. Unlike random displacement noise, we find that the loss-induced logical channel is not a stochastic Pauli channel. We also provide analytic expressions for the logical channel for “heralded loss,” when the light scattered out of the signal mode is measured either by photon number counting—i.e. photon subtraction—or heterodyne detection. These offer a pathway to intentionally inducing non-Pauli channels for, e.g., magic-state production.

Physics Education / 59

Competencies in first-year physics labs and tutorials

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Teaching physics is rapidly shifting from rote memorization to emphasizing conceptual understanding, constructing knowledge through lecture demonstrations and experiments, and applying that knowledge in hands-on situations. The desire for such change has been long expressed by major physics organizations, including the American Institute of Physics, the Australian Institute of Physics, and the Institute of Physics. Consequently, the format and style of assessments also need to evolve to support this emerging approach. The goal is to help students see physics as a practical tool for solving real-world problems.

In this talk, we report on a recent change at the University of Sydney, introduced in first-year student physics laboratories and tutorials. The competence-based assessment involves evaluating students’ ability to apply conceptual understanding to practical situations, communicate and negotiate tasks with peers, operate equipment, and critically evaluate measured data. We give an overview of this lab structure and how we implemented this form of assessment in a lab environment.

Quantum Science and Technology / 60

Molecular optomechanics with atomic antennas

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Co-authors: Alexander High²; Michael Steel¹

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A typical surface-enhanced Raman scattering (SERS) system relies on deeply subwavelength field localization in nanoscale plasmonic cavities to enhance both the excitation and emission of Raman-active molecules [1,2]. Here, we demonstrate that a germanium-vacancy (GeV) defect in diamond can efficiently mediate the excitation process, by acting as a bright atomic antenna [3]. At low temperatures, the GeV's low dissipation allows it to be efficiently populated by the incident field, resulting in a thousand-fold increase in the efficiency of Raman scattering in the hybrid system comprising a GeV atomic antenna and a plasmonic nanoparticle [4]. Additionally, we show that atomic antenna-enhanced Raman scattering can be distinguished from conventional SERS by tracing the dependence of Stokes intensity on input power, and the pronounced antibunching of the Raman emission.

We also discuss a simpler setup, in which GeV atomic antennas localize light in diamond, driving and enhancing the Raman response of the diamond lattice, in what would be a solid-state analogue of the canonical experiment demonstrating plasmon-enhanced Raman scattering from a solution of molecules [5].

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Focus Session: Emerging Materials and Physics for Energy Conversion / 61

Thermo-Electro-Magnetic Coupling in Functional Composite Materials

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A large fraction of global primary energy is dissipated as waste heat, motivating the search for materials that can directly convert heat to electricity via the Seebeck effect. Tin selenide (SnSe) is a leading thermoelectric candidate due to its ultralow lattice thermal conductivity and favourable electronic structure. Beyond conventional optimisation strategies such as doping or alloying, the incorporation of magnetic nanoparticles offers an alternative pathway to tune transport properties through thermo-electro-magnetic coupling.

We investigate SnSe-Fe₃O₄ nanocomposites as a platform to probe the interplay between electrons, phonons, and magnons in a thermoelectric matrix. Structural and transport characterisation reveal that Fe₃O₄ inclusions can both enhance and suppress performance metrics depending on composition, temperature, and processing history. Time-of-flight inelastic neutron scattering demonstrates pronounced broadening of SnSe optical phonons in the composites, beyond that expected from a

simple superposition of the constituent spectra, suggesting additional scattering channels, potentially from phonon–magnon coupling. In this presentation we highlight the complexity and tunability of multi-quasiparticle interactions in magnetic thermoelectric composites and provide new insights into strategies for controlling coupled thermal, electrical, and magnetic transport.

Condensed Matter & Materials / 62

Magnetic properties of L21- ordered Mn₃-xFexGa epitaxial thin films

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Co-authors: Sena Katayama¹; Toshiyuki Shima¹

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In this work, fabrication of Mn₃-xFexGa epitaxial thin films by using an ultra-high vacuum electron beam evaporation system, clarifying the relationship between composition of Fe, magnetic properties, crystal structure and film thickness were studied. The epitaxial growth of L21- ordered Mn-Fe-Ga thin films has been confirmed on the MgO (001) single crystalline substrate by using in-situ RHEED for all the samples. The a-axis was calculated by performing a lattice spacing analysis using RHEED patterns. From XRD, the L21(004) fundamental peak shift to the high angle side was confirmed as the film thickness decreased, which show that the c-axis becomes smaller. Decreasing of the c-axis and increasing of the a-axis was confirmed as the film thickness decreased from XRD and RHEED analysis, respectively. As the film thickness was reduced (tMn-Fe-Ga = 20 - 1 nm), increase of saturation magnetization (M_s) and magnetic anisotropy (K_u) are confirmed for all Mn-Fe-Ga thin films in which Fe is added to Mn-Ga. At tMn-Fe-Ga = 1 nm, the maximum extremely large K_u = 20.1 Merg/cm³ at x = 1.5 and maximum M_s = 878 emu/cm³ at x = 2.5 are confirmed. These results could be explained by the addition of Fe to Mn-Ga and the lattice distortion from the substrate into the film. Therefore, it was shown that the L21- ordered Mn₃-xFexGa epitaxial thin film is one of the magnetic materials having the perpendicular magnetization film which is suitable for the MTJs application.

Quantum Science and Technology / 63

Multi-time quantum process tomography—and beyond—on superconducting qubits

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All current quantum devices suffer from noise originating from system-environment interactions. Often the noise is non-Markovian, i.e. correlated across the time-steps of a quantum circuit—as reported in spin silicon platforms and the superconducting devices of IBM and Google. However, most characterisation techniques assume Markovian (uncorrelated) noise, which results in inaccurate gate fidelities and increased error rates.

Non-Markovian noise can arise from classical sources (temperature, electronic noise, etc.), or quantum sources (a nearby quantum system that mediates the correlations). Existing theoretical approaches typically only access two-time correlations (dynamical maps), while experimental mitigation strategies have been ad hoc, lacking a rigorous, general framework.

The process matrix formalism provides such a framework, encoding all multi-time correlations of a quantum process, allowing us to quantify the strength and nature of non-Markovian noise. Although this method has been used in various experiments, full process matrix reconstruction has remained out of reach because it was believed to require mid-circuit measurements with rapid feed-forward capabilities unavailable in current devices—leading only to partial characterisations.

Here, we present the first complete tomography of a multi-time quantum process on a superconducting qubit, providing a full description of its non-Markovian noise. We achieve this using mid-circuit measurements combined with a post-processing trick that avoids the need for a feed-forward mechanism. Our experiments use devices from the University of Queensland and IBM Quantum's cloud platform. We measure both general and quantum non-Markovian noise and construct a theoretical model to compare with our results. We also present several pathways to utilise this method for real impact on quantum devices, combining MPOs and AI to reduce the computational and experimental data overhead and the needs of experimentalists to achieve their goals. Our methods enable rigorous characterisation of non-Markovian noise, advancing our understanding and opening pathways to more effective noise mitigation.

Quantum Science and Technology / 64

Quadratically coupling DV detectors with QFT: tools for non-perturbative modelling of CV-DV hybrid systems

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QFT models involving detectors are usually modelled perturbatively out of necessity, however, there are certain situations when non-perturbative methods can be used. When the detector is a finite dimensional qudit, non-perturbative modelling is possible if the detector interacts suddenly and very quickly (δ -switching) or if the detector is degenerate (zero energy gap). When the detector couples linearly to the field, numerical evaluation of the model requires an understanding of the Lie Group of (Glauber) coherent states and linear displacement operators, including the exact evaluation of the inner product between two different coherent states. Fortunately, coherent states are frequently used in quantum optics and their algebraic properties are well known. When the detector couples quadratically to the field, we require an understanding of the Lie Group of quadratic displacement operators. Whilst these operators are used in quantum optics, there are some gaps in knowledge, specifically the exact evaluation (including complex phase) of the inner product between two different quadratically displaced states.

In this talk I will be introducing a technique for evaluating the inner product between two different quadratically displaced states and thereby filling the knowledge gaps of quadratic displacement operators. I shall then use this technique to model two example scenarios from relativistic quantum information, 1) how does the excitation probability of a detector change by the presence of another detector in its past? (Fermi problem); 2) What is the energy density of a scalar field after a detector interaction and measurement? These questions have been answered for linear detectors, although they have not previously been solved for quadratic detectors. This technique is generally useful for quadratic CV-DV couplings and can be used for non-perturbative modelling of hybrid systems when outside the standard quantum optics limits. PRD 111, 105031 (2025)

Industrial Applied Physics / 65

SET setups at the Australian and Canadian pulsed laser facilities in the chase of the critical parameters for direct comparison

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Single Event Effects are potentially catastrophic electric and electronic effects created in analog and digital electronic devices exposed to ionising radiation. They are particularly dangerous in Space, and so a radiation hardness qualification procedure is often required for electronic devices to be considered Space safe. Qualification requires the use of hadron accelerators but alternative techniques are emerging to reduce testing costs and facilities overcrowding issues. Implementation of laser based Single Event Effects testing methods requires careful consideration of the critical physical parameters responsible for charge generation within electronic devices. Comparisons of Single Event Transient amplitudes generated within the well-known operational amplifier LM124 between SEE laser facilities in Australia, Canada and results found in literature identified charge generation dependence on multiple parameters. Wavelength and pulse energy have well known effects on charge generation through the photoelectric effect, however focusing position and temporal pulse width show significant impact. Focusing position errors quickly lead to significant beam width dilation and shifting causing significant charge loss to insensitive volumes. Variation of the pulse width affects the total charge collection efficiency due to processes such as Auger recombination and variation of carrier mobility in diffusion regions. Reduction of pulse widths helps to mimic the timing characteristics of interaction of charged particles but charge collection becomes more sensitive to pulse energy. This introduces non-linear errors in methods which compare device response to pulse energy and not deposited charge. The Single Event Transient study presented highlights the importance of control of each of these parameters for accurate charge generation within a targeted volume using pulsed laser methods.

Condensed Matter & Materials / 66

Computational Discovery of Halide-Tuned Double Perovskites for Sub-1 eV Thermophotovoltaic Materials

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The search for novel semiconductors with sub-1 eV bandgaps is critical for efficient infrared photon-to-electricity conversion from high-temperature thermal emitters in thermophotovoltaic (TPV) systems. Double perovskites with the general formula $A_2B'B''X_6$ offer exceptional chemical tunability, making them attractive for targeted infrared bandgap engineering. For TPV devices operating with emitter temperatures in the 1100 - 1500 K range, the optimal bandgap lies between 0.6–0.75 eV, enabling spectral matching while minimizing thermalization losses.

Experimental studies of lead-free halide double perovskites report bandgaps in the ~1.8–1.9 eV range, well above the TPV-optimal window. These materials also exhibit relatively low mobilities compared to lead-halide perovskites; for example, $\text{Cs}_2\text{AgBiBr}_6$ thin films have a lower bound of $\sim 1 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$, while single crystals can reach $\sim 11.8 \text{ cm}^2 \text{ V}^{-1} \text{ s}^{-1}$. Given that both optimal bandgap positioning and balanced carrier transport are intrinsic design criteria for high-efficiency TPV converters, we conducted a computational screening of candidate double perovskites. Using density functional theory (VASP), Boltzmann transport modeling with AMSET, and structural data from the Materials Project API, we screened $\text{Cs}_2\text{CuSbCl}_6$, Cs_2SnBr_6 , and $\text{Cs}_2\text{CuSbBr}_6$. The computed bandgaps closely matched literature values, validating our approach and indicating that $\text{Cs}_2\text{CuSbBr}_6$ is the most promising candidate. High-throughput calculations were then performed to systematically vary the halide composition in the $\text{Cs}_2\text{CuSb}(\text{Br}_x\text{I}_{6-x})$ series.

Fully iodide-substituted $\text{Cs}_2\text{CuSbI}_6$ exhibits a direct bandgap of 0.683 eV, squarely within the TPV-efficient range. The evolution of bandgap with halide substitution, the temperature-dependent transport properties for the full halide series at $n_h = 10^{16} \text{ cm}^{-3}$, and the carrier mobilities calculated via AMSET will be demonstrated. While factors such as Auger recombination and phase stability are essential for practical implementation, this study will provide an initial screening for the batch of candidate materials that deserve future experimental investigations.

Solar Terrestrial and Space Physics / 67

Simulating a Wavefront Sensing Hybrid Mode-Selective Photonic Lantern

Author: Justin Vella¹

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¹ *University of Sydney*

The use of photonic alternatives to conventional optical trains in telescope instrumentation offers key advantages in satisfying near-impossible tasks demanded by astrophysics (such as imaging Earth-sized exoplanets within the habitable zone of their host star or their formation within a protoplanetary disc).

Current imaging instruments using adaptive optics account for atmospheric seeing conditions by using a Wavefront Sensor (WFS) to measure the aberrated wavefront and apply correction by a Deformable Mirror (DM). Pupil-plane WFS are the most common, but make optimal wavefront correction difficult due to non-common path aberrations with the focal plane, and the inability to detect modes such as low wind effect and petal modes. An effective focal-plane WFS would address these issues.

In recent years the Photonic Lantern (PL), used primarily in telecommunications, has become a promising photonic device with applications in astrophysics for ground-based telescopes to act as a focal-plane WFS and achieve this task. The PL is a device that encodes the phase and amplitude of the aberrated wavefront into the intensities of single-mode fibres at the output, meaning that one could tailor a PL for wavefront sensing and place it within the same focal plane as seen by the CCD/instrument. Furthermore, the PL can be itself used for the main science light injection (using a hybrid mode-selective PL), eliminating non-common-path aberrations entirely.

Theoretical Physics / 68

Novel droplet phase of exciton-polariton mixtures in atomically thin semiconductors

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Quantum droplets are self-bound low-density configurations which may appear in ultracold gases with competing interactions. Dilute bosonic mixtures, where the attractive mean-field energy is balanced by the repulsive Lee-Huang-Yang correction stemming from quantum fluctuations, are the prototypical platform where this novel state has been first predicted [1] and shortly after experimentally observed [2,3]. Since then, quantum droplets have gained significant interest, and their study has been extended to various cold-atomic settings.

In this talk, I will show how a similar scenario can arise in a solid-state system. Specifically, we consider an atomically thin semiconductor layer embedded in an optical microcavity, where exciton-polariton quasiparticles (polaritons) result from the strong coupling between semiconductor excitons and cavity photon modes. Polaritons carry a spin degree of freedom inherited from both their matter and light components, thus resulting in the possibility of interactions between these quasiparticles [4]. We show that the competition between the attractive spin-singlet and repulsive spin-triplet channels of the interaction can lead to the formation of a novel self-bound many-body state analogous to a quantum droplet, thus demonstrating that exciton-polaritons can display both liquid- and droplet-like phenomena.

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Condensed Matter & Materials / 69

Speeding up Simulations of Magnetic Nanoparticles

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Magnetic nanoparticles are used in biomedicine to treat and image cancer. This is because of their ability to generate heat within an alternating magnetic field and to track cells, respectively. Thus, it is important that their response to a magnetic field is simulated accurately to predict and understand their behaviour. However, simulations can be computationally expensive, so it is necessary to minimise the computational power used to generate results.

There are two ways that nanoparticles change their magnetisation direction under the influence of a magnetic field: (i) particles physically rotate and the magnetization moves with the particle (so-called Brownian motion), and (ii) the particle does not move, but the internal magnetic moments rotate (so-called Néel motion).

Of, course the real motion is a mixture of these two cases.

The goal of this work is to average over the faster Néel dynamics, to speed up simulations.

This is done by stochastically moving the internal magnetic moment inside nanoparticles every nanosecond, according to their thermodynamics. In comparison, full simulations usually involve integrating equations of motion forward in time. This requires timesteps that are at least 1000 times smaller.

Here, we detail computer simulations that simultaneously model both Brownian and Néel dynamics. These simulations are rigorously tested by comparing the Brownian and the Néel behaviour to literature results. To show its validity, we compare results of our stochastic, approximate method to treat the Néel dynamics with those from full time-integration of equations of motion.

Theoretical Physics / 70

Axion Quality, Clockwork & Extra Dimensions

Author: Marko Beocanin¹

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The Strong CP Problem can be solved elegantly and economically by introducing a spontaneously broken, anomalous, global Peccei-Quinn (PQ) symmetry, whose Goldstone boson - the axion - dynamically cancels out the CP-violating phase. However, the global-symmetry-breaking corrections expected to arise from quantum gravity can threaten this perfect cancellation, and need to be either enormously suppressed or otherwise forbidden. In this research, we focus on the former approach, asking: what sorts of axion models can provide a sufficient dynamical suppression of axion-gravity couplings in the effective theory? Rather strikingly, we prove a no-go theorem which rules out any 3+1D model where PQ symmetry arises residually from the spontaneous breaking of some larger (compact, connected) symmetry group. As a relevant application of this result, we explore how the so-called clockwork mechanism, which exponentially localises the axion field to tune certain couplings, fails to provide any relative suppression of quantum gravity corrections. Inspired by the deconstructive interpretation of clockwork, we also provide some clarity on the situation in 4+1D, where additional topological structure and spacetime curvature may offer a way past our 3+1D result.

Poster Session / 71

Self-Organising Maps with Relational Perspective Mapping (SOM-RPM); A practical tool for the evaluation hyperspectral data sets

Author: Sarah Bamford¹

Co-authors: David Winkler ¹; Paul Pigram ¹; Wil Gardner ¹

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Unsupervised machine learning, specifically self-organizing maps with relational perspective mapping (SOM-RPM), is a practical tool for thoughtful and considered analysis of complex hyperspectral data sets. The SOM-RPM approach treats each pixel in a hyperspectral image as a sample, clustering spectra based on similarity. This method creates a colour-coded similarity map in which changes in colour are specifically graded to accord with changes in the spectral dimension, by examining the entire data set. The SOM-RPM toolbox allows for interactive selection and exploration of the data, regardless of the data source. This methodology has proven to be a robust technique that has so far been demonstrated mostly on Time-of-flight secondary ion mass spectrometry (ToF-SIMS) data.

ToF-SIMS is a mass spectral imaging technique, which can be extended into a three-dimensional depth profiling using a secondary sputtering gun. ToF-SIMS images and depth profiles are large and complex hyperspectral data sets. Interpretation requires that the complexity of these data sets is reduced. For two-dimensional data, individual ion peaks are often extracted and overlaid or for three-dimensional data, a handful of peaks are plotted in one dimension as a function of depth. These simple methods work well for known or simple samples, however for complex or unknown samples, these methods struggle to convey the depth of information captured within the data set. Furthermore, the choice of displayed ion peaks has the potential to impart user bias and make a significant difference to the interpretation of results.

By pairing ToF-SIMS and SOM-RPM, the complete hyperspectral data set in 2D or 3D can be intuitively visualized, providing a unique picture of the local and global mass spectral relationships between individual pixels. This work will present several case studies across a broad range of sample types.

Barocaloric Materials –Cooling and Heat storage –Atomic Level Understanding with Neutrons

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Refrigeration is of vital importance for modern society—for example, for food storage and air conditioning—and 25 to 30 per cent of the world's electricity is consumed for refrigeration. Current refrigeration technology, mostly involving the conventional vapour compression cycle, is of growing environmental concern because of large amount of greenhouse gases released into atmosphere every year. As a promising alternative, refrigeration technologies based on solid-state caloric effects have been attracting attention for several decades. Searching for novel materials having large isothermal entropy changes upon phase transition induced by a small external field is the core activity in the study of solid-state caloric effects. To understand the mechanism of the large caloric effect and the associated phase transition is fundamentally important. In this presentation, I will discuss atomic-level understanding of the the colossal barocaloric effects (CBCEs) (large cooling effects induced by pressure) and inverse barocaloric effect (thermal battery for heat storage) of plastic crystals using inelastic and quasielastic neutron scattering [1-3].

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[3] Z Zhang, et al. *Science Advance* 9, eadd0374 (2023).

Quantum Science and Technology / 73

Q-PUF: Scalable, Hardware-Based Authentication for Quantum Processors

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Cloud-based quantum computing is transforming how sensitive algorithms are executed, enabling remote access to shared hardware—but also introducing new risks of device impersonation and unauthorized access. We present a hardware-intrinsic authentication scheme based on Quantum Physical Unclonable Functions (Q-PUFs), which exploit fabrication-induced variations in quantum devices to create unclonable hardware fingerprints.

We begin by fingerprinting quantum devices through stable, intrinsic physical properties that are unique to each individual device, forming the basis for our Q-PUF protocol. While adaptable to different quantum hardware modalities, we prototype and validate it on IBM Quantum devices using qubit frequency as the primary fingerprinting feature. To demonstrate the robustness of our protocol across many devices of the same technology—each possessing distinct physical characteristics—we used Monte Carlo simulations to model large populations of superconducting processors with realistic fabrication variability. This allowed us to assess scalability and key-generation performance in scenarios representative of a wide range of individual machines. The protocol employs fuzzy extractors to transform noisy fingerprint data into cryptographically secure keys while concealing raw hardware properties.

To enable scalability, we introduce q-tuples—qubit subsets that generate exponentially many challenge–response pairs—transitioning from weak to strong PUF behavior. Evaluation via Hamming weight and distance analysis confirms high entropy, uniqueness, and robustness. We also explore additional intrinsic quantum properties to strengthen security and resistance to compromise.

Beyond superconducting platforms, the protocol can be extended to other modalities, including silicon-based devices and neutral-atom systems, and adapted to future logical Q-PUFs for authenticating fault-tolerant qubits. These advances position Q-PUFs as a core security primitive for trusted quantum–classical networks, enabling scalable, verifiable, and hardware-rooted quantum cloud infrastructure.

Quantum Science and Technology / 74

Engineering tunable anharmonic potentials with light-atom interaction for chemical dynamics simulations

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Trapped-ion platforms have emerged as a powerful architecture for quantum simulation, offering high-fidelity universal control over both internal atomic states (spins) and bosonic motional modes. This makes them particularly well-suited for simulating molecular dynamics, where a natural analogy allows a molecule's electronic configuration to be mapped onto the ion's spin, and its vibrational structure onto the ion's motion.

This approach has enabled pioneering studies of time-resolved vibrational spectroscopy [1], geometric phase effects at conical intersections [2, 3], and open-system chemical dynamics of real molecules [4]. To date, however, these implementations have been restricted to harmonic oscillator models, failing to encapsulate the crucial anharmonicity present in most molecular potentials.

Here, we overcome this limitation by implementing anharmonic dynamics in a trapped-ion system using coherent, programmable quantum control with light-atom interactions. We present a flexible scheme that leverages state-dependent forces and qubit rotations to engineer widely tuneable anharmonic potentials. As a key demonstration, we realize a double-well potential of the form $V(x) = \delta x^2 + \epsilon \cos(\eta x)$. This allows us to access rich, nonlinear dynamics, most notably observing quantum tunnelling of a wavepacket between the two wells. These results establish a pathway for simulating chemically relevant potentials on a programmable quantum platform.

Poster Session / 75

Investigation of the physical properties and crystallography of Thin Film Multilayer YBa₂Cu₃O_{7-x} - NdBa₂Cu₃O_{7-x} Superconductors.

Author: Caleb Scarratt^{None}

As quantum nanotechnologies continue to advance, they require continually increasing physical properties from their thin film superconductive components, including a samples critical current density (JC) and critical temperature. This research focuses on characterising the impacts of varied layering designs, and alterations to deposition temperature, for films of less than 200 nm thickness. Monolayer and multilayered films were created using a Pulsed Laser Deposition technique, with samples magnetic and transport properties measured via a Physical Properties Measurement System, utilising the Vibrating Sample Magnetometer attachment for magnetic testing, and a combination of the prototype press contact developed by our labs and the rotating sample holder both with the Electronic Transport Option attachment. The YBa₂Cu₃O_{7-x} monolayer samples displayed the best magnetic properties under all conditions, except at high temperature (77 K) under an applied field greater than 0.01 T where the pair of 5 layered films (differed by varying deposition temperatures) displayed equal or greater JC values than the monolayer sample. Whilst little difference was observed between similar samples of varied deposition temperature, the surface roughness of all samples showed layered samples with a greater amount of NdBa₂Cu₃O_{7-x} had less surface pores than samples with little or none of the compound, though such samples did have an increased amount of surface protrusions, a noteworthy result considering the importance of surface smoothness in these films applications. These protrusions crystallography, and each sample's crystal structure at large, was investigated using TEM microscopy, observing the composition of such pores and protrusions to be bulk droplets of individual (or oxides) components of the deposited compounds, usually Cu. Further analysis and comparison of each crystals strain across interfaces, crystal phases, and d-spacings were undertaken to best assess the quality and viability of each sample for practical applications, as well as the deposition process as a whole.

Quantum Science and Technology / 76

A bivariate bicycle code architecture for quantum communication using ion traps**Author:** Anthony O'Rourke¹**Co-authors:** Campbell McLauchlan²; Madhav Vijayan¹; Rebecca Radebold²; Simon Devitt¹¹ *University of Technology Sydney*² *University of Sydney*

In the not-too-distant past, reliable transfer of data was largely done with small portable memories. This method is ideal for quantum communication in which the required resource for protocols such as quantum key distribution and quantum teleportation is distributed Bell pairs, as these can be distributed ahead of time using quantum memories [1410.3224].

Quantum low-density parity-check (qLDPC) codes are promising quantum-memory candidates because the distance and number of logical qubits of each qLDPC code 'module' increases with physical qubit count, unlike a surface code module in which only the distance increases. Additionally, intra-module [2410.03628, 2503.10390] and inter-module [2407.18393, 2410.03628] logical operations in qLDPC codes are possible, enabling the preparation of logical Bell states. The disadvantage of qLDPC codes is that they require long-range, rather than just nearest-neighbour, qubit connections, opening up many possibilities as to the ideal layouts and architectures to realise them with.

A popular family of qLDPC codes are the Bivariate Bicycle (BB) codes [2308.07915], for which proposed architectures include long chains of trapped ions [2503.22071, 2508.01879] and tiered superconductors [2507.23011]. Already-realised architectures include superconductors using air bridges [2507.00254].

Ion traps are ideal quantum memories due to their long coherence times and slow gate times. They additionally can be made portable enough to be used in technologies such as atomic clocks [2112.06816]. Consequently, we propose and benchmark an ion-trap architecture for realising a specific BB code memory with 6-12 months memory time. Being specific to quantum communication allows a fixed chip size and a tailored layout without needing to consider extra connections required for universal quantum computation. We benchmark our architectures with simulations implementing an ion trap noise model and a BPOSD decoder. We further benchmark the process of creating distributed logical Bell pairs in our architecture for the purposes of quantum communication.

Nuclear and Particle Physics / 77

Emergent Symmetry in a Two-Higgs-Doublet Model from Quantum Magic**Author:** Ewan Wallace¹¹ *University of Adelaide*

There is growing interest in the application of quantum information theory concepts to particle physics model-building. Recent research has established that the extremization of entanglement in particle scattering provides a natural way to realise interesting theoretical structure, both within and without the Standard Model. The success of these entanglement studies begs the question: can other information-theoretic measures be used in a similar manner? In this talk, I will present the results of our recent investigation into this question (arXiv:2506.01314), focusing on the application of "magic"—a concept originating in quantum computation—to a two-Higgs-doublet model. I will motivate the concept of magic, describe how magic conservation in a particular 2-to-2 scalar scattering channel reproduces Standard Model alignment, and outline how the formalism may be generalised to accommodate a broader class of processes in our two-Higgs-doublet framework.

Quantum Science and Technology / 78**Quantum circuits as a tool in materials science: using imperfect devices to build better quantum technology****Author:** Jared Cole¹¹ RMIT University

Superconducting electronics are one of the best understood and most promising platforms for realising quantum information processing. Unfortunately they suffer from the presence of defects and imperfections. These include uncontrolled two-level systems, which reside in the materials used to construct them. These defects can lead to loss of energy, coherence, device aging and imperfect control pulses.

Interestingly, this observation is directly related to a much older and well-known problem from solid-state physics; what is the origin of the two-level defects thought to dominate the behaviour of amorphous glasses at very low temperatures? At present the precise microscopic origin of these defects remains a mystery, but recent work both experimental and theoretical, is bringing us closer to an answer.

Using superconducting qubits as probes of metallic oxide thin films has opened up new opportunities to study individual two-level defects. New experiments have surveyed and characterised individual defects, as well as studying their electric field, temperature and strain dependence. Direct coupling between individual defects has also been measured for the first time. The next generation of experiments combined these ideas with acoustic probes of defect dynamics, neutron scattering experiments, models of dielectric breakdown and even probes of cosmic ray flux.

In this way, new information is being obtained about defects in amorphous materials. This not only improves low temperature electronics, it moves us closer to large scale fault tolerant quantum computers, as well as increasing our understanding of this critically important phase of matter.

Poster Session / 79**A new understanding of gravity and particles voids the need for dark matter****Author:** PETER LAMB^{None}

The gravitational redshift, as originally proposed by Einstein, has light emitted from atoms deeper in a gravitational potential redshifted. The frequencies of atoms slow in proportion to the fractional decrease in stored energy when the field from surrounding mass increases. Gravitational attraction arises from a loss in mass (stored energy) when closer to other massive bodies. The decrease in mass, as light-speed increases, is released as kinetic energy of motion. Neither emission of radiation nor an increased distortion of spacetime is required. The change in clock-rate is demanded by the change in energy. No change in 'space' (distance scale) is needed.

The gravitational redshift of distant galaxies is not an expansion of the scale of empty space. It simply reflects the lower energy held by matter going back in time when light-speed was faster. Correcting the supernovae data of the Dark Energy Survey for the faster light-speed accurately removes the accelerating expansion. Moreover, there is no need for any expansion at all. Consequences include - no need for dark energy, or an initial big bang, or cosmic inflation, or dark matter, or singularities inside black holes. The Hubble tension and the horizon and flatness problems are also removed. However, the revised theory still reproduces the many apparent successes of General Relativity.

Massive particles can be seen as non-diffusing 3-D standing-wave patterns of mixed chiral components in which energy is continuously conserved. They oscillate in a background medium from nearly equal contributions from matter and antimatter. Inertia then arises from rotations induced by any asymmetry. The $1/R$ dependence of gravitational potential, the separation into gravitationally isolated interlaced regions of matter and antimatter, and why distant galaxies dominate, follow.

The flat rotation curves, magnitude of gravitational lensing, rate of galaxy evolution, and the cosmic microwave background, do not need dark matter.

Atomic and Molecular Physics / 80

A vibronic approach to the hyperfine interaction observed in bio-magnetosensors

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The interactions of biological processes with magnetic fields can have significant impacts, with a strong example of this being magnetosensitivity in avian proteins allowing for migration[1]. The two main biological systems for optically-driven magnetosensing are cryptochrome (CRY) and light-oxygen-voltage (LOV) proteins[2,3], where each can be broadly summarised by 4 steps: photoactivation, radical pair generation, hyperfine hopping, and recombination/recycling. Understanding each through experimental observations and theoretical modelling is key to understanding and controlling the biomagnetoptical mechanism. The third step, whereby an induced coupling between the electronic and nuclear magnetic moments results in rapid spin-inversion, is incredibly sensitive to magnetic fields. Existing theoretical models typically consider the nuclei as frozen, however this neglects temperature-based effects, such as those due to vibronic oscillations (Herzberg-Teller contributions). In this work, I show that omission of these second-order contributions will result in a grossly underestimated kinetic model. Rate constants will be shown to increase by several orders of magnitude when incorporating vibronic effects, and will shift state lifetimes from microseconds to nanoseconds. This work addresses the hyperfine interaction taking into account these Herzberg-Teller terms to the correlated electronic-spin state matrix element. The second-order perturbative term is derived and applied to the magnetosensitive active site of a LOV protein. This approach more readily incorporates realistic temperature-based phenomena as vibronic contributions to the hyperfine interaction are explored, and acts as a solid first step towards a complete kinetic model within a complete protein system, which will ultimately require both temperature-dependant conformational sampling and anisotropic contributions to the second-order corrected isotropic matrix coupling element.

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Quantum Science and Technology / 81

Quantum Engineering of Qudits with Interpretable Machine Learning

Authors: Yule Mayevsky-Mattiaccio¹; Akram Youssry¹

Co-authors: Ritik Sareen¹; Gerardo A. Paz-Silva²; Alberto Peruzzo³

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Higher-dimensional quantum systems (qudits) offer advantages in information encoding, error resilience, and compact gate implementations, and naturally arise in platforms such as superconducting and solid-state systems. However, realistic conditions such as non-Markovian noise, non-ideal pulses, and beyond rotating wave approximation (RWA) dynamics pose significant challenges for controlling and characterising qudits. In this work, we present a machine-learning-based graybox framework for the control and noise characterisation of qudits with arbitrary dimension, extending recent methods developed for single-qubit systems. Additionally, we introduce a local analytic expansion that enables interpretable modelling of the noise dynamics, providing a structured and efficient way to simulate system behaviour and compare different noise models. This interpretability feature allows us to understand the mechanisms underlying successful control strategies; and opens the way for developing methods for distinguishing noise sources with similar effects. We demonstrate high-fidelity implementations of both global unitary operations as well as two-level subspace gates. Our work establishes a foundation for scalable and interpretable quantum control techniques applicable to both NISQ devices and finite-dimensional quantum systems, enhancing the performance of next-generation quantum technologies.

Physics Education / 82

Use of advanced mechanics problems for undergraduate research projects

Author: Michael Wheatland^{None}

Co-author: M.Z. Rafat

Mechanics problems (including advanced problems in rigid body dynamics) provide a basis for research projects which are attractive to high-achieving undergraduate students. These projects require students to draw on their knowledge from multiple areas, including mathematics, programming, and physics, and also require visualisation of the complex motion of extended objects. This integrated approach provides an authentic research experience. It deepens students' conceptual understanding and encourages a more reflective mindset when tackling unfamiliar problems, supporting the development of expert-like thinking in undergraduate science education. Here we describe student research projects including the dynamics of a tossed mobile phone, the motion of rolling biased balls (balls with an offset centre of mass) and the motion of rolling magnetised balls (which interact with the Earth's magnetic field). Each of these projects has been undertaken by undergraduate students in the physics major at the University of Sydney, and it has led to refereed publications, including for first-year students.

Poster Session / 83

Broadband Entanglement over Fiber: PMD Metrics and Mitigation

Author: Vadim Rodimin¹

Co-authors: Alexei Ponasenko¹; James A. Grieve¹; Konstantin Kravtsov¹; Rui Ming Chua¹; Yury Kurochkin¹

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Transmission of entangled photons through optical fiber underpins quantum key distribution (QKD), quantum computing, and the quantum internet. However, polarization mode dispersion (PMD) remains a key obstacle to distributing polarization-entangled photons over deployed fiber, especially for broadband sources where wavelength-dependent polarization rotation accumulates into measurement errors.

Using an intuitive graphical approach on the Poincaré sphere, we derive a closed-form expression

that links qubit infidelity to the channel's differential group delay (DGD) and source spectrum, yielding a simple engineering rule for setting filters and link budgets. We validate the framework with O-band experiments and QKD trials over tens of kilometers of deployed fiber, observing that first-order theory predicts a near-parabolic dependence of infidelity on bandwidth.

We then extend the model beyond first-order PMD. Our recent results show that higher-order PMD can partially average polarization errors, thereby mitigating infidelity relative to first-order predictions.

Finally, we propose practical mitigation strategies: (i) selecting fiber spans with PMD parameters optimized to limit PMD-induced errors; (ii) choosing measurement bases that minimize the average error; and (iii) employing non-local PMD compensation, in which a polarization transformation in one arm of an entangled-photon link counteracts distortions accumulated in the other. Together, these results recast PMD from a hard limit into a tunable parameter for robust, broadband, fiber-based quantum communications.

Physics Education / 84

(Mis)applying the Heisenberg uncertainty relations to the hydrogen atom

Authors: Karen Pagnoni^{None}; Alexys Bruno-Alfonso^{None}; Roger Lewis^{None}

As has been recently pointed out by Pagnoni *et al.* [[1]], care is required in applying the Heisenberg uncertainty relations. This care has sometimes been insufficiently realised in pedagogical settings. A case in point is the hydrogen atom. Here the singularity of the Coulomb potential causes difficulties in utilising the uncertainty relations. Clarification of this point is expected to improve both the learning and teaching of physics.

[[1]] K. F. Pagnoni, A. Bruno Alfonso and R. A. Lewis, *Eur. J. Phys.* **46** (2025) 045404. doi.org/10.1088/1361-6404/addfbf

Condensed Matter & Materials / 85

Polarised Terahertz Reflectance and Terahertz Transmission of Calcite

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¹ University of Wollongong

While the optical properties of calcite are well known in the visible region, that same cannot be said of the terahertz region. Campbell *et al.* [1] have reported attenuated total reflectance (ATR) spectra. Sakai *et al.* [2] used pulsed terahertz radiation ATR. ATR has the attraction of experimental simplicity; however, the results are not always easy to interpret, nor is information related to the polarisation routinely obtained. We have recently reported detailed polarised spectra from single-crystal calcite at near-normal incidence [3]. These data reveal a systematic variation in features with polarisation angle. With respect to transmission geometry, Mizuno *et al.* [4] analysed calcium carbonate transmission in the range 0.5-4 THz. They noted that the features at 2.12, 2.23 and 2.40 THz varied in intensity on rotating the angle of polarisation of the incident radiation. We have now supplemented our detailed reflection data on crystalline calcite with transmission data on powdered calcite to obtain a fuller picture of the many phonon features. We expect measurements at low temperature will improve this data further.

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Atomic and Molecular Physics / 86

Measurement of nuclear charge radius difference in metastable helium isotopes

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Co-authors: Srihari Padmanaban¹; Xintong Yan¹; Yogesh Athreya¹; Kenneth Baldwin¹; Sean Hodgman¹; Andrew Truscott¹

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One long-standing puzzle in modern physics is the discrepancy between the most accurate proton charge radius measurements from muonic hydrogen spectroscopy and electronic hydrogen spectroscopy [1]. Despite theoretical improvements over the last decade, the mismatch remains [2], potentially hinting at physics beyond the Standard Model [3].

Helium, the next simplest atom after hydrogen, provides another testbed. Muonic helium spectroscopy was performed by the CREMA collaboration [4, 5], while more work has been done in normal helium spectroscopy [6–11]. The nuclear charge radius can be extracted with greater precision from high-accuracy spectroscopic measurements. The $2^3S_1-2^3P$ transition in helium is theoretically calculated to 2 MHz accuracy, with predictions of reaching 10 kHz [12]. We can also determine the charge radius difference using difference measurement, enabling direct theory comparison. We aim to measure the $2^3S_1-2^3P$ transition frequencies in ^4He and ^3He using ultracold metastable atoms. Ultracold clouds minimize the first-order Doppler shift, a dominant error in previous isotope-shift determinations. We present the design of a sub-kHz-resolution precision absolute laser facility and methods to suppress systematic errors, paving the way for the most precise nuclear charge radius measurement in helium to date.

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Poster Session / 87

Progress Towards Quantum Many-Body Physics Experiments with a Metastable Helium Bose–Einstein Condensate.

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We present our ongoing efforts toward the preparation of Bose–Einstein condensate (BEC) of metastable helium 1, which enables several atomic quantum experiments.

To achieve a high phase-space density for BEC, the sequence starts with the atomic source and Low velocity intense source (LVIS), followed by MOT, compressed MOT, magnetic trap, 1D Doppler cooling, and ends with transfer to an optical dipole trap for final evaporative cooling to reach BEC.

Beyond BEC production, we outline future experiments, including the study of (i) superradiance in extended atomic ensembles, where cooperative light emission can reveal collective coherence properties; correlation function measurements at the single-particle and single-photon level, enabling detailed insight into coherence and quantum statistics [2]. Previous superradiance studies focused on photon–photon second-order correlations to probe the emitted light’s coherence [3]. In contrast, our work will probe into atom–photon second-order correlations, providing direct insight into the coupled dynamics of the atoms and scattered light; and (ii) quench dynamics, in which sudden parameter changes drive the system far from equilibrium, providing a powerful platform for investigating nonlinear dynamics, thermalization pathways, and relaxation processes in many-body systems [4]. Our research employs correlation functions as powerful probes of many-body dynamics during the non-equilibrium formation of a Bose–Einstein condensate. While previous work has primarily focused on first-order properties such as the correlation length [5], condensate atom number [6], and defect count, We extend this approach to second and higher order correlations, revealing deeper insights into the underlying many-body phenomena.

