# 2018 UQ Summer Research Scholarship Program

## Research Projects
## offered by the
## School of Mathematics and Physics (SMP)

## How to apply:

The UQ Summer Research Program is offered by the School of Mathematics and Physics (SMP) and UQ Student Employability Centre during the Summer vacation period (mid November to late February). This document provides a list of available projects of interest to students undertaking mathematics, statistics and physics. It is open to undergraduate (including Honours) and masters by coursework students.

1. Browse the list of projects
2. Contact the supervisor in the area of your interest, or the contact person listed, to discuss your interest and eligibility to undertake their research project. Gain the research project supervisor's tentative approval, and include this with your full UQ Summer Research Program application
3. Include the supervisor's approval with your full UQ Summer Research Program application
4. Submit your application via StudentHub by closing date: **Friday, 31st August 2018**

**School of Mathematics and Physics**
**Summer Research Scholarship Program**
**2018 / 2019**

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| **Supervisor's name** | Professor Dirk P. Kroese |
| **Supervisor's contact details** | kroese@maths.uq.edu.au<br>https://people.smp.uq.edu.au/DirkKroese/ |
| **Number of student places available** | 4 |
| **Project title**<br><br>**SMP-18-SRP01** | **Mathematical and Statistical Methods for Data Science and Machine Learning** |
| **Project description** | I am currently writing a book with the same title as above, due for publication in July 2019. You will get the latest version of the book, and will help to "test-drive" the book. This could mean, carefully proofreading various sections, trying the exercises, testing the programs, checking links, finding new data sets, etc. The book will have around 500 pages and discusses topics such as supervised and unsupervised learning, Monte Carlo methods, regression, classification, support vector machines, kernels, tree methods, and deep learning. It requires background knowledge in linear algebra, functional analysis, optimization, and probability and statistics. This background knowledge is given in the appendices (as well as primers on Matlab and Python).<br>We will work from a shared dropbox directory, and have regular meetings (say two per week) to monitor your progress. |
| **Project duration** | 1 December – 30 January with break (8 weeks total). |
| **Expected outcomes** | Better understanding of the mathematical and statistical methods that underpin the algorithms in modern data science and machine learning. Improved skills in programming (Python, Matlab) and mathematical writing (LaTeX). |
| **Suitable for** | Students with excellent knowledge of third-year mathematics, probability, and statistics. Students with a grade of 7 for STAT3004 or STAT3001 are given preference. |
| **Other important details (if applicable)** | During the winter break I have had a group of mostly second-year students on a similar project, which proved very successful for everyone involved. This time I would like to go a bit further and ask assistance of students who have enough experience to go deeper into the theory. |

**School of Mathematics and Physics**
**Summer Research Scholarship Program**
**2018 / 2019**

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| **Supervisor's name** | Professor Matthew Davis |
| **Supervisor's contact details** | Physics Annexe 06-309<br>mdavis@physics.uq.edu.au |
| **Number of student places available** | 2 |
| **Project title**<br><br>**SMP-18-SRP02** | **Non-equilibrium superfluid flows** |
| **Project description** | The aim of this project is to make a connection between classical mechanics and quantum mechanics - looking for the signatures of classical trajectories in the quantum wave functions. This is potentially interesting for superfluids, as to some extent they behave as classical fluids. This would require adding the effects of particle interactions - an additional nonlinear term in the Schrodinger equation. |
| **Project duration** | 6 – 10 weeks |
| **Expected outcomes** | Scholars will learn how to solve the linear and nonlinear Schrodinger equation computationally with sources and sinks. The results may influence the UQ experimental program on Bose-Einstein condensates. |
| **Suitable for** | Self-motivated third-year physics students who are interested in pursuing research in theoretical and computational quantum physics. |
| **Other important details (if applicable)** | Please get in touch with Professor Davis before applying for this project. |

**School of Mathematics and Physics**
**Summer Research Scholarship Program**
**2018 / 2019**

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| **Supervisor's name** | Professor Matthew Davis / Professor Margaret Mayfield |
| **Supervisor's contact details** | Physics Annexe 06-309<br>mdavis@physics.uq.edu.au |
| **Number of student places available** | 2 |
| **Project title**<br><br>**SMP-18-SRP03** | **Statistical physics model of abundances and interactions in plant communities** |
| **Project description** | This project aims to use the methods of statistical physics to help understand the equilibrium and dynamics and of interacting plant communities with Prof Margie Mayfield in the School of Biological Sciences. Prof Mayfield's group has collected a significant amount of data on plant abundances, and shown that the data suggests that nonlinear interactions between the plants affect their seed production. We hope to gain a new understanding of this data using equilibrium models of statistical mechanics. See:<br><br>Higher-order interactions capture unexplained complexity in diverse communities<br>Margaret M. Mayfield & Daniel B. Stouffer<br>Nature Ecology & Evolution 1, Article number: 0062 (2017)<br>doi:10.1038/s41559-016-0062 |
| **Project duration** | 6 – 10 weeks |
| **Expected outcomes** | Hopefully we will show that physics methods can be used to help understand the interactions between plants in a community. |
| **Suitable for** | Self-motivated third year science students with strong quantitative skills who are interested in pursuing an interdisciplinary project covering theoretical physics and biology. |
| **Other important details (if applicable)** | Please get in touch with Professor Davis before applying for this project. |

