



MONASH University

School of Physics

**MSc and PhD
PROPOSED PROJECTS**

FOR 2010

MSc and PhD Project Booklet for 2010

This booklet contains proposals for research projects for the MSc and PD degrees in Physics. Each proposal provides a brief project outline and, in some cases, a reference or two to the relevant literature. The project supervisors are named in the title boxes. They can be contacted by E-mail using:

FirstName.LastName@sci.monash.edu.au

Potential students are encouraged to discuss specific projects of interest with the supervisors concerned.

If you have any questions on our graduate programmes, please do not hesitate to contact the Postgraduate Coordinator: David.Paganin@sci.monash.edu.au or by telephone on +61 3 9905 3633.

Information on the J.L. William PhD Scholarships is available at:

<http://www.physics.monash.edu.au/scholarships.html>

Other Scholarship information may be found at:

<http://www.mrgs.monash.edu.au/scholarships/apply>

Please note the closing date for online scholarship application is 31st October 2009.

I hope you enjoy reading through this booklet, which contains many exciting physics projects spanning a very impressive breadth of research topics.

With very best wishes,

Dr David Paganin
Postgraduate Coordinator
School of Physics
Monash University
Victoria 3800
Australia

Web site: <http://www.physics.monash.edu.au>

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NAME	PAGE NOS.
Balázs, Dr Csaba	12,13,14,15,16,17
Bambery, Dr Keith (Chemistry)	31
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PROPOSED PROJECTS FOR 2010

H

EXTENDED SUPERSYMMETRIC MODELS

Supervisor: Dr Csaba Balázs

Terascale 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

A,H

SUPERSYMMETRIC DARK MATTER

Supervisor: Dr Csaba Balázs

Exceptionally precise astrophysical observations strongly support the thesis 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 remaining consistent with various collider, astrophysical and low energy measurements.

References:

- [1] H. Baer, C. Balazs, χ^2 analysis of the minimal supergravity model including WMAP, $g(\mu)-2$ and $b \rightarrow \gamma$ 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

A,H

SUPERSYMMETRIC ORIGIN OF MATTER

Supervisor: Dr Csaba Balázs

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 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

- [3] Y. Li, S. Profumo, M. Ramsey-Musolf, Bino-driven Electroweak Baryogenesis with highly suppressed Electric Dipole Moments, arXiv:0811

A,H

EXTRA DIMENSIONAL DARK MATTER

Supervisor: Dr Csaba Balázs

String theory suggests the possibility of new space dimensions opening up at the tera energy scale. The merit of these extra dimensional models can be tested by their solutions to problems of the standard particle model: electroweak symmetry breaking, dark matter, neutrino masses, gauge unification.

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 dimensional model, the amount of the lightest Kaluza-Klein particles is consistent with the measured amount of dark matter.

However, there exists no comprehensive calculation for the cosmological relic abundance of the lightest Kaluza-Klein particles in six dimensional extra dimensional models. Based on the five dimensional calculation, in this project we attempt this calculation.

H

HIGGS DISCOVERY AT THE LARGE HADRON COLLIDER

Supervisor: Dr Csaba Balázs

The CERN Large Hadron Collider (LHC) started operating in 2009. This is the most significant high energy particle physics experiment in the next decade. The LHC will shed light on a long-standing question of physics: What is the origin of the (inertial) mass of the elementary particles?

In the standard model particles acquire mass via spontaneous breaking of the electroweak symmetry. The central agent of this idea is the, to date undiscovered, Higgs particle. The LHC will either discover the Higgs boson, confirming the Higgs mechanism, or find an alternative mechanism of the electroweak symmetry breaking, opening new theoretical avenues.

In this project, we calculate various Higgs boson production (signal and background) cross sections that will be tested at the LHC. The results will assist the discovery or the

exclusion of the Higgs boson in the standard particle model and its theoretical extensions.

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
- [3] C. Balazs, E. L. Berger, P. M. Nadolsky, C.-P. Yuan, All-orders resummation for diphoton production at hadron colliders, arXiv:hep-ph/0603037
- [4] C. Balazs, C.P. Yuan, Higgs boson production at the LHC with soft gluon effects, arXiv:hep-ph/0001103
- [5] C. Balazs, P. M. Nadolsky, C. Schmidt, C.P. Yuan, Diphoton background to Higgs boson production at the LHC with soft gluon effects, arXiv:hep-ph/9905551
- [6] C. Balazs, C.P. Yuan, Higgs boson production at hadron colliders with soft gluon effects: Backgrounds, arXiv:hep-ph/9810319

H

**MINIMUM MESSAGE LENGTH ANALYSIS IN THE HIGGS
BOSON SEARCH**

Supervisor: Dr Csaba Balázs

The existence of the Higgs boson is central to the structure of the standard model of elementary particles. The current search for the Higgs boson involves experiments at the Fermilab Tevatron and at the CERN Large Hadron Collider (LHC). Simulation software is available for the outputs of the Tevatron and the LHC for the standard particle model and for various other competing models. This enables us to statistically analyze the signals of the presence of a Higgs boson in the data, in advance.

The main statistical approach considered would be the Minimum Message Length (MML) principle, an approach from Bayesian information theory which quantitatively trades off the simplicity of a hypothesis against its goodness of fit to the observed data. Our search problem is partly a problem in mixture modelling (or clustering), where we wish to identify whether or not there is sufficient evidence that there is a component of the observed data which is best explained by the presence of the Higgs boson.

The student should have a reasonably strong background in mathematics (partial derivatives, integration, matrix determinants, etc.) and advanced quantum physics.

References:

- [1] C. S. Wallace (2005) "Statistical and Inductive Inference by Minimum Message Length", Springer.
- [2] D. L. Dowe, S. Gardner and G.R. Oppy (2007) "Bayes not Bust! Why Simplicity is no Problem for Bayesians", British Journal for the Philosophy of Science (BJPS), Dec. 2007.

HOLOGRAPHIC VACUUM ENERGY

Supervisor: Dr Csaba Balázs

Astrophysical observations indicate that less than about 30 percent of the Universe is made of matter. The rest of the cosmological energy appears to be vacuum energy (popularly referred to as “dark energy”). Quantum theory necessitates the existence of non-vanishing vacuum energy in the form of quantum fluctuations. But the observation contradicts our quantitative predictions of quantum fluctuations by a staggering 120 orders of magnitude!

In this project, we concentrate on constraints on the vacuum energy of a quantum system emerging from the cosmic holographic principle. There are strong indications that the holographic principle limits the amount of quantum fluctuations to exactly the level of the measured critical density. We aim to understand the origin of holography in gravity. The problem can be approached by examining the emergence of rigidity and Lorentz invariance in the context of quantum field theory.

References:

- [1] C. Deffayet, G. Dvali, G. Gabadadze, and A. Vainshtein, Nonperturbative Continuity in Graviton Mass versus Perturbative Discontinuity, arXiv:hep-th/0106001
- [2] N. Arkani-Hamed, H. Georgi and M. D. Schwartz, Effective Field Theory for Massive Gravitons and Gravity in Theory Space, arXiv:hep-th/0210184
- [3] Petr Horava, Quantum Gravity at a Lifshitz Point, arXiv:0901.3775
- [4] C. Charmousis, G. Niz, A. Padilla, P. M. Saffin, Strong coupling in Horava gravity, arXiv:0905.2579
- [5] M. Li, Y. Pang, A Trouble with Horava-Lifshitz Gravity, arXiv:0905.2751
- [6] D. Blas, O. Pujolas, S. Sibiryakov, On the Extra Mode and Inconsistency of Horava Gravity, arXiv:0906.3046
- [7] A. Kobakhidze, On the infrared limit of Horava's gravity with the global Hamiltonian constraint, arXiv:0906.5401

COSMOLOGY OF THE ELECTROWEAK

SYMMETRY BREAKING

Supervisor: Dr Csaba Balázs

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 terascale, 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
- [3] W. Zhao, D. Baskaran, L. P. Grishchuk, On the Road to Discovery of Relic Gravitational Waves: the TE and BB Correlations in the Cosmic Microwave Background, arXiv:0810.0756
- [4] W. Zhao, Detecting relic gravitational waves in the CMB: Comparison of different methods, arXiv:0902.1848
- [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

UNIVERSAL RADIATION DETECTOR SIMULATOR

○

Supervisor: Mr Andy Berry
Instrumentation Group, Monash Centre for Synchrotron Science

Students would be using FPGA's and multiple D/A's to design an instrument capable of mimicking a broad range of analogue signals typically generated by radiation detectors. The output should accurately simulate true radiation statistics from a small number of sources and known detector behaviour. Additional user-defined parameters such as pulse shape and energy distribution should be programmable via PC interface while event rate and S/N ratio should also be manually adjustable.

To demonstrate the system, a comparison test with a 'real' detector can be performed, using the same pulse processing electronics

M,O

**VISUALISATION OF BLOOD VESSELS BENEATH
AN INTACT SKULL**

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 the red blood cells, illuminates the skull, which strongly diffuses the light without high absorption of the light. 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 a pressure transducer, which can be based on an optical interferometer that allows for simple 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 a system that is capable of visualising vessels equivalent to those found in the rat cortex beneath an intact rat skull. The project does not involve experimentation on animals, and will use simulated blood flow through capillaries.

Reference

- [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

A

EVOLVING RADIO GALAXIES

Supervisor: Dr Michael Brown

Massive galaxies in the nearby Universe host black holes with masses a billion times that of the Sun. When these black holes accrete material from their surroundings, a fraction of the energy of the in-falling material is converted into radiation, resulting in an active galactic nucleus (AGN) that can outshine its host galaxy. As a consequence, the AGN can alter the properties of its host galaxy, including the rate at which new stars are formed. Several models have suggested that star formation in galaxies is truncated primarily by AGNs, although this has yet to be verified with robust observations.

We will determine how the number of radio emitting AGNs has evolved since a redshift of $z=1$, corresponding to the past 7 billion years of the history of the Universe. To do this we will utilise optical and radio imaging from large ground-based telescopes and infrared imaging from Spitzer Space Telescope. We will identify radio-loud quasars and radio sources hosted by massive red galaxies. We will then determine number of sources per unit volume in a series of redshift slices, corresponding to different epochs in the history of the Universe. This will provide an accurate view of how this population of sources has evolved over half the history of the Universe.

