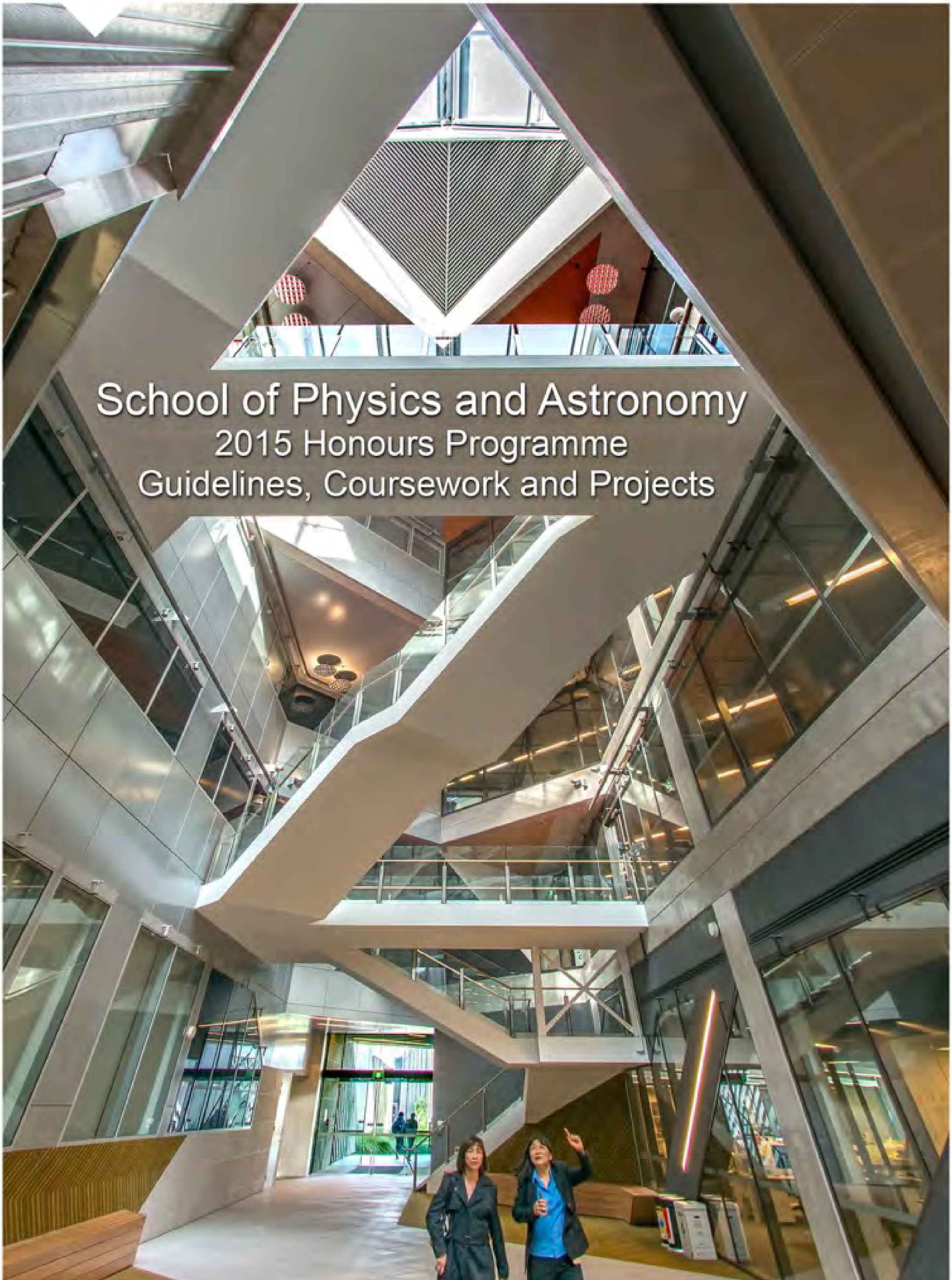
MONASH University



# School of Physics and Astronomy

## 2015 Honours Programme

## Guidelines, Coursework and Projects

MONASH University

## School of Physics and Astronomy

**B.Sc.(Hons)**

# GUIDELINES, COURSEWORK AND PROPOSED RESEARCH PROJECTS

# 2015

## Welcome to the Physics and Astrophysics Honours Booklet 2015

This booklet contains information on the BSc (Hons) in Physics and Astrophysics, including the names of project supervisors and areas of research.

Many of the potential supervisors may be familiar to you, while some will not. All students are encouraged to discuss specific projects of interest, with the supervisors concerned, before nominating preferences on the attached sheet. As the Honours Coordinator I am very happy to introduce you to any potential supervisors, so that you can discuss possible projects with them.

Students are requested to complete and return the Honours Physics and Astrophysics form at the back of this booklet, indicating three preferences for your supervisors and project areas. Potential BSc (Hons) students should note that this form is **not** your application for entry into Honours, for which a separate form is available from the Faculty of Science Office, or from the web at:

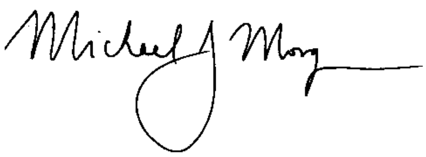
http://monash.edu/science/current/honours/how-to-apply/

**Please note the Faculty of Science closing date for Monash students is 14 November 2014. The closing date for external students is also 14 November 2014. For your convenience, the Faulty of Science Honours application form is attached to the end of this booklet.**

Honours in Physics and Astrophysics may be undertaken full-time or part-time, with intakes both at the start of each year, and mid-year.

I hope you enjoy reading through this booklet, which highlights many exciting areas in astrophysics and physics, spanning a very impressive breadth of research topics. Please do not hesitate to contact me if you require any further information. My office is Room 143B in Building 19. I can also be contacted by E-mail at michael.j.morgan@monash.edu or by phone on +61 3 9905 3645.

With very best wishes,



Michael J. Morgan
Honours Coordinator

# Physics & Astrophysics BSc(Hons) Assessment 2015

**PHS4000**: Coursework (45%), Project Literature Review (5%), Research Project (50%)
**ASP4000:** Coursework (45%), Project Literature Review (5%), Research Project (50%)

**Course Work:**

**Introduction to Honours Computing:** All honours students are required to take a non-assessed unit - "Introduction to Honours Computing". This will be run in the week prior to the start of formal honours coursework (i.e., during orientation week starting Monday 23rd February).

**PHS4000:** Physics Honours Students are required to undertake six coursework subunits from those offered in the School. All students in theoretical or experimental physics will take Quantum Mechanics. The remaining five sub-units are chosen, in consultation with the student's project supervisor and the Honours Coordinator, from those elective topics offered across the School at Level 4.

**ASP4000:** Astrophysics Honours Students without a major in physics, but with a major in astrophysics or a cognate-discipline may choose any 6 units from those offered in the School. **N.B.** Quantum Mechanics is not compulsory for astrophysics honours students.

In addition, with the agreement of the Coordinator and supervisor, a student may take elective units from another School/Department and the Coordinator will appraise their credit weighting, by comparison with that for Level 4 units in the School, on an individual basis. Most ASP4000 and PHS4000 students complete their coursework requirements by the end of Semester 1, although this is not compulsory. Assessment of individual coursework sub-units varies, and any individual student would experience an adequate and balanced assessment comprised of written examinations, assignments, research essays, oral presentations and reports. The lecturers for sub-units are required to return a numerical assessment, based on the standards for BSc(Hons) of 80-100 (Hons I), 70-79 (Hons IIA), 60-69 (Hons IIB), 50-59 (Hons III) and < 50 (Fail).

The following physics PHS4000 sub-units are on offer for 2015:

- Quantum Mechanics (Compulsory for PHS4000 students only)
- Advanced Quantum Mechanics
- Condensed Matter Physics
- Digital Image Processing
- Electrodynamics
- General Relativity
- Quantum Computation and Information Theory
- Quantum Field Theory
- Quantum Fluids
- Special Topics (TBA)
- Statistical Mechanics
- X-ray Optics

**Note:** Subject to approval**,** Physics Honours students may also choose units from ASP4000. The following astrophysics ASP4000 sub-units are on offer for 2015:

- Computational Astrophysics
- General Relativity
- The Sun and MHD
- Stars
- Exoplanets

**Note:** Subject to approval, Astrophysics Honours students may also choose units from PHS4000, or units from mathematics, e.g., Advanced Methods for Applied Mathematics.

**Project Literature Review**

This must be completed and presented to the Coordinator by Friday 5th June, following the end of Semester 1. Detailed notes on the format for the preparation of the Literature Review will be handed out early in the semester.

**Risk Assessment Report (Not assessed)**

All students are required to complete a Risk Assessment Report during the introductory stage of the project. This is to be done in conjunction with the supervisor.

**Introductory and Final Seminars (Not assessed)**

Each student is required to present an introductory seminar (10 minutes) in order to outline their project to the School in week 12 of first semester. The date, time and venue for the seminar to be advised. At the end of the second semester each student gives a final seminar (20 minutes) in which they summarize their results.

**Honours Project**

The project extends throughout the honours year. Its assessment comprises:

(a) The supervisor(s) assessment (20%);

(b) The final project report, normally presented about one week following the formal seminar, is examined by two independent readers, chosen by the project supervisor and Honours coordinator (40% by each reader);

(c) Once the report has been read, an Honours Project Oral Examination is conducted. The main purpose of this is to enable the two Readers to clarify any aspect of the project, following their reading of the report. The panel consists of the Head of School, the Honours Coordinator (Chair), the Project Supervisor(s) and the two independent Readers. The format followed is that the student makes a brief (5 minute) summary of the project (mainly for the benefit of panel members who have not been directly involved in the project), and the two independent Readers ask questions based on the Project Report. Anyone else present is then invited to ask questions. At the end of the oral examination the two Readers and the Supervisor(s) are asked if they wish to modify their assessment (given prior to the interview), and this is done if the panel feels it is appropriate;

(d) These "moderated" scores are then summed with the above weightings to produce a final grade for the "Project".

Please do not hesitate to contact me if you would like further information regarding the honours program in physics or astrophysics.

Michael J. Morgan
Honours Coordinator,
Room 143B, Building 19,
Phone: 61 3 9905 3645
E-mail: michael.j.morgan@monash.edu

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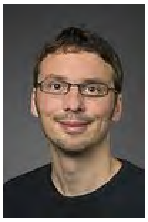
|  | Levinsen, Dr Jesper | 43, 52 |
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- P = Particle Physics and Cosmology
- S = Statistical Physics

**Category A – Astrophysics**

**Category AM – Atomic and Molecular Physics**

**Category C - Condensed Matter Physics**



**Category M – Medical Imaging and Biophysics**

**Category O – Optics**



**Category P – Particle Physics and Cosmology**

Category S – Statistical Physics

# PROPOSED PROJECTS FOR 2015

## ASTRONOMY AND ASTROPHYSICS

Category **A**

### A Far-infrared Atlas of galaxy spectra

**Supervisor:** A/Professor Michael Brown

To determine the distances and luminosities of distant celestial objects, we need models or templates of their spectra. Without such models and templates, gross errors can result in object luminosities. We have recently produced an atlas of 129 galaxy spectra spanning from the ultraviolet (0.1 micron) through to the infrared (30 micron). This project will use ISO satellite spectroscopy and Herschel satellite images to extend the wavelength coverage for several atlas galaxies out to a wavelength of 200 microns. This will measure the peak of dust emission in galaxies, making the spectra particularly useful for studies of obscured star formation in galaxies.

**References**


[1] Brown et al.., 2014, ApJS, 212, 18 (arXiv: 1312.3029).

[2] Moustakas et al.., 2010, ApJS, 190, 233 (arXiv: 1007.4547).

[3] http://ned.ipac.caltech.edu/level5/March10/Brauher/galaxies_lws.html


Category **A**

### Analysis of the excess noise in a gravitational-wave interferometer

**Supervisor:** Dr Yuri Levin

Laser interferometers around the world (LIGO, VIRGO, GEO600, TAMA300, AIGO) are being tuned to detect gravitational waves produced in violent cosmic events in distant parts of the Universe. One of the main tasks of the physicists working on the gravitational-wave interferometers is to control and reduce the noise. In this project, we will study theoretically a stochastic process responsible for a certain type of mechanical noise, called the excess noise. This is caused by spontaneous and localized tension relaxation in the inteferometers' suspension fibers, which causes spontaneous movement of the interferometer mirrors. A background in applied mathematics, theoretical physics, or material science is highly desirable.

Category **A**

## Asteroseismology of red giants

**Supervisors:** Professor John Lattanzio, Professor Paul Cally & Dr Simon Campbell

Stars are big balls of gas and they are excellent cavities for sound waves. The study of these waves in the Sun is known as selioseismology, in analogy with the seismic waves found on Earth. Recently, the Kepler satellite has been observing thousands of red-giants. This has allowed us to determine the seismic oscillations of these stars - a field of study known as "asteroseismology". The theory of these oscillations is well known but it is only now that we are getting real data for real stars. Kepler data is very accurate and it is allowing us to probe the interior of red-giants for the first time. The details of mixing during the phase of helium burning in the core are particularly poorly known. Recent work using Kepler data might allow us the possibility to determine the extent of the mixed region from observations!

This project would involve gaining a thorough understanding of seismology and also the details of core helium burning in low mass stars. Then you will modify the stellar evolution code to calculate the things that observers can measure. Can we then use the existing data to make some constraints on the mixing seen in the models?

**References**


[1] Seismology notes: users-phys.au.dk/jcd/oscilnotes/print-chap-full.pdf

[2] Recent papers: Bedding et al., 2011, Nature, 471, p608

[3] van Grootel et al.. 2010, Astrophysical Journal Letters, 718 L97


Category **A**

## Clouds across a neutron star: dipping in low-mass X-ray binaries

**Supervisor:** Dr Duncan Galloway

Some neutron stars are born in binary star systems, and if the stellar companion later expands during its evolution it may start to transfer mass to the neutron star. In that case, the gas flows onto the neutron star through an accretion disk, and is heated to tens of millions of degrees in the process. The intense X-rays from the neutron star can be interrupted intermittently by gaseous material at the outer edge of the accretion disk; this "dipping" is mainly known from high-inclination systems (i.e. where the disk is viewed almost-edge on).

Recently an example of intermittent dipping has been discovered, in the system Aquila X-1 (Galloway 2012, ATel #4014). This system is not known to be high inclination, so the exact cause of the dips is unclear. The goal of this project is to investigate the dynamics of the accretion disk via the dipping phenomenon. The student will be tasked with searching for additional examples of intermittent dips in a large sample of X-ray data collected by NASA's Rossi X-ray Timing Explorer satellite. Comparison of the measured inclination of this and any additional system shown to exhibit intermittent dips, to that of the systems that show no dips, will provide new measurements of how wide an angle the disk-edge gas can span.

Additional information: http://www.astronomerstelegram.org/?read=4014

Category **A**

## Constraining nuclear reactions with thermonuclear bursts

**Supervisors:** Dr Duncan Galloway & Professor Alexander Heger

Many of the thousands of thermonuclear reactions taking place in X-ray bursts from neutron stars have rates that cannot be measured precisely in terrestrial laboratories. In recent years, modelling efforts have begun to identify which specific reactions have the most influence on the observational properties of the bursts. At the same time, large samples of high-quality observational data on bursts exist, but comprehensive comparisons of the model predictions with observations have not taken place.

This project would involve comparisons of numerical burning model predictions with observations to attempt to constrain nuclear reaction rates. The student will take advantage of the sample of several 1000s of bursts as part of the Multi INstrument Burst ARchive (MINBAR), as well as existing collections of model runs from collaborators, and local modelling capabilities. Part of the project could involve development of online web-based tools to improve the usability of existing data. Additional work could include exploring varying stellar parameters including gravity (mass/radius) and heating rate.

**Reference:**

[1] Cyburt, R. H. et al.. 2010, Astrophysical Journal Supplements, 189, 240.

Category **A**

## Constraining supernovae properties by their nucleosynthesis

**Supervisors:** Professor Alexander Heger & Dr Bernhard Meuller

Most heavy elements from oxygen to iron are dominantly made by the deaths of massive stars as supernovae. Whereas fully understanding such core collapse supernovae requires multi-dimensional simulations including complicated and expensive radiation transport physics, there is some progress in developing simpler approximation formulae for these supernovae given the structure of the star at the time of its death. Depending on the explosion properties, supernovae synthesise and eject elements in different proportions, which can be used as a diagnostic of the explosion model.

For this project you will use an analytic model for supernova explosions and their energies to simulate the nucleosynthesis of these stars. The result is to be compared to the abundance patterns - elemental and isotopic - that we find in the in the universe today, in the sun, and on earth. The goal of the project is to constrain the properties of the analytic supernovae model in its ability to reproduce the observed data.

**References**


[1] 2012ARNPS..62..407J

[2] arxiv.org/abs/1409.0540

[3] 2002RvMP...74.1015W

[4] 2002ApJ...576..323R


Category **A**

## Core helium burning – too long under the carpet!

**Supervisor:** Professor John Lattanzio

One of the most controversial stages of evolution of low mass stars is the end of the core helium burning phase. There is an instability that is predicted by the models - but the details are not clear. Is it a real instability? Yes, if you assume instant mixing. But mixing is not instant.

Can we learn something by using a code that allows for time-dependent mixing processes?

Category **A**

## Does turbulence determine the mass of stars?

**Supervisor:** Dr Daniel Price

Predicting the initial mass function (the number of stars born as a function of their mass) is the holy grail of star formation research. In this project we will try to study whether or not the initial mass function produced in simulations of star cluster formation depends on the properties of the initial `turbulence' given to the model cloud. We will perform two large scale supercomputer simulations to test this link.

Category **A**

## Enhanced mass-loss on the horizontal branch

**Supervisors:** Professor John Lattanzio & Dr Simon Campbell

After stars ignite helium at the tip of the giant branch, they settle down to 100 million years of burning helium in their core. Some recent observations indicate that these stars are experiencing a higher rate of mass-loss than is expected. This can cause the star to alter its evolution and these stars may not continue to the AGB phase. Recent work by Simon Campbell indicates that some globular cluster stars do not reach the AGB. Could this be related? In this project we will make models of stars with enhanced mass-loss during their helium burning evolution and see what effect this has on the distribution of stars in globular clusters.

Category **A**

## Exploring the extreme transient sky

**Supervisor:** Dr Duncan Galloway

The European Space Agency's (ESA) XMM-Newton satellite routinely detects the brightest and faintest of X-ray sources, including accreting black holes and neutron stars, active galactic nuclei, and even distant galaxy clusters. The X-ray detectors feature large effective area in the 0.2–10 keV energy range, permitting sensitive observations for faint sources at good spatial and spectral resolution. XMM-Newton has been observing the X-ray sky for over 11 years, and has accumulated an extensive database of observations covering a substantial fraction of the sky. The July 2013 release of the 3rd XMM-Newton Serendipitous Source Catalogue, the largest X-ray source catalogue ever produced, includes detections of 372,728 unique individual sources from 7,427 observations.

A substantial fraction of these sources are "transients", that is, active for which the nature and characteristics are unknown. This project will involve developing strategies to select sources from the catalog and, using archived observations in other wavelengths, to deduce their nature. Work will be carried out in collaboration with researchers at the Centre for All-Sky Astrophysics based at the University of Sydney. The transient fraction of the catalog has barely been explored so far, so there is a good chance of discovery of new sources with unusual properties. Prompt transient followup strategies may also be adapted for use in the Variable and Slow Transients (VAST) program on the Australian Square Kilometre Array Pathfinder (ASKAP), currently under construction.

Additional information: http://xmmssc-www.star.le.ac.uk/

Category **A**

## Extending polytropic models

**Supervisors:** Professor John Lattanzio & Professor Paul Cally

Simple polytropic models have many uses in stellar astrophysics. The simple approaches can be extended by adding an equation for the luminosity as well. In this case one can include the H-burning reactions and calculate a luminosity for the model.

The idea is to try to construct polytropic models that represent the main phases of stellar evolution around the HR diagram. How can we best simulate a main sequence? Can we simply use the pp and cno cycle reactions? Will it be necessary to make some modifications? For example are all ms stars equally well approximated by polytropes with $n=3$? Maybe we will need to vary n? Can we simulate a red-giant somehow? Further, what is the best way to solve the Lane-Emden equation? We will investigate using a Runge-Kutta-Fehlberg scheme with a maximum specified error at each step. We can also write the Lane-Emden equation as a differential equation for $\xi$ as a function of $\theta$, so that the boundaries are now well known!

Category **A,P**

## Extra dimensional dark matter

**Supervisor:** A/Professor Csaba Balazs

String theory suggests the possibility of new space dimensions opening up at the tera-electron-volt energies. The merit of these extra dimensional models can be tested by their solutions to problems of the standard particle model: the generation of mass, dark matter, neutrino masses, and unification of forces.

Universal extra dimensional models fare well against this test. Among other virtues, they can explain dark matter by the lightest stable Kaluza-Klein particles. In the five and six dimensional models the amount of the lightest Kaluza-Klein particles is consistent with the measured amount of dark matter.

