PROJECTS FOR THE 2014 UWA-USTC/NANJING RESEARCH TRAINING PROGRAM

1. Professor Thomas Braunl

   a) Mobile Robot Programming
      - Integrating RoBIOS operating system on new interface board for Raspberry Pi
      - Testing and extending device drivers for robot sensors and actuators
      - implementing image processing library based on OpenCV for Raspberry Pi
      - Designing and implementing mobile robot navigation program with vision-based obstacle avoidance

   Info: http://robotics.ee.uwa.edu.au/eyebot/

   Required skills: Excellent programming skills in C or C++, some microprocessor interfacing experience

   b) Robot Simulation
      - Extend Mobile robot simulation system EyeSim
      - Include new hardware features, touch-screen input, high-res. camera, etc. (in simulation)
      - Include OpenCV image processing library
      - Include Pthread multitasking library
      - Extend robot command set


   Required skills: Excellent programming skills in C or C++, interface design

2. Professor Michael Small & Professor Kevin Judd

   One place available, you can choose from three projects:

   a) Network dynamics
      Networks of interconnected dynamical systems arise in many areas - the interaction between high voltage power plants in the electricity generation network, for example. The aim of this project is to study how the properties of the structure of the network affect the stability of the system and the interaction (synchronization) of the various dynamical systems.

   b) Ubiquity of scale free networks
      Scale free networks exhibit the unusual property of having a finite probability of possessing nodes with a very large number of connections. Despite this, scale-free networks have been found to arise in a surprisingly wide range of real world systems - from interconnection of neurons in the brain to the network of collaborations between Hollywood actors. However, there currently does not exist a good characterization of the expected distribution of scale-free networks. This programme aims to rectify this.

   c) Tracking and Flocking
      How do groups of animals interact with one another to generate collective (flocking, herding or schooling) behavior? We aim to construct mathematical models of interactions from real
observational data and use this to build realistic models of collective behavior.

3. Associate Professor Michael Renton

(Email: michael.renton@uwa.edu.au)

Professor Renton is an applied mathematician with a number of projects available in computational simulation modelling of plants in complex biological, agricultural and ecological systems. Some possible project topics are listed below, and for more details see: www.michaelrenton.info

- The spread of invasive biological organisms, such as weeds, insects and plant diseases, across space and time.
- Evolution of herbicide resistance in weeds and pesticide resistance in insects in agricultural systems, and the effect of different genetics and management strategies on the rate of this evolution.
- The optimisation of land use sequencing and analysis of tactical and strategic decisions in agricultural systems, taking into account the effects of factors such as weeds, disease, plant nutrients, yields, economics and climate variability.
- Simulating the dynamic processes involved in plant growth, competition and evolution in order to better understand plant function and structure in different environments.
- Predicting the fate of plant species under climate change, accounting for landscape characteristics, population dynamics and dispersal

Students will need a strong maths, stats and/or programming background. They would obviously need an interest in the project topic, but not necessarily any biological background.
A flowering time control protein destroyed repeatedly by evolution

The *Arabidopsis thaliana* strains used in the lab are typically rapid cycling, but many strains from the wild have a biennial life habit. These plants have a very strong requirement for winter; this prolonged cold treatment accelerates subsequent flowering and is a physiological process known as vernalization. A vernalization requirement is a dominant genetic trait conferred by a single protein called FRIGIDA (Johanson *et al.* 2000 *Science* 290:344). When *Arabidopsis* naturally evolves a rapid cycling habit it almost always mutates FRIGIDA although dozens of genetic mutations made by scientists in other genes can similarly suppress its action. The *Arabidopsis* races used in most labs (Columbia, Ler) have mutations in their *FRIGIDA* genes that disrupt their encoded protein from functioning. Dozens, if not hundreds of independent mutations have evolved to disrupt FRIGIDA, making it an interesting subject for understanding protein evolution.

Our lab ([www.mylne.org](http://www.mylne.org); e-mail [joshua.mylne@uwa.edu.au](mailto:joshua.mylne@uwa.edu.au)) is broadly interested in the evolution of proteins and we hope using recombinant protein approaches will help us understand why evolution in *Arabidopsis* repeatedly interrupts the FRIGIDA protein in order to acquire a rapid flowering habit.

Students interested in this project will require a basic understanding of molecular biology. Students with experience using *E. coli* for protein expression and purification will be preferred. You would be working with a young team of plant biologists and biochemists with a promise of plenty of hands-on supervision and training.

