

HELLO TOMORROW

Faculty of Science and Engineering

POSTGRADUATE RESEARCH

Department of Physics & Astronomy
Postgraduate Research Conference
25 September 2026
Programme of Events

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Contents

Welcome Statement 3

Schedule 4

Poster Abstracts 7

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Department of Physics & Astronomy

A very warm welcome to everyone for this year's Postgraduate Research Conference.

This event is a celebration of the creativity, hard work and enthusiasm that you all bring to the Department. One of the strengths of our PGR community is in fact the remarkable range of ideas, questions and research efforts. I am very pleased to be able to be with you for this occasion and I look forward to seeing your research on display.

Today you have the chance to step outside our own projects and discover what others are working on. It is also a great opportunity to exchange ideas and make new connections. I hope you will enjoy the opportunity to talk with fellow researchers, ask plenty of questions, and share your own work and experiences. I encourage you to make the most of the day by joining in as fully as you can.

Dr Alessandro Principi

Head of PGR

Department of Physics & Astronomy

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Schedule

Friday, 25th September 2025, 11:45 - 15:45	
J Bell Burnnell Lecture Theatre (GA.03A), Schuster Building	
11:45 – 12:00	Event Registration and PGRs to put up posters
12:00 – 13:00 Lunch	
12:00 – 14:30	Poster viewing/ networking
13:00 – 14:30	Submit votes via QR Codes
13:45	Tea, coffee and cakes
15:15	Announce winners / close events

Poster Numbers

First name	Surname	Poster number
Ahmed	Al-kharusi	1
Akshat	Gupta	2
Alex	Cai	3
Ashwat	Jain	4
Camilla	Colas	5
Charlie	Shakeshaft	6
Dominik	Nemeth	7
Edward	Smith	8
Fatimah	Alharthi	9
Fujia	Lu	10
Ghazwa	Alsubaie	11
Harry	Britton	12
Hei Chun	Chan	13
Heidi	Savey-Bennett	14
Hongkai	Zhou	15
Ian	Osborne	16
Jac	Fernandez-John	17
Jordan	Byrne	18
Joshua	Selfridge	19
Josie	Ball	20
Kai	Madgwick	21
Kai	Xu	22
Mathilde	Hanoune	23
Mohammed	Sultan	24
Muneeba	Nawaz	25
Oliver	Betteridge	26
Phil	Burdett	27
Rebecca	Fisher	28
Rishi	Sundar	29
Rohin	Bardan	30
Sabiar	Rahaman	31
Sam	Valentine	32
Sanjiban	Sengupta	33
Saule	Piguleviciute	34
Snehit	Panghal	35
Suad	Alshammari	36
Timothy	Lee	37
Tongtian	Ren	38
Victor	Carneiro da Cunha Martorelli	39
Xi	Luo	40
Xue	Li	41

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Faculty of Science and Engineering

POSTGRADUATE RESEARCH

Poster Abstracts

Nonlinear Electronic Effects in Moiré Superlattices – Agustin Montemurro

Moiré superlattices are long-period structures, formed in stacks of twisted or lattice-mismatched two-dimensional materials. They provide a highly tunable platform for controlling the electronic structure and transport properties of materials. Interlayer coupling reconstructs the band structure into minibands that can host magic-angle superconductivity, enhanced Berry curvature, correlated states and topological phases, while also exhibiting nonlinear electronic and optical responses.

This project aims to develop the theory behind electronic transport in moiré superlattices, with a particular focus placed on the anomalous and nonlinear Hall effects, nonequilibrium phenomena and nonlinear optical effects such as second harmonic generation. A long term goal is to construct a more comprehensive transport theory incorporating topological, scattering, phonon and disorder contributions into one framework. Current work has focused on multilayer graphene systems, where Berry curvature and orbital magnetic moment have been studied to calculate the anomalous Hall response as functions of carrier density and displacement field. These calculations provide a foundation for extending the numerical framework towards moiré minibands and to identify tunable electronic phases in these materials.

Topological phases of a generalised tripartite Haldane model

Ahmed Al-kharusi

The University of Manchester

This project was supervised by Niels Walet and Alessandro Principi

Abstract

We introduce a generalised Haldane model with complex nearest-neighbour hopping parameters. The primitive cell unit of the model consists of three graphene unit cells. We show that the model benefits from a simple analytical form but a complex topological phase diagram of the Chern number, including phases where the absolute value of the Chern number is 7. Additionally we show that some of the boundaries of the topological phases can be calculated analytically.

BOA Constrictor: A Mamba-based lossless compressor for scientific data

Name: Akshat Gupta

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Supervisor: Thomas Elliott, Caterina Doglioni

Research Area: Quantum and Classical Information Theory, High Energy Physics

Year of Study: 3rd

The experiments at the Large Hadron Collider produce of order thirty petabytes of data each year, stored with general-purpose codecs that exploit none of the structure specific to physics data. BOA (**B**ytewise **O**nline **A**utoregressive) Constrictor [1] is a lossless neural compressor in which a compact Mamba state-space model predicts each byte from its context and a range coder encodes the data under those predictions. With a model of about two megabytes, it reaches effective compression ratios of $9.13\times$ on simulated collision records and $7.23\times$ on ATLAS Open Data, against $5.33\times$ and $6.79\times$ for the best traditional codec, and a model trained on one file compresses others from the same source without retraining. The prototype is slow, at up to 45 MiB/s to compress and 25 MiB/s to decompress, and both directions need a GPU. A learned compressor also costs energy to train and run, so we compare its carbon footprint with that of the disks it saves. The break-even volume depends on the hardware and the electricity grid. A quantised successor, mBOA (**m**ulti-**B**ytewise **O**nline **A**utoregressive), drops the GPU requirement by running the network in integer arithmetic. One archive then decodes bit-identically on GPU, x86 and Arm hardware, at BOA's ratios while encoding up to $2.3\times$ faster.

[1] A. Gupta, C. Doglioni, and T. J. Elliott, 'BOA constrictor: a Mamba-based lossless compressor for scientific data', *Machine Learning: Science and Technology*, vol. 7, no. 3, p. 035014, May 2026.

Research Abstract

We are conducting the first-ever LHCb measurements of the branching fractions of the semileptonic decay channels $B \rightarrow \eta \mu \bar{\nu}$ and $B \rightarrow \omega \mu \bar{\nu}$. The branching fractions of these channels can be utilized to compute the CKM matrix element V_{ub} . The analysis is performed using data collected with the LHCb Upgrade I detector. The unprecedented data sample available from LHCb Run 3, combined with the detector's improved performance and the inclusion of two historically under-explored decay channels, provides a promising opportunity to improve the precision of the determination of V_{ub} . This potential is investigated through studies of the corrected-mass distribution of the B meson and the invariant mass distribution of the three-pion system.

