Swinburne Physics Honours 2019 Projects

This is the list of projects for 2019. Please also check the web pages of the Research Centres and feel free to contact researchers for possible honours projects.

List

Centre for Astrophysics and Supercomputing (CAS)

1. Mapping Electromagnetism's Strength throughout the Milky Way with Solar Twin Stars

Supervisor: Professor Michael Murphy
Contact: mmurphy@swin.edu.au

Project Description: The constancy of nature's laws, characterised by the fundamental constants, has been mapped out on all size-scales, from the laboratory through to the cosmic microwave background at redshift z=1100, except for one important size-scale: our own Milky Way galaxy. This project aims to make the first check on electromagnetism's strength in our Galaxy with high enough precision that a discovery of variation is possible (i.e. not already ruled out by previous, much less precise measurements). The idea is to use the spectra of solar twins – stars with spectra indistinguishable from our Sun's, and each other – as the probe because this allows for a highly differential measurement that will be immune to all manner of systematic effects that have precluded such a measurement in the past.

Depending on the status of this field at the time, the student will either be making the first measurements on existing solar twin spectra, contributing to an effort to identify very distant solar twins, analysing new spectra of these distant solar twins, or making measurements with them. The new spectra would be taken with a new instrument on the 8-metre Very Large Telescope in Chile. These and other options will be discussed with the candidate.

Further reading:

Murphy M.T., Cooksey K., 2016, Mon. Not. Roy. Astron. Soc., 471, 4930

2. Machine Learning for discovering High-Redshift and Exotic Objects

Supervisor: Professor Karl Glazebrook
Contact: kglazebrook@swin.edu.au

Project Description: The forthcoming launch of the James Webb Space Telescope (JWST) will dramatically open up the possibilities for object discovery in the z>4 Universe. Dozens of imaging bands from 2-28 microns will suddenly become available, and sensitive enough, to find diverse types of early galaxies, and potentially new populations of exotic objects that may appear in the early Universe. Traditional colour selection (2-3 photometric bands) is not optimal for this new data, and traditional photometric redshift type selections requires highly specific models of what to look for.

In this Honours project we will test the potential of neural networks to measure photometric redshifts and deliver spectral energy classifications of galaxies using data from deep multi-band surveys in a flexible and robust approach.

This project is a precursor to Professor Glazebrook's Laureate Fellowship project (starting end of 2019) and so there may be further opportunities to continue this research after Honours.

Further reading:

- Jacobs C., Glazebrook K., Collett T., More A., McCarthy C., 2017, Finding strong lenses in CFHTLS using convolutional neural networks, MNRAS, 471, 167
- Hezaveh Y. D., Levasseur L. P., Marshall P. J., 2017, Fast automated analysis of strong gravitational lenses with convolutional neural networks, Nature, 548, 555

3. Wrinkles in space: the varying expansion of the Universe

Supervisor: Professor Chris Blake
Contact: cblake@swin.edu.au

Project Description: The Universe is expanding from a hot Big Bang, causing distant galaxies to recede. However, this expansion rate varies from place-to-place, because the gravitational effect of cosmic large-scale structure -- consisting of clusters and voids -- imparts additional velocities to these galaxies, as clusters contract and voids expand. These velocities contain information about the laws of gravity, and how these laws may vary with environment in some theoretical models.

In this Honours project we will use galaxy and velocity datasets, simulations and theory, to measure how the expansion properties vary with scale and environment across the Universe, and what this variation might tell us about the physical laws controlling gravity and expansion.

The project would suit students with data analysis and computational skills, and an interest in cosmology.

4. Optical Site Testing for Robotic Telescopes

Supervisor: Professor Karl Glazebrook
Contact: kglazebrook@swin.edu.au

Project Description: Demand for future optical observing facilities dedicated to survey and fast response trigger follow up is only likely to increase. One such facility is the Gravitational wave Optical Transient Observer (GOTO), a project which is hoped eventually to consist of a pair of instruments, one in La Palma, Canary Islands, and one in Australia.

Analysis of meteorological and elevation data from across Australia has revealed potentially the best optical observing site on the continent, in the Hamersley Range in northwest Western Australia. This project will require compilation and analysis of test data from a special lightweight telescope and camera we have assembled which is designed to be transported to remote sites and measure seeing. Specifically:

(i) collect data with an optical bench lab setup in order to measure stability
(ii) analyse existing body of data to determine best measurement algorithm from time series data.
(iii) transport telescope to dark sites around Victoria and further around Australia to collect more data, including possibly the Hamersley range. This would result in a publication demonstrating about seeing measurement and site quality. This project is most suitable to students who like to get their hands dirty with small telescopes and have a taste for outdoor adventure in science.

The project would be in collaboration with Professor Duncan Galloway of Monash.

