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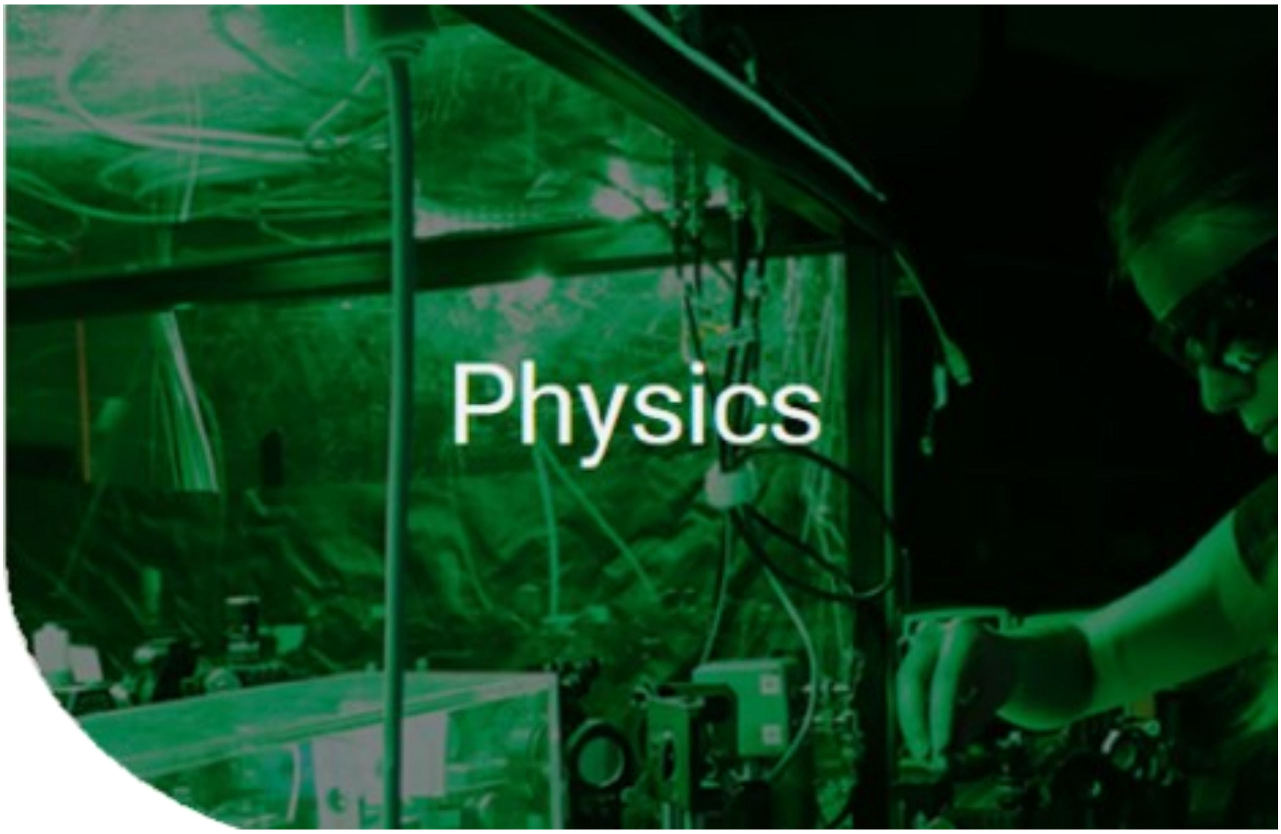
SMP Poster Day 2022
Abstract Booklet