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| **Supervisor's name** | Professor Matthew Davis |
| **Supervisor's contact details** | Physics Annexe 06-309<br>mdavis@physics.uq.edu.au |
| **Number of student places available** | 2 |
| **Project title**<br><br>**SMP-18-SRP04** | **Pairing phase of the attractive Bose gas** |
| **Project description** | In the 1970s there was speculation that the cause of superfluidity in helium-4 was not due to Bose-Einstein condensation, but a form of Cooper pairing between attractive bosons, similar to that which occurs for electrons in superconductors. More recent calculations for the homogeneous system suggest that the temperature for the pairing transition is higher than for BEC - but that both are preceded by the mechanical collapse of the gas. This collapse is however prevented in finite systems. This project will use the classical field method to determine whether a pairing phase is possible for degenerate Bose gas with attractive interactions, and compare the results to the predictions of the Hartree-Fock-Bogoliubov method. |
| **Project duration** | 6 – 10 weeks |
| **Expected outcomes** | The scholar will learn how to apply analytical and computational quantum-many body methods to Bose-Einstein condensates. The hope is to uncover a new possible phase of matter, and to describe how to observe it in the laboratory. |
| **Suitable for** | Self-motivated third-year physics students who are interested in pursuing research in theoretical and computational quantum physics. |
| **Other important details (if applicable)** | Please get in touch with Professor Davis before applying for this project. |

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| **Supervisor's name** | Professor Matthew Davis |
| **Supervisor's contact details** | Physics Annexe 06-309<br>mdavis@physics.uq.edu.au |
| **Number of student places available** | 2 |
| **Project title**<br><br>**SMP-18-SRP05** | **Superfluidity under a quench of interaction strength in a persistent current.** |
| **Project description** | One of the key insights of Landau was to derive a phenomenological formula for the critical velocity in a superfluid. In a Bose gas this is related to the speed of sound, which is directly related to the strength of repulsive interaction between particles. By making use of something known as a "Feshbach resonance" in the scattering properties of two atoms, it is experimentally possible to tune the strength of interactions in a Bose gas. This project will look at a ring system in which there exists a persistent current that if left undisturbed will never decay. However, if the interaction strength is sufficiently reduced, the speed of sound will decrease below the speed of the current and the superflow will break down. This project will characterize the non-equilibrium dynamics as the flow breaks down and thermalizes. It should be able to be related to the well-known "Kibble-Zurek" mechanism for phase transitions. |
| **Project duration** | 6 – 10 weeks |
| **Expected outcomes** | The scholar will learn how to apply computational methods to solve the nonlinear Schrodinger equation. A complete set of results with appropriate interpretation could be turned into a publication. |
| **Suitable for** | Self-motivated third-year physics students who are interested in pursuing research in theoretical and computational quantum physics. |
| **Other important details (if applicable)** | Please get in touch with Professor Davis before applying for this project. |

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| **Supervisor's name** | Professor Matthew Davis |
| **Supervisor's contact details** | Physics Annexe 06-309<br>mdavis@physics.uq.edu.au |
| **Number of student places available** | 2 |
| **Project title**<br><br>**SMP-18-SRP06** | **Interactions of polar core vortices in a ferromagnetic spin-1 Bose-Einstein condensate** |
| **Project description** | One of the features of superfluids is that they can only rotate via the formation of quantised vortices. Laboratory experiments with single component Bose-Einstein condensates can now create and manipulate single vortices at will, and these techniques have been used to study the properties of two-dimensional quantum turbulence.<br><br>This project will numerically study the properties of polar-core vortices in a spin-1 Bose-Einstein condensate – a superfluid that has three different components. The properties of vortices in this system are not well understood. This project will map out the energy of interaction of two polar core vortices as a function of distance, as well as the energy required to stretch the vortex core and determine if they can dissociate into free vortices. |
| **Project duration** | 6 – 10 weeks |
| **Expected outcomes** | The scholars will learn how to apply computational methods to find excited states of nonlinear Schrodinger equation with three components and spin-changing collisions. A complete set of results with appropriate interpretation could be turned into a publication. |
| **Suitable for** | Self-motivated third-year physics students who are interested in pursuing research in theoretical and computational quantum physics. |
| **Other important details (if applicable)** | Please get in touch with Professor Davis before applying for this project. |