Further Reading:

Hotan C. E., Tingay S. J., Glazebrook K., 2013, Testing Potential New Sites for Optical Telescopes in Australia, Publications of the Astronomical Society of Australia, 30, e002.

5. Probing Cosmological Variability of Fundamental Constants with Quasar Spectra

Supervisor: Professor Michael Murphy
Contact: mmurphy@swin.edu.au

Project Description: Distant galaxies, seen in silhouette against bright, background quasars, imprint a characteristic pattern of absorption lines onto the quasar light as it travels to Earth.

This pattern is determined by the fundamental constants of nature. Using spectra taken with the largest optical telescopes in the world (e.g. Keck and Subaru in Hawaii, VLT in Chile), this pattern can be compared with laboratory spectra to determine whether the fundamental constants were indeed the same in the distant, early universe as we measure them on Earth today.

Several different avenues are available for exploration in this project. For example, one option is to analyse new spectra taken from the Keck and/or VLT with the aim of measuring the variability of the fine-structure constant (effectively, the strength of electromagnetism). Another option is to improve the methods used to make these exacting measurements so that we can make the best use of a new instrument being built on the VLT specifically for such work. These and other options will be discussed with the candidate.

Further reading:

Evans T.M., Murphy M.T., Whitmore J.B. et al., 2014, Mon. Not. Roy. Astron. Soc., 445, 128.

Murphy M.T., Malec A.M., Prochaska J.X., 2016, Mon. Not. Roy. Astron. Soc., 461, 24613.

6. Searching for Rare Metals in the Distant Universe with Quasar Spectra

Supervisor: Professor Michael Murphy
Contact: mmurphy@swin.edu.au

Project description: How the heavy elements originated in stars is an enduring problem in astrophysics, as is the question of how exploding stars polluted the gaseous surroundings of galaxies. This project will draw upon a large database of the highest-quality spectra of quasars in the distant universe, the lines-of-sight to which probe gas around foreground galaxies. The aim is to combine these spectra to search for absorption lines from heavy elements not previously seen outside our own galaxy.

Identifying these rare metals can help diagnose the physical and nucleosynthetic origins of the absorption clouds, and may greatly improve future measurements of the fundamental constants in the distant universe.

Further reading:

Prochaska J.X., Howk J.C., Wolfe A.M., 2003, Nature, 423, 57.

7. Invisible Streams of Dark Matter

Supervisors: Associate Professor Alan Duffy
Contact: aduffy@swin.edu.au

Project description: There exists an unknown invisible mass in the Universe, outweighing everything we can see five times over. This mysterious new substance is called Dark Matter and is able to pass through solid matter without notice. Thanks to astronomical observations we are confident that it surrounds us, yet we have no idea at this stage what it is. Confirming the nature of this new particle is one of the greatest scientific endeavours of our century.

Swinburne is part of SABRE, a new experiment one-kilometre underground at a gold mine in Stawell, which will attempt to detect this dark matter. This R&D project will create and use high-resolution simulations of Milky Way like galaxies to explore the potential properties of the dark matter near the Sun's orbit and which SABRE may detect. This includes kinematics structures, known as streams, which can appear as unusually high or low densities of dark matter that would complicate interpretations of SABRE-like detections.

The velocity of the dark matter in the streams can also impart additional information into the nature of the dark matter. A key component of this project will be to test different dark matter models and determine whether the streams 'remember' the initial distribution and just how much direct detection experiments can ever tell us about this invisible side of our universe.

8. Calibrating the chemical content of galaxies near and far

Supervisors: Dr Sarah Sweet (ssweet@swin.edu.au)

Project description: Chemical content is an important signature of a galaxy's lifecycle, as the buildup of elements from hydrogen and helium to heavier 'metals' is intimately linked to its history of star formation. There are two equally-justifiable methods for measuring chemical content based on regions of active star formation within galaxies, but the methods are not properly calibrated, so they do not agree. Moreover, they are valid in different regimes, so that we cannot accurately compare distant galaxies with those nearby, or massive galaxies with small ones. We are using the tiny bundles of optical fibres of the Sydney-AAO Multiple Integral field unit (SAMI) on the Anglo-Australian Telescope to obtain a complete three-dimensional picture of star-forming regions in nearby galaxies, and recalibrate the chemical content measurements.

This project involves working with 3D spectroscopic data from SAMI to measure approximately one hundred star-forming regions, construct maps of their key properties such as temperature, ionization and emission line strength, and quantify the spatial variation in these key properties. The next phase is to derive chemical abundances in the two competing chemical content methods, and determine the impact of spatial variation on the lack of agreement in the two methods. This is an important contribution towards recalibrating the methods, which will enable more accurate comparison of galaxies near and far.