Physics

CONTENTS

1. Another One Bites the Dust: Redshift Errors Cannot Explain the Hubble Tension

Candidate: ***Anthony Carr***

Advisors: *Prof Tamara Davis, AsPr Daniel Scolnic*

Abstract: In light of the ‘Hubble tension’ reaching the 5σ level between supernova and cosmic microwave background measurements of the universe’s expansion rate, cosmologists are exploring every avenue to find a resolution. The Pantheon+ and SH0ES joint supernova analysis is the latest and greatest advancement in supernova cosmology. To date, most effort has been spent on the absolute distance calibration, but a topic that receives much less attention is the redshifts. The redshift is a fundamental measurement of any astrophysical object, and it forms the link between physical distance and apparent brightness of a supernova. So, it pays to make sure our redshifts are accurate and precise. As one of the many facets of Pantheon+, we take a deep-dive into the redshifts used in supernova cosmology and comprehensively review and improve them. We showcase the main ways we improve the redshifts and peculiar velocities, paying particular attention to the crucial ‘low-redshift’ sample. Importantly, we show that redshift errors in the past would have contributed a maximum error of only ~0.1 km/s/Mpc to the Hubble constant.

2. Particle Detectors with Quantised Mass Energy

Candidate: ***Carolyn Wood***

Advisors: *Dr Magdalena Zych, Prof Andrew White*

Abstract: A two-level quantum system coupled to a field is a simple but powerful model of a particle interacting with an external environment, e.g., a field. The particle's internal energy can increase (decrease) at the expense of decreasing (increasing) field energy. For this reason, the model is called a ``particle detector'' as it registers exchange of quanta with the field. Research using this model has mostly used detectors on classical trajectories, where only their internal state is a quantum degree of freedom. However, this doesn't capture the most natural application of such a system: a low-energy quantum particle, e.g. an atom, interacting with a quantum field, e.g. light. For that scenario, the detector's centre of mass requires a quantum description. To that end, it has recently been described either as moving in superposition along classical trajectories, or dynamically evolving under a non-relativistic Hamiltonian.

Yet results in atomic physics show mass-energy equivalence plays a crucial role in energy and momentum conservation for atom-light interactions. Neither of the above detector models can capture this effect, as absorption or emission of field quanta must also change the detector's rest mass by an equivalent energy.

Here we address this problem and incorporate the quantisation of the detector's mass-energy into the particle detector model. We show internal energy changes due to emission/absorption persist even in the lowest energy limit. Specifically, corrections to transition rates due to the mass changes cannot be ignored unless the entirety of the centre of mass dynamics is also ignored. Our results imply that one cannot have a consistent model of a massive particle interacting with a relativistic quantum field without at the very least including relativistic mass-energy equivalence in the particle's dynamics.

3. Cosmic cable

Candidate: ***Colin MacLaurin***

Advisors: *Prof Timothy Ralph, Dr Fabio Costa*

Abstract: I examine the relativistic mechanics of a rigid cable in curved spacetime. Such ropes have been applied to black hole thermodynamics, and energy in an expanding universe. Spool one end, and attach it to a winch or turbine at fixed location. By allowing the cable to lower under its own weight (this depends on the spacetime), energy is harvested, which loosely speaking is converted from gravitational potential. We generalise the quasi-static case to a moving cable.

4. Fast characterisation of low-loss optical switching using machine learning

Candidate: ***Fatemeh Mohit***

Advisors: *Prof Andrew White, Dr Marcelo Pereira de Almeida, Dr Till Weinhold*

Abstract: Multiple, identical sources of single photons are necessary for large-scale photonic quantum computing. Temporal-to-spatial demultiplexing schemes can be used to achieve this. While low -loss, compact integrated waveguide devices offer a scalable solution to demultiplexing, they suffer from inefficiencies due to fabrication imperfections. The efficiency of such devices is dependent on the driving parameters of the switches (e.g. electronic pulse height and width). The manual optimisation of demultiplexer chips is time-consuming due to the large number of driving parameters. In this poster, we present work on applying a machine learning (ML) algorithm to optimise the driving parameters for up to 4 switches on a single chip, achieving a significant speed up in tuning while retaining optimal performance.