![Fig. 1: The need for and effect of vernalization.](image-url)
5. Projects in Atomic and Surface Physics

ARC Centre of Excellence for Antimatter and Matter Studies (CAMS)

EXPERIMENTAL PROJECTS

Jim Williams jfw@physics.uwa.edu.au; Sergey Samarin samar@physics.uwa.edu.au; Luka Pravica luka@physics.uwa.edu.au; and research team and international visitors.

Projects may be selected and assembled to suit individual needs to concentrate on aspects of physics from the guide below and/or to gain experience and solve problems using combinations of the following techniques.

a) Positron and positronium spectroscopies of surfaces and materials.

Separate projects are:
   i. positron and positronium annihilation lifetime spectroscopies,
   ii. positron detection of nano-sized porosities of materials.

Positronium and positron lifetimes (pico- to 140 nano-sec) are determined by spin-dependent interaction with electron densities as found in the shapes of nano-sized pores and their unknown distributions in materials. The project traces positronium decay through 3 and 2-gamma Doppler (energy and angular) and time decays. The studies have many applications from characterization of materials (e.g. from nm graphene, silicates to cm concrete) to PET scans and pharmaceutical delivery by diffusion from nano-dimensioned pores.

b) Electronic structure and magnetic properties of surfaces and thin films.

Project: Experimental studies of electron correlations in metals (W, Cu, Fe), semiconductors (Si, GaAs) and magnetic thin films deposited on surfaces.

How does the Pauli exclusion principle influence the electron (angular and energy) spectroscopy of thin films? How do electron exchange and spin-orbit interactions influence such spectroscopy? How do geometric and physical asymmetries influence the observations? Guidance to answers will be obtained from a project observing the energy and angular distributions of electrons (and positrons) scattered from metals, semiconductors and insulators. The results have applications in the design and use of modern materials, for example in spintronics.

c) Electron spin.

Project: Prepare and detect a spin-polarized beam of electrons and observe correlated pairs of electrons.

(Longer project) How does an electron spin topological phase effect and affect its observation via radiated polarized photons? How do the observable wave functions superpositions change with collision process and in what time scale? How can direct, exchange and spin-dependent interactions separated and observed? The experimental project will explore the energy, angular and polarisation (spin) correlations which reflect structure and dynamic properties, how those properties depend on subshell configuration interactions, multipole moments and the spin and orbital angular momentum coupling between electrons. The project observes fundamental quantum phenomena.

Projects may be selected and assembled to suit individual needs to concentrate on aspects of physics from the above guide and/or gain experience and solve problems using combinations of the following techniques.

- Ultra high vacuum (10**-11) Torr). Turbo and ion pumps.
- Electron optics, electron energy analysis, time-of-flight electron energy analysers, electron-pair methods,
- Positron production and detection.
- Spin-polarised electron production via laser photoemission from GaAs crystals using circularly polarised laser.
- Surface science methods including LEED, Auger, X-ray techniques, ellipsometry, thin magnetic films, adsorbed molecules, Metal vapour beams.
- Stokes' parameter (polarization) analysis of photons, liquid crystal polariser and phase retarder, opto-acoustic wavelength filters.
- Single pulse counting (100 MHz), coincidence techniques. Position-sensitive-detection (imaging). Multidimensional histogramming techniques. Spectrum pulse height analysis, Angular correlation analysis.

6. Prof. Dylan Jayatilaka

School of Chemistry and Biochemistry

Talented third year students with strong computing backgrounds.

a) Experimental Wavefunction for vitamin B12

We have developed quantum chemistry and crystallographic computer codes for performing fitting of electronic structure wavefunctions to high quality experimental X-ray diffraction data. The purpose is to reconstruct the electron density in molecules using the best possible models, to help with determination of hydrogen atom positions, which are difficult to measure but critical for enzyme function, and to help in physical property determination e.g. the electrostatic potential, for drug docking studies. We want to see if we can optimize our codes and make them work for a vitamin B12 coenzyme, for which we have obtained data from our collaborators.

The candidate should be familiar with a programming language, preferably C or Python. Familiarity with MPI and Fortran 95/03 would be nice, however our codes are written in a preprocessor language which looks like python and translates to Fortran. Some modification of the codes may be necessary to run such a large system.

For details of the Tonto code see http://hirshfeldsurface.net/ and click the link to Tonto. See also tonto-chem on sourceforge.

b) Develop a BNF syntax for Foo

Tonto is a code for computing molecular properties from first principles using quantum mechanics. It comprises about 250k lines. Tonto is written in a language, called foo, which currently translates into Fortran 95. Foo is a generic object-based language which looks a bit like Python, with declarations. Foo was intended to translate to either Fortran, C, java, in order to extend the software lifetime by de-emphasising the dependence of the source code on a specific language.