However, there exists no comprehensive analysis of how these models fare against other experimental constraints such as indirect and direct detection bounds, collider limits, precision electroweak variables, rare decays, etc. In this project we attempt this calculation and using these results we perform a viability analysis of this model.

Category **A**

## Extra solar planets

**Supervisor:** Dr Rosemary Mardling

Observations and theory; Stability and long-term evolution of stellar and planetary systems; Tides in planets and stars; Planet formation; The three-body problem; Chaos in conservative systems.

Category **A**

## Galaxies in transition

**Supervisor:** A/Professor Michael Brown

Galaxies fall into two broad categories, those with and without star formation. These two categories are very clearly identified in WISE satellite infrared imaging, which detects the blackbody radiation produced by warm dust in star forming regions. What terminates star formation within galaxies is not clearly understood. Studies at optical wavelengths have been hampered by dust obscuration, which can make dusty star forming galaxies mimic older galaxies that don't have any star formation. We will identify galaxies that in transition using WISE infrared imaging combined with SDSS optical imaging and archival spectroscopy. We will search for evidence of what is driving the transition in galaxy properties, including galaxy mergers and proximity to galaxy groups.

**References**


[1] Brown et al.., 2008, ApJ, 682, 937.

[2] Brown et al.., 2011, ApJ, 731L, 41 (arXiv : 1103.2828).

[3] Croton et al.., 2006, MNRAS, 365, 11 (arXiv:astro-ph/0407537).

[4] Toomre & Toomre., 1972, ApJ, 178, 623.

Category **A**

## Giant waves on surface of neutron stars

**Supervisor:** Dr Yuri Levin

Thermonuclear explosions frequently occur on sufaces of neutron stars that rapidly accrete gas. Such explosions can be observed with x-ray telescopes and are known as type-I x-ray bursts. This project is concentrating on the theoretical study of the x-ray bursts (Monash is also host to an active program, lead by Duncan Galloway, to study these bursts from an observational point of view; see other projects in the astrophysics section). We will investigate the propagation of giant waves (super-tsunamis) which could be excited in the neutron-star ocean, and explore whether these waves could be responsible for the observed sinusoidal variationsof the x-ray flux during the burst. A background in applied mathematics or theoretical physics is a must.

Category **A**

## Hamiltonian dynamics near supermassive black holes

**Supervisor:** Dr Yuri Levin

Supermassive black holes (SMBHs) lurking at the centers of galaxies are surrounded by swarms (clusters) of stars. This project will develop a new method to study the dynamics of the stellar orbits near the SMBHs. This should lead to the better understanding of the astrophysical environment of SMBHs and help interpret the current astronomical observations of nearby galactic nuclei. A background in applied mathematics or theoretical physics is a must.

Category **A**

## How fast do old stars rotate inside?

**Supervisors:** Professor Alexander Heger, Professor John Lattanzio & Professor Paul Cally

The Kepler satellite mission became famous for finding hundreds of new planets around stars. To do so, it had to monitor them in minute detail, including all variations and oscillations of the star. Amazingly, the data was good enough to use seismology, similar to what we do on earth to determine its interior structure, or for the sun ("helioseismology"), to determine the interior structure and rotation rate of evolved -

old - stars that approach the end of their life. For the Sun, we can easily observe how fast it rotates on the surface, and we know that the same rotation rate, on average, is maintained all the way to the centre. But for all other stars, the interior rotation rate was not known to date. But now we have observations. The big question is whether our current model for transport of angular momentum and stellar evolution is good enough to explain this data. Having this data is a unique new opportunity to test physical models for the action of rotation inside stars.

The goal of this project is to model the evolution of a star like the long past its current age until the Red Giant and Horizontal Branch evolution phases. The project will use a modern stellar evolution code, and the code would also be modified to test different physics models for the action of magnetic dynamos and hydrodynamic instabilities due to rotation. The results will be compared to the observational data.

**References**


[1] http://adsabs.harvard.edu/cgi-bin/nph-data_query?bibcode=2005ApJ...626..350H

[2] http://adsabs.harvard.edu/cgi-bin/nph-data_query?bibcode=2002A%26A...381..923S


Category **A**

## How the oldest stars known were made

**Supervisors:** Professor Alexander Heger,
Dr Aldeida Aleti & Mr Steven Mascaro (Information Technology)

After the Big Bang it took about 300,000,000 yr before the first stars formed - now some 13,000,000,000 yr ago. Unfortunately, we can no longer observe these stars today directly, even with our best telescopes. But there is still some "fossil" record of them left behind, preserved in the oldest stars in our galaxy we can observe, dating back to pre-galactic times. When the first stars exploded as supernovae, their ashes were dispersed and the next generation of stars formed, incorporating some of these supernova debris. We can now measure these abundance patterns in those old stars (in particular done by astronomers in Australia, including Physics Nobel Laureate Brian Schmidt, and using telescopes here in Australia and the largest telescopes in the world in Hawaii and Chile). In fact, we have a rapidly growing catalogue of them. Hence to some extent, the abundance patterns are similar to a genetic fingerprint that allows us to identify our parents.

The goal of this project is to identify the "parents" of these old stars in our galaxy, i.e., find out about the now "extinct" first stars in the universe - what their properties where, how they lived and died, and in particular, how many parents there were, how different or how alike or different they were. You will be using a data base of predicted abundance patterns of supernovae from the first generation of stars to compare with the elements observed in the old stars. A particular goal will be to assess the likelihood of multiple stars fits as compared to the extra degrees of freedom introduced. This could be done, for example, using metricates like the minimum message length or Bayesian networks. You may also develop and employ new methods for optimal pattern matching using as much of the information available from observational data as possible.

**References**

[1] Nature, 506, 7489 (2014)

[2] 2010ApJ...724..341H

[3] 2002ApJ...567..532H

Category **A**

## Inhomogeneous cosmology in an anisotropic universe

**Supervisors:** Dr Daniel Price **&** Dr Paul Lasky

What if the accelerating expansion of the universe is just an artefact of assuming a perfectly homogeneous and isotropic universe? In this project we will try to test this hypothesis by performing numerical relativity experiments of model universes to see if the expansion rate is affected by the presence of structure.

Category **A**

## Making carbon in the universe: implications for life?

**Supervisor:** Professor John Lattanzio

This project will look at the production of carbon by red-giants. The aim will be to take the results from detailed stellar evolution calculations and include these in a new code which simulates the evolution of an entore Galaxy. With some simple approximations, we can produce a "population synthesis" code which can model a large population of stars. Then we can investigate the effect of binary stars, mass-transfer from one to another, the effect of mass-loss etc etc. It is possible, if time permits, to also include other species so we can look at the production of Oxygen also. This has many implications for the appearance of life in the Universe - planets forming in a carbon-rich environment are very different to those forming in a oxygen-rich environment!

This would be a good project for someone who wanted to improve their skills at computer programming: it will start with a very simple code to which you will add more and more and build it into a substantial piece of work.

Category **A**

## Mixing at the core flash

**Supervisors:** Professor John Lattanzio & Dr Simon Campbell

When a red-giant reaches the top of the giant branch, the temperatures in the core are high enough for He burning to begin. In a star with a degenerate core, this ignition is explosive. Some recent observations seem to indicate that mixing may be initiated that brings the products of the explosive burning to the surface. Some RR Lyrae variables (post-core flash objects) are rich in Carbon (produced at the flash). Some other post-core-flash stars seem rich in Lithium. Can we make lithium at the flash? In this project we will investigate explosive mixing in red-giants and see if we can mimic a situation that might explain these observations.

Category **A**

## Mixing in red giants

**Supervisor:** Professor John Lattanzio

We will investigate the implications some extra-mixing in red-giant stars. How does this affect the surface values of carbon isotopes? Does it affect other species? What do the observations require? How deep is the mixing? What nuclear processes are enabled as a result of the mixing?

Category **A**

## Mixing in red giants – attacked with telescopes and computers

**Supervisors:** Professor John Lattanzio & Dr Simon Campbell
and
Valentina D'Orazi (Monash) / Sara Martell and Gayandhi de Silva (AAO, Sydney)

Red-giants are fascinating stars and they continue to provide us with problems that as yet have no solutions. One of these concerns mixing as they stars climb the giant branch. The standard models do not predict as much mixing as is seen in the data. We recently discovered a mechanism that is likely to be involved in the solution of this problem, but there are aspects of the mechanism that are still unknown. We are trying to tackle this problem by combining observations and theoretical models. We will be taking new data in December for stars in the globular cluster NGC1851.

This project involves both running stellar models, so that the student investigates the theory of thermohaline mixing, as well as reducing data taken with Australia's largest telescope. This will likely involve a trip to the Australian Astronomical Observatory (AAO) to work with the co-supervisors in Sydney. The aim is to compare the observed data with the models run at Monash.

**References**


[1] Lardo, et al., 2012, Astronomy and Astrophysics, 541, p141

[2] Angelou et al., 2012, Astrophysical Journal, 749, p128

[3] Eggleton et al., 2006, Science, 314, p1580


Category **A**

## Nearby AGNs in the mid-infrared

**Supervisor:** A/Professor Michael Brown

Active galactic nuclei (AGNs) are located at the centres of galaxies and powered by the in-fall of gas towards a super-massive black hole. Often these objects are heavily obscured by gas and dust, largely hiding them from view. The mid-infrared wavelength range provides a powerful means of studying AGN, as the obscuring dust is heated by photons from the AGN and the dust radiates this heat at wavelengths of tens of microns. Using Spitzer mid-infrared images of nearby galaxies, we will measure the mid-infrared emission of AGNs and (more extended) mid-infrared emission resulting from star formation. This will allow us to measure the luminosity of the AGNs and the star formation rates of their host galaxies, allowing us to see if there is a meaningful connect between the two.

**References**


[1] Alonso-Herrero et al.. 2014, MNRAS, 443, 2766 (arXiv:1407.1154.)

[2] Brown et al.., 2014, ApJS, 212, 18 (arXiv: 1312.3029).

[3] Mason et al.., 2012, AJ, 144, 11 (arXiv: 1205.0029).


Category **A**

## Nucleosynthesis during the core helium flash

**Supervisor:** Professor John Lattanzio

After a star exhausts its central H supply it becomes a red-giant. For low mass stars this He core becomes electron-degenerate and continues to heat. When the temperature reaches about 100 million degrees we find helium burning is ignited. But due to the degenerate equation of state, this is almost explosive. The star generates about one billion times the energy of our Sun, but just for a few days. The structure of the star changes dramatically, of course. Although the details are very complicated, we know that most stars survive this phase, as we see them in the next stage of their lives.

Standard calculations with the standard assumptions (hydrostatic equilibrium, instantaneous convective mixing) seem to get through this phase, although clearly the details require multi-dimensional hydro-dynamical calculations. Nevertheless, since models made with these assumptions match the later phases, these standard assumptions must be OK for most stars. In this project you will evolve stars through this phase using a stellar evolution code, investigating the uncertainties in the calculations. Further, a separate code calculates the detailed nuclear reactions occurring and we will investigate the reactions and possible mixing mechanisms. Are there observational tests we can apply to the models?

Category **A**

## Optical site testing for future robotic telescopes

**Supervisors:** Dr Duncan Galloway & Professor Karl Glazebrook (Swinburne)

Demand for future optical observing facilities dedicated to survey and fast-response followup is only likely to increase. One such facility is the Gravitational wave Optical Transient Observatory (GOTO), a project aimed at detecting the electromagnetic counterparts of binary inspiral events detected with the Laser Interferometric Gravitational-wave Observatory (LIGO), expected from 2015 onwards. GOTO 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 is focussed on measurements of the astronomical "seeing", both the degree of blurring of stellar images by the atmosphere, and the brightness of the sky. Portable test equipment will be deployed at candidate sites to obtain empirical values for the seeing, and verify the remote measurements. The student will visit the observing sites to assist in data collection, and analyse the CCD data to estimate the seeing. Experiments at existing telescope sites will also be necessary to calibrate the test equipment.

Further reading: Hotan et al.. 2013, http://dx.doi.org/10.1017/pasa.2012.002

Category **A**

## Probing neutron stars via thermonuclear bursts

**Supervisor:** Dr Duncan Galloway

Studies of thermonuclear (X-ray) bursts in accreting neutron stars have historically relied on short observations of individual sources, resulting in (usually) a handful of bursts. Another approach is to gather large numbers of bursts from multiple sources and telescopes, and analyse the resulting combined sample to better understand the physics of this phenomena. Such an effort is currently underway at Monash with the Multi-INstrument Burst ARchive (MINBAR), which presently consists of approximately 2200 bursts from NASA's *Rossi X-ray Timing Explorer* satellite as well as the defunct Dutch/Italian mission *BeppoSAX*. The principal efforts at present are to add bursts in public data observed by the JEM-X camera onboard ESA's *INTEGRAL* satellite, likely adding another 2000 events and with new observations continually being added. The catalog, once complete, will prove a vital resource for studies of thermonuclear bursts and will be released to the public.

This project will involve analysis of burst data, cross calibration, and verification for addition to the burst sample. It is expected that the student will also work on burst data from newly-discovered transient neutron stars through the course of the project, and collaborate on papers resulting from this work.

This project will primarily involve analysis of reduced data from the various X-ray satellites with IDL. Opportunities exist for work with project partners at SRON (Netherlands) and DTU Space (Denmark).

Category **A**

## Exoplanets
## Resonance capture during planet formation

**Supervisor:** Dr Rosemary Mardling

Planets are formed in protoplanetary disks, the latter being composed of a mixture of dust and gas. The process involves accumlation of dust into planetesimals, which in turn collide to form planet "cores" which, if massive enough, go on to accrete a massive gas envelope to become gas giants. These nascent planets in turn raise a tide in the disk from which they form. Such a tide will be in the form of a spiral density wave, and since the associated density enhancement is non-axisymmetric, it will exert a torque on the planet and hence exchange angular momentum with its orbit.

The latter process is called planet migration. It causes the planet to move towards or away from the star, depending on the "balance of torques" (there will be perturbations to the planet's orbit coming from the interior and exterior portions of the disk), and in some cases such torques will balance and the planet will remain stationary (at least on some timescale which is probably short compared to the lifetime of the disk).

In the case that there is more than one planet (which is surely the general case), the rates of change of their semimajor axes will in general be different. As such, the ratio of the orbital periods will either increase ("divergent migration") or decrease ("convergent migration"). In the latter case, the planets would collide if it weren't for a beautiful process called *resonance capture* which prevents this from occurring.

This project will study the process of resonance capture with a view to understanding the period-ratio distribution of exoplanetary systems, especially those discovered by the Kepler space telescope. This is a prominent unsolved problem in exoplanet science, and its solution will give us deep insight into the process of planet formation.

Category **A**

## Searching for gravitational waves from neutron stars in binary systems

**Supervisor:** Dr Eric Thrane

The newly upgraded Advanced LIGO gravitational-wave detectors are set to begin taking science quality data in the next year. Spinning neutron stars are one of the most promising sources for gravitational-wave detection by LIGO. When neutron stars emit radio waves as pulsars, it is relatively straightforward to carry out a gravitational-wave search using a technique called matched filtering. Electromagnetically quiet neutron stars in binary systems, on the other hand, pose a significant data analysis challenge since the unknown signal evolution is complicated by additional binary motion. In this project, we will adapt a previously developed technique, the narrowband radiometer, in order to search for gravitational waves from spinning neutron stars in binary systems. The student will help develop and test Matlab code on LIGO data to estimate future sensitivity and to look for gravitational waves.

Additional reading:
http://journals.aps.org/prl/abstract/10.1103/PhysRevLett.107.271102
http://arxiv.org/abs/1109.1809

Category **A**

## Spectroscopy and the composition of stars in globular clusters

**Supervisor:** Professor John Lattanzio

Globular clusters are the oldest and most populous stellar aggregates in existence. Recent studies have shown that the stars in globular clusters show abundance patterns that are unique to the clusters. We do not know why they are not seen in the Galaxy, but only within the globular clusters. They may even be the remnants of collisions between dwarf Galaxies and our Milky Way. A fuller understanding requires us to determine the abundances of many stars in many clusters and to compare with theoretical models so we can see what stars produced the existing patterns.

We will source original data form the world's largest telescopes and then analyse this to determine the abundances of key species in globular cluster stars: perhaps Li, C, N, O, Mg, Al, Fe as well as the heavy elements made by neutron capture, such as Sr, Y, Zr, Ba, La. Stellar models that can produce these species will be compared with the abundances we measure.

This project will involve travel to the Australian Astronomical Observatory (in Sydney) to visit and work with Dr de Silva. There is also the opportunity to visit the 4m Anglo-Australian Telescope in Coonabarabran, NSW.

Category **A**

## Stellar population synthesis

**Supervisors:** Professor John Lattanzio & Dr Simon Campbell

Stars are born in clusters. These are very valuable tools for learning about stellar processes, because they provide us with a large number of stars, all born at the same time, but with different masses. Hence we can do statistical studies to understand what is happening to the stars. However, detailed stellar models take a lot of computer time. Yet it is possible to make some approximations that are very accurate, informed by the results of detailed models, which enable us to produce a statistical model of a cluster of stars. This is called "Population Synthesis". One application of this is to investigate the evolution of red-giants that become carbon stars. Does the predicted distribution match what we see in real clusters?

Skills required: Some interest in programming is needed. That could be fortran or another high level language, or even MATLAB or something similar. Some astronomy would be an advantage, especially second year units. But is not essential.

Category **A**

## Supercomputer simulations of superbursts

**Supervisors:** Professor Alexander Heger, Dr Duncan Galloway, Dr Yuri Levin and Dr Bernhard Mueller

Many stars are not single stars like the sun, but are born as binary stars, two stars in a close orbit about each other. If one of the stars is "massive," more than about ten times the mass of the sun, it may end is life in a supernova and leave bind a neutron star. In some cases where the other star in the system is of lower mass, and hence loves longer, the orbit could be tight enough that as this star evolves it swells up enough to transfer mass to the neutron star. The accreted mass accumulates in a layer at the surface, in some cases periodically igniting in a flash observed as Type I X-ray burst. These bursts leave behind ashes that accumulate - very few things ever escape from the surface of a neutron star. When the ashes layer gets quite thick, it may burn in a powerful flash called **superburst**, fuelled by the carbon left behind in the ashes.

You will use a two-dimensional hydrodynamic code to simulate the thermonuclear runaway and the explosion of such superbursts. You will follow the onset of nuclear burning through the thermonuclear runaway to the formation of a shock wave that travels to the surface of the stars where then a superburst can be observed. The question to answer is how character of the burst and the transitions depend on the neutron star properties and of the accreted layer.

**References:**


[1] 2004ApJS..151...75W

[2] 2003ApJ...599..419N

[3] 2001ApJS..133..195Z

[4] 2012ApJ...752..150K


Category **A**

## Supernovae making neutron stars or black holes?

**Supervisors:** Professor Alexander Heger & Dr Bernhard Mueller

When a massive star reaches the end if its life, the core collapses into a neutron star or, possibly, a black hole. In many cases, at first a shock is launched moving outward, ejecting the outer layers of the star. But there may not be enough energy to eject the entire core, or there can be hydrodynamic interactions in the envelope that push some of the matter onto the central object. How much of the material falls back will determine the final mass of the compact remnant that is left behind. If the mass exceeds the maximum mass for a neutron star, it will collapse to a black hole.

For this project you will use an analytic model for supernova explosions and their energies to simulate the explosion of these stars. You will then use a one-dimensional hydrodynamic code modified for proper inner boundary conditions, to simulate the dynamics of the explosion and how much mass is ejected or fall back. This will allow you to estimate the remnant mass (some of the rest mass is carried away by neutrinos). Using a range of supernova progenitor models, you can make perditions about the distribution of neutron star and black hole masses.

**References**


[1] 2008ApJ...679..639Z

[2] 2012ARNPS..62..407J

[3] arxiv.org/abs/1409.0540

[4] 2002RvMP...74.1015W

[5] 2003ApJ...591..288H


Category **A**

## Supermassive Stars: Explode or Die

**Supervisors:** Professor Alexander Heger & Dr Yuri Levin

One of the biggest puzzles in understanding the formation and structure of Galaxies are the huge black holes in their centres. Some of them have a billion time the mass of the sun, even when they are only a tenth of their percentage. One, highly speculative, theory is that they may start as the collapse of supermassive stars of maybe a million times the mass of the sun, from the first, or very early, generation of stars that precede the first galaxies ("pre-galactic stars"). Whereas supermassive stars of primordial composition either undergo hydrostatic burning or collapse to black hole, stars that have some enrichment in material from a previous generation of stars may instead explode, probably the most powerful explosions in the universe other than the big bang itself. But where exactly are the boundaries between explosion, collapse, and hydrostatic burning?