5. A New Dynamic Impurity Driven Model for 1-D Spincrossover Chains

Candidate: ***Finnian Rist***

Advisors: *Prof Benjamin Powell, Dr Henry Leonard Nourse*

Abstract: Spincrossover molecules are metal-organic complexes which exhibit a unique bistability – where the molecule has multiple stable spin-states that it can switch between. This makes these materials excellent candidates for molecular switches and experimental realizers for theoretical spin-chain predictions. We introduce a new mechanism through spin-orbit coupling which allows for spin-state switching and introduce a theoretical model which displays a rich phase diagram. We find a plethora of phases brought about by a new dynamic impurity scheme where spin-states are allowed to dynamically change between total spin.

6. Relativistic interacting particles with real trajectories

Candidate: ***Joshua Foo***

Advisors: *Prof Timothy Ralph, Dr Magdalena Zych*

Abstract: Bohmian mechanics is a nonlocal hidden-variable interpretation of quantum theory which predicts that particles follow deterministic trajectories in spacetime. Historically, the study of Bohmian trajectories has mainly been restricted to nonrelativistic regimes due to the widely held belief that the theory is incompatible with special relativity. Contrary to this belief, my collaborators and I recently developed a new approach for constructing the relativistic Bohmian-type velocity fiel**d** of single particles via weak measurements of the particle's momentum and energy. In this poster, I present an extension of our weak-value based relativistic Bohmian theory to include multiparticle interactions. I show that the Bohmian-type velocity fields of two photons constructed via weak measurements is entirely equivalent to that obtained from a manifestly Lorentz-covariant multitime, multiparticle Klein-Gordon theory. I specifically apply our formalism to a two-photon position-symmetrised state and calculate the resulting trajectories in the bunched interference pattern. In contrast with prior expectations, our results demonstrate that there is a consistent way of understanding multiparticle interactions in Bohmian mechanics alongside the tenets of special relativity.

7. Strain Engineering in Silicon Carbide Nanomechanical Resonators

Candidate: ***Leo Sementilli***

Advisors: *Prof Warwick Bowen, Dr Erick Romero Sanchez*

Abstract: Nanomechanical resonators are widely incorporated in sensing and computing technologies, as well as tests of fundamental science. Over the past few years, the performance of nanomechanical resonators has been pushed to unexplored limits through dissipation dilution and strain engineering. However, current experiments are nowhere near reaching the physical limit of dissipation dilution, which is set by the material yield strength. In this experiment we explore the limits of dissipation dilution using silicon carbide nano-strings. We develop a method to introduce tensile stress externally, allowing us to tune up to stresses near the yield strength limit of Silicon Carbide (21 GPa). This allows us to explore the trends and limits of dissipation dilution, as well as identify potential new regimes. These experiments seek to demonstrate the viability of silicon carbide as a material platform in optomechanical and spin-mechanical experiments.

8. Emergent Universal Drag Law in Superflow

Candidate: ***Maarten Christenhusz***

Advisors: Dr Tyler Neely, Dr Matthew Reeves, Dr Arghavan Safavi-Naini, Prof Halina Rubinsztein-Dunlop

Abstract: The presence of viscosity in classical fluids allows for energy dissipation and establishes drag due to viscous friction. In contrast, zero-temperature superfluids are known for their characteristic absence of viscosity. Despite this aspect, drag is indeed observed in superfluids and is due to energy dissipation facilitated by nucleation of vortices. Earlier works have shown the existence of a universal relation between the superfluid Reynolds and Strouhal number which is identical to that of a classical fluid. In this work, we characterize the drag behaviour of superfluids and establish the presence of another universal relation identical to the one of classical hydrodynamics: the relation between the Reynolds number and the drag coefficient.

9. Intrinsic, robust, and isolated flat bands present at half-filling in the minimal model of the superconducting metal-organic framework, Cu-BHT

Candidate: ***Miriam Ohlrich***

Advisors: *Prof Benjamin Powell, Dr Henry Leonard Nourse*

Abstract: Metal organic frameworks are a unique class of materials which have potential applications in carbon capture and storage. They can also be designed to have different lattice structures - something that is impossible in traditional solid-state materials. This is important because lattice structure has a huge impact on the properties of a material. A famous example of this is twisted bilayer graphene: graphene is a conductor, but when two graphene layers are twisted with respect to one another by 1.1 degrees, the material becomes a superconductor. This is linked to the appearance of a flat band at the Fermi energy. Flat bands systems are strongly correlated electron systems, which means that the Coulomb interactions determine the properties of the system. These systems display a wide range of properties, including metal-insulator transitions and high temperature superconductivity. Thus, the question is, can we design a metal-organic framework with flat