References

- [1] Sadler et al., 1989, *MNRAS*, 240, 591
[2] Fabian et al., 2006, *MNRAS*, 366, 417, (arXiv:astro-ph/0510476)
[3] Croton et al., 2006, *MNRAS*, 365, 11 (arXiv:astro-ph/0407537)
[4] Brown et al., 2008, *ApJ*, 682, 937

A

THE HABITATS OF RADIO GALAXIES

Supervisor: Dr Michael Brown

Active Galactic Nuclei (AGNs), including radio galaxies and quasars, are powered by the in-fall of material towards central black holes. There is increasing evidence that different classes of AGNs reside in different environments. For example, quasars appear to reside in galaxies with a limited range of dark matter masses. An enduring mystery is why only a fraction of all AGNs have significant radio emission. One popular theory is that radio emission only occurs when the surrounding medium is similar to that of a galaxy cluster.

We will determine if radio galaxies occur within particular environments. To do this we will measure the (mean) environment of radio galaxies using the correlation function. We will then compare the environments of radio galaxies with those of a control sample of galaxies, which have comparable ages and masses but no radio emission. To determine the physical properties of those environments, we will use halo occupation distribution (HOD) modelling to determine the dark matter masses of the groups and clusters in which the radio galaxies reside. We will thus determine if radio-loud AGNs occur in particular environments and the physical properties of those environments.

References

- [1] Croom et al., 2005, MNRAS, 356, 415, (arXiv:astro-ph/0409314)
- [2] Croton et al., 2006, MNRAS, 365, 11 (arXiv:astro-ph/0407537)
- [3] Brown et al., 2008, ApJ, 682, 937 (arXiv:0804.2293)

A

CLUSTER GALAXIES & THEIR EVOLUTION

Supervisor: Dr Michael Brown

Galaxies reside within gravitationally bound clouds of dark matter known as halos. In relatively small dark matter halos, with masses of 10^{11} times that of the Sun, one typically finds a single galaxy surrounded by some very small satellite galaxies. In the largest dark halos, with masses more than 10^{14} times that of the Sun, one finds many large galaxies in orbit around the common centre of mass. This is an unusual environment for galaxies, with few stars being formed and the only mode of galaxy growth being mergers with other galaxies. It is thus an interesting probe of this aspect of galaxy formation models.

A number of recent works have suggested that the number of satellite galaxies within clusters undergoes significant evolution between $z=1$ and $z=0$. This may be due to the (expected) evolution of the number of galaxies falling into clusters as a function of cosmic time. However, it may also be caused by systematic errors in the analysis of galaxy clusters. In particular, galaxies in neighbouring dark matter halos may be confused for cluster galaxies. This problem becomes worse in high redshift clusters, which have more neighbouring galaxies than clusters in the local Universe. We will

explore this problem, by studying simulated galaxy clusters in dark matter simulations and by studying the number of galaxies in distant clusters in the constellation Bootes.

References

- [1] De Lucia et al., 2007, MNRAS, 374, 809 (arXiv:astro-ph/0610373)
- [2] Rudnick et al., 2009, ApJ, 700, 1559 (arXiv:astro-ph/0905.4503)
- [3] Brown et al., 2008, ApJ, 682, 937 (arXiv:0804.2293)

A

THE ULTRAVIOLET LUMINOSITY FUNCTION

Supervisor: Dr Michael Brown

The ultraviolet emission from galaxies is dominated by light from massive stars with very short lifetimes. As a consequence, ultraviolet emission is correlated with recent star formation and the ultraviolet is used as a measure of star formation rate. While prone to dust obscuration, the ultraviolet is accessible across a broad swath of cosmic time, extending to a redshift of $z=8$ (when the Universe was less than a billion years old). This broad redshift range is not yet accessible to other star formation rate indicators.

The ultraviolet luminosity function has not been well measured at redshifts of $z < 1$, as far ultraviolet light is (thankfully) blocked by the Earth's atmosphere. We will use GALEX satellite imagery in the constellation Bootes to measure the ultraviolet luminosity function and star formation rate of $z < 1$ galaxies. This will provide constraints on the global star formation rate and provide a measurement of the ultraviolet luminosity function that can be compared directly with those determined for higher redshift galaxy populations.

References

- [1] Budavari et al., 2005, ApJ, 619, 31, (arXiv:astro-ph/0411305)
- [2] Arnouts et al., 2005, ApJ, 619, L43 (arXiv:astro-ph/0411391)
- [3] Brown et al., 2008, ApJ, 682, 937 (arXiv:0804.2293)

C

NANOSIZED ISLANDS IN GLASSY METAL SOFT MAGNETIC MATERIALS

Supervisors: A/Prof. John Cashion and

A/Prof. Kiyonori Suzuki (Dept of Materials Engineering)

Glassy metals, made as melt spun ribbons, have excellent soft magnetic properties for use in transformers, etc. These properties can be enhanced by light annealing which promotes the crystallization of nanometre-sized islands. This project will use a unique Mössbauer spectrometer, developed at Monash, to apply RF to the magnets and study the collapse of the hyperfine field as a function of time and power. When the field has collapsed, this also enables determination of the crystal structure of the new islands and also the original glassy material. This will lead to a better understanding of the way in which minimization of the hysteresis loop area is being achieved by various heat treatments.

**MODIFICATION OF PROPERTIES OF CLAY MINERALS
BY ION EXCHANGE**

C

*Supervisor: A/Prof. John Cashion
Dr Will Gates (Civil Engineering)*

One of the principal methods of characterizing clay minerals is through Mössbauer spectroscopy, but there has been a long running dispute in the literature about the assignment of the peaks to particular crystallographic sites. We have developed a technique to alter the iron valency through in-situ electrochemistry in a Mössbauer spectrometer, which we hope will solve this 20-year old problem. We have recently achieved the first positive identification of spectral feature with a particular crystallographic configuration [1]. The process also involves the exchange of alkali ions into the clay, which has important prospects for other potential uses of the clays. The project will involve taking Mössbauer spectra of suitable clays under an applied electric field and interpreting the results in terms of the crystallography of the clays.

Reference

- [1] J D Cashion, W P Gates and A Thomson, Clay Min., accepted for publication, 2007.

**MODELLING OF AN X-RAY ELECTRON EMISSION
MICROSCOPE**

A

*Supervisor: Dr Marian Cholewa
Dr Chris Hall*

Background: Photon Electron Emission Microscopy (PEEM) has been commonly used with synchrotron radiation to form an important tool for spectromicroscopy for local investigation of chemical properties of materials. There is a continuous demand for detector systems for imaging which could offer spatial resolution below 100 nm and high efficiency for X-rays. During this project we will perform modelling of behaviour of an X-ray Electron Emission Microscope (XEEM) [1] which combines PEEM technology with potential for high resolution imaging with X-rays.

Project outline: In this project we will perform theoretical modelling for PEEM system used as a high resolution imaging detector for coherent X-ray beam [2]. The student will perform theoretical modelling for the XEEM system.

References

- [1] Y. Hwu et al., *Surface Science*, **480** (2001) 188-195.
- [2] G. Margaritondo and G. Tromba, *J. Appl. Phys.*, 85 (1999) 3406.

A RECOGNITION OF UNSTAINED CELLS USING QUANTITATIVE PHASE IMAGING

*Supervisors: Dr Marian Cholewa
A/Prof. David Paganin*

Background: There is one main problems of living cell visualization under an optical microscope: cells, being almost transparent objects, are invisible under reflected light. Quantitative Phase Microscopy (QPM) [1,2] offers ability for the observation of transparent and semi-transparent objects, even those not visible by conventional visualization methods. In many areas of Science and Industry it is extremely important to develop fast and reliable optical imaging for fully automated recognition of living cells.

Project outline: This project seeks to use the QPM optical system to develop algorithms for imaging live cells and their components. In this project the student will explore possibility to develop a fully automated optical system for recognition of live cells or their components using a commercially available system from IATIA [2].

References

- [1] A. Barty, KA Nugent, D. Paganin, A. Roberts, *Optics Letters*, 23, (1998) 1-3.
- [2] <http://www.iatia.com.au/technology/>

PROFILE OF PHYSICS STUDENTS

*Supervisor: Dr Susan Feteris and
Dr David Mills*

Women drop Physics early in their first year at a much higher rate than men. Recent data suggests that most women in PHS1011 are from girls' schools. Are they particularly uncomfortable in male-dominated physics classes and more likely to drop PHS1011? Or are they more confident than women from co-educational schools and less likely to drop PHS1011? Even if we figure this out, can we do anything about it? Does it matter anyway?

The project will involve interviews of male and female 3rd year students who discontinued Physics in their 1st year (in 2007), to explore reasons for and possible gender patterns in students' abandonment of Physics. This project will build on work done by Susan Feteris with 3rd year 'Professional Studies' students in 2003 and 2004.

BURST OSCILLATIONS AND ANISOTROPIC X-RAY EMISSION IN NEUTRON STARS

A

Supervisors: Dr Duncan Galloway

Background: Thermonuclear (type-I) bursts are caused by unstable ignition of accumulated hydrogen and helium on the surface of neutron stars in binary systems. These events permit approximate measurement of the neutron star spin frequency via "burst oscillations", periodic variations in the X-ray intensity at frequencies characteristic for individual sources, and detected only during the bursts.

Oscillations that occur during the burst rise may be attributed to anisotropies in the surface X-ray emission as the burning spreads from the ignition point. However, oscillations may also occur after the burst peak, by which time the burning is thought to have spread over the entire surface of the star. The blackbody radius of the burst spectrum provides a measure of the physical emitting area.

Project outline: This project will compare the presence of oscillations with the measured blackbody radius using a large sample of bursts detected by NASA's Rossi X-ray Timing Explorer satellite, to test whether oscillations during the burst tail may be attributed to anisotropies in the X-ray emission.