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| **Supervisor's name** | Professor Ben Powell |
| **Supervisor's contact details** | powell@physics.uq.edu.au |
| **Number of student places available** | 2 |
| **Project title**<br><br>**SMP-18-SRP07** | **Can we engineer high-temperature superconductivity in metal-organic frameworks?** |
| **Project description** | Metal-organic frameworks are a class of materials that have enormous promise for applications ranging from carbon capture and storage to catalysis. They present unique possibilities for controlling their physical properties by making small changes to their chemistry. It has recently been discovered that some of these materials are metals. In this project you will use supercomputers to understand the metallic state and develop analytical theories to predict whether they superconduct and how to control the temperatures at which the superconductivity occurs. The ultimate goal is to learn how to make the superconductivity occur at the maximum possible temperature. |
| **Project duration** | 6-8 weeks |
| **Expected outcomes** | Skills in high-performance computing, model building for complex phenomena and advanced methods in quantum mechanics. |
| **Suitable for** | Strong physics background, no chemistry required. |
| **Other important details (if applicable)** | |

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| **Supervisor's name** | Professor Ben Powell |
| **Supervisor's contact details** | powell@physics.uq.edu.au |
| **Number of student places available** | 2 |
| **Project title**<br><br>**SMP-18-SRP08** | **The materials multiverse: spin-state ice** |
| **Project description** | I sometime pity particle physicists, who are limited to studying a single vacuum and its excitations, the particles of the standard model. For condensed-matter physicists, every new phase of matter brings a new "'vacuum." Remarkably, the low-energy excitations of these new vacua can be very different from the individual electrons, protons, and neutrons that constitute the material. The materials multiverse contains universes where the particle-like excitations carry only a fraction of the elementary electronic charge, are magnetic monopoles, or are fermions that are their own antiparticles. None of these properties have ever been observed in the particles found in free space. Often, emergent gauge fields accompany these "fractionalized" particles, just as electromagnetic gauge fields accompany charged particles.<br><br>We have recently discovered a new phase of matter, spin-state ice, that is predicted to show both fractionalised quasiparticles and an emergent gauge field. Furthermore, the spin-state ice has a remarkably simple theoretical description. In this project, you will study these materials theoretically and try to predict their properties. A range of methods from exact mathematical treatments through to models on supercomputers are possible, and can be selected to suit the interests and background of the student. |
| **Project duration** | 6-8 weeks |
| **Expected outcomes** | Skills in high-performance computing, Monte Carlo methods, model building for complex phenomena and advanced methods in statistical mechanics. |
| **Suitable for** | Strong physics or applied mathematics background. |
| **Other important details (if applicable)** | |

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| **Supervisor's name** | Dr Jacinda Ginges |
| **Supervisor's contact details** | j.ginges@uq.edu.au,<br>Physics Annexe, 06-330<br>Phone 3365 3413 |
| **Number of student places available** | 2 |
| **Project title**<br><br>**SMP-18-SRP09** | **Quantum electrodynamics and highly-charged ion clocks** |
| **Project description** | The definition of the unit for time — the second — is based on the ground-state hyperfine transition in cesium. Higher accuracy has been demonstrated in clocks based on optical transitions in neutral and near neutral atoms. An even greater gain may be achievable in optical transitions in highly-charged ions (HCI). As well as their appeal for metrology, HCI clocks offer a sensitive probe of possible new physics such as variation of fundamental constants. Realising HCI clocks is a challenge for experiment and theory. The optical transitions of interest are small on the scale of typical HCI binding energies, and highly accurate calculations — beyond the level currently achieved in neutral atoms — are required. The accurate account of quantum electrodynamic (QED) radiative corrections is particularly important. This project will involve the construction of a "radiative potential" — which allows one to take into account QED effects in complex many-electron atoms — that is suitable for use in highly-charged ions. |
| **Project duration** | 6-10 weeks |
| **Expected outcomes** | The scholars will use and develop analytical and numerical skills. The student can expect to learn some relativistic quantum mechanics and atomic many-body theory and gain some understanding of quantum electrodynamics. Successful completion of this project may lead to publication of a peer-reviewed paper. |
| **Suitable for** | This project is suitable for students in third and higher years. The student should have a solid background in quantum mechanics. |
| **Other important details (if applicable)** | Please contact Dr Ginges to discuss the project before applying, j.ginges@uq.edu.au |