10. Benchmarking Generalized Hydrodynamics in a 1D Bose Gas

Candidate: ***Raymon Watson***

Advisors: *Prof Karen Kheruntsyan, Prof Matthew Davis, AsPr Ian McCulloch*

Abstract: Generalized hydrodynamics (GHD) is a recent theoretical approach, discovered in 2016, which provides a hydrodynamic description of integrable quantum and classical models. This powerful new theoretical tool, when applied to the Lieb-Liniger model of a one-dimensional (1D) Bose gas with contact interactions, accurately describes the large-scale dynamics across a wider range of particle number and interaction strength than any other prior approaches, in addition to describing dynamics not previously accessible. Yet, despite its success in recent comparison with experiment, there are only a handful of cases where GHD has been benchmarked against alternative theoretical methods. We directly benchmark GHD against the wide array of theoretical tools capable of simulating the 1D Bose gas in several paradigmatic out-of-equilibrium scenarios across the entire range of interaction strength, exploring the limits of its applicability.

11. Detecting Non-Markovian Noise in Superconducting Qubits

Candidate: ***Tyler Jones***

Advisors: AsPr Arkady Fedorov, Prof Thomas Stace

Abstract: Quantum processors today produce results which are heavily corrupted by noise, largely attributable to the inescapable coupling of a quantum system to its environment. Describing the behaviour of an 'open quantum system' is generally done with the Markovian assumption intact; essentially, that the environment has no memory of past events. This blinds many quantum characterisation protocols to the existence of non-Markovian noise. We demonstrate a method to detect and characterise non-Markovian noise by performing and analysing a series of measurements on a real superconducting quantum chip.

12. What does the motion of galaxies tell us about the model of gravity?

Candidate: ***Yan Lai***

Advisors: *Dr Cullan Howlett, Prof Tamara Davis*

Abstract: Around 20 years ago, scientists discovered that the universe is undergoing accelerating expansion. The source of this accelerating expansion is called dark energy and it is still a mystery. One possible solution to the dark energy problem is a modified theory of gravity. In this poster, we present an improved method to determine the correct model of gravity by constraining the growth rate of matter in the universe. We determine this growth rate using the motion of galaxies. Our improved method reduces the systematics of the modelling and accounts for the data systematics in our final uncertainty. Additionally, our method could produce the growth rate measurement more than 30 times faster than the traditional approach. This new method was applied to the current largest galaxy velocity catalogue and we found our result is consistent with the prediction from general relativity.

13. Constraining spin-orbit angles for exoplanets orbiting rapidly-rotating stars with a new model of gravity-darkening and oblateness in transit

Candidate: ***Shashank Dholakia***

Advisors: *Dr Benjamin Pope, Prof Tamara Davis*

Abstract: Main sequence stars with effective temperatures above the Kraft break (~6200K) tend to rotate rapidly, causing effects which break spherical symmetry of the star. The centrifugal forces from rapid rotation cause gravity darkening, where the equator is cooler and less luminous than the poles, and oblateness. Exoplanets that transit these stars often display asymmetries in the transit light curve which can be used to determine the spin-orbit angle of the system. We create an efficient, semi-analytic transit model that incorporates gravity darkening and oblateness in the code package 'starry'. The implementation is orders of magnitude faster and more precise than equivalent numerical methods and well-suited to posterior inference. We test the model on a TESS light curve of the exoplanet system WASP-33, whose host is a rapidly-rotating delta Scuti star. After subtracting the pulsations from the light curve, we find an asymmetric transit characteristic of gravity darkening of the host. We find the projected spin-orbit angle is consistent with previous Doppler tomography studies, and constrain the true spin-orbit angle of the system. This method is complementary to spectroscopic measurements that provide the projected spin-orbit angle and paves the way to simultaneously model spectroscopy and photometry of exoplanets and eclipsing binary systems with rapidly-rotating stars. Due to the rapid rotation and relative rarity of early-type stars, traditional measurement and confirmation techniques such as radial velocity are difficult. Consequently, little is known about such systems. This method will allow the expansion of study in this area; space based missions such as CHEOPS, TESS, and PLATO will observe transits for hundreds of A/F stars, many of which will be amenable to constraints using this method.