This project will provide a good introduction to high-energy astrophysics, as well as expertise in analysis of X-ray data from RXTE, and possibly other satellites. Opportunities exist for collaborative work with project partners at MIT (USA).

References

- [1] Strohmayer & Bildsten, astro-ph/0301544

A

THE MULTI-INSTRUMENT BURST ARCHIVE (MINBAR)

Supervisors: Dr Duncan Galloway

Background: 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 3500 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 1000 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.

Project outline: 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).

A

STEADY HE-BURNING IN ACCRETING NEUTRON STARS

Supervisor: Dr Duncan Galloway

Background: Most neutron stars accreting from a binary companion exhibit thermonuclear (X-ray) bursts, caused by unstable ignition of accumulated hydrogen and helium on the surface of the star. Such unstable ignition is only possible for a range of accretion rates, and above a critical rate nuclear burning will stabilise and no further bursts are observed. Remarkably, for most sources, no bursts are observed above an accretion rate equal to about 1/3 of the theoretically-predicted critical rate. It is also possible that stable burning can occur at even lower rates. Current theory cannot reconcile simultaneous steady and unsteady burning, and detailed analysis of observations may hold the key to understanding these processes.

Project outline: This project will take advantage of large samples of thermonuclear bursts observed by NASA's *Rossi X-ray Timing Explorer*, the Dutch/Italian *BeppoSAX*, and ESA's *INTEGRAL* satellite to better understand the accretion rate regime where steady burning may be occurring. The project will largely make use of existing data, but may also take advantage of new opportunistic observations. Opportunities exist for collaborative work with project partners at SRON (Netherlands) and DTU Space (Denmark).

SEARCHES FOR SPECTRAL FEATURES IN THERMONUCLEAR (XRAY) BURSTS

A

Supervisor: Dr Duncan Galloway

Background: Spectral features arising from the surface of neutron stars are of the highest priority for observers, since they are imprinted with the gravitational redshift at the surface and can thus help to constrain the (highly uncertain) neutron star equation of state. Searches for such features have a long (and rather disappointing) history, but targeted searches for neutron stars during particular kinds of transient behaviour continue. One such behaviour is radius-expansion thermonuclear X-ray bursts, where the radiation pressure from X-rays produced by unstable nuclear burning of accreted hydrogen and helium is sufficiently strong to overcome the surface gravity, raising the photosphere above the surface of the star. Such bursts are rare and unpredictable, and hence difficult to observe; however, a large sample of such bursts has been detected over the 13-year mission lifetime of NASA's *Rossi X-ray Timing Explorer* satellite. Significant deviations from the usual smooth continuum have already been detected in some of these events.

Project outline: This project will involve a search for, and characterisation of, discrete features in low-resolution X-ray spectra during thermonuclear bursts observed by *RXTE*. The data in hand includes time-resolved spectra of more than 1500 bursts, presenting ample opportunity for the detection of significant features. Once detected, spectral model fits with standard tools will be used to attempt to identify the features and deduce the neutron star redshift. The student will gain an excellent introduction into X-ray data analysis and spectral fitting, as well as the IDL package. Opportunities

exist for collaborative work with project partners at SRON (Netherlands) and U. Arizona.

O,M
IMAGING TUMOR CELLS IN AN ANIMAL MODEL OF MALIGNANT BRAIN TUMOR
<i>Supervisor: Dr Chris Hall and Dr. David Paganin</i>

We have devised an x-ray imaging protocol that allows detection of small numbers of implanted cells in an animal central nervous system. The protocol is based on using nanometric sized gold particles as markers embodied within the cells by endocytosis. The research project is in its early stages. So far we have taken glioma cell cultures which were exposed to colloidal gold and implanted these into the brains of rats. After the tumours had developed for two weeks x-ray images of the heads and spinal cords were acquired at a synchrotron x-ray imaging station using standard absorption microtomography. The results so far show that the contrast enhanced tumours was clearly visible in the resulting images.

The next steps in the research will be to calculate the dose limitations of this technique. We believe that synchrotron-based imaging in animal models could become a powerful research tool in the assessment of brain tumour volume and growth, and the work is directly relevant to the new Australian Synchrotron, which is located next to the Monash University Clayton campus. However, at the moment the dose delivered during the microtomography is high making it unsuitable for studies involving making consecutive multiple images. There is a potential to use more sophisticated tomographic methods for the tomography. Algorithms which use a limited range of projection angles or *a-priori* knowledge of the constituent attenuation coefficients are just two we would like to investigate.

A thorough analysis of the existing data could be undertaken as well as some modelling and calculations of dose. You will learn to use an open source imaging application (ImageJ) to examine the 'slices' of the data. With this information and a model system you will calculate the x-ray flux and hence the dose required to see the contrast enhanced cells at various x-ray wavelengths.

A similar calculation for a different type of tomographic imaging could be made, that of fluorescence tomography. This technique will work with the same gold nanoparticles. It has the potential for high sensitivity but is more demanding on the instrumentation.

M

PEDRO - PIXELATED EMISSION DETECTOR FOR RADIOISOTOPES

*Supervisors: Dr Chris Hall,
Dr. John Gillam and Dr Matt Dimmock*

The Pixelated Emission Detector for Radioisotopes (PEDRO) is a state-of-the-art hybrid emission imaging system, optimised for small animal models. It utilizes a Compton-camera stack geometry behind a coded aperture mask to maximize detection efficiency whilst maintaining the enhanced resolution of pinhole imaging. Students working under this project will experience both Monte-Carlo simulations and a current developmental research system and be able to validate their simulations against experimental data.

1. Gamma-ray Tracking for PEDRO (Hons/PhD)

Gamma-ray tracking algorithms enable successful event ordering and improve the quality of the reconstructed image. Students will be required to write code to reconstruct the path of the gamma rays as they scatter through the detector volume. They will assess the implication of their algorithm on the final reconstructed image.

2. The Monte-Carlo Investigation of Collimator Effects on the Point Spread Function (PSF) for PEDRO (Hons/PhD)

The shape of the collimator aperture directly affects the magnification and quality of the reconstructed image. Students will be required to extend GEANT4 code (C++) to investigate the geometry of the pinhole and the variation in Point Spread Function.

3. Image Reconstruction for Single Photon Emission Imaging (Final year projects/Hons/PhD)

The type of image reconstruction, whether analytic or iterative, will affect the final image produced by a system. Students will be required to write (edit) an image reconstruction algorithm and quantify the resultant image quality.

4. An Investigation of Detector Efficiencies and Cross-talk Effects for PEDRO (Final year projects/Hons)

The use of segmented detectors leads to the requirement of add-back spectra to reconstruct the incident energy. This leads to cross-talk and noise effects that affect the detection efficiency of the system. The student will be required write an analysis code (in the language of their choice) and quantify these factors to validate simulations against experimental data. The extent of the investigation would depend on the level of the project.

C, O

ATOM BASED POTENTIALS FOR BOSE-EINSTEIN CONDENSATES

Supervisor: Professor Kris Helmerson

Bose-Einstein condensates (BECs) of atomic gases are new experimental systems in which to investigate phenomena previously studied using superfluid helium or even superconductors. BECs of atomic gases offer many advantages over the other systems in that they are well understood and perturbations can be controlled to a high degree. Because most of the atoms in BEC experiments have accessible optical transitions, lasers are commonly used to create potentials for perturbing and manipulating BECs. Although sophisticated techniques are available for creating essentially arbitrary patterns of light fields, the minimum size of such patterns is limited by the diffraction of light to on the order of the optical wavelength, typically around 0.5 microns. In solid-state systems, however, atomic scale perturbations can be created. The goal of this project is to develop atomic-based potentials for interacting with Bose-Einstein condensates. One approach is to trap and manipulate the perturbing atoms in optical potentials that do not directly perturb the BEC. The initial phase of this project will involve modelling the behaviour of a BEC in the presence of an atom-based perturbation. Subsequent work will involve the construction of an experimental apparatus capable of simultaneously trapping two atomic species and creating a BEC of one or both of the atomic species.

ROTATING OPTICAL LATTICES FOR ULTRACOLD ATOMS

Supervisor: Professor Kris Helmerson

Ultracold atoms can be trapped in the periodic potential formed by an optical standing wave, which is often referred to as an optical lattice. Because such a system is free of defects and dissipation, the atoms in the optical lattice exhibit behaviour similar to electrons in an ideal crystal. By including the interaction of the atoms, atoms in optical lattices can be used to study many-body phenomena observed in solid-state systems. One particularly interesting phenomenon is the quantum Hall effect, which can be realized using a rotating optical lattice. The goal of this project is to develop an optical system capable of generating a short period, rotating optical lattice for confining ultracold atoms.

M, 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.

M, O

DYNAMICS OF SINGLE MOLECULES IN 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.

C

PRECURSOR STRUCTURES FOR THE PRODUCTION OF BORON OXIDE NANORODS

*Supervisors: Dr Greg Jakovidis and
Dr Laure Bourgeois (MCEM) and
Dr Keith Bambery (Chemistry)*

Boron oxide nanorods have been previously produced by RF-magnetron sputtering, of a BN target followed by high temperature annealing at 1200 C [1]. In a first attempt to understand the chemical pathways leading to such nanorods, we will examine a room temperature boron nitride sputtered film, using Fourier Transform Infrared spectroscopy (FTIR), optical microscopy and Transmission Electron Microscopy (TEM). Precursor materials that are likely to be produced when sputtering a BN target in a water vapour rich sputtering environment include boric acid and boron oxide. To see if either of these materials are crucial for B₂O₃ nanorod formation, they will be annealed at 1200 C, in both dry and humid environments, followed by characterisation using FTIR and SEM/TEM.

Reference

[1] De Ming Zhu (Ph.D. thesis, Monash University, 2007).

C

BORON NITRIDE NANOSTRUCTURES SYNTHESIZED BY RADIO FREQUENCY MAGNETRON SPUTTERING

*Supervisors: Dr Greg Jakovidis and
Dr Laure Bourgeois (MCEM and Department of Materials Engineering)*

Boron nitride exhibits well ordered forms like graphite and diamond, in addition to exotic nanostructures and nanofibres. Applications include high temperature capacitors, wear protection coatings and tuneable band gap nanotubes.