Presenter: Ashwat Jain

Title: Nonlinear odd elasticity from quantum geometry

Abstract:

We uncover a class of nonlinear odd viscoelastic effects in three spatial dimensions [*Phys. Rev. Lett.* **137**, 036302 (2026)]. We show that these dissipationless effects arise upon combining geometric distortions in two orthogonal directions, yielding momentum flow in the third direction. We demonstrate that the effect arises from nontrivial geometric tensors in quantum states, and can be scaled up with integer topological invariants. We further show that the effect fingerprints the multiband Hilbert-space geometry of the underlying quantum states, as encoded in the nonmetricity and three-state quantum geometric tensors. Our findings unravel the role of multistate geometry in viscoelastic phenomena, paving a path for experimental observation of uncharted nonlinear odd viscoelastic responses in quantum systems.

Further, we show that certain three-dimensional topological phases can act as acoustic diodes realizing nonlinear odd acoustoelastic effects [*arXiv:2601.20951*]. Beyond uncovering topologically-induced anomalous acoustic second-harmonic generation and rectification, we demonstrate how such nonlinear responses are uniquely captured by multistate quantum geometry. We find that second-harmonic acoustic responses are naturally dominated by the previously unidentified quantum nonmetricity tensor. In addition to completing the classification of quantum geometric observables in the quadratic response regime, our findings reveal unexplored avenues for experimental realizations of topological acoustic diodes using effective θ vacua of axion insulators adaptable for future engineering applications.

A 4 to 20 GHz stacked Lange coupler design for super heterodyne receivers

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Supervisor: Danielle George and Gary Fuller

Research Area: Radio Astronomy Instrumentation

Year of Study: 2

Abstract body text; Times New Roman, Size 12; Left Justified; Max. 200 words; No figures or tables to be included.

The next generation of radio telescopes requires larger intermediate-frequency (IF) bandwidths to improve receiver sensitivity. However, many operational radio astronomy heterodyne receivers employ narrower IF bandwidths, such as 4–8 GHz or 4–12 GHz, due to challenges associated with broadband amplification and mixer design.

This work investigates the design and simulation of an ultrawideband Lange hybrid coupler operating from 4 to 20 GHz, with the aim of integrating it into a balanced low-noise amplifier (BLNA) within the IF chain of a superheterodyne receiver. The coupler uses a stacked topology implemented on Duroid 6010 with copper traces, providing a physically realisable approach compatible with fabrication in the University's PCB workshop.

A wideband hybrid coupler enables balanced signal processing across a broad frequency range, with the potential to improve the robustness and scalability of future receiver architectures. The next stage of this work will involve fabrication and experimental characterisation of the coupler, that will provide validation of the simulated performance and informing further optimisation for integration into a wideband receiver system.

Maximum-entropy ensemble of quantum subsystems with a thermal average

The reduced density matrices of a Haar-random bipartite state are distributed according to the induced measure, with the asymptotic eigenvalue density given by the Marchenko-Pastur law. We extend the random matrix treatment to physical constraints, constructing a maximum-entropy ensemble of subsystems subject to a fixed average state. We derive an expression for the corresponding partition function, using it to investigate the concentration behaviour of energy fluctuations for a single qubit coupled to an arbitrarily large environment. In the limit of large dimensions, we prove that the ensemble converges to the correlated Wishart ensemble (CWE) of random matrices, whose level density is given by a free convolution formula. Fixing the average to the thermal state of a random Hamiltonian, we derive a leading-order perturbative correction to the Marchenko-Pastur law at high temperatures. Finally, we prove that the spectral statistics of our constrained ensemble are asymptotically equivalent to those of the mixed-state ensemble generated by a random measurement on the canonical purification of the reference state, establishing a natural physical mechanism for the emergence of the constrained ensemble.

Topological Initial State Independence in Boundary Time Crystals

Name: Dominik Nemeth

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Supervisor: Alessandro Principi & Ahsan Nazir

Research Area: Theoretical Physics – Many-Body Open Quantum Systems

Year of Study: 2

Abstract: Boundary time crystals exhibit robust oscillations independent of initial state. We map collective-spin Lindblad dynamics onto an operator-space transport problem and identify an emergent winding number. A non-zero winding enforces delocalization of Liouvillian modes, enabling source-fed transport from the identity sector to observables and providing a microscopic explanation for robust BTC dynamics.

In the first year of my PhD, I focused on constructing the Pathfinder: an axion haloscope based in Manchester. This involved tuning the cryogenic cycle to reach a minimum temperature of 100mK. Once this was achieved, my efforts shifted towards the microwave electronics required to read out signals. The next step for this experiment is to test the magnet and the readout electronics when they are at cryogenic temperatures.

Performance Analysis of a Mach–Zehnder Interferometer Using Synthetic Interferograms

Name: Fatimah Saad H Alharthi

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Supervisor: Oznur Apsimon

Research Area: Acceleration Physics

Year of Study: 2025

Abstract

In this work, we assess the performance and limitations of Mach–Zehnder interferometry for plasma diagnostics using a fully synthetic, numerically generated dataset. We explore regions of parameter space that are difficult to access experimentally, including fringe behaviour, the dynamic range of measurable phase shifts, and the resolution limits for low-density plasmas. By introducing controlled phase errors, we quantify the robustness of common phase retrieval and phase unwrapping algorithms and identify the conditions under which these methods succeed or fail. Our results provide practical design guidelines for optimising interferometric measurements across a wide range of plasma conditions.

Buckling and crinkling of moiré networks in suspended bilayers of interfacial ferroelectrics

Name: Fujia Lu

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Supervisor: Vladimir Falko

Research Area: Condensed matter theory (2D materials)

Year of Study: 1

Reconstruction of moiré superlattices in small-angle-twisted rhombohedral-type bilayers of transition metal dichalcogenides generates ferroelectric domains separated by triangular networks of partial dislocations. Here, we note that, in suspended bilayers, the nodes of such networks buckle and twirl, with twirling and buckling directions linked by the chirality of the interlayer twist. While, for purely twisted bilayers, up- and downward buckling of individual sites is energetically equivalent, heterostrain lifts such a degeneracy by distinguishing the top and bottom layers. Also, their collective behaviour resembles that of an Ising ensemble, where the dislocations mediate an 'anti-aligning' interaction between neighbouring nodes, whereas heterostrain acts as a symmetry-breaking field, driving a transition from frustrated to globally aligned buckling patterns. A further increase of heterostrain (either isotropic, or uniaxial) leads to a crinkling transition, as dislocations start sticking out asymmetrically from the bilayer plane forming networks of ridges.