14. Confining sound in superfluids via optomechanics

Candidate: ***Raymond Harrison***

Advisors: *Dr Christopher Baker, Dr Andreas Sawadsky, Prof Warwick Bowen*

R.A. Harrison, W.W. Wasserman, G.I. Harris, A. Sawadsky, W.P. Bowen and C.G. Baker
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Abstract: Cavity optomechanics describes the coupling of light in an optical cavity with a mechanical degree of freedom. This coupling is generally limited to optical interactions (optical spring/ dynamical backaction) that perturb a pre-existing mechanical eigenmode. This mechanical perturbation is mainly driven by the radiation pressure or imparted momentum from the light onto the cavity it is confined to. Leveraging this interaction has allowed many significant advances in science, through the development of ultra sensitive sensors and the ability to use dynamical back action for heating and cooling [1].

While these interactions are very useful, here we go beyond this regime into a new paradigm where light fully defines new mechanical eigenmodes. We propose this though the use of silicon on insulator (SOI) photonic chips, which have been planarized to remove all geometric boundary conditions. This planarization allows us to use radiation pressure from light guided within the photonic chip to deform a thin layer of superfluid covering its surface. The radiation pressure here acts in the same way an optical tweezer operates [2]. Superfluid films are advantageous due to their extreme compliance (over 6 orders of magnitude softer than most solids), which allows even modest radiation pressure to deform them appreciably in a localised region. Using this mechanical compliance we can deform the superfluid using the evanescent field of an optical resonator. This localised region will follow the shape of the optical resonator and have a different speed of sound. This will result in an optically defined ring of superfluid that will act as an acoustic resonator, containing mechanical eigenmodes. This will present a new landscape with acoustic eigenmodes completely defined by the optical field. Building on our experience with superfluid optomechanics, we can use this to make fluidic circuits that allow the controlled interaction of phonons in this superfluid acoustic landscape for sensing applications [3] and for fundamental investigations of the properties of superfluid helium [4, 5]. I will be discussing progress towards this work including development of a cryogenic packaging system [6] that allows easier testing of superfluid optomechanical devices.

[1] M. Aspelmeyer, T. Kippenberg and F. Marquardt, Rev. Mod. Phys. 4 86 (2014)

[2] A. Ashkin, Phys. Rev. Lett. 24 156 (1970).

[3] Y. Sachkou, et al, Science 366 6472 (2019).

[4] G. Harris, et al, Nat. Phys. 12 8 (2016).

[5] Y. Sfendla, et al, npj Quantum Inf. 7 62 (2021).

[6] W. Wasserman, et al, arXiv:2205.14143 [physics.ins-det] (2022).

15. Experimental Observation of the Kelvin-Helmholtz Instability in a BEC

superfluid

Candidate: ***Simeon Simjanovski***

Advisors: *Dr Tyler Neely, Prof Halina Rubinsztein-Dunlop, Dr Guillaume Gauthier*