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Poster Session / 88

Relativity Principles and the Hyperbolic Brachistochrone Equation

Author: Peter Morrison¹

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Time optimal control theory is a new and emergent branch of physics that seeks to modify the dynamic operators encoding the time evolution of the system in order to achieve optimised transitions between input and output states. Recent progress in the analysis of the hyperbolic brachistochrone equation using this method has uncovered a link to the Fubini-Study metric, an important object in the study of differential geometry. This talk will focus on the development of some new techniques for finding metrics and pseudounitary operators in various hyperbolic geometries, and relate their properties to associated problems in heat flow and diffusion in curved spaces using an eigenvalue decomposition method. We discuss the properties of hyperbolic metrics, and show how these can be used to derive a theory of metric flow on surfaces that is analogous to general relativity.

Poster Session / 89

Hydrogen-manipulated atomic layer epitaxy of titanium nitride for superconducting devices

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Advanced epitaxy techniques have become essential for superconducting quantum circuits due to their ability to fabricate high-quality and low-loss superconductors. Atomic layer deposition, which provides precise layer-by-layer growth, is widely adopted in complex 3D architectures in advanced silicon manufacturing, such as FinFETs and gate-all-around transistors. In this study, we investigate the structural and electrical transport properties of titanium nitride (TiN) thin films grown by hydrogen-manipulated atomic layer epitaxy (HM-ALE). The epitaxial growth results in high-quality thin films, confirmed by synchrotron-based grazing-incidence wide-angle X-ray scattering (GIWAXS) and X-ray photoelectron spectroscopy (XPS). Electrical transport measurements on Hall bar devices reveal a superconducting transition temperature of 2.2 K with a kinetic inductance of 15 pH/sq, and superconducting resonators exhibit internal quality factors above 10000. Our findings highlight HM-ALE as a promising epitaxial method for superconducting quantum research and applications.

Poster Session / 90

Universal programmable waveguide arrays

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Implementing arbitrary unitary transformations is crucial for applications in quantum computing, signal processing, and machine learning. Unitaries govern quantum state evolution, enabling reversible transformations critical in quantum tasks like cryptography and simulation and playing key roles in classical domains such as dimensionality reduction and signal compression. Integrated optical waveguide arrays have emerged as a promising platform for these transformations, offering scalability for both quantum and classical systems. However, scalable and efficient methods for implementing arbitrary unitaries remain challenging. Here, we present a theoretical framework for realizing arbitrary unitary matrices through programmable waveguide arrays (PWAs). We provide a mathematical proof demonstrating that cascaded PWAs can implement any unitary matrix within practical constraints, along with a numerical optimization method for customized PWA designs. Our results establish PWAs as a universal and scalable architecture for quantum photonic computing, effectively bridging quantum and classical applications, and positioning PWAs as an enabling technology for advancements in quantum simulation, machine learning, secure communication, and signal processing.

Focus Session: Combining astronomy and particle physics in the hunt for dark matter / 91

Untangling the local Cosmic Web with Caustic Skeleton Theory

Author: Amelie Read¹

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The cosmic web is a vast large-scale network of interconnected filaments, clusters, and sheet-like walls surrounding voids that compose our Universe. The cosmic web is pivotal in galaxy formation and evolution, as studies have demonstrated a connection between the large-scale cosmic environment of a galaxy and its observed properties.

Caustic Skeleton (CS) theory offers a promising new approach to classifying present-day observed large-scale structures according to their origins and formation history. It is a fully analytic mathematical framework to describe the formation of singularities (caustics) in the density field during non-linear gravitational collapse, and how these thereby outline the key structures like voids, filaments etc. However, the CS framework is relatively new and has thus far remained abstract and in the mathematical world, despite the fact that it has proven very effective at classifying structure in simulations.

Hence, we are pulling CS theory into reality by applying it to observational data. We have access to the Manticore project, which provides a successful reconstruction of the initial conditions from which the structure observed in the 2M++ galaxy survey of the local Universe evolved. By generating a detailed map of caustics in the local Universe, we can investigate the connection between the properties of galaxies in the large-scale structures of the constructed caustic skeleton and thereby implications for our Universe's underlying cosmology.

Poster Session / 92

Iceberg resonance and Young's modulus

Author: Mitchell Bonham^{None}

Iceberg breakup, calving and frequency is dependent on the Young's modulus of the iceberg. However, in current models of iceberg calving, the effective Young's modulus is essentially guessed by tuning this parameter until the model works. Icebergs have been shown to resonate at certain wave periods with flexural amplitudes that cannot be explained by simple bending suggesting that spectral analysis of the modes of flexural vibration could be used to determine the Young's modulus of an iceberg. A model of coupled iceberg-water motion to determine the resonant periods of an iceberg is presented. This model is used to calculate the Young's modulus of an iceberg using surface strain measurements.

Solar Terrestrial and Space Physics / 93

Interstellar lightsails: enhancing asymptotic stability through optimised metasurface design

Author: Jadon Lin^{None}

Co-authors: Alex Song ; Boris Kuhlmeier ; Liam van Ravenstein ; Martijn de Sterke ; Michael Wheatland

Lightsails are an enticing proposal for spacecraft that can travel to nearby star systems such as Alpha Centauri. Their advantage is their ability to reach speeds up to $0.2c$ when accelerated by high-power lasers. One significant obstacle to lightsail missions is that the sail experiences perturbations (e.g. from laser-beam noise or atmospheric effects) that act to eject the sail from the beam. The sail has a tight mass budget, therefore, any transverse motion must be passively corrected using restoring mechanisms and damping mechanisms. Previous studies only determined how to trap the sail within the beam using carefully designed metamaterial membranes to scatter light momentum in appropriate directions. However, the restoring mechanism produces oscillations that may be exacerbated by perturbations, destabilising the sail. Hence, a damping mechanism to reduce the velocity of perturbations is also required. However, damping does not occur naturally in the vacuum of space. One novel solution utilises the Poynting-Robertson drag, which weakly damps mirror-based sails, but which can be enhanced by orders of magnitude for optimised metasurfaces. Recently, the Poynting-Robertson model was extended to completely account for restoring and damping dynamics for a sail

propelled by a Gaussian laser beam. The derived relativistic equations of motion highlight that translational and rotational damping can be greatly enhanced by engineering the sail's optical-scattering angular and frequency dispersion, but no such optimisations were performed. Here, we employ linear stability analysis to guide the optimisation of metasurfaces to achieve asymptotically stable sails. We find 3–4 times enhancement in damping coefficients compared to mirror-based sails over the $0.2c$ -acceleration bandwidth, and 10000 times enhancement in the rotational degree of freedom over narrow ranges. Then, we showcase the significant damping in nonlinear dynamical simulations.

Medical Physics / 94

Fast pre-insertion dosimetry and source validation for Ru-106/I-125 ophthalmic plaque brachytherapy with 2D pixelated semiconductor detectors

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Introduction

Accurate dosimetry in ophthalmic plaque brachytherapy is essential due to steep dose gradients and the proximity of critical ocular structures. Current clinical practice relies on manufacturer-certified data with limited independent verification. This study reports on the development of a novel system for rapid pre-insertion validation of Ru-106 and I-125 plaques using high-resolution pixelated semiconductor detectors.

Methods

Two systems were developed based on a radiation sensor with a pixel size of $55\text{ }\mu\text{m}$ and a sensitive layer of $14 \times 14 \times 0.3\text{ mm}^3$. The first uses a pinhole camera in air to image the activity distribution on the concave surface of a plaque. Pinhole geometry was optimized analytically and refined using Geant4 Monte Carlo simulations. The second system measures 2D depth-dose distributions in water by positioning the detector beneath a custom-designed phantom, with the plaque mounted on a movable stage to allow dose measurements at varying depths. Geant4 Monte Carlo simulations were performed to assess the feasibility of the dosimetry system.

Results

The activity-measurement system was manufactured and tested, demonstrating the capability to rapidly map activity distributions in both I-125 and Ru-106 plaques. Monte Carlo simulations confirmed the feasibility of Ru-106 electron field dosimetry using the 0.3 mm -thick silicon layer of the detector. A prototype dosimetry system was designed and manufactured, with validation measurements scheduled for the third quarter of 2025; results will be presented at the AIP Summer Meeting.

Conclusion

These developments demonstrate the feasibility of fast, independent verification of Ru-106 and I-125 plaques. The developed systems have the potential to improve clinical safety and confidence in ophthalmic brachytherapy without compromising current clinical workflows with time-consuming measurements.

Quantum Science and Technology / 95

Optical-microwave quantum state transduction beyond the ideal

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¹ *Macquarie University*

Leading designs for quantum networks require efficient microwave-to-optical signal transduction. One promising platform uses ensembles of atoms (Er³⁺) coupled to dual microwave-optical cavities [1]. It is projected that these devices can reach practical efficiencies by boosting the coupling between cavities and optical and microwave transitions in atoms. However, increasing these couplings (where the effective transduction rate exceeds cavity losses) simultaneously increases the rates of parasitic processes (e.g. Kerr) which degrade the fidelity of atom-based interfaces. Therefore, building efficient transducers requires an understanding of these additional effects, which have to date not been captured by theoretical models. Here we develop a theoretical framework that characterises rates of transduction and higher-order parasitic processes, and demonstrate their effect on different quantum states of interest.

We model the atom ensemble as three-level systems, with transitions coupled to microwave and visible optical photons, and controlled by a classical pump [2]. Extending the perturbation theory (Schrieffer-Wolff transformation [3]), we identify an effective description of the dynamics to arbitrary order. We go beyond lowest-order perturbations (that govern the transduction rates) to calculate rates of the parasitic processes, and account for the dynamics within the atomic excited states subspace.

We apply this effective model to analyse the fidelity of transduction of different quantum states of interests, like single-photon states, complex coherent states, and Gottesman-Kitaev-Preskil (GKP) states. We demonstrate our effective model for describing these nonlinearities and their impact on the overall transduction fidelity, giving insight into the performance of future microwave-optics transducers.

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Nuclear and Particle Physics / 96

Machine Learning in Simulation of Radiation for Defence and National Security Applications

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Simulations of radiation and particle transport via Monte Carlo (MC) codes are integral to the design and safety of nuclear reactors, medical radiation systems and detector systems. A lesser known application of these simulations is in defence and national security, where such tools can provide crucial information for threat assessments and analysis of real world detector readings. These applications, however, are dynamic and demand a fast calculation time, which is incompatible with the notorious computational intensity of MC simulations.

In recent years, machine learning (ML) has gained popularity rapidly as an expedient computational alternative for classically slow problems, yet it is often limited by the availability of training data. ML techniques have some academic precedent in application to radiation and nuclear physics simulations, with limited uptake in industry thus far. In these applications, MC simulations are leveraged

as a rich source of data to train models in a particular problem, such as dose map calculations, criticality calculations, or particle shower reproduction in collider detectors.

These applications demonstrate potential for further integration between MC simulation and ML networks. However, the models developed in these circumstances are specific to the geometries and parameters of the simulations they were trained on. If a different detector, or a new reactor were to be considered, these models would be ineffective without retraining and thus negate the computational benefits. Therefore a key challenge is the generalisation of ML-MC simulation techniques to a broader set of geometries and problems. We aim to evaluate the feasibility of combining the efficiency of ML with the flexibility of MC simulations to tackle more complex and demanding problems. To achieve this, a voxelisation approach is proposed where ML models are executed consecutively to propagate flux distributions through each voxel. The principles of this approach and initial findings will be discussed.

Quantum Science and Technology / 97

Noise mitigation of Quantum Circuits using Fictitious Copies

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Quantum computers promise better scaling for problems that are intractable on classical computers, however current devices are limited by noise, which only permits shallow depth circuits and restricts the potential algorithms that can be run. Nonetheless, many error mitigation schemes have been developed which use extra quantum or classical resources to recover corrected observables from noisy hardware. One such technique is virtual distillation (VD), which uses multiple copies of the circuit with entangled projections to give noise-free expectation values. However, direct implementation of VD requires prohibitively deep, noisy entangling circuits¹ or a large number of shallow circuits^[2]. Here, we present a novel error mitigation technique inspired by VD that generates fictitious, non-entangled copies and corrects expectation values in postprocessing based on their joint probability distribution. Rather than relying on additional qubits and circuit depth, our method only requires increased sampling with the desired amount of error mitigation. We find our technique, optimally, is equivalent to virtual distillation but has state dependent performance. We therefore combine our technique with the quantum computed moments (QCM) method^[3], which allows us to prepare the approximate ground states that are better corrected with our technique and still recover the ground state energy. We demonstrate our technique can find the exact ground state energy of molecular and spin models under simulated noise models as well as real experiments on IBM superconducting devices.

¹ Phys. Rev. X 11, 041036 (2021)

^[2] Phys. Rev. Research 6, 033223 (2024)

^[3] Quantum 4, 373 (2020)

Focus Session: Ultra-cold atoms and quantum technology / 98

Compact, Resilient, and Quantum: The Future of Atom-Based Inertial Sensors

Author: Simon Haine¹

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Atom interferometry has emerged as a powerful tool for precision inertial sensing, with applications ranging from gravimetry to navigation and geophysics. In this talk, I will explore recent advances

that push the boundaries of sensitivity and robustness in atom interferometers, with a particular focus on techniques relevant for real-world deployment.

A central theme will be the use of spatial fringe detection, which enables operation beyond the conventional two-mode paradigm. This approach facilitates multiparameter estimation and enhances resilience against external motion—an essential feature for field-deployable quantum sensors.

I will also discuss the implementation of quantum squeezing to surpass the standard quantum limit. By boosting sensitivity, squeezing allows for shorter interrogation times and more compact devices, reducing susceptibility to environmental noise. This is a key enabler for portable and scalable quantum technologies.

Finally, I will present recent developments in combining spin-squeezing with spatial fringe techniques. This hybrid approach leverages the strengths of both modalities, offering a pathway to high-performance atom interferometers that are both sensitive and robust.

Together, these innovations represent a significant step toward practical quantum sensors capable of operating outside the laboratory, with implications for fundamental science, resource exploration, and navigation.

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Focus Session: Ultra-cold atoms and quantum technology / 99

Quasiparticle interactions in quantum mixtures

Authors: Jesper Levinsen¹; Olivier Bleu¹; Meera Parish^{None}

¹ Monash University

We investigate the fundamental problem of a small density of bosonic impurities immersed in a dilute Bose gas at zero temperature. Using a rigorous perturbative expansion, we show that the presence of the surrounding medium *enhances* the repulsion between dressed bosonic impurities (polarons) in the regime of weak interactions. Crucially, this differs from prevailing theories based on Landau quasiparticles, which neglect the possibility of quantum degenerate impurities and predict an exchange-induced attraction. We furthermore show that the polaron-polaron interactions are strongly modified if the medium chemical potential rather than the density is held fixed, such that the medium-induced attraction between thermal impurities becomes twice the expected Landau effective interaction. Our work provides a possible explanation for the differing signs of the polaron-polaron interactions observed in experiments across cold atomic gases and two-dimensional semiconductors, and it has important implications for theories of quasiparticles and quantum mixtures in general.

1 J. Levinsen, O. Bleu, M. M. Parish, arXiv:2409.03406

Condensed Matter & Materials / 100

Characterisation of Ge-GeSn superlattices grown by remote plasma enhanced chemical vapor deposition

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Germanium-tin (GeSn) alloys have recently emerged as promising materials for infrared photodetectors due to their tunable bandgap, which ranges from the short-wavelength infrared ($<3\ \mu\text{m}$) to the mid-wavelength infrared ($\sim 3\text{--}10\ \mu\text{m}$). Ge-GeSn superlattices offer further advantages, including enhanced carrier confinement and improved absorption efficiency arising from quantum confinement effects. However, the growth of high-quality GeSn superlattices remains challenging, primarily due to strain management, defect suppression, and precise compositional control. We report here the growth of GeSn-Ge superlattices on Ge substrates using remote plasma enhanced chemical vapor deposition (RPECVD), an advanced technique that enables low-temperature, high-efficiency growth with more than 70% precursor utilization and improved Sn incorporation. The material quality of the films, grown with varying layer thicknesses, was systematically investigated using X-ray diffraction, atomic force microscopy, Rutherford backscattering spectrometry, and advanced transmission electron microscopy. These results highlight a viable pathway toward the fabrication of high-performance GeSn-based mid-infrared photodetectors.

Theoretical Physics / 101

Interactions between photons and gravitational field beyond the general theory of relativity

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According to Einstein's general theory of relativity, photons—though massless—are influenced by gravitational fields because gravity acts not as a force in the Newtonian sense but as a manifestation of spacetime curvature. In this framework, a photon follows a null geodesic, meaning its path bends when passing near massive objects due to the warping of spacetime. This leads to several key phenomena: gravitational lensing, where light from distant sources is deflected and magnified by intervening mass distributions; gravitational redshift, in which photons climbing out of a gravitational potential well lose energy and are observed at longer wavelengths; and Shapiro time delay, where light signals take slightly longer to travel past a massive body than they would in flat spacetime. These effects have been experimentally confirmed in contexts ranging from Eddington's 1919 eclipse observations to modern high-precision measurements with radio signals and space telescopes, and they remain essential tools for probing both astrophysical structures and the fundamental nature of gravity. Here we further explore the interactions between photons and gravitational fields beyond above mentioned effects predicted by the general theory of relativity. By utilising the laboratory-based experiments, we show the dependence of the speed of light on the gravitational fields and also demonstrate another source for generating redshift under the influence of the earth gravity.

Poster Session / 102

Dark matter hypotheses and modifications of gravity

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The measured orbital velocity distributions of stars in galaxies and the observed gravitational lensing effects in galaxy clusters suggest that there should be more mass than that can be explained by the visible mass of stars, gas and dust in the galaxies. This unseen mass or matter, generally referred to as dark matter, has puzzled physicists for a few decades and has now become one of the greatest unsolved mysteries in modern science. So far, all of the efforts aiming to generate and detect the exotic dark matter substance have yielded negative results. On the other hand, rather than introducing unseen matter, some physicists explore altering the laws of gravity at large scales or low accelerations. In contrast to the dark matter hypotheses, modifications of gravity theories propose that Newtonian gravity or general relativity breaks down in low-acceleration or large-scale regimes, requiring new dynamics—such as MOND or its relativistic extensions—to explain the same observations without invoking unseen matter. Here, starting from Newton's law of gravity, we show that the spherical mass distribution models originally employed for estimating the masses of galaxies could cause the discrepancy between the actual masses and those calculated from the rotational velocities. It is demonstrated that additional gravitational effects are generated from non-spherical mass distributions in the cosmic structures. The currently observed rotation curves and gravitational lensing effects in galaxies and galaxy clusters could be explained under the frameworks of Newtonian gravity and Einstein's general theory of relativity when proper mass distributions are considered.

Poster Session / 103

Fully convolutional 3D neural network decoders for surface codes with syndrome circuit noise

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Artificial Neural Networks (ANNs) are a promising approach to the decoding problem of Quantum Error Correction (QEC), but have observed consistent difficulty when generalising performance to larger QEC codes. Recent scalability-focused approaches have split the decoding workload by using local ANNs to perform initial syndrome processing and leaving final processing to a global residual decoder. We investigated ANN surface code decoding under a scheme exploiting the spatiotemporal structure of syndrome data. In particular, we present a vectorised method for surface code data simulation and benchmark decoding performance when such data defines a multi-label classification problem and generative modelling problem for rotated surface codes with circuit noise after each gate and idle timestep. Performance was found to generalise to rotated surface codes of sizes up to $d=97$, with depolarisation parameter thresholds of up to 0.7% achieved, competitive with Minimum Weight Perfect Matching (MWPM). Improved latencies, compared with MWPM alone, were found starting at code distances of $d=33$ and $d=89$ under noise models above and below threshold respectively. These results suggest promising prospects for ANN-based frameworks for surface code decoding with performance sufficient to support the demands expected from fault-tolerant resource estimates.

Condensed Matter & Materials / 104

Dirac and Weyl Physics with Plasmons

Author: Dmitry Efimkin¹

¹ *Monash University*

Over the past decade, the discovery of topological quantum matter—such as topological insulators, Weyl semimetals, and topological superconductors—has transformed condensed matter physics. Re-

markably, many of these concepts are not confined to electrons in solids, but also apply to classical waves, from light and sound to water ripples and plasma oscillations.

In this talk, I will show how the collective oscillations of electrons—plasma waves, or *plasmons*—can emulate exotic Dirac and Weyl particles known from high-energy physics. In particular, the hydrodynamic equations for plasmons in a two-dimensional electron gas can be rewritten in a form that mirrors the relativistic Dirac equation for massive spin-1 particles. This perspective makes it possible to realize plasmonic counterparts of well-known phenomena such as Jackiw–Rebbi bound states and other topologically protected modes. I will also discuss how plasmons scatter from tiny micromagnets in ways strikingly similar to Dirac electrons interacting with magnetic impurities—unveiling new regimes of resonant and skew scattering.

Finally, I will extend these ideas to three-dimensional systems, where magnetoplasma waves exhibit striking parallels to the Weyl quasiparticles of electronic materials. This opens new possibilities for engineering and controlling exotic, trapped plasmonic states in solids.

Topological spin-plasma waves - D. K. Efimkin and M. Kargarian - Phys. Rev. B 104, 075413 (2021)

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Weyl excitations via helicon-phonon mixing in conducting materials - D. K. Efimkin, and S. Syzranov - Phys. Rev. B 108, L161411 (2023)

Giant resonant skew scattering of plasma waves in graphene off a micromagnet - C. Finnigan and D. K. Efimkin - Phys. Rev. B 110, L041406 (2024) [Editors' suggestion]

Anomalous skew scattering of plasma waves in a Dirac electron fluid - C. Finnigan and D.K. Efimkin - Phys. Rev. B 111, 165404 (2025)

Astroparticle Physics / 105

Characterisation and Simulation of Photomultiplier Tube (PMT) Response in the SABRE South Experiment

Author: Sharry Kapoor¹

¹ The University of Sydney

Photomultiplier Tubes (PMTs) are central to the SABRE South experiment's ability to detect rare, low-energy events, such as potential dark matter interactions in ultra-pure NaI(Tl) crystals. To correctly interpret what the detector sees, we need simulations that faithfully reproduce how our PMTs respond to real signals. This work presents the comparison of the simulated PMT waveforms from our custom simulation framework with actual SABRE South PMT data.

Key properties such as gain, dark rate, timing response, and afterpulsing are studied in PMT tests to build a clear picture of how the PMTs behave under real experimental conditions. Alongside this, we develop and refine simulated PMT waveforms that aim to capture the key physical and electronic effects shaping the signal. By comparing these simulations directly with data, discrepancies are identified and used to refine the simulation framework. This iterative process helps to improve the accuracy of the detector response simulation, which is crucial for reliable event reconstruction and background rejection.

The major output from this work will be a realistic PMT response simulation framework tailored to SABRE South, built on detailed characterisation of PMT performance from calibration and background runs. Our goal is to bridge the gap between simulation and data, so we can confidently interpret the signals SABRE South observes

Quantum Science and Technology / 106

Cryogenic Memory Elements Using Rare-Earth Nitride Thin Films

Author: Catherine Pot¹**Co-authors:** Atif Islam ¹; Ben Ruck ¹; Jackson Miller ¹; Simon Granville ¹; Will Holmes-Hewett ¹¹ Victoria University of Wellington

The rare-earth nitrides are a series of ferromagnetic semiconductors with suitable properties for cryogenic memory applications, including quantum and superconducting computing systems. When grown as thin films, the magnetic and transport properties of rare-earth nitrides can be tuned independently by varying the growth conditions and rare-earth nitride selection [1]. In particular, solid solutions of two rare-earth nitrides allow for fine adjustment of the coercive field and magnetization [2, 3]. Here we form circular and elliptical islands (with lateral dimensions on the scale of 5 μm) from GdN/LuN/(Gd,Sm)N thin films for cryogenic memory applications. Binary memory states are achieved using the relative ferromagnetic alignment of the GdN layer and (Gd,Sm)N layer [4,5]. At 5 K, the alignment of the GdN layer can be reversed using applied fields in the order of 100 Oe while the (Gd,Sm)N layer maintains its original alignment. The magnetic field produced by the tri-layer islands in the aligned and anti-aligned states is modelled and found to be distinguishable for a nearby Josephson Junction.

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Poster Session / 107

Direct Detection of Dark Photons

Authors: Ashlee Caddell¹; Benjamin Roberts^{None}; Narise Williams²¹ The University of Queensland² The University of Physics

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 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 mass beyond ~ 0.1 GeV, making the detection of the dark photon predicted by Ref. [1] just out of reach.

1 N.T. Hunt-Smith, W. Melnitchouk, N. Sato, A.W. Thomas, X.G. Wang, M.J. White et al., Global QCD analysis and dark photons, *Journal of High Energy Physics* 2023 (2023) 96.

Nuclear and Particle Physics / 108

Developing a Plunger Device for Precise Magnetic-Moment Measurements

Author: Jack Woodside¹

Co-authors: AJ Mitchell¹; Andrew Stuchbery¹; Gregory Lane¹

¹ *Australian National University*

Comparison between large-basis shell-model calculations and experimental data gives insights into the emergence of nuclear collectivity. One experimental observable that can be examined is the g factor, which gives a sensitive test of the proton versus neutron character of the nuclear states. There are extensive data on the first-excited states of even-even nuclei measured by the transient-field technique [1]. However, these data have a large uncertainty due to the difficulty of calibrating the transient-field strength, and there are no suitably precise known g factors for nuclei with atomic numbers $14 < Z < 40$.

One way to provide applicable calibration g -factor values is the recoil-in-vacuum method using a plunger device [2]. The device consists of two parallel foils, with a mechanism to adjust the distance between them precisely. Once the nuclei of interest have been created via a suitable nuclear reaction in the first 'target' foil, they recoil through the vacuum towards the second 'stopper' foil. The hyperfine fields from the recoiling ion's electron configuration will couple with the nuclear spin, causing the nucleus to precess about the coupled spin with a frequency proportional to the g factor of the state, until the ion is stopped. This precession can be observed via the angular distribution of the emitted γ rays. Varying the distance between the foils allows the observation of the time-dependence of the nuclear precession, which in turn allows the measurement of the g factor, as the hyperfine fields can be calculated precisely [3].

This talk reports on recent progress in the development of a new plunger device. This new capability will allow precise reference measurements to be performed for a wide range of nuclei, providing crucial calibration values for a large set of both past and future g -factors measurements.

Poster Session / 109

Foundations of Quantum Tunnelling in Interacting Systems

Authors: Cedric Simenel^{None}; Max Fleming^{None}

Quantum tunnelling is a fundamental process, ubiquitous across nature and technology, with a prominent role in phenomena ranging from stellar fusion and ATP synthesis to nanoscale electronics. Standard descriptions based on single-particle quantum mechanics (QM) or its relativistic version (RQM) have demonstrated utility, accurately predicting alpha particle decay half-lives across 26 orders of magnitude. However, these frameworks are fundamentally incomplete as they do not account for many-particle effects. The need to incorporate interactions becomes apparent in many-body systems like nuclear fusion, where existing models fall short, accounting for these effects phenomenologically rather than from a fundamental theory.

This project aims to develop a Quantum Field Theoretic (QFT) formalism for tunnelling in interacting fermion (spinor) fields. A key motivation is to investigate how the extension to QFT resolves theoretical inconsistencies in RQM, such as the Klein paradox, by naturally including processes such

as pair production. In addition, QFT's precisely validated predictions, such as the electron g-factor's quantum correction, stand as a testament to the value of incorporating interacting field dynamics. The primary goal is a method for calculating QFT scattering amplitudes that extends into the non-perturbative tunnelling regime, thereby allowing an investigation of how interactions modify these amplitudes.

An approach was developed to evaluate the infinite S-matrix expansion for above-barrier fermion scattering, known as channelling. This involved deriving coupled recursion relations for the perturbative series of transmission and reflection amplitude contributions. The resulting non-perturbative, all-order coupled system was shown to extend into the previously divergent tunnelling regime, where the approach reproduced RQM tunnelling amplitudes. Subsequently, an extension of the method was investigated to incorporate leading-order interaction effects via QED-like vertex corrections.

The QFT formalism developed in this work provides a promising foundation for investigating how the quantum vacuum and many-particle dynamics influence tunnelling phenomena beyond the limitations of single-particle theories.

Focus Session: Frontiers of Medical Physics / 110

Development of a GEANT4 dosimetric system for orthovoltage x-ray minibeam radiation therapy clinical trials

Authors: Christopher White¹; Chrystian Quintero Mateus²; Darwin Garcia²; Douglas Moseley²; Jason Paino³; Marco Petasecca³; Maryam Mashayekhi²; Michael Grams²; Michael Lerch³; Mihails Nikandrov⁴; Robert Mutter²; Scott Lester²; Sean Park²; Susanna Guatelli³; Vincent de Rover³

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² Department of Radiation Oncology, Mayo Clinic

³ University of Wollongong

⁴ St. Luke's Radiation Oncology Network, Dublin

Aims:

Recently the first first-in-human minibeam radiation therapy (MBRT) treatments with an orthovoltage x-ray unit at Mayo Clinic, Rochester, Minnesota was presented. We present the development of a GEANT4-based radiation transport model to simulate the minibeam radiation field produced using a clinical orthovoltage machine.

Materials and Methods:

The full clinical orthovoltage machine was modelled in GEANT4 monte carlo toolkit (version 11.1.0) based off the Xstrahl 300 orthovoltage unit used in clinical treatments, with a Phase Space File created at the cone exit. A separate GEANT4 simulation was used to model the orthovoltage x-rays downstream from the cone, where the multi-slit collimator and PlasticWaterTM was setup with the same dimensions as those used when obtaining experimental measurements.

The experimental film measurements were compared to the resulting simulation dose results, for both broad beam and MBRT peak and valley percentage depth dose (PDD) curves. The model was validated for a range of cone sizes (3, 4, 5, 8 and 10cm) and beam energies (100, 180, 250kV).

Results:

For BB PDDs an agreement within 4% was observed between the GEANT4 simulation and experimental results for all field sizes and beam energies investigated. For the minibeam peak PDDs there was good agreement with the largest percentage difference of 9%. For the valley dose PDDs however, the GEANT4 simulations consistently underestimated the valley dose with average percentage differences ranging from 7% to 27%, depending on the cone size and beam energy. Furthermore, when simulating the MSC rotated 90 degrees, with respect to the anode-axis, this resulted in large differences in peak-to-valley-dose-ratio at depths from 40mm, which was confirmed experimentally. Overall, the model had good agreement between the broad beam and minibeam peak PDDs when compared to experimental results, presenting the first step towards MBRT dose calculations for patient specific volumes.

Poster Session / 111

Towards On-Demand Loading of Nanoparticles in Ultra-High Vacuum for Quantum Levitodynamics

Authors: Angus King¹; Cyril Laplane¹; Robert Wolf¹; Samuel McNeil²

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Levitated optomechanics offers a promising pathway to explore the boundary between quantum and classical physics, as well as for quantum-enhanced sensing with mesoscopic objects. In particular, levitated silica nanoparticles cooled to their quantum ground state could enable fundamental tests of quantum mechanics. Achieving this goal requires efficient particle loading into ultra-high vacuum (UHV) hybrid traps that combine optical and electrodynamic confinement, allowing for optimal quantum control.

We present progress towards implementing laser-induced acoustic desorption (LIAD) as a robust and clean method for loading on-chip hybrid traps with silica nanoparticles at UHV conditions. LIAD involves ejecting particles from the surface of a thin metal foil, initiated via a high-intensity laser pulse. Thin targets were fabricated and characterised using scanning electron microscopy, while tests were conducted in atmosphere to extract loading statistics. LIAD particle emission was monitored with high-speed imaging and analysed to determine the feasibility for UHV integration.

Integrating LIAD with on-chip hybrid traps in ultra-high vacuum allows experiments to reach pressures where decoherence from background gas collisions no longer constrains the observation of quantum effects. This advancement supports both high-precision sensing and rigorous experimental tests of quantum mechanics in the mesoscopic regime.

Nuclear and Particle Physics / 112

Enhancing Orbit Correction in Next Generation Lepton Accelerator Storage Rings

Author: Tasman Harvey¹

Co-authors: Jeremy Brown¹; Nadia Zatsepin¹; Rohan Dowd²; Tessa Charles²

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Accelerator storage rings for light sources and colliders are highly sensitive to magnet misalignments and field errors. These imperfections distort the orbit, which negatively impact the brightness or luminosity. Precise orbit correction plays a vital role in optimising the performance of next generation lepton accelerators.

CERN's proposed e⁺/e⁻ Future Circular Collider (FCC-ee) is a 91 km high energy dual lepton storage ring aimed at achieving unprecedented luminosities with energies from 45.6 GeV to 182.5 GeV per beam 1. ANSTO is also researching a fourth generation 3 GeV light source called AS2, proposed to replace the current Australian Synchrotron when it reaches end of life 2. Both accelerators require strong sextupoles to achieve ultra-low emittance at the pm-rad scale. The orbit offset inside these magnets strongly impacts optics distortion and ultimately accelerator performance. To correct the orbit distortion, numerical simulation toolkits developed by CERN including MAD-X, Xsuite, and Xutil, were used 3.

This presentation explores a systematic approach to linear orbit correction using Singular Value Decomposition (SVD) and how it could benefit current and next-generation storage rings. We demonstrate that the degree of correction is greater through certain magnets and discuss improvements

made by considering the Beam Position Monitor (BPM) noise floor to determine a threshold for the number of singular values included in the correction.

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Condensed Matter & Materials / 113

Emergent momentum-space topological pseudospin defects in non-Hermitian systems

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Point defects in spinor fields protected by topological invariants, the winding of the spinor configuration around the centre of the defect, have attracted a great amount of interests as they present a potential platform for spintronics and quantum communication. In this work, we present the generation of momentum-space pseudospin (polarization) defects in non-Hermitian exciton-polariton systems. Exciton-polaritons are hybrid light-matter systems arising from the strong coupling between the electron-hole pairs (excitons) in semiconductors and the cavity photons. The exciton polaritons have momentum-dependent dissipation inherited from their photonic components, and therefore, they can be described by effective non-Hermitian Hamiltonians, which give rise to complex-valued eigenenergies. Hence, exciton polaritons feature new types of complex energy structures, such as the bulk (imaginary) Fermi arcs, where the real (imaginary) parts of the eigenenergy cross, and degeneracies, where both the real and imaginary parts of the eigenenergies cross, such as the exceptional points and hybrid points. Therefore, exciton polaritons present an experimentally accessible platform to study the non-Hermitian physics where the exceptional points and the pseudospin textures have been directly measured.

In this work, we consider two non-Hermitian two-band two-dimensional models, and describe the emergence and dynamics of topological pseudospin defects that spontaneously appear on the vicinity of the imaginary Fermi arcs in momentum space. We also show that while in the fully gapped phase, the defects annihilated each other, in the gapless phases, the non-Hermitian degeneracies protect the defects from annihilation. We also show that the qualitative change of the defect dynamics from the gapped to gapless phases can potentially be experimentally measured using the skyrmion number. Our work shows the rich new physics in non-Hermitian systems and our theory can be realized using a liquid-crystal based exciton polariton system.

Condensed Matter & Materials / 114

Ion beam engineering of topological insulating surfaces drives electronic transitions via radiation-induced disorder

Author: David Cortie^{None}

The discovery of the topological phases of matter sparked a renaissance in solid-state physics; however, broader applications to materials engineering are still in their infancy. Three-dimensional

topological insulators offer a particularly simple new paradigm for developing unique functionality, which relies on the custom design of edges, surfaces, and interfaces.

The interplay between classical crystal and magnetic order parameters is critical in these materials, and glass transitions have important consequences for their electronic properties. For example, delicate van der Waals crystals are highly sensitive to electron and ion beam irradiation [1,2,5], which can be used to deliberately drive glass transitions and spatially control the topological invariant, toggling between $Z_2 = 1 \rightarrow Z_2 = 0$ at a threshold disorder strength 1. Controlled glass transitions are also important in the search for elusive higher-order amorphous topological insulators predicted by theory.

To enable accurate, non-destructive characterisation of electron density and spin density with atomic resolution, neutron and X-ray scattering have some intrinsic advantages. I will discuss how surface-sensitive neutron and X-ray techniques, including polarised neutron reflectometry, can provide unique insights into classical crystal and magnetic order-disorder transitions, and their concomitant electronic quantum transitions.

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Condensed Matter & Materials / 115

Single crystal developments on Wombat, the high intensity neutron diffractometer at ANSTO

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The Wombat instrument is one of a few neutron diffraction instruments in the world to have a large position sensitive (effective area) detector, which has greatly supported the wide range of science applications and outcomes the instrument is able to undertake 1. To date there have been limited single crystal studies undertaken on the Wombat instrument due to peak integration software being unavailable. Recently, we have liaised with the developers of the software INT3D 2 to overcome this. The work presented will showcase recent experiments on Wombat that have utilised this new analysis pipeline, as well as the Eulerian cradle with cryostat option. Coupled with this development in single crystal analysis, there is also work afoot to streamline crystallographic texture and diffuse scattering measurements on the instrument, which would also make full use of the detector capability.

1 Maynard-Casely, Tobin et al, (2025) arxiv.org/abs/2504.19429 submitted to J App Cryst

2 Katcho, N. A., et al (2021). Crystals, 11(8), 897.

Quantum Science and Technology / 116

Quantum State Preparation using Dynamical Invariants and Machine Learning

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Quantum technology is expected to have revolutionary impact on different areas including computation, communication, and sensing. The first step in any quantum application is state preparation, where it is required to transfer the system from a fixed initial state to a final target state. This task can be challenging to perform, especially in non-Markovian open quantum systems. Invariant-based inverse engineering provides an effective way to achieve desired state in quantum systems. However, the current methods mostly use parametrizations which could result in unrealistic pulses, limiting their applicability. Recently, noise mitigation methods have been proposed based on minimizing the overlap between the invariant operator and the dissipation operators in a Lindblad master equation, which is only valid for special classes of noise. In this paper, we address both these limitations and propose an invariant-based protocol for preparing single-qubit states under a general noise setting. We introduce two variants of the protocol, one based on the assumption of exact knowledge of the noise affecting the qubit, and the other for the more realistic case of unknown noise. Our numerical results show high fidelity for various target states in both scenarios showcasing the versatility of our approach. This opens new pathways for quantum control of NISQ devices.

Industrial Applied Physics / 117

Quantum nonlinear parametric interaction in realistic waveguides: a comprehensive study

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Nonlinear sources of quantum light are foundational to nearly all optical quantum technologies and are actively advancing toward real-world deployment. Achieving this goal requires fabrication capabilities to be scaled to industrial standards, necessitating precise modeling tools that can both guide device design within realistic fabrication constraints and enable accurate post-fabrication characterization. In this talk, we introduce a modeling framework that explicitly integrates the engineering tools used for designing classical properties of integrated waveguides with quantum mechanical theory describing the underlying nonlinear interactions. We analyze the validity and limitations of approximations relevant to this framework and apply it to comprehensively study how typical fabrication errors and deviations from nominal design – common in practical waveguide manufacturing – affect the nonlinear optical response. Our findings highlight, in particular, a critical sensitivity of the framework to group-velocity dispersion, the potentially disruptive role of geometric inhomogeneities in the waveguide, and an upper bound on single-mode squeezed-state generation arising from asymmetric group-velocity matching conditions.

Theoretical Physics / 118

The quantum theory of time: detail modelling of the effects of T violation

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The violation of the discrete symmetries of charge conjugation (C), parity inversion (P), and time reversal (T) observed in high energy physics are fundamental aspects of nature. A new quantum theory [1,2] has been introduced to explore the possibility of their large-scale physical consequences. The new theory does not assume any conservation laws or equations of motion at the outset. In particular, if T violation is turned off, matter is represented in terms of virtual particles that exist momentarily only. However, with T violation turned on, what was the mathematical structure of a virtual particle now traces out an unbounded world line that satisfies conservation laws and an equation of motion. Time evolution and conservation laws are found, therefore, to be phenomenological repercussions of T violation.