Charge, Spin and Ballistic Transport in a Graphene/WS₂ Heterostructure

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Supervisor: Dr Ivan Vera-Marun

Research Area: Condensed Matter Physics

Year of Study: 2

Graphene provides a high-mobility platform for charge and spin transport, while proximity to WS₂ offers a route to modify its electronic and spin properties. Here, we investigate a fully hBN-encapsulated graphene/WS₂ heterostructure comprising monolayer graphene, WS₂-covered monolayer graphene and WS₂-covered bilayer graphene regions, contacted by nine one-dimensional ferromagnetic Co edge contacts. Low-temperature transport measurements at 2.6 K reveal clear gate-dependent transport across all three regions, with the WS₂-covered monolayer region retaining a mobility comparable to bare graphene. Transverse magnetic focusing features follow the predicted $j = 1, 2, 3$ focusing trajectories, providing evidence of ballistic carrier transport. The one-dimensional Co edge contacts additionally exhibit conductance increasing with Fermi wavevector, with shoulder-like features consistent with progressive one-dimensional mode population. Non-local magnetic-field measurements show reproducible switching within an approximately gate-independent field range, consistent with magnetisation reversal of the Co contacts. Together, these measurements demonstrate charge, ballistic and spin-dependent transport within a single multi-region graphene/WS₂ heterostructure.

Magnetic-Field Stabilisation of Chiral p-Type Superconductivity in a Rashba Bilayer

Name: Harry Britton

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Supervisor: Mohammad Saeed Bahramy, Alessandro Principi

Research Area: Unconventional Superconductivity

Year of Study: 1st

The non-trivial topology of a chiral superconducting state makes it a highly sought-after form of unconventional superconductivity. Systems of large spin-orbit coupling offer a platform on which unconventional pairing mechanisms and symmetries can become the leading superconducting instability. We study a bilayer with opposite Rashba polarisation on each layer, such that the system locally breaks inversion symmetry but preserves it globally. The interlayer and intralayer pairing potentials are distinguished while the layer degree of freedom allows for odd-parity Cooper pairings. By classifying the pairings by the symmetries of the D_{4h} point group, it is shown that an out-of-plane magnetic field selectively enhances the pairing which transforms as the two-dimensional E_u representation. The external field breaks time reversal symmetry and specifically enhances the spin-aligned, chiral $p_x + ip_y$ superconducting mode, by coupling to the orbital moment of the pair. Above the transition field, the chiral pairing is found to emerge as the leading superconducting instability in a finite temperature window which broadens as the field increases. The effects on the leading instability from Rashba field strength, interlayer-hybridisation, temperature, and pairing strengths are discussed and non-trivial edge states are found for a finite size system.

Probing Proton Intercalation in few-layered Van der Waal Materials

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Supervisor: Prof. Irina Grigorieva

Research Area: Condensed Matter Physics

Year of Study: 2

Conventional batteries today run on a simple yet delicate mechanism, where ions diffuse in and out of the host material's interlayer gaps without breaking its crystal structure. Choosing the right combination of host and intercalant ion can result in functional compounds with great energy storage capabilities and tuneable electronic properties. While most commercial batteries utilise lithium ions, protons are an interesting alternative due to their comparatively smaller size and fast transport. Yet, our understanding behind their insertion mechanisms is still incomplete. Using few-layer Van der Waal materials as hosts, we aim to investigate how proton intercalation within angstrom-scale gaps modulates their electronic properties.

Here we present an on-chip device architecture consisting of a 2D MoS₂ crystal and counter electrode immersed under an electrolyte. By applying an electrochemical gate voltage, we can monitor signatures of intercalation during sweep cycles. Hall measurements and longitudinal voltage measurements are used to track changes in the carrier density and resistance during these cycles. Additionally, we have used electrochemical impedance spectroscopy (EIS) to probe charge kinetics at the host-electrolyte interface, providing mechanistic insights into their relationship with ion intercalation.

Modelling Vaginal Host–Microbiome Interactions on a Chip

Heidi Savey-Bennett

Department of Physics & Astronomy, University of Manchester, UK

The lack of physiologically relevant models of the vaginal microbiome limits our understanding of gynaecological diseases, contributing to gender health inequalities [1]. To address this, we are developing a vagina-on-a-chip platform that recreates host–microbe interactions in a microfluidic environment to enable mechanistic study of disease. The model will incorporate physiologically relevant flow, nutrient availability, and hormone cycles to mimic the in vivo vaginal environment. A baseline model containing vaginal epithelial cells, mucus, and *Lactobacillus* will first be established, before adding additional species to generate mixed-species biofilms.

The microfluidic device contains two cell-seeded compartments connected by vascular channels that regulate media flow, supply nutrients and remove waste (Figure 1a). This supports culture across timescales relevant to the menstrual cycle. Vaginal epithelial cells have successfully been seeded within the device, forming highly confluent monolayers (Figure 1b). In parallel, *Lactobacillus* species and *Candida* have been co-cultured in the device (Figure 1c). Growth curve assays have shown reduced *Candida* growth in the presence of *Lactobacillus*, providing insight into microbial interactions and informing the design of the metabolic environment for the model (Figure 1d). Future work will integrate epithelial cells with bacterial and fungal biofilms within the device to study host–microbiome interactions using imaging and metabolic analysis, enabling investigation disease signatures relevant to vaginal health.

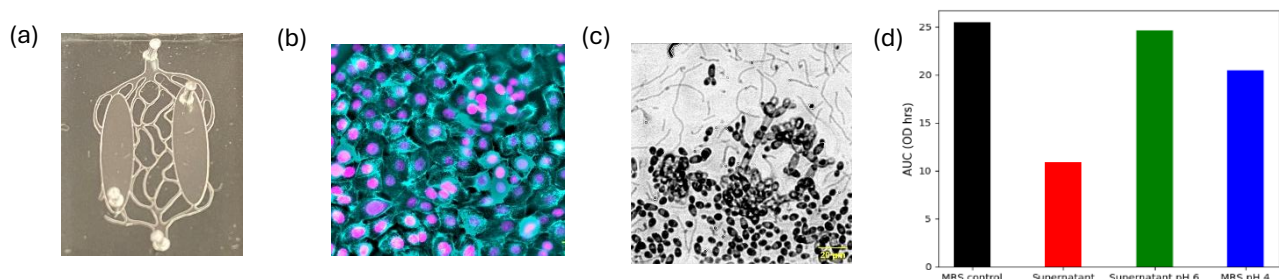


Figure 1: (a) Microfluidic device for culturing vaginal epithelial cells. (b) Composite fluorescence image of vaginal epithelial cells in the device, stained for actin (cyan) and nuclei (magenta). (c) *Lactobacillus rhamnosus* and *Candida albicans* cultured in the microfluidic device (d) Area under the curve (AUC) of *Candida albicans* growth (OD vs time), showing inhibition with *Lactobacillus* supernatant; this effect is lost at higher pH, with minimal inhibition in acidified MRS media.