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Abstract: Bose-Einstein condensate (BEC) systems can be employed to study a variety of superfluid behaviour, including superfluid turbulence and transitions to turbulence. Classical fluid transitions to turbulence are governed by instabilities. Numerical simulations have predicted the possibility for BEC superfluid systems to support an analogue to a specific class of classical instabilities, the Kelvin-Helmholtz instabilities (KHIs) [1]. Classical KHIs are characterised by the rolling up of a velocity shear layer between two fluid streams flowing with different velocities [2]. In the BEC superfluid analogue, the shear layer manifests as a line of quantised vortices, and the roll up of this interface appears as a progressive clustering of these vortices over time. Additionally, the decy rate of the vortex layer under the KHI is predicted to only have linear dependence on the relative stream velocity, with no dependence on channel width [3]. Here, we experimentally verify these predictions using quasi-2D, single component BEC superfluid trapped in a ring geometry. The BECs stirred via an optical barrier whose motion is optimised through machine learning. Evidence of the KHI is indicated by a highly unstable vortex shear layer that rapidly decays within 30 ms. The observed dynamics suggest increased clustering of the vortices with time, indicated by a decrease in the total number of clusters present. This is indicative of progressive clustering characteristics observed in decaying classical 2D turbulence. Additionally, dependence on channel width was found for the decay rate, suggesting a drift instability is superimposed alongside the KHI.

[1] A. W. Baggaley and N. G. Parker. Kelvin-Helmholtz instability in a single-component atomic superfluid. Physical Review A 97(5) (2018).

[2] Paulo Philippi, Keijo Mattila, Luiz Hegele, and Diogo Siebert. Kinetic Projection and Stability in Lattice - Boltzmann Schemes. Aug 2015.

16. Dark matter detection via atomic interactions

Candidate: ***Ashlee Caddell***

Advisors: *Dr Benjamin Roberts, Dr Patrick Scott, Dr Jacinda Ginges*

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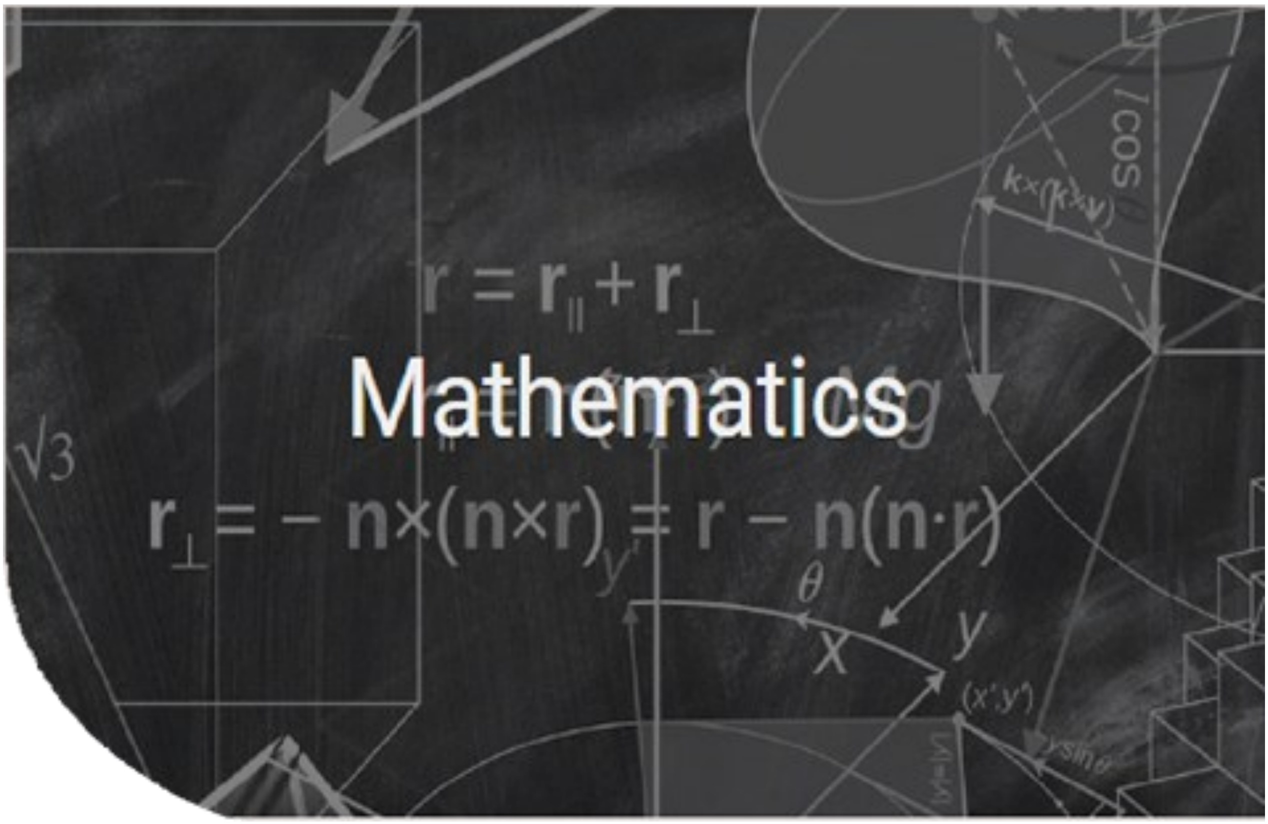
Abstract: The mystery of dark matter (DM) is a long-standing issue in physics, with numerous dedicated experiments returning no confirmed detections. With the constantly increasing sensitivity of direct detection experiments, much of the parameter space for Weakly Interacting Massive Particles (WIMPs) has been ruled out. However, low mass (sub-GeV) WIMP-like particles are less researched and yet to be excluded as a possibility, despite their potential for direct detection via atomic interactions. Due to these particles having masses comparable to or lower than nucleons, detection of any nuclear recoil in scintillation experiments proves difficult. Instead, a DM-electron interaction could be detected in conventional scintillators due to an enhanced scattering rate [1, 2]. Considering this possibility is important for assessing recent experimental results and upcoming scintillator-based DM searches. In this work, I will present atomic excitation factors and calculated event rates for DM-electron scattering, and how they can inform experimental searches.