The goal of this project is to find the boundaries between hydrostatic burning, thermonuclear explosion, and collapse to a black hole for supermassive stars, i.e., stars of some 100,000 times the mass of the sun. The student will use a hydrodynamic stellar evolution code that includes thermonuclear burning and post-Newtonian corrections for general relativity for non-rotating stars. The simulations will start with stars of different initial mass and different initial composition and will follow the early evolution of supermassive stars until they either collapse, explode, or reach hydrostatic burning. One possible extension of the project is to modify the stellar evolution code to include post-Newtonian corrections for rotating stars; another extension could be to follow the neutrino signal of collapsing stars and the neutrino-induced nucleosynthesis in the envelope of the star, as well as a possible explosion due to the mass carried away by the neutrinos.

**References**


[1] http://adsabs.harvard.edu/cgi-bin/nph-data_query?bibcode=2011JPhCS.314a2077M

[2] http://adsabs.harvard.edu/cgi-bin/nph-data_query?bibcode=2012ApJ...749...37M

[3] http://adsabs.harvard.edu/cgi-bin/nph-data_query?bibcode=2001ApJ...552..459H
[4] http://adsabs.harvard.edu/cgi-bin/nph-data_query?bibcode=1986ApJ...307..675F

Category **A**

## The ages of the star clusters

**Supervisors:** Professor John Lattanzio & Dr Simon Campbell

Stars are largely born in clusters. They are mostly born at the same time - the spread is usually very small, certainly small compared to the lifetime of a star. Hence a star cluster represents a collection of stars of the same age but different masses. When we observe such a cluster in the HR diagram we are seeing a superposition of many evolutionary points for lots of different masses but at the same age. When we calculate stellar evolution we select a mass and calculate how the star ages. To compare with a cluster we need to interpolate within the individual tracks to find how they would all look at the same age. Such a line in the HR diagram is called an "isochrone". In this project you will devise a good way to interpolate within existing evolutionary tracks to determine how cluster of different ages will look. If time permits we can compare with some real clusters and get estimates for the age of the cluster.

Category **A**

## The clustering of HI (21cm) galaxies

**Supervisor:** A/Professor Michael Brown

Neutral hydrogen (HI) is the fuel for star formation, and while it is found in abundance in some galaxies, it appears to be largely absent in others. Why this is the case is not entirely clear. A dependence on environment is highly likely, as neutral hydrogen gas can be tidally stripped from galaxies as they enter clusters of galaxies. How galaxies populate particular environments can be ascertained by measuring how galaxies cluster together. Galaxies that reside in massive clusters with be strongly clustered together while galaxies residing in the sparsely populated "field" environment will be weakly clustered.

The clustering of HI galaxies has not been explored in detail, as the sample sizes are currently relatively small. We will improve upon current studies of HI galaxy clustering by studying how optically selected galaxies cluster around HI selected galaxies. This will allow us to model when HI is stripped from galaxies and in which environments this occurs. This will provide important insights into how gas content and star formation are regulated within galaxies. The methods developed in this work will be directly applicable to upcoming surveys with the Australian Square Kilometre Array Pathfinder.

**References**

[1] Brown et al.., 2008, ApJ, 654, 858.

[2] Croton et al.., 2006, MNRAS, 365, 11 (arXiv:astro-ph/0407537).

[3] Meyer et al.., 2007, ApJ, 654, 702.

Category **A**

## The fate of the biggest stars

**Supervisors:** Professor Alexander Heger, Dr Bernhard Mueller & Dr Anthony Lun

One of the biggest puzzles in understanding the formation and structure of Galaxies are the huge black holes in their centres. Some of them have a billion time the mass of the sun. One, highly speculative, theory is that they may start as the collapse of supermassive stars of maybe a million times the mass of the sun, from the first, or very early, generation of stars that precede the first galaxies ("pre-galactic stars"). Whereas supermassive stars of primordial composition either undergo hydrostatic burning or collapse to a black hole. Stars that have some enrichment in material from a previous generation of stars may instead explode, probably the most powerful explosions in the universe other than the Big Bang itself. But where exactly are the boundaries between explosion, collapse, and hydrostatic burning?

The goal of this project is to find the boundaries between hydrostatic burning, thermonuclear explosion, and collapse to a black hole for supermassive stars, i.e., stars of some 100,000 times the mass of the sun. You will use a hydrodynamic stellar evolution code that includes thermonuclear burning and post-Newtonian corrections for general relativity for non-rotating stars. The simulations will start with stars of different initial mass and different initial composition and will follow the early evolution of supermassive stars until they either collapse, explode, or reach hydrostatic burning. A possible extension of the project is to modify the stellar evolution code to include post-Newtonian corrections for rotating stars.

**References:**

[1] 2011JPhCS.314a2077M

[2] 2012ApJ...749...37M

[3] 2001ApJ...552..459H

[4] 1986ApJ...307..675F

Category **A**

## The first dredge-up in stars in metal-poor globular clusters

**Supervisors:** Professor John Lattanzio & Dr Simon Campbell

Globular Clusters are among the oldest objects in the Universe. The stars in them show abundance patterns that are not seen in any other known stars! Various models have been proposed to explain this with varying degrees of success. But recently we have discovered that the most metal-poor globular clusters seem to show that the stars are behaving in a way that is not consistent with our understanding of the first dredge-up event on the giant branch. The stars seem to be mixing down to depths much deeper than predicted. In this project we will investigate the depth of mixing and how it varies with mass and composition in the range appropriate to these stars. We will investigate possible ways to make the mixing deeper.

Category **A**

## The formation of supermassive black holes

**Supervisors:** Professor Alexander Heger, Dr Bernhard Mueller & Dr Anthony Lun

One of the biggest puzzles in understanding the formation and structure of Galaxies are the huge black holes in their centres. Some of them have a billion time the mass of the sun. One, highly speculative, theory is that they may start as the collapse of supermassive stars of maybe a million times the mass of the sun, from the first, or very early, generation of stars that precede the first galaxies ("pre-galactic stars"). Models of supermassive stars of primordial composition suggest that these either undergo hydrostatic burning or collapse to a black hole. But these stars do not form at once, but rather start from a small core that accretes mass at a high rate, as current simulations of early start formation suggest, until a super-massive star is built up.

The goal of this project is to find how such stars with primordial composition and high accretion rates evolve and approach the point of collapse to a supermassive black hole, as a function of this accretion rate. And, in particular, what the mass of the star is by the time it collapses, i.e., what is the mass of the black holes formed. For example, is there an upper mass limit, and is this different from the one obtained for stars with a given fixed initial mass (see other project).

**References:**


[1] 2011JPhCS.314a2077M

[2] 2001ApJ...552..459H

[3] 1986ApJ...307..675F

[4] 2013ApJ...777...99W

Category **A,P**

# The holographic Universe

**Supervisor:** A/Professor Csaba Balazs

Astrophysical observations indicate that about 70 percent of the Universe is made up by a substance with negative pressure, popularly referred to as "dark energy". The only known substance with negative pressure consists of quantum fluctuations. It is also known that the Universe contains a substantial amount of quantum fluctuations. However, quantum field theory cannot predict the energy density of quantum fluctuations. Thus the measured energy density of the Universe is a complete mystery.

The holographic principle restricts the energy density of any gravitating systems. In this project, we study how the holographic constraint can be imposed on a quantum system. Since the root of the problem is the infinite number of degrees of freedom in a quantum field, we investigate how to limit the number of degrees of freedom in a quantum field in a holographic manner.

**References:**


[1] P. Horava, Quantum Gravity at a Lifshitz Point, arXiv:0901.3775.

[2] C. Charmousis, G. Niz, A. Padilla, P. M. Saffin, Strong coupling in Horava gravity, arXiv:0905.2579.

[3] M. Li, Y. Pang, A Trouble with Horava-Lifshitz Gravity, arXiv:0905.2751.

[4] E. Verlinde, On the Origin of Gravity and the Laws of Newton JHEP 1104:029,2011.

[5] T. Banks, TASI Lectures on Holographic Space-Time, SUSY and Gravitational Effective Field Theory, arXiv:1007.4001.

[6] R. Bousso, TASI Lectures on the Cosmological Constant, arXiv:0708.4231.

[7] J. Martin, Everything You Always Wanted To Know About The Cosmological Constant Problem (But Were Afraid To Ask), arXiv:1205.

Category **A**

## The slow neutron capture process from proton-ingesting episodes and the chemical composition of post-asymptotic giant branch (AGB) stars

**Supervisors:** Dr Simon Campbell

The abundances of the elements heavier than iron in post-AGB stars cannot be explained by current models of slow neutron captures in AGB stars (see references below). This project investigates the hypothesis that these abundances are the signature of proton-ingestion episodes driven by overshoot in He-burning convective regions. It involves computing stellar structure models of stars of 1.3 solar masses and metal content ~ solar/10 (to match the properties of the observed post-AGB stars) including a parametrized proton-ingestion episode to derive detailed predictions for the abundances of the elements from carbon to lead. Comparison of the results with the post-AGB star observations will allow us to understand if this is a viable hypothesis, generating new knowledge on the slow neutron capture process and on mixing in stars.

**References**


[1] de Smedt et al.. 2012, Astronomy & Astrophysics, Volume 541, id.A67.

[2] van Aarle et al.. 2013, Astronomy & Astrophysics, Volume 554, id.A106.


Category **A**

## The Spectra of active galactic nuclei

**Supervisors:** A/Professor Michael Brown

To determine the luminosities of distant celestial objects, we need to have models or templates of their spectra. Without such models and templates, gross errors can result in object luminosities. We have recently produced an atlas of 120 galaxy spectra spanning from the ultraviolet (0.1 micron) through to the infrared (30 micron). However, this atlas does not contain objects which significant emission from active galactic nuclei (powered by accretion towards black holes). We will produce an atlas of ten spectra of active galactic nuclei, combining data from satellites and ground-based telescopes. The atlas will enable astronomers to determine the luminosities of active galactic nuclei, and to model how the observed colours of these objects change as a function of redshift.

References


[1] Brown et al.., in prep. ApJSS.

[2] Landt et al.., 2011, MNRAS, 414, 218 (arXiv: 1101.3342).

[3] Hatziminaoglou et al.., 2005, AJ, 129, 1198.

Category **A**

## Thermonuclear bursts from millisecond pulsars

**Supervisor:** Dr Duncan Galloway

Millisecond X-ray pulsars consist of a rapidly-rotating neutron star accreting material from a low-mass stellar companion. These objects typically exhibit transient activity, becoming X-ray bright for a few weeks every few years. Thermonuclear bursts, caused by unstable ignition of the accreted material, are observed around the peak of the outburst, with burst recurrence times of order 10~hr or so.

These objects are a high priority for observers, and a substantial dataset of high-quality observations has been gathered over the last ten years by a number of missions, including NASA's Rossi X-ray Timing Explorer and Swift satellites, as well as ESA's INTEGRAL satellite. This project will involve matching the observed burst behaviour and properties to the predictions of numerical models, to infer the system properties, including distance and composition of accreted fuel. Because the bursts occurring in these neutron stars are also sensitive to the properties of the underlying crust and core, these comparisons may also allow a probe of the thermal properties of the crust.

**References:**

[1] Galloway & Cumming 2006, Astrophysical Journal 652, 559 (available at http://adsabs.harvard.edu/abs/2006ApJ...652..559G)

Category **A**

## Tidal disruption – stars being eaten by black holes

**Supervisor:** Dr Daniel Price & Dr Duncan Galloway

What happens when a star wanders too close to a black hole? We will perform 3D numerical simulations of the passage of a star close to a supermassive black hole near the centre of a galaxy. In particular, we will determine the effect of the black hole spin and whether or not nuclear reactions ignite during the passage.

Category **A**

# Exoplanets
# Transit timing variations (TTVs) in the Kepler planet candidates

**Supervisor:** Dr Rosemary Mardling

Before the Kepler space telescope was launched, the vast majority of exoplanet detections were made using the *Radial Velocity method*. This spectrocopic method measures the minute Doppler shifts in all available stellar spectral lines, and allows one to measure the *minimum mass* of the planet responsible for the motion of the star as long as one has a good estimate for the latter. In contrast, the *transit method* of detection is a photometric method which measures the deficit of photons when a planet passes across the face of the star being observed. This allows one to estimate the *radius* of the planet as long as one has a good estimate for the radius of the star. Thus the RV and transit methods are complementary, and if one detects a system both ways, one can estimate the *mean density* of the transiting planet. In turn, this allows one to say something about the likely internal structure of the planet, an amazing fact which has attracted geoscientists to join the burgeoning field of exoplanets.

Kepler has used the transit method to detect thousands of planet *candidates*, but unfortunately the Kepler field is very distant and so most of their host stars are too faint to follow up with RV measurements. [Kepler is not a "pointing telescope" (its field of view is fixed) and so a field towards the crowded Galactic centre was chosen to optimise the number of target stars.] Without RV follow-up, it is generally not possible to measure the planet's mass, and since there are "non-planet" ways to produce a planet-like signal (for example, if the star is orbited by a distant close binary), one cannot *confirm* the planetary nature of the detection. Fortunately, there are quite a few bright stars with planet candidates in the Kepler field which are amendable to RV analysis, and since their planet transit, their actual masses and hence their densities have been determined. However, the vast majority of candidates are not in this category.

This would have been a disaster for the Kepler mission had it not been realised that the presence of a second planet could reveal itself through the perturbations it causes to the *timing* of the observed transit, in particular, to the time at which the planet crosses the midline of the star *even when the second planet is not detectable (by transiting itself or by RVs)*. By forming a time series of these transit timing variations, one is then able to use it to deduce (in favourable cases) many of the orbital parameters of the whole system including the planet masses.

TTVs have been a boon to the Kepler mission, but the vast majority of planets candidates still remain just that - candidates. This project will use new mathematical methods to reveal the planetary nature of some of these systems, thereby adding to our knowledge of the rich variety of planets and planetary system architectures revealed by Nature so far.

Category **A**

## Weak helium flashes in accreting neutron stars

**Supervisors:** Dr Daniel Price and Dr James Wurster

Many stars are not single stars like the sun, but are born as binary stars, two stars in a close orbit about each other. If one of the stars is "massive," more than about ten times the mass of the sun, it may end is life in a supernova and leave bind a neutron star. In some cases where the other star in the system is of lower mass, and hence loves longer, the orbit could be tight enough that as this star evolves it swells up enough to transfer mass to the neutron star. The accreted mass accumulates in a layer at the surface, and usually stars some burning immediately (hot CNO cycle). When the layer gets thick enough, it may burn in a brief powerful flash burning material all the way to quite heavy material. This is observed as a Type I X-ray burst. If the accretion is very slow, however, the layer may be so cool, the burning does not start immediately, and when it starts, it may just start hydrogen burning, then subside. Only after several of these weak flashes, a more powerful burst might result.

We will use a hydrodynamic stellar evolution code including an extended nuclear reaction network to follow the accretion and burning flashes. The goal is to explore the regime of weak flashes and where they occur and what is their behaviour as a function of neutron star properties and accretion rate and composition (originating from the companion star). A possible extension of the project is to implement the physics of gravitational settling in the present code.

**References**


[1] http://adsabs.harvard.edu/cgi-bin/nph-data_query?bibcode=2004ApJS..151...75W

[2] http://adsabs.harvard.edu/cgi-bin/nph-data_query?bibcode=2010ApJ...725..309P

[3] http://adsabs.harvard.edu/cgi-bin/nph-data_query?bibcode=2003ApJ...599..419N

[4] http://adsabs.harvard.edu/cgi-bin/nph-data_query?bibcode=2007ApJ...654.1022P


Category **A**

## What are the initial conditions for planet formation

**Supervisors:** Dr Daniel Price and Dr James Wurster

In this project we will model how dust from molecular clouds ends up in protoplanetary discs. We will use our PHANTOM code to perform simulations of star cluster formation, similar to earlier calculations, but here we will model the dust dynamics as well as the gas. We will study how interstellar dust present in the molecular cloud collects in the disc to provide the initial conditions for planet formation.

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# ATOMIC AND MOLECULAR PHYSICS

Category: **AM, O**

## Anomalous vortex precession in Bose-Einstein condensates

**Supervisor:** Dr Tapio Simula

Superfluids such as Bose-Einstein condensates can support quantized vortices. Such vortices can be made to behave as quantum mechanical gyroscopes by exciting Kelvin waves along the vortex line.

The aim of this computational and theoretical project is to investigate an anomalous phase shift predicted to be observable in the gyroscopic motion of a quantized vortex placed in a superfluid Bose-Einstein condensate when the condensate is focussed using atom-optical techniques.

Category: **AM**

## Atom based potentials for atomtronics

**Supervisor:** Professor Kris Helmerson

Atomtronics is an emerging research area that seeks to develop devices that will exploit the unique properties of ultracold atoms to deliver benefits over conventional technologies. Potentials based on optical fields are currently used to manipulate and pattern ultracold atoms, which limits feature sizes to the wavelength of light. This project would investigate potentials for ultracold atoms based on atom-atom interactions. In this manner, we can realize corrals, interfaces, barriers and junctions for ultracold atoms that can be more than 10 times finer than what can be currently achieved. Of particular interest is the realization of an atom-based Josephson tunnel junction for use in an atomic SQUID device.

Category: **AM, O**

## Atom-optical matter wave diffraction catastrophes

**Supervisor:** Dr Tapio Simula

When waves pass through, for example, an acoustic, optical or gravitational lens, the imperfections of the lens cause the emerging wave field to be aberrated. These aberrations lead to the formation of caustics. Hidden inside the caustics there are vortices, which form as a consequence of multi-wave interference.

The aim of this computational and theoretical project is to investigate such lensing and aberrations in nonlinear matter waves using Bose-Einstein condensates and to study the vortex structures.

Category: **AM, M**

## Atomic relaxation modelling of ionised elements from low energy photon interactions

**Supervisor:** Dr Marcus Kitchen

Monte Carlo modelling of radiation transport is a vital tool utilised throughout physics to explore the impact of radiation on matter, design/optimise large scale experiments and develop/prototype novel technology. Of the available Monte Carlo radiation transport platforms, Geant4 [1], a simulation toolkit commissioned by CERN, is the most widely employed. The Monash University arm of the Geant4 Low Energy Electromagnetic Working Group [2], also a member of the Geant-DNA project [3], is focused on the development, and further increasing the accuracy, of photon and electron transport models at low energies (10 MeV down to 10 eV) [4]. The aim of this honours project will be to address the limitation that currently exists in the atomic relaxation models of Geant4 for ionised medium to high Z elements from low energy photon interactions. The participant will undertake a combination of model refinement, experimental work and computational modelling to correct the atomic relaxation models adding to the functionality of Geant4.

**References:**


[1] http://geant4.cern.ch

[2] http://twiki.cern.ch/twiki/bin/view/Geant4/LowEnergyElectromagneticPhysicsWorkingGroup

[3] http://geant4-dna.org/

[4] Brown J. M. C., Dimmock M. R., Gillam J. E. and Paganin D. M., MULECS: The Monash University Low Energy Compton scattering package, IEEE NSS MIC Symp. Record, 1385-1389, 2011.

Category: **AM**

## Atomic sunglasses at the rubidium magic wavelength

**Supervisor:** Dr Lincoln Turner

In this project you will build a matter-wave interferometer using a Bose-Einstein condensate, and use it to measure the "magic wavelength" of rubidium with record precision. Only at the magic wavelength (near 790.035 nm, but you will add another few sig figs), the energy levels of the atom are not shifted by laser light. Lasers at the magic wavelength can probe the spin of BECs with the absolute minimum perturbation of the condensate. Your project will be to pin down the exact magic wavelength using atom interferometry. As part of the project, you will use atom interference to purify the laser polarisation to an extreme state of linearity - making the world's best pair of "atomic" polaroid sunglasses.

Category: **AM**

## Bound states in a heteronuclear fermi gas

**Supervisor**: Dr Jesper Levinson

The development of ultracold atomic gases with tunable interactions and dimensionality has led to a new era of precision studies of fundamental quantum mechanical phenomena. In the context of few-body bound states, experiments have until now focussed on bosons, which display the celebrated Efimov effect, where three identical bosons can form a fractal set of states related by a discrete scaling symmetry. However, such states are inherently unstable, and at present a new generation of experiments are emerging which use two different fermionic species. The interest here is that, unlike bosons, identical fermions naturally feel a centrifugal barrier, which prevents losses and can lead to stable bound states.

When the heteronuclear Fermi gas is confined to one spatial dimension it has been predicted that trimers (bound states of 1 light atom, 2 heavy atoms) can form, while more exotic bound states (p light, q heavy) can exist for a rational density ratio p/q and sufficient mass imbalance [1]. The question which this project will address is whether the same phenomenon can occur in the two-dimensional Fermi gas. Here much less is known, but trimers and tetramers are predicted to exist [2]. The question may be investigated using a combination of scattering theory and Feynman diagrams.

**References:**

[1] E. Burovski, G. Orso, T. Jolicoeur, Phys. Rev. Lett. 103, 215301 (2009).

[2] J. Levinsen and M. M. Parish, Phys. Rev. Lett. 110, 055304 (2013).