References

- [1] Kavousi, S., Maharlouei, N., Rezvani, A., Aliabad, H.A. and Vardanjani, H.M., 2024. Worldwide association of the gender inequality with the incidence and mortality of cervical, ovarian, endometrial, and breast cancers. *SSM-Population Health*, 25, p.101613.

Hybrid Plasmonic Photoanodes for Water and Seawater Splitting

Name: Hongkai Zhou

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Supervisor: Professor Alexander N. Grigorenko

Research Area: Condensed Matter Physics / Plasmonics

Year of Study: Year 3

Earth-abundant metal diborides offer an alternative to noble-metal plasmonic photoanodes, but efficient light harvesting remains a challenge. We investigate mechanically rolled MgB_2 –transition metal dichalcogenide composites and AlB_2 hybrids containing FeSe, WS_2 or ZrO_2 . Repeated rolling of mixed powders between copper foils produces nanostructured coatings without high-temperature processing. Under simulated AM1.5G illumination (100 mW cm^{-2}), MgB_2/WS_2 exhibits a light-induced current-density increase of approximately 2.7 mA cm^{-2} in 0.5 M NaCl at a cell bias of 0.3 V , compared with approximately 0.6 and 0.3 mA cm^{-2} for MgB_2 and WS_2 alone. MgB_2/WS_2 remains photoactive after 60 hours of operation. Extending this approach, AlB_2/FeSe achieves a peak current density of approximately 10.5 mA cm^{-2} and an applied-bias photon-to-current efficiency approaching 10% in 0.5 M LiOH at 0.3 V . AlB_2 -based hybrids also show enhanced photoresponses in 0.5 M NaCl , used as a model seawater electrolyte. Ellipsometry and electromagnetic modelling support reduced reflection and improved light absorption, with interface and edge fields contributing to the proposed plasmonic response. These results establish a common fabrication route for boride hybrid photoanodes and motivate further investigation of interfacial charge transfer and product selectivity.

Diffusion in NEXT-100

Diffusion in NEXT-100

Ian Osborne, University of Manchester

The NEXT experiment uses high-pressure gaseous xenon Time Projection Chambers (TPCs) to search for the neutrinoless double beta decay ($0\nu\beta\beta$) of the ^{136}Xe isotope. This is an extremely rare decay that can only occur if neutrinos are Majorana, i.e. their own antiparticle. Observing this decay would offer insight into the origin of neutrino mass and provide evidence for physics beyond the Standard Model. In order to have the best chance of discovering $0\nu\beta\beta$, NEXT detectors combine excellent energy resolution with topological event classification.

A major limiting factor in the TPC performance is electron diffusion: as ionisation electrons drift through the detector towards the readout plane, they undergo random collisions with the medium atoms, causing them to spread both longitudinally and transversally. This effect smears out track information, degrading the detector's topological capabilities. Understanding and quantifying diffusion is essential to mitigate its effects on track topology. This work characterises longitudinal and transversal diffusion in the NEXT-100 detector, with results showing good agreement with previous measurements and Monte Carlo (Magboltz) predictions.

Amplitude Analysis of $T_{cc}^+ \rightarrow D^0 D^0 \pi^+$ and Mighty Tracker Simulation Studies at LHCb

Name: Jac Fernandez-John

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Supervisor: Ivan Polyakov

Research Area: Particle Physics

Year of Study: End of 1st/Start of 2nd

This poster presents the first work carried out towards determining the J^P quantum numbers of the T_{cc}^+ tetraquark. This analysis is carried out using Run3 proton-proton collision data obtained with the LHCb experiment, at centre-of-mass energies $\sqrt{s} = 13.6 TeV$, currently corresponding to an integrated luminosity of $18.9 fb^{-1}$. Additionally, Mighty Tracker simulation studies to determine the detector's optimal sensor and stave overlap, as well as the placement tolerance of its modules, are discussed.

Laser Wakefield Acceleration (LWFA) offers orders of magnitude larger accelerating gradients than conventional RF, promising future compact accelerator design and broadening accelerator accessibility. External injection into LWFA offers improved injection control but challenges remain in achieving high quality and stable beams suitable for applications. Compact external injection design will require a compromise between achievable witness beam parameters upon injection and the final beam quality post-plasma; hence it is important to understand the sensitivity of such a system to sub-optimal beam injection. This study identifies key contributions to overall beam quality degradation including the initial beam parameters and driving laser parameters. To explore compensating sub-optimal injection parameters, optimisation is performed to explore the trade-off between energy gain and beam quality preservation.

Investigating outshining with a spatially resolved view of stars and ionised gas in H α -bright galaxies at $z \sim 6.1$

Name: Joshua Selfridge

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Supervisor: Rachel Cochrane

Research Area: Astrophysics (high-redshift extragalactic astronomy)

Year of Study: 2

Abstract: The total light of a galaxy can be dominated by young, bright stars that ‘outshine’ older, fainter stellar populations. When inferring the physical properties of galaxies by fitting model spectra to their observed light, this outshining can bias stellar mass estimates to be too low as the contribution of older stars is missed. With spatially resolved data, we can fit the light of individual pixels or regions within a galaxy independently, allowing for populations of different ages to be separated out and accounted for, mitigating the outshining bias. The exquisite sensitivity and wavelength coverage of the James Webb Space Telescope (JWST) now offer the opportunity to extend studies of this kind to higher redshift, probing earlier in the history of the Universe. In this work, we use high-resolution imaging provided by JWST’s Near Infrared Camera (NIRCam) to take a resolved view of a sample of star-forming galaxies at the tail end of the Epoch of Reionisation, selected on their H α emission through the JWST Emission Line Survey. Comparing results of integrated and spatially resolved SED fitting, we characterise the extent of outshining in this regime and test the sensitivity and resolution limits at which this analysis can be performed.