[1] B. M. Roberts, V. V. Flambaum and G. F. Gribakin, Phys. Rev. Lett. 116, 023201 (2016).

[2] B. M. Roberts and V. V. Flambaum, Phys. Rev. D 100, 063017 (2019).



CONTENTS

17. An Algorithm for Recognising Handlebodies

Candidate: ***Alexander He***

Advisors: *Prof Benjamin Burton, AsPr Barbara Maenhaut*

Abstract: Roughly speaking, topology is about studying shapes up to stretching and squishing. One application is describing the shape of data, since we want such a description to be resistant to noise. In light of the potential applications, it would be nice to have better algorithmic tools for solving topological problems. This poster gives an illustrated overview of two recent developments: (1) a new algorithm for recognising an important family of objects called handlebodies; and (2) an application of this algorithm to answering a question in knot theory.

18. Computing Heegaard Genus of 3-Manifolds

Candidate: ***Finn Thompson***

Advisors: Prof Benjamin Burton, Dr Anna Puskas

Abstract: Topological invariants are critical to the classification and recognition of manifolds. One such invariant for 3-manifolds is the Heegaard genus, which is the minimal genus of a surface that splits a 3-manifold into two handlebodies. This is hard to determine theoretically, and little work has been done in developing an explicit and efficient algorithm. We aim to implement a theoretical algorithm of Hyam Rubinstein to find the Heegaard genus of a given 3-manifold, particularly for hyperbolic 3-manifolds. Here we present a heuristic which successfully calculates the genus of many such manifolds.

19. The Ghost Algebra

Candidate: ***Madeline Nurcombe***

Advisors: *Prof Jorgen Rasmussen, AsPr Jon Links*

Abstract: The Temperley-Lieb algebra has many diverse applications in mathematics, from physical models of polymers and percolation in statistical mechanics, to knot theory. It is also a diagram algebra; its basis elements can be expressed as string diagrams, which are multiplied by concatenation. The one-boundary Temperley-Lieb algebra is similar, but its basis diagrams have an additional boundary line that the strings may be connected to. There is also a two-boundary Temperley-Lieb algebra, with a second boundary, but its diagrams require an even number of strings connected to each boundary, and it is infinite-dimensional, unlike the zero- and one-boundary algebras. This poster introduces the ghost algebra, a finite-dimensional two-boundary version of the Temperley-Lieb algebra that allows diagrams with odd numbers of connections to each boundary. Its diagrams contain ghosts: dots on the boundaries that act as bookkeeping devices to ensure associativity of multiplication.