The relative scale for clock time is determined by the effective strength $\lambda = i\langle[\hat{H}_F, \hat{H}_B]\rangle$ of the T violation, where $\hat{H}_F$ and $\hat{H}_B = \hat{T}\hat{H}_F\hat{T}^{-1}$ are the Hamiltonians for forward and backward time evolution, respectively, and $\hat{T}$ is the time reversal operator. It implies that the time shown by an accurate clock depends on the value of λ in its local region, and so two identical clocks will lose synchronicity if they are in spatial regions with differing values of λ . Importantly, this effect is manifested as differences in the *quantum states of the clocks* rather than differences in coordinate times.

I will present the latest results of modelling T violation in kaons, neutrinos, and spontaneously broken symmetries in scalar fields. The focus is the potential for experimental tests of the loss of clock synchronicity using neutrinos emitted by nuclear reactors.

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Nuclear and Particle Physics / 119

Parity Violation as a Tool to Perform Spectroscopy Inside Quantum Materials Using β -NMR

Author: David Cortie^{None}

Nuclear magnetic resonance exploits the delicate sensitivity of nuclear spin to characterise the local dynamics and structure of the surrounding chemical and magnetic environment inside materials. β -NMR is an extension of this technique, similar to muon spectroscopy, which relies on the detection of anisotropic beta emission produced by a polarised radioactive isotope such as ^8Li . This allows for the measurement of local magnetic susceptibility, electric field gradients, and ionic transport processes.

In the past, this technique was successfully deployed as a bulk probe of matter using the capture of polarised thermal neutrons at Grenoble 1. More recently, low-energy spin-polarised beams have been prepared at TRIUMF, Canada, enabling depth profiling of thin films and surfaces at depths ranging from 1 to 100 nm [2,3]. The ability to study surfaces and buried interfaces makes low-energy β -NMR a local real-space probe that complements reciprocal space techniques like polarised neutron reflectometry, offering different sensitivity to low-moment magnetism and the inelastic regime of dynamics and fluctuations.

We present a specific example of β -NMR in antiferromagnetic epitaxial $\alpha\text{-Fe}_2\text{O}_3$ [4] and in 2D antiferromagnet FePS_3 . This study shows that the nuclear spin-lattice relaxation rate of the implanted ^8Li spin provides a sensitive measure of surface-localised spin dynamics and spin reorientation of the antiferromagnetic interface near the Morin transition. A variant of the technique using polarised neutron capture at ANSTO is also discussed.

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Poster Session / 120

Reflectometry using polarised cold neutrons to probe quantum heterostructures

Author: David Cortie^{None}

The pioneering experiments of Fermi and others in the 1940s revealed that thermal and cold neutrons exhibit coherent quantum wave phenomena such as interference, diffraction, and reflection 1.

It was soon recognised that this unique quantum beam offered major advantages for studying atomic structures in solids. Today, numerous international facilities produce brilliant neutron beams to probe soft and hard condensed matter across scales from sub-nanometers to centimetres, and dynamics ranging from hours to picoseconds. These include instruments at the Australian Centre for Neutron Scattering 2 and other sources in Asia-Oceania 3.

This poster explores neutron surface reflection from ultra-thin films and presents the exact solution to the 1D Schrödinger equation describing this process. This enables modelling of experimental data to probe nanometer-scale magnetic depth profiles of surfaces and thin films, down to the monolayer limit. Experiments are routinely conducted on the Platypus reflectometer at the Australian Nuclear Science and Technology Organisation, supporting diverse studies in physics, chemistry, and biology, with over 198 publications [4]. The technique is ideal for investigating quantum heterostructures with magnetic or superconducting components. Applications include ultrathin “2D” magnetic films [5], topological insulators [6], strongly correlated oxides [7], hydrogen reactions [8], superconductors [9], and graphene growth [10]

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Atomic and Molecular Physics / 121

Accessing higher-order nuclear magnetization moments with muonic atoms

Authors: Thakur Giriraj Hiranandani¹; Odile Smits²; Benjamin Roberts^{None}; Jacinda Ginges^{None}

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Little is known about the distribution of magnetization inside the nucleus. While nuclear charge distributions may be well understood through techniques like electron scattering, muonic atom spectroscopy, and precision measurements of atomic isotope shifts, nuclear magnetization distributions are much harder to probe.

We highlight and exploit a property of heavy muonic atoms that enables the determination of higher-order magnetization moments of the nucleus. Contrary to the electronic wave functions in usual atoms and ions, muonic wave functions are distinct for different states in the nuclear region. We show that measurements of hyperfine constants for several different states of muonic atoms give access to magnetization moments of the lowest $\langle R^2 \rangle$ and higher orders, $\langle R^4 \rangle$, $\langle R^6 \rangle$, etc. A measurement for an electronic system (H-like ion) gives additional information, though there is little, if any, benefit from a second electronic state. We demonstrate our approach in the nuclear single-particle model, and show how it may be used in a model-independent way. We demonstrate our approach

using ^{209}Bi and ^{205}Tl , for which data are available for multiple muonic atom states and for H-like ions. We hope work stimulates new hyperfine measurements with muonic atoms, together with H-like ions, and provides a unique avenue for testing nuclear structure models and probing the neutron distribution.

Quantum Science and Technology / 122

Transient Coherence Dynamics of Trapped Exciton-Polariton Condensates

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Co-authors: Andrew Truscott¹; Elena Ostrovskaya²; Eliezer Estrecho²; Mateusz Król¹; Thomas Donda²

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Exciton-polaritons (polaritons), hybrid quasiparticles formed by excitons coupled to microcavity photons, are known to undergo Bose–Einstein condensation at elevated temperatures. One of the defining features of polariton condensation is the formation of long-range order both in space and time, as demonstrated in continuous wave measurements, which is non-trivial due to the inherently non-equilibrium nature of the system. Since coherence lies at the heart of most polaritonic applications, understanding how long-range order is established within the condensate is crucial for designing polaritonic devices.

Here, we study early dynamics of the temporal evolution of a trapped polariton condensate's spatial coherence by measuring the first-order correlation function under pulsed excitation conditions.

Our results reveal a significant time gap between condensate formation and coherence establishment. Before coherence is fully established, there is transient behavior characterized by the sudden growth and decay of spatial coherence for up to ~300 ns. After the transient period, the system transitions into a steady-state regime characterized by high correlation values, indicating a well-established, high degree of coherence within the condensate. This later behavior persists, even though polariton density is continuously decaying after the initial excitation.

Our results suggest that the observed transient dynamics comes from the multimode character of the polariton condensate at the early stages of condensation. In particular, the overlap between the incoherent excitonic reservoir and the higher-energy modes of the condensate, degrades the polariton coherence and competes with the energy relaxation process that drives the condensation into a highly coherent ground state. As the condensation progresses, all polariton population collapses to the ground state (trap's center), spatially separating the condensate from the reservoir and eradicating the decoherence effects.

The insights gained from this study will enable more precise engineering of stable, coherent polariton condensates, and therefore enhance the scalability and performance of polaritonic devices.

Quantum Science and Technology / 123

Moments-based ground-state energy estimation for pre-fault tolerant quantum hardware and beyond

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Ground-state energy estimation of chemical systems is perhaps one of the most promising applications of emerging quantum processors. However, the presence of noise makes near-term implementation of quantum algorithms challenging, while fault-tolerance at the scale required for useful computation remains a medium-term prospect. We present Hamiltonian moments-based approaches to ground-state energy estimation that aim to bridge the gap between near-term variational methods and fault-tolerant quantum phase estimation. The methods avoid the challenges faced by variational methods stemming from iterative trial-state optimisation, while the quantum circuits are both shorter and more robust to noise than those necessary for phase estimation. Our proof-of-principle quantum hardware demonstrations combined with numerical and analytic investigations give insight into the requirements for scaling to treatment of larger systems as hardware improves and enters the fault-tolerant regime. Since the error correction overheads required for phase estimation prohibit near-term or early fault-tolerant implementation for chemical systems of meaningful sizes, alternatives, such as moments-based methods, are much more promising pathways to achieving a useful quantum advantage in the near- or medium-term.

Poster Session / 124

Exploring superconductivity of the $(Hf_{0.2}Mo_{0.2}, Ta_{0.2}, Nb_{0.2}, Ti_{0.2})B_2$ high entropy alloy and its metal diborides: The effect of adsorbed hydrogen

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Interest in 2D superconducting materials has been gaining momentum in recent years due to its potential applications for nanoscale devices such as superconducting transistors, quantum interferometers, and superconducting qubits. In particular, a family of materials known as layered hexagonal metal borides (MB_2) has garnered intrigue as a probe for investigating the behaviour of superconductivity at the 3D to 2D transition. This is due to the fact that many of these MB_2 compounds are chemically exfoliable from single-crystalline layered ternary borides. Numerous MB_2 compounds have been shown experimentally to be superconducting in bulk form. Among them MgB_2 has demonstrated the highest electron-phonon mediated superconducting transition temperature ($T_c = 39$ K) at ambient pressure to date. Furthermore, MgB_2 is shown to be strongly influenced by surface states, as demonstrated by significant changes in its T_c when thinned down to monolayer thickness, as well as to surface hydrogenation of the 2D structure. Interestingly, the formation of high-entropy metal diborides have been reported. These structures are composed of 2D high-entropy metal layers, separated by 2D boron nets. They represent a new class of high-entropy materials, which are not only among the first high-entropy non-oxide ceramics fabricated, but also possess a unique non-cubic (hexagonal) and layered (quasi-2D) crystal structure.

Using density functional theory with the Eliashberg formalism we investigate phonon-mediated superconductivity in the 2D $(Hf_{0.2}Mo_{0.2}, Ta_{0.2}, Nb_{0.2}, Ti_{0.2})B_2$ high entropy alloy and its metal diborides with varying surface hydrogenation to provide insight into how different metal dopants and surface hydrogenation impact the transition temperature of these materials.

Quantum Science and Technology / 125

Quantum phase estimation with optimal confidence interval using three control qubits

Author: Kaur Kristjuhan^{None}

Co-author: Dominic Berry

Estimating the ground state energy of a physical system is an important task in quantum algorithms. If the ground state can be prepared on a quantum computer, then its energy can be estimated using the quantum phase estimation algorithm, which involves applying multiples of a unitary to the ground state, controlled on an auxiliary state prepared on a control register. Textbook descriptions of quantum phase estimation prescribe preparing an equal superposition state on the control register, but much better performance can be achieved with more complicated, entangled states. The state which provides the optimal confidence interval for the estimate is a discrete prolate spheroidal sequence (DPSS) state, which can be difficult and costly to prepare, especially for early-generation fault-tolerant quantum computers.

In this work, we describe an efficient procedure for preparing a DPSS state by using a matrix product state (MPS) approximation and provide an explicit quantum circuit structure for its implementation. We provide numerical evidence showing that for DPSS states configured for confidence levels up to 99.99% and with dimension up to 2^{25} , an MPS approximation with bond dimension 4 achieves fidelity exceeding $1 - 10^{-7}$, inducing a negligible relative decrease in confidence level. Furthermore, we show that when the dimension is a power of two, we can combine our technique with the semi-classical quantum Fourier transform to enable quantum phase estimation with only three qubits allocated to the control register. The ability to freely adjust the dimension of the state on the control register enables the user to pick the most suitable trade-off between confidence interval width and the number of controlled unitary operations applied during the quantum phase estimation algorithm. The scaling and flexibility of our technique make it suitable for performing accurate ground state energy calculations on early-generation fault-tolerant quantum computers.

Poster Session / 126

AI Optimised scalable process matrix tomography

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Noise characterisation is a critical bottleneck in scaling quantum technologies. While uncorrelated errors are relatively well understood, correlated or non-Markovian noise, where memory effects persist across multiple operations remains far harder to capture. This non-Markovian noise has been detected in state-of-the-art quantum devices like those of IBM and Google. However, standard characterisation techniques fail to capture these multi-time dynamics.

The process matrix formalism provides a powerful operational framework for modelling arbitrary multi-time quantum processes, including those with non-Markovian noise. Full knowledge about a multi-time process matrix tells us about both the amount and the type of noise present in the process. However, performing full process matrix tomography requires performing informationally complete operations at each time-step. This implies an exponential increase in the size of the process matrix and the number of operations required.

Here, we use the full characterisation offered by the process matrix approach, but avoid the curse of exponential scaling of resource. We overcome this challenge by combining tensor network techniques with AI-driven optimisation to perform scalable process matrix tomography. Tensor decompositions exploit the underlying structure of correlated noise to compress its representation, while machine learning strategies optimise measurement selection and parameter estimation. This hybrid approach drastically reduces resource requirements, enabling multi-time process reconstruction far beyond the reach of conventional methods.

Our method aims to offer a resource-efficient route to characterise non-Markovian noise in large multi-time processes. It offers not only to quantify the degree of non-Markovianity present, but also to predict future experimental outcomes with high fidelity. These predictive capabilities open

new pathways for noise-aware control, error mitigation, and design of adaptive experiments; the essential steps to robust, large-scale quantum technologies.

Quantum Science and Technology / 127

Exponentially Enhanced Laser Coherence through Cascaded Cavities

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The pursuit of highly coherent light sources is fundamental to advancements in quantum metrology, sensing, and communication. Although the Schawlow-Townes limit, where coherence scales as the square of the number of photons in the laser cavity, has long defined the standard for laser coherence, recent work ¹ established a more fundamental limit, the “Heisenberg limit”, where coherence scales as the fourth power of the photon number. This is achievable with specially engineered input-output relations.

We present a novel and more accessible architecture that exponentially surpasses the Heisenberg limit using only standard optical components. Our method involves cascading a series of standard subthreshold laser cavities, where the output of one cavity serves as the input of the next. We demonstrate analytically that a simple two-cavity cascade reproduces the Heisenberg scaling without requiring unconventional cavity designs.

In general, we show that for N cascaded cavities, coherence can scale exponentially with the total intracavity photon number. This is made possible by violating the assumption of ideal Glauber coherence statistics, upon which the Heisenberg limit is predicated. The cascaded system introduces correlations across multiple, distinct timescales corresponding to the linewidth of each cavity, allowing it to store significantly more phase information than a single cavity.

However, this exponential scaling is not without caveats. As we discuss within the paper, the practical implementation faces considerable challenges, including the utility of the resulting non-standard photon statistics and the demanding experimental conditions required. Our work therefore initiates an analysis of this fundamental trade-off, highlighting the path for future research into overcoming these limitations.

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Bragg medal session / 128

Magnetically ordered erbium crystals for microwave-to-optical transduction

Authors: Matthew Berrington¹; Toby Hardcastle²; Lara Gillan²; Matthew Sellars²; Jevon Longdell³; Henrik Ronnow⁴; Hyma Vallabhapurapu¹; Chris Adambukulam¹; Arne Laucht¹; Rose Ahlefeldt²

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A transducer capable of converting quantum states from the microwave domain to the optical domain would greatly enhance the capabilities of superconducting qubits. The long-distance transmission capabilities permitted in the optical domain would allow distributed computing, paving the way for a worldwide quantum internet.

One approach to building a quantum transducer exploits the spatially uniform magnons present in fully concentrated rare-earth crystals. Fully concentrated rare-earth crystals have received little attention for quantum technology applications yet offer unique capabilities due to their strong optical resonances and magnetic interactions.

We experimentally characterised the 1540nm optical transitions of LiErF_4 , a planar dipolar antiferromagnet that orders at $T_c=370\text{mK}$. The spectrum was dominated by strong lines that modify the bulk refractive index of the crystal, as well as magnon sidebands to these strong lines. The observed optical structure was well described by a mean-field magnetic model applied to a single erbium ion. Extraordinarily narrow satellite lines were present in the magnetically ordered phase, with an inhomogeneous linewidth of 18MHz. This is among the narrowest optical inhomogeneous linewidths ever observed in the solid state. The properties of LiErF_4 were suitable for quantum transduction, and could support a transduction bandwidth of several megahertz.

Focus Session: Emerging Materials and Physics for Energy Conversion / 129

Adsorption of Water on Cocatalyst Surfaces for Photocatalytic Water Splitting

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Photocatalytic water splitting is a promising technology for using solar energy to produce directly hydrogen (green hydrogen (GH₂)). GH₂ is considered to be environmentally friendly and renewable energy based fuel. However, only a few semiconductor materials have been developed as efficient photocatalyst, amongst them photocatalysts based on Al:SrTiO₃. (1) A typical photocatalyst consists of three components: i) a semiconductor absorbing light and generating electron/hole pairs which migrate to ii) co-catalysts driving the hydrogen evolution reaction (HER) and oxygen evolution reaction (OER) and iii) a protective overlayer blocking the reaction of the produced H₂ and O₂ back to H₂O, i.e. blocking the backreaction. (2, 3) Co₃O₄ can be used as OER co-catalyst and Rh NPs as HER co-catalyst SrTiO₃ (STO) while Cr₂O₃ as overlayer to block the backreaction. One of the questions which is not well understood is the contribution of the adsorption process of H₂O onto the photocatalyst in driving the H₂O splitting reaction. Does H₂O adsorb as water onto the photocatalyst or does it turn into e.g. OH⁻ as a first step in the H₂O splitting process. In the present work this question is investigated. This question is investigated with electron spectroscopy. Firstly, X-ray Photo-electron Emission Spectroscopy (XPS) is employed as a common technique to investigate the chemical compositions of the surfaces including the adsorbates. Secondly, Metastable Induced Electron Spectroscopy (MIES), the most surface-sensitive technology for analyzing the surface, to determine the electronic structure and thus the molecular composition of the outermost layer. It was found with XPS and MIES that on STO (100) water partially dissociates forming OH⁻ and H₂O on the surface. However, Rh NPs and Cr₂O₃ photodeposited on STO (100) resulted that only OH⁻ was detected for both materials. These observations may support the Rh NPs and Cr₂O₃ rules to enhance the overall photocatalysis water splitting.

Focus Session: Ultra-cold atoms and quantum technology / 130

Experiments on mass and momentum-entangled pairs of ultra-cold He* atoms

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Nonlocal entanglement between pair-correlated particles is a highly counter-intuitive aspect of quantum mechanics. While the rigorous Bell's inequality framework has enabled the demonstration of such entanglement in photons and atomic internal states, no experiment has yet involved motional states of massive particles. Here we report the experimental observation of Bell correlations in motional states of momentum-entangled ultracold helium atoms, with entanglement generated via s-wave collisions. Using a Rarity-Tapster interferometer and a Bell-test framework, we observe atom-atom correlations sufficient to violate a Bell inequality. A theoretical proposal is also discussed for how this system could be extended to an entangled state of different mass atoms generated between ³He and ⁴He collisions. This would potentially open new avenues for studying gravitational effects in quantum states.

Theoretical Physics / 131

Wavelet analysis of quantum fields that self interact

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Shannon theory has been a very useful tool for studying quantum field theories with an ultraviolet cutoff as simultaneously continuous and discrete on a lattice. Recently this has been extended to fields without a cutoff using wavelets, presenting free (continuous) quantum fields in n dimensions as equivalent discrete lattice theories in n+1 dimensions with potentially holographic properties. This work furthers this endeavor through the use of Shannon wavelets on quantum field theories that can self interact, answering the question of 'how can particles in a wavelet decomposition *jump* from one wavelet scale to the next?'

We also present a ruleset towards what types of interactions and correlations are allowed or disallowed in wavelet based quantum field theory.

Condensed Matter & Materials / 132

Magnetic twists: Micromagnetic simulations to describe polarised neutron reflectometry data

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Magnetic thin films are important for computing technologies, where atomic-scale control of magnetic properties is required. Here, we present a 1D micromagnetic simulator (microM-ref1D) for thin film magnets with twisted magnetization profiles. Importantly, it is integrated with the Ref1D software for polarized neutron reflectometry fitting to accurately extract magnetic parameters.

Using this new software approach, we show that exchange interactions and other atomic-level magnetic parameters can be probed using neutron reflectometry. Mechanical rotation of a film in an applied magnetic field can be used to manipulate magnetization at the nanoscale, to wind a variety of distinctive 1D magnetic structures: exchange springs, propellers and solitons. Each of these structures can be identified by its unique finger print in the Q -dependent neutron spin flip signal of the reflection pattern.

A proof-of-concept experiment using the Platypus polarised reflectometer at the ACNS was conducted to explore the magnetic winding in the ferromagnetic/antiferromagnetic $\text{Ni}_{80}\text{Fe}_{20}/\text{Fe}_2\text{O}_3$ thin film system.¹ After field-cooling and rotation, the presence of a non-collinear component in the spin structure was detected using neutron spin flip analysis. The data is described well using the 1D micromagnetic model for the twist.²

The 1D micromagnetic simulation is general and can be widely applied in polarised neutron reflectometry fitting to constrain complex models of planar magnets. The aim is to also incorporate simulations into RefNx software at ANSTO.

This research was supported by an IEEE Magnetics Society Education Seed Grant.

¹ D. L. Cortie et al. Phys. Rev. B 86, 054408 (2012).

² B. McGrath, K. L. Livesey & R. E. Camley, Phys. Rev. B 111, 094422 (2025).

Atomic and Molecular Physics / 133

Axion Dark Matter Detection Using Atomic Clocks

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Axions are a promising dark matter candidate as well as a compelling solution to the strong charge-parity problem. Axion dark matter can be modelled as a background, classical field, whose interactions with Standard Model particles and forces give rise to observable effects. Although there are many experiments that search for these axion-induced experimental observables, given the mystery of dark matter, it is vital to develop new experiments.

We propose a novel detection scheme using atomic clocks to detect axion dark matter. The interaction between the axion field and the electron axial vector current can produce time-dependent mixing of opposite-parity states in atomic systems, resulting in an oscillating electric dipole moment (EDM). In the presence of an external electric field, this EDM induces an oscillating Stark shift which can be detected using atomic clocks.

In this work, we estimate the achievable axion mass-coupling parameter space given current atomic clock performance. Preliminary order of magnitude calculations shows promising sensitivity of axion mass-coupling parameter space beyond current astrophysical and laboratory limits. We report on the optimal experimental parameters, including electric field configurations and clock species, that maximise sensitivity while alleviating systematic error.

This new detection scheme has the potential to either detect axions, demonstrating a novel application of atomic clocks in the search for dark matter, or constrain physical axion parameters, in the case of non-detection.

Solar Terrestrial and Space Physics / 134

Data-driven flux emergence with Athena++: comparison of boundary driving strategies

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Despite the large quantity of observational data available, the Sun's magnetic field dynamics remain a mystery. Solar flares and eruptions, which result from the field evolution, can have significant impacts on Earth and our space environment. Data-driven modelling of the solar magnetic field uses photospheric observations as boundary conditions to drive a simulation of the field above the photosphere with the goal of recreating flux emergence and eruptive events. Different strategies for characterising the driven boundary exist in the literature, but there is no consensus on the most effective method. We restrict our focus to treatment of the boundary driving and exclude the considerations associated with augmenting the data itself (e.g. initial field inversions, postprocessing to improve consistency with Maxwell's equations etc). We consider driving using (i) the magnetic field (∇B) or (ii) the electric field (∇E) data. We present simulation results with different choices of data-driving method but under identical problem conditions and with the same numerical tool (Athena++). Previous comparisons in the literature have used different simulation conditions and numerical tools. We compare the results qualitatively (field structures) and quantitatively (magnetic helicity, magnetic energy injection, total energy, and magnetic flux) with results indicating that electric field driving is superior, numerically speaking.

Poster Session / 135

Beyond S_2 : Generalized Higher-Order Product Formulae

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Quantum simulation of molecular Hamiltonians represents one of the most promising applications of quantum computing. At the heart of most quantum simulation algorithms lies the fundamental challenge of decomposing the evolution operator e^{-iHt} for a composite Hamiltonian $H = X + Y$ into a sequence of implementable quantum gates. Product formulae, also known as Trotter-Suzuki decompositions, provide a direct and practical approach to this problem by approximating the full evolution as a product of exponentials of individual Hamiltonian terms.

The systematic construction of high-order product formulae has been extensively studied, with fractal methods providing a general framework for achieving arbitrary accuracy orders. However, these approaches suffer from rapidly growing gate counts, making them impractical for near-term quantum devices. Recent advances have shown that numerically optimized product formulae can dramatically outperform their analytical counterparts.

A common assumption for constructing higher-order product formulae is that they are products of S_2 (second-order Trotter-Suzuki decompositions) operators. In this work, we search for formulae without this constraint, enlarging the solution space with additional free parameters while potentially reducing the total number of required exponentials. In this approach, we systematically derive order conditions from Baker-Campbell-Hausdorff (BCH) expansions in a chosen basis for the evolution operator, yielding systems of nonlinear equations that we solve using numerical root-finding methods. Our fourth-order formula achieves a 79% reduction in eigenvalue error while using fewer exponentials than existing methods. For sixth-order, our formula achieves a 50% reduction in eigenvalue error with a comparable number of exponentials to state-of-the-art approaches. These results show that exploring the enlarged parameter spaces combined with advanced numerical optimization can help us find better product formulae for Hamiltonian simulation, particularly relevant for early fault-tolerant quantum computers, where gate count remains critical.

Physics Education / 136

The importance of teacher upskilling in physics: Insights from the design and delivery of a Physics Skills Enhancement Micro-credential

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Australia faces a significant shortage of qualified high school physics teachers, with over 1 in 5 reportedly teaching “out-of-field”. This scarcity negatively impacts student choices and success, contributing to a broader skilled worker shortage. There is also substantial demand for individuals with physics skills to support the Australian Government’s investment in nuclear technology and to build an AUKUS-ready workforce.

To address this skill gap and better prepare students for future STEM success, Flinders University designed and delivered a Micro-credential Physics Skills Enhancement course (MCPSE) in 2025. The key objective of this course is to upskill teachers and equip them to deliver physics effectively, thereby preparing students for careers in high-demand industries such as nuclear, defence, and submarine construction. The course is open to both physics and non-physics teachers and has no prerequisites. Its content is comprehensive focusing on building nuclear and submarine physics knowledge, training teachers in using hands-on demonstrations and storytelling approaches, and developing experimental skills using the tools of physics.

Initial findings from the pilot intake, which included teachers from South Australia (SA), Northern Territory (NT), and New South Wales (NSW), suggest the course is highly valuable. Teachers reported that it equipped them to utilise unused science equipment in their schools and affirmed that the course was meeting their needs for future teaching. Early indications show that the program is effectively boosting teachers’ confidence in delivering physics through hands-on methods. The strong demand for the course is evident, as teacher enrolments more than doubled for the second intake, which now includes teachers from across Australia, encompassing various states and regional areas like Victoria (Vic), Queensland (QLD), Western Australia (WA), NSW, SA and NT. These preliminary findings underscore the importance and high demand for teacher upskilling in physics.

Quantum Science and Technology / 137

Quantum Fast Multipole Method

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In quantum algorithms for simulation of quantum systems, a leading method is to use a product formula approach. The Hamiltonian is written as $H = T + V$, where the kinetic energy T and potential energy V are each calculated. Whereas T can be calculated with complexity n for a system with n charges, calculating V has complexity n^2 and is therefore a bottleneck. This complexity is from summing the pairwise potentials between all charges, but in classical computing the fast multipole method (FMM) enables complexity scaling linearly in n .

FMM uses a sequence of boxes at finer and finer grids. Level 1 is the complete volume, level 2 divides that volume into $2 \times 2 \times 2$ boxes, level 3 further subdivides each of those boxes, and so forth. Each box requires multipole information to be computed from the charges in the box, as well as boxes in its interaction list. In a quantum algorithm, which charges are in each box is governed by values in quantum registers, which would cause an extra factor of n for data access in the complexity for a

naïve application of the classical algorithm. That factor would negate the speedup otherwise enabled by FMM.

Here, we solve that problem by using an approach using quantum sorting. Sorting in quantum computers uses sorting networks with memory accesses in a fixed sequence to eliminate the overhead from memory accesses. We perform a recursive procedure using sorts in each of the three directions to move registers for the charges into the appropriate boxes. To enable an adaptive grid, for each charge we add registers for multipole information for its box and neighbouring boxes. In this way we overcome the data access problem and provide an algorithm nearly linear in n .

Atomic and Molecular Physics / 138

Beyond Mean-Field: Modelling Atom Interactions in Compact Rotation Sensors

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Atomic matter-wave interferometers have demonstrated exceptional long-term stability in precision rotation sensing under controlled laboratory conditions 1. Translating this performance to compact, mobile platforms could revolutionise navigation technologies. Guided matter-wave gyroscopes, which confine ultracold atomic gases in optical potentials, offer a promising route toward miniaturisation and ruggedisation 2. However, the tight confinement required for portability inherently enhances interatomic interactions—introducing complex many-body effects that are absent in free-space configurations 3.

To assess the feasibility of such devices, it is essential to quantify how atom-atom interactions degrade interferometric sensitivity. In this work, we present a detailed numerical characterisation using the multi-mode truncated Wigner (TW) method [4], which captures quantum fluctuations and spontaneous scattering processes beyond the scope of mean-field Gross-Pitaevskii treatments [5]. We also perform an analytical analysis using a simple few mode ansatz in order to fully understand the underlying mechanisms by which the atom-atom interactions cause significant degradation.

By isolating and characterising the degradation due to phase diffusion and four-wave mixing, we identify optimal operating regimes and design parameters for guided matter-wave gyroscopes. This work lays the foundation for compact, high-precision rotation sensors suitable for mobile platforms, and highlights the necessity of many-body quantum modelling in the development of practical cold atom technologies.

1 R. Geiger et al. *AVS Quantum Sci.* 2, 024702 (2020).

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[5] J. L. Helm et al. *Phys. Rev. Lett.* 114, 134101 (2015).

Quantum Science and Technology / 139

Grand Unification of All Discrete Wigner Functions on $d \times d$ Phase Space

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Discrete Wigner functions (DWFs) are central tools for visualising states, signifying nonclassicality, and supporting quantitative analysis in quantum information, yet many inequivalent constructions coexist for each Hilbert-space dimension. This fragmentation obscures which features are fundamental and which are artefacts of representation, and it impedes quantitative comparison of operational properties such as negativity. We present a unifying, dimension-preserving framework that exhausts all possible $d \times d$ DWFs for a single qudit. The key result (Stencil Theorem) shows that every valid DWF arises by cross-correlating a single parent function—the “doubled” Wigner function defined on a $2d \times 2d$ phase space—with a suitable stencil, and that all valid choices of stencils are characterised by simple projection criteria. This construction also yields explicit, invertible linear maps connecting any two DWF definitions at fixed d , enabling representation-independent benchmarking of resource measures and side-by-side comparison of physical predictions, further unifying the landscape.

We illustrate the approach with concrete stencils. For odd d , a reduction stencil reproduces standard frames (Wootters, Leonhardt, Gross). For even d , a coarse-grain stencil averages neighbouring cells—to remove existing redundant information within the doubled phase space—and generates a novel $d \times d$ DWF that lies outside previously studied families. A third, Dirichlet-kernel stencil produces a DWF valid for odd- d yet distinct from Gross’ construction.

Beyond unification, stencils convert redundancy removal from a nuisance into a design choice. The framework organises the landscape of DWFs to a landscape of easily constructible stencils. Furthermore, by relaxing certain criteria, our framework also extends to other quasidistributions (e.g., Kirkwood–Dirac). Overall, this work clarifies what is truly representation-independent at fixed dimension and opens new avenues for studying dimension-agnostic features in discrete phase space.

Condensed Matter & Materials / 140

Domain dynamics regulation in ferroelectric crystals

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In light of the integration requirements of optoelectronic functional devices, the multifunctional optoelectronic crystal lithium niobate has emerged as a crucial matrix material. This development has imposed new demands on crystals, including uniformity of crystal structure, stoichiometric crystals, large diameter, and long equal diameter. Through the innovation of the growth technology of lithium niobate crystal and the upgrading of crystal growth equipment, the growth process technology for high-quality and large-size lithium niobate crystals has been realized, thereby providing high-quality matrix materials for subsequent periodic polarization devices. By conducting in-depth research on the physical mechanism of the microscopic domain structure and domain wall motion of lithium niobate crystal under the influence of a polarized electric field, particularly exploring the coupling between the lattice electronic structure induced by external electromagnetic fields, ionic vibrations, ultrasonic waves, and other mechanical forces and the piezoelectric characteristics of ferroelectric materials, the synergistic effect between the external field and the polarized electric field has been clarified. This has guided the establishment of an efficient periodic polarization technology. A breakthrough has been achieved in the key technology for preparing large-aperture periodic polarized lithium niobate crystals.

Condensed Matter & Materials / 141

Nonlinear wave dynamics on a chip

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Dissipative solitons and localized dissipative structures are ubiquitous, from optomechanics 1 to fluid dynamics 2, and even cosmological defects 3. Dissipative solitons exist in systems far from equilibrium, where energy is continuously being lost and resupplied, which introduces unique properties distinct from analogous systems at equilibrium. These dynamics have been studied extensively in classical systems in wave flumes that are hundreds of metres long [4]; however, in addition to being extremely cost and labour-intensive, these systems still cannot span the entire nonlinear parameter space. We have engineered an optomechanical platform called a wave flume that, combined with nanometre-thick films of superfluid helium, can achieve high nonlinearity and form nonlinear dissipative systems capable of supporting dissipative solitons in several regimes [5]. In this work, we have demonstrated the ability to drive the system such that a single dissipative soliton is produced and locked in position among the fundamental mode of the superfluid third sound wave. Using cavity optomechanics, we are able to couple an optical field to the third sound waves of superfluid helium. Here, the photonic crystal cavity acts not only as the wave generator, but also as the sensor for the wave dynamics; as waves travel across the flume, the local film thickness of the superfluid is changed, which can be optically read out. By increasing the optical intensity, we can generate a dissipative soliton, which locks onto the front of the sinusoidal-like fundamental mode of the wave flume due to its natural tendency to travel faster than the underlying wave. The addition of gain and loss to the system means that the dissipative solitary wave can maintain its amplitude and position along the wavefront ‘forever’, or as long as the optical drive is applied.

Quantum Science and Technology / 142

Enhanced Optomechanical Cooling In Brillouin Waveguides Using Squeezed Light

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Over the past two decades, the field of cavity optomechanics has succeeded in cooling resonant mechanical oscillators down to their quantum ground state. The success of cavity optomechanics has led to various proposals which aim to harness the quantum properties of cooled mechanical systems, including in tests of fundamental physics 1, quantum state preparation 2 and quantum metrology 3. More recently, analogous cooling without optical cavities has been explored using Brillouin-Mandelstam scattering in waveguides. These systems host a continuum of acoustic modes, making them a potential platform for quasi-broadband cooling. However, ground state cooling in waveguides has yet to be demonstrated, with recent experiments achieving cooling of 219 K, but still with a minimum phonon population in excess of $\langle n \rangle = 200$ [4].

In this work we propose a method to enhance the optomechanical cooling in waveguides using squeezed light. We demonstrate how non-classical driving may selectively boost Brillouin scattering from high-frequency phonons. These improvements are analysed from the perspective of the quantum spectral noise. Squeezing the optical field modifies the spectral noise of the nonlinear Brillouin interaction, leading to increased photon-phonon scattering. These results indicate that squeezed light may modify the phononic density of states beyond the standard optomechanical interaction. We find expressions for the strength of these enhancements and find that in certain regimes phononic decay rates can be increased compared to typical laser driving. This work offers a potential avenue for further reducing phonon populations bringing these systems closer to the quantum regime. Additionally, this proposal introduces only minor additional complexity to typical Brillouin cooling experiments and should be readily implementable.

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- [2] M. D. LaHaye, et al., *Science* **304**, 74 (2004).
- [3] M. R. Vanner, et al., *Phys. Rev. Lett.* **110**, 010504 (2013).
- [4] L. Blázquez Martínez, et al. *Phys. Rev. Lett.* **132**, 023603 (2024).

Quantum Science and Technology / 143

Development of a Hybrid Optical-Electrical trap for levitated nanoparticles for quantum sensing and fundamental science

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Levitated optomechanics, the trapping and control of microscopic and mesoscopic particles in vacuum, has seen recent and widespread success including record torque sensitivity 1, and yoctonewton force sensing 2. A levitated nanoparticle is ideal for a ‘macroscopic’ quantum platform due to its intrinsic mass and low coupling to the environment. This presents an exciting avenue for fundamental physics with macroscopic objects as well as providing a system for unparalleled precision sensing 3. The quantum regime for optically levitated systems is primarily impeded by the photon-recoil-shot-noise from the optical levitation field [4], prompting the use of “dark”, non-optical, potentials. Recently, optically levitated systems in vacuum have entered the quantum realm with recent demonstration of cooling to the motional quantum ground state using passive (2D) and active feedback (1D) methods [5, 6, 7]. From here the new frontier is to utilize dark potentials to create non-classical states of motion, requiring both an expansion of the wave-packet and a non-linear interaction. Recent proposals investigate [8] and analyse [9] a double-well dark potential which provides both requirements natively.

We approach this problem with a hybrid planar trap design with a Point-Paul-Trap electrode configuration natively providing a double-well dark potential, and large optical access for a parabolic mirror yielding high quantum measurement efficiency. We will present numerical simulations matching our experimental setup and propose a modified protocol to produce the double-well dark potential which should be robust against the micromotion that usually plagues Paul traps. Finally, we will present results from our experimental implementation, in particular the cooling of the centre-of-mass motion using optical and electrical means, and trapping with RF electric fields and optical potentials. An on-chip hybrid trap would provide state-of-the-art quantum enhanced sensing with both squeezed states and non-gaussian states.

Quantum Science and Technology / 144

Validation tests of Gaussian boson samplers with photon-number resolving detectors

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The development of linear optical quantum computers (QCs) has accelerated in recent years, in part, due to experimental implementations of large-scale Gaussian boson sampling (GBS) devices. These QCs send squeezed state photons into a linear photonic network and output a series of photon count patterns. This seemingly simple task is $\#P$ -hard because, for implementations utilizing photon-number resolution (PNR), output probabilities correspond to the matrix Hafnian, which cannot be computed in less than exponential time for networks with more than 50-modes.

This raises the question, how does one validate the outputs of such devices to determine whether they are producing the correct results? To answer this, we simulate the binned photon counting probabilities of GBS using phase-space representations.

For networks with photon loss, we show that the positive P-representation is accurate and efficient by simulating the GBS experiments of Madsen et al 1, which claimed quantum advantage on a 216-mode network. Utilizing statistical tests such as χ^2 and Z-scores, we show that these experiments do not produce the correct output distribution. Instead, their distribution more accurately replicates a distribution with additional decoherence and measurement errors, although discrepancies remain.

In the lossless and ultra-low loss regimes, the positive P-representation suffers from large sampling errors and slow convergence. To validate GBS in these regimes, we introduce a new type of phase-space representation: the matrix P-representation. This representation unifies group theoretic and phase-space methods by including symmetries and conservation laws in the basis. We show that, by including a phase symmetry generated from a superposition of Schrodinger cat states, one can simulate the binned photon count distribution in these regimes for very large system size.

1 L. Madsen. “Quantum computational advantage with a programmable photonic processor.” Nature 606, 75-81 (2022).

Poster Session / 145

Scalable Preparation of Dicke States via Global Spin Squeezing in 2D Ion Crystals

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Dicke states, permutationally symmetric superpositions of two-level excitations, are pivotal resources in quantum information science and metrology [1, 2]. Their robust multipartite entanglement makes them ideal candidates for surpassing standard quantum limits in sensing and computation. However, generating arbitrary symmetric states in ion traps, Dicke states being a subset, remains challenging due to the need for precise control in large-scale systems.

We propose experimentally implementing a variational quantum circuit protocol, as described in 3, to prepare Dicke states. The protocol consists of initializing a coherent spin state, then interleaving global one-axis twisting (OAT) gates with global Pauli rotations, optimized variationally to minimize infidelity. Numerical simulations indicate that this method can produce Dicke states, such as $|J, M\rangle = |N/2, 0\rangle$, with infidelities below 10^{-3} for a qubit number $N = 300$ 3.

In our lab, a 2D crystal of hundreds of trapped Beryllium ions, in a highly optically addressable Penning trap, is a particularly well-suited platform for this protocol. Squeezing is achieved through spin-dependent optical dipole forces (ODF) coupling the ion $2s^2S_{1/2}$ electronic levels (the qubits) to the center-of-mass mode of the crystal (i.e., motional degrees of freedom), generating an effective Ising-type spin-spin interaction that yields entanglement, as demonstrated in large ion ensembles [4, 5]. On the other hand, arbitrary global Pauli rotations are implemented by high-fidelity microwave pulses.