9. Estimating parameters of black hole binary gravitational wave signals detected with LIGO and Virgo.

Supervisors: Dr Jade Powell, Prof Matthew Bailes
Contact: jpowell@swin.edu.au

Project description: The Advanced LIGO and Advanced Virgo gravitational wave detectors have made the first direct detections of gravitational waves from compact binary neutron stars and black holes. The waveforms of the gravitational wave signals can tell us information about the parameters of the source, such as the masses and spins of the black holes. Accurate estimates of the parameters of the sources will be essential for astrophysics with gravitational waves. The parameters of the gravitational wave signals are currently estimated using computationally costly Bayesian inference methods. This project involves either development of new methods for gravitational wave parameter estimation, or adding new features to existing LIGO parameter estimation tools, which can then be used to analyze current and future gravitational wave detections.

Further reading: J Veitch et al. Robust parameter estimation for compact binaries with ground-based gravitational-wave observations using the LALInference software library. Phys. Rev. D 91, 042003 (2015)

10. A handful of nuts: (peanut-shell)-shaped structures in face-on disk galaxies

Supervisor: Professor Alister Graham (agraham@swin.edu.au)

Project description: A growing number of galaxies with a bar-like feature – residing within the galaxies' flattened disk of stars - are known to additionally display a (peanut-shell) shaped pattern. It is commonly thought that the stellar bar wobbles and buckles in and out of, i.e. above and below, the disk plane to form these "peanuts". We have recently developed a new method for quantifying these structures in real astronomical images. However, unbeknown to most astronomers, and rarely observed, this bar-buckling phenomenon can also occur _within_ the plane of the disk. In 2018 we provided the first measurements of such a "peanut" in a galaxy whose disk is orientated face-on to us. We have identified 8 more such galaxies and wish to measure their physical structure for comparison with the "peanuts" already measured in galaxies whose disks are orientated edge-on to us, yielding insight into the relative strength of the vertical and horizontal bar-instability.

Further Reading:
https://astronomynow.com/2016/05/08/astronomers-detect-double-peanut-shell-galaxies/
https://arxiv.org/abs/1603.00019
https://arxiv.org/abs/1712.00430

11. Galactic candy: quantifying the ansae of galaxies (for the first time)

Supervisor: Professor Alister Graham (agraham@swin.edu.au)

Project Description: Galaxies possess a range of features, including bars, disks, bulges, rings, and more. Partial rings, known as ansae, are located at the ends of galactic-bars. Collectively, with the other galaxy components, the isophotal structure, i.e. the contours of equal intensity, in these galaxies resemble the silhouette of a candy wrapper. Perhaps surprising, given the long history of astronomy, such features have never been quantified. Using Fourier harmonics, we have developed a technique which quantifies the departures of a galaxy's isophotes from pure ellipses, enabling us to measure such features. This project will work with ground and/or space-based images of galaxies in an effort to better understand ansae.

Further Reading:
https://arxiv.org/abs/1507.02691
https://arxiv.org/abs/1603.00019
https://arxiv.org/abs/1712.00430

12. The nature of the first stellar populations in the Universe

Supervisor: Professor Karl Glazebrook
Contact: kglazebrook@swin.edu.au

Project Description: The forthcoming launch of the James Webb Space Telescope (JWST) (jwst.nasa.gov) will dramatically open up the possibilities for learning about the first billion years of cosmic history (redshifts z>4). JWST is a 6.5m space telescope, significantly larger than the 27 year old 2.5m Hubble Space Telescope and will extend much further in to the infrared due to its cold location, one million km from the Earth.

Especially significant is that JWST spectroscopy will enable the first detailed measurements of the stellar populations of early galaxies. (Hubble has not had a high-resolution spectrograph and has not been able to reach the long wavelengths needed). This will lead to new discoveries on topics such as the Initial Mass Function (IMF), rate of formation, elemental abundances and the presence of exotic populations. These studies will probe the fundamental physics of galaxy formation at $z>4$ in detail previously not possible. Recent discoveries of massive evolved galaxies (stellar masses $>10^{11}$ Msun) in such an early Universe point to an epoch of extremely fast star-formation followed by just as rapid quenching.

A variety of next generation spectral synthesis codes have been developed in the past few years which allow more sophisticated treatment of emission lines, binary populations, abundances, complex star-formation histories and the IMF. In this Honours project, we will test the ability of neural networks to 'learn' the solutions to models with complex star-formation histories, using the Prospector code, and speed up the results for fitting individual spectra.

This project is a precursor to Professor Glazebrook's Laureate Fellowship project (starting end of 2019) and so there may be further opportunities to continue this research after Honours.