Elucidating the magnetism in $\text{Na}_{0.5}\text{CoO}_2$

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Supervisor: Harry Lane

Research Area: Condensed matter physics

Year of Study: 1

Sodium cobaltate (Na_xCoO_2) has been the subject of intense scientific discussion since the demonstrations of its large thermoelectric power [1], and superconductivity in the hydrated compound [2]. The structure consists of alternating layers of Na ions and edge-sharing CoO_6 octahedra, with vastly differing properties depending on the sodium content. The $x = 0.5$ system is of particular interest due to the interplay of magnetic and charge degrees of freedom, with the triangular lattice of cobalt ions ordering antiferromagnetically below 88 K. A previous neutron scattering study [3] suggests a valence disproportionation resulting in stripes of ordered Co^{4+} ions and nonordered Co^{3+} ions. However, this local moment description still leaves open questions. For instance, the nonordered stripes may be localised but dynamic, or an itinerant model may be required. Therefore, the microscopic picture of the magnetism in this material remains unresolved. High-quality single crystals of $\text{Na}_{0.5}\text{CoO}_2$ were prepared via chemical deintercalation of the parent compound $\text{Na}_{0.8}\text{CoO}_2$, and the composition verified by powder X-ray diffraction and magnetisation measurements. A comparison of inelastic neutron scattering calculations for charge disproportionation and itinerant magnetism models is presented, providing new insight and a framework to analyse data from future neutron scattering experiments.

References:

[1] Terasaki, et al. PRB 56, R12685 (1997)

[2] Takada, et al. Nature 422, 53 (2003)

[3] Gašparović, et al. PRL 96, 046403 (2006)

COSMOS-Web is a survey field with an area of ~ 0.5 square degrees, observed by the James Webb Space Telescope (JWST). It contains $\sim 800,000$ galaxies, many of which lack detailed morphological labels. Supervised Machine Learning models such as Convolutional Neural Networks (CNNs) have been successful at identifying common galaxy morphologies (spirals, ellipticals) but struggle with more Peculiar galaxies (irregulars, mergers) due to their comparative rarity and wide-ranging appearances. Since merging galaxies can provide plenty of information about the processes of galaxy evolution, finding an efficient way to detect them in large-scale survey fields is an essential problem to solve. In this poster we present a hierarchical approach of identifying a general class of Peculiar galaxies using a supervised CNN model, then identifying further morphological information about our sample of peculiars using unsupervised feature extraction, followed by active learning using these features to detect mergers.

Synaptic Plasticity and Temporal Computing in 2D COFs Membranes

Name: Kai Xu

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Supervisor: Radha Boya

Research Area: COF, Synaptic Plasticity

Year of Study: 2nd Year

Here we report a nanoporous covalent organic framework (COF) ionic device exhibiting history-dependent ion transport and nonlinear dynamics. Controlled electrical stimulation reveals characteristic synaptic plasticity, including paired-pulse facilitation (PPF), long-term potentiation and depression (LTP/LTD), and spike-timing-dependent plasticity (STDP), arising from coupled ionic states within the nanoporous membrane. These internal dynamics provide a physical basis for higher-order temporal processing. By exploiting the device dynamics as a physical reservoir, we demonstrate reservoir-computing functions including time-series prediction and waveform classification. The same history-dependent dynamics further enable comparison-based operations and logic functions, illustrating the potential of nanoporous ionic membranes for neuromorphic computing and temporal information processing.

Robust fabrication of ultra-soft microcapsules as a biomimetic model for red blood cells

Name: Mathilde Hanoune

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Supervisor: Anne Juel, Finn Box

Research Area: Physics of Fluids and Soft Matter

Year of Study: 2

Red blood cells (RBCs) display a range of behaviors in flow, depending on the capillary number of the external fluid phase Ca (ratio of viscous to surface tension forces), the confinement and the viscosity ratio λ (ratio of core viscosity to suspending fluid viscosity). However, RBC experiments are difficult to reproduce due to intercellular variability and ageing. Since they do not contain a nucleus, we propose modelling RBCs as membrane-encapsulated liquid droplets. Our first generation of capsules relied on nested capillaries to produce a double emulsion, which forms elastic capsules by curing the polymer phase. The capsules were deflated by osmosis to reproduce the physiological ratio of surface area to volume in RBCs. The second generation aims to make the capsules softer to extend the range of available flow conditions parametrized by Ca . The composition of the PDMS membrane can be tuned with the addition of a solvent, and swelling the capsules before curing using controlled osmotic flows allows us to thin the membrane. We are also exploring the use of a selectively functionalized microfluidic chip as a faster, more robust method to produce the double emulsion. We can then explore the motion and deformation of capsules under shear flow by comparison with RBC dynamics. This will allow us to benchmark the model for the study of suspension flows, to identify the role of mechanics in the microcirculation.

Unsupervised anomaly detection provides a label-free approach to particle identification in liquid argon time projection chambers (LArTPCs), but conventional methods summarise each event as a scalar score that quantifies how anomalous it is without characterising the nature of the deviation. We train a convolutional β -VAE ($\beta = 0.5$) exclusively on proton wire-plane images from the LArIAT test beam and show that, without labels, its latent space organises unseen kaons and muons according to the physical mechanism of their deviation from a proton. Kaons, whose decays distort track topology, are displaced along the latent axis encoding track regularity; minimum-ionising muons are mainly displaced along the axis encoding charge density. Each species is anchored to the dimension encoding the property by which it most departs from the training distribution.

Impacts of gene mutations in sodium channel beta-subunits in atrial arrhythmogenesis—insights from computational modeling

Muneeba Nawaz ¹, Henggui Zhang¹

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Abstract

Rationale: A previous study has identified 4 genetic defects in the beta-subunit gene *SCN1B* (R85H, D153N) and *SCN2B* (R28W, R28Q) of the sodium channel from patients with atrial fibrillation. These gene mutations cause a loss of function of the sodium channel, resulting in a reduced sodium channel current (I_{Na}). However, the causal link between impaired I_{Na} arising from the *SCN1B* (R85H, D153N) and *SCN2B* (R28W, R28Q) gene mutations and atrial arrhythmogenesis is not completely elucidated yet.

Objectives: This study aimed to use multi-scale computational models of the human atrial tissue to study the functional effects of the *SCN1B* (R85H, D153N) and *SCN2B* (R28W, R28Q) gene mutations on atrial electrical excitation conduction and tissue vulnerability to arrhythmogenesis.