This work provides a path for experimental realization of symmetric states and enables exploration of quantum simulation of Dicke state dynamics in ion trap-based quantum simulators, opening the possibility for simulating systems known for displaying distinctive collective physical phenomena 3.

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Atomic and Molecular Physics / 146

Atomic parity violation and the caesium polarisability puzzle: A possible solution from inseparable contributions to perturbative expansions

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The measurement of atomic parity violation in Cs currently provides the most precise test of electroweak theory at low energies. High precision calculations of the Stark-induced 6S-7S vector transition polarisability are required to interpret this measurement and determine the level of agreement with the Standard Model prediction. However, there is currently a 2.8σ discrepancy between values obtained for this quantity using two different semi-empirical approaches and the subsequent “polarisability puzzle” is a major source of uncertainty. In this work we propose that the disagreement may be explained by a specific subset of contributions to the relevant perturbation expansion which have thus far been neglected in calculations.

For heavy atoms, the precision of *ab initio* calculations is primarily determined by the perturbative treatment of many-body electron correlation effects. An important class of correlation corrections to valence electron wavefunctions arise due to the presence of additional external fields. Indeed, one must account for the shift in valence-core interactions resulting from the polarisation of the atomic core by the external field.

Stark-induced transition polarisabilities parameterise E1 amplitudes induced when both a static and oscillating electric (laser) field are present. When including core polarisation corrections to second-order amplitudes of this nature, a subset of potentially non-negligible contributions to the perturbation expansion are often neglected in calculations due to their inherently inseparable nature. These corrections correspond to the simultaneous action of both fields in the atomic core.

This so-called double core polarisation has only been considered explicitly for second-order E1 amplitudes induced by the weak interaction. In this presentation, I will outline how one can generalise this formalism to include inseparable contributions for second order amplitudes involving arbitrary fields. In particular, we show that this correction may be large enough to resolve the disagreement between semi-empirical calculations of the 6S-7S vector transition polarisability in Cs.

Poster Session / 147

Quantifying MGD in Heterogeneous Breast Phantoms for Synchrotron Phase Contrast CT- A Simulation-Based Study

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With clinical breast imaging trials soon taking place at the Australian Synchrotron using phase contrast CT, accurately characterising the radiation dose, specifically the Mean Glandular Dose (MGD), is essential for ensuring radiation safety and optimising beam parameters. A GEANT4 simulation study was performed to investigate the effects of beam energies, 32 keV and 35 keV, on anthropomorphic breast phantoms. These phantoms, representing different breast cup sizes ranging from A to D, were modelled as homogeneous and heterogeneous distributions with 30% glandularity. The heterogeneous phantoms had glandular tissue embedded within adipose tissue, consisting of 30% of the breast volume, to simulate realistic tissue distribution. To comply with the 4mGy dose limit

for breast imaging, exposure times were calculated. For homogeneous breast models, safe exposure times ranged from (43 ± 7) seconds at 32 keV to (33 ± 4) seconds at 35 keV, depending on breast size. In the heterogeneous models, individualised glandular distributions led to higher MGD, requiring shorter exposure times to stay within safety limits. Importantly, when the dose was determined using a homogeneous breast tissue distribution and compared to that of a heterogeneous model, the resulting MGD was found to be approximately 30% higher, indicating a potential overestimation of patient dose if homogeneity is assumed in clinical assessments. This highlights the need to incorporate realistic tissue distributions in clinical practice to avoid overestimating patient dose and optimise exposure parameters.

Condensed Matter & Materials / 148

From Mobility to Fidelity: Demonstrating High-Quality Hole-Spin Qubits in a Natural Silicon Foundry Platform

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The global effort to develop a quantum computer is driving the search for scalable methods to manufacture quantum chips and qubits. One promising pathway is to adapt the mature and highly-scalable silicon manufacturing processes that underpin modern electronics. However, the demands on quantum devices are markedly different from those placed on conventional transistors. Quantum chips must operate at temperatures below -270°C and require precise control at the level of a single charge. As a result of these new demands, realising mass-produced silicon quantum chips will require new materials and methods to be integrated into foundry processes. This integration must be accompanied by ongoing evaluation to ensure that new approaches maintain the existing quality and reproducibility of established semiconductor manufacturing.

In this work, we present an experimental characterisation of qubits fabricated using a foundry-compatible natural silicon platform. First, we assess device quality at the wafer scale by examining interface quality and charge trap density. Using transport measurements we observe a peak electron mobility of $40,000 \text{ cm}^2/\text{Vs}$ and the highest reported hole mobility for a silicon MOSFET of $2,000 \text{ cm}^2/\text{Vs}$. Building on this, we investigate the suitability of these materials for spin qubit devices. Here we investigate the coherence and relaxation times of hole spins. Hole spins exhibit strong spin-orbit coupling, making them highly sensitive to disorder and allowing them to act as detailed quantum probes of material imperfections. Finally, we investigate the operation of single- and two-qubit gates of hole-spin qubits, achieving fidelities up to 99.8% and a two-qubit gate quality factor of 240, indicating a physical fidelity limit near 99.7%. These results highlight the maturity of silicon hole-spin platforms and their potential for integration into future quantum CMOS technologies. This comprehensive suite of measurements provides a snapshot of the current state of the art in foundry-based quantum chips.

Poster Session / 149

Effects of the Weak Quadrupole Moment in Atoms and Molecules

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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 (Flambaum, Dzuba, & Harabati, 2017).

Nuclei with a quadrupole deformation have an enhanced WQM which induces the tensor weak electron-nucleus interaction in atoms and molecules. Recently, it has been shown that in diatomic molecules containing an atom with a quadrupole deformation, the WQM can become the dominant contributor to the PNC amplitude (Skripnikov, Petrov, Titov, & Flambaum, 2019). Studying this moment in molecules presents a promising avenue for the experimental verification of the WQM, with ideal candidates already identified. Utilising relevant atomic and molecular theory, I calculate the PNC amplitude of the WQM for triply-ionised thorium which is an ion of recent interest in its own right. Additionally, I compute the PNC amplitudes for diatomic molecules containing thorium, which have been flagged as promising candidates for future high-precision measurements.

Theoretical Physics / 150

A new time-dependent approach to modeling nuclear fusion

Author: Aditya Singh Tejas¹

Co-author: Edward Simpson¹

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Nuclear fusion not only promises carbon-free energy but also drives deeper insights into fundamental quantum dynamics under extreme conditions. Non-relativistic quantum scattering theory informs our broad understanding of nuclear collision processes. However, detailed theoretical insights remain elusive with conventional approaches.

In this work, we investigate a new time-dependent (coupled channels) formulation that treats nuclear fusion as formation and decay of quasi-bound states of the interaction potential, thereby avoiding artificial boundary conditions that can obscure critical details of the process. With this, we aim to better understand and predict fusion probabilities for a wide range of collision energies and nuclei pairs, which remains challenging for current theoretical approaches. While focused on fusion, the theory can be extended to any non-relativistic potential scattering problem where such an analysis would be beneficial, for example, atomic and molecular collisions.

The scattering (S)-matrix captures all the details of a scattering process. This work extends the application of the time-correlation formalism for calculating the energy-resolved S -matrix (developed in quantum chemistry) to nuclear physics, where the presence of the long-range Coulomb potential needs to be accounted for. A novel time-domain analysis on separability of the contributions to the S -matrix from resonances (which, in our case, models fusion) in the potential has been performed. We demonstrate how this new perspective can enable us to gain first theoretical insights into Bohr's (1936) independence hypothesis. Furthermore, we lay the foundations for examining the consequences of the experimentally observed interactions at larger distances (before fusion is initiated) in case of heavier nuclei, which can aid in the synthesis of the next super-heavy element.

Poster Session / 151

Time Optimal Quantum Computers

Author: Peter Morrison¹

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The science of time optimisation has a long and illustrious history dating to the original investigations of Fermat in discovering the ray principle of optics and the brachistochrone; others such as Pontryagin followed with many applications in control theory, physics and engineering science. In this talk we will discuss how to apply the methods of time optimisation and variational calculus to derive unitary operators that are useful for quantum computation, in particular simple logic gates that can be used to process quantum information and perform basic computational tasks in a timely fashion.

We show how these can be used to form a universal set of gates and the connection between these ideas and other concepts such as the Bloch equation and Floquet theorem. Using some simple physical implementations, we show how some types of these time optimal quantum computations can be carried out in low dimensional spin systems.

These methods form much in common with the ideas of analog computation, involving a periodic signal to process the information instead of a digital/binary formalism, and we discuss how the implementation of these processes will require significant alteration in our understanding of quantum computing in order to approach the quantum speed limit.

Quantum Science and Technology / 152

Demonstrating single-ion addressing of dynamic 2D ion crystals for quantum simulation

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Co-authors: Gustavo Miranda ¹; Joseph Pham ¹; Julian Jee ¹; Michael Biercuk ¹; Robert Wolf ¹

¹ *The University of Sydney*

Coherently manipulated large ion crystals in a Penning trap are a promising candidate for near-term quantum simulation of complex many-body phenomena ¹. At the University of Sydney, we have developed a Penning trap to perform such experiments with crystals containing hundreds of beryllium ions ². The system has recently demonstrated efficient site-resolved imaging, enabling single-shot experiments to investigate dynamics in correlated systems ³. To further advance the quantum simulation capabilities to tackle more exotic many-body systems [4], we have developed a technique to address individual ions in these fast-rotating crystals. To this end, an acousto-optic modulator (AOM) with variable driving frequency deflects a 313nm optical pumping laser beam to address different radii in the ion crystal. A second AOM is used to rapidly modulate the laser power, thereby addressing individual ions at a certain radius. An optical system has been built which generates a laser beam displacement large enough to cover ion crystals with more than 300um diameter and, at the same time, achieves a focus size small enough to hit only a single ion at a time (~30um). The system design, characterisation as well as a first application to create an exotic collective spin state [4] will be presented.

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Poster Session / 153

KINETIC INDUCTANCE TRAVELLING-WAVE PARAMETRIC AMPLIFIERS USING NbTiN FILMS ON HIGH DIELECTRIC CONSTANT SUBSTRATES

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Travelling-wave parametric amplifiers (TWPAs) are critical components for improving the readout fidelity of superconducting qubit systems [1]. While Josephson junction-based TWPAs offer excellent broadband noise performance and are widely adopted in quantum computing architectures, their limited dynamic range, fabrication complexity, and sensitivity to magnetic fields and elevated temperatures present significant limitations. These challenges have driven the development of kinetic inductance-based TWPAs (KITWPAs) [2], which utilize the intrinsic nonlinearity of a superconducting film's kinetic inductance rather than relying on engineered Josephson junctions. KITWPAs inherently support higher dynamic range, greater resilience to magnetic fields, higher operation temperature, and enable simpler, single-layer fabrication. Despite these advantages, KITWPAs demonstrated so far [2-3] require transmission lines with lengths of several tens of centimeters. While meandering helps reduce the physical footprint, the long propagation paths still limit scalability and lower fabrication yield. To address this, we explore an alternative design approach that combines high-kinetic-inductance superconducting films with non-standard substrates possessing high dielectric constants. This strategy reduces the phase velocity of propagating signals—allowing for substantial device miniaturization. In this work, I present our experimental efforts focused on this approach, including precise extraction of substrate dielectric constants, measurement of film kinetic inductance, and nonlinear response characterization through a narrowband kinetic-inductance parametric amplifier (KIPA). These results demonstrate a promising pathway toward scalable KITWPAs with wideband, quantum-limited gain, extended dynamic range, and enhanced robustness—key attributes for next-generation superconducting quantum technologies.

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Quantum Science and Technology / 154

Classical Approximate Algorithms for Gaussian Boson Sampling: Has quantum advantage been achieved?

Authors: Alexander Dellios¹; Ned Goodman¹; Peter Drummond¹

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Gaussian Boson Samplers (GBS) are non-universal optical quantum computers introduced to demonstrate quantum advantage without requiring full error-correction by efficiently sampling from a classically-hard distribution. These devices are relatively simple: just squeezed states fed through a random, precise array of linear optics. Recently, the first large-scale GBS devices were created: the

Jiuzhang series at China's USTC, the latest of which has reached 1152 modes, and the Borealis device made by Canada's Xanadu corporation. Both groups have claimed their GBS achieves quantum advantage.

However, verifying this is difficult. Both groups' results deviate markedly from those of an ideal implementation of their experiments. As such, multiple groups have contested the experimentalists' claims by producing results closer to the ideal ground-truth using classical sampling algorithms that replicate the output photo-count patterns. Nevertheless, while the experiments do not sample from the ideal, there is no evidence that the distribution they sample from is classically easy.

To address this concern, we use phase-space simulations to find simple, well-motivated corrections to the ground-truth to use as the basis of our comparison. In addition, we introduce two novel classical sampling algorithms for the GBS. The first approach is a relative of Google's low-order sampling method, but it samples from a physical state rather than a synthetic non-i.i.d. distribution. The second approach is based on a novel mapping of quantum-jump-method equations into phase space. Thus, we both give the experiments a fairer test and provide new challengers.

These new samplers beat the experiment on both ground-truths for the Jiuzhang 2.0, 3.0, and Borealis experiments and outperform the best current tensor-network approach. We also find evidence that previous classical sampling techniques cannot beat the experiment on the realistic ground-truth, but our novel algorithms can.

Thus, we provide more rigorous evidence against demonstrable quantum advantage in current GBS experiments.

Condensed Matter & Materials / 155

Enhanced Robustness and Performance Flexibility of $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ Films via High-Fluence Pulsed Laser Deposition with a Variable Target-to-Substrate Distance

Authors: Alexey Pan¹; Simone Cunzolo¹

¹ University of Wollongong

The established guiding principle for pulsed laser deposition (PLD) of high-quality $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$ (YBCO) superconducting films suggests that the optimal target-to-substrate distance (TSD) lies near the visible tip of the laser-induced plume, with deviations from this point expected to degrade film properties. We modified our PLD system to allow precise external TSD adjustment over a 110 mm range and systematically studied its influence on the electromagnetic, micro- and nanostructural properties of YBCO thin films. Our analysis, referencing plume propagation models and growth processes, reveals that the optimal TSD range can, in fact, be extended under relatively high laser fluence, depending on the desired film performance and properties. We identify four TSD regimes, each exhibiting unique film characteristics. X-ray diffraction (XRD) θ -2 θ scans reveal lattice parameter splitting at the 001 and 002 reflections through the formation of triple peaks, indicative of a tri-layered strain structure. This is the first report of such a structure under nominally monolayer growth conditions without additional fabrication techniques, spanning a 50 mm TSD range. The phenomenon arises from the combined influence of TSD and laser fluence, driving transitions between monolayer and multilayer-like growth. Remarkably, high-quality superconducting properties and crystallinity are preserved across a broad 50 mm TSD window, yielding films with variable total thickness, layer thickness, surface structure, and growth modes. This insight and tunability deepen understanding of growth mechanisms and deposition dynamics, offering new pathways to tailor surface morphology and performance in electronics and high-power applications through controlled structural evolution and efficient deposition rates.

Quantum Science and Technology / 156

Resource estimates for the open-system simulation of chemical reactions

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Open quantum systems evolving under time-dependent Lindbladian simulations dynamics arise in diverse contexts, yet efficient algorithms for large-scale, time-dependent Lindbladian dynamics remain underexplored. In the fault-tolerant setting, the time required to propagate a state by a complex, time-dependent Hamiltonian is prohibitive. We circumvent this issue by introducing a discretization-and-thermalization framework for simulating such dynamics, followed by detailed numerical analysis and resource estimation for chemically reactive systems undergoing environment-influenced reaction pathways. The inclusion of T-gate and logical qubit counts offers practical guidance for future implementations, making this framework relevant to a broad range of applications, including fermionic, spin, and chemically reactive systems.

Poster Session / 157

Constant Factor Analysis of Optimal Quantum Linear Solvers in Practice

Authors: Alexander M. Dalzell¹; Dominic Berry²; Dong An³; Pedro Contino da Silva Costa⁴

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⁴ *BQP*

We extend the findings of Costa et al. (arXiv:2312.07690), which demonstrated that the discrete adiabatic quantum linear system solver exhibits constant factors approximately 1,200 times smaller in practice than previously estimated by worst-case bounds. In the present work, we introduce a comparison between the adiabatic-based quantum walk method and the more recent “shortcut” quantum linear system solver proposed by Dalzell (arXiv:2406.12086), which achieves asymptotically optimal scaling $O(\kappa \log(1/\epsilon))$ with favourable constant factors, especially when the solution norm is known. Specifically, we conduct a comprehensive numerical analysis contrasting the two methods in two regimes: when the norm of the solution is unknown and when it is known. Our results reveal a region in parameter space—particularly where the solution norm is known—where the shortcut method outperforms the quantum walk approach in terms of constant factor. This advantage may prove especially valuable for algorithms solving differential equations via Hamiltonian simulation.

Medical Physics / 158

Development of an optimised method for tracking chemical species in Geant4-DNA enabling in-silico radiobiology in a cosmic radiation environment

Author: Jay Archer¹

Co-authors: Dousatsu Sakata ²; Hoang Tran ³; Jeremy Brown ⁴; Kiarn Roughley ¹; Melanie Ferlazzo ⁵; Moeava Tehei ¹; Ryan Drury ⁵; Sebastien Incerti ³; Stefania Peracchi ⁵; Susanna Guatelli ; Zeljko Pastuovic ⁵

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⁵ *Australian Nuclear Science and Technology Organisation (ANSTO)*

Modelling the early DNA damage induced by radiation is critical for understanding its biological impact. Radiation traversing a cell induces DNA damage through both physical interactions (direct damage) and chemical interactions of radiochemical species (indirect damage) with the DNA strand. Through the combination of DNA geometry models, physics models and chemical tracking, the early DNA damage in a cell can be simulated in silico using the Geant4-DNA toolkit. However, there are great computational requirements for the simulation of high linear energy transfer (LET) particles because of the great number of chemical species requiring simultaneous tracking.

In this study, a new chemical species tracking model was developed to improve the computational efficiency of the chemical tracking. This was achieved by applying the Synchronous Independent Reaction Time model in different spatial segments simultaneously. This led to an improvement in execution time by over an order of magnitude for particles with an LET beyond ~10 keV/um. This model allows the chemical process to be distributed over multiple computer cores, leading to an improvement in computational resource utilisation.

The new chemical tracking model was validated using radiobiological experiments undertaken at ANSTO. 149BR human skin fibroblasts were irradiated with protons and carbon ions having the same energy per mass unit of 3 MeV/u. The cells were stained for γ -H2AX foci, which represent the location of double strand breaks (DSBs). Confocal imaging was used to obtain the three-dimensional foci distribution. These were compared with simulated γ -H2AX foci images using Geant4-DNA, demonstrating the ability of Geant4-DNA to predict radiobiological effects of radiation.

Astroparticle Physics / 159

From symmetries to gravitational waves: a self-consistent calculation

Authors: Chi Tian¹; Csaba Balazs²; Xiao Wang²

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Predicting the gravitational wave spectrum from symmetry breaking in the early universe during first-order phase transitions is key to understanding these symmetries. In this talk I present our recent advancements in developing a self-consistent framework for predicting such gravitational wave spectra. Our approach enhances existing calculations by providing a more comprehensive treatment of the underlying physics, from the particle physics model to the hydrodynamic evolution of bubbles and the resulting gravitational wave production. The talk will emphasize how this self-consistency refines gravitational wave predictions and explore its implications for understanding early universe cosmology.

Quantum Science and Technology / 160

Quantum-enabled optical large-baseline interferometry: applications, protocols and feasibility

Authors: Benjamin Pope¹; Daniel Oi²; Gavin K. Brennen¹; Mikolaj Schmidt¹; Pieter Kok³; Zixin Huang⁴

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Optical Very Long Baseline Interferometry offers the potential for unprecedented angular resolution in both astronomical imaging and precision measurements. Classical approaches, however, face significant limitations due to photon loss, background noise, and the requirements for dynamical delay lines over large distances.

We survey recent developments in quantum-enabled VLBI, which aim to address these challenges using entanglement-assisted protocols, quantum memory storage, and nonlocal measurement techniques. While its application to astronomy is well known, we also examine how these techniques may be extended to geodesy – specifically, the monitoring of Earth's rotation.

Particular attention is given to quantum-enhanced telescope architectures, including repeater-based long-baseline interferometry and quantum error-corrected encoding schemes, which offer a pathway toward high-fidelity optical VLBI.

To aid the discussion, we also compare specifications for key enabling technologies to current state-of-the-art experimental components, including switching rates, gate times, entanglement distribution rates, and memory lifetimes.

By integrating quantum technologies, future interferometric networks may achieve diffraction-limited imaging at optical and near-infrared wavelengths, surpassing the constraints of classical techniques and enabling new precision tests of astrophysical and fundamental physics phenomena.

arXiv:2505.04765

Industrial Applied Physics / 161

Response of Sea Urchins to Light Polarisation

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Co-authors: Celine Boehm ; Filippo Menolascina ; Helena Reinardy ; Julien Reboud ; Ken-Tye Yong ; Maria Bryne ; Zhenxu Yang

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The usefulness and importance of light polarisation have skyrocketed in recent times with applications found in biomedicine, imaging, characterisation of biological and chemical systems, and astrophysics just to name a few. Ecologically, more and more examples of flora and fauna are found to utilise the polarisation of light for growth, navigation, and communication, increasing the need for polarisation characterisation. Current polarimetric photodetectors for visible light generally use a polarising filter, which reduces their overall sensitivity and effectiveness. This motivates the search for better alternatives, both for linear and circular polarisations. In this work, we explore the possibility of polarisation detection via biomimicry by investigating the linear and circular polarisation sensitivity of the sea urchin species *Paracentrotus lividus*, *Echinus esculentus*, and *Psammechinus miliaris* through their phototactic responses under illumination of light. It was discovered that *P. miliaris* has

the ability to differentiate between horizontally and vertically polarised halogen light and additionally P. lividus potentially has the ability to differentiate circularly polarised light. These findings could lead to a novel mechanism of polarisation detection in the visible domain and a step toward a new technology or its determination. Such a detector would be simpler compared to current alternatives, making it cheaper and easier to produce, and also allow for direct detection of polarised light in the visible wavelengths.

Nuclear and Particle Physics / 162

Investigating the $N = 28$ shell closure with single-nucleon transfer reactions

Author: Aditya Babu¹

Co-authors: AJ Mitchell¹; Benjamin Kay²; Yassid Ayyad³; Khushi Bhatt²; Alex Brown⁴; Frank Browne⁵; Ben Coombes¹; Sean Freeman⁵; Calem Hoffman²; Vasil Karayonchev²; Anna Kawecka⁶; Greg Lane¹; Juan Lois-Fuentes⁴; Eilens Lopez-Saveedra²; T.L Tang⁷; Ivan Tolstukhin²; Nate Watwood²; Alan Wuosmaa⁸

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The calcium ($Z = 20$) nuclides have long been considered as “textbook” shell-model nuclei, with established doubly magic isotopes at $N = 20, 28$ and proposed shell gaps emerging at $N = 32, 34$. Despite this, a growing body of evidence suggests that the shell model requires deeper investigation in this region. In ^{48}Ca , a reduction of the $f_{7/2}$ strength across the $N = 28$ shell gap was observed from neutron-knockout reactions from the $f_{7/2}$ ground states of $^{48, 50}\text{Ca}$.

This is inconsistent with shell-model predictions using both phenomenological effective interaction Hamiltonians like $GXPf1$ and microscopically derived $NN + 3N$ interactions in the pf model space. Furthermore, this result is also in disagreement with spectroscopic strengths determined from single-nucleon transfer reactions although the historical data here are sparse.

We will report on a first-of-its-kind simultaneous measurement of the $^{48}\text{Ca}(d, p)$ and $^{48}\text{Ca}(d, t)$ reactions with the Helical Orbit Spectrometer (HELIOS) at Argonne National Laboratory. For this experiment, HELIOS was equipped with dual Si-Arrays: the “standard” 6×4 HELIOS array positioned at $z = 900$ mm downstream to enable triton detection, and a “stub” 2×4 array at $z = 50$ mm upstream to detect protons. Additionally, a four quadrant $E\Delta E$ recoil detector with an attached ~ 1 -m-long blocker was positioned at $z = 750$ mm downstream. This ensured the acceptance of tritons while blocking scattered, multi-orbit protons and deuterons. Preliminary results from this experiment will be discussed and compared with shell-model calculations. The importance of demonstrating the capability of simultaneous reaction studies with solenoidal spectrometers including the SOLARIS device at FRIB, will be discussed.

This work is supported by the Australian Research Council Grant No. DP210101201, the International Technology Center Pacific (ITC-PAC) under Contract No. FA520919PA138, the Australian National University Major Equipment Committee, and the U. S. Department of Energy, Grant No. DE-SC0014552.

Quantum Science and Technology / 163

Ballistic Optical Tweezers for Measuring Fast Protein-Receptor Binding Dynamics**Author:** Jackson Lucas¹**Co-authors:** Alex Terrasson¹; Nico Mauranyapin¹; Lars Madsen¹; Warwick Bowen¹¹ *Australian Research Council Centre of Excellence in Quantum Biotechnology (QUBIC), The University of Queensland*

Despite significant advances in molecular biology and microscopy techniques, many questions remain regarding the interactions between a single cell and its environment. In particular, understanding protein-membrane binding is vital for optimising the delivery of vaccines and medicines. By studying these transmembrane behaviours, we can improve drug delivery and increase the specificity of cell targeting. A powerful tool for probing these interactions is optical tweezers, which allow for the precise control and tracking of microparticles. However, conventional optical tweezers used in biological settings are limited by the slow tracking of diffusive Brownian motion, which prevents the observation of binding dynamics at their native rates. I will present the use of state-of-the-art ultrafast optical tweezers that resolve the ballistic Brownian motion of functionalized microspheres, enabling the measurement of local viscosity changes and, thus, the binding dynamics of single protein-receptor pairs with up to three orders of magnitude higher temporal resolution.

Quantum Science and Technology / 164

Classical simulation of noisy quantum circuits via locally entanglement-optimal unravelings**Author:** Hakop Pashayan¹**Co-authors:** Jens Eisert²; Lennart Bittel²; Paul K Faehrmann²; Simon Cichy²¹ *Hon Hai (Foxconn) Research Institute, Free University Berlin*² *Free University Berlin*

Classical simulations of noisy quantum circuits is instrumental to our understanding of the behavior of real world quantum systems and the identification of regimes where one expects quantum advantage. The presence of noise can decay quantum entanglement. Our work capitalizes on this idea. We employ new methods that push the boundaries of noise-induced entanglement decay, using it to significantly improve the classical simulation of noisy quantum systems. This approach makes simulating these complex circuits less computationally intensive—a crucial step for better understanding the behavior of real world quantum systems and the identification of regimes where one expects quantum advantage.

In this work, we present a highly parallelizable tensor-network-based classical algorithm – equipped with rigorous accuracy guarantees – for simulating n -qubit quantum circuits with arbitrary single-qubit noise. Our algorithm represents the state of a noisy quantum system by a particular ensemble of matrix product states from which we stochastically sample. Each single qubit noise process acting on a pure state is then represented by the ensemble of states that achieve the minimal average entanglement (the entanglement of formation) between the noisy qubit and the remainder. This approach lets us use a more compact representation of the quantum state for a given accuracy requirement and noise level. For a given maximum bond dimension and circuit, our algorithm comes with an upper bound on the simulation error, runs in poly-time and improves upon related prior work (1) in scope: by extending from the three commonly considered noise models to general single qubit noise (2) in performance: by employing a state-dependent locally-entanglement-optimal unraveling and (3) in conceptual contribution: by showing that the fixed unraveling used in prior work becomes equivalent to our choice of unraveling in the special case of depolarizing and dephasing noise acting on a maximally entangled state.

Focus Session - From edge states to emergent phases / 165**The Interplay of Electron Correlation, Electron-Phonon Coupling, and Nontrivial Topology in High Temperature Superconducting FeSe/SrTiO₃ Heterostructure****Author:** Subhasish Mandal¹¹ *Department of Physics and Astronomy, West Virginia University*

High-temperature superconductivity and topological phase transition are among the most debated and intriguing phenomena in modern condensed matter physics. Their combined manifestation in either a single or hybrid material structure is of great interest for exhibiting Majorana zero modes. So far, the study of topological materials and the role of electron-phonon coupling in superconductivity has been focused mostly on the single-particle regime. Two fundamentally unaddressed questions are: (a) how the correlation affects the coupling with phonon and vibrational properties to determine high-temperature superconductivity [1, 2], and (b) what will happen when strong electron-electron interactions drive a topological system far from the single-particle limit, potentially causing electrons to be localized [3]. Here, by exploiting the interplay between electron and lattice through the combination of first principles embedded dynamical mean field theory (eDMFT) calculations and epitaxial growth, ARPES, and STM/S measurements, we demonstrate (a) sensitivity of superconducting transition temperature (T_c) as a function of tetrahedral bond angle and (b) the evidence of topological superconductivity in FeTe_{1-x}Se_x thin film grown on a SrTiO₃(001) substrate [3]. We demonstrate a unique topological superconducting phase in competition with electronic correlations [3]. Additionally, we show that the measured superconducting gap and eDMFT computed phonon coupling with correlated electrons follow a similar superconducting dome as a function of a Se-Fe-Se angle [4]. Our work demonstrates that doping FeSe thin films can create a unique platform where electronic correlations sensitively modulate both superconductivity and topological superconductivity, offering opportunities to tune electron-electron interactions and engineer new topological phases in a broad class of materials [3-5].

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Solar Terrestrial and Space Physics / 166**A Machine Learning Framework for Building a Refined GOES Flare Catalog****Author:** Nastaran Farhang¹**Co-authors:** Michael Wheatland ¹; Andrew Melatos ²¹ *University of Sydney*² *University of Melbourne*

We present a new catalog for solar flares derived from Geostationary Operational Environmental Satellite (GOES) data using a deep learning-based detection method. Unlike the conventional rule-based methods, our approach identifies flare rises directly from the time series with a model that integrates multi-scale convolutional layers, a bidirectional long short-term memory (BiLSTM), and Transformer encoders. Trained on 7,700 manually labeled events and applied to GOES/XRS observations from 2018 to mid-2025, the method detects 201,463 flares, far exceeding the 14,612 listed in the GOES archive. The greatest relative increase appears for C-class events, many of which are

often overlooked. Background subtraction of peak fluxes produces more symmetric waiting-time statistics, reducing bias from obscuration, while Bayesian-block analysis highlights strong temporal variability in flare rates. A complementary procedure links detected events to active regions using Solar Dynamics Observatory imaging. Together, these advances provide a more complete and less biased picture of flare occurrence, with potential applications for flare forecasting and solar-activity modeling.

Quantum Science and Technology / 167

Resource efficient multi-time process tomography using superinstruments

Author: Abhinash Roy¹

Co-authors: Christina Giarmatzi¹; Alexei Gilchrist¹

¹ *Macquarie University*

Precise and robust control of sequences of quantum operations is essential for quantum information processing. The present quantum hardware is plagued with correlated noise, i.e., non-Markovian noise. The existing mitigation strategies, which are based on Markovian assumption, are ineffective. Multi-time process tomography aims to provide a complete description of the nature and strength of the environmental memory, which can then be used to develop control strategies. However, it requires performing an informationally complete set of operations at every intermediate intervention, which include non-deterministic operations such as mid-circuit measurement. These are noisy and slow for the present hardware, making the tomography unreliable and impractical beyond a few steps.

In this work, we provide an efficient procedure for complete characterisation of multi-time processes using superinstruments. Superinstruments are generalisation of local operations to correlated operations across time and can be efficiently implemented through interaction with ancillary systems. Remarkably, we show that a minimal-dimensional quantum ancilla (a qubit) and final measurement is enough to implement an informationally complete set of superinstruments for completely characterising multi-time processes with arbitrary dimensions and arbitrary number of intermediate interventions. Our approach eliminates the error accumulation from repeated measurements and feed-forward, and aligns with capabilities on current platforms where mid-circuit readout is either unavailable or fidelity-limited. The resulting protocol enables practical, scalable identification of non-Markovian memory effects with minimal resource overhead.

Poster Session / 168

Blind Spots of Randomized Benchmarking in the Presence of Temporal Correlations

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Randomized benchmarking (RB) is the most widely used characterisation technique for assessing gate quality via a single decay parameter, but standard protocols implicitly assume temporally uncorrelated (Markovian) noise. In realistic devices, environmental fluctuations induce correlations in time (non-Markovianity), motivating extensions of RB beyond the Markovian regime. Recently,

some efforts have been made to formalise RB in non-Markovian scenarios. However, RB's behaviour across non-Markovian noise classes with differing environmental memory structures remains largely unexplored.

In this work, we study the randomised benchmarking protocol in the presence of a classical memory environment, where the memory can have its origin from interactions with nearby quantum systems. We show that the average sequence fidelity (ASF) curve is monotonically decreasing with sequence length for classical memory processes. Therefore, a deviation from monotonic behavior is a witness of a quantum memory environment. Moreover, we show that there are classes of processes for which, regardless of the amount of non-Markovianity, RB yields an identical average sequence fidelity, whereas the worst-case error—a relevant metric for fault-tolerant computation—correlates significantly with the amount of memory, resulting in RB characterisation missing important aspects of memory. In addition, we provide a class of interactions that results in an ASF identical to the Markovian case, making this class of non-Markovian processes inaccessible through randomised benchmarking.

Atomic and Molecular Physics / 169

Fast and low-loss, all-optical phase modulation in warm rubidium vapour

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Low-loss high-speed switches are an integral component of future photonic quantum technologies, with applications in state generation, multiplexing, and the implementation of quantum gates. Phase modulation is one method of achieving this switching; however, existing optical phase modulators, such as Pockels cells and waveguided lithium niobate, offer either high bandwidth or low loss—not both. We demonstrate fast (100 MHz bandwidth), low-loss (83(2)%) phase shifting ($\Delta\phi = 0.90(0.05)\pi$) in a signal field, induced by a control field, and mediated by the two-photon $\{5S_{1/2} \rightarrow 5P_{3/2} \rightarrow 5D_{5/2}\}$ transition in ^{87}Rb vapour. The all-optical nature of the scheme circumvents restrictions of electronic phase modulators, where bandwidth and repetition rate can be limited by the requirement to rapidly modulate high voltages. We discuss routes to enhance both performance and scalability for application to a range of quantum and classical technologies.

Poster Session / 170

Towards single-longitudinal mode monolithic diamond Raman lasers

Authors: William O C Davis¹; Adam Sharp¹; Osama Terra¹; Saurabh Bhardwaj¹; Rich Mildren¹

¹ *Macquarie University*

Raman lasers are a promising platform for narrow linewidth single-longitudinal mode lasers, and their Raman shifts provide access to wavelength ranges not easily reached with commercial lasers. Moreover, the Raman process provides intrinsic line narrowing, recently shown to greatly reduce linewidth and suppress high-frequency noise relative to the pump. Diamond, in particular, has the

highest known thermal conductivity for a bulk material, making it less susceptible to thermal effects; and possesses a high laser damage threshold, making it ideal for high power operation. These properties make diamond Raman lasers attractive for both high-power applications and for systems requiring narrow linewidth and low high-frequency phase noise, such as quantum technologies and precision metrology.

However, diamond presents challenges in terms of polishing and coating compared to other materials, meaning that existing continuous wave diamond Raman lasers have so far been realized only in free-space cavities. These systems are sensitive to alignment, suffer from excess low-frequency noise due to cavity length fluctuations, and are not easily miniaturized. In contrast, a monolithic cavity geometry—formed entirely within either a single crystal or multiple bonded crystals—offers improved passive stability, reduced vibration sensitivity, and a more compact and robust design.

Herein, we discuss our progress towards demonstrating a continuous wave monolithic diamond Raman laser through both a total-internal reflection geometry and through bonding cavity mirrors to diamond.

Condensed Matter & Materials / 171

Special Displacement Method for Single-Photon Emitters in Diamond and h-BN

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¹ *the Cyprus Institute*

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Single-photon emitters (SPEs) are key components for quantum technologies, particularly in sensing and secure communication. In solids, SPEs often originate from point defects that introduce discrete states within the band gap. Electron–phonon coupling can strongly affect these defect levels by renormalizing their energies, thereby shifting the emitted photon energy. Common theoretical approaches to account for electron–phonon coupling, such as Monte Carlo-based methods, are computationally expensive, requiring hundreds to thousands of supercell configurations. The Special Displacement (SD) method proposed by Zacharias et al. offers reliable accuracy at significantly lower computational cost. While successfully applied to pristine materials, its validity for defect systems remains unclear. In this work, we apply the SD method to evaluate electron–phonon coupling in defect structures. We focus on two important SPE systems: the NV[−] center in diamond and the carbon dimer defect in h-BN. After validating the SD method for the NV[−] center, we apply it to h-BN and compute defect-level renormalization energies and their temperature variation. Furthermore, we explore strategies to further reduce the computational cost of such calculations. By enabling more accurate predictions of emission energies and their temperature dependence, this framework is a step forward toward efficient and predictive modeling of next-generation single-photon emitters.

Medical Physics / 172

Synchrotron Light: A Physics Journey from Laboratory to Cosmos

Authors: Daniele Pelliccia¹; David Paganin²

¹ *Instruments & Data Tools Pty Ltd*

² *Monash University*

Why have we chosen to write yet another book on synchrotron light? After all, the classical physics of synchrotron-light emission is an established field, and many excellent books on the topic have

already been published. In this talk we will present our recently published book and the educational approach we took.

Most existing textbooks on the subject either cover a wide range of applications of synchrotron light, or are pitched at an advanced (i.e. graduate) level. The inspiring motivation for us was to find a middle ground and write an upper-undergraduate-level book, but with a wider perspective encompassing the broader conceptual fabric of physics research.

Our book provides a broad introduction to the topic in an easy-to-read format, describing the fundamental underpinning physics, and combining rigorous treatment of the main concepts with a fresh outlook. The presentation is rich in images and graphics, that is typical of basic physics textbooks. All topics are described in a way that requires only undergraduate knowledge in physics and mathematics, and, with only a few exceptions, all results are derived from first principles.

In this spirit, this talk will highlight a few of the connecting threads which the synchrotron-emission concept weaves through the fabric of physics, including quantum-mechanical aspects of synchrotron light, astrophysical sources of synchrotron light, and generalisations of the concept of synchrotron light to fundamental interactions beyond the electromagnetic force.

Reference: D. Pelliccia and D. M. Paganin, *Synchrotron Light: A Physics Journey from Laboratory to Cosmos*, Oxford University Press, 2025 (see <https://global.oup.com/academic/product/synchrotron-light-9780192846280>).

Focus Session: Frontiers of Medical Physics / 173

Accelerating Innovation: Strategies for Translating Medical Physics Research into the Clinic

Author: Joel Poder¹

¹ *St. George Hospital Cancer Care centre*

Hospital based medical physicists are uniquely positioned at the interface between fundamental research and direct patient benefit. Translating innovations from academia and industry into the hospital setting, however, presents both opportunities and challenges. Translational pathways typically involve the progression of prototypes through feasibility testing, clinical trials, and eventual commercialisation. At each stage, challenges emerge. Ethics and governance approvals can significantly delay studies, while questions of intellectual property (IP) ownership between universities, hospitals, and industry partners often require lengthy negotiation.

This presentation will draw on examples of translational research at St. George Hospital Cancer Care Centre within the medical physics group. From these experiences, key recommendations can be made, focussing on early engagement: when academic groups, hospitals, and potential industry partners establish clear frameworks for collaboration at the outset, both time and uncertainty can be reduced.

Our research team has developed several strategies can help overcome these barriers. Early pre-submission ethics consultation, can streamline approval timelines. Standardised IP frameworks and early negotiations on scope and ownership reduce uncertainty and conflict between partners. Engaging hospital-based medical physicists and clinicians at the earliest stages of research ensures user-centred design, improving both clinical relevance and commercial potential. More broadly, formalised partnerships across academic, clinical, and industrial sectors, supported by shared infrastructure and joint appointments, can provide the continuity needed to move innovations efficiently along the translation pathway.

Looking ahead, building stronger and more integrated collaborations will be essential for maximising the impact of medical physics research. By aligning scientific innovation with practical implementation, the physics community can accelerate the delivery of new technologies to patients and ensure that breakthroughs in the laboratory translate into meaningful clinical outcomes.