The original foo translator evolved from a script and is now written in perl. The project is to develop a BNF syntax for Foo, and use this to generate a lexer/parser/generator for the Tonto codes.

This project will suit a student experienced in programming, with skills in, for example, Scheme, Haskell, Perl6 or some other language suitable for generating parser generators.
7. Prof Ajmal Mian and Asst/Prof Faisal Shafait


We are looking for a computer science or electrical engineering student with background in image processing and a working knowledge of Matlab. The student will be placed in our hyperspectral imaging lab and will be working alongside other research students with similar projects related to hyperspectral image analysis. The student will gain knowledge of using hyperspectral imaging systems and processing the generated images. The project aims at forensic examination of documents to detect forgery such as the use of different inks, writing styles, and examination of paper material. The student will be required to generate test data and develop Matlab based image processing techniques for automatically detecting manipulated parts / forgeries in documents.

8. Prof Anas Ghadouani and Asst Prof Elke Reichwaldt

a) Application of attached-growth media in waste stabilisation ponds to enhance treatment capacity and efficiency

Attached-growth biological processes can significantly improve the treatment capacity and efficiency of waste stabilisation ponds (WSPs) through alterations in both biological and physical treatment parameters. Such an attached-growth system can be encouraged by introducing baffles into WSPs. Microbial and algal communities will attach to the baffles (= attached-growth) and these communities can incorporate high amounts of nutrients during their growth, thus stripping the wastewater off its nutrients.

In this ongoing project baffle systems will be implementation in WSPs in Western Australia that encourage these attached-growth biological processes. The treatment efficiency of WSPs will be determined before and after the installation of these baffles to analyse their effect on the treatment efficiency and capacity of the WSPs.

The student working on this project will be involved in this ongoing study and will have the opportunity to work with environmental data that will indicate if attached-growth improves the efficiency of the WSPs. The student will have the opportunity to assist in laboratory work and the data analysis of water quality and biological data.

b) The development of novel indicators to characterise performance levels of waste stabilisation ponds (WSPs)

Conventional methods to assess performance of WSPs include determining concentrations of nutrients, the pathogen \textit{E. coli}, and biological oxygen demand (BOD) in the effluent. While this in general suffices for regulatory purposes, it does not assist us in understanding the reasons for differences in performance level. This ongoing project will investigate a suite of possible indicators that will be identified through metabolomics (e.g., sterols, metabolites associated with functional groups of bacteria), FISH (identification of functional groups, e.g. nitrifier, denitrifier), and flow-cytometry (e.g., abundance and viability of specific groups of the microbial community), to describe treatment efficiency.

The student involved in this project will have the opportunity to assist in the laboratory and perform data analysis.

c) Quantifying greenhouse gas emissions from waste stabilisation ponds

In the context of climate change, there is an increasing concern to evaluate the contribution of different systems to atmospheric GHG concentrations. At this stage, the dynamics of carbon
emission from WSPs is unknown. Municipal wastewaters being very rich in organic matter are potentially large greenhouse gas emitters, including carbon dioxide (CO$_2$), methane (CH$_4$) and nitrous oxide (N$_2$O). However, their contribution to the global carbon cycle is not well known. As hydraulics and pond ecology very likely influence GHG emissions, this ongoing project will investigate the spatiotemporal variability in GHG flux in WSPs and identify its controlling factors, including pond chemical properties, presence/absence of cyanobacterial blooms, sludge distribution and level of treatment efficiency.

9. Professor Ian Small and A/Professor Sandra Tanz

A decisive biological advantage of C$_4$ plants is their spatial separation of photosynthetic reactions between two different cell types, mesophyll (M) and bundle sheath (BS). This compartmentalization allows greater metabolic efficiency, with studies showing up to 50% greater biomass accumulation and a higher water- and nitrogen-use efficiency in C$_4$ plants compared to C$_3$ plants. Consequently, research is focusing on transferring the C$_4$ pathway into C$_3$ crop plants such as rice, wheat and soybean (1, 2).

Previous studies have concentrated on nuclear gene expression of M and BS cells in C$_3$ and C$_4$ plants (3, 4), whereas gene expression in chloroplasts and mitochondria has mostly been overlooked. This is unfortunate because the differential expression of organellar genes between M and BS cells is fundamental to the modified biochemistry of photosynthetic reactions in C$_4$ photosynthesis. The overall project examines the regulation of gene expression in chloroplasts in M and BS cells, comparing closely related C$_3$ and C$_4$ species. Using laser capture microdissection to separate M and BS cells followed by quantitative PCR, in situ hybridization, ribosome footprinting and deep sequencing, we are studying transcription, RNA processing and translation of chloroplast genomes in the C$_4$ species Cleome gynandra. We are using these results to identify potential regulators of chloroplast gene expression in M and BS tissues using the laboratory’s discoveries on similar regulators in Arabidopsis (5). We focus on elucidating the regulation of the production of the carbon-fixing enzyme Rubisco, a major target in the implementation of the C$_4$ pathway in C$_3$ crop plants.

