PHYSICS

Academic Researcher:	Dr Ben Fulcher
Project Title:	**Algorithmic principles of navigating the brain using nanorobots**
Project Summary:	Over the past several years, high-throughput neuroscience methods have yielded comprehensive cellular maps of the entire brain. These data have revealed features, like distinctive marker cells and low-dimensional molecular patterns, that could be exploited by nanoscale devices to enable efficient navigation. At the same time, nanoscale sensing devices, such as those fabricated using DNA origami, are becoming increasingly sophisticated in their ability to perform useful computations. Accurate nanoscale navigation would enable transformative new treatments of brain diseases and cognitive therapies via targeted drug delivery.
Project Synopsis:	In this project, we will perform new physics-based characterizations of molecular patterning in the brain, and use physical simulations to investigate how nanoscale sensing rules can efficiently navigate to a given target location in the brain. The student will work with whole-brain neuroscience datasets, and use methods from statistical learning and physics to develop optimal sensing rules required for accurate and efficient brain navigation. This project is supported by a diverse team as part of the School of Physics Grand Challenge in Nanoscale Brain Navigation.
Additional Information:	Excellent facilities are available to carry out all aspects of the work, including access to computing resources, cellular brain maps, and, where required, a diverse supporting team ranging from Engineering, Neurobiology, and Chemistry. The student should have a strong interest in mathematical modeling (with a quantitative background in e.g., physics, mathematics, statistics, engineering, or computer science) and enjoy working as part of a vibrant interdisciplinary team. Top-up funding is available for the highest quality of applicants, with additional funding available to support travel to present research results at national and international conferences and to visit collaborators.

Academic Researcher:	Professor Anita Ho-Baillie
Project Title:	**Accelerating perovskite solar cells for the real world**
Project Summary:	Hydrogen is an extremely important industrial chemical but is also a clean fuel or as an energy carrier whether in the form of liquid hydrogen or liquid ammonia replacing carbon-containing fuels thereby reducing CO2 emission. The concept of using H2 as an energy carrier has generated immense research and development activities as well as investment opportunities to promote the use of and the import of zero-emission hydrogen causing a resurgence of hydrogen economy. Cleary, carbon-free production of H2 (without the use of carbon-containing feedstock or the release of carbon-containing gas) is most desirable.

Project Synopsis:	The direct solar-to-hydrogen conversion via solar power electrolysis or photoelectrochemical (PEC) water splitting is a clean route for synthesizing high purity H2. The "storing" of solar energy in H2 also solves the problem of solar intermittency problem. In addition, stored solar energy is made "mobile" where liquid H2 or NH3 can be shipped from one geographical location to another. For practical application, high solar-to-hydrogen (STH) conversion efficiency is required motivating research into i) low cost and high performance photovoltaic tandem devices and ii) the use of tunnelling for the solid-liquid junction for efficient electron to ion transfer.

Academic Researcher:	[Professor Anita Ho-Baillie]
Project Title:	**The power of perovskites**
Project Summary:	Metal halide perovskites have attracted global research attention in the last decade. While their application for solar is promising being the fastest advancing PV technology with many start-ups commercialising the technology now, have we fully capitalised on the enabling properties of metal halide perovskites for other high-performance optoelectronics devices that have different cost structure and stability requirements? Join Anita Ho-Baillie's group and explore the use of this material for IR LED's, UV LED's, nanowire lasers, memristors useful for telecommunications, sterilization, on-chip devices and neural networks. The new science and new applications that will be explored and demonstrated will provide students with exciting opportunities to tackle challenging problems creating new inventions.
Project Synopsis:	Multiple projects will allow students to develop new sub-classes of metal halide perovskites such as layered perovskites, double perovskites and lead-free counterparts for engineering key properties such as binding energy, photo-responsibility, and for functionalizing material system. The goal is to improve performance and stability of perovskite optoelectronic devices exceed those of the state of the art. The relationship between dimensionality, properties and performance will also be explored.

Academic Researcher:	[Professor Anita Ho-Baillie]
Project Title:	**Accelerating Hydrogen Economy**
Project Summary:	While perovskite solar cells have been the fastest advancing PV technology, what else is needed to accelerate the deployment of this technology in the real world? Can more be “squeezed” out of the sun? Why do demonstrated modules have much lower efficiencies than world record cells on sub-millimetre size? Can perovskite solar cell last long? How long? What will be the most cost-effective method for manufacturing on large scale? Can we make solar cell cool when they are design integrated? Join Anita Ho-Baillie's group working with industry partners to accelerate the progress of perovskite solar cell technology providing students with exciting opportunities creating new inventions for clean energy technology.

Project Synopsis:	Multiple projects will be available for answering questions above. In particular, perovskite tandem solar cells with much higher efficiency potential are promising undergoing rapid performance improvement in only 5 years surpassing the efficiency record of single junction solar cells. The scope of research is immense. You will be given the challenges to overcome interesting problems such as electrical losses in the interlayers, process incompatibility, instability, and un-optimised optical coupling.