Validation of Geant4 fragmentation for broad beam heavy-ion therapy

Authors: Kristie Elaine Moore^{None}; Susanna Guatelli^{None}; David Bolst^{None}

Heavy-ion therapy (HIT) is a growing cancer treatment modality due to its dose sparing and high biological effectiveness. However, a major challenge in heavy-ion therapy is nuclear fragmentation, where primary ions break into smaller particles, resulting in complex secondary radiation fields. Monte Carlo simulations are commonly used to study the secondary radiation field, such as to estimate secondary cancer risk for healthy tissue, making it crucial to know how Monte Carlo models perform against experimental measurements. Several comparison studies have been performed for HIT, though these have mainly focused on narrow-beam geometries, however, clinically the treatment area of the beam will typically be much larger, which may result in a significant difference in Monte Carlo models.

This study compared experimental 12C and 20Ne ion broad beams, with 100 mm diameter, against the Monte Carlo toolkit Geant4. Additionally, a 12C ion pencil beam, ~2 mm sigma, was also compared to see if any systematic differences occur between the two beam sizes for the models. The models evaluated in Geant4 against experimental measurements were the: BIC, INCL, QMD and LiQMD.

For the 12C ion broad beam, the LiQMD model agreed the best with experimental measurements, achieving a mean percentage error of less than 20% for all secondary fragments, except for lithium. Similarly, the LiQMD physics constructor also performed the best for the 20Ne beam with the exception of the lithium, carbon and nitrogen fragments. For the 12C narrow beam, the fragmentation models produced smaller mean percentage errors with experimental data than the broad beams. This discrepancy was primarily due to the model's difficulties in accurately replicating the angular distributions of the fragments. Notably, the LiQMD constructor exhibited the lowest percentage errors in modelling the angular distributions for the narrow beam, therefore confirming the importance of angular distributions in broad beam simulations.

Theoretical Physics / 175

Selection rules for charged lepton flavour violating processes from residual flavour groups

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⁴ UNSW Sydney

We present a systematic investigation of the possible phenomenological impact of residual, abelian flavour groups in the charged lepton sector. The allowed flavour structures of operators in the Standard Model Effective Field Theory (up to dimension six) lead to distinctive and observable patterns of charged lepton flavour violating processes. We illustrate the relevance of such selection rules displaying the current bounds on and the future sensitivities to the new physics scale. In particular, these results demonstrate the importance and discriminating power of searches for lepton flavour violating τ -lepton decays and muonium to antimuonium conversion in the hunt for signatures of physics beyond the standard model.

Medical Physics / 176

High-fidelity Geant4 simulation of the Elekta Unity MR-LINAC for dose prediction

Author: Christopher White¹

Co-authors: Ah Chung Tsoi¹; Anatoly Rosenfeld¹; Brad Oborn¹; David Bolst¹; Jack Humphreys¹; Markus Hagenbuchner¹; Michael Jameson²; Michael Lerch¹; Stéphanie Corde³; Susanna Guatelli⁴; Tomas Kron⁴

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The Elekta Unity is an MR-LINAC that integrates a 7 MV linear accelerator with a 1.5 T MRI in order to provide adaptive online radiotherapy. Using Geant4 version 11.1 and the EMStandard Option 4 Physics Constructor a highly accurate simulation of the Elekta Unity MR-LINAC was developed to produce patient specific dose maps. These dose maps are utilised for the training of a robust dose prediction machine-learning based model. The simulation contains a full model of the treatment head, including the MLC and jaws, as well as the MR cryostat, treatment couch and anterior coil. Simulation of the treatment head allows for positioning to any gantry angle, and individual leaf and jaw positioning allows for the generation of any beam profile, permitting complete control point replication. A uniform 1.5 T magnetic field is applied to the simulated MRI bore through Geant4's field manager with the Dormand-Prince 745 Runge-Kutta stepper so that the simulation is capable of accurately modelling the effects of the magnetic field on the dose profile. The X-ray beam was finely tuned by investigating the dose profiles for different electron beam configurations. Simulations of a water phantom and surrounding PMMA walls are used to validate the simulation to experimental measurements at gantry angles of 0 and 270 degrees, performed using different detector types. This paper will show that the simulated dose profiles have very strong agreement with the experimental results, with 100% 2%/2mm gamma pass rates for a variety of field sizes and detector depths, including in the crossplane direction, and mean and maximum relative error of less than 1% for the depth dose profiles.

Poster Session / 177

Linear and nonlinear propagation of cylindrical vector beams through a nondegenerate four-level atomic system

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Co-author: Tarak Nath Dey¹

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In this work, we consider a nondegenerate four-level closed-loop system where the relative phase shift between various applied fields can effectively modulate the response for the probe field. This configuration can be realized in the ${}^6\text{Li } D_1$ line transition hyperfine structure. Due to the closed-loop structure, the phase difference between the control and the probe field gives rise to different excitation pathways. The interference between different paths affects the linear response of the medium. Also, at higher densities, the nonlinear effect introduces self-focusing and defocusing of the probe vector beam (PVB) as it propagates through the medium. In our work, self-focusing with cylindrical vector (CV) beams controls the polarization, a feature that is limited in scalar beams. To validate the linear response of PVB, we present the atomic coherences numerically which align precisely with our analytical findings. The analysis of susceptibilities affords important insights into the physics underlying phase-dependent interference. We demonstrate that at two-photon resonance, transitioning phase shift from 0 to $\pi/2$ can convert an absorber into an amplifier. Further, we investigate the state of polarization (SOP) of the PVB at the input and a distance of one Rayleigh length inside the medium for all three kinds of CV beams (radial, azimuthal, and spiral). We find, for a phase shift of zero, the polarization ellipse rotates $\pi/2$ at each point in the transverse plane after traversing a distance of one Rayleigh length. However, for a phase shift of $\pi/2$, the polarization rotation is smaller

than in the previous scenario, albeit accompanied by variations in ellipticity. At strong probe intensities, a phenomenon known as “self-focusing” emerges, attributed to the dominant effects of the medium’s third-order nonlinearity. The implementation of self-focusing has resulted in a reduction in the spot size of the beams, which could prove beneficial in enhancing resolution.

Nuclear and Particle Physics / 178

Bottom-up perspective on baryon number violation

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¹ *UNSW Sydney*

Baryon number is an accidental symmetry of the Standard Model. Its violation is one of the most compelling phenomena predicted by physics beyond the Standard Model (SM). Within the framework of effective field theory, I will discuss how next-generation neutrino experiments including Hyper-Kamiokande, DUNE, and JUNO can provide new insights on minimal extensions of the SM.

Industrial Applied Physics / 179

Contactless magnetoresistance and magnetic hysteresis sensor for measuring minerals in industrial applications

Authors: Larissa Huston¹; Sy Nguyen¹; Richard Yong¹; Peter Coghill¹; David Miljak¹

¹ *CSIRO Minerals Resources*

In many minerals, the magnetic permeability and/or the resistance depends on the applied magnetic field. These properties, magnetic hysteresis and magnetoresistance, could therefore be used as a way of identifying minerals to differentiate ore from waste in the mining industry. This application requires the properties to be measured without electrical contacts, operate at room temperature and in low magnetic fields. We have created a lab-based instrument that is capable of simultaneously measuring the magnetoresistance and magnetitic hysteresis of granular materials at room temperature. This instrument is designed to be scaled up for use in a mining application. The instrument consists of a Helmholtz coil, a radiofrequency power supply, a simple well-characterised radiofrequency circuit and custom circuitry for analogue processing of the signal before it is digitized. In this setup, a periodic time varying magnetic field is applied to the circuit using the Helmholtz coil, thereby inducing a periodic resistance and permeability change in the material. The periodic changes in the impedance of the radiofrequency circuit at the resonant frequency that are induced by the oscillating magnetic field are measured. Using Fourier analysis, the coefficient of magnetoresistance and the parameters of a magnetic hysteresis model to be determined. The magnetoresistance of bismuth and simultaneous resistance and permeability changes in an iron ore sample were successfully measured with this setup.

Poster Session / 180

Electrically Driven Hole Spin Resonance Detected with Charge Sensor in a Planar Si CMOS Structure

Author: Aaquib Shamim¹

Co-authors: A. Hamilton ²; A. S. Dzurak ³; Fay E Hudson ³; J. Hillier ²; Scott Liles ²; Wee Han Lim ³

¹ *University of New South Wales*² *UNSW*³ *Diraq***Electrically Driven Hole Spin Resonance Detected with Charge Sensor in a Planar Si CMOS Structure**

A. Shamim {1}, S. D. Liles {1}, J. Hillier {1}, I. Vorreiter {1}, F. E. Hudson {2}{3}, W. H. Lim {2}{3}, A. S. Dzurak {2}{3}, A. R. Hamilton {1}.

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Hole-spin qubits based on Si CMOS devices have garnered attention due to their intrinsic spin-orbit interaction (SOI), weak hyperfine interaction, and anisotropic g-tensor. The SOI allows all electrical control of qubits via electric dipole spin resonance (EDSR) which removes the need for the micro-magnets or electric spin resonance strip (ESR) lines making devices less bulky. The weak hyperfine interaction increases the coherence times. The planar Si CMOS structure is industry compatible and combined with individual spin addressability via EDSR, is apt for scaling up to a larger number of qubits. This integration has not yet been shown for a known number of holes in Silicon CMOS.

We studied a hole double quantum dot (DQD) operating in the Pauli spin blocked $(2,8) \rightarrow (1,9)$ charge transition regime. We were able to operate it as a singlet (S)-triplet (To) qubit which enabled determination of the g-factors of the dots. We performed microwave driven EDSR of the spins and coherently rotate the spins with a Rabi frequency up to 200 MHz. We also studied the in-plane g-factor anisotropy which varies by 100%. The result demonstrates the capability of industry compatible Si CMOS structure for operating hole spin qubits and allowing local EDSR spin control leading to rapidly driven spin qubits.

Medical Physics / 181**A Seed Activity Reconstruction Algorithm for a Novel Fast Pre-Insertion Verification System for I-125 Eye Plaques****Author:** Adam Marsic^{None}**Co-authors:** Anatoly Rozenfeld ¹; ILIA FILIPEV ²; Marco Petasecca ¹; Stéphanie Corde ³; Susanna Guatelli ; Syed Jawad Ali Shah ⁴; Tomas Kron ⁵¹ *University of Wollongong*² *Centre for Medical Radiation Physics, University of Wollongong*³ *Prince of Whale Hospital Sydney*⁴ *University Of Wollongong*⁵ *Peter MacCallum Cancer Centre*

Ocular melanoma is the most common intraocular malignancy in adults and is potentially life-threatening if left untreated. A common alternative to enucleation (removal of the eye) is eye plaque brachytherapy, where small Iodine-125 seeds are arranged on the surface of a circular ophthalmic plaque. Currently, there is no rapid method to measure the activity of individual seeds, preventing hospitals from independently verifying plaque loading in a sterile environment before insertion. We present a seed activity reconstruction algorithm for I-125 ophthalmic plaques measured using a novel fast pre-insertion verification system developed at the Centre for Medical Radiation Physics, University of Wollongong.

In this system, a plaque is positioned above a tungsten collimator that projects emitted photons onto a pixelated high-spatial-resolution silicon detector, effectively forming a pinhole camera. Due to the apparatus geometry, raw detector data do not directly correspond to seed activity and require correction and calibration. These filters were established by measuring a single AgX-100 seed at various

positions in ROPES 15 mm plaque and fitting the results to interpolate responses across all possible seed locations. The results were compared both analytical solution and a Monte Carlo simulation model developed using the Geant4 toolkit.

The system, combined with the reconstruction algorithm, enabled identification of each seed's activity (with mean activity 0.4 mCi per seed) in a fully loaded plaque within 5 minutes. Clinical application of this method could prevent misloaded plaques from reaching patients and enable tailored loading with seeds of varying activity to achieve tumor-specific dose profiles. In the future, the apparatus could be easily expanded to work for other plaque diameters, making it viable for larger scale clinical adoption.

Astroparticle Physics / 182

ORGAN-Low : Probing Sub- μeV Axion Dark Matter with Optimised Haloscope Design

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The QCD axion is a well-motivated hypothetical particle that offers simultaneous solutions to two major open questions in physics: the Strong CP problem and the nature of dark matter. If axions make up the dark matter halo of our galaxy, they may be detected through their resonant conversion into microwave photons in the presence of a strong magnetic field—a technique used in the axion haloscope.

To date, haloscope experiments have achieved impressive sensitivity at GHz frequencies, targeting axion masses in the tens of μeV range. However, a significant region of parameter space at lower frequencies ($\sim$ hundreds of MHz), corresponding to axion masses in the sub-to-few μeV range, remains largely unexplored. This is primarily due to engineering challenges in building large-volume, high-Q resonant cavities that are required to probe such low-mass axions effectively.

In this work, we present a comprehensive framework for designing and optimizing axion haloscopes operating in this lower frequency range. We explore the trade-offs involved in cavity geometry, material selection, mode structure, and coupling mechanisms, with the goal of maximizing sensitivity while maintaining experimental feasibility. Our approach includes full 3D electromagnetic simulations using COMSOL Multiphysics to identify cavity configurations that offer high form factors and scan rates.

By addressing key design challenges, our study aims to pave the way for next-generation haloscope experiments capable of probing currently inaccessible regions of axion parameter space. This would significantly enhance our ability to test the axion dark matter hypothesis at lower masses and contribute to solving one of the most profound mysteries in modern physics.

Atomic and Molecular Physics / 183

Improved differential charge radii of heavy alkali metals using isotope shift

Author: Zachary Stevens-Hough¹

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¹ University of Queensland

Isotope shift spectroscopy has repeatedly demonstrated its efficacy in high-precision tests of fundamental physics and the Standard Model. Its ability to benchmark atomic models and determine sizes of atomic nuclei has been well established, and in recent years, it has also been identified as one method for searching for potential dark matter particles.

The isotopic shift in transition frequencies between pairs of isotopes follows a linear ‘King’ relation, and deviations from this linear relation may indicate new physics. However, the prevailing belief now is that these arise due to non-linear Standard Model contributions including nuclear deformation.

In this work, we consider the isotope shifts in heavy atomic systems using state-of-the-art atomic many-body methods. We present significantly improved theoretical calculations of the field isotope shift and deduced differential nuclear charge radii for heavy alkali metals and alkali-metal-like ions of interest to fundamental physics studies. Our results resolve the discrepancies between previous calculations using isotope shift spectra and other experimental methods.

Medical Physics / 184

A Fibre-Optic Dosimeter for Real-Time Tracking of HDR Brachytherapy Source

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Precise source localisation is vital for safe HDR brachytherapy. This study examines a fibre-optic dosimeter for real-time tracking of a ¹⁹²Ir source, using a new calibration approach that incorporates fluorescence and Cherenkov contributions alongside scintillation signals. Unlike conventional stem-effect correction methods, which rely on hardware modifications or spectral separation, this technique offers a more integrated and streamlined solution for reliable signal correction and source tracking. A real-time source tracking system for HDR brachytherapy was developed using a fibre-optic dosimeter. The phantom consisted of multiple PMMA slabs, each 90 mm wide and 10 or 5 mm thick, with drilled slabs for detector and source placement. A high-yield CsI(Tl) scintillation detector measured the radial dose function (1–5 cm) and anisotropy function (15°–155°). These data supported source characterisation and the development of a calibration model, enabling accurate source localisation. Tracking was assessed with 5 mm and 3 mm step sizes and a 5-second dwell time. Real-time source tracking was successfully demonstrated for both step sizes. Using the reference dataset, large deviations occurred at the beginning of the plan, where the source travelled perpendicular to the detector. In this region, the signal was strongly influenced by the stem effect, as contributions originated from both the scintillator and optical fibre. As the source passed the central region, the signal became dominated by scintillation, leading to improved agreement. Overall, deviations reached 5 mm (3 mm step plan) and up to 6 mm (5 mm step plan) using the reference calibration model. With the new calibration model, deviations were reduced to within ±1.2 mm for both plans. This study demonstrates the feasibility of a fibre-optic dosimeter for real-time HDR brachytherapy source tracking, achieving improved accuracy through an integrated calibration approach. The results indicate strong potential for clinical implementation, offering enhanced precision in source localisation and treatment delivery.

Condensed Matter & Materials / 185

Negative hybridization: How to cure imperfect Majorana modes

Authors: Cole Peeters¹; Themba Hodge¹; Stephan Rachel^{None}

¹ University of Melbourne

Majorana modes (MMs), the elementary building blocks for the quantum bits of topological quantum computers, are known to suffer from hybridization when they get too close to each other. In that case, their wavefunctions start to overlap and the energy of the MMs is pushed to finite energies,

causing errors during the braiding process of the MMs. Here we introduce *negative hybridization*, a fundamental property of MMs which can be thought of as an intrinsic error correction mechanism of MMs.

We discuss several instructive cases where the phenomenon of negative hybridization improves the braiding performance, thus allowing *imperfect* Majorana modes to be braided with negligible braiding error.

Poster Session / 186

Optimal Placement of Beam Position Monitors for the Australian Synchrotron 2

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The deflection of relativistic electron beams by magnetic fields leads to synchrotron radiation, which has found broad use in the fields of materials science, biology, medicine, cultural heritage, and more. Although the performance of synchrotron light sources may be quantified by various metrics, their spectral brightness, which is in turn inversely proportional to the electron beam emittances, is a practically relevant and computable quantity. Therefore, the development of fourth-generation synchrotrons, including the proposed next generation Australian Synchrotron (AS2), aims to achieve ultra-low emittance by mitigating the beam dynamics effects, such as feed-down from off-axis motion and magnet misalignments. More specifically, AS2 aims to deliver an ultra-low emittance of ~ 100 pm-radians and highly coherent, bright light. Constraints on emittance place tight demands on beam optics correction techniques like linear optics of closed orbit (LOCO), and consequently, constraints on accurate

estimation of the beam centroid along the orbit. For this purpose, synchrotrons employ Beam Position Monitors (BPMs) which measure the beam centroid position and hence, play an essential role in controlling the beam orbit and correcting these perturbations. However, existing BPM placement strategies rely on heuristic rules rather than formal optimization which may limit their performance. In this work, we propose a Fisher Information Matrix (FIM) -based method for optimising BPM placements. To achieve this, we use the fully differentiable accelerator code Cheetah, which integrates accelerator modelling with automatic differentiation to enable fast simulations and efficient computation of partial derivatives - including the FIM from the second derivative. Using this, we derive optimal

BPM placements that minimise variance in estimation of the beam centroid parameters for a segment of the AS2 system and demonstrate an extension of the methodology to the entire AS2 sector

Condensed Matter & Materials / 187

Decoherence of Majorana Qubits by $1/f$ Noise

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Qubits based on Majorana zero modes (MZMs) in superconductor–semiconductor nanowires have attracted intense interest as a platform for utility-scale quantum computing, due to their promise of intrinsically low error rates enabled by topological protection. These error rates are expected to be

suppressed exponentially with increasing nanowire length or decreasing temperature. Here we identify a fundamental decoherence mechanism that challenges this expectation. The high-frequency components of $1/f$ charge noise, ubiquitous in semiconductor devices, can excite pairs of quasiparticles in the bulk of the topological superconductor, which travel to the ends of the nanowire to poison the MZMs. This mechanism leads to qubit errors that grow with the length of the nanowire. We calculate the excitation rates for clean nanowires and show that this noise imposes a strict limit on the coherence times of the qubits currently being developed¹, reducing them to less than one microsecond even under ideal conditions. These timescales are significantly shorter than those required for gate operations, posing a serious obstacle to the scalability of Majorana-based quantum computing.

¹ M. Aghaee et al. (Microsoft Azure Quantum), Nature 638, 651 (2025).

Condensed Matter & Materials / 188

Tailoring Functional Properties of Perovskite Oxides Using Anisotropic Epitaxy

Author: David Walker¹

Co-author: Daniel Sando¹

¹ University of Canterbury

The ability to tailor functional properties of complex oxide thin films through epitaxial engineering has opened new avenues for oxide electronics and spintronics applications 1. Lanthanum strontium manganite ($\text{La}_{1-x}\text{Sr}_x\text{MnO}_3$, LSMO) is a half-metallic perovskite oxide exhibiting a strong coupling among lattice strain, magnetism, and electronic transport 2. Epitaxial strain engineering 3 of LSMO has been widely studied with both tensile and compressive strain reducing the magnetic transition temperature and controlling the orientation of the magnetic easy axis [4]. However, the influence of substrate miscut remains less understood.

This work investigates how anisotropic epitaxy, defined as the combined effects of epitaxial strain and substrate miscut, governs the structural, electronic, and magnetic properties of LSMO thin films. The films are grown by pulsed laser deposition on SrTiO_3 , LaAlO_3 , and LSAT substrates corresponding to tensile strain, compressive strain, and lattice-matched conditions, respectively. Substrate orientations include (001), (101), (102), and (103), enabling variation of miscut across the different strain states. High-resolution x-ray diffraction and reciprocal space mapping assess the crystallinity and strain relaxation, while atomic force microscopy characterises the surface morphology. Four-probe resistivity measurements as a function of temperature and magnetic field provide insights into the transport and magnetoresistive behaviour.

The findings aim to advance the understanding of how anisotropic epitaxy can be utilised to tailor perovskite-based materials for applications in spintronics and energy technologies. These results will provide a general framework for designing high-performance materials and devices based on epitaxial perovskite oxide thin films, highlighting the potential of anisotropic epitaxy in material science.

¹ Žužić, A., et al. (2022). *Ceramics International*, 48(19):27240–27261.

² Sando, D. (2022). *Journal of Physics: Condensed Matter*, 34(15):153001.

³ Dhole, S., et al. (2022). *Nanomaterials*, 12(5), 835.

[4] Takamura, Y., et al. (2008). *Applied Physics Letters*, 92(16).

Atomic and Molecular Physics / 189

Metastable Helium Atom Production by Positron Impact

Authors: Joshua Machacek¹; Liam Wymer¹; Sean Hodgman²; Sharan Kumar¹; Stephen Buckman³; Tim Gay⁴

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We have adapted one of the ANU positron beamlines, which use a Surko buffer gas trap and a strong magnetic field, to enable direct measurements of reaction products from atomic collision experiments. An effusive gas jet was added to the beamline, which allowed us to cross a helium beam with the high-resolution, pulsed positron beam. Long-lived (metastable) neutral excited helium atoms formed in the positron collisions were detected by a strategically positioned channel electron multiplier (CEM).

Helium has two long-lived metastable states (2^3S and 2^1S), though only the 2^1S state is directly accessible to positrons. Excitation of the 2^3S state requires a spin-flip from the ground state and since positrons do not have access to the exchange interaction like electrons, they instead require the spin-orbit interaction, which is both weaker for positrons than electrons and weak for helium in general (spin-orbit scales roughly with atomic number Z^4). Thus, we expect only 2^1S excitation.

In the experiment, a pulsed positron beam crosses a He beam and metastable atoms are detected with high efficiency ($\sim 90\%$) by a CEM. Time-of-flight techniques and electrostatic retardation are used to separate the relatively slow He atoms from faster reaction products (ions, positrons, electrons, positroniums). The 2^1S state has a lifetime of ~ 19 ms, which is far longer than the average flight time of the atoms from the collision volume to the detector ($\sim 40 \mu s$).

Excitation of the He 2^1S state as a function of incident positron energy will be presented and compared with previous measurements using conventional gas-cell arrangements and with theory.

Poster Session / 190

Hyperentanglement-empowered quantum waveguide optics

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Hyperentanglement, a sophisticated form of quantum entanglement across multiple degrees of freedom (DOFs), holds immense potential for revolutionizing quantum technologies in communication, sensing, and computing. This work presents a computational approach to generate hyperentanglement using waveguides, a method shown to be more efficient than traditional techniques and capable of producing a higher number of hyperentangled biphoton pairs. By acting as a tunnel for photons, waveguides minimize unwanted interactions with the environment [1], leading to a more robust and higher-fidelity hyperentangled state.

Our methodology is grounded in the theoretical framework of biphoton wavefunction dynamics [2], where we have expanded four equations to generate a set of 16 coupled differential equations with the basis equation shown below. These equations model the propagation of signal and idler photons through a system of two waveguides to generate $\Psi_{n_s, n_i, p_s, p_i}$ wavefunctions for signal waveguide (n_s), idler waveguide (n_i), signal polarization (p_s), idler polarization (p_i) and consider key parameters to generate the 16 equations such as phase mismatch, effective refractive indices and coupling coefficients to determine the optimal conditions for hyperentanglement generation [3].

$$-id \frac{dz}{dz} \Psi_{n_s, n_i, p_s, p_i} = - \left[C_{p_s}^{(s)} \Psi_{n_s, n_i, p_s, p_i} + C_{p_i}^{(i)} \Psi_{n_s, n_i, p_s, p_i} \right] + id_{eff} A_{n_s} \delta_{n_s, n_i} \exp(i\Delta\beta^{(0)}z) \quad (1)$$

We numerically solve these equations using Python to simulate and calculate the final coupled states and biphoton correlations in a histogram and density matrix respectively to be presented. The simulations we are exploring show how varying system parameters, such as spatial (waveguide number) and polarization DOFs, affect the generation of hyperentangled states. Our waveguide platform is quite powerful, allowing the generation of various two-photon states [2] and we are working on the extension to hyperentanglement where we are systematically exploring which hyperentangled states can be generated for which sets of parameters, and what the limits are in this context. This research represents a significant step forward in scaling these technologies toward practical quantum devices.

Poster Session / 191

Quantum advantage without exponential concentration in kernel methods for learning data with group symmetries

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Quantum machine learning (QML) has the potential to outperform classical methods for certain structured data problems. For datasets with specific group structures, quantum kernels have been shown to learn more efficiently than classical approaches. These kernels use unitary representations of groups to construct feature maps that are covariant under group actions, enabling the algorithm to exploit symmetries in the data. They have been demonstrated, both theoretically and experimentally on a 27-qubit superconducting quantum processor, to effectively classify coset-structured data, which remains challenging for classical models unless the symmetry is explicitly encoded.

A significant challenge in QML is the occurrence of barren plateaus, where gradients vanish exponentially with system size, making training infeasible. We prove that kernel-based learning for the aforementioned group-structured problems avoids kernel concentration, ensuring trainability even as system size increases. Since kernel concentration is known to be equivalent to barren plateaus, our result connects to this broader challenge —showing that, contrary to growing skepticism, QML is not dead and trainable quantum models with performance advantages exist under the right conditions.

We introduce covariant quantum kernels tailored for data with an underlying group structure, enabling symmetry-aware quantum learning. Interpreting quantum kernels as variational quantum circuits provides a unifying perspective that connects kernel methods and parameterized quantum models for group-symmetric data. We extend the coset quantum kernel beyond two cosets and analytically show that the variance of the resulting kernels remains non-vanishing even as qubit number increases —our main result —demonstrating that the exponential advantage persists in the large-system limit. Finally, numerical simulations and analysis of bounded noise sources show that the kernels continue to separate data and avoid concentration, enabling symmetry-informed quantum learning on near-term hardware.

Poster Session / 192

Epitaxy of CdS on highly mismatched Al₂O₃ substrates

Author: Anouk Jurewicz¹

Co-authors: Erik Bakkers¹; Marcel Verheijen; Ries Koolen¹

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Hex-SiGe is a promising material for the photonic integration of data communication, as its direct bandgap allows for silicon-based optoelectronic interconnects. However, hex-SiGe is synthesised in core-shell nanowire structures that are not suitable for future scalability and probing of fundamental properties is difficult due to their small size. To overcome these challenges, it is proposed to grow planar hex-SiGe on wurtzite CdS substrates epitaxially. However, wurtzite CdS substrates are small and expensive. Therefore, investigating the heteroepitaxy of CdS on another substrate becomes worthwhile.

In this research, heteroepitaxial growth of monocrystalline CdS films on highly mismatched (1-102) Al₂O₃ substrates via molecular beam epitaxy is achieved and the effects of the growth temperature and VI/II ratio are investigated. Characterisation of the CdS film surface morphology, roughness, thickness and crystalline structure is performed. All CdS films exhibit mostly a (0001) oriented crystal structure, which is unsuitable for the epitaxial growth of planar hex-SiGe. However, an improved crystal structure in the CdS film is obtained by increasing the sulfur flux, as observed with rocking curves. Pole figure analysis of the samples grown at a VI/II ratio of 4 indicates the formation of two distinct (0001) oriented CdS domains on the (1-102) Al₂O₃ substrate. In addition, SAED patterns and cross-sectional BF-TEM images reveal the epitaxial relationships of the (0001) oriented CdS domains on the (1-102) Al₂O₃ substrate. The achievement and understanding of the heteroepitaxial growth of monocrystalline CdS films on (1-102) Al₂O₃ will serve as an important basis for future research into this material system.

Poster Session / 193

Fast qubit parameter estimation using quantum circuits

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Performing experiments on qubit devices require the implementation of quantum gates, which are prone to errors. It could be stochastic errors introduced by the noisy environment or unitary errors due to miscalibration or drifts in the system, resulting in sub-optimal fidelities. Therefore, we required a formalism to understand the unitary errors as they appear and how the quantum gates are behaving when these errors happen. Mitigating these errors will allow us to achieve high-fidelity quantum gates. Ideally, this should all be done while the experiment is in progress. In this poster, we present a method to analyze the experiments and estimate Rabi and Larmor errors during the experiment. This method provides system parameters that closely approximate the qubit system upon completion. We benchmark the method against both simulations and experiments, where we attempted to verify the output of this method against a known input. We can potentially integrate this with the quantum experiments in real-time closed feedback loops. This could help to track the Rabi and Larmor drifts as they appear and correct them at the same time providing a pathway towards improving the performance of quantum gates.

Focus Session - From edge states to emergent phases / 194

Chiral topological superconductivity in Sn/Si(111) and related compounds

Author: Stephan Rachel¹

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Motivated by the recently discovered superconductivity in boron-doped Sn/Si(111) with a T_c as high as 10K [1], I will focus on unconventional superconductivity of correlated electrons on the triangular lattice. I will further demonstrate the significance of Rashba spin-orbit coupling for materials such as Sn/Si(111) and show that, as a consequence, the superconducting phase possesses a surprisingly rich Chern-number landscape [2]. I will discuss the implications of our findings for Sn/Si(111), compare observables and also emphasize the significance of related compounds such as Pb/Si(111), Sn/SiC(0001) and Pb/SiC(0001) [3].

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Nuclear and Particle Physics / 195

Low Mass WIMP searches with the Migdal Effect in XLZD

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XLZD is a future dark-matter direct detection experiment that will use a liquid Xenon (LXe) based Time Projection Chamber (TPC) to search primarily for Weakly Interacting Massive Particles (WIMPs), with sensitivity all the way to the neutrino-fog for WIMP candidates with mass above about 3 GeV/c². The typical channel used to search for these particles is through their recoil on the nuclei of the xenon atoms producing both light and charge signals, that are collected using photomultiplier tubes (PMTs). This channel has been used by current generation LXe TPC experiments to set world leading limits on the WIMP-nucleon cross section for WIMP masses above 3 GeV/c². The recoil signals produced by even lower mass WIMPs are typically lower than the detection threshold leading to much of the phase-space remaining unexplored.

In this talk I will present the prospects of utilizing possible signals from the Migdal Effect to search for Low Mass WIMPs in XLZD. According to the Migdal Effect, the electron cloud of a target atom may lag behind a recoiling nucleus which may lead to some electrons being emitted. Since electrons produce electronic recoil signals, with a larger charge to light ratio and less energy lost to heat, low mass WIMPs (0.1 GeV/c² to 2 GeV/c²) can also produce signals that are larger than the detection threshold. When searching for signals near the detection threshold, instrumental noise like the mispairing of waveforms becomes a major background. In my talk, I will summarize the XLZD experiment and how the sensitivity to WIMP interactions with this channel vary considering different sizes of the detector, levels of backgrounds and the strength of the electric field in the future TPC.

Astroparticle Physics / 196

Dark matter across scales: ultralight fields, Bose-star signatures, and massive compact composites

Author: Igor Samsonov¹

Co-author: Victor Flambaum²

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Light scalar and pseudoscalar fields—such as axion- and dilaton-like particles—are well-motivated dark-matter candidates. Their couplings to Standard-Model fields can induce tiny, stochastic modulations of atomic transition frequencies. A statistical framework for clock-based searches is developed, showing that higher-order statistical moments of the measured fluctuations (e.g., skewness, kurtosis, intermittency) can provide distinctive signatures of ultralight scalar and pseudoscalar dark matter.

Astrophysical implications of self-gravitating bosonic configurations (“Bose stars”) are also examined. In certain regimes, their interaction with the interstellar medium may seed high-metallicity molecular clouds, offering an indirect observational handle on this scenario.

Separately from the ultralight sector, models of modified gravity with extra dimensions—such as the Arkani-Hamed–Dimopoulos–Dvali framework—admit extremely compact massive composite objects made from quarks or antiquarks. Detection strategies for these heavy composites will be discussed.

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Poster Session / 197

Frequency noise suppression in GdVO₄ Raman laser for linewidth narrowing

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Raman lasers make use of inelastic, third-order nonlinear light-matter interaction and inherent phase matching to shift optical frequencies and enhance beam quality by transferring pump energy into the cavity’s fundamental mode. These processes have a linewidth-narrowing effect, expected to reduce laser linewidth by up to eight orders of magnitude, outperforming Brillouin lasers, with reported reductions from hundreds of MHz-GHz to approximately 1 kHz in certain systems, with pulsed configurations approaching their Fourier limit [1,2]. However, many applications in precision metrology, next-generation atomic clocks, high-resolution spectroscopy, and enhanced qubit manipulation in quantum technologies, benefit from much narrower linewidths and increased wavelength options.

We report the development of a single-longitudinal-mode Raman laser operating at 1164 nm and/or 1174 nm, using the two primary Raman modes (834 cm⁻¹ and 882 cm⁻¹) of GdVO₄ as the Raman medium and a 1064 nm pump laser. We obtain first order Stokes emission at a threshold power of 1.3 W. We implement Pound-Drever-Hall (PDH) locking of the cavity to the Stokes resonance to ensure stable single-frequency operation. Further, we plan to characterize the frequency noise damping and linewidth using a short delay self-heterodyne interferometric technique. We expect to measure exceptionally large noise damping and linewidth reduction due to the use of a broad-linewidth pump and a lower noise floor measurement system. We aim to show that the laser concept is promising for simultaneously satisfying the linewidth, power, and wavelength requirements of ultra-narrow linewidth applications.

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Atomic and Molecular Physics / 198**Nuclear Clock and the Search for New Physics****Author:** Victor Flambaum¹**Co-authors:** Igor Samsonov ¹; Vladimir Dzuba ¹¹ *University of New South Wales***Nuclear Clock and the Search for New Physics**

The isomeric transition in ^{229}Th - recently laser-excited by multiple groups ¹ - opens a path to a nuclear clock with accuracy competitive with, and potentially exceeding, the best optical atomic clocks. Because the nucleus is well shielded from environmental perturbations, systematic shifts can be intrinsically small; however, the surrounding electrons strongly mediate excitation and decay via the electronic-bridge mechanism and can modify both transition frequency and lifetime by orders of magnitude ². Electron-induced shifts of the nuclear transition must therefore be quantified ³. A “stretched-state” scheme suppresses leading-order electron–nucleus entanglement and mitigates key systematic effects [4].

The ^{229}Th transition is exceptionally sensitive to physics beyond the Standard Model: spatial/temporal variation of fundamental constants (α , quark masses, Λ_{QCD}) [5], ultralight dark-matter couplings to gluons and nucleons [6], and violations of Lorentz invariance and Einstein’s equivalence principle [7]. Four orders enhancement factors relative to electronic transitions, together with frequency-ratio networks linking nuclear and atomic references, enable stringent, model-aware constraints.

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Poster Session / 199**On the Copenhagen Interpretation of Quantum Measurement****Author:** MICHAEL WALKER¹¹ *Australian Institute of Physics*

We claim that quantum collapse, as per the Copenhagen interpretation of quantum mechanics, follows naturally from the energetics of measurement. We argue that a realistic device generates an interaction energy that drives a random walk in Hilbert space and generates the probabilistic interpretation of Born.

Atomic and Molecular Physics / 200**Atomic clocks, space-time variation of the fundamental constants and dark matter**

Authors: Victor Flambaum¹; Vladimir Dzuba¹

¹ *University of New South Wales*

Fundamental constants—such as the fine-structure constant α , the strong-interaction scale, and particle masses—may vary in an expanding Universe. A spatial variation could help explain apparent fine tuning: we inhabit a region where the values permit life. Hints from quasar absorption spectra suggest a gradient in α , but decisive confirmation requires laboratory tests. Atomic clocks provide such tests and, through their exquisite stability, enable sensitive searches for new physics.

Interactions between dark matter and ordinary matter can induce temporal variation of constants. For low-mass bosonic dark matter produced after the Big Bang, the field behaves classically, yielding first-order effects in the coupling—an enormous advantage over traditional second-order responses. Using clock comparisons, existing bounds on scalar dark-matter couplings to photons, electrons, quarks, and the Higgs can be tightened dramatically; our analyses improved previous limits by up to 15 orders of magnitude.

We assess several promising clock candidates - metastable transitions in Cu II, Yb III, Hf II, Hf IV, and W VI - where s-d transitions deliver enhanced sensitivity to α variation (enhancement coefficients up to $K \approx 8$) while offering accessible cooling E1 lines. Using relativistic many-body theory, we compute energies, Landé g factors, E1/E2/M1 amplitudes, lifetimes, quadrupole moments, scalar polarizabilities, second-order Zeeman shifts and black body-radiation shifts (BBR). Forming suitable linear combinations of clock transitions suppresses BBR.

Finally, highly charged-ion clocks offer reduced systematics due to their compact size, with α - variation and dark-matter responses enhanced by 1–2 orders of magnitude. Together, these strategies link precision metrology to cosmology, enabling high accuracy searches for space-time variation of the constants and for dark matter.

Poster Session / 201

Nuclear Wasteforms Studied with Positron Annihilation Lifetime Spectroscopy (PALS)

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A nuclear wasteform serves to contain radionuclides and enable safe disposal of nuclear waste over long timeframes. In ceramic wasteforms, radionuclides are locked into specific atomic sites within the crystal structure through strong inorganic bonds, effectively preventing their release. Fluoride-pyrochlores are being explored for the immobilisation of actinides from Generation IV molten salt nuclear reactors. However, the mechanisms by which actinides are incorporated into the fluoride-pyrochlore matrix remain poorly understood. Key factors include the actinide valence state and whether the atoms occupy substitutional or interstitial sites within the structure.

When positrons are introduced into well-crystallized ionic solids, they thermalize and annihilate with electrons, typically within 0.1–0.2 ns. However, the presence of cation vacancies or other structural defects creates regions of low electron density where positrons become trapped and/or form positronium, resulting in extended lifetimes of up to 1 ns or more. Consequently, positron annihilation lifetime spectroscopy (PALS) serves as a highly sensitive technique for detecting cation vacancy mechanisms involved in actinide incorporation into ceramic wasteforms.

In this study, a desk-top PALS system with a ²²Na source was employed to investigate the potential involvement of a cation vacancy mechanism for the incorporation of actinides in fluoride-pyrochlore

structures. Cerium (Ce^{4+}) was used as an actinide surrogate to simulate U^{4+} , Pu^{4+} and Th^{4+} . Ce^{4+} was targeted for substitution at the Ca^{2+} site in the series $(\text{NaCa}_{1-2x}\text{Ce}_x)\text{Nb}_2\text{O}_6\text{F}$, with x values of 0, 0.1, 0.2, and 0.25. Prior to analysing the fluoride-pyrochlore samples, the validity of the PALS technique was confirmed using a model system in which Nb^{5+} was incorporated into rutile (TiO_2) via a charge-compensating vacancy mechanism.

The experimental and data analysis techniques will be outlined, and PALS results for both the rutile and pyrochlore structures will be presented and discussed.

Atomic and Molecular Physics / 202

Polarised Positron Interactions with Cold, Polarised Atoms

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The positron is the antimatter counterpart of the electron. They can annihilate directly, producing gamma rays (e.g., two 511 keV) or form a bound state known as positronium (Ps). The bound state has two forms: a singlet or para-Ps (125ps lifetime), and a triplet state or ortho-Ps (142ns lifetime). These states decay into a number of gamma rays (even or odd, respectively), which can be measured to determine the quantum state of the Ps.