Category: **AM**

## Correlations and coherent interactions in quantum metrology

**Supervisor**: Dr Kavan Modi

The aim of this project is to better understand the role of quantum correlations, coherent interactions, and quantum measurements in quantum information processing. Namely, we want know which of these elements lead to the quantum advantage? In specific we will focus on quantum metrology, the science of precision measurements using quantum probes.

Quantum metrology can be split up into three parts: preparing the probe; encoding the parameter in the probe; and measuring the probe (read-out phase). We will explore, when a coherent quantum interaction is necessary in the read-out phase?

Along the way we will study quantum correlations, quantum measurements, and quantum Fisher information in concert with each other. Our goal will be to formalize the connections between these elements and make concrete statements. Our goal is to prove the following statements: For which quantum probes does a local-adaptive decoding suffice? For which classical probes does a local-adaptive decoding suffice? Do all non-pure quantum probes require coherent read-out?

**References**


[1] V. Giovannetti et al.., Phys. Rev. Lett. **96**, 010401 (2006).

[2] K. Modi et al.., Rev. Mod. Phys. **84**, 1655-1707 (2012).

[3] M. Gu et al.., Nature Physics **8**, 671-675 (2012).


Category: **AM, P**

## Dirac monopoles in spinor Bose-Einstein condensates

**Supervisor:** Dr Tapio Simula

Notwithstanding the fact that magnets have two poles, it is not possible to isolate them by cutting a bar magnet in two pieces in order to create two magnetic monopoles. Genuine magnetic monopoles have not been found to date to exist as elementary particles. Monopoles can, nevertheless, be formed as emergent objects.

The aim of this computational and theoretical project is to investigate the so-called Dirac monopoles in spinor Bose-Einstein condensates using the Gross-Pitaevskii theory and to study their properties.

Category: **AM**

# Entanglement in quantum computation

**Supervisor:** Dr Kavan Modi

It is customary to think that correlations are the source for exponential speed-up of quantum computation (so called quantum enhancement). Indeed Jozsa and Linden[1] showed that the growth of entanglement is crucial in *pure state* universal quantum computation. However, intermediate models of quantum computation, i.e., not universal computation, can have little entanglement and still yield exponential speed up over classical computation, see Knill and Laflamme and Datta et al..[2]

Parker and Plenio[6] showed that the Shor's factoring algorithm could be implemented using a single pure qubit, which is not a universal quantum computer. It remains an open question how many standard quantum computation algorithms can be implemented efficiently on an intermediate computer. An example is the (failed) attempt by Santos and Duzzioni[4]. An obvious candidate seems to be the model by Latorre and Sierra[5] of quantum computation of prime number functions. Their algorithm is similar in spirit to Shor's algorithm.

The student will learn about universal quantum computation and intermediate models of computation. You will explore several algorithms that are designed to run on a universal quantum computer. Then you will attempt to find intermediate models of computation that can implement these algorithms efficiently.

**References:**

[1] R. Jozsa and N. Linden, Proc. Roy. Soc. A **459**, (2003).

[2] E. Knill and R. Laflamme, Phys. Rev. Lett. **81,** 5672 (1998).

[3] A. Datta, S. Flammia and C. Caves, Phys. Rev. A **72**, 042316 (2005).

[4] M. M. Santos and E. I. Duzzioni arXiv:1307.6286 (2013).

[5] J. I. Latorre, G. Sierra, arXiv:1302.6245 (2013).

[6] S. Parker and M. B. Plenio Phys. Rev. Lett. **85**, 3049 (2000).

Category: **AM**

# Experiments on two-dimensional quantum turbulence

**Supervisor**: Professor Kris Helmerson

Two-dimensional turbulence is even more fascinating than its three-dimensional counterpart. Here, the turbulent energy is predicted to go into the formation of increasingly larger size eddies and vortices in a so-called inverse energy cascade process. Hence 2D turbulence exhibits a peculiar self-organization, giving rise to order out of chaos. This project will involve investigating two-dimensional turbulence in a superfluid atomic gas (a Bose-Einstein condensate). The turbulent behaviour and emergence of order in the superfluid gas will be studied using a number of techniques including particle imaging velocimetry and observation of Kelvin wave dynamics.

Category: **AM, A**

## Gravitational collapse of boson stars

**Supervisor**: Dr Tapio Simula

In space, the gravitational interaction between particles is responsible for the formation of relatively stable structures of matter such as stars and planets. In the laboratory, a gas of bosons can be held together by confining the atoms using external magnetic or optical potentials, to allow them to be cooled to a Bose-Einstein condensed state. By dressing the condensate atoms in suitably tuned laser fields, it may be possible to mimic gravity for such condensates.

The aim of this computational and theoretical project is to investigate the structure and nonlinear dynamics of gravitationally self-interacting Bose-Einstein condensates by numerically solving the stationary and time-dependent Gross-Pitaevskii equation and to study Bose-nova explosions – superfluid laboratory analogues of supernovae.

Category **AM**

## Modularity of quantum computation

**Supervisor**: Dr Kavan Modi

In conventional programming, if statements are commonly used. For instance,

```
IF r=0 THEN RUN A; ELSE RUN B.
```

We call this the modularity of computation. Programs A and B are available but may be unknown. Nevertheless, in conventional programming can A and B can be called based on the value of some variable r. Suppose that A and B are quantum programs and r is a quantum state. Can we still run programs A and B in a modular fashion dependent on the value of r?

Recent findings show that general this cannot be done [1 2]. It is surprising that very little is known about the extent of modularity of quantum computation. The no–modularity theorem has similar structure as the no–cloning theorem. By this analogy we will search for other no–modularity theorems. Such a theorem will be seen a hindrance to the technological development of quantum technologies. However, note that the no cloning theorem has deep consequence and allows for quantum key distribution. Therefore it is viable the no–modularity theorem could lead to useful tasks of quantum cryptography.

**References:**
[1] Chiribella, D'Ariano, Perinotti, & Valiron. Phys. Rev. A **88**, 022318 (2013).
[2] Thompson, Gu, Modi, & Vedral, arXiv:1310.2927 (2013).
[3] Friis, Dunjko, Dur̈, & Briegel. Phys. Rev. A 89, 030303(R) (2014).

Category **AM**

# Multiphoton ionization of helium

**Supervisor**: Dr Alexis Bishop

There is interest worldwide in focussing a beam of Helium atoms to be used as the probe for a neutral helium beam microscope. One significant hurdle is that Helium is very difficult to detect with high efficiency. Conventional electron-impact ionisation efficiencies are very low (1 x $10^{-4}$) and have poor temporal and spatial resolution.

Due to Helium possessing the highest ionisation energy of any atom, optically accessible transitions between levels are in the extreme UV (58 nm), a wavelength not able to be generated by any conventional laser source. Recent preliminary experiments have shown that detection of helium can be achieved using non-resonant multiphoton ionisation techniques combined with microchannel plate detectors that can count single charges. The technique allows the detection of helium with a spatial resolution of microns and with nanosecond time resolution.

The extreme nonlinearity of the process (7 photon transition) means that extreme intensities on the order of 1 x $10^{17}$ W/m$^2$ are required, which requires focusing the beam from a high energy pulsed UV laser source. Saturation of the ionisation signal can be used as a convenient marker for calibrating the ionisation process which aids determination of the order of the nonlinearity [1].

This experimental project involves characterising the ionisation process and making absolute number density measurements of helium in both a reservoir and supersonic helium beam using a highly focused high-energy pulsed laser source.

**Reference:**
[1] N.E. Schofield, D.M. Paganin, A.I. Bishop, Beam diagnostics for Helium beam microscopy, Poster TH101, ICAP2010, Cairns, Australia 2010.

Category: **AM, P**

## Non-Abelian fractional vortices in vector Bose-Einstein condensates

**Supervisor**: Dr Tapio Simula

Conventional quantized vortex filaments naturally emerge in rotating superfluids described by scalar order parameters. The collision of two such vortex filaments typically leads to a vortex reconnection process. For certain vortex types in vector superfluids such vortex reconnections have been predicted to be topologically forbidden leading to the formation of vortex-rung-networks.

The aim of this computational and theoretical project is to investigate fractional-charge quantized vortices in vector Bose-Einstein condensates and, in particular, to study the non-Abelian collision dynamics and rung formation of such fractional vortices.

Category: **AM, C**

## Optical Lattices for ultracold atoms

**Supervisor**: Professor Kris Helmerson

Ultracold atoms can be trapped in an optical lattice, the periodic potential formed by optical standing waves. The atoms in the optical lattice exhibit behavior similar to electrons in an ideal crystal. By including the interaction of the atoms, such a system can be used to study many-body phenomena traditionally in the realm of solid-state physics. This project will investigate the emergence of many-body behaviour of particles as various parameters such as interaction strength and disorder as varied in this model system.

Category: **AM**

## Probing magnetic-dipole radiative shifts in a Bose-Einstein condensate

**Supervisors:** Dr Lincoln Turner & Dr Russell Anderson

How well we can measure space and time drives the evolution of technology, and our understanding of the physical universe. Bose-Einstein condensates (BECs) – the coldest matter known – are a new type of quantum sensor allowing exquisite measurements of gravity, time, and electromagnetic fields. Understanding the interaction between atoms and light dictates the utility of such precision measurements, and this project will investigate the effect of microwave and radiofrequency fields on the energy levels of atoms in a BEC. To this effect, atom interferometry will be implemented on the recently operational Spinor Bose-Einstein Condensate machine in the School of Physics, resulting in the most precise measurements made in over 50 years of experimental physics at Monash. The project will involve mastering techniques in radio-frequency and microwave electronics, imaging ultra-cold atoms, optics, lasers, and the theory of light-atom interactions.

Category **AM**

## Quantum maps and quantum Zeno Effect

**Supervisor:** Dr Kavan Modi

Quantum Zeno effect is one of the most mysterious features of quantum theory. Its name stem from the paradox named after the Greek philosopher, Zeno of Elea, who claimed that "*a watched pot never boils*". Quantum theory is a reversible theory and hence cannot account for exponential decay of unstable particles. Therefore, according to the quantum Zeno effect, if an unstable quantum system is observed frequently then its time evolution slows down. Moreover, the Zeno effect ties the seemingly conflicting elements of quantum mechanics, evolution and measurement.

Monars et al..[2] recently asked whether one could use the quantum Zeno effect to test quantum coherence in a natural system. For instance, the Fenna-Matthews-Olson photosynthetic complex[3] has been claimed to contain quantum coherence. The proposal of [2] is to use a classical field with varying strength as a continuous measuring device. Then the preparation and measurement statistics will reveal whether the system of interest is a classical stochastic in nature or utilises quantum coherence.

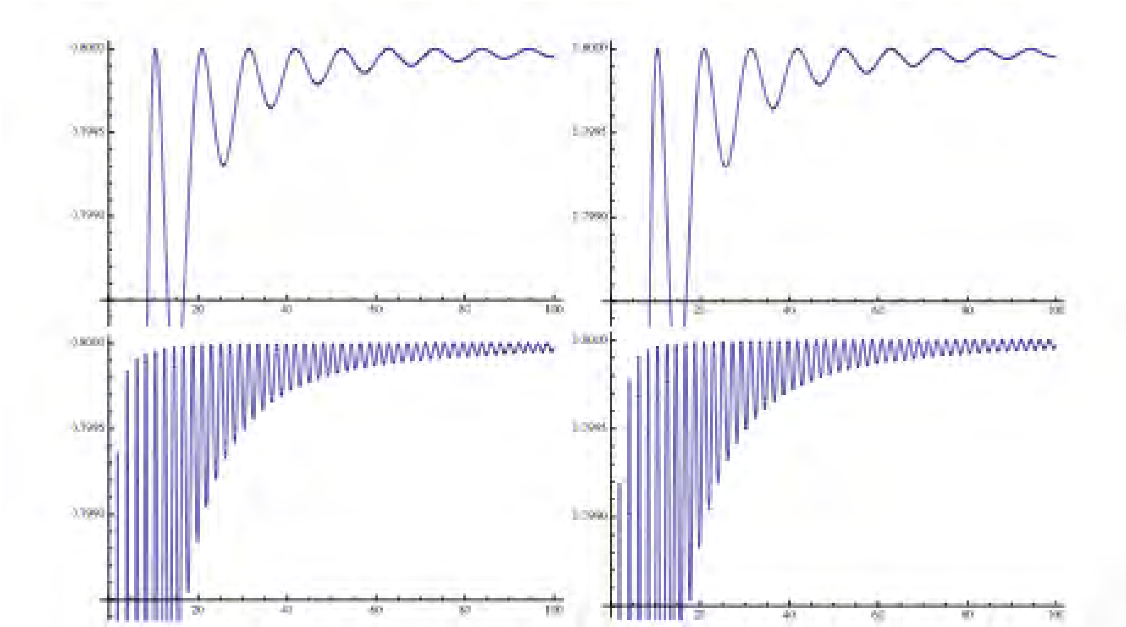
We will investigate a similar feature for quantum maps, two-point function. A primitive numerical investigation shows that for random quantum processes with a continuous monitoring via a classical field will suppress the dynamics. However, the suppression of the dynamics oscillates with a constant frequency, which only depends on the overall timescale of the process. This is shown in the figures below for T=0.3 and T=3, respectively. Therefore just knowing the timescale of the problem and observing the frequency of the oscillation should reveal the fundamental constant of quantum mechanics, i.e., the Planck's constant. This is indeed a strong distinction between a quantum process and a classical one.

**References:**


[1] Sudarshan & Misra, J. Math. Phys. **18,** 756 (1977).

[2] Monras, Chęcińska, & Ekert, arXiv:1312.5724 (2013).

[3] Engel et al.. Nature **446**, 782 (2007).



Category **AM**

## Quantum metrology with Rydberg atoms

**Supervisor**: Dr Kavan Modi

Metrology is the science of precision measurements. It is of huge importance with applications in technology and fundamental sciences. For instance, methods of metrology are utilised to measure the three fundamental constants of nature: the gravitational constant, speed of light, and Planck's constant.

Recent discoveries have taught us that quantum effects can yield a better measurement precision over classical methods. We will explore a hybrid model for metrology that utilises quantum coherence distributed through a large number of particles that are nearly classical. Our aim is to implement this model in a Rydberg-atom system to measure electric fields and the gravitational constant. Our goal is to determine whether our model can challenge the state of the techniques in this field.

The project will consist of two stages. In the first state the student will learn about metrology using Rydberg atoms. You will determine what is considered to be state of the art. The second stage will consist of theoretical calculations and realistic simulations of our model. At the end we are interested in comparing and contrasting our model with other metrology techniques.

This project is part of a larger collaborative effort that includes an experimental group at the Open University in the UK. The student will work with experimentalists who will carry out a series of tests based on these findings. The project comes with potential for long-term collaboration.

**References**

[1] J. A. Sedlacek et al.., Nature Physics 8, 819–824 (2012).

[2] J. D. Carter, et al.., Phys. Rev. A 86, 053401 (2012).

[3] M G Bason et al.., New J. Phys. 12, 065015 (2010).

[4] A. Osterwalder and F. Merkt, Phys. Rev. Lett. 82, 1831–1834 (1999).

[5] V. Giovannetti et al.., Nature Photonics 5, 222 (2011).

[6] V. Giovannetti et al.., Science 306, 1330 (2004).

[7] K. Modi et al.. Phys. Rev. X 1, 021022 (2011).

Category **AM, C, P**

## Skyrmions in Bose-Einstein condensates with synthetic spin-orbit coupling

**Supervisor**: Dr Tapio Simula

Skyrmions are topological excitations originally predicted in the context of elementary particle physics. More recently, skyrmions have been shown to emerge in experimentally realizable systems such as Bose-Einstein condensed superfluids described by a vector order parameter.

The aim of this computational and theoretical project is to investigate the structure and stability of skyrmions and to study the methods to create them experimentally in the ground states of spinor Bose-Einstein condensates with synthetic spin-orbit coupling.

Category **AM**

## Slowing of neutral molecules using intense lasers

**Supervisor:** Dr Alexis Bishop

There is interest in being able to slow, trap and cool neutral molecules for use in a range of experiments. The techniques developed by the ultracold atom community over the last two decades are unfortunately largely inapplicable to molecules due to the lack of "closed" transitions, and strict selection rules for molecular systems.

A useful interaction between molecules and light is provided by the second order Stark shift and is known as the "dipole force". Any species of atom or molecule will experience the dipole force which can then be used to perturb its motion. Unfortunately, the dipole force is weak and useful effects only occur for intensities on the order of $10^{15}$ W/m$^2$, but this can be achieved by focused, pulsed laser technology.

Cold molecules (<1 K) formed in a supersonic expansion can be slowed by controlling their motion in a moving optical lattice, formed by two crossed laser beams that are frequency shifted [1, 2]. However a highly efficient scheme for achieving stationary molecules with a realistic achievable experimental setup has yet to be shown. A suggested improvement on previous experiments is to create a frequency shifted beam using an electro-optic element rather than using two lasers.

This computational/theory project is to develop an accurate 3-D simulation of the dynamics of the new slowing experiment, using typical laser beam spatial and temporal profiles. The project will also investigate the nature of the required time evolution of the frequency shift between the two beams to achieve highly efficient slowing, without heating, for a range of molecular species.

**References:**

[1] Bishop AI, Wang L, Barker PF, Creating cold stationary molecular gases by optical Stark deceleration, New J. Phys. 12 073028, 2010.

[2] Fulton R, Bishop AI, Shneider MN and Barker PF, Controlling the motion of cold molecules with deep periodic optical potentials, Nature Physics 2, 465-468, 2006.

Category **AM, C**

## Strongly interacting SU(N) Fermi gases in one dimension

**Supervisors**: Dr Meera Parish & Dr Jesper Levinsen

The one-dimensional Fermi gas with repulsive short-range interactions provides an important model of strong correlations in few- and many-particle systems. However, in the presence of a harmonic potential, no exact solution is known in general for strongly interacting fermions. We have recently shown that this problem in the regime of strong repulsion can be mapped onto a Heisenberg spin chain, where approximate analytic expressions for the spin-spin interactions may be derived [1]. This effectively allows one to solve the problem for the case of a single spin-down impurity in a spin-up Fermi sea, a scenario that has recently been considered in cold-atom experiments [2].

The aim of this project is to generalise the above approach for spin-1/2 fermions to that of SU(N) Fermi gases, where there are N different flavours of fermions instead of just two.

**References:**

[1] J. Levinsen, P. Massignan, G. M. Bruun, & M. M. Parish, arXiv:1408.7096.

[2] A. N. Wenz et al.., Science 342, 457 (2013).

Category **AM**

# Thermodynamics at the nanoscale

**Supervisor**: Dr Kavan Modi

Modern computers use millions of times more energy than what is required theoretically. As components become smaller it is harder to cool them. This makes understanding thermodynamics at the nanoscale a fundamentally important area of research.

When talking about quantum processes one of the most general descriptions available is that of completely positive trace-preserving (CPTP) maps, often simply called "quantum channels" or "quantum operations"[1]. Despite their easy and straightforward use CPTP maps are a very powerful tool and allow for the description of non-unitary processes, thus allowing for dealing with open quantum systems. An alternative but closely related description is offered by master equations, which explicitly include the time-dependence of the system dynamics [2].

Recently a framework has been proposed that relates quantum channels to thermodynamic quantities such as work and heat[3], exploiting previous results from out-of-equilibrium quantum thermodynamics[4]. This project will allow the student to explore the language of open quantum systems (i.e. CPTP maps and master equations) and its application to thermodynamics.

In a first step you will explore expressions for operational work and heat for a number of generic quantum channels, such as dephasing and depolarising channels. In a second step, you will study standard thermodynamic processes (i.e., isothermal, adiabatic, etc.), express them in open quantum systems language, and relate it to the expressions from the operational framework. In a last step, it will be possible to analyse a full heat engine (e.g., Carnot) and study its efficiency within the same framework.

**References:**


[1] Breuer & Petruccione: The Theory of Open Quantum Systems, Oxford University Press 2002.

[2] Nielsen & Chuang: Quantum Computation and Quantum Information, Cambridge University Press 2000.

[3] Binder, Vinjanampathy, Modi, Goold arXiv: 1406.2801 (2014).

[4] Allahverdyan, Balian, and Nieuwenhuizen, Europhysics Letters 67, 565 (2004).

Category **AM**

# Using noisy teleportation to test quantum computers

**Supervisor**: Dr Kavan Modi

In a recent discovery Gu et al.[1] utilized noisy dense coding to test for coherent processing. Coherent processing is the basis for quantum computation. We need mechanisms to test for coherent processing for technological and foundational reasons. For instance, we may utilize such a protocol to check whether a natural process is quantum.

Dense coding is closely related to quantum teleportation. It is then natural to generalize the protocol of Gu et al.[1] for teleportation. Furthermore, quantum teleportation is the key ingredient in measurement-based quantum computation. We will use the above protocol to check whether a black box is able to perform a quantum computation.