Methods: The formulations of I_{Na} for human atrial action potentials (APs) in the Colman et al. model were modified based on the experimental data from Watanabe et al. for wild-type and the mutations in the sodium channel beta-1 (*SCN1B*: R85H & D153N) and beta-2 (R28W & R28Q) subunits. The modified I_{Na} formulation was then incorporated into the single-cell, 1D, 2D, and 3D models of human atrial tissue to quantify the functional impact of the mutations on atrial action potential, conduction of excitation waves, vulnerability of tissue to re-entry, and the dynamical behaviours of re-entrant excitation waves. To characterize possible effects of high vagal tone in atrial arrhythmogenesis, the combined actions of the beta-subunit gene mutations of I_{Na} with the acetylcholine (ACh)-activated potassium channel current ($I_{K,ACh}$) were also investigated.

Results: At the single-cell level, the gene mutations of *SCN1B* (R85H, D153N) and *SCN2B* (R28W, R28Q) caused a marked reduction in the overshoot and the maximal upstroke velocity of the atrial APs, without noticeable effects on their durations (APDs). However, when the combined action of $I_{K,ACH}$ and any of the gene mutations occurred, a marked abbreviation of the atrial APD was observed, as well as the marked abbreviated effective refractory period (ERP) and the wavelength of the excitation waves (WL). Notably, APD and ERP abbreviations were enhanced in the presence of acetylcholine (ACh), with associated reductions in APD, ERP, and wavelength (WL). These effects were more pronounced in those of the *SCN1B* mutations as compared to those of the *SCN2B* mutations, leading to the loss of the rate-dependence of APD, ERP, and WL in the former mutation cases. Furthermore, results from the 1D model simulations show that the mutations caused the restitution curves for conduction velocity (CV) and excitation thresholds to shift leftward, demonstrating that the gene mutations facilitated the conduction of atrial excitation at fast excitation rates, which favoured the rapid excitation of atrial fibrillations. In 2D simulations, acetylcholine (1.0 μ M) promoted sustained re-entrant excitation waves in both wild-type and mutant tissues; however, re-entry was more stationary in mutant tissues, indicating enhanced arrhythmogenic stability. Consistently, 3D atrial simulations demonstrated that re-entrant activity was more persistent and spatially stable in the presence of *SCN1B* and *SCN2B* mutations, particularly under acetylcholine-mediated parasympathetic conditions.

Conclusions: Collectively, these simulation results showed pro-arrhythmogenic effects of the gene mutations of *SCN1B* (R85H, D153N) and *SCN2B* (R28W, R28Q), which can be further augmented by the active parasympathetic system.

Title (Times New Roman Bold, Size 12)

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Supervisor: Dr. Oznur Apsimon

Research Area: Accelerator Physics

Year of Study: 3

We investigate whether a compact RF cavity formed from the superposition of TE modes can provide useful transverse emittance compensation in a simple photoinjector beamline. A fixed 12GHz field-map cavity is implemented in OPAL using imported three-dimensional field maps, and its settings are varied using Bayesian optimisation over the amplitudes and rotations of the TE_{01} , TE_{21} , TE_{31} , and TE_{41} modes together with a global RF phase. Three independent Bayesian optimisation runs converge to the same sparse solution, with only TE_{31} retaining a finite amplitude. In the best case, the final projected normalised emittance objective is improved 12.6 %. Sensitivity scans in gun phase and solenoid current show that this improvement persists over a finite but bounded region. Our main outcome is a TE_{31} -dominated beam-dynamics working point.

Polarisation Sensitive Optical Coherence Tomography to Measure Biomarkers of Systemic Sclerosis

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Research Area: Photon Physics (Biomedical)

Year of Study: 2nd Year

Abstract (Max 200 words).

Optical Coherence Tomography (OCT) is a high resolution, cross-sectional, 3D imaging modality, capable of imaging the internal structure of biological tissues. It works by measuring the echo time delay of backscattered light from a sample, using the principles of low-coherence interferometry. Polarisation-Sensitive Optical Coherence Tomography (PS-OCT) is a functional extension of OCT, which incorporates a measurement of the polarisation state of the backscattered light. In biological tissue, one of its key components is collagen, a structural protein that makes up around a third of the human body. Collagen is naturally birefringent and modifies the polarisation of light as it passes through. This shift in polarisation is detectable with PS-OCT, allowing collagen to be contrasted against surrounding tissue. Systemic Sclerosis is a rare autoimmune condition, causing an increase in collagen in skin resulting in “scleroderma”, or hard skin. The extent of skin hardening has been shown to be a good predictor of disease progression, which can include serious life-threatening internal organ complications e.g. pulmonary fibrosis. This project is to investigate whether skin metrics (biomarkers), based on PS-OCT measurements, could be used to track skin changes over time in Systemic Sclerosis, which could be useful in evaluating the effectiveness of new treatments.

Illuminating UV-FIR spatial offsets in high-redshift galaxies with FIRE

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Research Area: Astrophysics

Year of Study: Final Year

Spatial offsets between rest-frame UV and dust continuum emission in high-redshift galaxies are among the most interesting results to emerge from high-spatial-resolution, multiwavelength observations, but their physical origin has remained elusive. We investigate the prevalence, evolution, and physical nature of UV-FIR spatial offsets in 26 galaxies from the FIRE high-redshift suite ($z=12-5$). FIRE naturally reproduces the range of offsets observed in high-redshift galaxies of comparable stellar masses and we find that both their prevalence and the median size increase with stellar mass. UV-FIR offsets arise either from intrinsic spatial separation between UV- and FIR-emitting regions or from spatial variations in dust attenuation, which produces apparent offsets between intrinsically co-spatial emission. A transition occurs at $\log(M^*/M_{\text{sun}}) \approx 8$. Below this mass, offsets are predominantly intrinsic, while above it, dust-obscuration-driven offsets start to become increasingly important, although intrinsic offsets persist. A cross-correlation analysis shows that intrinsic offsets lag recent star formation rates by ≈ 40 Myr, suggesting a stellar feedback-driven origin, while dust-obscuration offsets follow the build-up of dense cold gas. Finally, we compare with the REBELS and ALPINE surveys, showing that the infrared excess (IRX) traces the fractional contribution of dust-obscuration-driven offsets in massive galaxies, with larger IRX corresponding to a greater dust-obscuration contribution.

How Much Can I Forget and Still Be Right (Even if I Have a Quantum Computer)?

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Research Area: Quantum Information / Theoretical Physics

Year of Study: 4

In the clicks of a detector or the motion of a particle, correlations carry traces of the past. Reproducing them requires a model to carry information from one moment to the next. The least memory it needs offers a measure of the structure behind the observations. Can closer agreement with measurements tell us how much must be remembered? For any chosen observation window, we construct processes that match every record probability of one fixed, simple source, yet need arbitrarily more memory to reproduce their statistics exactly at all durations. Even quantum models, which can store information more economically, must preserve distinctions that longer observations gradually reveal. A model may account for the record in hand while leaving open how much memory is needed to carry on.