20. Simplifying 4-Manifold Triangulations

Candidate: ***Rhuaidi Burke***

Advisors: *Prof Benjamin Burton, Dr Ramiro Lafuente*

Abstract: Despite many problems being undecidable in 4-dimensional computational topology, heuristics which work for a large number of cases can often be used to tackle a variety of problems, and make software implementations possible. The feasibility of analysing the combinatorial structure of triangulations of manifolds often relies on having a sufficiently small triangulation to work with, and so having a tool which can efficiently simplify large triangulations is crucial. Currently available simplification heuristics are predominantly tailored towards 3-manifold triangulations or triangulations in the form of simplicial complexes. Here we present a new heuristic for simplifying 4-manifold triangulations, which has proven highly successful at simplifying large triangulations and in cases where other heuristics have been ineffective.

21. Dilaton Weyl multiplet of conformal supergravity

Candidate: ***Saurish Khandelwal***

Advisors: *Dr Gabriele Tartaglino Mazzucchelli , Prof Jorgen Rasmussen*

Abstract: Supersymmetry and supergravity have been one of the main research avenues of theoretical and mathematical physics over the past few decades. To efficiently study general supergravity-matter system by using superconformal techniques, a multiplet of conformal supergravity (Weyl multiplet) is required. There was only one known representation of the 4D, N=2 Weyl multiplet, the standard Weyl multiplet, until recently, when Butter et.al. found another such multiplet, the vector-Dilaton Weyl multiplet \cite{Butter:2017pbp}. We define a new Dilaton Weyl multiplet in our latest paper \cite{HDWM} and are further extending this construction for higher-dimensional conformal supergravity multiplet, namely 5D, N=1 and 6D, N=(1,0) [3]. These are computed by reinterpreting the equations of motion of an on-shell hypermultiplet as constraints that render some of the fields of the standard Weyl multiplet composite. The resulting "hyper-Dilaton Weyl" multiplet defines an off-shell representation of the local superconformal algebra. Coupling the hyper-Dilaton Weyl multiplet to an off-shell vector multiplet compensator leads to Poincaré supergravities. These new Weyl multiplets can be used to engineer new supersymmetry breaking mechanisms.

[1] D. Butter, S. Hegde, I. Lodato and B. Sahoo, “N = 2 dilaton Weyl multiplet in 4D supergravity,” JHEP 03,
154 (2018) [arXiv:1712.05365 [hep-th]].
[2] G. Gold, S. Khandelwal, W. Kitchin, and G. Tartaglino-Mazzucchelli, “Hyper-Dilaton Weyl Multiplet of 4D,
N = 2 conformal supergravity ,” JHEP 09, 016 (2022) [arXiv:2203.12203 [hep-th]].
[3] J. Hutomo, S. Khandelwal, G. Tartaglino-Mazzucchelli, J. Woods, “Hyper-Dilaton Weyl Multiplets

22. Cosmological Particle Production: A Functional Approach

Candidate: ***Gregory Gold***

Advisors: *Dr Gabriele Tartaglino Mazzucchelli*, *Dr Patrick Scott*

Abstract: To describe quantum particles in curved backgrounds, one may reasonably assume a unified theory of quantum gravity is required. However, if we take inspiration from the first attempts at quantum electrodynamics and limit the energy and length scales of interest so that gravity is approximately classical, as described by the Einstein's theory of general relativity, we may describe the behavior of quantum matter in gravity by a semiclassical field theory. This approximate description does indeed predict particle creation including:

Hawking Radiation: Black holes emit particles causing their decay. The black hole information paradox naturally follows from this result.

Cosmological Particle Production: Particle pairs are created in expanding spacetime backgrounds thereby having a back-reaction on the expansion itself. This has relevance in the large-scale structure of the universe and primordial black hole formation.

These results inspire ongoing developments in modern physics, and thus we describe here a novel way to calculate particle production in various backgrounds by the use of modern functional methods.