2018 UQ Winter Research Scholarship Program

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

How to apply:

The UQ Winter Research Program is offered by the School of Mathematics and Physics (SMP) and UQ Student Employability Centre during the winter vacation period (late June to late July). 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 Winter Research Program application.

(3) Submit your application via StudentHub by closing date: **11.59pm, Tuesday 3 April 2018**.

UQ Winter Research Project Description

Project title: **SMP-WRP01-18**	**Deep learning enhanced tracking of biological targets**
Project duration:	6 weeks
Description:	At sub-cellular scale, biological systems seethe with motion, from the motor molecules that transport nutrients along microtubules to neurotransmitter receptors the motion of which is important for neural plasticity. Measurements that track the motion of biological targets over time are crucial, and widely used to understand these important processes. However, the clutter of organelles and other components in a biological specimen often make it challenging to effectively and accurately track targets. This project will employ deep learning approaches to train a neural network to distinguish the target from the clutter, and therefore improve our ability to track biological dynamics.
Expected outcomes and deliverables:	The scholar should expect to learn about machine learning and artificial intelligence. Most specifically, how to apply deep learning algorithms to train a neural network to out-perform conventional methods of imaging analysis. The scholar should, further, expect to learn the state-of-the-art in approaches to track biological targets. Should the project be successful, it may result in a peer-reviewed publication.
Suitable for:	This project is open to second, third or fourth year students with a background in physics and with a solid foundation of programming in Matlab.
Primary Supervisor:	Professor Warwick Bowen
Further info:	Applicants should register their interest to Prof Bowen to applying - w.bowen@uq.edu.au

UQ Winter Research Project Description

Project title: **SMP-WRP02-18**	**Smart Microscopy**
Project duration:	6 weeks
Description:	Laser scanning microscopes are widely used in the biological and medical sciences. The need for high specificity, contrast and resolution often leads to long acquisition times, frequently precluding video rate imaging. This project will use deep learning techniques to improve the frame rate of laser scanning microscopes. The key idea is to train an artificial neural network to identify regions of interest within a biological specimen, as information is extracted from the microscope. The trajectory of the scan can then be adapted in real-time to focus the attention of the microscope on these regions of central interest. We expect this technique to allow order-of-magnitude level frame rate improvements for some microscopy techniques.
Expected outcomes and deliverables:	The scholar should expect to learn about machine learning and artificial intelligence. Most specifically, how to apply deep learning algorithms to train a neural network to out-perform conventional methods of imaging analysis. The scholar should, further, expect to learn the state-of-the-art in laser microscopy. Should the project be successful, it may result in a peer-reviewed publication.
Suitable for:	This project is open to second, third or fourth year students with a background in physics and with a solid foundation of programming in Matlab.
Primary Supervisor:	Professor Warwick Bowen
Further info:	Applicants should register their interest to Prof Bowen to applying - w.bowen@uq.edu.au

UQ Winter Research Project Description

Project title: **SMP-WRP03-18**	**Markov modulated Contact Processes**
Project duration:	6 weeks
Description:	A Contact process is continuous time Markov process, which can be interpreted as a model for the spread of an infection. The basic (one-dimensional) contact process is considered to be the simplest such case, this project will start off with the student gathering theorems and their proofs (filling in any gaps) to grasp an understanding of the model. It will then be extended to a Markov modulated Contact process, with the aim to understand how characteristics change where the rates of the spread of infection vary according to a Markov process.
Expected outcomes and deliverables:	The student will study one of the most interesting types of stochastic process that is not covered in the usual undergraduate curriculum: the contact process. The extension of key results to a Markov modulated environment may lead to publishable work. At the conclusion of the project, a project report typeset in LaTeX is expected.
Suitable for:	This project is open to applications from students with a background in probability and stochastic processes at the third-year level or higher.
Primary Supervisor:	Dr Thomas Taimre
Further info:	Dr Thomas Taimre - t.taimre@uq.edu.au

UQ Winter Research Project Description

Project title: **SMP-WRP04-18**	**Nonequilibrium superfluid flows**
Project duration:	4 – 8 weeks
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.
Expected outcomes and deliverables:	Students 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.
Primary Supervisor:	Professor Matthew Davis - mdavis@physics.uq.edu.au
Further info:	Please get in touch with Professor Davis before applying for this project.

UQ Winter Research Project Description

Project title: **SMP-WRP05-18**	**Pairing phase of the attractive Bose gas**
Project duration:	4 – 8 weeks
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 Copper 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.
Expected outcomes and deliverables:	The student 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.
Primary Supervisor:	Professor Matthew Davis - mdavis@physics.uq.edu.au
Further info:	Please get in touch with Professor Davis before applying for this project.

UQ Winter Research Project Description

Project title: **SMP-WRP06-18**	**Superfluidity under a quench of interaction strength in a persistent current**
Project duration:	4 – 8 weeks
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.
Expected outcomes and deliverables:	The student 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.
Primary Supervisor:	Professor Matthew Davis - mdavis@physics.uq.edu.au
Further info:	Please get in touch with Professor Davis before applying for this project.

UQ Winter Research Project Description

Project title: **SMP-WRP07-18**	**Tensor Network Methods for Quantum Many-Body Systems**
Project duration:	6 weeks
Description:	Tensor Networks provide a representation of a quantum many-body wave-function (or a classical partition function) that is suitable for computational methods, mainly for low-dimensional problems (1D and 2D). The most mature branch of tensor networks is known as Matrix Product States (MPS), often called DMRG. These days this is the widely used method to solve 1-dimensional quantum many-body problems. At UQ, we have developed the Matrix Product Toolkit, which is a comprehensive software toolkit for many kinds of MPS-based computations, including ground-states, real-time dynamics, and thermal and dissipative states. This winter project will involve learning how MPS methods work, and either developing some code from scratch or trying some physics simulations using the existing Matrix Product Toolkit.
Expected outcomes and deliverables:	Students will gain an understanding of how computational methods are used in quantum science, and in particular, how tensor networks are used to represent many-body wave functions. The student will perform some computational simulations and understand how the numerical algorithms work.
Suitable for:	Good background in quantum mechanics and computing.
Primary Supervisor:	Dr Ian McCulloch - ianmcc@physics.uq.edu.edu
Further info:	For further information see - https://people.smp.uq.edu.au/IanMcCulloch/mptoolkit/

UQ Summer or Winter Research Project Description

Project title: **SMP-WRP08-18**	**Finite element study of energy and stress in simple fracture**
Project duration:	6 weeks
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 will progress only when it is energetically favourable. This started the field of fracture mechanics. 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.
Expected outcomes and deliverables:	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. The student will be expected to write a report detailing project results.
Suitable for:	Students with experience in Matlab and an interest in computational algorithms and solid mechanics.
Primary Supervisor:	Associate Professor Anthony Roberts
Further info:	Dr Vivien Challis will also supervise this project. Please contact the project supervisors (apr@maths.uq.edu.au and vchallis@maths.uq.edu.au) before applying for this project.

UQ Summer or Winter Research Project Description

Project title: **SMP-WRP09-18**	**Quantum electrodynamics and highly-charged ion clocks**
Project duration:	6 weeks
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. Realizing 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 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.
Expected outcomes and deliverables:	The student will use and develop analytical and numerical (programming) skills. The student can expect to learn some relativistic atomic theory and gain a basic 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.
Primary Supervisor:	Dr Jacinda Ginges
Further info:	j.ginges@uq.edu.au . Please contact Dr. Ginges to discuss this project in more detail before applying.