A Photonic Structure for a Colloidal Quantum Dot based Quantum Information Device

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Supervisor: Professor David Binks

Research Area: PhD Photon Physics

Year of Study: First Year

Colloidal quantum dots (CQDs) are promising platforms for quantum information technologies owing to their size-tunable band gaps, strong exchange interactions with dopants, and large optical cross-sections. Doping CQDs with individual atoms or ions also provides optically addressable spin manifolds suitable for photonic quantum information processing. Furthermore, integrating CQDs with photonic structures offers a route to further enhance their optical interaction with these spin states. Recent advances in the nano-positioning and integration of CQDs provide promising opportunities for the realization of solid-state quantum information devices. In this work, we present preliminary three-dimensional finite-difference time-domain (3D-FDTD) simulations of a photonic structure intended to enhance the optical cross-section of a doped CQD, providing an initial step towards the development of CQD-based quantum memory devices.

Multivalent ions as gatekeepers of monovalent transport in Ångström-scale channels

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Abstract

Ion channels control ionic conduction in nerve, muscle, and heart cells by opening or closing in response to changes in voltage, chemical messengers, mechanical stretch, temperature, and intracellular signals. Here we report ion gating in angstrom-scale channels made from van der Waals assembly of two-dimensional (2D) materials, where multivalent ions act as ligands that regulate nanochannel ionic conduction. Small additions of divalent (Mn^{2+} , Ca^{2+}) or trivalent (Al^{3+}) cations produce strong, polarity dependent conductance suppression/enhancement up to ~20 times. We study the dependence of the modulation of conductance on the nanochannel characteristics such as confinement level and surface charge, as well as its voltage dependence. The mechanism of ion-gating was investigated through experiments and continuum modelling where they reveal an entrance localized mechanism in which multivalent ion adsorption neutralizes or inverts the local surface charge, inducing rectification inversion. With divalent Mn^{2+} ions acting as a neurotransmitter analogue, angstrom-scale channels trigger threshold-driven spike-like voltage responses that yield an all-or-none ionic behaviour reminiscent of neuronal firing. Under constant current conditions, concentration-dependent voltage shifts also enable selective detection of multivalent ions.

This poster summarises the body of work put together for a qualification task within the ATLAS jet tagging combined performance group. A new machine learning algorithm has been proposed for the identification of large radius jets within the ATLAS detector that correspond to top-quarks. The presented studies assess the efficiency of the tagger across transverse momentum ranges and various simulations reflecting different data taking periods within the ATLAS detector. The performance of this new tagger is discussed for the $t\bar{t}b\bar{1}L$ decay channel, as well as for samples the tagger is trained on and background samples for the tagger to reject. Next steps for further investigation and plans for implementation of the tagger for ATLAS analyses are then briefly outlined.

Direct detection experiment data is typically interpreted in terms of a single non-relativistic effective theory (NREFT) operator - for instance, liquid argon detector data is historically interpreted only in terms of spin-independent dark matter interactions due to the zero nuclear spin of argon. However, in the NREFT framework multiple operators contribute. While the contribution of the canonical SD operator O_4 vanishes for argon, additional operators involving the dark matter spin remain non-zero. For sufficiently large target masses, the sum of these surviving contributions can be large enough to produce observable nuclear recoil signals.

We perform a scan over the NREFT parameter space, considering all isospin-conserving couplings of dark matter to protons and neutrons in liquid argon and liquid xenon. We then produce sensitivity projections for DarkSide-20k and LZ and show maximal enhancement and suppression arising from the additional NREFT operator contributions. The results demonstrate that, contrary to expectations, large liquid argon detectors such as DarkSide-20k can indeed probe SD dark matter models, highlighting the importance of operator-level analyses in future direct detection searches.

Experiments at the Large Hadron Collider (LHC) at CERN are undergoing a major transformation as they enter the High-Luminosity phase of the LHC, during which they are expected to produce substantially more data and therefore require advances in data-processing technologies.

Triggers are systems that process data from the detectors in real time to select events that are potentially interesting for a particular physics analysis while discarding the rest. These systems are being upgraded to process data at the expected higher rates. They employ sophisticated algorithms, including machine learning and statistical methods, to identify interesting events, while also requiring efficient data-processing architectures. The algorithms are deployed in low-level triggers, which use FPGAs and ASICs to process and select events with ultra-low latency, and high-level triggers (HLT), which use CPUs and GPUs to run more sophisticated algorithms. Optimizing such processes in the HLTs broadly requires three key aspects: efficient computation, reduced data movement between devices and CPUs, and improved data compression to transfer compressed states across different HLT subsystems.

Within the Next-Gen Triggers project at CERN, an initiative to develop the technologies required for the High-Luminosity phase of the LHC, we have been developing SOFIE, a tool that translates a trained machine learning model into self-contained C++ code that leverages the abstractions provided by the alpaka library to support inference on heterogeneous architectures. The generated code is performance-portable, hardware-agnostic, and highly optimized, while depending only on BLAS libraries.

The generated code incorporates several inference optimizations, including kernel fusion, efficient memory usage, and support for quantized models, enabling high-performance inference on modern CPU and accelerator platforms. Beyond standalone inference, SOFIE serves as a component in several projects. It powers Yukti, a header-only interface that provides a unified zero-copy API for machine learning inference runtimes, and can embed a hardware-agnostic, optimized compression and decompression pipeline for BOA Constrictor.

In this work, we present SOFIE and its capabilities, together with benchmarking results for several models primarily used in the HLTs of LHC experiments. We evaluate inference latency, memory footprint, and scalability across different hardware backends, highlighting the impact of SOFIE's code-generation and optimization strategies.

PGR Conference Poster

Name: Snehit Panghal

Title: Critical Unstable Qubits in the Bloch Sphere

Abstract:

We study in detail the dynamics of unstable two-level quantum systems by adopting the Bloch-vector representation. We identify a novel class of critical scenarios, named Critical Unstable Qubits (CUQs), whereby these unstable qubit systems exhibit atypical behaviours like coherence–decoherence oscillations and anharmonic oscillations under time evolution when analysed in an appropriately defined trace-preserving map of the density matrix of the system. In particular, we provide for the first time explicit geometric constructions to obtain trajectories of both pure and mixed CUQs in and on the Bloch sphere.