Positrons obtained from nuclear beta decay (e.g., from Na-22) are produced with non-zero helicity. It has been previously demonstrated that positrons retain their spin polarisation when moderated and accumulated. Thus, these positrons can be used to measure spin-dependent scattering processes.

For spin-polarised scattering studies, a desirable choice of target is atoms confined in a Magneto-Optical Trap (MOT). The key benefit of the MOT is the control of the polarisation of the trapped atoms (e.g., Rb-87). Additionally, the trapped atomic cloud provides a uniform target for the positron scattering experiments. These aspects allow for the measurement of the quantum state of Ps as a function of the MOT polarisation.

We will report on experimental progress on our Rb-MOT built for positron scattering experiments. Additionally, we will discuss progress on the integration of the Rb-MOT with the positron beam-line.

Quantum Science and Technology / 203

Quantum imaging of living cells with bright squeezed light

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Microscopy is central to biological discovery, but high performance often requires high illumination powers that induce photodamage. Quantum correlations offer a way to overcome this limit by enhancing the signal-to-noise ratio at fixed optical intensities.

We present a quantum microscope based on stimulated Raman scattering (SRS), a widely used technique for molecular fingerprinting through vibrational frequencies. By illuminating living cells with bright squeezed light—a quantum resource compatible with the high intensities relevant to biological samples—we improve both probe quality and signal-to-noise compared to previous single-beam SRS implementations.

These advances enable fast, multispectral quantum imaging with noise levels below the shot-noise limit of state-of-the-art classical SRS microscopes. As an initial application, we demonstrate drug testing by monitoring the response of A549 cancer cells to Mycetin.

Condensed Matter & Materials / 204

Temperature dependence of the mixed antiferro-/ferro- magnetic structure of the compositionally complex perovskite L5BO

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Spintronic devices offer fast, non-volatile, and more energy-efficient computing and memory compared to conventional electronic approaches. Compositionally complex oxides (CCOs) are an emerging class of materials for spintronic applications due to their low cost, robust magnetic stability, and high tunability. We are investigating $\text{La}(\text{Cr}_{0.2}\text{Mn}_{0.2}\text{Fe}_{0.2}\text{Co}_{0.2}\text{Ni}_{0.2})\text{O}_3$ (L5BO), a perovskite CCO which exhibits the coexistence of antiferromagnetic (AFM) and ferromagnetic (FM) ordering, due to competition among its 15 different exchange interactions. Bulk magnetic properties are controlled by varying Mn concentration. At a concentration of 40% Mn, exchange biasing behaviour (normally only accessible through intentionally designed heterojunctions) and a gradual transition region in M-T curves, rather than a well-defined transition temperature, has led to the suggestion that AFM and FM ordering can both coexist in relatively equal proportions. Because AFM and FM ordering lead to result in neutrons being scattered at different reflections, using temperature dependent magnetic neutron powder diffraction we have been able to confirm that both AFM and FM ordering coexist within 40% Mn L5BO. We also demonstrate that the AFM and FM fractions of the material have separate transition temperatures, lowering the operational temperature for prospective devices than that given by standard magnetometry. Furthermore, this implies that neutron scattering is an essential tool for future research into similar compositionally complex mixed-magnetic oxides in order to fully understand how different magnetic phases evolve with temperature versus bulk magnetometry.

Condensed Matter & Materials / 205

Using shear to lower transition pressures to new phases in Carbon, Si and Ge

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This study investigates the impact of shear strain on the phase transformation behavior of Si and Ge under high-pressure conditions. Si and Ge are known to undergo a series of pressure-induced phase transformations, resulting in new phases with technological potential [1,2]. Utilizing both traditional diamond anvil cells (DAC) and a new rotational diamond anvil cell we demonstrate that high-shear environments reduce the pressure threshold required for the semiconductor-to-metal phase transformation from diamond cubic (dc) to (β -Sn) structures in both materials. In situ Raman spectroscopy and X-ray diffraction experiments reveal that with rotational shear the metallic β -Sn phase can form in Ge at pressures well below the threshold required under hydrostatic conditions. In a rotational DAC, the transformation occurs at approximately 4 GPa, significantly below the conventional 10 GPa threshold. Furthermore, we observe unexpected decompression pathways that deviate from established behavior. When (β -Sn)-Ge forms below 10 GPa under high shear, it directly reverts to the original dc-Ge structure upon decompression, contrasting with the formation of the exotic metastable phases (r8-Ge, bc8-Ge, st12-Ge) typically observed after decompression from (β -Sn)-Ge. A similar behavior is seen for Si. Microstructural analysis of single crystal Si samples using transmission electron microscopy suggest that this pressure reduction phenomenon may be facilitated by shear-induced defects, particularly stacking faults along {111} planes, which serve as nucleation sites for the phase transition [3].

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Quantum Science and Technology / 206

Integrating gate-defined quantum dots with nuclear spin qubits in silicon

Authors: James Zingel¹; Benjamin Wilhelm¹; Rocky Y Su¹; Martin Nurizzo¹; Sarah Kruskic¹; Tim Botzem²; Shao Qi Lim³; Wee Han Lim²; Alexander M Jakob³; Fay E Hudson²; Kohei M Itoh⁴; Andrew S Dzurak²; David N Jamieson³; Danielle Holmes¹; Andrea Morello¹

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High-dimensional qudit systems yield the exciting prospect of hosting error-correctable logical qubits. 1. The antimony (¹²³Sb) donor in silicon is ideal for this purpose, because its spin-7/2 nucleus embeds an 8-dimensional Hilbert space (or 16-dimensional, including the electron) that can encode Schrödinger cat states [3].

Scaling up this donor nuclear qubits requires using electrons to mediate the interaction between distant nuclei [4]. Using ion-implanted donors in metal-oxide-semiconductor devices opens the possibility of using the electrons in gate-defined quantum dots as the mediators of the interaction between multiple nuclei.

Here, we present experiments on a device that combines an implanted ¹²³Sb donor in silicon with gate-defined quantum dots. We demonstrate tunability of the electron occupation in the donor-dot system, and measure strong exchange interaction between the donor- and dot-confined electrons when two electrons are loaded into the system. Additionally, we operate the device with only one electron and demonstrate controlled shuttling of the electron between the donor and the dot. This capability is key to operating the electrically-driven 'flip-flop' qubit [5] at the maximum speed, and opens the possibility of coupling distant flip-flop qubits via their induced electric dipole.

Our results open new pathways for donor-dot hybrid devices, where mobile electrons can be coupled to highly coherent, high-spin donor nuclei that locally encode logical qubits.

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Poster Session / 207

Mechanisms of Spontaneous Vortex Clustering in Turbulent Two-Dimensional Superfluids

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Turbulence in two-dimensional (2D) fluids often leads to the formation of long-lived, large-scale vortex structures. In 2D quantum fluids, such as Bose–Einstein condensates, these structures manifest as clusters of singly quantised vortices [1,2]. Simula et al. showed via Gross–Pitaevskii simulations that vortex clustering can spontaneously emerge from an initially random distribution of vortices and antivortices, even in the absence of external driving [3]. This behaviour was attributed to an “evaporative heating” mechanism, where vortex-antivortex annihilations preferentially remove low-energy vortices, increasing the average energy per vortex, leading to clustering. However, Kanai and Guo [4] later proposed that boundary annihilations play a dominant role in driving clustering, while bulk annihilations suppress it due to the generation of sound waves.

To investigate these competing mechanisms, we have studied vortex clustering in both the point vortex and Gross-Pitaevskii models. In the point vortex model, we can tune the ratio of bulk versus boundary annihilations by manually adjusting the boundary annihilation radius. While increased boundary annihilation rates correlate with more ordered vortex structures at later times, we find this is primarily due to a higher overall annihilation rate. Crucially, the heating per annihilation event remains independent of the boundary annihilation frequency.

In the Gross-Pitaevskii model we can introduce a “potential trench” at the edge to suppress vortex-boundary interactions. At the time of writing these simulations are ongoing, but the final results will determine the relative importance of bulk versus boundary annihilations for spontaneous vortex clustering.

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Quantum Science and Technology / 208

Electromagnetic helicity in twisted cavity resonators

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Through left- or right-handed twisting, we investigate the impact of mirror-asymmetry (chirality) of the conducting boundary conditions of an equilateral triangular cross section electromagnetic resonator. We observe the generation of eigenmodes with nonzero electromagnetic helicity as a

result of the coupling of near degenerate $TE_{11(p+1)}$ and TM_{11p} modes. This can be interpreted as an emergence of magnetoelectric coupling, which in turn produces a measurable shift in resonant mode frequency as a function of twist angle. We show that this coupling mechanism is equivalent to introducing a nonzero chirality material parameter κ_{eff} or axion field θ_{eff} to the medium. Our findings demonstrate the potential for real-time, macroscopic manipulation of electromagnetic helicity.

Industrial Applied Physics / 209

Accelerating physical systems with quantized utility agents

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The automation of complex experimental systems has been a long-standing goal with numerous real-world applications. While reinforcement learning (RL) has achieved breakthroughs across many domains, prior approaches to physical system control required crafting realistic simulations, complex reward engineering, and extensive training times, limiting practical deployment.

Saha et.al. (2025) introduce a “quantized utility agent”(AQUA), a novel framework that aims to simplify RL for autonomous control in complex physical systems. It declutters the learning process, allowing operational control agents to be pre-trained offline using existing datasets, boosting sample efficiency significantly.

The framework employs generative “world models” that extract meaningful representations from noisy experimental data, encoding inputs and outputs into a compressed feature space that captures process states without explicit temporal ordering. During deployment, AQUA executes efficient searches in this compressed space to imagine outcomes and plan optimal actions through population refinement techniques.

Demonstrated performance across complex optical 1 and quantum systems, AQUA performs optimally out-of-the-box, when deployed on physical systems, adapts to changing conditions, fine-tunes online and surpasses human-level performance.

Emerging quantum computing, communications, sensing and space technologies are carefully assembled, collection of inter-dependent components. As the complexity of these systems grows, maintaining optimal performance manually becomes a major bottleneck, especially for remotely deployed systems. AQUA’s task-agnostic, pre-trainable and adaptable design could effectively streamline these processes, allowing them to scale.

Besides saving hours of human labour, the method’s implied ability to learn features from raw experimental data could, in principle, be used to study the underlying properties of the physical system that are hard to describe in theory, potentially bridging the gap 2.

References:

1. A. Saha, et. al., Automating experimental optics with sample-efficient machine learning methods, *Optica* 12, 1304-1310 (2025)
2. S.J. Wetzel, et.al., Interpretable Machine Learning in Physics: A Review, arXiv:2503.23616 (2025)

Poster Session / 210

Development of WSi Superconducting Nanowire Single Photon Detectors

Authors: Alexey Lyasota¹; Alison Goldingay¹; Gabriele de Boo^{None}; Hassan Jamal Latief¹; Justin Brown¹; Sven Rogge¹; Upender Singh²

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The detection of infrared photons is critical to the successful readout of single photon states of spin qubit platforms such as embedded ions. Superconducting nanowire single photon detectors (SNSPDs), based on the simple principle of the generation of a hotspot in a superconducting nanowire upon photon absorption leading to a resistance spike, provide an excellent platform for fast and efficient detection of infrared photons. SNSPDs have been shown to achieve near unity efficiency including at the critical telecommunication wavelength of 1550 nm, with extremely low near-zero dark counts, low reset times and low jitter. Tungsten silicide (WSi) is a common choice of nanowire material since it has a high internal efficiency, is amorphous in nature and allows for embedding of the material inside an optical stack to enhance absorption.

Here, we report the development of WSi films for nanowire fabrication and incorporation into SNSPDs which will be fabricated and tested in-house. We report the resistance of these films as well as their critical temperature, marking their transition to a superconducting state at cryogenic temperatures, for films sputtered onto a variety of substrate surfaces, such as silicon and silicon oxide. We then report on their inclusion into optical stacks for full SNSPD devices optimized for 1550 nm photon detection. Finally, we report an outlook on how these SNSPDs can enable ultrafast measurement of spin qubit systems such as embedded rare-earth ions.

Focus Session: Ultra-cold atoms and quantum technology / 211

Realising solitonic edge states of vortex lattices in planar Bose-Einstein condensates

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Edge states are excitations in many-body systems that are spatially localised at the boundary. They exhibit desirable properties such as dissipationless transport and robustness against disorder. These features make them central to phenomena like the quantum Hall effect and topological insulators.

In a rotating planar Bose-Einstein condensates (BECs), the ground state forms a triangular lattice of quantized vortices. While the linear normal modes of such vortex lattices have been well studied ¹, recent theoretical work by Bogatskiy and Wiegmann ² predicts the existence of nonlinear solitonic edge states which are the hydrodynamic analogue of the edge states of the fractional quantum Hall effect.

Here we search for solitonic edge excitations in finite systems within the nonlinear regime of the point vortex model, going beyond the coarse-grained hydrodynamic approximation. We compare our results to the predictions of Bogatskiy and Wiegmann and explore the feasibility of experimentally observing these edge states in ultracold atomic BECs ³.

¹ L. J. Campbell, Transverse normal modes of finite vortex arrays, *Physical Review A* **24**, 514 (1981).

² A. Bogatskiy and P. Wiegmann, Edge wave and boundary layer of vortex matter, *Physical Review Letters* **122**, 214505 (2019).

³ T. W. Neely et al., Melting of a vortex matter Wigner crystal, arXiv:2402.09920 (2024).

Poster Session / 212

Impact of uncertainties in CO₂, HCl, and H₂O cross sections on simulations of Venus atmospheric chemistry

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The atmospheres of Venus and Mars are primarily CO₂. CO₂ photolyses at wavelengths *less than* 200 nm to CO and O. Direct recombination via CO+O+M → CO₂+M is very slow so the rate of production of CO₂ to balance its loss via photolysis is controlled by the abundances of trace radicals that catalyse production of CO₂ (eg., Yung and DeMore, *Icarus* 51, 199, 1982). These trace radicals, such as OH and ClCO, are derived directly or indirectly from photolysis of H₂O and HCl. Previous large uncertainties in the rates of some of the key reactions that comprise these catalytic processes have been significantly reduced (eg., Mills and Allen, *PSS* 55, 2007; Marcq et al., *Space Sci Rev* 214, 10, 2018; Chao et al., *AGU Fall Mtg Abst* P11B-2985, 2024). In addition, several studies in the past 15 years have refined our understanding of the UV cross sections of CO₂ and H₂O (eg., Ranjan et al., *Astrobio* 17, 687, 2017; Schmidt et al., *PNAS* 110, 17691, 2013; Venot et al., *A & A* 609, A34, 2018; Archer et al., *JQSRT* 117, 88, 2013; Ranjan et al., *Ap J* 896, 148, 2020). Consequently, it is appropriate to examine again the impact on atmospheric simulations of the remaining uncertainties in the photolysis and extinction cross sections for CO₂ and H₂O. This poster will present the results from numerical simulations of the atmospheres of Venus and/or Mars conducted using the Caltech/JPL KINETICS photochemical model (eg., Allen et al., *JGR* 86, 3617, 1981).

Quantum Science and Technology / 213

Quantum Entanglement as a Resource for Secure Navigation

Authors: Eduardo Villasenor Alvarez¹; Kenji Shimizu¹; Matt Broome¹; Rakhitha Chandrasekara¹; Sarah Lau¹; Stephen Gensemer^{None}

¹ *CSIRO*

Secure Position, Navigation and Timing (PNT) is of critical importance in modern day to day life and the contemporary state-of-the-art radio frequency-based systems are vulnerable to various intercept and signal jamming attacks. Thus, the need for development of more secure alternative PNT capabilities. Quantum entanglement provides an elegant way of sharing tightly correlated time synchronization capabilities at arbitrary long distances whilst allowing the authenticated parties to perceive unauthorised intercepts via Bell tests. Long distance photon entanglement distribution in free space is affected by high optical link losses and background counts, requiring high spectrally bright entangled photon sources. Contemporary workhorse photonic entanglement technologies rely on spontaneous parametric down conversion (SPDC) process in bulk crystals having high second order nonlinearity coefficients like Periodically Polled Potassium Titanyl Phosphate (PPKTP). In this poster, we present the design and field results of such a PPKTP based entangled photon source configured in a Sagnac interferometer which aims to demonstrate quantum secured time synchronization protocols over a 7 km free space optical link.

Condensed Matter & Materials / 214

First-Principles Study of Multiferroicity in 1T-FeCl₂/Bilayer-GaSe Heterostructure

Author: Fahmida Fakhera^{None}

Co-authors: Carla Verdi ¹; Catherine Stampfl ²; Oliver Conquest ²

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Multiferroic materials have gained significant attention as promising candidates for next-generation electronic applications due to their ability to exhibit multiple ferroic orders simultaneously, including ferromagnetism and ferroelectricity ¹. Importantly, controlling magnetism by switching polarization states of ferroelectric materials offers more flexibility for information storage and processing in high-performance electronic devices ². Here, we employ first-principles density functional theory (DFT) calculations to investigate the binding energies, electronic, magnetic, and ferroelectric properties of a two-dimensional van der Waals multiferroic heterostructure composed of 1T-FeCl₂ and bilayer GaSe. While pristine 1T-FeCl₂ exhibits half-metallicity with robust ferromagnetism, bilayer-GaSe remains a semiconductor with sliding ferroelectricity. The electronic band structure retains its half-metallic character in the spin-up channel, while in the spin-down channel, significant contributions from bilayer GaSe appear at the conduction band minimum and valence band maximum at the heterostructure interfaces. The ferroelectric polarization in the GaSe bilayer significantly modulates the magnetic anisotropy energy of the heterostructure compared to the free-standing FeCl₂ monolayer. The charge transfer from the GaSe bilayer to the ferromagnetic monolayer is facilitated by their work function difference, 5.35 eV and 4.98 eV, respectively. This is also confirmed by studying the differential charge densities and Bader charges of the heterostructures. The contact interface forms Ohmic contacts, enabling sufficient charge transfer between the layers. This study presents a theoretical framework for designing artificial multiferroics, paving the way for controlled magnetism with switchable polarization states in next-generation devices, including non-volatile memory and spintronic applications.

Reference:

1 X. Feng, J. Liu, X. Ma, and M. Zhao, *Physical Chemistry Chemical Physics* 22, 7489 (2020).

2 K. F. Mak, J. Shan, and D. C. Ralph, *Nature Reviews Physics* 1, 646 (2019).

Focus Session: Frontiers of Medical Physics / 215

Of dogs and humans: Does the number of legs matter in the bench-to bedside translation of spatially fractionated radiotherapy techniques?

Author: Elisabeth Schueltke¹

Co-authors: Bernd Frerker²; Elette Engels²; Michael Lerch²; Vincent de Rover²

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² *University of Wollongong*

Of the fundamental components of cancer therapy, radiotherapy is by far the one causing the least ecological foot print, compared to surgery and systemic therapy (chemotherapy, immunotherapy). While radiotherapy is mainly a local therapeutic approach, it can help to significantly reduce the requirement for extensive surgery as well as for the need of systemic therapy. From clinical radiotherapy, we already know of the advantages coming with neoadjuvant radiotherapy: besides contributing to the preservation of organ function, it significantly reduces the risks for metastatic disease. Based on the results from in-vitro and pre-clinical studies, spatially fractionated radiotherapy (SFRT) should offer an additional benefit over clinically established broad beam radiotherapy techniques.

Veterinary patients, especially larger and older dogs, develop cancers very similar to human patients. These similarities include tumour size and depth from surface, which are important parameters in medical physics for treatment planning. Radiotherapy is an accepted component of veterinary cancer treatment. Thus, if veterinary trials are conducted to challenge cancer entities considered difficult to treat with currently established irradiation techniques, canine patients and their owners are likely to benefit immediately.

The logistic challenges of irradiating dogs include the necessity of anaesthesia for every single irradiation fraction, similar to irradiation in young children. Therefore, a low number of short neoadjuvant SFRT treatment sessions or even irradiation in one single treatment session (radiosurgery) would be favourable and enhance the quality of the patient's life. Developing treatment schedules with this fact in mind, this will also benefit human patients. SFRT, which has been shown to be a powerful irradiation technique already in first veterinary trials, might become a favourite option in both veterinary and clinical cancer radiotherapy. This and the question of how we can extrapolate from the results obtained in veterinary studies to the potential outcome of clinical studies will be discussed.

Atomic and Molecular Physics / 216

Recent Progress in the Ultranarrow Linewidth Multiwatt Diamond Raman Lasers in the Visible

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¹ EOS

² Macquarie University

Lasers with ultra-narrow linewidths, stable single-frequency operation, exceptional beam quality, and high power in the visible spectrum are indispensable for applications such as artificial guide star generation and optical lattices in next-generation clocks. Diamond Raman Lasers (DRLs) represent a compelling solution, as they enable access to spectral regions that are otherwise challenging for conventional laser technologies. Their excellent thermal conductivity allows power scaling without degrading beam quality, while their intrinsic phase-noise suppression outperforms traditional Brillouin lasers [1, 2]. Despite these advantages, achieving long-term stable single-frequency performance remains a central challenge. We have recently demonstrated free-running single-mode operation sustained for 35 minutes, highlighting the feasibility of extended operation when both the diamond and LBO crystals are carefully temperature-stabilized, and optimization of cavity parameters has been considered [3, 4]. For guide star and quantum applications, however, frequency locking to an external atomic reference is essential. Here, we demonstrate, for the first time, frequency locking of a DRL to the sodium D2a transition at 589 nm.

1 E. Granados et al., 'Spectral synthesis of multimode lasers to the Fourier limit in integrated Fabry-Perot diamond resonators', *Optica*, vol. 9, no. 3, p. 317, (2022).

2 R. L. Pahlavani, et al 'Linewidth narrowing in Raman lasers', *APL Photonics*, vol. 10, no.7 (2025)

3 O. Terra, et al., "Towards Stable, Low-Phase-Noise, and Multi-Watt Single Frequency Diamond Lasers in the Visible,"(CLEO/Europe-EQEC), Munich, Germany, 2025, pp. 1-1, doi: 10.1109/CLEO/Europe-EQEC65582.2025.11109760

[4] A. Sharp et al., "Optimising Single-Frequency Intra-Cavity-Doubled Diamond Raman Lasers," (CLEO/Europe-EQEC), Munich, Germany, 2025, pp. 1-1, doi: 10.1109/CLEO/Europe-EQEC65582.2025.11111260.

Quantum Science and Technology / 217

Quantum Signal Processing Interferometry: Detecting Rare Events at the Single-Shot Limit

Author: Frank Scuccimarra¹

Co-authors: Cameron McGarry¹; Christophe Valahu¹; Maverick Millican¹; Teerawat Chalermputitarak¹; Ting Rei Tan¹

¹ The University of Sydney

Quantum sensing leverages quantum resources to achieve measurement capabilities beyond what is possible classically [1,2]. While there is great focus on precision parameter estimation, an underexplored application is single-shot binary-decision making, where the task is to decide whether a signal has been detected. This is particularly advantageous when the underlying event is rare. Quantum Signal Processing Interferometry (QSPI) [3] provides a framework for such decision tasks, allowing one to determine whether the displacement signal's magnitude was above or below a given threshold.

Here, we summarise theoretical and experimental progress toward the realisation of single-shot displacement sensing using the QSPI framework. Our experiment [4] uses a spin-oscillator system in a trapped-ion system. The QSPI protocol consists of a sequence of single-qubit rotations and spin-dependent oscillator displacements that transform an incoming signal applied to the oscillator into a spin projective measurement with a binary outcome. We report extension towards phase-insensitive QSPI with tuneable response functions and dynamic ranges.

1 Vittorio Giovannetti et al., Quantum-Enhanced Measurements: Beating the Standard Quantum Limit. *Science* 306,1330-1336 (2004). DOI:10.1126/science.1104149.

2 Christian L. Degen et al., Quantum sensing. *Rev. Mod. Phys.* 89, 035002 (2017). DOI:10.1103/RevModPhys.89.035002.

3 Jasmine Sinanan-Singh et al., Single-shot Quantum Signal Processing Interferometry. *Quantum* 8, 1427 (2024). DOI: 10.22331/q-2024-07-30-1427.

[4] Alistair R. Milne, Construction of a linear ion trap and engineering controlled spin-motional interactions. PhD thesis, The University of Sydney (2021).

Medical Physics / 218

Developing a very high-energy electron radiotherapy facility at the ANSTO Australian Synchrotron

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Co-authors: Anatoly Rosenfeld¹; Dean Cutajar¹; Elette Engels²; Eugene Tan³; Jason Paino⁴; Joel Poder⁴; Marco Petasecca²; Michael Lerch²; Tessa Charles⁵

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³ Australian Synchrotron - ANSTO

⁴ St George Hospital Cancer Care Centre

⁵ Australian Synchrotron (AU)

Ultra-high dose-rate, very high-energy electrons (VHEE, electrons with energy greater than 50 MeV) are of increasing interest to the field of radiotherapy, due to their ability to penetrate deeply into tissue and reach tumours that are out of reach to clinical electrons of lower energies. Linacs capable of reaching these energies are also capable of exceedingly high dose-rates, many orders of magnitude above that of the threshold for FLASH radiotherapy (40 Gy/s), an emerging modality praised for its normal tissue sparing qualities.

While ongoing efforts are being made globally to quantify the exact parameters that deliver a FLASH effect, clearly, dosimetry for ultra-high dose-rate environments is required. The Australian Synchrotron's emerging Pulsed Energetic Electrons for Research (PEER) beamline delivers 100 MeV electrons and has been used to investigate the dose-rate (DR) and dose-per-pulse (DPP) independence of the MOSkin detector, a promising candidate for FLASH dosimetry. Previously, DR independence was established and, more recently, DPP independence was investigated. With up to 28 Gy DPP delivered in 200 ns, corresponding to average DRs as high as 1.65×10^8 Gy/s, the MOSkin was shown to remain linear in its response (Figure 1) and is currently the only suitable candidate for on-patient quality assurance dosimetry during FLASH radiotherapy.

With suitable dosimetry established, in-vitro biological investigations have been conducted to investigate cell survival curves at VHEE ultra-high dose-rates and compared to 2 Gy/s, 100 keV synchrotron x-rays, as well as another VHEE facility for the purpose of benchmarking the facility.

Engineering continuous-variable entanglement in mechanical oscillators with optimal control

Authors: Maverick Millican¹; Vassili Matsos²; Christophe Valahu¹; Tomas Navickas¹; Liam Bond³; Ting Rei Tan¹

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³ University of Amsterdam

We demonstrate an optimal quantum control strategy for the deterministic preparation of entangled harmonic oscillator states in trapped ions. The protocol employs dynamical phase modulation of laser-driven Jaynes-Cummings and anti-Jaynes-Cummings interactions. We prepare Two-Mode Squeezed Vacuum (TMSV) states in the mechanical motions of a trapped ion and characterize the states with phase-space tomography. First, we verify continuous-variable entanglement by measuring an Einstein-Podolsky-Rosen entanglement parameter of $0.0132(7)$, which is below the threshold of 0.25 for Reid's EPR criterion. Second, we perform a continuous-variable Bell test and find a violation of the Clauser-Horne-Shimony-Holt inequality, measuring $2.26(3)$, which is above the entanglement threshold of 2 . We also demonstrate the flexibility of our method by preparing a non-Gaussian entangled oscillator state—a superposition of TMSV states.

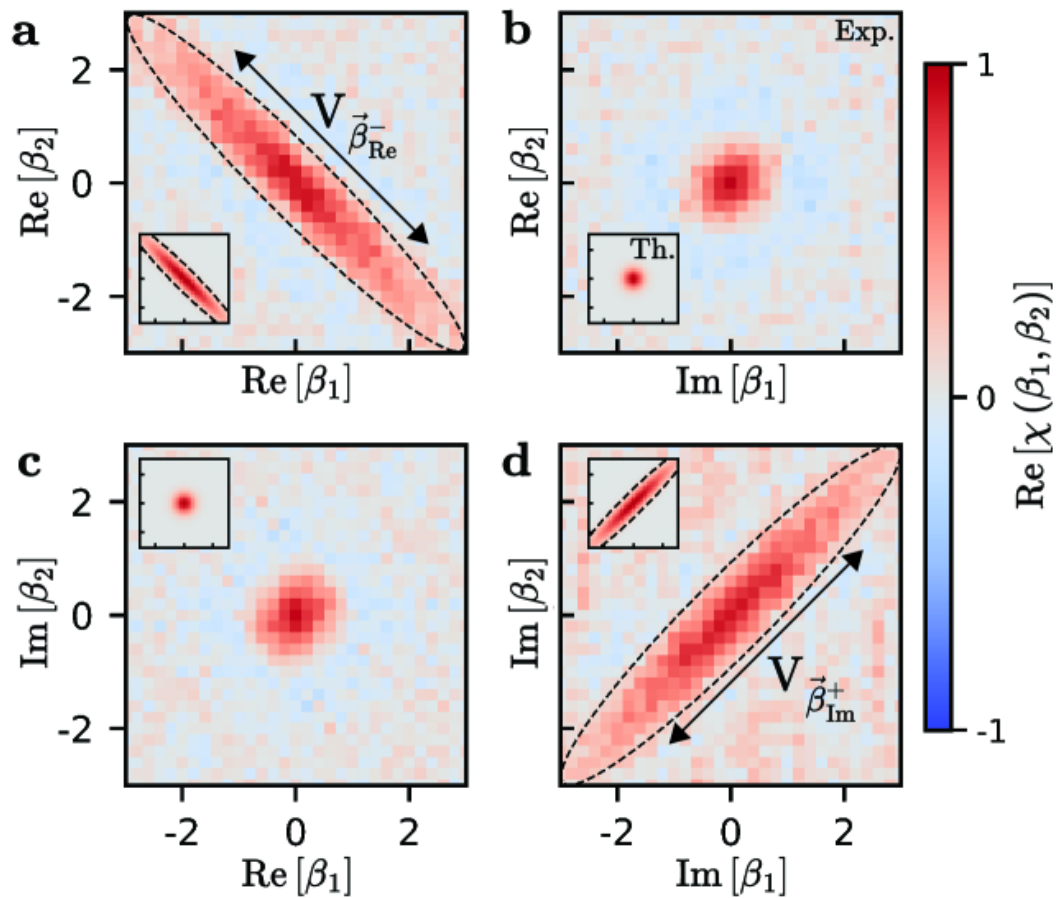


Figure 1:

Figure 1. Experimental characteristic function tomography of a two-mode squeezed vacuum (TMSV) state with target squeezing parameter, $r=1$. All panels show the real component of the two-mode

characteristic function. Panels a. and d. exhibit anticorrelation and correlation, respectively, consistent with two-mode squeezing. Dashed lines plot the Gaussian functions that are fitted to the data, from which variances are extracted and used to quantify entanglement with Reid's EPR criterion. Panels b. and c. show negligible correlation, consistent with uncorrelated orthogonal quadratures. Insets show the theoretical target characteristic function obtained from numerical simulations.]¹

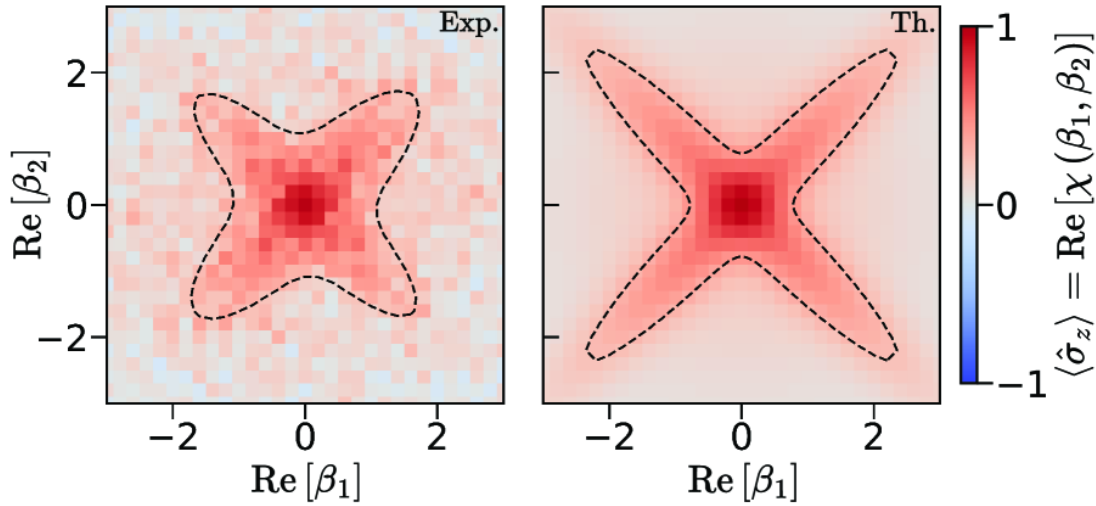


Figure 2:

Figure 2. Joint characteristic function reconstruction of an experimentally prepared superposition of TMSV states. The targeted state is an even superposition of two TMSV states. The experimentally reconstructed characteristic function shows features of the superposition state, with correlation along both axes, $(\beta, \pm\beta)$. The characteristic function is fitted to a distinct sum of two two-dimensional Gaussian functions (dashed lines) to estimate the relative amplitudes and squeezing. Inset shows the theoretical target characteristic function obtained from numerical simulations.

Theoretical Physics / 220

Emergent metric from wavelet-transformed quantum field theory

Author: Simon Vedl¹

Co-authors: Dan George¹; Gavin K. Brennen¹

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We introduce a method of reverse holography by which a bulk metric is shown to arise from locally computable multiscale correlations of a boundary quantum field theory (QFT). The metric is obtained from the Petz-Rényi mutual information defined with input correlations computed from the continuous wavelet transform. We show for free massless fermionic and bosonic QFTs that the emerging metric is asymptotically anti-de Sitter space (AdS), and that the parameters fixing the geometry are tunable by changing the chosen wavelet basis. The method is applicable to a variety of boundary QFTs that need not be conformal field theories, such as theories with mass or temperature for which we compute the emergent geometries.

Atomic and Molecular Physics / 221**Demonstration of a photonic time-frequency Fourier transform and temporal double slit****Authors:** Ankit Papneja¹; Cameron Trainor¹; Jesse Everett¹; Aaron D. Tranter¹; Ben C. Buchler¹¹ *Australian National University*

We present a novel demonstration of an optical memory-based time–frequency Fourier transform (TFFT) using an ensemble of cold ^{87}Rb atoms. Our approach combines two widely studied light–matter interaction protocols, Gradient Echo Memory (GEM) for storage and Electromagnetically Induced Transparency (EIT) for recall, to perform a Fourier transform directly within the atomic medium. Optical pulses are first mapped into a spin-wave using GEM, and subsequently retrieved under EIT conditions, producing an output that corresponds to the Fourier transform of the input temporal profile. This in-memory processing is experimentally characterised through the observation of temporal double-slit interference: two time-separated input pulses yield a modulated output (and vice-versa) with modulation frequencies that scale linearly with the input temporal separation, while relative phase controls the interference phase (Fig.1). The experimental results are supported by numerical simulations based on optical Bloch equations, which account for effects such as finite optical depth, decoherence, and the limited transparency bandwidth of the EIT process. Additionally, simulations show similar behavior when storage is performed with EIT and recall with GEM.

These results demonstrate how atomic quantum memories can be used not only for storage but also as functional devices for manipulating time–frequency structure. While the present demonstration is limited by technical factors such as decoherence and bandwidth constraints, the approach provides a flexible route to studying dispersion and interference phenomena in light–matter systems. Although this work is a proof-of-principle demonstration, the behavior can be tuned through storage gradients, retrieval conditions, and input pulse parameters. We believe this method can support applications such as temporal mode characterization, basic signal reshaping in communication channels, and controlled studies of quantum interference in stored optical fields, contributing to the gradual expansion of memory-based optical processing capabilities.

Astroparticle Physics / 222**Testing general relativity with the latest gravitational-wave ringdown signals****Author:** Neil Lu¹¹ *Australian National University*

The post-merger stage of a binary black hole coalescence is known as “ringdown”, when the remnant settles into a stable state through the emission of quasi-normal modes. Analyzing ringdown signals from gravitational-wave events offers a powerful test of general relativity in the strong-field regime and provides an independent consistency check on the full waveform analysis. In this talk, I will present new results from the fourth LIGO-Virgo-KAGRA observing run, highlight particularly informative events, and discuss the unique insights obtained specifically from ringdown observations.

Poster Session / 223**Erbium 3+ Ions in Silicon Nanostructures****Author:** Justin Brown¹

Co-authors: Alexey Lyasota ²; Alison Goldingay ²; Jeffrey McCallum ³; John Bartholomew ⁴; Matthew Killen ²; Matthew Sellars ⁵; Mrigendra Yadav ²; Rose Ahlefeldt ⁵; Sven Rogge

¹ *University of New South Wales*

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⁴ *University of Sydney*

⁵ *Australian National University*

Optically active spins in solids are promising for many applications in quantum information science, such as entanglement distribution nodes in quantum networking, single photon sources for linear optical quantum computing, and as a platform for cluster state quantum computing. Their optical connectivity could also be leveraged to implement low-density parity check (LDPC) error correction codes. Erbium ions implanted in silicon are a particularly promising system, due to their excellent optical and electron spin coherence properties, erbium's emission in the Telecom C band, and the maturity of Silicon nanofabrication. We undertook PLE spectroscopy of Erbium in Silicon nanopillars to study the effect of surface proximity on Erbium Sites in Silicon. We find that annealing in a nanostructure results in formation of different sites compared to the bulk. Also detailed are our design and fabrication of a electrode integrated waveguide to probe the Stark shifts of Erbium in silicon. This study will tell us the tunability of our emitter, their robustness to electric noise, and provide us information about the symmetry of these Erbium sites.

Poster Session / 224

DFT vs ARPES: Comparing DFT Approaches for TMDCs Band Structure

Author: Amal Alsaedi¹

¹ *Flinders University*

Layered transition metal dichalcogenides (TMDCs) are among the two-dimensional (2D) materials family. They have been extensively studied due to their intriguing physical properties and potential for many applications, for optical, electronic and optoelectronic devices.

Conventional solid-state band theory with density functional theory (DFT) has achieved a high degree of success in predicting electronic properties of materials despite the simplicity of the independent-electron model. Our aim here is to provide a systematic assessment of the accuracy of theoretical methods to determine the bulk and monolayer electronic band structures of 2D metal dichalcogenides.

The electronic structures of materials derived from ab initio calculations are compared with angle-resolved photoemission spectroscopy (ARPES) data.

Atomic and Molecular Physics / 225

Detecting dark matter with atomic systems

Author: Ashlee Caddell¹

¹ *The University of Queensland*

The mystery of dark matter (DM) is a long-standing issue in physics, with numerous dedicated experiments returning no confirmed detection. 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.

For DM particles with masses just above electrons, we can search for signals of atomic ionisation from DM scattering off atomic electrons. If we instead move to DM with masses just below electrons, then we look to absorption of DM on atomic electrons.

For both cases, accurate treatment of the atomic physics plays an important role when calculating the possible scattering rates. To assess the accuracy of DM-electron scattering rates, we can find some comparison to electron-electron scattering experiments, providing an ability to test the theoretical calculations.

In this work, I will discuss the prospect for DM detection with atomic systems, the tools needed to accurately assess the possibility, and potential extensions of the calculations to include other types of scattering.

Quantum Science and Technology / 226

Superfluidity with Penetrable Obstacles

Author: Charlotte Thomson^{None}

Co-authors: Angela White¹; Matt Reeves²; Matthew Davis

¹ *The University of Queensland*

² *University of Queensland*

When a conservative superfluid flows about an impenetrable cylindrical obstacle, vortex pairs will arise at the lateral edges of the obstacle and be shed into the background fluid flow when the critical velocity is exceeded. This phenomenon was characterised using the Gross-Pitaevskii equation in a theoretical study by Frisch et al. in 1992¹. In 2021 Stockdale et al.² looked at vortex pinning in a superfluid flow about a penetrable cylindrical obstacle (with non-zero superfluid density inside). They found that above a particular flow velocity a vortex pair would nucleate inside the obstacle. Using the Gross-Pitaevskii equation, we have since shown that increasing the superfluid velocity would cause the vortices in the pair to move towards opposite sides of the obstacle boundary and be shed once they reach the edges.