Further reading:

- Hezaveh Y. D., Levasseur L. P., Marshall P. J., 2017, Fast automated analysis of strong gravitational lenses with convolutional neural networks, Nature, 548, 555
- Leja J., Johnson B. D., Conroy C., van Dokkum P. G., Byler N., 2017, Deriving Physical Properties from Broadband Photometry with Prospector: Description of the Model and a Demonstration of its Accuracy Using 129 Galaxies in the Local Universe, ApJ, 837, 170

Centre for Quantum and Optical Science (CQOS)

1. Table-top Cosmology with Ultracold Atoms

Supervisors: Professor Andrei Sidorov and Professor Peter Drummond
Contact: asidorov@swin.edu.au

Project description: The area of ultracold atoms is a burgeoning field of research with an unprecedented ability to mimic complex physical phenomena in a table-top experiment in clean and carefully controlled environment. This project focuses on the application of a Bose-Einstein condensate as a quantum simulator of the early Universe inflation. Under appropriate conditions the scalar field describing the cosmological "Big Bang" and the relative phase of two Bose condensates are described by the same equations, with terms analogous to the speed of light and the Hubble constant. This project will target different scenarios of simulating the Big Bang with Bose condensates.

Further reading:

http://www.swinburne.edu.au/engineering/caous/bec_on_a_chip.htm

2. Josephson Junction with Ultracold Atoms

Supervisor: Professor Andrei Sidorov
Contact: asidorov@swin.edu.au

Project description: The Josephson effect is a remarkable manifestation of macroscopic quantum coherence. A solid-state Josephson junction is made of two superconductors separated by a thin insulating layer where the current is driven by the phase of two wavefunctions. The Honours project will focus on the study of an ultracold Josephson junction where two Bose-Einstein condensates (BEC) are coupled by the microwave field and exhibit ultimate coherent properties. Numerous fascinating quantum effects were predicted and are still to be observed. The project will target practical implementations of the BEC Josephson junction for quantum sensors and metrology and involve theoretical modelling and experimental investigations.

Further reading:

http://www.swinburne.edu.au/engineering/caous/bec_on_a_chip.htm

3. Dynamics and interactions of exciton-polaritons in semiconductor microcavities

Supervisors: Associate Professor Jeffrey Davis
Contact: jdavis@swin.edu.au

Project description: A polariton is a quasi-particle that is part photon and part exciton. (When an electron is excited from the valence band into the conduction band, it leave behind a hole, with effective positive charge. The electron and hole experience a Coulomb attraction much like the electron and proton in a hydrogen atom, forming an exciton.) In this project, you will use femtosecond (10^{-15} s) laser pulses and state of the art coherent multidimensional spectroscopy experiments to measure the dynamics and interactions between polaritons and excitons in GaAs quantum wells. This work is part of the Centre of Excellence for Future Low-Energy Electronic Technologies, where we hope to be able to find a way to utilise the unique properties of polaritons for next generation electronics solutions.

4. Coherent Dynamics in High-Temperature Superconductors

Supervisors: Associate Professor Jeffrey Davis
Contact: jdavis@swin.edu.au

Project description: Understanding the mechanisms of high-temperature superconductivity has been one of the great challenges in condensed matter physics over the past 30 years since superconductivity was first observed in cuprate materials. In the past 12 months we have been able to successfully realise the first measurements of coherent dynamics in these materials, which we expect will help to provide great insight into the mechanisms responsible for superconductivity in these materials. This project will continue and extend that work, measuring the coherent dynamics using femtosecond (10^{-15} s) laser pulses and state of the art coherent multidimensional spectroscopy experiments.

5. Floquet Physics in Atomically Thin 2D Semiconductors

Supervisors: Associate Professor Jeffrey Davis
Contact: jdavis@swin.edu.au

Project description: This project is part of the ARC Centre of Excellence for Future Low-Energy Electronics Technologies (FLEET: www.fleet.org.au). Here you will utilise femtosecond laser pulses to transiently alter the band structure of 2D semiconductors by driving so-called “Floquet-Bloch” states.

You will probe these states with state-of-the-art coherent multidimensional spectroscopy capabilities developed at Swinburne to reveal coherent dynamics and the physics underlying the switching on and off of the applied field. Understanding this transient switching will help to realise and understand Floquet topological insulators.

Further reading:
www.swin.edu.au/caous/UltrafastSpec.htm

6. Exploring the role of Quantum Coherence and Electronic-Vibrational Coupling in Photosynthesis

Supervisors: Associate Professor Jeffrey Davis
Contact: jdavis@swin.edu.au

Project description: Recent work has identified the presence of long-lived coherences amongst different molecules within some light-harvesting complexes involved in photosynthesis. Using the techniques developed here at Swinburne, we are able to study directly the sequantum mechanical processes in detail. This project will explore the role of quantum coherence and electronic-vibrational coupling in photosynthesis by studying the dynamics of both coherent and classical energy transfer, within the isolated molecules and between the molecules within light-harvesting complexes. The ultimate aim is to develop an in depth understanding of the mechanisms responsible for the efficient energy transfer in photosynthesis.