Monolayer MoS_2 Conduction Band: Spin orbit Splitting and Effective Parameters

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Supervisor: Vladimir Fal'ko

Research Area: Theoretical Physics

Year of Study: 3rd year

In transition metal dichalcogenides (TMDs) such as MoS_2 , spin-orbit coupling plays a key role in determining the electronic properties. This role lies in the splitting of electronic states into distinct energy levels, particularly at high-symmetry points such as the K-point. However, it was observed that the magnitude of the conduction band spin splitting obtained from the standard Density Functional Theory (DFT) data at this point (3 meV) is unexpectedly small compared with experimental measurements (8 meV), raising questions about the physical origin of the discrepancy. In this work, we analyse spin splitting within the framework of perturbation theory, considering first and second-order contributions arising from interband transitions. Our findings indicate that this splitting arises from the interaction of two interrelated and opposing effects. The first is a direct contribution from the Sulphur p orbitals, while the second is an indirect effect resulting from coupling with higher energy states of the metal d orbitals. Since these two effects act in opposite directions, the competition between their contributions leads to partial cancellation, which explains the small and sensitive nature of the spin splitting in this band. The resulting theoretical expression has been evaluated using both standard DFT and DFT+U+V (with on-site and inter-site Hubbard corrections) to compare electronic interactions. The results showed that while calculations based solely on standard DFT yield lower values than experimental measurements, the inclusion of DFT+U+V data readjusts the orbital hybridisation and the balance of contributions, thus improving the agreement with experimental values. This correction to the DFT results allowed for the extraction of effective spin-orbit coupling constants J_M (corresponding to the metal atoms) and J_{Ch} (corresponding to the chalcogen) through fitting. Overall, this work presents a comprehensive theoretical framework that enables an understanding of the spin-orbit coupling mechanism in MoS_2 .

References

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Modern AI systems often become more capable when they are trained to do multiple complementary tasks, rather than being trained only to produce one final singular. Language models such as ChatGPT, for example, learn many aspects of language at once, allowing skills learned for one purpose to support others. Inspired by this idea of multi-task learning, this work asks whether the same principle can help in particle physics: can a machine-learning model become better at identifying interesting collisions if we also teach it how those collisions are physically put together? I train machine learning models to filter out background events from signal events while also learning which detected particles are likely to belong to different parts of the underlying collision. Across the cases studied, this additional reconstruction task improves classification (determining if an event is signal or background) suggesting that teaching a model complementary information about the physics can help it organise the event more effectively and make better decisions.

Uncovering the Nature of Dyson Sphere Candidates

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Supervisor: Michael A. Garrett

Research Area: astrophysics, SETI

Year of Study: 4th year

Dyson Spheres are hypothetical extraterrestrial megastructures that could produce detectable infrared waste heat. In mid-2024, seven nearby M-dwarf stars were identified as Dyson Sphere candidates based on unusual WISE infrared excesses. Our work has investigated their nature using archival surveys and high-resolution radio observations with e-MERLIN and the European VLBI Network. We also participated in JWST observations of selected candidates. These studies revealed background galaxies associated with the candidate stars, notably infrared-bright hot, dust-obscured galaxies (hot DOGs), providing a natural astrophysical explanation for some of the apparent Dyson Sphere-like infrared excesses.

AC electro-osmosis in bacterial communities with fluorescence-based electrophysiology measurements using exogenous fluorophores

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Research Area: Biophysics

Year of Study: 4

Synthetic cationic fluorophores are widely used to measure membrane potentials in electrophysiology experiments and live/dead assays. We applied oscillating electric fields to *Escherichia coli* using microelectrodes and found that AC electro-osmosis (ACEO) generated fluorescence transients independent of bacterial electrophysiology, which could be mistaken for membrane depolarisation events. Fluorophores were transported within the microfluidic device by vortical flows, producing local concentration changes observed as fluorescence dips. These dips occurred with multiple cationic fluorophores, including thioflavin-T, propidium iodide, Syto9 and Sytox Green, both with and without *E. coli*. We further demonstrate that ACEO produces similar fluorescence transients within dense bacterial communities, highlighting a potential artefact in electrically stimulated fluorescence-based electrophysiology. Relaxation times depended on fluorophore and cellular environment, although dense communities did not significantly alter relaxation compared with single-cell experiments. Fluorescently labelled DNA and 30–100 nm colloidal particles were also transported by ACEO, demonstrating the mobility of charged molecules and nanoparticles within dense bacterial assemblies. To our knowledge, this is the first characterisation of ACEO in dense bacterial communities, highlighting both the need to account for electrokinetic effects and their potential use for enhancing molecular delivery.

Terahertz Active Dechirping for Energy-Spread Reduction in Laser-Plasma Electron Beams

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Supervisor: Rob Appleby

Research Area: Particle Accelerator Physics

Year of Study: year 1

Laser-plasma accelerators can generate compact, ultrashort electron bunches with very high accelerating gradients, but their relatively large energy spread remains a major limitation for downstream applications. Here we investigate terahertz (THz)-driven active dechirping as a method for improving the longitudinal beam quality and generating high quality bunches.

A magnetic chicane first stretches the electron bunch and introduces a correlation between particle position and energy. The bunch then interacts with a 0.4 THz-driven resonant structure, which applies an opposing energy modulation and reduces the correlated energy spread. Particle modelling show a reduction in relative energy spread from approximately 1.8% to 0.10% for the nominal bunch parameters. When shot-to-shot energy fluctuations are included, the THz system also improves the beam energy stability.

This work demonstrates the potential of THz-driven resonant structures as a compact tool for energy-spread reduction and longitudinal phase-space control in laser-plasma accelerator systems, opening the door to high-quality bunches.

Density Functional Theory for 2D Transition-Metal Dichalcogenides with Extended Hubbard Parameters

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Research Area: Theoretical Physics

Year of Study: 4

Accurate first-principles simulations are important for understanding the electronic and optoelectronic properties of transition metal dichalcogenides (TMDs), such as monolayer MoS₂. However, standard DFT has limitations in accurately describing some important band-edge properties. In this work, Hubbard corrections are applied to both metal orbitals (U) and metal–chalcogen interactions (V) to improve the description of the electronic structure. The U and V parameters are optimized by comparing the calculated results with available experimental data, especially the spin–orbit splitting. The optimized parameters improve the prediction of several important properties, including the band gap, spin–orbit splitting, effective masses, band-edge offsets, interlayer coupling, and ferroelectric potentials. For MoS₂, fitting U and V to the experimental spin–orbit splitting also improves the calculated band gap and ferroelectric potential. Overall, this approach provides an efficient and accurate method for modelling monolayer and multilayer TMDs and can be used for high-throughput calculations of 2D materials.