This study aims to numerically characterise the stationary solutions for the system which include vortex pairs for a penetrable cylindrical potential obstacle within a conservative superfluid flow in two-dimensions. We observed multiple coexisting solution pathways with varying quantities and configurations of vortex pairs. We present a map of these solution pathways as a function of superfluid flow velocity and classify the dynamical stability of each.

Finally, we will present our findings of vortex formation for a superfluid flow past a penetrable obstacle for a driven-dissipative superfluid of exciton-polaritons. Excitons-polaritons are quasiparticles which are formed by the strong coupling between an exciton (electron-hole pair) and a photon. We present an experimentally realistic protocol with which we can control the superfluid flow velocity while simultaneously observing spontaneous vortex formation. We compare the vortex solutions to those observed in the conservative superfluid system.

¹ T. Frisch, Y. Pomeau, S. Rica, Phys. Rev. Lett. 69(11), 1644 (1992).

² O. R. Stockdale, M. T. Reeves, M. J. Davis, Phys. Rev. Lett. 127(5), 255302 (2021).

Atomic and Molecular Physics / 227

Coarsening dynamics of a spinor condensate in the broken-axisymmetric phase

Authors: April Weyling¹; Lewis Williamson^{None}; Matthew Davis^{None}

¹ *The University of Queensland*

Non-equilibrium systems underpin a range of phenomena and can often evolve to form emergent structures. Understanding these fundamental processes advances our grasp of complex physical behaviour, and remains a central challenge of physics. One method to drive a system out of equilibrium is via a quench, such as dropping temperature or applying a magnetic field. If this instantaneous shift is done over a phase transition, it breaks a symmetry in the system. This forces the system to locally choose a new ground state, forming domains. One rich aspect of these dynamics is involved in the late-time ordering of these domains. As domains grow and compete for the equilibrium phase, their growth can become scale-invariant, with domain size growing according to a universal scaling law $L(t) \sim t^{1/z}$.

We study the universal coarsening dynamics of spin domains in a ferromagnetic spin-1 condensate in a two-dimensional geometry. The system can be quenched by tuning external Zeeman fields, giving rise to a variety of magnetically ordered phases. When the system is magnetised perpendicular to the applied Zeeman fields, the ordering of spin domains is well understood and yields a universal coarsening exponent of $z \approx 1$. Our study focuses on how the late-time dynamics shift as we tune the magnetisation out of the plane and in line with the applied field. With large enough tilt out of the perpendicular plane, the system crosses over to a different universality class with universal coarsening characterised by $z \approx 2$. We further analyse the role of topological defects (vortices) in the coarsening behaviour.

Quantum Science and Technology / 228

Precision Bounds for Characterising Quantum Measurements

Author: Aritra Das¹

Co-authors: Simon K. Yung ; Lorcan O. Conlon ; Ozlem Erkilic ; Angus Walsh ; Yong-Su Kim ; Ping Koy Lam ; Jie Zhao ; Syed M. Assad

¹ *Australian National University*

Quantum measurements, alongside quantum states and processes, form a cornerstone of quantum information processing. The precise characterisation of this triad—of states, processes, and measurements—underpins how well quantum devices used across computation, communication, and sensing platforms can be calibrated, benchmarked, and ultimately trusted. However, while state and process characterisation benefit from rigorous theoretical foundations that guide the optimal estimation strategies and set performance benchmarks, the precise characterisation of quantum measurements lacks a similar theoretical grounding. This asymmetry is not just of fundamental concern but also has practical implications; for instance, despite several experimental demonstrations of quantum detector tomography, there is no clear guideline yet on the optimal probing strategy or the best precision attainable in this task.

In this work, we resolve this asymmetry by introducing a comprehensive framework for detector estimation that links the parameter information content of measurements to the ultimate precision with which they may be characterised. By identifying a fundamental quantum limit to the information that can be extracted from a measurement—termed the detector quantum Fisher information—we determine the precision limit for detector tomography and the optimal probing strategies that attain this benchmark. Our framework is applied to physically motivated examples and validated through a provably-optimal detector estimation experiment on a superconducting platform, demonstrating relevance and robustness for current quantum detector technologies.

More broadly, our formalism presents a dual perspective to the well-studied problem of quantum state estimation, while also highlighting unique aspects of detector analysis, such as scaling advantages, that differ from state estimation. This development connects and completes the triad of high-precision state, process, and detector tomography, thereby advancing quantum information theory

with wide-ranging implications for emerging technologies reliant on precisely calibrated measurements.

Poster Session / 229

Charmed states and SU(3) flavour symmetry breaking from lattice QCD

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The strong interaction binds up and down quarks together to form hadrons such as protons and neutrons and heavier states containing strange or charm quarks. At low energies, hadron properties cannot be determined via analytic or perturbative approaches to quantum chromodynamics (QCD). Instead, we make use of a numerical approach to QCD known as lattice QCD (LQCD). In this work, we calculate the ground state spectrum of hadrons containing up, down, strange, and charm quarks in the isospin symmetric limit, where the up and down quarks are taken to be mass degenerate. This study focuses on charmed mesons, and singly- and doubly-charmed baryons, together with light-quark states for reference. We study the quark mass dependence and analyse the LQCD results using flavour symmetry breaking polynomial expansions. Our results are in good agreement with experimental measurements, and we make a prediction for the mass of the doubly charmed Ω_{cc} baryon, which has not yet been observed in collider experiments.

Focus Session: Frontiers of Medical Physics / 230

Opportunities and Challenges of learning from Medical Imaging Data

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Medical Imaging data provides a wealth of information to the health care pathway including diagnosis, understanding disease extent, prognosis, outcome and follow-up. Medical image data can capture anatomical, biological and physiological information through computed tomography, positron emission tomography, magnetic resonance imaging and other approaches. To use this data effectively for an individual patient we need to understand uncertainties related to generating the imaging data as well as uncertainties related to the use of the imaging data. Understanding similarities of imaging data from a particular patient compared to others in a patient cohort is also key in being able to diagnose and predict outcomes effectively.

Although the principles behind medical image generation are consistent there are implementation differences between different scanner versions and different scan settings. These differences can result in differences in quantitative image information. Use of these images will also be different between clinicians, for instance the inter-observer variation for defining radiation oncology treatment volumes. Automated approaches can provide a pathway for presenting the estimated variation to clinicians to ensure this variation is understood when making clinical decisions.

Considering differences in images (and other medical data) across patient cohorts requires access to large datasets. This can be challenging as medical data is often stored in local institution silos. Combining this data can be challenging both from a governance and a data transfer perspective. Federated learning where data remains at local institutions but can be learnt from in a combined iterative manner can provide a solution to this challenge but requires significant support from local centres and a strong collaborative approach.

Addressing these challenges is important to ensure that medical imaging data can be used most effectively in all areas of medicine.

Quantum Science and Technology / 231

Spectroscopy with Undetected Photons for Biomedical Diagnostics in Mid-Infrared

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Co-authors: Meryem-Nur Duman ; Isa Ahmadalidokht ; Christopher G. Poulton ; Irina Kabakova ; Alexander S. Solntsev

Sensing and detection in the mid-infrared (MIR) range are crucial, as many molecules exhibit characteristic absorption bands ¹. However, traditional techniques like Fourier Transform Infrared (FTIR) spectroscopy rely on costly lasers, complex and noisy detectors often requiring cryogenic cooling, all of which limit their applicability ². To address these limitations, we propose a quantum spectroscopy approach based on spontaneous parametric down-conversion (SPDC), where a single pump photon is converted into a pair of time-space correlated photons, one in the MIR (idler) and its partner in the near-infrared (NIR) or visible range (signal) ³. Because of their strict energy-momentum correlations, detecting the signal photon provides full information about the idler's properties. This enables MIR spectral analysis without direct detection and measuring molecular absorption and refractive index using standard silicon-based devices.

Simulations using a 660 nm pump laser and an AgGaS₂ crystal confirmed phase matching for photon pairs with signal photons ranging from 732 to 743 nm and idler photons spanning 5.88 to 6.66 μ m, covering the Amide I and II protein absorption bands. Quantum spectroscopy simulations were performed both without and with the sample, incorporating experimental FTIR spectra of biomarkers such as bovine serum albumin (BSA) and NT-proBNP. The resulting interference patterns showed clear differences between the absence and presence of the sample, revealing sample-specific signatures detectable in the NIR range. Comparisons between different protein samples demonstrated distinct spectral patterns, highlighting the technique's ability to discriminate biomolecules based on unique fingerprints. Temperature-dependent FTIR measurements revealed changes in protein secondary structure, which were successfully reproduced in quantum simulations, showing sensitivity to subtle biochemical variations.

This study demonstrates the feasibility of quantum MIR spectroscopy as a compact, cost effective, room-temperature alternative to conventional MIR methods, with potential for early disease detection, real-time biomarker monitoring, and broader applications in various disciplines.

Poster Session / 232

Designing cleaner microwave environments for superconducting quantum circuits

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Superconducting electronics are central to emerging, high-impact quantum technologies. Operating in the microwave regime, these systems require cryogenic environments and electromagnetic shielding to suppress unwanted electromagnetic interactions, blackbody radiation and quasiparticle interactions that can degrade coherence (Krinner et.al, 2019) or introduce experimental interference.

On-chip design has long been explored to improve device performance, with significant advances achieved, e.g., through using novel device geometries (Corcoles et.al, 2015) and novel materials to reduce system losses and enhance qubit coherence (Place et.al, 2021), or deep substrate etching to reduce dielectric loss (Bruno et.al 2015). Recently, however, more attention is being given to the environment immediately around the device. As on-chip performance has improved, it is now reaching the point where devices can be limited by their packaging and interconnects, if not designed carefully enough (Huang et.al 2021).

In this work, we explore how a device's microwave environment and physical connections to microwave control electronics contribute to loss. Using electromagnetic modelling, we analyse the impact of shielding geometries, connector placement, microwave interfaces, and on-chip features such as airbridges on propagating modes and impedance mismatches, to cause microwave reflections and loss. In describing the approach we take for integrating superconducting devices into larger systems without compromising performance, we consider where careful design of the packaging and interconnects can be expected to reduce loss and interference, enabling better utilization of high-performance devices. We also explore trade-offs between electromagnetic optimization and practical constraints imposed by precision machining of shielding and packaging and on-chip processes, such as airbridge nanofabrication.

Quantum Science and Technology / 233

Using coherence as a resource in a two-mode BEC thermal quantum engine

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Converting disordered energy (heat) into ordered energy (work) is a fundamental objective in thermodynamics. In classical systems, disorder reflects practical limits on the knowledge of the microscopic state of a large system. Quantum systems, however, introduce an additional uncertainty arising from the fundamental structure of quantum mechanics 1. Features such as coherence and entanglement, which have no classical counterpart, can be used to surpass classical limits or enable new thermodynamic protocols 2. Williamson and collaborators 3 demonstrated that work can be extracted from a two-mode Bose-Einstein Condensate (BEC) initialized in a coherent state, even when the initial and final states have the same energy and the number-state probability distribution $P(n)$. This establishes coherence as a purely quantum source of work.

The thermodynamic transformation in 3 represents only half of a thermal engine cycle. Here, we extend this idea by constructing closed thermodynamic cycles for a two-mode BEC, where the work steps utilise coherences and are performed by adjusting the coupling, detuning, and interaction strength as a function of time. We examine possible zero-temperature initial states, focusing on coherent states, and analyse their evolution through processes that reduce coherence while conserving energy and number statistics. This allows us to distinguish systematically between classical and quantum contributions to the extracted work. By closing the cycle and returning the system to its initial configuration, we establish a repeatable framework for quantum heat engines and quantify the role of coherence as a thermodynamic resource.

1 J. Aberg, "Quantifying superposition", arXiv:quantph/0612146 (2006).

2 N. M. Myers, O. Abah, and S. Deffner, "Quantum thermodynamic devices: from theoretical proposals to experimental reality", AVS Quantum Science 4, 027101 (2022).

3 L. A. Williamson, F. Cerisola, J. Anders, and M. J. Davis, "Extracting work from coherence in a two-mode Bose-Einstein condensate", Quantum Science and Technology 10, 015040 (2024).

Medical Physics / 234

Surface-Guided Radiotherapy for Motion Management - from Conventional to Ultra-High Dose Rate Treatments**Author:** Malin Kügele¹**Co-authors:** Bernd Frekerer¹; Elisabeth Schültke¹¹ *Universitätsmedizin Rostock*

Approximately half of all cancer patients receive radiotherapy, with external beam radiotherapy being a cornerstone of treatment. The objective is to deliver radiation with high precision to achieve tumor control while minimizing exposure of surrounding healthy tissue. Despite major technological advances, some radioresistant tumors remain incurable with conventional methods.

Microbeam Radiotherapy (MRT) is a promising experimental technique that may overcome these limitations. At synchrotron facilities, low-divergence X-ray beams can be spatially fractionated into arrays of extremely narrow ($\approx 50 \mu\text{m}$) microbeams separated by $\approx 400 \mu\text{m}$. These beams deliver extremely high doses (hundreds of Gray) and dose rates (hundreds to thousands of Gy/s), while sparing normal tissue in between. This unique dose distribution has demonstrated potential to improve tumor control and could provide curative treatment options in diseases where current approaches are palliative. However, the very high precision of MRT also demands strict patient positioning and robust motion management.

Patient and tumor motion remain major challenges in radiotherapy. While intracranial tumors move very little, thoracic and abdominal tumors are significantly affected by respiration. Furthermore, patients may move during treatment due to nervousness, discomfort, or involuntary actions, compromising treatment accuracy.

We are, for the first time to our knowledge, investigating the role of optical surface scanning for motion management in a microbeam radiotherapy setting. Surface-guided radiotherapy (SGRT) provides a non-ionizing solution through optical surface scanning. SGRT monitors the patient's position continuously, in real time, with sub-millimeter accuracy and high update frequency. Unlike other imaging systems used in radiotherapy, SGRT enables immediate detection of even the smallest deviations, can automatically interrupt beam delivery, and can guide breathing to optimize tumor positioning relative to nearby organs. We are presenting QA strategies using SGRT for advancing microbeam radiotherapy toward clinical application.

Quantum Science and Technology / 235

Electromagnetically-induced transparency assists the Raman gradient echo memory at moderate detuning, dependent on gradient order**Authors:** Jesse Everett¹; Ankit Papneja¹; Arindam Saha²; Cameron Trainor¹; Aaron Tranter¹; Ben C. Buchler¹¹ *Australian National University*² *The Australian National University*

Optical quantum memories are an essential optical technology with applications in quantum communications and networking, quantum sensing and optical quantum computing. Ensemble optical memories rely on a controllable, coherent interaction between light and a long-lived electronic state, with the light absorbed into and regenerated from a collective excitation of the ensemble of emitters. Ensemble optical memories based on 3-level interactions are a popular basis for implementing these memories. In previous work with Raman gradient echo memory (GEM) an efficiency of 87% was demonstrated first with warm vapour and then cold thermal atoms. GEM combines the off-resonant

Raman interaction with a frequency gradient along the length of the atomic ensemble, typically a Zeeman shift due to a magnetic field gradient. One of the most important metrics for a quantum memory, when considering practical deployment, is the combined efficiency of the storage and recall process. This efficiency places hard limits on a platform's utility and has ultimately prevented many platforms from surpassing a simple fibre spool. When seeking high efficiency, scattering loss is often a major concern, with mitigation strategies generally involving increasing the detuning from the intermediate state.

In this work, we show how electromagnetically induced transparency adjacent to the Raman absorption line plays a crucial role in reducing scattering loss (See Figure 1.), so that maximum efficiency is in fact achieved at a moderate detuning. Furthermore, the effectiveness of the transparency, and therefore the efficiency of GEM, depends on the order in which gradients are applied to store and recall the light. We present theoretical simulations and experimental results that demonstrate this concept and further working towards reliable ensemble quantum memories.

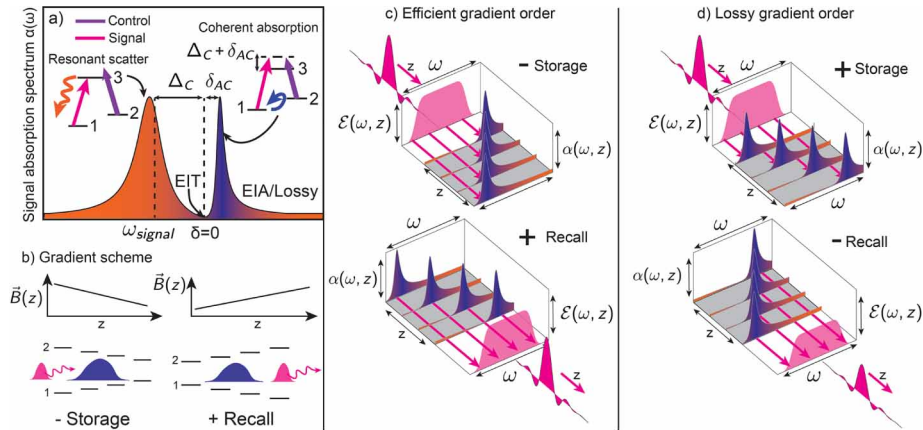


Figure 3: Figure 1. Demonstration of the gradient order effect for GEM. (a) the signal absorption profile when applying gradients in (b). (c,d) Efficient and lossy gradient orders.

Poster Session / 236

Quantum State Tomography of Exciton-Polariton Bose-Einstein Condensates

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A Bose-Einstein condensate (BEC) is an example of a macroscopic quantum state where many particles occupy the same state, making them useful for fundamental tests of quantum physics and quantum applications such as computing and sensing. Non-equilibrium BECs of exciton-polaritons, quasiparticles in semiconductors arising from the strong coupling between excitons (bound electron-hole pairs) and microcavity photons, can form at room temperature due to their small effective mass. They are promising for applications because they can be integrated onto semiconductor chips to form on-chip BEC devices, unlike traditional atomic BECs, which require complex cooling and vacuum systems.

As a hybrid light-matter system, polaritons harness many experimental advantages of both light-based and matter-based systems. Polaritons decay by emitting light that carries all the information

about the system, making them highly accessible BEC systems. Additionally, the non-linear interactions between its excitonic components are predicted to give rise to many non-classical effects such as squeezing and non-Gaussian states. Despite this, experimental measurements show weak signatures of quantum effects and are restricted to cryogenic temperatures, raising questions regarding the applicability of polariton BECs for quantum technologies.

In this work, we aim to address this problem by performing a complete characterisation of the quantum state of polariton BECs. We leverage recent advancements in the field of quantum optics that have enabled highly precise measurements of the quantum state of optical fields to reconstruct the density matrix of the light emitted by a polariton BEC. While phase-averaged measurements have been performed, a complete reconstruction of the quantum state of polariton BECs remains an open problem. Our measurements will provide greater experimental insight into the compounding effects of experimental parameters on the behaviour of the system than achieved previously, setting a new benchmark for characterising the system and informing the direction for future experiments developing quantum polaritonic devices.

Medical Physics / 237

From palliative to curative microbeam radiation therapy at the Australian Synchrotron: Increasing the irradiated area to achieve complete coverage of the tumor

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Radiation therapy is an important component of cancer treatment. Microbeam radiation therapy (MRT) is an experimental irradiation technique in which a synchrotron-generated X-ray beam is spatially fractionated into an array of quasi-parallel microbeams by a multislit collimator, leading to an inhomogeneous dose distribution in the target. In preclinical studies, this results in good tumor control and better tolerance for healthy tissue.

Currently, MRT is often used in unidirectional mode with a single treatment field that is limited in width to 30 mm due to the lateral roll-off in intensity of the synchrotron generated X-ray beam. In a veterinary study at the Australian Synchrotron, dogs with tumors (bone cancer) in their legs have received only partial tumor irradiation as palliative treatment. To irradiate larger tumors with curative intent, we propose to increase the irradiation field by laterally patching multiple microbeam arrays and rotate them around the isocenter to achieve complete coverage of the tumor. Dose fractionation at the micrometre scale and irradiation from multiple angles, similar to the clinically already established stereotactic radiotherapy, makes dosimetry extremely challenging. Equally interesting is the correlation between spatial dose distribution and radiobiological response. To explore the latter, we have conducted in-vitro studies in human brain and lung cells at the Imaging and Medical Beamline (IMBL) of the Australian Synchrotron and at the P61A beamline of the PETRA III synchrotron on the DESY campus in Germany as part of an international collaboration project between Australian and

German research groups. Our initial pre-clinical results demonstrate with high precision that both patching and rotating MRT arrays can be executed reliably and without compromising treatment accuracy. Irradiated cells only survived outside the irradiation fields. In an ongoing study, we aim to establish a quality assessment procedure for the curative, complete irradiation of primary and secondary malignant tumors.

Poster Session / 238

An Exploration of (SO)₂ as a Source for Polysulfur within a Simulated Venus Atmosphere with an Overabundance of Oxygen

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⁴ California Institute of Technology

Venus at ultraviolet (UV) wavelengths exhibits distinct light and dark markings (Rossow et al., 1980). The discovery of sulfur dioxide (SO₂) using a ground-based high resolution spectrometer explained Venus' albedo at wavelengths < 320 nm but not these dark markings at 320-500 nm (Esposito et al., 1979; Pollack et al., 1980; Pérez-Hoyos et al., 2018). So at least one other absorber must be important at these wavelengths.

Radiative balance simulations suggest this unidentified absorber is responsible for about half of the solar energy absorbed by Venus' atmosphere (Titov et al., 2018). Polysulfur species (S_x) have been suggested but the pathway to how these polysulfur species are formed hasn't been fully agreed on (Mills et al., 2007). Pinto et al. [2021] proposed the production rate of S_x could be enhanced via production of disulfur, S_2 , from photodissociation of SO dimer, (SO)₂. However, Francés-Monerris et al. [2022] found a much lower yield for S_2 from photodissociation of (SO)₂ in their ab initio simulations and proposed that S_2 production could be enhanced instead via disulfur oxide (S₂O) reacting with sulfur oxide, SO. The atmospheric model used by Francés-Monerris [2022] did not include all important feedback processes. This present work evaluates both the Pinto et al. [2021] and Francés-Monerris et al. [2022] pathways in a comprehensive 1-d photochemical model. This study demonstrates that elevated oxygen abundances suppress polysulfur formation in both the Pinto et al. [2021] and Francés-Monerris et al. [2022] pathways, resulting in optical depths for polysulfur that are too low to explain Venus' "missing" UV absorber.

Atomic and Molecular Physics / 239

Probing nuclear structure via hyperfine splittings in Yb-173

Author: Jayden Hasted¹

Co-authors: Benjamin Roberts ; Jacinda Ginges

¹ The University of Queensland

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.

Medical Physics / 240

Development of a simple, silicon based, dose equivalent neutron dosimeter for radiation protection purposes through GEANT4 modelling.

Author: Matthew Roberts¹

Co-authors: Anatoly Rozenfeld¹; James Vohradsky¹; Linh Tran¹; Vladimir Pan¹

¹ *University of Wollongong*

A GEANT4 study into the concept for a simple, silicon-based, electronic fast neutron dosimeter for radiation protection purposes is presented. The circular shaped dosimeter utilised the fluence approach to neutron dosimetry to achieve a dose equivalent response. This approach involved using the neutron dose equivalent conversion coefficients to relate the dosimetry quantity fluence, to the radiation protection quantity dose equivalent. The dose equivalent is key in monitoring personnel exposure as it reflects the biological effect of the radiation.

To measure the neutron fluence, the dosimeter used a polyethylene layer to convert incident neutrons into recoil protons through elastic scattering. The protons were subsequently counted by the silicon detector.

To accommodate the wide range of neutron energies typically present, the detector's sensitive area was split into ring segments that could be readout independently. Each segment was covered with a different thickness of polyethylene, ranging from 0.01 to 1 millimetre. The multiple thickness converter allowed for a range of incident neutron energies to be detected with a high efficiency. The segmented detector allowed weighting factors to be introduced to each segment to adjust the overall detector response to ensure that the number of recoil protons counted per increment of dose equivalent was independent of the neutron energy. With the segmented detector and the weighting factors, calculated based on mono-energetic neutron simulations, the dosimeter showed a significantly reduced energy dependence in the 0.2 to 15 MeV energy range with a real-time, dose equivalent readout.

To address background measurements, particularly from gamma radiation present in neutron fields, one segment of the detector had no converter and so exclusively measured background events. These events were then subtracted from the polyethylene covered segments to estimate the counts from recoil protons. This background subtraction technique was able to provide a good estimate of the recoil proton counts.

Theoretical Physics / 241

Baryon number violating nucleon decay with a light scalar in effective field theories

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Baryon number violating (BNV) nucleon decays can serve as an interesting probe to physics beyond the Standard Model, especially in upcoming experiments with increased sensitivity. We investigate such decays using effective field theories and present relevant BNV operators at leading order in a low energy effective field theory framework extended with a light scalar. We derive current experimental constraints on associated Wilson coefficients and decay modes, as well as project sensitivities for future experiments. We also discuss select UV-complete models and possible connections to dark matter.

Focus Session: Emerging Materials and Physics for Energy Conversion / 242

Tuning Terahertz Vibrations for Thermal Energy Management

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Co-authors: David Cortie²; Dehong Yu²; Jarad Mason³; Karolina Matuszek¹; Roger Lewis

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³ *Harvard University*

Atomic vibrations on the terahertz (THz) scale play a central role in determining a material's optical, electronic, thermal, and mechanical properties. In particular, the coupling between vibrational dynamics and thermal transport or phase transitions offers opportunities to design materials for efficient energy conversion and storage.

This presentation will highlight recent work investigating THz vibrations in functional materials used for thermal energy management. Neutron spectroscopy measurements—conducted on the Pelican spectrometer at the Australian Centre for Neutron Scattering—will be presented, demonstrating the ability of neutrons to directly measure THz-scale atomic motions. Case studies will include nanoparticles, thermoelectrics, simple organic molecular solids, layered organic–inorganic perovskites, and spin-crossover complexes.

Across these diverse systems, a unifying theme emerges: tailoring vibrational dynamics enables control over thermal transport and phase-change behaviour. For example, nano-carbon doping can suppress or redirect phonon transport in thermoelectrics, enhancing energy conversion efficiency 1. Similarly, understanding vibrational modes in sugar alcohols informs their potential use as phase-change and thermal storage materials 2.

By comparing results across multiple classes of materials, this presentation will demonstrate how THz-scale dynamics underpin both fundamental understanding and practical advances in thermal materials. Neutron spectroscopy is shown to be an essential tool for this task, providing insights that bridge atomistic physics and macroscopic energy applications.

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2 Matuszek, K.; Kar, M.; Pringle, J. M.; MacFarlane, D. R. Phase Change Materials for Renewable Energy Storage at Intermediate Temperatures. *Chemical Reviews* 2023, 123 (1), 491–514.

Quantum Science and Technology / 243

Quantum Approaches to Biomedicine: Hybrid Algorithms and Rydberg-Atom Sensing

Author: Teague Tomesh¹

¹ *Inflection*

Quantum technologies are rapidly emerging as powerful tools for addressing complex challenges in biology. In this talk, I will share a cross-section of Inflection's research at the intersection of both quantum computing and quantum sensing with applications in biomedicine. On the computing side, I will describe our ongoing work within the Wellcome Leap Q4Bio program, where we have developed a hybrid quantum-classical algorithm for biomarker discovery on high-dimensional, multimodal cancer datasets. By framing the problem as a higher-order combinatorial optimization task, we use a quantum processor to strategically constrain the search space before passing the reduced problem to a classical solver finish the problem. This approach enables us to identify small, clinically interpretable feature sets that enhance predictive accuracy on downstream tasks such as tumor classification and treatment response. On the sensing side, I will discuss our development of Rydberg-atom based electric field sensors for next-generation terahertz (THz) imaging. These sensors offer high sensitivity, broad tunability, and spectral selectivity, making them well-suited for biological applications where THz signals provide insights into water content, molecular structure, and tissue composition. Together, these projects demonstrate how quantum tools can unlock new biological insights and drive innovation in healthcare.

Nuclear and Particle Physics / 244**Investigating structural characteristics of deformed, odd-odd nuclei in the A~100 mass region**

Author: Abhijith Aswathy Gopakumar¹

Co-authors: A.J. Mitchell ²; Anna Abramuk ³; Greg Lane ⁴; Jan Kurpeta ³; Jean-Michel Daugas ⁵; Laszlo Stuhl ⁶; Tomasz Krakowski ⁷; Ulli Koester ⁸; Yung Hee KIM ⁶

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Neutron-rich nuclei around A~100 present intriguing cases in nuclear structure due to their significant deformation and complex shapes, including predicted triaxiality as well as rare oblate-deformed ground states. These features pose challenges for theoretical models, especially in describing the abrupt shape transitions observed between N = 58 and 60. Even-even nuclei in this region exhibit low-lying excited states characteristic of collective rotational behavior, where both axial symmetry and triaxiality are essential to understanding their structural evolution. For example, Coulomb-excitation studies on ¹¹⁰Ru indicate pronounced triaxiality, whereas decay spectroscopy on ^{106,108}Mo suggests a more axially symmetric shape.

In contrast, odd-odd nuclei remain less well understood due to limited experimental data on spin and parity. The Gallagher–Moszkowski (GM) rule is relevant for describing energetically favoured nucleon spin couplings; however, many nuclei have uncertain or inconsistent assignments. For example, recent work on ¹⁰⁶Nb has revised long-standing ground-state properties, with unpublished data suggesting similar cases are widespread.

To address these uncertainties, detailed γ -ray and conversion-electron coincidence measurements are essential for establishing level schemes and constraining spin-parity assignments. An experiment was conducted in June 2025 at the LOHENGRIN recoil mass spectrometer at the Institut Laue–Langevin, Grenoble, using neutron-induced fission of ²⁴¹Pu. Fission fragments were detected with Clover HPGe and silicon detectors, enabling high-resolution spectroscopy well suited to these studies.

Preliminary results from this experiment will be presented, including newly identified transitions and updated level schemes for nuclei in the $A = 100\text{--}104$ mass region. These data provide new insights into nuclear structure and proton–neutron coupling in deformed, odd-odd systems in this region.

Poster Session / 245

Design and fabrication of air bridges for superconducting electronic circuits

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Co-authors: Giorge Gemis¹; Nathan Langford²

¹ *University of Technology Sydney*

² *Centre for Quantum Software and Information, School of Mathematical and Physical Sciences, University of Technology Sydney*

Coplanar waveguides (CPWs) are used ubiquitously for microwave signal transmission in superconducting quantum processors, and air bridges are crucial to maintain signal hygiene and enable high-density, space-efficient routing. While their use in quantum processors to maintain ground connections across complex circuit topologies is well established empirically (Janzen et al., 2022, and related works), their impact on quantum device performance has not been studied very quantitatively or systematically. In addition, cleanroom process flows and outcomes are often highly facility-specific, necessitating the development of air-bridge nanofabrication recipes for local cleanrooms.

Here, we use electromagnetic modelling to explore how physical fabrication constraints impact the electromagnetic (EM) performance of both air bridges and their host devices, focussing on suppressing slot-line modes emerging during signal transmission along CPWs. We also develop a nanofabrication method to construct aluminium air bridges on a Tantalum thin film (similar to both Chen et al., 2013, and Bu et al., 2025), using the tools and materials available at the University of Sydney Research and Prototype Foundry (using lithography, evaporative deposition and lift-off techniques to define bridge width, thickness, and height).

Our EM modelling is carried out using ANSYS HFSS, including EM mode analysis and full-wave 3D simulations of representative CPW sections. Informed by our parallel nanofabrication work, we vary air-bridge geometry and placement density and evaluate scattering parameters over the operating band to quantify microwave reflections and scattering loss. We then study how air bridges impact the performance of specific on-chip design features like CPW bends and high-Q resonators. Using these results, we optimise air-bridge performance under practical constraints imposed by nanofabrication processes and sample-holder design, identifying parameter windows that meet impedance matching and microwave scattering loss targets. This in turn informs our fabrication recipe, which is designed to be transferable to a wide range of superconducting processor layouts.

Quantum Science and Technology / 246

Tunable qubit-cavity gates for digital quantum simulations in circuit QED

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Digital quantum simulation (DQS) is a promising application of quantum computers. Typically, short Trotter step sizes are required to realise accurate DQS. In the context of Trotterised DQS, it is also useful to be able to tune interaction times and even implement “negative-time” gates, when implementing higher-order digitisation algorithms and to control the amount of digitisation error, especially to stay below Trotterisation thresholds 1. In superconducting qubit systems, one of the most widespread methods for implementing qubit-qubit and qubit-cavity gates is through fast frequency tuning of qubits via magnetic flux, particularly for planar chip architectures. It is also useful to be able to implement fast-flux-tuned qubit-cavity gates, either for additional control gates for 3D-qubit or higher-dimensional oscillator qubit toolboxes, or for simulations involving directly-encoded oscillator modes, such as the quantum Rabi model 2. Yet implementing gates for short interaction times using square pulses can be extremely challenging due to finite system bandwidths arising from electronics or flux control, and the precision of gate tunability is limited by the sampling rates of the arbitrary waveform generators.

In this work, we show that novel smooth-shaped qubit-cavity flux tuning can be used to realise low-bandwidth pulses that do not require flux pulse predistortion, highly tunable gate parameters, ultra-short effective pulse lengths, and negative-time evolution. We design different techniques for achieving high-fidelity gates. Using relevant experimental system parameters 2, we show that smooth pulses applied to a transmon can simulate high-fidelity qubit-cavity interactions with short effective interaction times. These pulses extend the available quantum computing gate set with useful potential applications for quantum simulations, including for studying advanced Trotterisation techniques and novel phenomena such as the Rabi quantum phase transition, where extreme coupling regimes are required.

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Medical Physics / 247

Characterisation of angular response in an improved tissue-equivalent microdosimetry probe for proton therapy applications

Authors: Allegra Villar^{None}; James Vohradsky¹; Vladimir Pan¹; Martin Grossmann PSI²; Oxana Actis³; David Meer⁴; Andrew See⁵; Marco Petasecca¹; Anatoly Rosenfeld⁶; Linh Tran¹

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Proton therapy offers a more conformal dose distribution and higher linear energy transfer (LET) than conventional X-ray therapy, reducing dose to healthy tissue while enhancing tumour control. The relative biological effectiveness (RBE) quantifies radiation-induced tissue damage, and accurate RBE values are critical for treatment planning. Although an RBE of 1.1 is commonly assumed for proton therapy, in reality, RBE varies with factors such as LET. Neglecting these variations can lead to incorrect dose prescriptions and range shifts, which are particularly critical for surrounding sensitive organs.

Microdosimetry provides useful quantities such as yD (close form of LET_d) and to derive RBE for treatment plan verification. The Centre for Medical Radiation Physics (CMRP) has developed a portable, low-voltage supplied SOI microdosimeter with high spatial resolution, demonstrated as

an effective tool for quality assurance for proton and heavy ion therapy. However, advanced techniques such as ARC therapy and intensity-modulated proton therapy (IMPT) plans involve multiple beam angles, requiring a redesign to minimise high-Z material surrounding the detector. To address this CMRP developed a new SOI microdosimeter probe with thin PCB packaging instead of previous ceramic-gold DIL package. The angular dependence of this improved design was evaluated at the Paul Scherrer Institute (PSI), Switzerland using a proton beam of 70, 150 and 230 MeV delivered at 0°, 30°, 60°, 90° and 180° with both spot and layer techniques. 10 mm thick PMMA cylindrical sheath was used to house the probe ensuring a consistent PMMA thickness at any angle of incidence.

Results showed that angular dependence increased above 60°, with reduced dependence at higher proton energies. For oblique angles, pathlength corrections can be used to correct the energy deposition spectra.

Overall, the current microdosimeter design demonstrated an acceptable response for incidence angles up to 60°.

Industrial Applied Physics / 248

Activation SPECT for 3D elemental mapping of a neutron-irradiated ore sample

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Co-authors: David Zahra ²; Joseph Bevitt ²; Klaudiusz Jakubowski ²; Nick Howell ²; Andrew Chacon ; Frederic Sierro ²; Attila Scopic ²; Richard Henley ³; Mitra Safavi-Naeini ²

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Non-destructive mapping of elemental distribution in bulk samples is hard to achieve with standard analytical tools: neutron activation analysis (NAA) allows for elemental identification but provides no spatial localisation, while X-ray or neutron computed tomography (CT) can provide structural information but often fall short in confidently extrapolating elemental distributions. We demonstrate that single photon emission computed tomography (SPECT) performed after thermal neutron activation ("Activation SPECT") can address this gap, that is, to localise activated nuclides in 3D and thus identify their parent element.

A successful proof-of-concept study has been conducted at the Australian Nuclear Science and Technology Organisation (ANSTO). Samples with known distributions of copper (Cu) and gold (Au) were irradiated at ANSTO's Dingo thermal neutron beamline to produce Cu-64 and Au-198 through neutron capture. The characteristic gamma emissions from the decay of these radionuclides can be used to identify the parent isotope. Through SPECT imaging of the neutron-activated samples, list-mode data was then acquired and used to reconstruct separate 3D activity maps using isotope specific energy and timing windows.

This workflow was applied to a 1 x 1 x 8 cm drill-core from Cobar, NSW with unknown spatial distribution and composition. Following neutron irradiation at Dingo's tertiary shutter position and subsequent SPECT imaging, the spatial distribution attributable to Cu-64 and Au-198 was determined. An unexpected component in the list-mode spectra was identified later as Mn-56 from matrix activation and reconstructed.

Activation-SPECT adds isotope-specific volumetric information to conventional NAA/CT workflows for mining, mineral exploration and cultural heritage. Combined with structural imaging modalities, this approach enhances our capacity to estimate elemental distributions in bulk samples of unknown compositions. Simulation modelling is also employed to assess the feasibility of Activation SPECT for other elements and sample geometries, and guide future experimental set-ups using this technique.

Industrial Applied Physics / 249

A novel wavelength-modulation spectroscopy gas sensor for methane detection

Author: Matteo Colombo¹

¹ *The University of Sydney*

We present a novel gas sensor based on wavelength modulation spectroscopy to measure methane concentrations in the farming and food industry. Methane is a highly impactful greenhouse gas, and its monitoring is essential for environmental surveillance, the development of low-emission breeding strategies, and the detection of leaks across production and processing stages. Moreover, captured biogas from wastewater treatment plants, primarily methane and carbon dioxide, can be repurposed as renewable natural gas, transforming emissions into a valuable energy resource. The proposed sensor uses a broadband 1685 nm super luminescent diode (SLD) coupled to an aperiodic Fiber Bragg Grating (FBG), whose reflectance spectrum mimics methane absorption features between 1630 nm and 1675 nm. A stacked piezoelectric actuator periodically modulates the FBG spectral response which is recovered by a circulator and routed to a 50:50 coupler. The signal is then split in two paths: one goes directly to a balanced photodetector, while the other passes through a methane sample before reaching the detector. The latter stage was implemented in two different ways: a multi-pass fibre-coupled 80 cm gas cell and a 450 cm free-space optics path. Methane was successfully detected at concentrations of 500 ppm, 200 ppm, 100 ppm, 50 ppm, 10 ppm, and 5 ppm in the fibre-coupled setup, and at 50,000 ppm, 5,000 ppm, 500 ppm, and atmospheric levels in the free-space setup. Specificity was confirmed by testing 50 ppm methane against 2.5% carbon dioxide, a potential interloping species. These results demonstrate that the proposed instrument is a compact, selective, and highly sensitive tool for methane characterisation. Future developments include the employment and simultaneous testing of different gas species, mitigation of atmospheric scintillation, environmental vibrations and jitter-induced coupling noise.