In this project radio frequency sputtering will be used to examine the conditions under which BN amorphous and crystalline nanoscale fibres and nanorods can be reproduced. Specifically the sputtering conditions that determine abundance, uniformity and reproducibility of the nanofibres and nanorods will be determined. The principal techniques to investigate the nanofibres and nanorods will be scanning electron microscopy with energy dispersive x-ray analysis (EDS) and x-ray diffraction.

C

Si on MoS₂ (MOSI) PHOTOVOLTAIC SOLAR CELLS

Supervisor: Dr Greg Jakovidis

MOSI photovoltaic solar cells aim to provide a good match with the solar spectrum by utilising an inexpensive, larger band gap material, as the top layer. To date, such cells display good open circuit voltage but poor short circuit current. The latter is not surprising given that measurements have been made without a collector grid and the high number of recombination centres associated with dislocations and reactive MoS₂ edges. Such defects are crucial for catalysis (e.g. hydro-desulphurisation) but for solar cells, they effectively reduce the minority carrier diffusion length. This project aims to improve the photovoltaic current, in the MOSI system by using single crystals of MoS₂. Polycrystalline silicon thin films will be deposited on single crystal MoS₂ by RF-magnetron sputtering. At the completion of this project you will have acquired research skills in RF-magnetron sputtering, XRD, SEM, and I-V measurements.

O,C

IMAGING SURFACE TOPOGRAPHY USING LLOYD'S FRINGES IN PHOTOEMISSION ELECTRON MICROSCOPY

*Supervisors: Prof David Jesson and
A/Prof Michael Morgan*

In the classic experiment known as 'Lloyd's Mirror' an interference pattern is formed from the superposition of light from a point source with its reflection in a plane mirror [1, 2]. We have recently combined the Lloyd's Mirror geometry with photo-emission electron microscopy (PEEM) to develop a new approach to imaging surface topographic features. Interference fringes in the incident UV radiation modulate electron photoemission and the observed interference pattern in the PEEM image provides important information on the surface height. However, the fringe positions are shifted by an electric field which is part of the PEEM system and which also depends on the surface topography itself! We have recently developed an elegant method to reconstruct the surface from the distorted fringe pattern which works in 1D [3]. This project will extend the analysis to 2D and will open up the exciting possibility of reconstructing surface shape changes during dynamic processes such as coalescence. This is a project for students with a good theoretical background interested in diffraction physics.

References:

- [1] S. G. Lipson and H. Lipson, Optical Physics (Cambridge University Press, Cambridge, 1981) 2nd ed.
- [2] M. Born and E. Wolf, Principles of Optics (Cambridge University Press, Cambridge, 1999) 7th ed..
- [3] D. E. Jesson, K. M. Pavlov, M. J. Morgan and B. F. Usher, *Phys. Rev. Lett.* **99** (2007) 016103.

C,O

TOY MODELS OF SURFACES

*Supervisors: Prof David Jesson and
A/Prof David Paganin*

Surfaces of solids are often thought of as static objects. However, at moderate temperatures they are highly dynamic. Atoms move around laterally on the surface, attaching and detaching from surface steps so that they ‘wiggle’ if looked at closely by surface electron microscopy. An extremely simple but powerful means of modeling this type of behaviour is through kinetic Monte Carlo simulations where thousands of atoms can be included [1]. Surface atoms migrate via nearest neighbour hopping with a site dependent diffusion barrier, taking into account the number of nearest neighbour bonds. This project will set up such ‘toy’ KMC simulations to model the basic properties of surfaces. Depending on the interests of the student the model will be used to investigate dynamical behaviour which could include the growth of nanowires, quantum dots or surface melting phenomena. The project will suit those students interested in computational physics.

Reference

- [1] An application of KMC to model step density is contained in S. Clarke and D. D. Vvedensky, *Physical Review Letters* **58** (1987) 2235.

A

MIXED-MORPHOLOGY SUPERNOVA REMNANTS: NATURE OR NURTURE

Supervisors: Dr Jasmina Lazendic-Galloway

The main thrust of this study is to determine whether mixed-morphology (described below) supernova remnants (SNRs) are “normal” SNRs in an unusual environment, or

if they evolve differently than the rest of the SNRs. This question of “nature or nurture” may potentially reveal an entirely new evolutionary pathway for SNRs.

In detail: A supernova explosion is the cataclysmic end of the life cycle of massive stars, releasing energy equivalent to 10 billion years of our sun's energy output in a fraction of a second. Supernova remnants (SNRs) are often observed as shells of optical, X-ray and radio emission caused by shock-heated ejected material and swept-up gas from the interstellar medium. However, there is a significant fraction of Galactic SNRs discovered in the last decade that shows different morphology: central X-ray emission found in these “mixed-morphology” SNRs contradicts the standard SNR model, which predicts peak brightness at the SNR shell where most of the mass is concentrated. The evolutionary processes which lead to mixed-morphology properties in SNRs are not well understood. It is widely believed that this peculiar morphology is linked to evolution of SNRs in a dense environment, but none of the proposed models can account for all the observed properties. This inability to account for mixed-morphology SNR properties is a significant shortfall in our understanding of the evolution of these key objects, since mixed-morphology SNRs constitute a significant fraction (about 10%) of Galactic SNRs.

To investigate the mechanisms responsible for the creation of mixed-morphology SNRs, primarily via high-spatial and spectral resolution observations of remnants with the NASA's Chandra X-ray Observatory, in combination with radio observations from Australia Telescopes to examine the SNR environments and its influence on mixed-morphology SNRs. Chandra data can provide more accurate representation of crucial SNR parameters (e.g. density, temperature, ejecta distribution) than previous X-ray observations and allow better comparison with models. Also, none of the models for mixed-morphology SNRs considered so far include any contributions from ejecta to the central emission. X-ray emission expected from an ejecta component alone or from the forward shock component alone have been modelled in detail, but the mixing of the two component is becoming an increasingly important issue, for all SNRs.

An honours project would include a study of one or two sources, while a PhD project would include the whole class. Also, a student can choose to do more observational or more theoretical approach. The student will gain expertise on analysis and interpretation of X-ray and radio observations, and will also become familiar with standard SNR evolution and physics. Part of this project will be an opportunity to work with project partners at Harvard-Smithsonian Centre for Astrophysics and NASA.

Reference

[1] Lazendic & Slane 2006, The Astrophysical Journal, Vol. 647, p. 350

PARTICLE ACCELERATION IN GALACTIC SOURCES

A

Supervisors: Dr Jasmina Lazendic-Galloway

The main thrust of this observational and theoretical study is to find strong evidence of particle acceleration in supernova remnants potentially shedding light on a 50-year-old problem in astrophysics: "Where do cosmic rays come from?".

In detail: Cosmic rays are comprised mainly protons and heavier nuclei, from helium upwards, and come in a wide range of energies. The most energetic cosmic rays are believed to come from outside the Milky Way, possibly from distant active galaxies. The much more numerous lower-energy cosmic rays are believed to be accelerated at the rapidly expanding shockwaves created by powerful supernova explosions. But this 50-year-old hypothesis - associating supernova remnant shocks and Galactic cosmic rays - remains unproven.

Significant observational breakthroughs in the last ten years in X-ray and gamma-ray bands, however, hold out the promise of finally supplying the missing direct evidence for the association. Sensitive X-ray observatories with NASA's Chandra X-ray Observatory, and gamma-ray observations from ground-based HESS (High Energy Stereoscopic System) telescope offer a pool of objects to study particle acceleration in Galactic sources, including supernova remnants.

On the observational side, the project will involve gathering mostly (publicly available) archival data on SNRs and performing detailed examination of SNR properties and their surroundings. The student will gain expertise on analysis and interpretation of X-ray data and will also become familiar with standard SNR evolution and physics. On the theoretical side the project will involve using existing and possibly creating new emission models in order to theoretically reproduce observed broadband emission (from radio to gamma-ray energies) from SNRs.

For this project, opportunities exist for collaborative work with project partners at Harvard-Smithsonian Centre for Astrophysics and Max Planck Institute

Reference:

[1] Lazendic et al. 2004, The Astrophysical Journal, Vol. 602, p. 271

A

**SUPERNOVA REMNANTS INTERACTION WITH
MOLECULAR CLOUDS**

Supervisor: Dr Jasmina Lazendic-Galloway

The main thrust of this study is to research chemical and physical properties of interaction regions between supernova remnants (SNRs) and molecular clouds through multi-wavelength studies of SNRs associated with the 1720-MHz OH maser emission.

The young, massive progenitor stars live only a relatively short time (a few million years) and have not moved far from the molecular clouds (MC) from which they are born. Hence it is expected that SNRs, the gaseous remains of these massive stars, and molecular clouds are found in close proximity. However, there have been difficulties in identifying clear-cut cases of SNR-MC interactions. As both classes of objects tend to lie close to the galactic plane, line of sight confusion is common. 1720-MHz OH maser emission, detected in about 10% of the galactic SNRs, is believed to arise from gas shocked by the impact of the expanding SNR into the molecular material. These maser-emitting SNRs have the advantage in that we know the location of the on-going interaction with molecular cloud, and also the velocity of molecular material which is interacting with the SNR. We can use millimeter wavelength observations of molecular gas in conjunction with the radio and X-ray observations, to derive SNR parameters such as the density profile of the molecular gas and the magnetic and thermal pressures, which will contribute to understanding of evolutionary path of SNRs evolving in dense environments.

On the other hand, the shocks driven by SNRs into dense molecular clouds compress, accelerate and heat the gas. They can partially or completely disrupt the clouds and may also initiate star formation by triggering further gravitational collapse upon cooling of the compressed gas. The shocks also provide energy to excite higher molecular transitions and activate chemical reactions forbidden in cold molecular clouds, changing the chemical abundances in the cloud. Thus, observations of molecular clouds which have encountered a supernova blast wave can provide an important information on physical and chemical processes associated with the shocks.

The project will involve using existing radio or X-ray data on SNRs and performing detailed examination of SNR properties and their surroundings. The student will gain expertise on analysis radio, and/or X-ray data. Opportunities exist for collaborative work with project partners at the Macquarie University and Massachusetts Institute of Technology (MIT).