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| **Supervisor's name** | Associate Professor Tim McIntyre, Chris James |
| **Supervisor's contact details** | t.mcintyre@uq.edu.au |
| **Number of student places available** | 2 |
| **Project title**<br><br>**SMP-18-SRP10** | **Investigation of time resolved post-shock radiative intensity in the X2 expansion tube** |
| **Project description** | The X2 expansion tube is a flow facility capable of replicating the conditions experienced by a spacecraft as it enters a planetary atmosphere. A test gas is heated and accelerated into the test section of the facility reaching speeds of around 10 km/s and temperatures up to 10,000 K. This project will examine the use of optical fibres to capture light from the flow as it passes along the length of the facility. The purpose is twofold. Firstly, time resolved measurements of the total intensity may be useful for determining the flow velocity of the test gas. Secondly, spectrally resolved measurements can provide information about the state of the gas before it reaches the test section. The scholar will develop and test a pilot system in the laboratory and evaluate its usefulness for capturing data. |
| **Project duration** | 8 weeks |
| **Expected outcomes** | The scholar will gain experience in working in an experimental laboratory developing an optical technique of general interest to the research group. The scholar can also expect to spend time assisting other researchers with their experimental measurements. |
| **Suitable for** | Students with a physics or engineering background. Some understanding of geometric optics and/or spectroscopy would be of benefit. |
| **Other important details (if applicable)** | |

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| **Supervisor's name** | Associate Professor Tim McIntyre, Chris James |
| **Supervisor's contact details** | t.mcintyre@uq.edu.au |
| **Number of student places available** | 2 |
| **Project title**<br><br>**SMP-18-SRP11** | **Investigation of time resolved aluminium contamination in the X2 expansion tube** |
| **Project description** | The X2 expansion tube is a flow facility capable of replicating the conditions experienced by a spacecraft as it enters a planetary atmosphere. A test gas is heated and accelerated into the test section of the facility reaching speeds of around 10 km/s and temperatures up to 10,000 K. As part of this process, aluminium foil is used as a thin diaphragm to separate two sections of the facility before the experiment. As the test gas passes through this diaphragm as it travels through the facility, the test flow always contains some aluminium contamination. Recent experiments using a high-speed camera and a spectrometer have shown that the aluminium contamination generally arrives in the final third of the experimental test time, is more concentrated in the bottom half of the test flow, and is also a visible radiator in the free-stream flow. The aim of this project is to design and test a simple but semi-permanent optical system using a photodetector so that aluminium contamination can be examined in a time-resolved manner for all X2 experiments. |
| **Project duration** | 8 weeks |
| **Expected outcomes** | The scholar will gain experience in working in an experimental laboratory developing an optical technique of general interest to the research group. The scholar can also expect to spend time assisting other researchers with their experimental measurements. |
| **Suitable for** | Students with a physics or engineering background. Some understanding of geometric optics and/or spectroscopy would be of benefit. |
| **Other important details (if applicable)** | |

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| **Supervisor's name** | Associate Professor Tim McIntyre |
| **Supervisor's contact details** | t.mcintyre@uq.edu.au |
| **Number of student places available** | 3 |
| **Project title**<br><br>**SMP-18-SRP12** | **Development of a second-year e-learning module for teaching surface waves and magnetohydrodynamics** |
| **Project description** | The second-year physics course, PHYS2055 *Introduction to Fields in Physics*, covers a wide range of topics all of which can be described using field equations. The course is supported by on-line material including text, images, videos and simulations ("Five Minute Physics"). This project involves developing new material for the course covering the module on surface waves and magnetohydrodynamics. The module is currently taught using two papers which are provided to students to read prior to lectures. We aim to replace this material with self-authored text, and supporting simulations, developed as part of this project. |
| **Project duration** | 8 weeks |
| **Expected outcomes** | The scholar will gain experience in developing teaching material including the use of newer on-line interactive approaches. |
| **Suitable for** | Students with a physics or engineering background with an interest in the scholarship of teaching and/or pursuing teaching as a career. Some programming experience would also be useful. |
| **Other important details (if applicable)** | |

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| **Supervisor's name** | Associate Professor Tim McIntyre |
| **Supervisor's contact details** | t.mcintyre@uq.edu.au |
| **Number of student places available** | 2 |
| **Project title**<br><br>**SMP-18-SRP13** | **Development of a second/third year undergraduate experiment on imaging using a spatial light modulator.** |
| **Project description** | A spatial light modulator (SLM) is an addressable array like a CCD camera array that can be used to control the phase or amplitude of a beam of light. When connected to a computer, an SLM acts like an external monitor so that a pattern displayed on the computer screen is also displayed on the SLM. A beam of light incident on the SLM is modulated (phase or intensity) according to the displayed pattern. The purpose of this project is to develop and test an undergraduate experiment that uses the SLM to perform measurements. |
| **Project duration** | 8 weeks |
| **Expected outcomes** | The scholar will gain experience in working with optical components. The eventual outcome of the project is the development of an experiment that can be incorporated into the laboratory component of an advanced physics course. |
| **Suitable for** | Students with a physics background with an interest in experimentation. |
| **Other important details (if applicable)** | |