Further reading:
www.swin.edu.au/caous/UltrafastSpec.htm

7. Few-body Physics and Virial Expansions

Supervisor: Professor Xia-ji Liu (xliu@swin.edu.au)

Project description: Few-body systems have become increasingly crucial to the physics of strongly correlated ultracold atomic gases. Because of large interaction parameters, conventional perturbation theory approaches such as mean-field theory, simply break down.

A small ensemble of a few fermions and/or bosons, which is either exactly solvable or numerically tractable, is more amenable to non-perturbative quantal calculations. The few-body solutions can be efficiently used for investigating high temperature properties of strongly correlated quantum gases, through the well documented virial expansion method.

This Honours project will investigate few-body exact solutions and high-temperature properties of ultracold atomic gases with s-wave and p-wave interactions. In particular, the project will focus on the few-body solutions of a one-dimensional Bose/Fermi gas and obtain several low-order virial expansion coefficients.

8. Theory of One-Dimensional Fermi/Bose Polarons

Supervisor: Professor Hui Hu
Contact: hhu@swin.edu.au

Project description: The theory of strongly interacting fermions/bosons is of great interest. Interacting fermions/bosons are involved in some of the most important unanswered questions in condensed matter physics, nuclear physics, astrophysics, and cosmology. Though weakly interacting fermions/bosons are well understood, new approaches are required to treat strong interactions. In these cases, one encounters a "strongly correlated" picture which occurs in many fundamental systems ranging from strongly interacting electrons to quarks.

This project will consider a simplified case of "polarons", which involves one impurity immersed in a background of N fermions or bosons. In this N+1 problem, the strongly interaction between impurity and background atoms might be handled. To further simplify the problem, we will focus on the one-dimensional situation by using the Bethe Ansatz technique. The results of this project can be tested in future coldatom experiments.

9. Tests of Macro and Local Realism using Entangled Twin Beams and Bose-Einstein Condensates

Supervisor: Professor Margaret Reid (mreid@swin.edu.au)

Project description: Schrodinger puzzled over the interpretation of the quantum mechanical state where a system is in a superposition of two macroscopically distinguishable states. He considered the odd case where apparently, according to the Copenhagen interpretation of quantum mechanics, a cat could be simultaneously dead and alive. The odd predictions of quantum mechanics can be rigorously shown different to those of a whole class of classical theories based on no 'spooky action at a distance' and the idea that a system is predetermined to be in a state prior to measurement.

This is a theoretical project that will study how to realise such regimes of quantum predictions using optical or atomic entangled systems. The project will utilize and develop extensions of Leggett-Garg and Bell inequalities that apply to practical atomic systems.

10. Universal Trimers in 2D Fermi Gases

Supervisors: Professor Chris Vale, Dr Paul Dyke, Dr Ivan Herrera
Contact: cvale@swin.edu.au

Project description: Super fluidity is the remarkable ability of certain materials to transport particles with zero energy loss. In Fermi gases, super fluidity relies on atoms pairing up and these pairs can flow with zero resistance. In addition to forming pairs, it is also possible for atoms to produce three-body bound states or trimers. Such states have been observed in 3D gases but these suffer from rapid decay. In 2D gases however, these states are predicted to be more stable, potentially allowing the study of strongly interacting gases of trimer molecules. This would represent a new frontier in cold atom research and this project will attempt to create such states on the Swinburne ultra-cold Fermi gas apparatus.

11. Bragg Spectroscopy 2D Fermi Gases

Supervisors: Professor Chris Vale, Dr Sascha Hoinka, Dr Carlos Kuhn
Contact: cvale@swin.edu.au

Project description: Superfluidity in 2D gases is known to differ in fundamental ways from 3D systems. Rather than being associated with Bose-Einstein condensation, 2D superfluidity involves the binding of pairs of vortices that form at finite temperatures in 2D gases with phase fluctuations. Using the experimental technique of Bragg spectroscopy that has been pioneered at Swinburne this project will measure the properties of 2D superfluids produced in an ultracold Fermi gas.

12. Projects on Theoretical Quantum Physics

Supervisor: Professor Peter Drummond (pdrummond@swin.edu.au)

13. Bragg spectroscopy of ultracold gas and linear response

Supervisor: Prof. Chris Vale and Dr. Carlos Kuhn (cvale@swin.edu.au)

Project description: Elementary excitations are interesting and fundamental to the understanding of transport properties of a fluid (gas). This project has the goal to understand the effects of the probe in the measurement. We will theoretically lift the veil of the linear response by understanding its limitations when applied to a fermi gas at degeneracy. The final goal is to get an analytical expression and numerical simulations that would describe quantitively the experimental results obtained by the Fermi Group at Swinburne.