Nuclear and Particle Physics / 250

Determination of the electromagnetic form factor of the Pion at large Q^2 using lattice QCD

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¹ *The University of Adelaide*

The electromagnetic form factor, $F_\pi(Q^2)$, of the pion describes how quarks are distributed inside the pion and is of considerable phenomenological interest. However, $F_\pi(Q^2)$ at large values of momentum transfer, Q^2 , has proven difficult to measure experimentally. This motivates numerical approaches to its calculations, such as lattice QCD. Though Lattice QCD calculations of $F_\pi(Q^2)$ exist for low Q^2 , it is also desirable to understand the behaviour of $F_\pi(Q^2)$ at large Q^2 in order to help guide future experimental measurements, for example at Jefferson Lab in the US. Accessing $F_\pi(Q^2)$ at high Q^2 , however, also presents challenges for Lattice QCD. This is due to the increased computational cost required to overcome gauge noise, as well as increased difficulty in extracting signals for boosted particles. We present a lattice QCD calculation of $F_\pi(Q^2)$ using the Feynman-Hellmann technique. We employ two noise reduction techniques, all-mode averaging (AMA) and momentum smearing (MS). Additionally, we also apply variational techniques between different operators which create the pion state to further improve correlator signal to noise ratios. By performing calculations on SU(3)-flavour symmetric ensembles, where light and strange quark masses are degenerate, as well as for ensembles where SU(3)-flavour symmetry is broken, i.e. where the light and strange masses are not degenerate, we find that these methods significantly improve the extraction of $F_\pi(Q^2)$, allowing access to $F_\pi(Q^2)$ at around $Q^2 = 10 \text{ GeV}^2$.

Physics Education / 251

Developing Learning Resources for Honours-Level Atomic Physics Courses

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Although students are expected to begin fourth-year atomic physics with a strong understanding of quantum mechanics (QM) developed in second and third year, it has been identified that students often struggle to link theoretical QM concepts with real-world atomic phenomena and applications. We have developed a series of computational workbooks that are self-directed, interactive and have been designed to bridge the gap between the theory and application of core atomic physics concepts introduced in lectures. The workbooks are designed in such a way as to target key graduate attributes and learning outcomes including: competently using computing technology for the simulation of physical systems, presenting and interpreting information graphically, undertaking numerical manipulation as needed, and producing self-directed and motivated learners.

Each workbook walks students through chosen topics in atomic physics and has been built using a combination of markdown (to present the theory and a series of questions/prompts), modifiable code, graphs, visuals, and animation. These workbooks have been developed alongside additional questions that can be integrated directly into tutorial problem sets and written assessment. In addition to deepening understanding of atomic physics, the aim of these workbooks is to improve student engagement with the atomic physics course content as well as increase student satisfaction.

Medical Physics / 252

Systematic benchmarking of Monte Carlo Codes for accelerator-based BNCT neutron production targets

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Beam-shaping assembly (BSA) design using Monte Carlo techniques for accelerator-based boron neutron capture therapy (BNCT) requires accurate modelling of light-ion reactions on thin or thick targets, which define the neutron source term for subsequent beam shaping. Geant4 11.1.3, PHITS 3.33, FLUKA 4-4.0 and MCNP 6.3 have been benchmarked for thick-target neutron yield and spectra from ${}^7\text{Li}(p,n){}^7\text{Be}$, ${}^9\text{Be}(p,n){}^9\text{B}$, ${}^9\text{Be}(d,n){}^{10}\text{B}$, $\text{C}(d,n)\text{N}$, and the inverse-kinematics reaction $p({}^7\text{Li},n){}^7\text{Be}$ in the low-energy regime relevant to accelerator-based BNCT.

Using each code's recommended physics settings, predictions of total neutron yield, forward (0 degrees) yield, neutron energy spectra and angular distributions were compared with compiled experimental data. To quantify agreement, metrics of mean relative error and sMAPE for yields and Pearson Correlation Coefficient for spectral shapes were reported. Single-core throughput for each code on a fixed workstation is provided as a simple computational performance indicator.

Results show varying levels of agreement between the codes depending on the reaction type, energy range, and beam characteristics. Across most reactions, Geant4, MCNP and PHITS reproduce total and forward yields within typical experimental scatter, while PHITS shows the most consistent agreement with experimental energy spectra for ${}^9\text{Be}(p,n){}^9\text{B}$. The largest discrepancies occur near threshold energies and for $p({}^7\text{Li},n){}^7\text{Be}$, where none of the default models capture angular behaviour observed during experiment. Under our settings, PHITS delivered the highest single-threaded throughput per history.

These results clarify the strengths and limitations of widely used codes for accelerator-based BNCT

target modelling and provide a practical basis for selecting and tuning models when generating neutron source input for BSA design and optimisation.

Medical Physics / 253

Quantum-AI Biophotonic Diagnostics for Point-of-Care Brain Tumor Screening

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This talk introduces *Quantum-AI Biophotonic Diagnostics for Point-of-Care Brain Tumor Screening*, a next-generation framework that unites quantum computing, artificial intelligence, and nanoscale biophotonics to transform biomedical diagnostics. We present an integrated approach for early cancer detection that combines plasmonic biophotonic sensors with a quantum machine learning (QML) pipeline, designed for high-sensitivity, non-invasive detection and classification of brain tumors in a compact point-of-care device.

Our system harnesses spectral data from nanoscale plasmonic biosensors, encoding these features via quantum-enhanced methods into a quantum kernel-based learning model. This platform uses quantum-driven feature encoding to process both spectral and imaging signals, enhancing diagnostic accuracy while reducing computational overhead. The framework's architecture emphasizes efficiency and portability, enabling real-time analysis suitable for clinical and bedside applications.

We further detail the system's architecture, simulation fidelity, and early experimental results, which demonstrate promising performance in distinguishing tumor signatures. The multidisciplinary innovation—situating light-matter interactions at the nanoscale in concert with quantum intelligence—opens new opportunities for intelligent diagnostic devices capable of immediate cancer screening. Importantly, the implementation highlights pathways for clinical translation, including integration with existing healthcare workflows, regulatory considerations, and validation methodologies.

By leveraging the synergy of quantum technology, artificial intelligence, and biophotonics, this approach has the potential to reshape the landscape of precision oncology and personalized healthcare. Attendees will gain insights into how quantum-biophotonics convergence can revolutionize diagnostic capabilities, enabling earlier and more reliable detection of brain tumors.

Poster Session / 254

Revealing Structural Features of Amorphous Monolayer Carbon Using Persistent Homology Analysis

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Amorphous Monolayer Carbon (AMC), a disordered form of graphene first synthesised in 2020, displays high flexibility but has low mechanical strength, restricting potential application in areas such

as flexible electronics.

Existing descriptions of 2D amorphous materials generally fall between assigning materials to Zachary-assen continuous random networks, as frequently ascribed to bulk amorphous materials, or to the crystallite model - but a universal framework is not yet present. Since AMC does not possess obvious order, it cannot be characterised using approaches relying on unit cells, such as Monte Carlo techniques.

Some promise lies in recently synthesised forms of AMC with particular distributions of local “graphene-like” nano-crystallite areas. Nano-crystallite forms of AMC have been shown to maintain AMC’s flexibility, while adding graphene-like strength. However a general understanding has not been obtained.

To address this, we apply Persistent Homology to atomic configuration data of AMC. This method allows computation of topological features of a space, persisting across length scales. Features remaining present after performing Persistent Homology are more likely to represent features of the underlying space, potentially revealing previously obscured features.

Our approach gives both insight into the structural and mechanical properties of AMC, in addition to gaining general insight into amorphous 2D materials. Understanding of hidden order may allow strategies in design and synthesis of amorphous materials in such a way that maintains strength and flexibility, to reconcile gaps between theory and implementation. This approach underscores the potential of topological data analysis to add universality to materials science as a whole, on a pathway to technological evolution.

Quantum Science and Technology / 255

Engineered Dissipation in Digital Quantum Simulations for Complex Resource State Generation

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Quantum hardware processing power is normally optimised by minimising decoherence effects from unwanted interactions with noisy environments. Yet paradoxically, carefully tailored bath interactions can be exploited to preserve coherence rather than degrade it. Engineered dissipation, or reservoir engineering, introduces tailored couplings between a quantum system and its environment to serve as a beneficial resource for tasks of interest, such as deterministically or low-overhead autonomous preparation and stabilization of quantum states (including computationally interesting entangled or multipartite resource states, e.g., Murch 2012), and is a promising route toward always-on error correction (Kapit 2017). Recent work has shown that Floquet engineering, a technique where systems are driven under a periodic Hamiltonian to achieve new effective time dynamics, is also compatible with reservoir engineering in superconducting quantum simulators (Petiziol 2022). In this work, we extend reservoir engineering to the domain of digital quantum simulation (DQS), which can be interpreted as discretized periodic time-evolution. We describe two proof-of-concept examples: 1) the generation and stabilization of arbitrary quantum states within a single-qubit toy-model Trotterisation, identifying parameter regimes that optimize fast driving and high-fidelity state preparation; and 2) a fully autonomous implementation of the three-qubit phase-flip error-correcting code within a DQS framework without the need for measurement-based feedback.

More generally, DQS allows arbitrary Hamiltonians to be simulated on any universal quantum processor, within the bounds of decoherence and control precision. Our illustrative examples of how to integrate DQS with reservoir engineering highlight its potential role in extending existing noisy intermediate-scale quantum (NISQ) devices to produce, stabilize, and passively correct much more complex resource states which we will explore in future work. We also discuss directions for integrating control protocols that maintain compatibility with continuous autonomous error correction.

Quantum Science and Technology / 256

Identifying quantum chaos using rigorous statistics and random matrix theory

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Simulating chaotic systems is difficult, due to randomness from divergent sensitivity to system parameters, and the same holds for quantum chaos—often understood as dynamics in quantum systems that exhibit classical chaos in a large-system limit. Yet in quantum technologies, quantum chaos also arises in systems which do not possess any straightforward classical limit. For example, quantum computing algorithms such as digital quantum simulations only become interesting in large-system regimes which *cannot* be simulated classically: the dynamical randomness in quantum chaotic systems makes them good candidates for computationally complex quantum simulations ¹. We therefore need to be able to characterise quantum chaos independent of a classical reference system.

Essentially, a system is quantum chaotic if its unitary dynamics follow the predictions of *random matrix theory* (RMT): that is, if it samples from a universal RMT unitary matrix ensemble, as some parameter is varied. While this understanding is not new, it is difficult to quantify, and most previous analysis has relied on direct analytics, inconclusive methods like qualitative visual comparisons [2,3]. Recently, we introduced a new, quantitative and objective technique based on statistically rigorous comparison of a unitary with RMT predictions, at the full distribution level, using chi-squared tests [4]. Here, we describe the general technique, and illustrate its performance in the context of recently demonstrated digital quantum simulation performance thresholds arising from an onset of quantum chaos. We use it to objectively characterise RMT correspondence through quantitative comparisons with standard chi-squared confidence regions, and demonstrate the technique's versatility by analysing eigenvector and level-spacing statistics, individual eigenvectors, mixed phase-space regions, chaos-to-chaos transitions, and characterisation of small-system quantum chaos.

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³ Kargi, et al. *arXiv:2110.11113v4* (2025).

Focus Session: Frontiers of Medical Physics / 257

A modular Geant4 framework for rapid beam shaping assembly design for neutron capture therapy

Author: Sherryn MacLeod¹

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Accelerator-based neutron sources (ABNS) are reviving interest in neutron-capture therapy (NCT) for cancer treatment. However, each facility needs a custom beam-shaping assembly (BSA) to tailor

the neutron spectrum, flux, spatial profile and gamma contamination. We have developed a modular, macro-driven Geant4 framework that accelerates BSA prototyping and adaptation across facilities. Our framework allows users to configure beam components - reflector, moderator, filter and collimator - at run-time from declarative macros. Facility-specific source terms (energy, current, reaction and phase-space files from dedicated target simulations) are used to define injected primaries. Built-in scorers report standard NCT beam-quality indicators - epithermal/thermal flux, fast-neutron and contamination at phantom entrance, beam uniformity.

We follow a validation-then-adapt workflow: (1) reproduce published BSA geometries that meet IAEA-style beam criteria to establish baseline fidelity; (2) substitute site-specific source terms for two systems: ANSTO's ANTARES 10 MV tandem accelerator and an RFQ linac driven lithium neutron source at Brookhaven National Laboratory; and (3) iteratively adjust geometry under facility constraints (footprint, shielding, available materials) to approach target figures of merit. We will present preliminary designs and sensitivity analyses for both sites, together with a roadmap for experimental characterisation.

By making geometry, physics lists and scoring fully declarative, the framework improves reproducibility, shortens design cycles and provides a common basis for cross-facility comparison of NCT beam options.

Atomic and Molecular Physics / 262

Probing the nuclear structure with precision atomic theory for heavy and exotic atoms.

Author: Odile Smits¹

Co-authors: Ben Roberts¹; Giriraj Hiranandani¹; Jacinda Ginges¹

¹ *University of Queensland*

One avenue to test and advance nuclear structure theory is by comparing the hyperfine energy splitting measured by experiment, to those calculated theoretically. In this talk I will share our recent advances on precision atomic hyperfine calculations of heavy atoms and exotic muonic atoms. I will highlight the motivation to study these two atomic classes.

The hyperfine structure arises in odd isotopes from the interaction of the magnetic field produced by the electron with the magnetic moment of the nucleus. To accurately calculate the energy splitting, the charge distribution of the protons and the magnetic distribution of the unbound nucleon must be accounted for. QED effects and nuclear polarisation may also lead to considerable contributions. Muons are about 207 times heavier than an electron, but other than that have the same fundamental properties and, just like an electron, can orbit an atomic nucleus. Due to its mass, the orbit of the muon is much closer to the nucleus, making it very sensitive to the effects of the nuclear structure. Heavy atoms, on the other hand, have many electrons and large nuclei, posing its own numerical challenges.

Focus Session - From edge states to emergent phases / 263

Three-dimensional flat band in ultra-thin Kagome metal Mn₃Sn film

Author: Mengting Zhao¹

Co-authors: Anton Tadic²; Grace L. Causer¹; Hongrun Zhang³; James Blyth¹; Jiayu Liu⁴; Mao Ye⁴; Mark T. Edmonds¹; Michael S. Fuhrer¹; Mohammad T. H. Bhuiyan Bhuiyan¹; Tianye Yu⁵; Wenchuan Jing⁴; Yi Du³; Zheng-Tai Liu⁴; Zhiping Yin⁶

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Flat bands with narrow energy dispersion can give rise to strongly correlated electronic and topological phases, especially when located at the Fermi level. Whilst flat bands have been experimentally realized in two-dimensional (2D) twisted van der Waals heterostructures, they are highly sensitive to twist angle, necessitating complex fabrication techniques. Geometrically frustrated kagome lattices have emerged as an attractive alternative platform as they can natively host flat bands which have been observed experimentally in quasi-2D bulk-crystal kagome metals. An outstanding experimental question is whether flat bands can be realized in ultra-thin metals, with opportunities for stronger electron-electron interactions through tuning of the surrounding dielectric environment. Here we use angle-resolved photoelectron spectroscopy, scanning tunnelling microscopy and band structure calculations to show that ultra-thin films of the kagome metal Mn₃Sn host a robust dispersionless flat band with a bandwidth of 50 meV. Furthermore, we demonstrate chemical tuning of the flat band to near the Fermi level via manganese defect engineering. The realization of tunable kagome-derived flat bands in an ultra-thin kagome metal, represents a promising platform to study strongly correlated and topological phenomena, with applications in quantum computing, spintronics and low-energy electronics.

Plenary / 264

Helping Physics Students Thrive

Author: Elizabeth Angstmann¹

¹ *University of New South Wales*

Over the past five years, university education has undergone significant transformation. The lingering effects of COVID lockdowns have reduced student attendance, while the widespread availability of AI tools has made it easier for students to outsource the cognitive effort behind many assessments. These shifts have contributed to increased isolation, declining wellbeing, and a rise in mental health concerns. As a result, student engagement has diminished, negatively impacting learning outcomes for many.

While our teaching methods have had to adapt to this new reality, some core goals remain unchanged. We continue to strive for deep understanding of fundamental physics principles - a pursuit that remains both challenging and rewarding for engaged students. Importantly, students are still people with enduring psychological needs: a sense of belonging, a desire for mastery, and autonomy. Yet, in our efforts to be flexible and efficient, we may inadvertently undermine these needs by prioritising convenience over connection, competence, and academic challenge.

In this talk, I will explore how we can help physics students thrive by returning to the foundational elements of good education: a well-designed curriculum, meaningful assessment and grading aligned with learning outcomes and academic integrity, and opportunities for students to build relationships with staff and peers. I will share strategies that can be implemented at the individual, departmental, and university levels to support student engagement, wellbeing, and learning.

Nuclear and Particle Physics / 265

Dark matter detection in condensed systems

Author: Jayden Newstead¹

¹ *University of Melbourne*

Dark matter detectors, in particular those based on dielectric materials, are among the best tools for probing light dark matter. In the coming years detectors of this type will become sensitive to solar neutrino scattering. For dark matter scattering at very low recoil energies, collective excitations of the electrons in the solid become important. In this talk I'll share some new results incorporating collective excitations due to neutrino scattering on electrons and nuclei. I'll then show what sensitivity future detectors of this type can hope to achieve.

Focus Session: Frontiers of Medical Physics / 266

From physics to patients: Medical physicists driving improved patient outcomes in radiation oncology

Author: Nick Hardcastle¹

¹ *Peter MacCallum Cancer Care Centre*

Radiation oncology is a cornerstone of modern cancer care, with approximately 40% of patients receiving radiotherapy (RT) during their cancer journey. Central to its success is achieving an optimal therapeutic ratio: maximising tumour control while minimising side effects. Radiation oncology is a highly technical field, where new algorithm and hardware advances drive improvements in patient outcomes. Radiation oncology medical physicists are critical to this endeavour, driving innovation, ensuring safety, and enabling consistent translation of new technology into clinical practice.

At the Peter MacCallum Cancer Centre, translational research in radiation oncology encompasses a spectrum of approaches, from the adoption of novel technologies to the development of new treatment paradigms. Current projects include investigating the feasibility of novel patient positioning to expand treatment options and tolerance, exploring new techniques for delivery of radiation such as particle and synchrotrons, leveraging artificial intelligence to reduce burden of repetitive tasks, and advancing novel imaging methods to guide radiation therapy.

Clinical trials remain the key enabler in translational research. This can be achieved with 'virtual clinical trials' where in silico models are used to model tumour control and side effect outcomes, providing cost-effective early evidence to guide technology adoption before use in patients, or to inform clinical trial design. Clinical trials in patients however remain the gold standard in assessing the benefit of new technology on not only patient outcomes but in health economics.

Major challenges remain; aligning technological advances with meaningful patient outcomes; integrating research and learning culture into routine clinical workflows where outcome data may be sparse; and balancing cost, accessibility, and usability with efficacy. Addressing these challenges requires close collaboration between physicists, clinicians, and trialists, ensuring that cutting-edge research translates into tangible improvements in survival, quality of life, patient experience and health economics.

Medical Physics / 267

Geant4 for medical physics applications: novel developments and next steps

Author: Susanna Guatelli^{None}

Geant4 is an open-source Monte Carlo radiation physics simulation code, extensively used in medical physics, including verification of radiotherapy treatment planning systems, and the design of equipment for radiotherapy and nuclear medicine. It is also used in medical imaging for dosimetry, to improve detectors and reconstruction algorithms, and for radiation protection assessments. Geant4 can be used in stand-alone applications or via software tools like GAMOS, GATE, PPSim, and TOPAS. This presentation will show the latest developments of Geant4 in terms of physics modelling

capability of interest for radiotherapy, nuclear medicine and radiation protection. An overview of anticipated future developments will be presented.

Focus Session - From edge states to emergent phases / 268

Bimerons and Antibimerons in Magnetic Topological Materials

Author: Oleg Tretiakov¹

¹ UNSW

I will discuss topological magnetic textures, such as skyrmions, merons, and (anti)bimerons, which constitute tiny chiral whirls in the magnetic order. They are promising candidates as information carriers for next generation electronics, as they can be efficiently propelled at very high velocities employing current-induced spin torques 1. First, I will talk about bimerons 2 and antibimerons 3 in ferromagnetic systems coupled to heavy metals and topological materials. Then I will show that antiferromagnets can also host a variety of these textures, which have gained significant attention because of their potential for terahertz dynamics, deflection free motion [4], and improved size scaling due to the absence of stray fields. Finally, I will demonstrate that topological spin textures, merons and bimerons, can be generated at room temperature and reversibly moved using electrical pulses in antiferromagnets [5] and ferromagnets [6].

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Plenary / 269

Positron and Positronium interactions in atomic and molecular systems

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Antimatter remains one of the most intriguing frontiers in modern physics. The most readily available form of antimatter is the positron, the electron antiparticle, which can briefly bind with an electron to form positronium (Ps)—a short-lived, hydrogenic ‘atom’. Positron and positronium can be used to explore and test our understanding of scattering dynamics and fragmentation in antiparticle interactions with atomic and molecular systems.

These interactions are not only of fundamental interest but also underpin key technologies. Positron Emission Tomography (PET), for example, relies on an understanding of how positrons and positronium behave in biological media. Similarly, Positron Annihilation Spectroscopy (PAS) is used to probe structures in materials at the nanometre scale. Central to both is the formation, transport, and decay of positronium—particularly ortho-positronium, which can diffuse and interact before annihilation, affecting both image resolution and radiation dose models.

A striking feature of positronium is its tendency to scatter like a heavy electron. This raises the possibility that Ps could induce molecular damage through mechanisms similar to dissociative electron attachment (DEA), a known cause of DNA strand breaks. Yet, the fate of positronium after formation

in complex biological environments remains poorly understood.

Even small atoms pose challenges when describing positron and positronium interactions in theoretical models. The treatment of positron-electron correlations and the formation of positronium in positron collisions with atoms requires innovative and complex theoretical approaches.

This talk will highlight some of our recent work on positron and positronium physics as well as indicate future plans for studies of spin-dependent interactions with cold, trapped Rb atoms where positronium formation will dominate, and Ps scattering from molecules to investigate DEA-like fragmentation of biological molecules. Hopefully these insights will inform applications in medical imaging, materials science, and fundamental antimatter research.

Plenary / 270

Peering Inside the Proton: How Lattice QCD Reveals the Building Blocks of Matter

Author: James Zanotti¹

¹ *The University of Adelaide*

The proton sits at the heart of every atom, yet its internal structure remains one of the deepest challenges in physics. Its properties, such as its mass and spin, do not arise simply from its constituent quarks, but from the complex, strongly interacting dynamics of Quantum Chromodynamics (QCD). At low energies, QCD is strongly coupled and resists analytic solutions, making the emergent structure of hadrons a profound challenge. Lattice QCD offers a unique window: by discretising space and time, we can compute proton properties directly from the underlying theory. In this talk, I will show how lattice QCD calculations illuminate the proton's inner workings, such as its mass, spin, and charge distributions. I will also discuss how these results underpin precision tests of the Standard Model and highlight the interplay between lattice results and experimental measurements, and discuss how upcoming advances in algorithms and exascale computing promise to transform our quantitative understanding of hadronic structure.

Focus Session - From edge states to emergent phases / 271

Group theory method for extracting order parameters from scanning tunneling microscopy data

Author: Harley Scammell¹

¹ *University of Technology Sydney*

Scanning tunneling microscopy (STM) is a powerful local probe of correlated electronic states. We introduce a group-theoretical framework for STM analysis that decomposes images into components corresponding to irreducible representations of the local density of states, providing a real-space map of symmetry properties. This decomposition enables the direct detection of spatial symmetry-breaking patterns; an ongoing challenge in the field. In the process, we uncover a selection rule, "Bragg peak extinctions," which renders certain symmetry channels invisible to standard STM analysis, and we show how to circumvent this limitation. We also discuss practical considerations such as piezomagnetic drift and point to future applications, including quasiparticle interference.

Poster Session / 272

Electronically-controlled one- and two-qubit gates for transmon quasicharge qubits

Authors: Abhijeet Alase¹; Deniz Stiegemann^{None}; Nicholas Christopher²; Tom Stace²

¹ *Concordia University, Montreal*

² *University of Queensland, Brisbane*

The transmon qubit, in which a qubit is encoded in the anharmonic spectrum of a superconducting circuit, is a leading hardware platform for building utility-scale quantum computers. Thanh Le, Cole and Stace propose an alternative encoding for transmon qubits and demonstrate that a 4π -periodic inductive element can be used to access states which are forbidden in the traditional encoding. However, they did not provide a physical system that realises such an element. We show that a topological superconducting junction realises this 4π -periodic inductive element by employing a minimal model to simulate the dynamics of the system. A single-qubit gate can be applied to the qubit by electronically controlling the tunnelling potential across the junction and an identical mechanism enables entangling two-qubit gates. Therefore, one- and two-qubit gate speeds are identical. The coupling to a topological junction requires the transmon to be treated as a topological-transmon hybrid.

Physics Education / 273

Quantum Begins at School: The Einstein-First project

Author: Anastasia Lonshakova^{None}

Einstein-First is an Australian initiative with a decade-long history. Its mission is to modernise school science curricula by embedding Einsteinian physics—relativity, quantum mechanics, and their technological applications—into core science education. The revolutionary physics of the 20th century is almost entirely absent from schools, reserved for the small minority who study physics in Years 11–12. As a result, most students complete school without exposure to the ideas underpinning contemporary science, technology, and innovation.

The project offers a coherent sequence that introduces modern physics from Year 3 onwards. Quantum concepts appear early, with uncertainty and interference introduced in Year 5 and revisited in Year 9, ensuring age-appropriate progression. Key topics include quantum probability, spin, wave-particle duality, and non-locality, supported by hands-on activities. These link directly to applications such as quantum computing, medical imaging, spin-based astronomy, and gravitational wave detection, helping students grasp both the concepts and their relevance to modern technologies.

Over more than a decade of research, development, and classroom trials, Einstein-First has shown that students from Year 3 can meaningfully engage with Einsteinian concepts when supported by suitable models, activities, and mathematical tools. The same resources, delivered through structured micro-credential courses, enable teachers without prior science training to gain the confidence to teach programs up to Year 10. Professional development guides teachers through a progression from informal reasoning to formal understanding.

By embedding Einsteinian physics into the mainstream curriculum, Einstein-First aligns school science with the foundations of modern knowledge and prepares Australian students for the quantum technologies of the 21st century. This work highlights Australia's leadership in science education reform and its contribution to the International Year of Quantum Science and Technology.

Nuclear and Particle Physics / 274

Warm ingredients in a cold soup: The role of warm and cold dark matter in cosmological structure formation

Author: Amrita Mukherjee¹

¹ UNSW

The interplay between theoretical cosmology and particle physics seeks to answer fundamental questions related to our Universe's formation and constituents. Today, it is well established that dark matter (DM) accounts for nearly 30% of the cosmic energy budget ¹. Several particle physics models of DM are being extensively studied; however, there has yet to be any luck with its detection. The weakly interacting massive particles (WIMPs) are a class of cold (negligible free-streaming effects) DM (CDM) candidates whose number density evolution is dictated by the commonly known chemical freeze-out mechanism. These are one of the most theoretically motivated DM candidates because calculations leading to the present-day DM relic density produce an interaction cross section of the weak scale. However, all the experiments dedicated to the search for WIMPs have produced null results and the Λ CDM model of cosmology, though successful in describing structure formation on large length scales, has tensions with observations on small (sub-galactic), non-linear length scales. These

shortcomings require us to move beyond the cold WIMP paradigm to explore other particle models like the feebly interacting massive particles (FIMPs) that behave as warm DM (WDM) with significant free-streaming length, washing off structures in small scales ². The mass of thermally produced WDM has stringent constraints from observations, hence, the idea is to look at non-thermal production mechanisms and at scenarios where the dark matter relic has a mixture of warm and cold components. In this talk I will be describing such scenarios and motivate the connection between the particle models of WDM and their cosmological impact on structure formation.

¹ B. Dutta, Indian J. Phys. 97 (2023) 3269; B.-L. Young, Front. Phys. (Beijing) 12 (2017) 121201.

³ R. Murgia et al, JCAP 11 (2017) 046; A. Banerjee et al, Phys. Rev. D 108 (2023) 043518.

Focus Session: Combining astronomy and particle physics in the hunt for dark matter / 275

Cosmic Structure Formation & Dark Matter Physics: Insights from Theoretical Modelling

Author: Chris Power^{None}

In this talk, I'll explore how theoretical modelling—particularly N-body simulations and semi-analytic approaches—can shed light on the nature of dark matter and the formation of cosmic structure. I'll highlight recent work on modelling classes of dark matter beyond Λ CDM, discuss approximate schemes that are especially useful for interpreting cosmological surveys, and examine how extended Press-Schechter frameworks can be adapted to general dark matter scenarios. I'll also touch on the role of subgrid models in linking dark matter physics to galaxy formation, and share some thoughts on where I see the most exciting opportunities for progress.

Focus Session: Combining astronomy and particle physics in the hunt for dark matter / 276

Astronomical constraints on dark matter in the local environment

Author: Joss Bland-Hawthorn^{None}

The spatial and velocity distributions of dark matter in the local environment are a crucial input to searches for particle dark matter, for both direct experiments based on Earth, and astronomical observations of the galactic centre. Despite this, there are considerable uncertainties that directly impact the current and future sensitivity to particle dark matter signals. I will summarise what constraints astronomical observations currently place on the local dark matter population.

Focus Session - From edge states to emergent phases / 277**Some Recent Developments in SPM Probing of Ferroelectrics: Crackling Noise Microscopy, Phonon-Nanoscopy and Optically Manipulated Ferroelectricity in BiFeO₃****Author:** Jan Seidel^{1None}

I will discuss our recent work on various ferroelectric and multiferroic oxide material systems using scanning probe microscopy (SPM) as the main investigative tool, with a focus on nanoscale functional property measurements of individual topological defects and new SPM instrument capability developments.

The nanoscale phonon properties of BiFeO₃ structural variants have rarely been investigated at the nanoscale. Here, we combine nano-Fourier transform infrared spectroscopy (nano-FTIR) and scattering scanning near-field optical microscopy (s-SNOM) imaging to report on the first direct mid-IR imaging of such nanoscale phase variants in mixed-phase BiFeO₃ based on their distinct vibrational signatures. The noninvasive optical reading in the infrared, i.e. 'phonon-nanoscopy' can further successfully detect electrical switching of ferroelectric BiFeO₃, providing insight into future infrared photoelectric applications. Our work demonstrates that scanning near-field techniques are versatile and sensitive for probing the structural and physical properties of nanoscale entities with subtle distinctions.

Other types of optical control of polar order in ferroelectric and multiferroic materials include photostriction, i.e. optomechanical coupling in BiFeO₃ thin films. We demonstrate a strong photostrictive response in nanocrystallite BiFeO₃ thin films synthesized through cost-effective, scalable spray pyrolysis under relatively low optical power (~1.7 W cm⁻²). This response is accompanied by synchronous light-driven enhancements in piezoelectricity and polarization switching. The effective separation of photogenerated excitons, facilitated by a high density of domain walls characterized through piezoresponse force mapping, leads to an effective screening of the depolarization field and compensation for the built-in field induced by charged defects. A photostriction coefficient of 4.5×10^{-7} m² W⁻¹ - five times higher than bulk BiFeO₃ and comparable to leading halide perovskites - was measured using scanning probe microscopy, offering new opportunities to integrate these materials into innovative devices.

The discussion will include a newly-developed SPM method to investigate crackling noise of domain walls in ferroelectrics with an AFM system.

Focus Session: Emerging Materials and Physics for Energy Conversion / 278**Development of Photocatalysts for Water Splitting through Modifying their Surface Structure****Author:** Gunther Andersson^{None}

Photocatalytic water splitting allows producing green hydrogen without the need to be connected to the electric grid. Photocatalysts absorb light and generate electron hole pairs. Provided that the energy levels of the valence band and conduction band are positioned below and above the energy levels required for the oxygen and hydrogen evolution reaction, respectively, the absorbed light energy can be used to generate H₂ and O₂.¹ Photocatalysts consist typically of three components: the light absorbing material, the co-catalysts for facilitating the hydrogen evolution reaction (HER) and the oxygen evolution reaction (OER).

This presentation focuses on two aspects of developing photocatalysts. The first aspect is the use of atomic precise nanoclusters as HER and OER co-catalysts.² These nanoclusters can be tailored for specific reactions. The second aspect is the application overlayers. These overlayers both protect the nanoclusters from agglomeration and protect the water splitting process from the backreaction

to occur. The backreaction converts the generated H₂ and O₂ back to H₂O reducing the efficiency of the photocatalytic process.

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1. Wang, Q.; Domen, K. Particulate Photocatalysts for Light-Driven Water Splitting: Mechanisms, Challenges, and Design Strategies. *Chem. Rev.* 2020, 120, 919-985.
2. Alotabi, A. S.; Small, T. D.; Yin, Y.; Osborn, D. J.; Ozaki, S.; Kataoka, Y.; Negishi, Y.; Domen, K.; Metha, G. F.; Andersson, G. G. Reduction and Diffusion of Cr-Oxide Layers into P25, BaLa₄Ti₄O₁₅, and Al:SrTiO₃ Particles upon High-Temperature Annealing. *ACS Applied Materials & Interfaces* 2023, 15, 14990-15003.

Quantum Science and Technology / 279

“Atomtricity” the world of matter wave circuitry for precision sensing and signal processing

Author: Dana Anderson^{None}

Matter wave-based sensors have demonstrated exquisite sensitivity and precision, for example, for acceleration and rotation measurements that utilize interferometry. This work takes a new look at matter waves, in particular those associated with alternating currents (AC) of interacting identical neutral particles such as rubidium atoms. The semi-classical mechanics of such waves are governed by a set of matter-wave duals to Maxwell's equations rather than by Schrödinger's equation. There is such a faithful analogy between the physics of electron currents and neutral particle currents, that it is meaningful to refer to the latter as the laws of atomtricity as the analog to the laws of electricity. These laws include duals to Ohm's law, for example, connecting particle current to a “tronic” potential, the dual of voltage in electrical circuits, and Maxwell matter waves as the dual to electromagnetic waves. The analogy is useful when considering how one might design atom-based circuitry to perform measurements and carry out subsequent signal processing. There are, though, surprises lying within the laws of atomtricity, such as a particle speed that has a lower, rather than an upper bound, as is the case with the speed of light. In contrast with the more familiar matter waves of quantum mechanics Maxwell matter waves are associated with two quantum numbers –the total energy, as is the case with vacuum solutions to Schrödinger's equation, and the oscillation energy, associated with the time-variation of the current. Importantly, the temporal coherence imbedded in Maxwell matter waves gives rise to considerably useful yet different behavior than that of the more familiar Schrödinger, or deBroglie, matter waves. For example, the transmission through potential barriers as a function of particle energy is very different for Maxwell matter waves compared to Schrödinger waves, as will be illustrated.

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Designing the Quantum Future: Novel Quantum Materials and Devices for Emerging Quantum Technologies

Author: Xiaolin Wang¹

¹ *University of Wollongong*

Designing the Quantum Future: Novel Quantum Materials and Devices for Emerging Quantum Technologies

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talk**Bragg medal session / 290****talk****Plenary / 291****2D Quantum Materials for Next-generation Quantum Photonic Devices****Author:** Yuerui (Larry) Lu^{None}

Two-dimensional (2D) van der Waals quantum materials have become important building blocks for future electronic, photonic, phononic and quantum devices. The highly enhanced Coulomb interactions in the atomically thin quantum 2D materials, arising from the reduced dimensionality and weak dielectric screening, allows the formation of tightly bound excitons, biexcitons and interlayer biexcitons. These tightly bound quasi-particles have been of keen interest for both fundamental studies and novel device applications, such as entangled photon sources, quantum logic gates, etc. The recently discovered single photon emitters at room temperature from the defects in 2D hexagonal boron nitride could find promising applications for quantum sensing and quantum communications. Because of their ultra-light weight, defect-less surface and low intrinsic losses, atomically thin 2D materials are also perfect candidate materials for ultra-sensitive transducers for sensing and communication applications. In this talk, I would like to talk about how to tailor the van der Waals interactions and engineer the light-matter interactions in ultrathin quantum materials, for next-generation nano-photonic and quantum devices. I will highlight our recent work on the discovery of new quantum phases from freestanding hetero bilayers, as well as the generation of entangled quantum light sources using ultra-thin nonlinear quantum materials. Finally, I will talk about my vision and discuss some possible future directions regarding the photonic and quantum applications of novel 2D materials and their heterostructures.

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Advanced cancer treatment with radiation and space exploration: synergy of fundamental particle physics and medical physics research

Author: Anatoly Rozenfeld¹

¹ *University of Wollongong*

Many discoveries in particle physics obtained on high luminosity colliders will be impossible without development of sophisticated semiconductor radiation detectors and Application Specific Integrated Circuits (ASICs) for their multichannel readout electronics. Among them different kind of strip detectors, pixelated detectors, detectors utilising 3D detector technology, Low Gain Avalanche Detectors (LGAD) and many others. Many years of their radiation damage studies by high energy physics community led to material engineering realised in extremely radiation hard silicon, diamond, silicon carbide and other semiconductor detectors.

Radiation detection science driven by fundamental particle physics was paramount for advanced medical imaging of cancer and its treatment using ionizing radiation. The talk will demonstrate the link between fundamental research in particle physics and advancement in medical radiation physics including overview of 30 years of R&D in radiation detection at Centre for Medical Radiation Physics (CMRP) that realised in family of sophisticated radiation detection systems important for error free radiation therapy and success of space missions and lead to their commercialisation for benefit of cancer patients.

Supporting fundamental physics research is investment in our healthy future.

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Seismic Echoes of Magnetism: Sunspots and Starspots

Author: Alina Donea¹

¹ Monash University

Sunspots, together with their stellar counterparts—starspots—serve as powerful tracers of magnetic activity on solar and stellar surfaces. Although visually dark, these regions are acoustically rich, as their intricate magnetic structures strongly influence the propagation of pressure waves. In this work, I present a comparative helioseismic investigation of sunspots on the Sun and extend the insights gained to the study of starspots on other stars, with the goal of decoding subsurface magnetic geometries through acoustic diagnostics. Using high-resolution Dopplergrams and intensity observations from the Solar Dynamics Observatory, we apply advanced helioseismic methods to examine the acoustic signatures of sunspots of varying size, age, complexity, and evolutionary stage. Measurements of wave absorption, phase shifts, and scattering properties provide new constraints on sunspot morphology and the underlying magnetic topology. These solar diagnostics form a benchmark for stellar applications, enabling us to better interpret magnetic activity and rotation in other stars—and ultimately advancing our understanding of stellar/solar evolution through the physics of magnetism and sound.

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Testing the Standard Model with Molecules

Author: Anastasia Borschevsky^{None}

Search for violation of fundamental symmetries provides a unique opportunity for testing the Standard Model. Atomic and molecular experiments offer a low energy and comparatively inexpensive alternative to high energy accelerator research in this field. As the observable effects (such as parity violation, PV) are expected to be very small, highly sensitive systems and extremely precise measurements are required for the success of such experiments. Atomic and molecular theory can provide crucial support for these experiments.

An important task of theoretical research is to identify optimal molecular and atomic systems for measurements and to understand the mechanisms behind the enhanced sensitivity, which is strongly dependent on the electronic structure. Thus, accurate computational methods are needed in order to provide reliable predictions rather than estimates, and to obtain the various parameters that are required for the interpretation of the experiments.

I will present the results of our recent investigations of molecules in the context of search for parity violating effects. An overview of the theoretical methods will be provided, including the recently developed scheme for assigning error bars on theoretical predictions. Then, I will focus on showcasing the different types of systems (diatomic, triatomic, and chiral molecules) that are promising candidates for experiments that aim to test the Standard Model and perhaps detect new physical phenomena [1-3].

1 Y. Hao, ... A. Borschevsky

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Chem. Commun., 59, 14579 (2023)

3 M. R. Fiechter, ... A. Borschevsky

Toward Detection of the Molecular Parity Violation in Chiral Ru(acac)₃ and Os(acac)₃

J. Phys. Chem. Lett. 13, 10011 (2022)

Plenary / 309

Semiconductor Nanostructures for Optoelectronics Applications

Author: Chennupati Jagadish^{None}

Semiconductors have played an important role in the development of information and communications technology, solar cells, solid state lighting. Nanowires are considered as building blocks for the next generation electronics and optoelectronics. In this talk, I will present the results on growth of nanowires, nanomembranes and microrings and their optical properties. Then I will discuss theoretical design and experimental results on optoelectronic devices. In particular I will discuss nanowire and micro-ring lasers and integration of nanowires and microrings. I will also present the results on polarization sensitive, broad bandwidth THz detectors operating at room temperature. Nanowire based energy devices such as solar cells and photoelectrochemical (PEC) water splitting will be discussed. I will discuss about Neuro-electrodes to study brain signaling to understand dementia. Future prospects of the semiconductor nanostructures will be discussed.