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| **Supervisor's name** | Senior Lecturer Zoltan Neufeld |
| **Supervisor's contact details** | z.neufeld@uq.edu.au<br>0452413659<br>Building 69-710 |
| **Number of student places available** | 6 |
| **Project title**<br><br>**SMP-18-SRP14** | **Mathematical and computational modelling of tumour growth; and modelling the mechanics of multicellular systems** |
| **Project description** | Research projects are available in the area of cancer modelling and multicellular tissue mechanics. The projects involve computer simulations based on differential equations, stochastic models etc. It is suitable for students with background in a Quantitative Discipline such as Mathematics, Physics, Engineering and with interest in Mathematical and Computational modelling applied to cell biology and medicine. Previous background in biology is not a requirement for the projects. |
| **Project duration** | 8 weeks |
| **Expected outcomes** | The students will learn about mathematical modelling and computer simulations applied to biology. |
| **Suitable for** | It is suitable for scholars with background in a quantitative discipline such as Mathematics, Physics, and Engineering and with interest in Mathematical and Computational modelling applied to cell biology and medicine. Previous background in biology is not a requirement for the projects. |
| **Other important details (if applicable)** | |

**School of Mathematics and Physics**
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| **Supervisor's name** | Professor Geoffrey Goodhill |
| **Supervisor's contact details** | g.goodhill@uq.edu.au |
| **Number of student places available** | 2 |
| **Project title**<br><br>**SMP-18-SRP15** | **Computational neuroscience: decoding neural activity** |
| **Project description** | We aim to understand the computational principles by which stimuli in the world are represented by patterns of brain activity, and how these representations emerge during development. To do this we are recording the activity of hundreds to thousands of neurons simultaneously, at single-cell resolution, in the brain of the larval zebrafish. These data require the development of sophisticated mathematical/computational tools..You will join an interdisciplinary team working on these problems. |
| **Project duration** | 8-10 weeks |
| **Expected outcomes** | You will be exposed to an interdisciplinary environment ranging from experimental neuroscience to mathematical analysis. The main deliverables will be Matlab code implementing particular algorithms for analysing our data. |
| **Suitable for** | A strong background in mathematics and computer programming is required. Previous knowledge of biology is optional. |
| **Other important details (if applicable)** | |

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| **Supervisor's name** | Dr Vivien Challis and Associate Professor Anthony Roberts |
| **Supervisor's contact details** | vchallis@maths.uq.edu.au<br>apr@maths.uq.edu.au |
| **Number of student places available** | 1 |
| **Project title**<br><br>**SMP-18-SRP16** | **Finite element study of energy and stress in simple fracture** |
| **Project description** | In 1921, Griffith compared the energy released by a crack as it progresses with the energy required to break the bonds in the material. He suggested that a crack would progress only when it is energetically favourable. This started the field of fracture mechanics.<br><br>This project will investigate Griffith's failure criterion numerically. We will study the fracture of simple cracks under tension utilising a linear elasticity finite element code written in Matlab. We wish to learn more about how crack length and computational resolution affect the calculated stress and energy fields around the crack tip. |
| **Project duration** | 8 weeks |
| **Expected outcomes** | The student will gain an understanding of linear elasticity and simple fracture mechanics. They will further develop their existing Matlab skills to solve problems in solid mechanics. They will write a report detailing results of the project. |
| **Suitable for** | Students with experience in Matlab and an interest in computational algorithms and solid mechanics. |
| **Other important details (if applicable)** | |

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| **Supervisor's name** | Dr Vivien Challis |
| **Supervisor's contact details** | vchallis@maths.uq.edu.au |
| **Number of student places available** | 1 |
| **Project title**<br><br>**SMP-18-SRP17** | **Nonlinear optimisers for multiscale structural optimisation** |
| **Project description** | Structural optimisation is a difficult, computationally expensive optimisation problem with a large number of variables. In recent work designing multiscale structures, we have found that our optimisation codes sometimes give solutions that are obviously not optimal.<br><br>In this project, we will re-solve these difficult multiscale structural optimisation problems using a range of nonlinear optimisers. Our aim will be to find an optimisation algorithm that works well for the multiscale structural optimisation problems we wish to solve. |
| **Project duration** | 8 weeks |
| **Expected outcomes** | The student will extend their C++ programming and high performance computing skills. They will contribute to an existing C++ structural optimisation codebase. An exceptional study and report may lead to a publication. |
| **Suitable for** | Students with experience in scientific programming (C++ preferred) and an interest in computational algorithms. |
| **Other important details (if applicable)** | |