14. An ultracold source of Dy atoms

Supervisor: Prof. Chris Vale, Dr Sascha Hoinka and Dr. Carlos Kuhn (cvale@swin.edu.au)

Project description: The Australian Quantum gas microscope is a new facility being constructed at Swinburne for the study of quantum superfluids and topological matter using ultracold gases of dysprosium atoms. The apparatus is currently being designed and built in a new laboratory. An essential aspect of the design work is the theoretical modelling of the laser cooling and trapping processes for Dy atoms as they travel from the oven, through the Zeeman slower and into the science chamber. This project will develop such a model to identify the best strategies for cooling and trapping the largest numbers of atoms with the highest flux and lowest temperatures, including the design of a Dy fountain

Centre for Micro-photonics (CMP)

1. '1/f' Frequency Scaling in the Human Electroencephalogram

Supervisors: David Liley (FHAD), Damien Hicks (FSET) (dhicks@swin.edu.au)

Project description: 1/f scaling of power has been of persistent interest in the study of the human electroencephalogram, particularly given its association with self-organised criticality. However recently there have emerged alternative attempts to explain its existence in terms of the sum of a distribution of damped oscillatory processes that accord more meaningfully with the underlying physiology. This project will investigate the sensitivity of the frequency scaling of band limited EEG power in terms of parameter variations in a physiologically well-defined theory of the human electroencephalogram.

2. Silicon Nanoparticle based Magnetic Nanoantenna in the Visible Range

Supervisors: Associate Professor James W. M. Chon, Professor Saulius Juodkazis
Contact: +61 3 9214 4326 jchon@swin.edu.au

Project description: Silicon nanoparticle have recently received increased attention due to its ability to pick up magnetic field of visible and near-infrared light. Traditionally, plasmonic nanoantennas in the visible range are detecting the electric field of the light, with no magnetic response. The additional ability to pick up magnetic fields provide wealth of choice for oscillation modes in the visible and NIR range, which makes silicon nanoparticle attractive. Recently the fabrication methods of silicon nanoparticles have greatly improved with femtosecond laser irradiation. In this project, we use laser fabrication technique to synthesise silicon magnetic nanoantennas and characterise them, before applying them for emission and photothermal enhancement in Ramanscattering and nonlinear absorption.

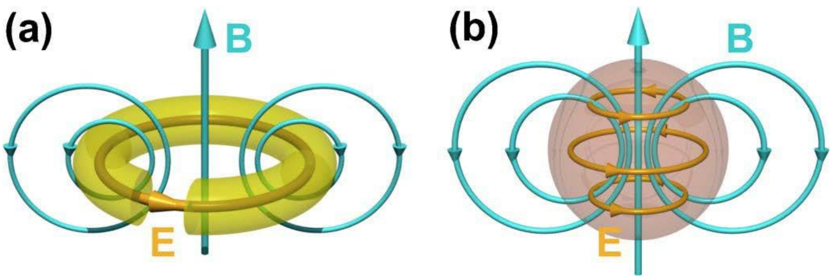


Fig. 1. (a) Split ring resonator element that is capable to pick up magnetic field of light. (b) Silicon nanoparticle equivalent. From ref. 1.

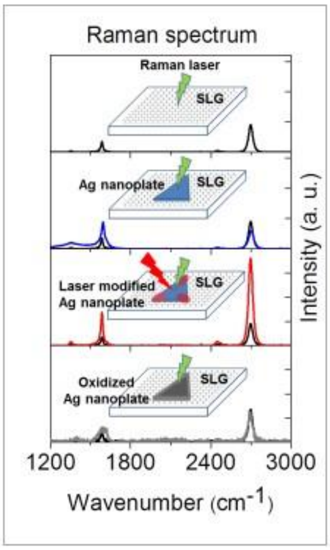
Further reading:

S Arseniy I. Kuznetsov, Andrey E. Miroshnichenko, Yuan Hsing Fu, JingBo Zhang and Boris Luk'yanchuk, "Magnetic Light," Sci., Rep., 2, 492 (2012).

3. Graphene Hybridisation with Plasmonic Nanostructures

Supervisors: Associate Professor James W. M. Chon
Contact: +61 3 9214 4326 jchon@swin.edu.au

Project description: In this project, we study single layer graphene hybridised with plasmonic nanosheets using Raman spectroscopy, nonlinear spectroscopy and dark-field scattering microscopy to understand the interaction between the two materials. This new hybrid material will be applicable to single molecule sensing, sub-nanometre distance and charge sensing. The electron beam lithography platform (Raith II) within the university will be utilised to fabricate the nanoplasmonic hybrid materials. Finite difference time domain simulation package of plasmonic wave propagation (Lumerical package) will also be utilised, with access to supercomputers within the University.