You will learn about dense coding and teleportation to start the project. Next, you will study the protocol by Gu et al.[1] and attempt to recast it in terms of quantum teleportation. Next, you will examine measurement-based quantum computation. We will then seek a method to test a black box measurement based quantum computer with noisy teleportation.

**Reference**

[1] M. Gu et al., Nat. Phys. **8**, 671675 (2012).

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# CONDENSED MATTER PHYSICS

Category C

## A radially symmetric scattering matrix formalism for scattering along atomic columns in scanning transmission electron microscopy

**Supervisor**: Dr Scott Findlay

One of the challenging aspects of understanding the dynamics of fast electron probes scattering through materials is that the simulations can be time consuming. In the atomic resolution regime, the fundamental unit of the image is the atomic column. On the basis that the presence of other columns is an unwanted (though in practice unavoidable) complication detracting from the ability to analyse individual columns, this project will merge analytical theory and numerical simulation to explore a promisingly efficient way to explore scattering of a radially symmetric probe along a radially symmetric column. The method involves using a Bessel function basis and is an application/extension of the formalism set out in Ref. [1].

**Reference:**


[1] M. Op de Beeck and D. Van Dyck, Physica Status Solidi (a) 150 (1995) 587.


Category C

## Atomic resolution imaging modes with a segmented area all field (SAAF) detector


**Supervisor**: Dr Scott Findlay

Colleagues at the University of Tokyo have recently constructed a segmented detector for use in atomic resolution imaging [1,2]. Such data sets have not hitherto been obtained at atomic resolution, and there is much scope for developing novel imaging modes and for increased quantitative analysis of material structure down to the level of individual atoms. This project involves computation and experimental data analysis (on data obtained at the University of Tokyo) with the aim of exploring the imaging capabilities of the new segmented detector.

Research questions include:

- For the present detector, what camera lengths are optimal in a signal-to-noise ratio sense?
- How well can a segmented detector approximate a so-called "first moment detector"? How well does the differential phase contrast theory formally hold up?
- What is the sensitivity of the ratios of ring signals to:
    - Thickness
    - Tilt
    - Static disorder
    - Variations in thermal vibrational amplitude of the atoms?

**References**


[1] N. Shibata et al.., Journal of Electron Microscopy 59 (2010) 473.

[2] N. Shibata et al.., Nature Physics 8 (2012) 611.


Category C

## Can electric fields be imaged reliably at the nanoscale in ferroelectric devices using scanning transmission electron microscopy?

**Supervisors**: Dr Scott Findlay & Dr Amelia Liu

Ferroelectric materials for memory devices can have a nanoscale domain structure. In the scanning transmission electron microscope, the electric polarisation associated with these domains may deflect the sub-nanometre probing electron beam. Colleagues at the University of Tokyo have recently constructed a segmented detector [1] to detect these deflections and so probe the domain structure in ferroelectric materials [2,3]. However, structural effects like crystal orientation can also lead to a deflection of the beam. This project involves computation and experimental data analysis (either on data obtained at the University of Tokyo or else acquired in a proof-of-concept experiment at the Monash Centre for Electron Microscopy), seeking to predict the relative magnitude of these effects and exploring methods for distinguishing between them.

**References**


[1] N. Shibata et al.., Journal of Electron Microscopy 59 (2010) 473.

[2] N. Shibata et al.., Nature Physics 8 (2012) 611.

[3] M. Lohr et al.., Ultramicroscopy 117 (2012) 7.

Category C

## Defocus scanning as a means to determine the depth of single atom impurities

**Supervisor**: Dr Scott Findlay

Atomic resolution scanning transmission electron microscopy has proven itself able to identify the presence of single atom impurities within crystal columns, provided either that the scattering power of the dopants is much larger than that of the host matrix [1] or else that spectroscopic signals unique to the dopants are used [2]. Moreover, it has proven broadly possible to obtain some sensitivity to the depth of the dopants by so-called “depth sectioning”, i.e. scanning the beam waist of a focused probe through the sample [3]. Recently, a new inversion technique has been proposed to remove the effects of probe scattering on spectroscopic images to improve the interpretability, casting the problem as an inversion problem and taking care over the well-known potential for instability in such inversions [4]. This project looks to adapt that approach to a more precise identification of the depth of single atom impurities within a crystal via defocus scanning.

**References**


[1] P.M. Voyles et al.., Nature 416 (2002) 826.

[2] M. Varela et al.., Physical Review Letters 92 (2004) 095502.

[3] K. van Benthem et al.., Applied Physics Letters 87 (2005) 034104.

[4] N.R. Lugg et al.., Applied Physics Letters 101 (2012) 183112.


Category C

## Dirac Electronic Materials

**Supervisor**: Professor Michael Fuhrer

Recently new materials have emerged in which the electron dynamics are described by the Dirac equation in two dimensions. An example is graphene, the two-dimensional honeycomb lattice of carbon atoms that is the basic building block of graphite. In graphene, the electrons obey a massless Dirac equation, with the role of the relativistic electron spin played by a spinor (“pseudospin”) composed of the two $\pi$ orbitals in the unit cell. Single layer molybdenite ($MoS_2$) has a massive Dirac equation and is a direct-bandgap semiconductor while retaining the chiral properties of the spin-1/2 pseudospin. Three-dimensional topological insulators such as $Bi_2Se_3$ are insulating in their interiors, but exhibit metallic surface states with a massless Dirac structure similar to graphene, but with the real quantum mechanical spin as the Dirac spinor. Professor Michael Fuhrer’s group is studying these materials experimentally in order to understand how their unusual band structures determine their electronic and optical properties. The experimental research involves:

- Electronic transport measurements on microfabricated devices[1-3,5-10,12]. Semiconductor micro- and nano-fabrication tools (at Monash and at the Melbourne Centre for Nanofabrication) are used to create electronic devices with controlled geometry. Cryogenic electronic measurements of resistivity, Hall effect, etc. are used to understand scattering by disorder and phonons, quantum transport (weak localization or anti-localization, quantum Hall effects), etc.
- Scanning-probe microscopy[4,7,11]. Scanning-probe microscopy techniques, such as scanning tunnelling microscopy (STM) and atomic force microscopy (AFM) are used to understand the atomic structure and electronic properties of two-dimensional materials. By coupling scanned-probe techniques with micro-fabricated devices, new information can be gained using techniques such as Kelvin probe microscopy (to measure local potentials in current-carrying devices) or scanned-gate microscopy (to measure the local sensitivity to a tip acting as a gate to induce charge in a device).
- Surface modification[1,3,5]. Two-dimensional Dirac materials are atomically confined at surfaces and interact strongly with their environments. Ultra-high vacuum surface science techniques are used to controllably modify the properties of two-dimensional materials, introducing charged impurities, point defects, modifying the dielectric constant, adding magnetic interactions, and changing the dopant density. Coupled with electronic transport experiments and scanned probe experiments surface modification allows insight into the relationship between atomic structure and electronic properties of these materials.
- Optical spectroscopy and optoelectronics[9]. Dirac semiconductors such as $MoS_2$ have direct bandgaps, and chiral optical excitation can be used to excite spin and pseudospin polarizations. Additionally, two-dimensional materials have strong and tunable electron-electron interactions because the dielectric properties are determined by the surrounding media, leading to large excitonic effects. Optical spectroscopy can be used to study these effects in Dirac semiconductors.

A range of projects involving these experimental techniques are available for Honours students; the specific project can be tailored to match the skills and interests of the student.

**References**


[1] J. H. Chen, C. Jang, S. Adam, M. S. Fuhrer, E. D. Williams, and M. Ishigami, "Charged Impurity Scattering in Graphene," *Nature Physics* **4**, 377 (2008).

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Category C

## Experimental and theoretical vector tomography for measuring electromagnetic fields

**Supervisors:** Dr Tim Petersen & Professor Michael Morgan

Accurate measurements of magnetic structure are vital for research efforts as diverse as improved information storage, the function of 'magneto-tactic' bacteria and geomagnetic records in natural minerals. Quite recently, the scientific literature has reported numerous theoretical and experimental findings of new physical phenomena in topical materials, such as stable vortex configurations of magnetic fields, vortical domains in electrically polarized solids and synthesis of new solids in which electric and magnetic polarizations are coupled and can be manipulated. Trailing upon recent excitement fuelled by discovery of the 'giant magneto effect', magnetic and electrically textured materials such as these and similar thin-film hetero-structures have received a resurgence of scientific interest at present.

By combining phase maps of electron waves with computed tomography, it is possible to measure magnetic and electric fields in three dimensions (3D) using an electron microscope. It is truly remarkable that propagating electrons can 'see' magnetic and electric fields in much the same way that water bends and distorts light rays through a drinking glass or the surface of a swimming pool. As the only instrument of its kind in Australia, the Monash Titan electron microscope can uniquely quantify three dimensional magnetic and electric fields of solid materials. The data reconstructed from an array of electron microscope images reveals the strength and direction of electric and magnetic fields within every point of a nano-scale volume of space. Since both orientations and magnitudes are required to specify electro-magnetic fields, this new form of 3D reconstruction is colloquially known as 'vector tomography'. Still in the developmental stage, there has been only one experimental demonstration of vector tomography in the literature to date, as reported in Physical Review Letters last year.

We are seeking an enthusiastic student to analyze electron phase maps and reconstruct vector tomography data for interesting specimens such as magnetite nano-particles and multi-ferroic complex oxides. There is ample flexibility to enjoy the theoretical aspects of phase mapping, electron wave optics and vector tomography reconstruction or apply these techniques to analyze high quality experimental data. Join our research team to utilize the classical and quantum mechanics you have learnt thus far - working at the forefront of electron microscopy research.

Category C

# Magnetoresistance of semiconductors in the non-linear regime

**Supervisor:** Dr Meera Parish

The change of electrical resistance in a magnetic field (i.e., the magetoresistance) is typically rather small in many materials, but it can have important technological applications when it is sizeable. For instance, the "giant magnetoresistance" of magnetic multilayer structures provides the basis for magnetic sensors used in hard disks and other devices. However, magnetism is not the only route to a large magnetoresistance. Material inhomogeneities or the sample geometry can also generate a substantial magnetoresistance in non-magnetic systems [1]. It has also been demonstrated that a similar effect can be achieved in a semiconductor subjected to a high electric field, where the electrical transport is no longer ohmic [2]. The aim of this project is determine whether the inhomogeneous electric field present in this non-linear transport regime is sufficient to produce a large magnetoresistance or whether something further is required.

**References:**

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Category C

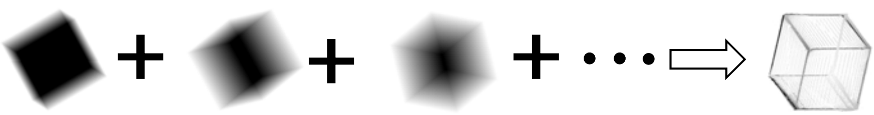
# Measuring 3D differential geometry at the nanoscale

**Supervisors:** Dr Tim Petersen & Professor Michael Morgan

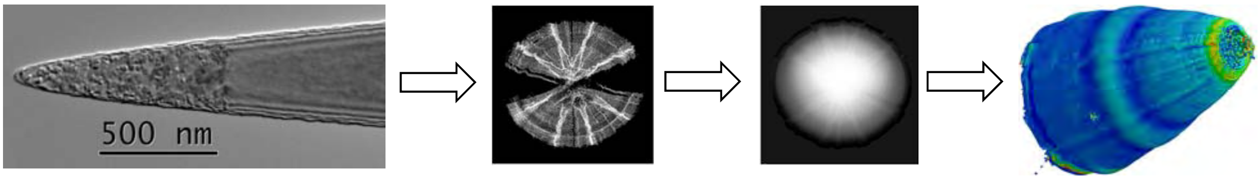
Electron tomography is an imaging technique capable of reconstructing three dimensional (3D) structures on the nano-scale by collating and processing images over a range of different specimen orientations, acquired in a transmission electron microscope (TEM). The historical development of electron tomography has largely been motivated by an interest in the 3D structure of biological specimens at high resolution, for which electron scattering physics fulfils the 'projection requirement', associated with the inverse problem of back-projection. For strongly-scattering non-biological specimens, often crystalline in nature, the projection requirement can be difficult to justify; particularly if conventional TEM imaging approaches are used. Electron tomography of non-biological specimens is however possible, owing to significant research efforts in recent years. Issues with strong scattering have been demonstrably suppressed by utilising alternative imaging modalities, such as annular dark-field imaging, electron energy loss filtering or careful choice of crystal orientations throughout the tilt series.

When the mere 3D morphology is of interest (as opposed to the complete 3D scattering density), the reconstruction of external and internal scattering surfaces can be simplified. Under quite general TEM operation conditions, reconstruction can be achieved by measuring the smooth angular movement of characteristic image features using geometric principles alone. Provided such interfaces are sufficiently visible over a range of tilt angles, the magnitudes of actual projected intensities, which are coupled to complex diffraction physics and used in conventional back-projection, can then be principally ignored.

An alternative reconstruction approach known as the 'surface tangent algorithm' (STA) has been developed to implement 3D reconstruction of external and internal interfaces using the ideas discussed here. One benefit of this algorithm is that limitations in angular range, known as the 'missing wedge', do not geometrically distort the reconstructed tomogram. For smooth objects, the missing wedge can be accurately filled to estimate the entire 3D shape. Furthermore, using 2nd order partial derivatives of the 3D morphology, it is possible to compute the 1st and 2nd fundamental forms for a complete differential-geometric characterization of the specimen shape, from which quantities such as principle curvatures can be estimated in 3D.



The next row of figures show an experimental example of an electro-polished Al needle for which the missing wedge has been filled in and the mean curvature (displayed in color) was computed at every point of the STA reconstructed surface.




We are seeking an enthusiastic and talented student to use existing experimental data to measure the differential geometry of similar nano-scale projects, to be published in the scientific literature. The student will gain expertise in numerical analysis and image processing. There are also opportunities to develop C++ code for measuring nano-scale differential geometry, with the aim to distribute the software as open-source.

Category C, AM

## Searching for quantum time crystals

**Supervisor:** Professor Victor Galitski

Spontaneous symmetry breaking is one of the fundamental concepts in physics, where the symmetry of the lowest energy state is lower than that of the underlying theory describing the system. Superfluidity, superconductivity, ferromagnetism, and other quantum phases in condensed matter systems as well as the Higgs mechanism of elementary particle physics are all manifestations of spontaneous symmetry breaking. Another more familiar example of this basic phenomenon is a crystal structure of a solid, where the continuous translational symmetry (i.e., translations by an arbitrary distance) is broken down to a discrete translational symmetry of the crystal (i.e., translations by a lattice constant). Theoretically, there exists another exotic possibility to have spontaneously broken symmetry of translations in time, by forming a quantum time crystal [1]. Physically, this state of quantum matter (hypothetical at this stage) would imply that a physical system would spontaneously exhibit oscillations in time. In this project, we are going to use recent developments in understanding periodically-driven systems (so-called Floquet systems [2]) and non-linear soliton dynamics [3] to search for a physical realization of the quantum time crystal in cold atom superfluids.

**References:**

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[3] D. Efimkin and V. Galitski, "Moving solitons in a one-dimensional fermionic superfluid," http://arxiv.org/abs/1408.6511

Category C

# Shattering insights towards the atomic structure of glasses

**Supervisors:** Dr Tim Petersen & Dr Amelia Liu

The formation and atomic structure of glasses remains a long-standing important and unsolved problem in condensed matter physics. Despite continued international efforts, there are many intriguing scientific questions which remain unanswered. For example, how can a brittle solid maintain short range order yet still possess the structure of a liquid, supposedly devoid of long range order? What is the atomic structure of an archetypal vitrified monatomic solid, such as pure amorphous silicon or diamond like carbon? Do the atoms form continuous random networks or, as recently and hotly debated in Science [1, 2, 3], are there nano-scopic 'para-crystals' inter-dispersed within a structurally-frustrated meta-stable ensemble? For low density carbonaceous solids, do Fullerenes, such as interwoven, buckled, graphene sheets and nanotubes, provide an adequate description of the medium range order [4, 5]?

Using high-resolution transmission electron microscopes (TEMs), this project will acquire experimental data to address several of these fundamental questions. There are also opportunities to implement modeling techniques to interrogate the structure of such glasses, ranging from Monte Carlo integration techniques to the advanced processing of scanning electron nano-diffraction patterns [6]. Theoretically inclined students could also develop associated Hybrid Reverse Monte Carlo source code [7, 8], to increase the number of many-body inter-atomic potentials for describing bonding configurations in multi-component glasses.

Modern wonder materials like metallic glasses have interesting properties, such as substantial hardness, and can undergo super-plastic deformation [9]. The glass forming abilities of bulk metallic glasses are sensitively tied to composition and generally a multitude of elements are required to cause structural arrest in rapid thermal quenching from the liquid state. However, several binary and ternary alloys have been identified as good glass formers. Such metallic glasses are being synthesized by collaborators at CSIRO and are available for this project. Several pertinent questions concerning these alloys need to be addressed. For example, on the atomic scale, are these glasses partially crystallized? Can the pair correlation functions be reliably measured and how do these correlate with the alloy properties? Experimental students would be trained to prepare ultra-thin metallic glass foils and will analyze high quality experimental data from TEMs at the Monash Centre for Electron Microscopy.

**References:**


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Category C, AM

## Spin-1 magnons: Surfing ultracold spin waves in Bose-Einstein condensates

**Supervisor**: Dr Lincoln Turner

In this project you will create a new form of quantum spin-wave ("magnon") driven by spin-1 interactions in a spinor Bose-Einstein condensate. Spin waves can be created in all magnetic materials, and have potentially much lower losses than conventional electromagnetic modes, making "magnonics" a future alternative to conventional electronic devices. Yet creating a single magnon is elusive: and may only be possible in a spinor Bose-Einstein condensate at ultracold temperatures. You will use precisely controlled magnetic fields to excite a single magnon in a BEC, and measure its wavelength with Stern-Gerlach imaging. You will explore how the physics of a spin-1 magnon differs from conventional spin-1/2 magnons which exist in electron systems, and map the spectrum of the spin-1 magnon for different spinor BEC phases for the first time.

Category C

## Towards quantitative atomic resolution scanning transmission electron microscopy via energy-dispersive X-ray spectroscopy

**Supervisor**: Dr Scott Findlay

At low resolutions, energy dispersive X-ray (EDX) analysis has long proven to be one of our best tools to quantify chemical composition of materials [1]. Instrumental developments in the last five years have made it possible to perform atomic resolution EDX imaging in scanning transmission electron microscopy [2,3]. In the atomic resolution regime, the strong interaction between the probing electrons and the atomic columns (sometimes called "channelling") means that the low resolution approach to quantification breaks down. This project will use numerical simulation to explore how quantification might be achieved in the atomic resolution regime. Associated questions include:

- What is the optimum thickness to maximize signal while minimizing probe spreading artefacts?
- Does X-ray absorption in the material impair quantification in crystals thin enough to enable atomic resolution imaging?

**References:**


[1] J.I. Goldstein, D.B. Williams and G. Cliff, Chapter 5 in "Principles of Analytical Electron Microscopy", Eds. D.C. Joy, A.D. Romig and J.I. Goldstein, 1986.

[2] A.J. D'Alfonso et al.., Physical Review B 81 (2010) 100101(R).

[3] M.-W. Chu et al.., Physical Review Letters 104 (2010) 196101.


Category C

## Use of waveguides for high resolution x-ray microscopy

**Supervisors**: Dr Daniele Pelliccia & A/Professor David Paganin

X-ray waveguides have been the first optics to enable a sub-micron focusing of hard x-rays, using synchrotron radiation [1]. A waveguide works by confining the optical power into a narrow channel by a discontinuity in the index of refraction, working as a potential well for photons. In this way, sub-micron focusing with conventional x-ray sources can be reached and exploited for x-ray microscopy [2].

This project will study the optical configuration (waveguide design and geometrical settings) for an efficient x-ray microscope with hard x-rays. The project can have either a theoretical or experimental approach, depending on the interest and taste of the student.

Choosing the theoretical project will involve the solution of the paraxial wave equation for hard x-rays propagating in the microscope, and the study of image formation in such device. For an experimental project the fabrication of the waveguides - using the Melbourne Centre for Nanofabrication - and the characterization of their properties with x-rays will be undertaken.

**References:**


[1] S. Lagomarsino et al.., *J. Appl. Physics*, **79**, 4471, (1996).

[2] D. Pelliccia et al.., *Opt. Express*, **18**, 15998, (2010).


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# MEDICAL IMAGING AND BIOPHYSICS

Category M

## A gold-standard for CT image reconstruction quality

**Supervisors:** Dr Imants Svalbe &
Dr Andrew Kingston (Research School of Physics & Engineering ANU)

There has been much research on the relative merit of different tomographic image reconstruction methods and their tolerance to real noise and the effects of finite and regular or asymmetric sampling of the projection data from which the image result is obtained.

The final quality of any CT result is, however, very difficult to assess, as the image that is reconstructed from a set of projected views is a discretised and sampled model of the 'continuous' object that was scanned. The use of high SNR projection data obtained at very fine resolutions in detector spacing and angle increments produces incrementally 'better' images, but this just gets us closer towards the unknown ultimate reality of the result.