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| **Supervisor's name** | Dr Taras Plakhotnik |
| **Supervisor's contact details** | taras@physics.uq.edu.au |
| **Number of student places available** | 1 |
| **Project title**<br><br>**SMP-18-SRP18** | **Raman scattering by spheroids** |
| **Project description** | The aim of the project is to develop numerical methods for calculations of Raman scattering by small (but significantly larger than the wavelength of the exciting light) not spherical particles. |
| **Project duration** | 8 weeks |
| **Expected outcomes** | The student will gain and/or develop his/her knowledge and skills in the following areas -- classical electrodynamics, programing, numerical methods of solving PDE, special mathematical functions, application of Raman scattering to meteorology. |
| **Suitable for** | Basic knowledge of classical electrodynamics (Maxwell equations, level of *PHYS2055*), good mathematical skills (some knowledge about Bessel functions, spherical harmonics, spheroidal harmonics), and a reasonable level of programing skills (e.g. matlab). |
| **Other important details (if applicable)** | |

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| **Supervisor's name** | Dr Fred Roosta-Khorasani |
| **Supervisor's contact details** | fred.roosta@uq.edu.au |
| **Number of student places available** | 1 |
| **Project title**<br><br>**SMP-18-SRP19** | **Geometric aspects machine learning** |
| **Project description** | This project aims at studying the extensions of several machine models, e.g., deep learning, to non-Euclidean spaces such as graphs and manifolds. An aspect of this project involves understanding the properties, advantages and limitations of such extensions without regards to the underlying computational challenges. Another aspect involves designing algorithms that can be efficiently applied to such models. |
| **Project duration** | 8 weeks |
| **Expected outcomes** | N/A |
| **Suitable for** | Mathematics undergraduate/graduate students |
| **Other important details (if applicable)** | |

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| **Supervisor's name** | Dr Tyler Neely |
| **Supervisor's contact details** | 06-401 Physics Annex; t.neely@uq.edu.au; 0431999606 |
| **Number of student places available** | 1 |
| **Project title**<br><br>**SMP-18-SRP20** | **Optimising Spun-Up Superfluids with Machine Learning** |
| **Project description** | In the Bose-condensation lab at UQ ( http://bec.equs.org ), we cool small samples of gas to nearly absolute zero, resulting in Bose-Einstein condensates (BECs). One of the special properties of BECs is their superfluidity, meaning they have zero viscosity and can flow without frictional losses. The archetypical example of this property is known as a persistent current: superfluid flow inside a donut-shaped container (trap) will result in a circulating current that flows perpetually.<br><br>We are interested in creating rapidly-spinning BECs, for a variety of pure physics experiments and the applications of BECs to gyroscopic sensors. However, discovering an optimal method to stir and rotate the initially-stationary BEC involves walking through a large parameter space, potentially with little intuition --- exactly the sort of situation for which machine learning has proven an efficient tool.<br><br>The goal of this project will be to adapt the machine learning protocol M-LOOP (https://github.com/michaelhush/M-LOOP) to the UQ BEC apparatus. By letting the computer optimise the spinning protocol, we expect that higher BEC rotation rates may be achieved.<br><br>Some coding knowledge is a prerequisite for this experimental/computation project. In particular, familiarity with MATLAB and Python is desired. Additional C++ knowledge would be preferred. |
| **Project duration** | 10 weeks |
| **Expected outcomes** | Learning basic optics and laboratory skills; learning the basics of BEC physics; data processing/image analysis skills; computer programming skills. |
| **Suitable for** | Any student who has completed 1st year with some physics knowledge, and who also has some basic coding background (i.e. has completed a course with a computational component). |
| **Other important details (if applicable)** | Please contact Dr Tyler Neely above for additional inquiries, and to discuss the details of the project prior to applying. |