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M, O
TISSUE SPECIFIC PROJECTION X-RAY IMAGING
<i>Supervisor: Prof Rob Lewis Monash Centre for Synchrotron Science</i>

Using polychromic x-ray sources and an energy resolving position sensitive photon counter, a study will be made of the potential for clinical radiography using the energy of the transmitted x-ray beam to distinguish tissue type. The work will involve

modelling the forward transforms of the x-ray field from the source, on paths through the specimen to the detector. The model will include considerations of both elastic and inelastic scattering in the object, intervening air, and the detector.

By using probability theory and iterative algorithms a most likely solution to the object tissue type and morphology will be generated by comparing the observed data to that from the model. The errors in the solution will be examined and explained with a view to minimisation to a level of clinical usefulness.

The detector to be used in this work is a state of the art hybrid pixel detector which has been recently purchased by the MCSS.

M,O

**REDUCING DOSE IN RADIOGRAPHY USING AN ENERGY
RESOLVING POSITION SENSITIVE PHOTON
DETECTOR ARRAY**

*Supervisor: Prof Rob Lewis
Monash Centre for Synchrotron Science*

It has been hypothesised that by suitably weighting the signal that a photon provides to an image by its energy, lower doses for clinical radiographical examination can be obtained. This study will develop the theory behind this idea and test out this novel imaging process using laboratory prototype equipment. Computer models of energy resolving x-ray radiography systems will be developed using sophisticated Monte Carlo codes. Images of test objects will be generated and compared to real data obtained in the laboratory. The model will be used to generate data on phantoms which will be used to assess the quality of the images in a realistic medical application.

M,O

**SMALL ANGLE X-RAY SCATTERING AS A
POTENTIAL DIAGNOSTIC TOOL FOR CANCERS**

*Supervisors: Prof Rob Lewis and
Dr Karen Siu*

Traditional diagnostic methods for malignancy rely upon detection of abnormalities by chemical/histopathological techniques or by the appearance of symptoms/signs that are recognised by a clinician. The resulting diagnosis is often highly subjective, equivocal and heavily dependent upon expert training. It follows therefore that more direct

methods of detecting biochemical and structural changes, preferably at the molecular level, would be an extremely valuable addition to the diagnostic armoury. Small angle X-ray scattering (SAXS) produces ultrastructural information on length scales from 10-200nm and is therefore ideal for characterising the proteins that make up the extracellular matrix (ECM). It is known that the degradation and penetration of the ECM are major processes in the morbidity and mortality of cancers. Exciting results on the diagnostic potential of small angle X-ray diffraction patterns have been reported on breast cancer tissue by two independent groups, focusing on the changes in the extracellular matrix (ECM) of the tissue.

This project currently has several different avenues of enquiry, utilising both synchrotron and laboratory based sources:

- Diagnostic efficacy of SAXS for breast cancer
- SAXS as a indicator of advanced breast cancer chemotherapy response
- SAXS as a predictor of metastatic potential in an animal model of breast cancer

O,M

LUNG DISEASE DETECTION USING PHASE CONTRAST X-RAY IMAGING

*Supervisors: Prof Rob Lewis (MCSS), Dr Marcus Kitchen and
A/Professor Stuart Hooper (Physiology)*

Phase contrast X-ray imaging greatly enhances the visibility of the air-filled lung over attenuation contrast alone. This imaging technique is able to resolve the very smallest of terminal respiratory units (alveoli; <100 micrometers) as they fill with air. Since phase contrast is highly sensitive to density variations within the lung we hypothesise that it will be sensitive to pathological changes associated with lung disease. We aim to determine the potential for phase contrast X-ray imaging as a diagnostic tool for detecting lung disease, such as pulmonary fibrosis and emphysema, during the early pathogenic phase. Mouse models of lung disease will be imaged using phase contrast imaging techniques using highly coherent synchrotron radiation.

This project will involve the development of imaging techniques to enhance in the detection of lung disease. For example, we will be exploring the using of Particle Image Velocimetry (PIV) for tracking variations in shear stresses in the lungs due to changes in tissue compliance associated with lung disease. We will also be investigating methods of numerically segmenting lung images to remove the ribcage from lung images to assist with disease detection. This will involve developing new imaging techniques alongside an appropriate mathematical framework to enable image segmentation. Image processing will form a major component of the project, with the ultimate aim of developing computer assisted disease detection from phase contrast images of the lung. Computer simulations will also be employed to model the imaging systems for optimization of the imaging setup.

O,M

MEASURING LUNG AERATION AT BIRTH USING PHASE CONTRAST X-RAY IMAGING

*Supervisors: Prof Rob Lewis (MCSS), Dr Marcus Kitchen and
A/Professor Stuart Hooper (Physiology)*

Before birth, the future airways of the lung are filled with liquid which must be cleared at the time of birth to allow the entry of air and the initiation of air-breathing. This process is critical for the transition to pulmonary gas exchange at birth and is markedly impaired in infants born very premature. As a result, respiratory failure at birth is the greatest cause of morbidity and mortality in newborn infants.

Synchrotron-based phase contrast x-ray imaging has made it possible to visualise and measure the rate and spatial pattern of lung aeration in animals in real-time, from birth. The very high spatial resolution allows us to visualise the smallest terminal respiratory units (alveoli; <100 micrometers) as they fill with air. We have developed phase retrieval algorithms that accurately calculate total lung air volumes from these 2D images and have validated them using a plethysmograph. As a result, we can now accurately measure, on a breath-by-breath basis, lung air volumes within different regions of the lungs from two-dimensional phase contrast x-ray images. This project aims to refine this technique to enable quantitative local measures of regional lung air volume. This will enable us to determine how to safely aerate the lungs of preterm infants that require mechanical ventilation without inducing lung injury; a significant problem faced in the neonatal ward.

M

CHARACTERISATION OF MICROBEAM RADIATION THERAPY COLLIMATORS USING LABORATORY AND SYNCHROTRON X-RAY SOURCES

*Supervisors: Prof Rob Lewis (MCSS), Dr Andrew Stevenson (CSIRO)
Dr Jeff Crosbie (MIMR)*

Synchrotron microbeam radiation therapy (MRT) is an experimental treatment modality for certain cancers with the potential to revolutionise how clinical radiotherapy is performed. We will perform the first MRT experiments on tumor-inoculated mice on the

Imaging & Medical Beamline of the Australian Synchrotron in November 2009. There is important commissioning work required in order for us to perform the best possible MRT right here in Australia without having to go synchrotrons overseas. We are currently constructing a range of microbeam collimators which require characterisation of geometry and dosimetry. We will use both laboratory (CSIRO) and synchrotron X-ray sources to irradiate the collimators, and high resolution film densitometry to measure the absorbed radiation dose. Furthermore we will investigate the feasibility of using the CSIRO laboratory X-ray source at Clayton to irradiate biological cells, which would be of tremendous benefit to our radiobiology colleagues within the Monash Institute of Medical Research (MIMR).

M

MONTE CARLO COMPUTER SIMULATION OF SYNCHROTRON MICROBEAM RADIATION THERAPY

*Supervisors: Prof Rob Lewis (MCSS), Dr Imants Svalbe
Dr Jeff Crosbie (MIMR)*

Synchrotron microbeam radiation therapy (MRT) represents a paradigm shift in radiotherapy and has shown promise in pre-clinical studies on tumour-inoculated rodents. The lack of a suitable method to measure the absorbed dose distribution from a lattice of microbeams has hampered progress towards clinical use of MRT. Furthermore, computerised simulations of radiation transport (Monte Carlo methods) have not adequately modelled the physical setup. We will perform the first MRT experiments on tumor-inoculated mice on the Imaging & Medical Beamline of the Australian Synchrotron in November 2009. We have already pioneered the 'two-film' method of measurement-based dosimetry for MRT (Crosbie et al, 2008) and now we wish to create a realistic Monte Carlo computer model of X-ray microbeam transport through tissue equivalent material. Such a model would be enormously useful to our research efforts and would greatly inform our decisions in pre-clinical or clinical trials of MRT.

Reference:

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C,O

ICOSAHEDRAL ORDER IN METALLIC GLASSES

*Supervisor: Dr Amelia Liu
Dr Laure Bourgeois (Monash Centre for Electron Microscopy)*

Frank hypothesized that icosahedral short-range order in liquids was a hallmark of the liquid state.[1] The five-fold symmetry represents density maximization over the short-range at the expense of the long-range packing efficiency that we see in crystals. “Gaps” occur in the structure of the liquid as icosahedra can’t be used to fill all space. The “gaps” and the ease with which they move around explain liquid behaviour: the thermal disorder, ease of flow and high atomic diffusivities.

Metallic glasses form when melts are quenched at extremely high cooling rates. Some of these metallic glasses when heated, crystallize to the icosahedral quasicrystalline phase, a phase with 5-fold symmetry that has long-range orientational order but is aperiodic in 3-dimensional space.[2] Does quenched-in icosahedral order from the melt constitute “seeds” from which the quasicrystalline phase forms? State-of-the-art scanning transmission electron microscopes allow diffraction patterns to be collected from nanoscale volumes. In this project nano-diffraction patterns from as-quenched metallic glasses will be collected and analyzed. The spatial and angular *fluctuations* in the diffracted intensity will be statistically analyzed, a technique known as “fluctuation electron microscopy”. [3] This will allow signatures of icosahedral order, if they exist, to be identified.

The project takes advantage of the suite of microscopes in the Monash Centre for Electron Microscopy and will develop expertise in practical transmission electron microscopy and computational techniques for the statistical analysis of diffraction patterns. Zr-based metallic glasses from Ames Laboratory, Iowa, USA will be studied.

References:

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C,O

**FREE VOLUME AND DEFORMATION IN
METALLIC GLASSES**

*Supervisor: Dr Amelia Liu
A/Professor David Paganin*

Some theories of the glass transition discuss it as a process of freezing, or “kinetic arrest” whereby the atoms simply don’t have time to get into low energy, ordered configurations before they stop moving. Excess “free volume” from the liquid state is also frozen in.[1] In metallic glasses the localization of “free volume” in shear bands is thought to control the deformation behaviour.[2] What form does this “free volume” take in metallic glasses, and how is it distributed?