If we use a discrete image as the reference object, then the difference in real versus synthetic projected views of the object introduces further ambiguity into the comparison. We propose here to perform an experimental test for the absolute quality of CT methods using a purpose built 'phantom' and also a computational test that uses specially acquired MRI projection data.

The phantom will be a 3D, discrete, "Lego-brick' like object, comprised of finite voxels with known size and densities that are equivalent to those estimated in a typical tomographic reconstruction scheme. The object may be constructed using an assembly of finite "bricks' or fabricated using a high-resolution 3D printer (where the density of the 'ink' can be adjusted by the addition of fixed concentrations of x-ray contrast media). The aim is to then take projections of this object and compare the discrete reconstructed data with the discrete input model of the chosen phantom

(see: http://physics.anu.edu.au/projects/project.php?ProjectID=133)

The computational approach will acquire some real MRI data for some chosen phantom (possibly, but not necessarily using the Lego-phantom object above) under two sets of conditions: one standard 3D MRI acquisition, where the phase- and frequency-encodings exactly fill the k-space of the image at the selected resolution and a second set, where the data are acquired as slices in 2D Radon/CT-mode, i.e. as frequency-encoded data but with gradients that provide projections at a range of discrete view angles (i.e. a sinogram). We then would compare the traditional (Cartesian FFT inverted) image data with the result from 'polar CT' reconstructions derived from the MRI sinogram data. An ideal Radon inversion algorithm would replicate the Cartesian-sampled result. This method also applies to discrete tomography algorithms.

**Reference:**

[1] Exact image representation via a number-theoretic Radon transform, Shekhar Chandra and Imants Svalbe, IET Computer Vision, **8,** 4, 338-346, 2014.

Category: **M**

## Coherence from chaos

**Supervisors**: Dr Marcus Kitchen & Dr Kaye Morgan

Phase contrast X-ray imaging (PCXI) is being explored to revolutionise radiography for biomedical imaging applications and materials analysis [1]. PCXI modalities increase the contrast of the interfaces between materials by rendering gradients in the X-ray wavefield visible. Each technique requires a moderate to high degree of spatial and/or temporal coherence to achieve phase contrast. This requirement limits the use of conventional laboratory sources for most PCXI modalities. This project will investigate a means of enhancing the coherence of X-ray sources with the aim of allowing phase contrast to become a potential tool in diagnostic imaging and for industrial imaging application. Both computational simulation and experiment are likely to be employed in this research.

**Reference**

[1] Fouras, A., M.J. Kitchen, S. Dubsky*, et al.*., *J. Appl. Phys.*, 2009. **105**(1): 102009.

[2] Kitchen, M.J., D.M. Paganin, K. Uesugi, B.J. Allison, R.A. Lewis, S.B. Hooper, and K.M. Pavlov, *X-ray phase, absorption and scatter retrieval using two or more phase contrast images.* Optics Express, 2010. **18**(19): 19994-20012.

Category: **M**

## Coherent brain imaging

**Supervisors**: Dr Marcus Kitchen & Dr Kaye Morgan

Phase contrast X-ray imaging (PCXI) is being explored to revolutionise radiography for medical imaging and materials analysis. PCXI modalities increase the contrast of the interfaces between materials by rendering phase gradients in the X-ray wavefield visible. We have been exploiting this phase information to extract quantitative information about specific materials for the purpose of segmenting two- to three-component materials from phase contrast images [1,2]. Our goal is to isolate the brain from the skull using phase contrast image segmentation to produce high contrast, artefact free images of the brain in 3D. This will assist our preclinical studies of brain injury and disease progression, including Alzheimer's disease. Future studies will ultilise this approach toward early diagnosis of brain pathologies. The participant will be involved in developing theory and performing image reconstruction on data to be collected using synchrotron and/or laboratory-based X-ray sources.

**Reference**

[1] Kitchen, M.J., D.M. Paganin, K. Uesugi, B.J. Allison, R.A. Lewis, S.B. Hooper, and K.M. Pavlov, *Phase contrast image segmentation using a Laue analyser crystal.* Physics in Medicine and Biology, 2011. **56**(3): 515-534.

Category **M**

## Grating interferometry for x-ray phase imaging at the synchrotron

**Supervisor**: Dr Daniele Pelliccia

Most of the radiographic clinical techniques are based on the x-ray absorption contrast between different tissues. Nevertheless, many clinical situations, such as mammography, depend on the contrast of different types of soft tissues. This task is generally very hard to achieve with conventional absorption radiography, whereas the radiation dose limits the exposure time and consequently the achievable contrast resolution. At the same time high contrast resolution is absolutely essential to make the methods capable of early detection of tumors.

To this goal the clinical implementation of phase contrast x-ray imaging is crucial to achieve high resolution imaging with low dose.

A promising technique to measure phase contrast is the grating interferometry. Soon after its first applications to hard x-rays [1-2], it has been demonstrated very successful to detect high resolution hard x-rays phase contrast. The method is based on a relative scan between two gratings: the first is a phase grating acting as a beam-splitter. The second, an amplitude grating, is used to analyze the wave front diffracted from the first grating. If a sample is placed before the first grating, the modification of the wave front can be directly detected with this system. Therefore both absorption and refraction can be simultaneously measured by a relative scan of the grating system.

Recently a new approach [3] for low-dose imaging with grating interferometer has been proposed. It relies only on three raw images, thus reducing the need of a scan.

The aim of this project is to evaluate advantages and disadvantages of the new approach compared to the existing ones and find experimental situations that would favour one or the other approaches.

The student undertaking this project will have to write scripts to analysis experimental data and quantitatively compare different models.

Depending on the availability of synchrotron beam time, the project might also include experimental activity at the Australian Synchrotron.

**References:**
[1] T. Weitkamp et al., *Optics Express* **13**, 6296 (2005).
[2] A. Momose et al.., *Jpn. J. Appl. Phys.* **42**, L866 (2003).
[3] D. Pelliccia et al., *Optics Express* **21**, 6296 (2013).

Category M

## Iterative phase retrieval procedures for partially coherent diffraction imaging

**Supervisors**: Dr Daniele Pelliccia & A/Professor David Paganin

When an electromagnetic wave interacts with a sample, both its amplitude and its phase are affected. The amplitude decrease is proportional to the sample absorption while the phase shift is related to the local refraction of the field in the specimen.

In many experimental situations the phase sift cannot be measured directly, yet it is encoded in the diffracted amplitude, which is experimentally accessible. Many procedures have been devised to retrieve this "hidden" information [1].

In many cases though, the phase information (and by extension the wave front) is not well defined. The field is said to be only "partially" coherent [2]. This is for example the case of the light randomly emitted in a light bulb or in an x-ray apparatus for medical imaging. In such cases the concept of a coherence function is introduced, which extends the concept of wave front to partial coherence.

The project will explore the development of the phase retrieval procedures to the coherence functions. The student will gain expertise in image processing and numerical methods. This project is well suited for students interested in diffraction and optical physics as well as computational methods.

**References:**
[1] D. Paganin, *Coherent X-Ray Optics*, Oxford University Press (2006), Ch. 4.
[2] M Born and E. Wolf, *Principles of Optics*, 7th ed. Cambridge University Press, (2003), Ch.10.

Category M

## Optimal image sampling for CT cone-beam reconstruction

**Supervisors:** Dr Imants Svalbe &
Dr Andrew Kingston (Research School of Physics & Engineering ANU)

Image plates that are used to record 2D patterns of x-ray intensity distributions are conventionally constructed (or are read by some scanning device) as a rectangular array of pixels arranged in straight lines as rows and columns. Whilst rows and columns of pixels do uniformly sample a 2D array, it is well known that a hexagonal array of pixels also provides a uniform but denser array of sampled pixels (evident in the hexagonal close packed structures common in solid state physics). Hexagonal sampling also has the advantage of having stronger symmetry properties, with each pixel having six equally-spaced neighbours, rather than the 4- or 8-connected neighbours characteristic of square arrays.

This project will examine the effect of local pixel sampling structure on the quality of images that can be reconstructed using computed tomography based on high-quality (high SNR) projected views of objects taken at very fine angular intervals.

The aim is to compare reconstructed images derived from an array of either square or hexagonally based samples. Data from a ultra-high resolution 2D arrays will be used to build “equivalent” arrays of hexagonal and square lattices on which the reconstructions are based.

Manufacturers of 2D arrays may be persuaded to revert to fabricating 2D arrays for detectors and display devices with hexagonally sampled pixels (as used by Leica in the past for many microscopic imaging applications) should the results of this project point sufficiently in favour of hexagonal structures.

**References:**


[1] Quantisation error in hexagonal sensory configurations, Behzad Kamgar-Parsi and Behooz Kamgar-Parsi, IEEE T-PAMI, 14, 665-671, 1992.

[2] Sampling properties of the discrete Radon transform, I. Svalbe, Discrete Applied Mathematics, 139 (2004) 265-281.


Category M

## Pedro – pixelated emission detector for radioisotopes - Compton imaging

**Supervisors:** Dr Matt Dimmock & A/Professor David Paganin

The Pixelated Emission Detector for RadioisotOpes (PEDRO) is a state-of-the-art hybrid emission imaging system, optimised for small animal studies. It is composed of a Compton-telescope situated behind a variable mechanical aperture. The experimental system is in the early stages of development and a series of commissioning experiments are being performed. The imaging data is filtered and processed with a suite of in-house developed algorithms. There exists a range of opportunities (beyond the few listed below) for the collection and analysis of Compton, mechanically and hybrid collimated data. The results can also be compared to those produced with Monte-Carlo simulations that have also been developed.

The multi-layer Compton camera experimental phase of PEDRO has recently been commissioned. Compton imaging offers significant gains in sensitivity over mechanically collimated imagers. However, the resolution of the reconstructed image is limited by the detector performance. There exists the opportunity to investigate the possibilities and limitations of performing Compton imaging with a multi-layer stack detector through both experiment and simulation.

Category M

## Pedro – pixelated emission detector for radioisotopes - Hybrid imaging

**Supervisors:** Dr Matt Dimmock & A/Professor David Paganin

The Pixelated Emission Detector for RadioisotOpes (PEDRO) is a state-of-the-art hybrid emission imaging system, optimised for small animal studies. It is composed of a Compton-telescope situated behind a variable mechanical aperture. The experimental system is in the early stages of development and a series of commissioning experiments are being performed. The imaging data is filtered and processed with a suite of in-house developed algorithms. There exists a range of opportunities (beyond the few listed below) for the collection and analysis of Compton, mechanically and hybrid collimated data. The results can also be compared to those produced with Monte-Carlo simulations that have also been developed.

Mechanical collimation offers high resolution, low sensitivity data for estimating the distribution of radiation in an object. Compton collimation offers low resolution, high sensitivity information for the same purpose. The PEDRO has been developed to investigate the optimization of the combination of these techniques with sophisticated collimators. This optimization has currently been performed in the context of the available hardware. A different and more fundamental approach is to perform the investigation in terms of the completeness conditions that would yield the optimal data set for performing the reconstruction (analogous to the Radon transform in transmission imaging).

Category M

## Pedro – pixelated emission detector for radioisotopes - Multi-pinhole imaging

**Supervisors:** Dr Matt Dimmock & A/Professor David Paganin

The Pixelated Emission Detector for RadioisotOpes (PEDRO) is a state-of-the-art hybrid emission imaging system, optimised for small animal studies. It is composed of a Compton-telescope situated behind a variable mechanical aperture. The experimental system is in the early stages of development and a series of commissioning experiments are being performed. The imaging data is filtered and processed with a suite of in-house developed algorithms. There exists a range of opportunities (beyond the few listed below) for the collection and analysis of Compton, mechanically and hybrid collimated data. The results can also be compared to those produced with Monte-Carlo simulations that have also been developed.

Experimental and simulated data have and can be collected for investigating imaging performance with a variety of multi-pinhole apertures. The existing algorithms perform iterative Maximum-Likelihood Expectation-Maximization to remove the blurring due to multiplexing of the pinholes. A recent development has enabled the technique of Laplacian erosion for the removal of additional blurring to be performed. However this has not been implemented in the context of iterative reconstruction. Investigation into and implementation of the combination of these techniques should enable significant gains in the speed of convergence of the reconstruction and enhance the features in the image.

Category: **M**

## Phase Contrast X-ray Imaging for Lung Disease Detection

**Supervisors:** Dr Marcus Kitchen & Dr Kaye Morgan

Phase contrast X-ray imaging (PCXI) has the potential to provide significantly more clinical information about biological soft tissue health than conventional radiography [1-3]. We are exploiting the advantages of phase contrast to extract quantitative information regarding the morphology of the lungs. Using coherent synchrotron radiation we are examining the lungs of a mouse model of emphysema, a form of chronic obstructive pulmonary disease (COPD). Two phase contrast modalities, namely propagation-based (PBI) and analyser-based (ABI) phase contrast X-ray imaging, are being tested to assess their ability to detect structural changes in the tissue associate with disease. This project may involve image reconstruction, synchrotron-based experimentation and/or computational simulation.

**References**

[1] Kitchen, M.J., D.M. Paganin, K. Uesugi, B.J. Allison, R.A. Lewis, S.B. Hooper, and K.M. Pavlov, *Phase contrast image segmentation using a Laue analyser crystal.* Physics in Medicine and Biology, 2011. **56**(3): 515-534.

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Category M

# Rapid x-ray phase imaging with a liquid metal x-ray source

**Supervisors:** Dr Kaye Morgan & Dr Karen Siu

X-ray- imaging has become an essential tool in the medical field, but conventional absorption methods are still limited in their ability to differentiate between different types of soft tissue. Various methods of phase-contrast x-ray imaging enable visualisation of soft tissue by taking advantage of the real part of a material's complex refractive index, and have already been utilised in biomedical research [1]. Many of these methods require multiple images to reconstruct the phase depth of the sample, which is an obstacle when imaging breathing, moving subjects. Our recently published method [2-4] requires just a single exposure, and is already proving valuable within the larger project, imaging changes in the airways in response to treatments for Cystic Fibrosis [5].

This project will involve translating this method from a synchrotron source to a bright new liquid-metal-jet x-ray source, a step that not only provides greater opportunities for researchers seeking to use the technique, but also moves towards clinical implementation.

There are opportunities for computational modelling for set-up optimisation, experimental implementation on the new x-ray source and numerical analysis of the resulting images. Depending on the preferences of the student, the project could also look at incorporating new algorithms into the image analysis code.

**References:**

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[3] Quantitative single-exposure phase contrast imaging using a single attenutation grid, K. S. Morgan, D. M. Paganin, K. K. W Siu, Optics Express 19, p.19781-19789 (2011).

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Category M, O

## Stealth functions: objects with low visibility

**Supervisor:** Dr Imants Svalbe

Ghosts are digital images comprised of positive and negative valued pixels that are so arranged as to sum to zero and vanish when projected at one or more digital angles. These ghosts have strong links to the artefacts that are created when real images are reconstructed from projected views, as done in conventional x-ray CT.

These ghosts originate from a result obtained long ago by Katz [1] that determines if any digital object can be reconstructed exactly from any set M of projected views. The properties of ghosts are thus of quite general importance in deciding if any set of projection data can be reconstructed exactly or not. In an odd twist, it turns out the ghosts can be used for the exact recovery of lost projection data, providing there is some redundancy in the image data [2].

Ghost functions exhibit very strong symmetries and remarkable survival properties; they can be subjected to a variety of affine transforms, including discrete rotations [3], to produce a large family of ghosts which are close to orthogonal but persistently vanish at a pre-determined number of projection angles [4-6].

One aim of this work is to use these low-visibility shapes as a sensitive probe to test the efficacy of different image reconstruction approaches [7]. Another aim is to exploit their strong "near-perfect" auto-correlation properties to embed hidden data or water-marks in documents for image labelling or security applications [8].

### References

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[2] An exact, non-iterative Mojette inversion technique utilising ghosts, Shekhar Chandra, I. Svalbe and Jeanpierre Guédon, Discrete Geometry for Computer Imagery, Lyon, April, 2008, Springer, LNCS volume 4992, pp. 401-412.

[3] Exact, scaled image rotations in finite Radon transform space, Imants Svalbe, Pattern Recognition Letters, online http://doi:10.1016/j.patrec.2010.06.015

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Category M

## Tissue/material segmentation using phase contrast x-ray imaging

**Supervisors:** Dr Marcus Kitchen & A/Professor David Paganin

Phase contrast X-ray imaging (PCXI) is being explored to revolutionise radiography for medical imaging and materials analysis. PCXI modalities increase the contrast of the interfaces between materials by rendering gradients in the X-ray wavefield visible. We have been exploiting the phase information to extract quantitative information about specific materials for the purpose of segmenting two- to three-component materials from phase contrast images [1,2]. Our goal is to isolate as many materials as possible from a given dataset. This would assist with material identification in earth and materials science applications and tissue identification for disease detection in biomedical imaging. To that end we are developing novel methods to segment multi-materials objects using analyser-based phase contrast X-ray imaging. The student will be involved in developing theory and performing image reconstruction. There may also be a possibility of performing experiments as the Australian Synchrotron SPring-8.

**References:**

[1] Kitchen, M.J., D.M. Paganin, K. Uesugi, B.J. Allison, R.A. Lewis, S.B. Hooper, and K.M. Pavlov, *Phase contrast image segmentation using a Laue analyser crystal.* Physics in Medicine and Biology, 2011. **56**(3): 515-534.

[2] Kitchen, M.J., D.M. Paganin, K. Uesugi, B.J. Allison, R.A. Lewis, S.B. Hooper, and K.M. Pavlov, *X-ray phase, absorption and scatter retrieval using two or more phase contrast images.* Optics Express, 2010. **18**(19): 19994-20012.

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# OPTICS

Category O

## Dynamics of single molecules in a nanotube

**Supervisor:** Professor Kris Helmerson

The cell is a crowded environment where complex chemical reactions take place, typically involving only a few numbers of molecules. While a number of these reactions have been studied in bulk assays or even at the single molecule level, the role of crowded environment or confinement has typically not been investigated. The goal of this project is to study the dynamics of single molecules and molecular complexes under the influence of confinement. An apparatus will be developed to create nanotube extensions from vesicle by pulling on self-assembled vesicle membranes. The nanotube-vesicle structures can be made stable in the case where the membranes are formed by cross-linkable polymers. Single molecules, such as genomic length DNA, will be driven to enter the nanotube and the dynamics of the molecule will be studied by fluorescence microscopy.

Category O

## Modelling the interaction of atoms with an optically trapped microsphere

**Supervisor:** Professor Kris Helmerson

The interaction of light with matter invariable involves the exchange of momentum. This exchange of momentum can be exploited to trap and remotely manipulate particles from the size of individual atoms to objects at the micron scale. Typically, the study of optical forces on these vastly different size objects is performed independently. The purpose of this project is to investigate the combined effect of these two, seemingly different, applications of optical forces. In particular, the project will involve modeling the optical field at the surface of a microsphere trapped by a focused laser beam and studying the interaction of laser cooled atoms with the field at the surface of the microsphere.

Category O

## Optical trapping of microscopic water droplets for single molecule studies

**Supervisor:** Professor Kris Helmerson

Techniques for optically observing single molecules are extending and even changing our understanding of molecular processes in biology. Often, it is desirable to follow the dynamics of a single molecule for several seconds or longer. Methods have been developed to immobilize and isolate or confine single molecule in order to study their dynamics on such long time scales. One such approach is to confine the molecule of interest in a microscopic water droplet immersed in an immiscible background fluid, and then trap the water droplet using optical tweezers. For a sufficiently small water droplet, the molecule of interest will remain within the detection volume of a confocal microscope allowing continuous measurement of the molecule's behaviour. This approach has advantages over other approaches for immobilizing single molecules, such as surface attachment - the molecule is free to diffuse within the water droplet away from an uncharacterized surface. The goal of this project will be to develop an apparatus capable of trapping and manipulating microscopic water droplets containing single molecules and studying the behaviour of the single molecules. In addition to the development of the necessary optical technologies for such studies, microfluidic-based approaches will be investigated for generating single, microscopic water droplets on demand.

Category O

## Photoacoustic sensor for brain visualisation

**Supervisor:** Dr Alexis Bishop

There is much interest in being able to visualise the small blood vessels of the brain and measure the velocity and oxygenation levels of blood travelling in vessels within surface layer without removing the scalp, or using dangerous ionising radiation.

Recently developed photoacoustic techniques [1] have the ability to provide visualisation of the vascular structure as well as measurements of these other properties. In the photoacoustic technique an intense pulsed laser beam, with a wavelength that is absorbed by the haemoglobin in red blood cells, illuminates the skull, which strongly diffuses the light without appreciable absorption. The blood cells in the vessels of the brain absorb the scattered light and in a near-instant heat (by a small fraction of a degree) and expand slightly, which generates an outward pressure pulse. The pressure pulse can travel largely unimpeded through the brain and skull to the surface where it can be detected by an optical pressure transducer which allows two-dimensional visualisation. By observing the pressure signal at different times, images of different depths in the brain can be made, which allows three dimensional imaging of the vasculature to be made without resorting to tomographic inversion.