Academic Researcher:	Dr Robert Wolf
Project Title:	**Ground-state cooling and high-fidelity detection of large ion crystals in a penning trap for quantum simulations**
Project Summary:	The understanding of the dynamics of many-body quantum systems is one of the most challenging problems in physics today. Advancing our knowledge of these systems can lead to significant benefits in the understanding of condensed matter phenomena such as high-temperature superconductivity and spin liquids but also enable insights into dense astrophysical matter as found e.g. in neutron stars. To gain controlled access to these systems and engineer their interaction, we are using some of the most precise tools in atomic physics, the Penning ion trap and laser systems, to build and investigate multi-particle systems ion by ion.
Project Synopsis:	The controlled simulation of dynamics in quantum-many body systems is of central interest in the pursuit to further our understanding of condensed matter phenomena. Specially designed Penning ion traps enable experimental investigations into these topics using hundreds of ions trapped simultaneously. We have recently brought online the first and only such system in Australia at the Sydney Nanoscience Hub and now routinely trap large crystals of beryllium ions. The focus of the work is on finalizing the setup of the laser-based beryllium qubit manipulation and implementing software-based state analysis. Lasers near 313nm are used to address electric dipole transitions in beryllium ions. These transitions can be used to effectively Doppler laser cool an ensemble of ions to ~1mK temperature, such that it forms an ion crystal – a regular and stable lattice of charged particles, formed due to the equilibrium of Coulomb repulsion and electromagnetic confinement. However, for many envisaged experiments, the residual motional temperature has to be decreased even further, close to the ground state of motion. This can be achieved by implementing so-called ground state cooling techniques using lasers with different beam geometry and characteristics. The development and setup of this system, followed by the before mentioned state-of-the-art quantum simulation and metrology experiments is a possible project. To investigate correlations between individual ions, or qubits, in a quantum simulation, the spin state of the ion has to be read out. This is accomplished by detecting the ion's fluorescence photons. Ion crystals in a Penning trap rotate in the strong external magnetic field of a superconducting magnet due the Lorentz force. Therefore, a precise correlation between photon

	time an position is required. The setup of such detection systems and its integration into the existing experimental control software in combination with the development of algorithms employing machine learning is a possible project. These projects are expected to generate new knowledge in the area of quantum science and have a multitude of possible future applications in quantum technology, such as quantum scale materials, quantum sensing and quantum computation. In particular, understanding quantum magnetism is on the forefront of modern physics.

Academic Researcher:	Dr Ting Rei Tan
Project Title:	**Quantum Control Engineering with trapped ytterbium ions**
Project Summary:	The development of well-controlled quantum systems for computational purposes is one of the most promising avenues to unlock solutions to hard and often intractable problems in areas ranging from chemistry and materials science to physics. While much progress has been made over the last decades, further improvements to the performance of quantum operations are required to turn small proof-of-principle demonstrators into reliable quantum computers and simulators that produce results even in the presence of unavoidable noise perturbing the quantum system. In this project, we use the most advanced trapped-ion quantum computing platform in Australia to experimentally realize novel quantum control schemes that are specifically tailored to suppress noise in quantum operations, aiming to bridge the gap to near-term usefulness by combining quantum physics with control engineering approaches.
Project Synopsis:	Classical electrical engineering uses a variety of techniques to characterize the time-domain evolution of control pulses and their corresponding representation in frequency space. This approach, known as the filter-function formalism, allows one to predict the performance and noise-susceptibility of control processes. In the quantum domain, a similar framework can be established and has been underpinning the research at the Quantum Control Laboratory for a number of years, yielding many contributions in both theory and experiment. Our experimental work is carried out using trapped ytterbium ions that encode quantum information in their internal hyperfine energy levels, which we manipulate using microwave and laser radiation. With phase coherence times beyond one second, ytterbium ions are among the best performing quantum bits available, offering a chance to work at the cutting-edge of what is technologically possible. This project will develop and use techniques to characterize both environmental noise and disturbances that are intrinsic to our control pulses. You will then craft special modulation sequences that change their frequency, amplitude and phase to suppress the detrimental effects of the noise and allow for an improved performance of the desired operation.

	Expected outcomes are both a full characterization of the error robustness of the augmented quantum operations as well as their use in a demonstration of superior performance in an application targeting a specific problem of interest, e.g. the experimental quantum simulation of chemical reaction.
Additional Information:	This project requires experimental work in a laboratory, operating and controlling lasers as well as microwave systems and a broad range of electronics. Previous experience in any of those fields is welcome; interest in hands-on laboratory work is a requirement.

Academic Researcher:	Professor Tim Bedding
Project Title:	**Asteroseismology: Probing Inside Stars Using Stellar Oscillations**
Project Summary:	Measuring oscillations in stars using asteroseismology is a powerful new method for exploring their internal structures and testing physical theories. This project will use data from NASA space missions to study oscillations in stars and advance our understanding of stellar physics.
Project Synopsis:	Asteroseismology involves using the oscillation frequencies of a star to measure its internal properties. Measuring stellar oscillations is a beautiful physics experiment: a star is a gaseous sphere and will oscillate in many different modes when suitably excited. The frequencies of these oscillations depend on the sound speed inside the star, which in turn depends on density, temperature, gas motion and other properties of the stellar interior. This analysis, called asteroseismology, yields information such as composition, age, mixing and internal rotation that cannot be obtained in any other way and is completely analogous to the seismological study of the interior of the Earth. Many stars, including the Sun, are observed to oscillate. Asteroseismology is a new and rapidly developing field and there are several possible PhD projects, depending on the preference of the student. The projects will use observations from NASA's Kepler and TESS spacecrafts.