Phase contrast transmission electron microscope images are sensitive to density fluctuations in materials.[3] This project will investigate “free volume” in as-quenched and deformed metallic glasses using quantitative phase contrast transmission electron microscopy.

The project may be tailored to suit a student with either practical or computational interests. If practical, training in the use of transmission electron microscopes will occur at the Monash Centre for Electron Microscopy and some experience will be gained in advanced image analysis. If computational, advanced image analysis and simulation will be undertaken. Zr-based metallic glasses from Ames Laboratory, Iowa, USA will be studied.

References:

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C,O
STRUCTURE OF AMORPHOUS SILICON FORMED BY INDENTATION
<i>Supervisor: Dr Amelia Liu</i>

When pure crystalline silicon is indented with a micron-sized spherical tip the deformed material might be composed of metastable high-pressure phases of Si (slow unloading) or an amorphous phase of Si (fast unloading).[1] In comparable high-pressure experiments using a diamond-anvil cell, such a transformation to an amorphous phase is not observed. What is the route to the amorphous phase in the case of indentation?

Using a sub-nanometre scanning electron probe in a state-of-the-art transmission electron microscope, the nanoscale structure of the deformed regions will be investigated. Parameters such as mass density and crystal structure in the indent will be mapped.

The project will make extensive use of the transmission electron microscopes at the Monash Centre for Electron Microscopy and investigate Si indented at the Australian National University.

Reference:

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E
REJUVENATION OF THE SECOND YEAR LABORATORY

*Supervisors: Dr David Mills and
Dr Susan Feteris*

The Second Year Laboratory will see undergo a major overhaul in 2009: an extended Problem-Based Learning (PBL) component will be introduced, and some new open-ended experiments will challenge students.

We believe we will be the first to introduce PBL to 2nd year Physics; how effective will it be as a learning experience? How will students respond to open-ended experiments? Can we meaningfully blend the new components with the 'old' pracs, which will still be a major component of lab? What features of Scientific Enquiry will students demonstrate as they progress through the programme?

The project will examine features of the tasks (as per laboratory scripts), design and administer questionnaires and conduct group interviews of demonstrating staff and of students. It will build on questionnaire and interview work done by Susan Feteris on the Monash Physics undergraduate laboratory programme between 2001 and 2004 (allowing a 'before' and 'after' comparison) and studies of how level 1 students respond to open-ended challenges (Mills and Feteris, 2005-2008).

A,H

STRING AND TEXTURE DEFECTS IN PARTICLE COSMOLOGY

Supervisor: A/Prof Michael Morgan

Topological defects, such as cosmic strings and textures [1-4], have been postulated as a mechanism for generating anisotropy in the cosmic microwave background (CMB) radiation. However, recent CMB maps have revealed inconsistencies with models based on topological defects. At present there remain many unresolved issues related to string and texture defects in particle cosmology. Projects will be directed towards understanding the role of hybrid models involving topological defects, including cosmic superstrings, and their impact on our understanding of the CMB radiation, baryon asymmetry and large-scale structure. Topics include:

- (i) Large scale numerical simulations of topological defects, such as cosmic strings, loops and textures.
- (ii) Dirichlet defects in non-Abelian unification models.
- (iii) Topological defects in higher dimensions and in multiply connected universes.
- (iv) Topological defects in condensed matter analogues.

- (v) The role of cosmic superstrings in understanding the structure of the CMB radiation [5,6].

References

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- [5] http://arxiv.org/PS_cache/hep-th/pdf/0410/0410082.pdf
- [6] http://arxiv.org/PS_cache/hep-th/pdf/0505/0505050.pdf

C,O

ELECTRON TOMOGRAPHY OF FIELDS, POTENTIALS AND SOURCES

Supervisor: A/Prof Michael Morgan

The exit phase of an electron moving through an electromagnetic potential can be written in the form of a path integral of the potential [1]. This project explores the technique of vector tomography and applies it to reconstructing electromagnetic potentials from phase measurements (in a transmission electron microscope). Electromagnetic fields and sources can similarly be reconstructed from phase gradients and Laplacians, respectively [1,2]. As an extension of the project we consider the possibility of using these techniques to reconstruct geometric phases.

References

- [1] S. L. Lade, D. Paganin and M.J. Morgan, *Optics Commun.*, **253**, 382-391-(2005).
- [2] S. L. Lade, D. Paganin and M.J. Morgan, *Optics Commun.*, **253**, 392-400-(2005).

S

STATISTICAL MECHANICS OF RANDOM GRAPHS AND COMPLEX NETWORKS

Supervisor: A/Prof 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).

C

EXOTIC STRUCTURES IN BOSE-EINSTEIN CONDENSATES

Supervisor: A/Prof Michael Morgan

Exotic structures, such as skyrmions [1,2] and hedgehogs arise in multi-component Bose-Einstein condensates (BECs). This project will:

- (i) Numerically simulate the evolution of the two-component Gross-Pitaveski equation in 2D and 3D, in order to explore how skyrmions arise in a BEC.
- (ii) Apply the technique of wavefunction reconstruction to elucidate the phase structure of textures [3].
- (iii) Investigate possible connections with homilia textures in models of non-Abelian symmetry breaking [4].

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M

MODELLING LIQUID CLEARANCE FROM THE LUNG USING COMPUTATIONAL FLUID DYNAMICS

*Supervisors: A/Prof Michael Morgan
and Dr Marcus Kitchen*

The mechanisms of lung aeration and liquid clearance at birth are poorly understood. Recently we have has applied phase contrast X-ray imaging to study how air fills the lungs of new born rabbit pups [1]; these studies provide important information on the rate and pattern of aeration. This project will use computational fluid dynamics to elucidate liquid clearance and aeration in 2D and 3D models of the lung. These models will be correlated with phase contrast X-ray images acquired using synchrotron radiation.

References

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3D DIFFRACTION IMAGING OF EMBEDDED NANOPARTICLES

O

Supervisor: A/Professor Andrei Nikulin

Conventional microscopic approaches to 3D characterization of the structure of materials are inevitably destructive and thus prohibit in-situ studies of dynamic behaviour. Emerging 3D imaging techniques employing high energy x-ray diffraction permit such studies in samples representative of bulk behaviour, with nano-scale spatial resolution.

This interdisciplinary project involves development of novel techniques of high-resolution x-ray diffraction and imaging, and their application to the study of critical structure-property relationships in contemporary materials where key structural elements range from a few microns to the nano-scale. The focus will be on nano-structured materials which promise new applications in modern technology and manufacturing. The experiments are to be performed using the new state-of-the-art rotating anode facility now available at Monash University, synchrotron radiation facilities in Japan and, in near future, in Australia.

X-RAY DIFFRACTION STUDIES OF NANOSCALE INTERFACES

O,C

Supervisor: A/Professor Andrei Nikulin

Interfaces and boundaries play a fundamental role in determining the physical and mechanical properties of all materials. Recent advances in diffraction physics have allowed us to image some interfaces with a spatial resolution of 20-50 nm. Furthermore, non-destructive nature of x-ray methods allows us to image the development of such interfaces under external influences such as stress and temperature.

This project aims to establish what we can learn about the structure of such boundaries using x-ray diffraction and, in particular, whether we can detect structural changes in these boundaries as a function of composition, stress and/or temperature. The project will involve simulation of x-ray diffraction patterns from model structures, and experimental studies of various interfaces using x-ray diffraction and imaging. Novel experiments to study *in-situ* formation and development of interfaces and cracks in nano-structures are also scheduled for this project. The experiments are to be performed using the new state-of-the-art rotating anode facility now available at Monash University, synchrotron radiation facilities in Japan and, in near future, in Australia.

C,O

HIGH-RESOLUTION PROFILING OF NANOSTRUCTURES USING FRAUNHOFER X-RAY DIFFRACTION

Supervisor: A/Professor Andrei Nikulin

An x-ray diffraction technique has recently been developed and successfully applied to comprehensively, including both phase and amplitude contrast, map the complex refractive index of non-crystalline materials with nano-scale spatial resolution. The methodology is based on the measurement of a high angular resolution x-ray Fraunhofer diffraction pattern with further application of the phase-retrieval formalism using a logarithmic dispersion relation.

The project is concerned with the perspective of its ability to deliver ultra-high, order of several nanometres, spatial resolution and to uniquely determine both the real and imaginary components of the complex refractive index of the material under analysis. The project includes the development of novel theoretical and simulation approaches, as well as experimental data collection using various x-ray sources and different optical layouts. The experiments are to be performed using the new state-of-the-art rotating anode facility now available at Monash University, synchrotron radiation facilities in Japan and, in near future, in Australia.

O

COHERENT SYNCHROTRON X-RAY OPTICS

Supervisor: A/Professor Andrei Nikulin

Gaussian-like shaping of the forward-diffracted intensity was recently observed from an initially rectangular cross-section of coherent x-rays. The effect occurs when a coherent

x-ray wavelength inside a crystal exactly matches the period of atomic net planes lying perpendicular to the incident beam. The transmitted peak intensity rose when the lateral width of the rectangular-shaped incident beam increased. The transmitted Gaussian-like shaped intensity profile was significantly narrower than that of the incident beam size. The observations showed that coherent and incoherent x-rays produced different dependencies of the peak intensity and its width on the incident beam size.

The project aims to perform thorough studies of this new phenomenon and established its applications in modern synchrotron optics. The experiments are to be performed using synchrotron radiation facilities in Japan and, in near future, in Australia.

COHERENT 3D DIFFRACTION IMAGING AT THE NANOSCALE

Supervisor: A/Professor Andrei Nikulin

Unlike in conventional imaging of macro objects, radiation that is diffracted from a small object “knows” about the thickness of the object it has passed through. When the sample is thinner than the temporal coherence length, the emerging diffracted intensity depends on the sample thickness, and this dependence can be used to reconstruct 3D images of very small objects from experimentally recorded 2D diffraction patterns.