This experimentally-based project is to develop an optical sensor system that is capable of visualising vessels equivalent to those found in the rat cortex beneath an intact rat skull. The sensor will utilise the reflection that occurs at the boundary of two different refractive index materials [2] and exploit the relatively large compressibility of silicone polymers in response to a pressure wave.

The project does not involve experimentation on animals, and will use simulated capillaries.

**References:**


[1] Laufer J., Zhang E., Raivich G., Beard P., Three-dimensional noninvasive imaging of the vasculature in the mouse brain using a high resolution photoacoustic scanner. Applied Optics, 48, 10, D299-D306, 2009

[2] Paltauf G, and Schmidt-Kloiber H, Measurement of laser-induced acoustic waves with a calibrated optical transducer, Journal of Applied Physics, 82, no. 4, p. 1525, 1997.


Category O

## Singular Electron Optics

**Supervisors:** Professor Michael Morgan, Dr Tim Petersen & A/Professor David Paganin

This project will explore a new field of optics - called singular electron optics, based on work published recently in Physical Review Letters [1]. A major focus of the project will be to develop and implement techniques for producing and controlling electron beams, using both probe and image forming aberrations in high resolution transmission electron microscopy (HRTEM). A wide range of experiments, complemented by foundational theoretical studies, will be conducted to explore electron diffraction catastrophes, vortex beams, and the relationship between the Gouy phase, the geometric (Berry) phase and Maslov indices. To experimentally demonstrate these connections for matter waves, we will also develop an in-line holography approach to measure Gouy phase anomalies for astigmatic electron beams. It is also possible to exploit electron vortices to investigate analogues of condensed matter systems.

Wave dislocations, such as vortices, are a ubiquitous feature of all wavefields. At the core of a vortex the intensity (or probability density) vanishes, with a concomitant singularity in the phase. The singularity is characterised by a winding number $m$ (topological charge), which measures the number of $2\pi$ rotations in the phase of the wavefunction. Phase singularities have been studied extensively in light optics [2], matter waves [3] and x-ray optics [4]. In particular, optical vortices have been investigated by Berry *et al.*. [5], who showed that optical caustics are not sharp, as predicted by geometrical (ray) optics, but have a fine structure arising from diffraction. These optical diffraction patterns are associated with a vortex lattice that is robust to perturbations. Vortices in electron wavefields have been the subject of recent work reported in the journals Nature [6, 7] and Science [8]; these papers demonstrate that it is possible to produce electron vortex beams, including those with large orbital angular momentum (OAM). In a recent paper [1] on catastrophe electron optics, we have shown that it is possible to produce a lattice of electron vortices using only the aberrations in HRTEM and create probes with large OAM density, without recourse to high order topological charges, which are known to be unstable to perturbations. This project aims to develop the new field of singular electron optics, including, but not limited to producing and controlling electron beams and vortices with sub-nanometre core sizes.

Specific aims topics include:

(i) Conduct comprehensive analytical and numerical studies of singular electron optics, including electron vortex beams and vortex lattices produced by diffraction catastrophes;

(ii) Experimentally realise the elementary and higher order catastrophes using aberrations in high resolution transmission electron microscopy, and use the framework of catastrophe theory to explore the equivalence classes of electron vortex lattices that arise;

(iii) Investigate the relationship between the Gouy phase, the geometric (Berry) phase and Maslov indices in singular electron optics;

(iv) Experimentally measure and exploit the Gouy phase for electron matter waves;

(v) Synthesise micron scale masks (e.g., 3-pinhole apertures and narrow annuli), to create highly ordered electron vortex lattices and diffraction-free vortex lattices;

(vi) Explore the possibility of creating knotted electron wavefunctions using nano-engineered masks.

(vii) Utilise vortex lattices and diffraction catastrophes to develop a new electron holography technique, which exploits the sensitivity of vortices to phase shifts induced by an object;

(viii) Use electron beams and vortex lattices to investigate novel analogues of condensed matter systems.

**References:**


[1] T. C. Petersen, M. Weyland, D. M. Paganin, T. P. Simula, S.A. Eastwood and M. J. Morgan, *Phys. Rev. Lett.* **110**, 033901 (2013).

[2] J. F. Nye and M. V. Berry, *Proc. Roy. Soc.* A **336**, 165 (1974).

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[4] D. Paganin, *Coherent X-ray Optics* (Oxford University Press, Oxford 2006), Chapter 5, and references therein.

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[8] B. J. McMorran *et al.., Science* **331**, 192 (2011).


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# PARTICLE PHYSICS AND COSMOLOGY

Category P

## Bremsstrahlung on a GPU

**Supervisor:** A/Professor Peter Skands

In this project, we will consider a simplified approach to Bremsstrahlung radiation in quantum field theory (called 'parton showers') and investigate the feasibility of constructing a parton-shower algorithm suitable for implementation on graphics processing units (GPUs). This has the potential to enable massively parallel shower calculations, which could be crucial for comprehensive uncertainty evaluations in state-of-the-art high-energy physics simulations. Prior programming experience is required, preferably at a fairly advanced level, though not necessarily involving GPUs.

Category P

## Cosmology of the electroweak symmetry breaking

**Supervisor**: A/Professor Csaba Balazs

Standard elementary particles acquire their masses via the mechanism of spontaneous electroweak symmetry breaking. The accompanying electroweak phase transition took place in the early Universe when its temperature fell below the tera-electron-volt scale, and its Hubble horizon was about 23 orders of magnitude smaller than today.

If the electroweak phase transition was strongly first order it proceeded via bubble-nucleation. Collision of the bubble walls containing the broken phase lead to gravitational disturbances, traces of which have been shown to be observable in future gravitational wave experiments such as LISA.

The aim of this project is to estimate the effect of these gravitational waves on the cosmic microwave background, the imprint of energy density fluctuations from the time of the last photon scattering.

**References:**


[1] C. Caprini, R. Durrer and G. Servant, Gravitational wave generation from bubble collisions in first-order phase transitions: an analytic approach, arXiv:0711.2593.

[2] S. J. Huber and T. Konstandin, Gravitational Wave Production by Collisions: More Bubbles, arXiv:0806.1828.

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[5] W. Zhao, D. Baskaran, Detecting relic gravitational waves in the CMB: Optimal parameters and their constraints, arXiv:0902.1851.
[6] C. Caprini, R. Durrer, G. Servant, The stochastic gravitational wave background from turbulence and magnetic fields generated by a first-order phase transition, arXiv:0909.0622.

Category P

## Electrons and photons as emergent Phenomena

**Supervisor**: Professor Michael Morgan

This project addresses the question: are electrons and photons fundamental particles or emergent phenomena? In ref. [1] it was demonstrated that one could construct a U(1) gauge theory (of light) based on a local bosonic model. Fundamental to this approach is the notion of a new kind of order, called topological order, in which particles arise from excitations of a string-net condensed phase. However, these strings are fundamentally different from the superstrings in high-energy particle physics. A simple lattice bosonic model will be used to explore the emergence of U(1) gauge theory in the low energy regime. Possible extensions will include an exploration of how spin-2 gravitons might arise from a lattice bosonic model.

**Reference**

[1] M. Levin and Xiao-Gang Wen, Rev. Mod. Phys. **77**, 871-879 (2005).

Category P

## Extended supersymmetric models

**Supervisor**: A/Professor Csaba Balazs

Tera-scale supersymmetry is the most promising theoretical extension of the standard particle model. While supersymmetry solves numerous theoretical problems of the standard model, its breaking mechanism remains an open question. Also uncertain is the electroweak breaking (Higgs) sector in supersymmetric models.

In gaugino mediated models supersymmetry breaking is mediated by superpartners of standard gauge bosons (such as the photon) propagating in extra space dimensions. These models produce successful but somewhat fine-tuned phenomenology. Combining gaugino mediation with an extended Higgs (electroweak symmetry breaking) sector has the promise of removing the fine-tuning from the minimal model.

The aim of this project is to construct and analyze a phenomenologically viable gaugino mediated scenario in the framework of the next-to-minimal supersymmetric standard model.

**References:**


[1] C. Balazs et al., Viable models with non-universal gaugino mediated supersymmetry breaking, arXiv:hep-ph/0204108

[2] C. Balazs, R. Dermisek, Yukawa coupling unification and non-universal gaugino mediation of supersymmetry breaking, arXiv:hep-ph/0303161

[3] C. Balazs, D. Carter, Discovery potential of the next-to-minimal supergravity motivated model, arXiv:0808.0770

[4] C. Balazs, D. Carter, Likelihood analysis of the next-to-minimal supergravity motivated model, arXiv:0906.5012


Category P

## High-efficiency Monte Carlo with maximally helicity-violating amplitudes

**Supervisor:** A/Professor Peter Skands

Quantum field theory amplitudes involving particles with definite helicities have a particularly simple structure in the so-called maximally helicity-violating (MHV) case, when all gauge-boson helicities, but two are identical. These are simultaneously the most singular and hence dominant contributions to the Bremsstrahlung processes that accompany the scattering of fundamental particles at high-energy colliders. In this project, we will combine the elegant analytical formulae for MHV amplitudes with a numerical Monte-Carlo sampling program to deliver a proof of concept for an extremely efficient and accurate "event generator" for high-multiplicity final states with real-word collider-physics applications.

**References:**


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[2] http://arxiv.org/abs/arXiv:0808.3319,

[3] http://arxiv.org/abs/arXiv:1301.0933,

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Category P

## Is dark matter superfluid light?

**Supervisors:** A/Professor Csaba Balazs, Professor Michael Morgan & Dr Tapio Simula

There are numerous observations shedding light on the properties of dark matter, however its decomposition is unknown. Based on its known properties, we examine whether dark matter can be superfluid light. Our speculation is motivated by the recent observations of Bose-Einstein condensation of photons [1] and by the successes of the bosonic star dark matter models [2].

In this project, we examine the quantitative details of the above proposal. Under what conditions do photons condense in the early Universe? Is the condensate "dark"? Is it destroyed by ordinary matter? Does the average energy density trapped in the condensate match the measurements? Do vortices in the condensate correspond to galaxies, clusters or larger observed structures? Can the mass distribution of galaxy clusters be explained? Do the galactic rotation curves agree with this model?

Based on the general properties of Bose-Einstein condensates and the standard (ΛCDM) cosmological model each of these questions can be quantitatively answered [3,4].

**References**

[1] J. Klaers, H. Schmitt, F. Vewinger and M. Weitz Nature 468, 545 (2010).

[2] J.-W. Lee arXiv:0801.1442 and references therein.

[3] M. Morgan and R. Yu Classical and Quantum Gravity 19, L157 (2002).

[4] T. Simula and C. Balazs in preparation

Category P

## Supersymmetric dark matter

**Supervisor:** A/Professor Csaba Balazs

When interpreted within the standard (ΛCDM) cosmological framework astrophysical observations indicate that some 85 percent of the matter in the Universe is non-luminous (dark). Supersymmetry offers a natural explanation for this dark matter in the form of the lightest supersymmetric particle.

While the minimal supersymmetric extension of the standard particle model is constrained into a fine-tuned theoretical region by experiments, extending the Higgs (electroweak symmetry breaking) sector of these models can remove this problem.

This project examines whether we can obtain an amount of dark matter consistent with observations within a particular realization of the next-to-minimal supersymmetric standard model while staying in the natural part of the parameter space and remaining consistent with various collider, astrophysical and low energy measurements.

**References:**

[1] H. Baer, C. Balazs, $\chi^2$ analysis of the minimal supergravity model including WMAP, g(mu)-2 and b → gamma constraints, arXiv:hep-ph/0303114.

[2] C. Balazs, M. S. Carena, A. Menon, D.E. Morrissey, C.E.M. Wagner, The Supersymmetric origin of matter, arXiv:hep-ph/0412264.

[3] C. Balazs, D. Carter, Discovery potential of the next-to-minimal supergravity motivated model, arXiv:0808.0770.

[4] C. Balazs, D. Carter, Likelihood analysis of the next-to-minimal supergravity motivated model, arXiv:0906.5012.

Category P

## Supersymmetric origin of matter

**Supervisor:** A/Professor Csaba Balazs

Supersymmetry has the potential to explain the origin of all, baryonic (visible) and non-luminous (dark), matter in the Universe. While dark matter may be the lightest supersymmetric particle, a baryon-antibaryon asymmetry can be generated by electroweak baryogenesis in the (next-to-)minimal supersymmetric extension of the standard particle model.

Electroweak baryogenesis is typically driven by charged superpartners of the standard gauge bosons (gauginos). While in the minimal models the matter content of the Universe is successfully reproduced, these scenarios face stringent constraints from experiments measuring the electric dipole moments of electrons.

In this project, we explore the possibility that electroweak baryogenesis can be driven by neutral gauginos, gauge singlet scalars or by non-standard gauge bosons. In such models the electric dipole moment constraints would not apply, but the question whether the dark matter content is consistent with measurements remains to be examined.

**References:**

[1] C. Balazs, M. S. Carena, A. Menon, D.E. Morrissey, C.E.M. Wagner, The Supersymmetric origin of matter, arXiv:hep-ph/0412264.

[2] C. Balazs, M. S. Carena, A. Freitas, C.E.M. Wagner, Phenomenology of the nMSSM from colliders to cosmology, arXiv:0705.0431.

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Category P

# The origin of inertia

**Supervisor:** A/Professor Csaba Balazs

While Isaac Newton and Albert Einstein created remarkable theories explaining the dynamics of gravity, they both omitted to clarify the meaning of mass in their equations. Today, in the context of the standard particle model, we understand inertial mass as a consequence of an interaction with a hypothetical Higgs field filling space and "dragging" on matter similarly to viscose fluid.

In 2012 the LHC discovered a new bosonic state and over 2013 the experimentalists established that its properties are consistent with those of a Higgs boson. (It is remained to be seen whether the particle is composite or an elementary Higgs without substructure.)

The next step is to find out if it is the standard Higgs boson. This step will require the detailed measurements of the properties of the particle which in turn will need lot more data. Fortunately the number of LHC collisions still increases exponentially.

The long-term question: is there anything else to discover at the LHC? The Higgs might hold part of the answer because if it's a non-standard Higgs than it's almost certain that there's more to come. Supersymmetry, extra dimensions, strings? In this project we investigate some of these possibilities.

**References:**


[1] C. Balazs, E. L. Berger, P. M. Nadolsky, C.-P. Yuan, Calculation of prompt diphoton production cross-sections at Tevatron and LHC energies, arXiv:0704.0001.

[2] P. M. Nadolsky, C. Balazs, E. L. Berger, C.-P. Yuan, arXiv:hep-ph/0702003.

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Category P

# What have we learned from the large hadron Collider?

**Supervisor:** A/Professor Peter Skands

High-energy collisions between elementary particles normally give rise to complex final states, with large numbers of hadrons, leptons, photons and neutrinos. The relation between these final states and the underlying physics description is not a simple one, for two main reasons. First, we do not even in principle have a complete understanding of the physics. Secondly, any analytical approach is made intractable by the large number of particles. Monte Carlo (MC) event generators - computer programs based on quantum field theory, random-number theory, and phenomenological models - are able to bridge the gap, providing simulated events in as much detail as the real collider events. However, the necessity to make approximations implies that no model is perect. In this project, we will consider the constraints imposed on some important MC models by the measurements so far performed at the Large Hadron Collider (LHC), and what this implies for predictions for Run 2 of the LHC, due to start in early 2015.

**References:**


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[2] http://arxiv.org/abs/arXiv:1101.2599,

[3] the MCPLOTS web site (http://mcplots.cern.ch)

[4] http://arxiv.org/abs/arXiv:1404.5630


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# STATISTICAL PHYSICS

Category S, AM

## Quantum chaos, turbulence and vortices

**Supervisor:** Dr Tapio Simula

Several projects are on offer under this category including those listed below:

**I: Role of quantized vortices in quantum chaotic systems**

Consider a system whose classical behaviour is chaotic. According to the correspondence principle, quantum mechanics should reproduce such behaviour in the classical limit. However, quantum systems are described in terms of eigenstates, which correspond to perfectly periodic motion with well defined frequencies. How then, can chaotic behaviour arise in the context of quantum mechanics?

The aim of this computational and theoretical project is to investigate the relationship between quantized vortices and caustics and their role in understanding quantum chaotic systems.

**II: Quenced random environments in chaotic dynamical systems**

Chaotic dynamical systems are characterized by their vulnerability to perturbations: small changes in the initial conditions lead to exponentially large deviations in the final state. Such behaviour often emerges in the simplest of models yet they can exhibit the most interesting features such as fractal structures.

The aim of this computational and theoretical project is to investigate the two-dimensional chaotic dynamics of billiards in the presence of quenched random environments with potential extensions involving implementing a memory for the particles.

**III: Point-vortex model of two-dimensional quantum turbulence**

The two-dimensional point-vortex model by Onsager suggests the emergence of a peculiar inverse energy cascade in which energy is transported from small scale structures to ever larger ones. This process may lead to negative temperature states corresponding to giant coherent vortex structures in turbulent two-dimensional fluids.

The aim of this computational and theoretical project is to integrate the chaotic Hamiltonian dynamics of point vortices and apply the above ideas to investigate two-dimensional point-vortex turbulence and to study the applicability of the obtained results to the experimentally realizable two-dimensional superfluid turbulence in Bose-Einstein condensates.

**IV: Modeling quasiparticle vortex waves using point vortices**

When a superfluid such as a Bose-Einstein condensate is rotated, quantized vortices are nucleated in it, which in equilibrium arrange in a triangular lattice structure. Small perturbations to such equilibrium results in the collective motion of the quantum vortices.

The aim of this computational and theoretical project is to integrate the Hamiltonian dynamics of point vortices and to compare the vortex orbits to the corresponding trajectories predicted by a Bogoliubov–de Gennes field theory.

**V: Monte Carlo study of negative temperature phase transitions**

Onsager developed a statistical mechanics description of point-like vortices confined to move in two-dimensions. A remarkable feature of such systems is the emergence of absolute negative temperature equilibria and coherent large scale vortex clusters.

The aim of this computational and theoretical project is to perform Monte Carlo calculations of point vortices to study emergent negative temperature phases of vortex matter.

**VI: Quantum turbulence of superfluid Bose-Einstein condensates**

Turbulence is one of the great open problems in physics. Fresh new insights into this outstanding problem are expected to be gained by studying turbulence in two-dimensional superfluid systems where the motion of individual quantized vortices can be tracked.

The aim of this computational and theoretical project is to investigate two-dimensional superfluid turbulence in experimentally realizable Bose-Einstein condensates by numerically solving the Gross-Pitaevskii equation governing the dynamics of quantum turbulence in such laboratory superfluids.

Category S

## Statistical mechanics of random Graphs and complex networks

**Supervisor:** Professor Michael Morgan,

Many systems in nature can be described in terms of complex networks. Non-trivial examples include genetic networks, ecological networks and spin networks. This project will apply the principles of statistical mechanics to explore the organising principles and dynamics of random graphs and complex networks. Field theoretic techniques will be used to investigate an ensemble of random graphs, including networks that exhibit a Bose-Einstein phase transition.

**Reference**

[1] R. Albert and A.L. Barabasi, *Statistical Mechanics of Complex Networks*, *Rev. Mod. Phys.* **74**, 47 (2002).

---oOo---

MONASH University

**School of Physics and Astronomy**

# Honours in Physics and Astrophysics 2015

I wish to be considered for a place in Honours Physics and Astrophyiscs in 2015

NAME: ………………………………………………………………………………….

ADDRESS: ……………………………………………………………………………

…………………………………………………………………..POSTCODE…………

TELEPHONE: …………………………………………

Please list three project preferences, in decreasing order of preference.

| | Area of research | Supervisor(s) |
|---|---|---|
| 1 | | |
| 2 | | |
| 3 | | |

Signed ………………………………………………………………………

Date: ……………………………………………………………………….

By **October 31, 2014**, please return completed form to:
Mrs Jean Pettigrew in, Room 143E, Bldg 19, School of Physics

Note: You must also submit a separate Honours Application Form, to the Faculty of Science, by **Internal - November 14, 2014, External - November 14, 2014.**
This is available at http://monash.edu/science/current/honours/how-to-apply/

For your convenience, a copy is included at the end of this booklet.

# School of Physics and Astronomy

## J L William Honours Scholarships

Outstanding physics and astrophysics graduates are encouraged to apply for the prestigious J. L. William Scholarships to undertake honours studies within the School of Physics and Astronomy at Monash University. The Scholarships are available to Australian citizens and permanent residents; they provide a non-taxable stipend of $5,000 for one year.