Further reading:

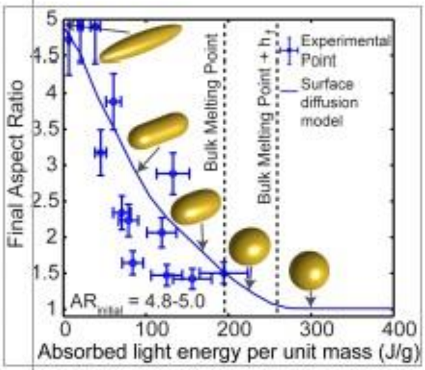
S. Syed, G. H. Lim, A. B. Taylor, S. Flanders, B. Lim and J. W. M. Chon, "Single Layer Graphene Band Hybridisation with Silver Nanoplates: Interplay Between Doping and Plasmonic Enhancement," Appl. Phys. Lett., 109, 103103 (2016)

S. Syed, G. H. Lim, A. B. Taylor, S. Flanders, B. Lim and J. W. M. Chon, "Measurement of the third order non-linearity of gold-graphene hybrid nanocomposite for near-infrared wavelengths," Proc. SPIE, vol. 9894, 98941G (2016).

4. Plasmonic Nanostructure Instability due to Surface Diffusion

Supervisors: Associate Professor James W. M. Chon
Contact: +61 3 9214 4326 jchon@swin.edu.au

Project description: In this project, we propose to design and fabricate nanoplasmonic waveguide structures and study the fundamental material properties of these plasmonic elements under operation. In particular, the surface diffusion induced instability of the structures will be studied in conjunction with the surface plasmon propagation, which involves three-dimensional simulations into shape evolution with given laser power. This project will be of importance to nanoplasmonic circuitry in general, and also to high density optical storage based on plasmonic nanoparticles, linear and nonlinear biolabelling application of plasmonic nanorods, solar cells and photovoltaics, and optical nanoantennas.



Further reading:

A. B. Taylor, A. M. Siddiquee and J. W. M. Chon, "Below melting point photothermal reshaping of single gold nanorods driven by surface diffusion," ACS Nano, 8 (12), 12071-12079 (2014)

5. Multidimensional Optical Data Storage using Lithographed Plasmonic Nanorods

Supervisors: Associate Professor James W. M. Chon
Contact: +61 3 9214 4326 jchon@swin.edu.au

Project description: Metallic nano-structured materials such as nanorods (NRs) has huge potential in applications such as a biosensor, micro-laser, flexible display devices and multidimensional optical data storage. ONSPA group has been focusing recent research effort on microscopy/spectroscopy of a single NR, and its application to multi-dimensional optical data storage. Previously we successfully implemented 5-dimensional optical data storage using photothermal melting of nanorods. The project aims to fabricate large array of silver plasmonic nanorods using electron beam lithography and to characterise them using various spectroscopic/microscopic methods and try to address the low photothermal stability in 5D optical storage. The project will also involve fabricating the multilayered disk and drive for prototype development.

Further reading:

A. B. Taylor, A. M. Siddiquee and J. W. M. Chon, "Angular Photothermal Depletion of Randomly Oriented Gold Nanorods for Polarisation-Controlled Multilayered Optical

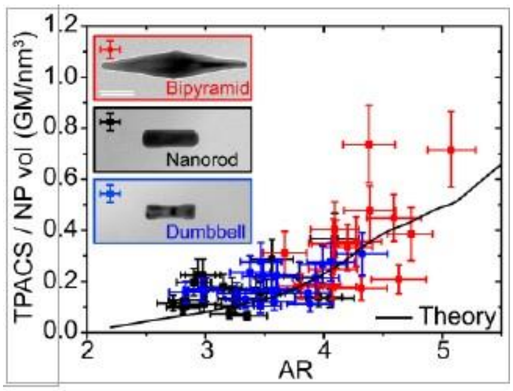
Storage," Adv. Opt. Mater., 3, 695-703, (2015)

A. B. Taylor, P. Michaux, A. S. M. Mohsin and J. W. M. Chon, "Electron-beam lithography of plasmonic nanorod arrays for multilayered optical storage," Opt. Express, 22 (11), 13234-13243 (2014)

6. Two-photon Luminescence of Plasmonic Nanoantennas and Superstructures

Supervisors: Associate Professor James W. M. Chon
Contact: +61 3 9214 4326 jchon@swin.edu.au

Project description: Recent development in optical nanoantennas provide means to control emission directions, field enhancement and plasmon coupling. In this project, we propose to study plasmon coupled nanoantenna and superstructures by means of linear and non-linear luminescence spectroscopy, to understand the field enhancement mechanisms and to increase its luminescence quantum efficiency.