The project involves fundamental theoretical studies of diffraction phenomena from thin samples, as well as the proof-of-concept experimental studies using model nano-scale structures. The experiments are to be performed using the new state-of-the-art rotating anode facility now available at Monash University, synchrotron radiation facilities in Japan and, in near future, in Australia.

PHASE-RETRIEVAL X-RAY DIFFRACTOMETRY

Supervisor: A/Professor Andrei Nikulin

X-ray diffraction methods are well-established non-destructive diagnostic techniques for single-crystal and multi-layer systems. A new method has recently been developed for direct characterization of modern semiconductors. It has been applied successfully to image displacements of atomic planes in silicon crystals with SiGe/Si and SiGe/Si:C superlattices with sub-nanometre spatial resolution.

The project involves the development and application of a novel experimental-analytical method for the phase-amplitude contrast mapping of single-crystal alloy multilayers. The experiments are to be performed using the new state-of-the-art rotating anode facility now available at Monash University, synchrotron radiation facilities in Japan and, in the near future, at the Australia Synchrotron.

X-RAY MICRO-DIFFRACTION STUDIES OF NANOROLLS

O

Supervisor: A/Professor Andrei Nikulin

The study of nanomaterials, particularly in recent times has greatly increased the capacity for engineering, electronics and optics in the nano- and even micro-scale. Multilayered nanorolls display a very high symmetry and their small size allows them to be used as waveguides or capacitors which can be stored on a single chip. These applications, however, require extremely specific scroll diameter. In the interests of examining the effects of the rolling mechanism on the atomic spacing of layered films, the project aims a series of AlGaAs nanorolls, that were grown on a GaAs substrate, to be examined using x-ray micro-diffraction. X-ray micro-diffraction allowed the researchers to directly examine the effects of strain on the diffraction pattern and therefore lattice spacing. The project involves experiments using the new state-of-the-art super bright rotating anode facility at Monash University and possible experiments at SPring-8 synchrotron facility in Japan. It also involves a large fraction of data analysis using original phase-retrieval technique with an application of neural network calculations.

STUDIES IN WAVE PHYSICS

C,O

Supervisor: Dr David Paganin

David is a theoretical physicist who studies the physical optics of matter and radiation wave-fields. His current research interests include: coherent X-ray optics, phase retrieval and aberration balancing in imperfect coherent imaging systems, topological defects in radiation and matter wave-fields, foundations of coherence theory of stochastic fields, phase retrieval in dissipative non-linear quantum systems, phase-contrast tomography, X-ray lithography, holographic microscopy, and hybrid hardware–software optical imaging systems (“omni optics”). If you might be interested in working in these or related areas, please drop me a line so that we can discuss possible projects that are aligned with your interests. Depending on your taste, the project can have a negotiated mix of theoretical and computational components. To give you a better feel for the scope and nature of the collaborative student projects that I have been involved with in the past, see the references below, all of which are recent first-author papers of Monash research students.

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M,O

PHASE CONTRAST TOMOSYNTHESIS: A POTENTIAL TOOL FOR IN VIVO ASSESSMENT OF CYSTIC FIBROSIS THERAPIES

*Supervisor: Dr Karen Siu
Monash Centre for Synchrotron Science*

Cystic Fibrosis (CF) causes chronic, progressive, infective and inflammatory lung disease that begins in childhood and eventually leads to death in early adulthood. This project is part of an exciting wider study led by Dr David Parsons at the Women's and Children's Hospital, Adelaide, that is developing airway gene transfer for CF gene therapy. Gene therapy offers real hope for curing this often debilitating and early fatal disease, but its effectiveness, longevity and safety have yet to be established.

Unlike conventional X-ray imaging, synchrotron-based phase contrast (PC) imaging has the ability to reveal the soft tissues with extremely high resolution and is proposed as a non-invasive, in vivo method of assessing the effectiveness of CF gene therapies. When coupled with computed tomography (CT), this technique can provide excellent three

dimensional visualisation of the airways. However, CT at the high resolutions necessary to observe the terminal airways of the lungs is extremely time consuming and hence unsuitable for in vivo applications, as it involves the acquisition of many hundreds or thousands of single images. This project will investigate the use of tomosynthesis techniques with synchrotron based PC imaging to form a new PC imaging modality that maintains the ability to generate cross sectional images at depth, but requiring far fewer images. This resulting reduction in radiation dose would make this modality extremely attractive for in vivo imaging.

C

**FIRST PRINCIPLES QUANTUM CALCULATIONS OF
LIGHT METAL ALLOYS**

Supervisor: Dr Andrew Smith

This project involves the application and modification of state of art quantum mechanical codes run on super computers to help design better light alloys and light metal hybrid materials based on aluminium, magnesium and titanium. It is part of the collaboration within the Australian Research Council Centre of Excellence: Design in Light Metals which has recently been awarded \$14.5m to establish a strategic fundamental research platform for expansion of the light metals industry in Australia.

Reference

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- [2] A.E. Smith, Surface Science 601 5762-5765 (2007) .

C

**THE EXCITED STATE INTERACTING FERMI
SYSTEMS**

Supervisor: Dr Andrew Smith

Whilst great progress has been made in the application of Density Function Theory to the understanding and predication of realistic systems, it is formally based on the ground state properties of interacting Fermi systems. This project will consider the excited state properties of such systems and in particular be associated with low energy electron measurements (Low Energy Electron Microscopy [LEEM] at Monash University; synchrotron based photoelectron spectroscopy at La Trobe University and BESSY).

Reference

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C,O
REFLECTION MULTI-SLICE X-RAYS
<i>Supervisor: Dr Andrew Smith</i>

Following the application of the reflection multi-slice method to both low and high energy electron diffraction together with atom scattering, this project extends such methods to the reflection of X-rays from crystalline materials.

References

- [1] J. Murphy, L.C.L. Hollenberg and A.E. Smith, Physical Review A49, 3100 (1994).
[2] A.E. Smith, Acta Crystallographica A48, 36-41 (1992).
[3] A.E. Smith and D.F. Lynch, Surface Science 184, 189 (1987).

C,O
PHOTOELECTRON SIMULATIONS
<i>Supervisor: Dr Andrew Smith</i>

This project applies first principles quantum mechanical descriptions of electron scattering to describe photoelectron excitation and diffraction processes close to the surfaces of crystalline and nano-materials. In doing so it will further develop synchrotron-based photoelectron techniques to improve nano-device development. This work will be carried out in collaboration with electron spectroscopy groups based at La Trobe University and the Berlin Synchotron. (BESSY).

References

- [1] A. Tadich, L. Broekman, J. Riley, S. Homolya, A.E. Smith, T. Seyler, K. Emtsev and L. Ley, 'Mapping disorder-order induced changes to the Fermi surface of Cu₃Au using a new toroidal electron energy analyser,' *Journal of Electron Spectroscopy and Related Phenomena* 144-147 (2005) 515-518, 2005.

M,O

RADON/MOJETTE RECONSTRUCTION OF IMAGES FROM NOISY PROJECTION DATA

*Supervisors: Dr Imants Svalbe
Dr Nicolas Normand, Nantes'Polytech*

Tomographic reconstruction of images from projections is relatively well-behaved, except for the most interesting cases where data is collected at asymmetric angles or for sparse projection data. Often statistical iterative techniques are applied, but these methods are slow to compute, have poor spatial resolution and uncertain convergence properties. The addition of noise to the collected projected intensities makes problems harder still. The Mojette transform [1] is an exact, digital projection method that copes well with asymmetric or sparse sets of data. It also has strong predictive constraints on the reconstructed image values (i.e. the depth of greyscale reconstruction or number of distinct densities or materials of which an object is composed). It can be mapped neatly onto the finite Radon scheme [2], which has the advantages of an exact inversion algorithm and strong symmetry properties [3]. The project will build on recent advances [4, 5] in reconstructing discrete images from real projection data.

References

- [1] The Mojette Transform, Theory and Applications, Jeanpierre Guédon (Ed.), ISTE, Wiley, 2009.
- [2] Image Representation via a Finite Radon Transform, Mateus, F. and Flusser, J., *IEEE Trans. Patt, Anal. Machine Intell.* 15(10), 996-1006, 1993
- [3] Projective Transforms on Periodic Discrete Image Arrays, A. Kingston and I. Svalbe, *Advances in Imaging and Electron Physics*, 139, pp 75-177, 2006.

- [4] Applying Mojette discrete Radon transforms to classical tomographic data, H.Fayad, JP. Guédon, I. Svalbe, Y. Bizais, N. Normand, SPIE Medical Imaging, San Diego, 16-12 February, 2008.
- [5] The discrete Radon transform: A more efficient approach to image reconstruction? A. Kingston, I. Svalbe and J-P. Guédon, SPIE, Developments in X-ray tomography, VI, August, 2008.

M,O

**GHOSTS AND ANTI_IMAGES IN DISCRETE
GEOMETRIES**

*Supervisors: Dr Imants Svalbe
Dr Nicolas Normand, Nantes'Polytech*

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 x-ray CT.

These ghosts originate from a wonderful 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].

This project involves methods to construct the ghost of an individual pixel and then build anti-images from these ghosts. The coupling of image and anti-image has shades of the two-state entanglement one sees for example in quantum spins. An anti-image makes a whole image invisible from certain angles when seen in projected views. It turns out that whole rows of image data share the same ghost images, i.e. ghosts are horizontally translation-invariant. The aim of the project is to be able to use these anti-images to correct the original data when part of a set of transmitted data is lost or corrupted. One significant application of this technique is to recover data lost or corrupted during transmission on a network such as the internet.

References

- [1] Questions of Uniqueness and Resolution in Reconstruction from Projections, Katz, M., Springer Verlag, 1977
- [2] Projective Transforms on Periodic Discrete Image Arrays, A. Kingston and I. Svalbe, Advances in Imaging and Electron Physics, 139, pp 75-177, 2006.
- [3] A method for removing cyclic artefacts in discrete tomography using Latin squares, S. Chandra and I. Svalbe, Int. Conf. on pattern Recognition, Tampa, Florida, 8-11 December, 2008.
- [4] 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.