An important feature of the Honours year is the research project, which is devoted to exploring in depth some contemporary topics in astronomy, astrophysics, experimental or theoretical physics. Research themes in the School of Physics and Astronomy are listed at: http://physics.monash.edu/research/

Further information on the honours programme in physics and astrophysics may be found at: http://monash.edu/science/about/schools/physics/honours/

Honours enquiries to Professor Michael Morgan: Michael.J.Morgan@monash.edu

**Les William** was born in Melbourne on January 18, 1915. He was a leading scientific instrument maker. From the 1930s to the 1980s there cannot be many Australian laboratories that have not possessed an example of his beautiful craftsmanship. His name on an electrical instrument was a guarantee of excellence, both in terms of precision and beauty. Les William liked to recall Lord Kelvin's dictum that one did not truly understand a scientific quantity until one could measure it and provide an accurate numerical value.

# School of Physics and Astronomy

## J L William Honours Scholarship

## APPLICATION FORM

**Name:** _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

**Address:**_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

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**Telephone: (MOB)**_ _ _ _ _ _ _ _ _ _ _ _ **(BH)** _ _ _ _ _ _ _ _ _ _ _ _ **(AH)** _ _ _ _ _ _ _ _ _ _ _ _

**E-mail Address:** _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

**Details of undergraduate qualifications:** _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

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_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

**Are you currently enrolled? Yes ☐ No ☐**

**If yes please specify the University and course:**

_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

**Research Interests:** _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

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_ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

Please forward this application together with your Academic Record, CV and the contact details of two referees to Mrs Jean Pettigrew via E-mail at: jean.pettigrew@monash.edu or by mail to: Mrs Jean Pettigrew, Staff and Student Services Officer, School of Physics and Astronomy, Monash University, Victoria 3800. Telephone enquiries: (03) 9905 3651; Fax: (03) 9905 3637.

The closing date for this scholarship is Friday 12th December 2014

MONASH University
Science

# DIRECT APPLICATION FORM
# FACULTY OF SCIENCE HONOURS PROGRAMS - Semester 1, 2015

**APPLICATION CLOSING DATE**
**Friday 14 November, 2014**
Late applications will be considered

## GENERAL INFORMATION

This form is to be used by **local/domestic students** seeking admission to the following courses:

- **Bachelor of Science (Honours)**
- **Honours Degree of Bachelor of Science (Science Scholar Program) – (internal students only)**

This form can also be used **by internal Monash local/domestic and international students** seeking admission to the 4th year Honours component of:

- **Bachelor of Biotechnology (students who commenced the course prior to 2014)**
- **Bachelor of Environmental Science (students who commenced the course prior to 2014)**
- **Bachelor of Science Advanced – Research (Honours)**

For information on courses and entry requirements, please refer to the Monash Course Finder or the relevant Handbook entry.

**This form is for:**

- **Australian citizens**
- **New Zealand citizens**
- **Australian Permanent resident visa holders**
- **Australian Permanent humanitarian visa holders**

International students, including permanent residents of New Zealand, applying for one year Honours courses, must apply through Monash International Admissions

## COMPLETING THIS FORM

- Please print boldly in blue or black ink using block letters
- Please attach one set of supporting documentation (all documents must be **hardcopy** original or certified documents (see **Applicant checklist** over the page)
- Faxed or emailed supporting documentation will not be accepted.

## PSYCHOLOGY HONOURS DISCIPLINE

**DO NOT use this application form. Please apply online via** the School of Psychological Sciences by **31 October 2014**. International applicants **will also need to apply** through International Admissions'

**RECEIVED STAMP:**
**Please retain this copy as proof that your application has been submitted.**

**STUDENT ID number (Monash only)** ____________________

**NAME:** ____________________________________________

## IMPORTANT APPLICATION INFORMATION

- **Please read the Applicant checklist over the page and follow all the steps (Clayton campus only).**
- Students wishing to apply for Honours in more than one discipline must submit a **separate application form** for each discipline. Please check the list of Honours disciplines on the web.
- **Please ensure that you have made contact with the relevant Honours Coordinator and supervisor to discuss your potential honours program BEFORE** completing and submitting this form to the relevant Faculty of Science office.
- Students enrolled in a double degree at Monash who have not completed the non-science component **must re-enrol** in their current course until they are made an offer to enrol in the Honours program. Students will then be intermitted from their double degree, after they have accepted and been enrolled into the Honours program.
- Only the Faculty of Science can make an offer of admission for the Honours program. Completion of this form and any recommendation(s) made by the School/Department do not constitute an offer for the Honours program.
- Offers are subject to the availability of adequate supervision and facilities and meeting the minimum academic entry requirements does not guarantee admission to Honours. In some disciplines there are limited projects and/or competition for more popular projects.

## BACHELOR OF BIOTECHNOLOGY students

- Please get your form signed by Lynne Mayne, as well as your Honours discipline coordinator.

## LODGEMENT OF APPLICATIONS AND ENQUIRIES

- Mail or hand-deliver to the relevant Science office on your campus as follows:

**Clayton Campus:**
Student Services Office
Building 19, G26
Faculty of Science
Monash University
Clayton VIC 3800
Email: sci-enquiries@monash.edu
Phone: + 61 3 9905 4604

**Monash University Malaysia:**
Science Course Management Office
Building 4, Level 8
Jalan Lagoon Selatan
47500 Bandar Sunway
Selangor Darul Ehsan, Malaysia
Email: scienceinquiries.my@monash.edu
Phone: + 60 3 5514 6186/6187/6120

# APPLICANT CHECKLIST – CLAYTON CAMPUS ON LY

**(For MONASH MALAYSIA application process go to: http://sci.monash.edu.my/honours-program/Honours-Applications.html)**

| | |
|---|---|
| **INTERNAL DOMESTIC APPLICANTS (and INTERNAL INTERNATIONAL applicants applying for the Honours components of 4 year degrees)** | |
| 1. Contact the relevant Honours coordinator and supervisor to discuss your potential Honours program. At this point you may need to complete an internal school/departmental form to indicate your project preferences. This does not replace, but is in addition to, the Faculty Honours application form. | ☐ |
| 2. Complete Sections A and B of the Faculty of Science, Honours application form. | ☐ |
| 3. Come in to the Faculty of Science, Student Services office for an eligibility check to ensure that you are/will be eligible to commence the relevant Honours program in Semester 1, 2015. This should be done as soon as possible; do not wait until the last week before applications close. | ☐ |
| 4. Take the form to your Honours coordinator who will complete Section D including listing the relevant Level three units. (Depending on the project, Section C may need to be completed as well prior to Section D) | ☐ |
| 5. Read the applicant's declaration and sign at the bottom of Section E. | ☐ |
| 6. Return the completed Faculty form to the Faculty of Science, Student Services office. | ☐ |
| **EXTERNAL DOMESTIC APPLICANTS** | |
| 1. Contact the relevant Honours coordinator and supervisor to discuss your potential Honours program. At this point you may need to complete an internal school/departmental form to indicate your project preferences. This does not replace, but is in addition to, the Faculty Honours application form. | ☐ |
| 2. Complete Sections A and B of the Faculty of Science, Honours application form. | ☐ |
| 3. Contact the Faculty of Science, Student Services office for an eligibility check to ensure that you are/will be eligible to commence the relevant Honours program in Semester 1, 2015. This should be done as soon as possible; do not wait until the last week before applications close. | ☐ |
| 4. Take the form to your Honours coordinator who will complete Section D including listing the relevant Level three units. (Depending on the project, Section C may need to be completed as well prior to Section D) | ☐ |
| 5. Read the applicants declaration and sign at the bottom of Section E. | ☐ |
| 6. Attach the relevant original or certified **hardcopy** documentation as follows:<br>• Official academic transcript and, if not indicated on the transcript, an official statement or certificate confirming that you have qualified for a Bachelor of Science degree or a comparable qualification.<br>• Proof of Australian citizenship or permanent residency, eg birth certificate, passport, citizenship certificate.<br>• If previous tertiary study was completed overseas in a non-English speaking country, then proof of meeting English language proficiency requirements will also be required.<br>**Please seek advice from the Faculty of Science if you need clarification regarding required documentation. Faxed or emailed documents will not be accepted.**<br>**NOTE:** If final transcripts and course completion evidence are not available by the application closing date, please provide interim transcripts listing all completed and enrolled units. Final transcripts must be supplied at least five working days prior to commencement of the relevant School/Department Honours program. A full offer for the Honours program will not be made until all official documentation is received. | ☐<br>☐<br>☐ |
| 7. Return the completed Faculty form and all documentation to the Faculty of Science, Student Services office. | ☐ |
| **EXTERNAL INTERNATIONAL APPLICANTS (and INTERNAL INTERNATIONAL applicants applying for Courses 0051 & 2188):** | |
| 1. Contact the relevant Honours coordinator and supervisor to discuss your potential Honours program. At this point you may need to complete an internal school/departmental form to indicate your project preferences. This does not replace, but is in addition to, the application process through International Admissions. | ☐ |
| 2. **DO NOT Use this application form.** Please apply through **International Admissions** via the following website: http://www.monash.edu/study/international/apply/<br>When making your application through International Admissions, **you are required to indicate the Honours discipline you are applying for and the name of the Honours coordinator and supervisor you have been in contact with.** International Admissions will forward your application to the Faculty of Science for consideration. The Faculty of Science will determine if you have met the academic eligibility requirements and also contact the relevant school/department Honours coordinator to ensure you have arranged an approved project and supervisor. | ☐ |
| **PSYCHOLOGY HONOURS DISCIPLINE** | |
| **DO NOT use this application form. Please apply online via** the School of Psychological Sciences. by 31 October, 2014. International applicants **will also need to apply** through International Admissions | |

## WHAT HAPPENS NEXT – CLAYTON CAMPUS ONLY

- **Students already complete or due to complete their course, science component or 3rd stage in Semester 2, 2014** will be notified via email of the outcome of their application by **4:00pm on Friday 12 December, 2014.** (Internal students with deferred exams, enrolled in Summer units, or external students yet to supply full documentation, will be sent **conditional** offers only)
- **Internal domestic students (and internal internationals applying for Honours component of 4 year degrees)** will be notified via their Monash email account and, if successful, will need to accept their offer via return email. They will then be given further instructions via email regarding enrolment in their Honours program. You will not be required to attend in person for enrolment.
- **External domestic students, provided all relevant documentation has been received,** will be notified via email and, if successful, will be required to attend an enrolment session on **8 January 2015.** If you are unavailable on that date, another date can be arranged in consultation with the Faculty.
- **External International students (and internal internationals applying for courses 0051 & 2188)** will be notified by International Admissions and, if successful, will be required to attend an enrolment session on **17 February 2015.**
- **Commencement dates** vary depending on the Honours discipline. Please check with your school/department Honours coordinator.

MONASH University
Science

## SECTION A

**Personal details**

| | | | |
|---|---|---|---|
| Monash Student ID (if applicable): | | Date of Birth: / / | Sex: F ☐ M ☐ |
| Title: | Surname: | Given Names: | |
| Phone: | Mobile: | Email: (Monash student email if applicable) | |

***Are you an international student?** **Yes** ☐ **No** ☐

***Please note *ALL* International (external and internal) students applying for course 0051 or internal students applying for course 2188, on Australian campuses, must apply through International Admissions, NOT via this form.**

Postal address for correspondence: (for external applicants only) :

Number and Street:

| | | |
|---|---|---|
| Suburb: | State: | Postcode: |

**Details of Previous or Current Course**

| | | |
|---|---|---|
| Institution/University: | Major / Specialisation: | |
| Campus: **(Monash only)** | Course Title: | Course Code: |

**Completed** Ugrad degree (or Science component of double degree or 3rd stage of 4 year Honours degree) **Yes** ☐

**NO:** Expected completion: **Sem 2, 2014** ☐ **Deferred Exam/s 2015** ☐ **Summer 2014/15** ☐

## SECTION B

**Honours program you are applying for**

**Clayton** 0051 BSc (Hons) ☐ 2340 BEnvSci ☐ 3527 BBiotech ☐

3520 BScAdv Research (Honours) ☐ 2188 BSc (Sci Schl Prog) (Hons) ☐

**Malaysia** 0051 BSc (Hons) ☐

**Study Mode**

The Honours program requires one year of full time study. Part-time study, **over two years** is available in some specialisations. Please indicate your intended mode of study, after consulting with the school/department Honours coordinator.

**Full-Time** ☐ **Part-Time** ☐

**Details of Honours Study - *Please consult with Honours Coordinator in the nominated School/Department.***

| | |
|---|---|
| **SCHOOL/DEPARTMENT** | |
| **HONOURS DISCIPLINE**<br>Please refer to web for a list of Honours disciplines | |

**FACULTY OFFICE USE ONLY**

**AVERAGE**

**NOTES:** ____________________

____________________

**ELIGIBILITY CHECK** **Staff name:**____________ **Date:** / / **LOGGED** ☐ **DOCS** ☐

**CONDITIONAL OFFER SENT Date:** / / **PENDING** ____________________

**FINAL OUTCOME:** **OFFER** ☐ **NO OFFER** ☐

**Selection Officer:** **Signature:** **Date:** / /

## SECTION C

***Only complete this section if you are applying for an MIMR-PHI Institute of Medical Research OR Monash Medical Centre Clayton (MMC) OR Southern Clinical School (SCS) project.***

**Students applying for a research project with these entities will need to have this section authorised by A/Prof. Mark Hedger. Note that you must also get Section D signed by the relevant school/department Honours Coordinator of your honours discipline. You will be enrolled in the project code relevant to the Honours school/department in a location code of MMC.**

**MIMR-PHI/MMC/SCS Honours Coordinator Name:** ***Associate Professor Mark Hedger***

**MIMR-PHI/MMC/SCS Honours Coordinator Signature:** ________________________ **Date:** __ / __ / __

**Name of Project:** _______________________________ **Supervisor name :** ______________________________

## SECTION D

### To be completed by the Honours Coordinator or nominated representative

### School/Department Authorisation

**Subject to the student meeting all course requirements and subject to availability of a supervisor and other relevant resources** I recommend that the applicant be accepted as an Honours candidate.

***Honours Coordinators, please list the enrolled or completed relevant level three units or equivalent that could count towards the 70% average. If the listed units are not part of the published major and prerequisite requirements for your discipline, please provide the Faculty with a supporting statement/documentation explaining the inclusion of these units.***

**COMMENTS:**

_______________________________________________________________________________

_______________________________________________________________________________

| UNIT CODE (AND NAME FOR NON-MONASH UNITS) | FACULTY OFFICE USE ONLY | | |
|---|---|---|---|
| | | | |
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**Honours Coordinator**
***(or nominated representative)***

**School / Department:**

**Name:** **Signature** **Date: / /**

## SECTION E – Applicant Declaration

☐ **I have consulted with the Honours Coordinator (or nominated representative) in regards to the proposed Honours Program**

**Student Acknowledgement, Agreement and Consent**

- I warrant that the information on this form, or provided in support of my application, is correct and complete.
- I acknowledge that provision of incorrect information or the withholding of relevant information relating to my application, including academic transcript/s, might invalidate my application and that the University may withdraw an offer of a place or cancel my enrolment in consequence.
- Should the University determine that I have submitted a false document, I consent to the University disclosing this information to other relevant tertiary institutions.
- I consent to any educational institution at which I am or have been a student and/or any current or past employer providing Monash University with any information which that institution or employer holds about me concerning my attendance, conduct, grades and/or qualifications or experience to assess my suitability for an offer and/or enrolment.
- I have read the University's statement on privacy and the purposes for which my personal information will be used (available at http://www.privacy.monash.edu/guidelines/collection-personal-information.html
- If sponsored, I permit Monash University to release details of my academic progress to my sponsoring body on their request.
- I agree to abide by the statutes, regulations and policies of the university as amended from time to time and agree to pay all fees, levies and charges directly arising from my enrolment.
- I agree to access the correspondence of my University email account on a regular basis.

**Applicant's Signature:** **Date: / /**

# Monash – AAO

# Honours Scholarships in Astrophysics

*Physics student?*

*Doing Honours in 2015?*

*Thinking of astrophysics?*

*Interested in collaborating with astronomers from Australia's national optical observatory?*

The **Australian Astronomical Observatory** and **Monash School of Physics & Astronomy** are offering one **$5000 Honours Scholarship** to the most meritorious student undertaking a joint Monash – AAO Honours astrophysics project in 2015. (Conditions apply.)

**For more information (and how to apply):**
Dr Michael Brown (School of Physics & Astronomy),
Michael.brown@monash.edu (03) 9905 4498

**Closing date for applications:** 15 Feb 2015

*Image: D. Malin, (AAO)*

# Monash – AAO

# Honours Scholarships in Astrophysics

**More information:**

Dr Michael Brown

School of Physics, Monash University 3800 Victoria
Michael.brown@monash.edu
ph: (03) 99054498 fax: (03) 99053637

**Closing date:**

15 February 2015

# Monash – Australian Astronomical Observatory Honours Scholarships in Astrophysics 2015

## Application Form

The **Australian Astronomical Observator**y in Sydney (AAO) and the **Monash School of Physics & Astronomy** are offering one **$5000 Honours Scholarship** to the most meritorious student undertaking a joint Monash – AAO Honours astrophysics project in 2015.

Applications are due by the **15th February 2015** and should include:

1. this Application Form, including a brief statement (100 words or less) describing your interests and experience in astronomy or astrophysics,
2. a copy of your academic transcript, and
3. letters from two academic referees, sent directly to the address below.

Send your completed application to:
**Ms Jean Pettigrew**, School of Physics & Astronomy, Room 143E, Building 19, Monash University 3800 VIC; or via jean.pettigrew@monash.edu by the due date.

### Personal Details

Full Name ______________________________________________

Postal Address ______________________________________________

Town/Suburb/City ____________________ Postcode ____________

Email address ____________________ Telephone ____________

Degree(s) currently being undertaken at Monash ____________________

Other tertiary education qualifications ____________________

### Honours Project

Title ______________________________________________

Monash supervisor(s) ______________________________________________

AAO supervisor(s) ______________________________________________

Other supervisor(s) ______________________________________________

## 1st Academic Referee

Title & Name ______________________

Position ___________________________

Institution _________________________

Address ___________________________

Town/City _________________________

Email _____________________________

Phone _____________________________

## 2nd Academic Referee

Title & Name ____________________

Position _________________________

Institution _______________________

Address _________________________

Town/City _________________________

Email ____________________________

Phone _____________________________

Please arrange for your referees to send their reference letters **directly** to:
**Ms Jean Pettigrew**, School of Physics, Room 143E, Building 19, Monash University 3800 VIC; or via jean.pettigrew@monash.edu by the due date.

## Interests and Experience

Please including a brief statement **(100 words or less)** describing your interest in astronomy and astrophysics, and any relevant experience you have. This might include (but is not limited to) any undergraduate courses you have taken, any summer vacation scholarships or awards received, the pursuit of amateur astronomy as a hobby or membership of astronomical societies, or any other astronomical experiences that have influenced you in some way. **(This statement can be attached on a separate page if necessary.)**

## Declaration

I declare that the above is true and understand that Monash reserves the right to vary or cancel any decision on the basis of incomplete or wrong information supplied in the application. I have also read the Terms and Conditions of the award on the attached pages.

Signed ________________________________________ Date ________________

# Monash – Australian Astronomical Observatory Honours Scholarships in Astrophysics 2015

## Terms and Conditions of the Award

1. One Honours scholarship (to the value of $AUD 5000) will be jointly offered by the Australian Astronomical Observatory in Sydney (AAO) and the Monash School of Physics & Astronomy in 2015. Scholars will conduct their Honours research on a project co-supervised by at least one Monash and one AAO astronomer.

2. To be eligible, applicants should have completed a Bachelor programme in Science (or an appropriately related area) to at least third year. The Scholarships are awarded on the basis of merit and academic excellence (at the high distinction or distinction level in relevant subjects). The potential of the applicant for research is also used to determine whether an award is made.

3. The Scholarship is awarded by Monash and the AAO subject to the agreement of both organisations through the Head of the School of Physics & Astronomy, Monash, and the Director of the AAO, following the recommendations of the Selection Committee. The Selection Committee consists of staff from both the AAO and the School of Physics & Astronomy who will meet shortly after the application deadline to consider all applications. The decisions of the Selection Committee and the Head of Physics & Astronomy and AAO Director are final.

4. Scholarships are tenable for the Honours year, meaning that awardees must also be eligible for entry into the Honours programme at Monash for the year of the award. Applicants may apply for other Monash Honours scholarships in addition to Monash – AAO but can only hold one during their Honours year.

5. The value of the Scholarship is $AUD 5000 to be paid in two instalments (of $2500) at the commencement of first and second semester.

6. Monash and the AAO reserve the right to not award a scholarship in a given year if the standard of applications is below the standard usually accepted.

7. Applications must consist of a completed Application Form, a copy of the applicants full university academic transcript, and letters from two academic referees (sent directly to the lodgement address on the application). All application documentation should sent to Ms Jean Pettigrew, School of Physics & Astronomy, Monash University, at the address given on the Application Form.

8. Applications for the 2015 Monash – AAO Honours Scholarships in Astrophysics should be received at the above address no later than **15th February 2015**.