In particular, the plasmon coupling will be maximised to increase field strength inside the structure. This project will help develop novel non-toxic, highly efficient, linear and nonlinear luminescent markers that are stable and free of blinking/bleaching. Such markers will be great assets for targeted cell imaging, photodynamic cancer therapy, and high density optical storage.

The cutting-edge electron beam lithography platform (Raith II) within the centre will be utilised to fabricate the nanoplasmonic elements, and an ultrafast lasers (Spectra Physics, Broad band Ti: Sapphire Tsunami) will be used to excite surface plasmons in the structure. Finite difference time domain simulation package of plasmonic wave propagation (Lumerical package) will also be utilized, with access to supercomputers within the University.

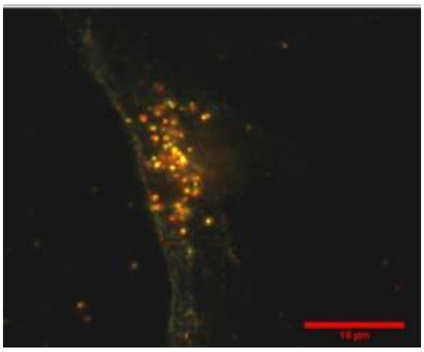
Further reading:

A. B. Taylor, A. M. Siddiquee and J. W. M. Chon, "Below melting point photothermal reshaping of single gold nanorods driven by surface diffusion," ACS Nano, 8 (12), 12071-12079 (2014)

7. Aggregation and Uptake Kinetics of Gold Nanoparticles in Biological Cells using Image Correlation Spectroscopy

Supervisors: Associate Professor James W. M. Chon, Professor Andrew Clayton
Contact: +61 3 9214 4326 jchon@swin.edu.au

Project description: Gold nanoparticles (AuNPs) are one of the most widely used nanoplasmonic building blocks, and its application into linear and nonlinear biomarker and cancer therapy has seen some important breakthroughs in biomedical area. For the full realisation of their potential in this area, AuNP uptake, aggregation and its cytotoxicity inside cells have to be studied in more detail.



The aim of this project is to test a new technique called high order ICS (HICS) to quantify the uptake and aggregation of AuNPs inside live cells. We propose to use HICS together with plasmon coupling. The combination of these techniques overcome the limitations of ICS, and provides microscopic and macroscopic information of nanoparticle interactions within a cellular environment. This technique could be used in many biological applications including cancer therapy, drug delivery, disease diagnosis and also for probing membrane protein stoichiometry and dynamics.

Further reading:

C Paviolo, J WM Chon, AHA Clayton, Inhibiting EGFR Clustering and Cell Proliferation with Gold Nanoparticles, Small, 11, 1638-1643, 2015

G D Ciccotosto, N Kozer, TTY Chow, JWM Chon, AHA Clayton, Aggregation distributions on cells determined by photobleaching image correlation spectroscopy, Biophys. J., 104, 1056-1064, 2013.

8. Integration of quantum cascade lasers for cavity ring-down spectroscopy for advanced sensing

Supervisors: Associate Professor James W. M. Chon, Professor Charles Harb
Contact: +61 3 9214 4326 jchon@swin.edu.au
Project description: RingIR Pty Ltd would like to work with enthusiastic Honours students to develop new laser sources for industrial monitoring of gas and dust. The projects will be focused on developing Quantum Cascade Laser into ruggedized field portable cavity ring-down spectroscopy instruments. The project will be vital to the products being developed for defense by RingIR Pty Ltd.

Other Centres

1. Functional Role of Beta Band Frequency Oscillations in Humans

Supervisor: Dr Tatiana Kameneva
Contact: tkameneva@swin.edu.au

The field of brain-machine interfaces is rapidly growing. New neural decoding algorithms are proposed to control a robotic arm, a wheel chair or a cursor on a screen. Recorded power in beta (10-45 Hz) oscillations may be used to detect the patient's attention and readiness to make a movement; therefore, enhancing the existing decoding algorithms. The aim of this project is to explore if phenomena observed in monkeys related to beta band frequency networks involved in the movement control, apply to human brain networks. The project involves collecting and analysing magnetoencephalography data (MEG) from healthy humans. The project would suit someone with an interest in gaining experience in signal processing of biological data. The student should have strong analytical skills and should also have an interest in working in a multidisciplinary environment.

2. Computational Modelling of the effects of Electrical and Light Stimulation on Neural Response

Supervisor: Dr Tatiana Kameneva
Contact: tkameneva@swin.edu.au

Project description: Electrical stimulation has been used to restore sensory functions in people who lost their vision or hearing. A novel way to stimulate neurons is to combine conventional electrical stimulation with targeted optical stimulation. The aim of this project is to explore the effects of electrical and light stimulation on neural responses in computer simulations. The project would suit someone with an interest in gaining experience in simulation of biological processes. The student should have strong analytical skills and should also have an interest in working in a multidisciplinary environment.