M,O

QUANTISED ANGULAR MOMENTUM

Supervisor: Dr Imants Svalbe

The quantisation of the vector representing the angular momentum of an object is critical to the description of all quantum mechanical systems, such as atoms. The magnitude of the vector has a simple formula, but the allowed directions of the vector with respect to some reference axis is also quantised, due to the requirement that changes in angular momentum must always occur in steps that are multiples of Planck's constant, h . The pattern of allowed orientation directions is an interesting geometric discretisation of space that has relevance to discrete projection theory.

Work in 2009 by students in the Honours Data Representation Unit examined the patterns of allowed directions for integer and half-integer spin systems. The quantised vectors show remarkable properties, including an extremely low level of directional redundancy, that is very few angular momentum vectors can ever point in the same direction and the number of these "degenerate" directions is extremely limited. The same orientation patterns can be extended to other fractions of integer spins, e.g. h/n . The project would further examine these interesting phenomena and relate the findings to seek experimental data where angular momentum vectors change in magnitude but not direction.

Reference:

Projective Transforms on Periodic Discrete Image Arrays, A. Kingston and I. Svalbe, Advances in Imaging and Electron Physics, 139, pp 75-177, 2006.

MINIMUM-MESSAGE-LENGTH TECHNIQUES FOR IMAGE RECONSTRUCTION FROM NOISY PROJECTION DATA

*Supervisors: Dr Imants Svalbe, Physics
A/Prof. David Dowe, Information Technology*

Minimum message length (MML) is an explicit algorithmic version of Ockham's Razor; that the shortest (most concise) description provides the most accurate explanation of the data [1, 2].

Traditional tomography relies on a series of regular parallel (or fan-beam) profiles of an object, with many profiles being obtained over some range of angles (usually 0 to 180 degrees). In Computed Tomography, these object profiles correspond to the intensity of transmitted x-rays.

A recent paper (with lead author PhD student Gerhard Visser) [3] demonstrated that it is possible, via MML, to "explain" i.e. to reconstruct accurately, quite intricate spatial data patterns from a set of projected views of the data (in that case, "random" sets of summed image values). The guiding principle here is that the simplest image that preserves local spatial properties can provide a "unique" correct explanation. There the projected data was obtained in less-ordered fashion than the straight-line ray paths usually specified for the Radon integral transform.

How data should be projected and how many projections are sufficient to be able to exactly (or even approximately) reconstruct images remains an interesting current research topic. Compressed sensing is an approach that uses what would usually be regarded as an under-sampled data set to recover data or reconstruct images [4].

The Finite Radon Transform [5] is an exact discrete projective transform that also sums random-looking patterns of image values. These distinctive patterns arise from the way lines wrap periodically (like a torus) around the image array. The FRT has already been used to reconstruct images from real x-ray absorption data [6]. This project involves development of a thermal or entropy-guided approach to MML that recovers spatial data patterns from FRT-like sets of their partial sums.

References

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- [6] The discrete Radon transform: A more efficient approach to image reconstruction? A. Kingston, I. Svalbe and J-P. Guédon, SPIE, Developments in X-ray tomography, VI, August, 2008

LARGE ATOM NUMBER MAGNETO-OPTICAL TRAPPING OF RUBIDIUM-87

Supervisor: Dr Lincoln Turner

Magneto-optical traps (MOTs) are the centerpiece of almost all cold atom experiments, collecting up to 10^{10} atoms at temperatures well below 1 mK. In this project, you will build a MOT trapping a large cloud of rubidium-87 atoms inside a glass ultrahigh vacuum cell. This is a hands-on project during which you will assemble lasers, fibre optics, acousto-optical light switches and numerous mirrors, lenses and waveplates to form the six orthogonal beams needed to cool atoms. You'll also construct the high-current coils and control electronics to make the magnetic quadrupole field which traps the atoms, and interface the MOT to the experiment control computer.

Trapping many atoms in the MOT leads to a large Bose-Einstein condensate after evaporative cooling. You will build and calibrate the CCD camera system which measures the MOT, and optimise the number of atoms in the MOT by varying the laser power, detuning and magnetic field gradients. During this project you will learn about laser cooling and trapping, laboratory optics, CCD imaging and LabVIEW computer control.

HIGH-RESOLUTION OBJECTIVE LENSES FOR IMAGING BOSE-EINSTEIN CONDENSATES

Supervisor: Dr Lincoln Turner

Bose-Einstein condensates are famous for being “macroscopic wavefunctions” in which a million atoms behave as a single quantum object. They are certainly “macroscopic” compared to a single atom, but typical BEC diameters of between 10 and 100 μm are small enough to require sophisticated optics to image them at high resolution. Conventional microscope objectives need to be very close to the object, but it is difficult to get close to a BEC inside an ultrahigh vacuum chamber. In this project, you’ll design a very high resolution lens to image Bose-Einstein condensates onto a CCD camera. The lens will work with monochromatic light, so chromatic lens aberrations are irrelevant. Monochromatic aberrations such as spherical aberration, coma and astigmatism must be reduced to the minimum achievable. You’ll use specialist lens design software (Lambda Research OSLO) to perform the multidimensional optimisation needed to design a lens with several glass elements. You’ll then construct the lens and test it on laser-illuminated resolution targets. This project will involve working not just with standard lenses and optics but with exotic optics such as large-diameter aspheres and gradient-index lenses.

At the end of this project you will have designed, built and tested a very high performance purpose-specific optical system. During this project you will learn about resolution in imaging systems, aberration theory and the use of modern lens design software, as well as developing skills in laboratory optics and image processing.

A NANOKELVIN QUANTUM REFRIGERATOR: MONTE CARLO SIMULATION OF EVAPORATIVE COOLING

Supervisor: Dr Lincoln Turner

Evaporative cooling is a powerful quantum refrigeration technique, and works just as well on laser cooled atoms as it does in air-conditioners. It is the only cooling method that can achieve the nanokelvin temperatures needed for Bose-Einstein condensation. In the lab, we will hold atoms in a hybrid magnetic and optical trap, and force the evaporation of the “hottest” atoms with radiofrequency waves.

In this project, you will use Monte Carlo methods to simulate trajectories of atoms in a hybrid magnetic and optical trap. The existing code only simulates the classical motion of the atoms. You will add time-dependent quantum mechanics to the code, simulating the internal spin state of the cold atoms as they move in the magnetic trap. Your results will guide the optimisation of evaporative cooling in the lab, and help achieve a large atom number spinor Bose-Einstein condensate. You may also have the chance to collaborate with researchers at the National Institute of Standards and Technology, in Washington DC, who want to use this code to simulate cooling of rubidium/lithium mixtures.

This project will involve programming in Matlab and C, and possibly the use of high-performance computing clusters. No prior programming experience is required. You will also learn about powerful numerical and analytic methods for integration of the time dependent Schrodinger equations, Landau-Zener transitions and the quantum theory of scattering at ultracold temperatures.

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**IRIDESCENCE AND NATURAL NANOPHOTONICS:
THE OPTICS OF SCARAB BEETLES**

Supervisor: Dr Lincoln Turner

Scarab beetles (family *Scarabaeidae*) have shiny iridescent shells, which appear an intense and metallic-looking green, red or blue colour. What we can't see with human eyes is that some of these beetles reflect light that is almost purely left-handed circularly polarised! This striking optical phenomenon was first noticed by Michelson in 1911, but only last year did electron microscope studies reveal that it is a cholesteric (chiral) liquid crystal in the shell which does the polarising.

This project is a collaboration with CSIRO Entomology to study various aspects of Beetle Optics, all revolving around a central theme of the nanophotonics of these remarkable insects. Possible research topics include:

- Thin-film optics modelling of iridescent reflections from elytra of Australian beetles
- Synchrotron studies (SAXS) of microstructures in beetle elytra
- Can beetles *see* circular polarisation? Behavioural studies of beetle polarisation perception
- Natural photonic crystals: photonic bandgap modelling of insect shell structures

QUANTUM NONLINEARITY AND COHERENCE IN AN ATOMIC GAS: THEORY AND EXPERIMENT

Supervisor: Dr Lincoln Turner

Slow light, fast light, stopped photons, lasing without inversion: all of these “new” quantum effects are due to atomic coherences induced by lasers. In this project, you will study a nonlinear coherent process called *four-wave mixing*, and apply this process to stabilising a diode laser to a rubidium atomic resonance.

The project will be a blend of theory and experiment, balanced according to your preferences. On the theory side, you might use the Maxwell-Bloch equations to model the interaction of four light waves with the 24 relevant states of the rubidium-87 atom. On the experimental side, you will have lasers, an atomic vapour cell and radiofrequency hardware already set up to test your model and try new configurations. You will work closely with local experts in Maxwell-Bloch equations (Martijn Jasperse) and modulation-transfer experiments (Vlad Negnevitski). This project offers the ultimate in tight-binding between theory and experiment: what you model in the morning in Mathematica, you can test in the afternoon in the lab.

In this project you will learn about the interaction of light with multilevel atoms, the optical Bloch equations, and efficient solutions for large systems of coupled ordinary differential equations. You will also learn about the high-frequency modulation of laser light, and making optical measurements at the quantum shot-noise limit.

A LASER THERMOMETER FOR ULTRACOLD ATOMS

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Supervisor: Dr Lincoln Turner

Measuring the temperature of cold atoms can be difficult – you can’t use a thermometer made of matter, because it’s too big and too hot! Laser probes *can* give information about how fast atoms are travelling (and so their temperature), but for really cold atoms the Doppler shift is less than the natural linewidth.

In this project, you will use *recoil induced resonances* to measure the Doppler shifts of ultracold atoms. Using multiple laser beams to induce atomic coherences in the cold rubidium atoms, you will produce spectral features much narrower than the natural linewidth, and use these to measure microkelvin temperatures.

This project is primarily experimental, but there will be some background theory in understanding the recoil-induced resonance phenomenon. You will develop the laboratory optics for interacting the laser beams with the ultracold atoms in a magneto-optical trap. You will also develop the photodetection electronics and signal processing

needed to extract a temperature from your measurements. Your results will guide the development and optimisation of laser cooling the magneto-optical trap, on the path to Bose-Einstein condensation.