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| **Supervisor's name** | Dr Tyler Neely |
| **Supervisor's contact details** | 06-401 Physics Annex; t.neely@uq.edu.au; 0431999606 |
| **Number of student places available** | 1 |
| **Project title**<br><br>**SMP-18-SRP21** | **Art with Matter Waves: Artistic Media Moves into the Quantum Realm** |
| **Project description** | In the Bose-condensation lab at UQ ( http://bec.equs.org ), we cool small samples of gas to nearly absolute zero, resulting in Bose-Einstein condensates (BECs). In this state of matter, the strange quantum-nature of the atoms composing the BEC is manifest. In particular, the atoms in the BEC can no-longer be considered point-particles --- instead best described as a giant matter-wave. We have developed exquisite techniques to manipulate and sculpt our matter waves (some examples can be found at https://bec.equs.org/news/art-bec ). These examples represent an exciting opportunity for creative expression --- in the history of humanity, physical media have always belonged to the classical-physics world of our everyday experience. Here, a new medium governed by quantum mechanics is available for the first time. The aim of this unconventional research project is to understand what this means in the context of art and science to date. How does this compare to other examples of scientifically inspired/collaborative art? Can this be placed in that context and is it truly unique? What form can this take to best interact with and also inform the general public? The overall aim of this project is to develop a project brief for presenting to institutions such as the Queensland Museum. Clearly, there could be opportunity for continued involvement subsequent to the end of the Summer Research programme, as the project continues to develop. Broad backgrounds will be relevant to this project, as it will primarily involve scholarly research. A person with some background or deep interest in modern art would be preferred. Opportunities to interact/sculpt the BECs in the lab will be part of the project. Some knowledge of the MATLAB computing language would be desirable. |
| **Project duration** | 8 weeks |
| **Expected outcomes** | Learning the basics of BEC physics, developing skills in scholarly research, basic coding and data analysis, laboratory skills (if relevant). |
| **Suitable for** | Any student, preferably with an interest/background in modern art, and some exposure to science coursework. |
| **Other important details (if applicable)** | Please contact Dr Tyler Neely above for additional inquiries, and to discuss the details of the project prior to applying. |

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| **Supervisor's name** | Dr Ian McCulloch |
| **Supervisor's contact details** | ianmcc@physics.uq.edu.au |
| **Number of student places available** | 1 |
| **Project title**<br><br>**SMP-18-SRP22** | **Tensor network representations of classical transfer matrices** |
| **Project description** | There is an exact mapping between quantum models in *d* dimensions and classical models in dimension *d*+1. This transformation is effected via the transfer matrix formalism, and has a form of a tensor network. The aim of this project is to implement a numerical scheme for obtaining the transfer matrix for 2-dimensional classical models, building upon existing tools for 1d quantum wave functions. |
| **Project duration** | Up to 8 weeks |
| **Expected outcomes** | An understanding of classical models in statistical mechanics, 1d quantum systems, and transfer matrix methods. Programming skills in c++ and/or Python. Linear algebra techniques for large-scale eigenvalue problems. |
| **Suitable for** | Good background in statistical mechanics and quantum mechanics. Some programming experience. Some existing knowledge of tensor networks is advantageous. |
| **Other important details (if applicable)** | |

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| **Supervisor's name** | Professor Ross McKenzie |
| **Supervisor's contact details** | r.mckenzie@uq.edu.au |
| **Number of student places available** | 1 |
| **Project title**<br><br>**SMP-18-SRP23** | **Theoretical Condensed Matter Physics** |
| **Project description** | Interesting new materials have unusual properties arising from strong interactions between electrons in the material. This project will consider some simple models to explain the competition between different phases: magnetic, superconducting, metallic, and insulating. |
| **Project duration** | 8 weeks |
| **Expected outcomes** | |
| **Suitable for** | A strong interest and motivation to learn new material. Solid mathematical and physical reasoning skills essential. |
| **Other important details (if applicable)** | |

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| **Supervisor's name** | Dr Mark Baker |
| **Supervisor's contact details** | m.baker@physics.uq.edu.au |
| **Number of student places available** | 2 |
| **Project title**<br>**SMP-18-SRP24** | **Magnetometry of ultra-cold atom gases using optical Faraday effect at magic wavelengths** |
| **Project description** | The Faraday effect is a magneto-optical phenomenon; the rotation of the polarization of light as it passes through a medium. In addition to being a measure of the density of the medium, the polarization rotation is additionally sensitive to magnetic fields, and so this technique can be used to probe the local magnetic field on a sample. In our experiment we cool dilute clouds of rubidium (Rb) down to ultra-cold temperatures (<100 nK) using laser cooling and magnetic trapping techniques, resulting in a quantum state of matter called a Bose-Einstein condensate (BEC). For many experiments where want exacting control over the magnetic properties of our BEC, it is critical to reduce and control the background magnetic field to extremely low levels (< milliGauss). One method is to use the atoms themselves as a probe for the magnetic field, through the Faraday effect.<br>The Rb atoms have strong optical transitions at the D1 (795 nm) and D2 (780 nm) lines. Typically, the Faraday effect is strongest in close proximity to these lines, but light at these wavelengths has the disadvantage of causing unwanted scattering of photons, which heats the atoms where they are then lost from the trap. Also, the light itself creates a strong electric field gradient, which creates an additional unwanted potential on the atoms. At so-called magic wavelengths (790 nm for Rb) between the two lines, the unwanted scattering is greatly reduced, and the electric field contributions of the light cancel. This means that the light at these wavelengths can be used to continuously probe the cloud of atoms and measure the magnetic field without disturbing the trapping or the temperature of our atoms. |
| **Project duration** | 8 weeks |
| **Expected outcomes** | In this project, we will setup and stabilise a laser system at 790 nm, at these magic wavelengths. We will initially observe the Faraday effect on a vapour cell of Rubidium, and try to extract both the DC and AC magnetic field noise by looking at the polarization rotation. If there is time, we will then apply it to our cold atom samples, and observe the effect on our BEC. This project will give the student exposure to concepts in atomic physics, laser systems, magnetic fields, and data acquisition and signal extraction techniques. |
| **Suitable for** | This project is open to applications from UQ enrolled students with a background/major in physics. Some experience with MATLAB/Mathematica/Labview would be advantageous. |
| **Other important details (if applicable)** | |

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| **Supervisor's name** | Dr Mark Baker |
| **Supervisor's contact details** | m.baker@physics.uq.edu.au |
| **Number of student places available** | 1 or 2 |
| **Project title**<br><br>**SMP-18-SRP25** | **Magnetic field stabilization of ultracold atoms using FPGA devices** |
| **Project description** | In our laboratory, our research interest is in understanding the spin and magnetic properties of dilute gases of trapped ultra-cold atoms cooled to nanoKelvin temperatures. Many of the subtle effects we expect to observe, such as transitions between magnetic ordering (eg ferromagnetism), and excitations and vortices in the spin degree of freedom, require careful control and removal of stray background magnetic fields in order to be observed. To this end, we would like to build a magnetic field stabilization system that actively corrects the background field experienced by our trapped cold atoms. The heart of this system will be to use Field Programmable Gate Arrays (FPGA), which are powerful programmable and configurable logic devices. Using fluxgate magnetic probes to measure the field, the FPGA will use appropriate feedback control to minimise and correct for stray DC and AC magnetic fields, applied through controlling the current in biasing coils. |
| **Project duration** | 8 weeks |
| **Expected outcomes** | In this project, we will construct an electronic device that couples the signal from magnetic fluxgate sensors into a programmable FPGA device. The student will gain experience in feedback control, electronic design, coil construction, and programming of FPGA devices. Initially we will build a demonstration test system, before trying to implement on our experimental apparatus. |
| **Suitable for** | This project is open to applications from UQ enrolled students with a background/major in physics. Some experience with electronics would be advantageous. |
| **Other important details (if applicable)** | |

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| **Supervisor's name** | Dr Mark Baker |
| **Supervisor's contact details** | m.baker@physics.uq.edu.au |
| **Number of student places available** | 1 |
| **Project title**<br><br>**SMP-18-SRP26** | **Construction of a "two colour" extended cavity diode laser with modulation sidebands** |
| **Project description** | In our laboratory, we use extended cavity diode lasers (ECDL) at 780 nm for our laser cooling of rubidium. Typically, we require two separate lasers at two separate but closely spaced wavelengths at (the cooling and repumping transitions), separated by a frequency difference of 6.8 GHz. Rather than using two separate lasers, however, a possible solution is to use one single laser, but modulate the current through the diode at 6.8 GHz. This produces sidebands in the optical modes, corresponding to the other laser frequency we desire, greatly simplify the required hardware. The optical power in the sidebands can be controlled by the amplitude of the modulation. In this project, the student will design and construct a new ECDL system, which uses a piezo-controlled diffraction grating (the extended cavity) to frequency stabilize the laser diode at the desired wavelength. The design will also incorporate an additional high frequency connection, allowing modulation at the high frequency of 6.8 GHz. It will then be used to simultaneously observe lasing on both the cooling and repumping transitions, in a vapour cell of rubidium, and then coupled to the experimental system. |
| **Project duration** | 8 weeks |
| **Expected outcomes** | This project will introduce the student to laser design and construction, atomic spectroscopy, electronic design and feedback control theory. |
| **Suitable for** | This project is open to applications from UQ enrolled students with a background/major in physics. Some experience with electronics would be advantageous. |
| **Other important details (if applicable)** | |

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| **Supervisor's name** | Professor Warwick Bowen |
| **Supervisor's contact details** | w.bowen@uq.edu.au |
| **Number of student places available** | 1 |
| **Project title**<br><br>**SMP-18-SRP27** | **Nonlinear fluid dynamics in a quantum liquid** |
| **Project description** | This project will investigate fluid dynamics in superfluid helium, a fluid with esoteric quantum properties including flow without dissipation and quantised vortices. The project will experimentally test the idea that nonlinear interactions are required to understand the fluid dynamics and lead to interesting phenomena such as solitons. |
| **Project duration** | 8 weeks |
| **Expected outcomes** | The scholar will gain skills in Nanophotonic experiments, analysing the data they produce and in simulation of nonlinear dynamics. |
| **Suitable for** | Experience in laboratory based physics and matlab is essential. |
| **Other important details (if applicable)** | N/A |