REFERENCES

10. Professor Michael Guidici

Research projects in the Centre for the Mathematics of Symmetry and Computation

Members of the Centre conduct research in group theory and combinatorics. Group theory is the mathematical abstraction of symmetry and one can use groups to understand combinatorial structures such as graphs or geometries, or one can use combinatorial structures to understand groups.

Members of the Centre are willing to supervise a project on the topic of group theory or combinatorics, or some combination of the two. Possible projects include:

- Graphs with certain symmetry properties, such as Cayley graphs or vertex-transitive graphs;
Projects have the potential to involve the use of computation through computer algebra packages such as GAP or Magma. They will also involve learning the research and publication process including the use of tools such as Math-SciNet to search the literature, LATEX to typeset mathematical papers, and arXiv for their distribution. We are looking for students with a mathematics major with some evidence of coursework in group theory or combinatorics.

More information about research in the centre can be found at: http://www.cmsc.uwa.edu.au/research

11. Asst/Prof Charles Price (www.chuckprice.info)

The following projects are available:

a) Surface area scaling in succulents

Metabolic theory and limited empirical data suggest that the allometry of surface area to mass in succulents has an exponent of $\frac{3}{4}$. This means that as cacti get bigger (larger mass), their surface area increases with an exponent of $\frac{3}{4}$. This is in contrast to what would be expected if cacti could be approximated by geometric shapes with a slope of $\frac{2}{3}$. An additional prediction is that the total metabolic rate of the cacti is proportional to surface area and thus should also scale as mass to the $\frac{3}{4}$ power. Using new 3D scanning equipment and gas exchange analysers, we will determine the mass and respiration (a proxy for metabolism) of a range of cacti of different size to determine if in fact these predicted scaling relationships occur.

b) Biomechanical vs. hydraulic investment in leaf veins:

Recent empirical work has demonstrated that as leaves increase in size, they invest more in network (vein) tissue relative to non-network (lamina) tissue. This is due to both increased biomechanical and hydraulic demands. However, it is unclear which of these (biomechanical or hydraulic) plays a greater role in increased network investment. To begin to address this, we will take vein cross sections at a number of levels throughout a small collection of leaves in an attempt to quantify the relative investment in these tissue types.

c) Leaf vein topology and hydrology:

Leaf networks display a dizzying array of hierarchical complexity. A distinguishing feature of many leaf networks is their reticulate nature (they are loopy), which stands in contrast to other types of biological distribution networks which are tree-like and strictly hierarchical. The reticulate nature of leaves has been linked to network redundancy, or the ability to maintain flow even when disturbed by things such as herbivory or embolism. Different leaves have different topologies that have been described using subjective classification criteria, with names such as pinnate, actinodromous, or brochidodromous. The consequences of these different branching topologies are unknown. Using cleared leaves and novel software routines, this project will explore how leaves of differing topology maintain flow relative to one another in the face of disturbance.

d) Surface area and volume scaling of mammalian scale models:

The scaling of metabolism to mass in animals has been shown to have an exponent of $\frac{3}{4}$ in contrast to the geometric expectation of $\frac{2}{3}$ (i.e. surface area is proportional to length$^2$, mass is proportional to length$^3$, hence, $\frac{2}{3}$). Hypotheses for the origin of this scaling relationship have focused on the geometry of vascular networks, and to date have largely ignored animal shape.
Using a new 3D scanner, we will create 3D representations of animal scale models in silico, and explore if animal geometry and topology change as a function of animal size.

e) Comparison of different leaf vein measurement approaches:

There have been two main semi-automated approaches used to identify the dimensions of veins in leaves. The first is based on identifying triangular regions that correspond to nodes in segmented leaf vein images. The second utilizes skeletonization to determine the leaf vein medial axis which is then used to make measurements. Both approaches have advantages and disadvantages. Using novel software routines we will compare results from these two approaches using cleared leaf images from locally growing taxa, and a suite of different statistical measures.

f) Vein dimensions in monocot leaves:

Vein dimensions in monocot leaves: Recent work has shown that the dimensions of leaf veins and the areoles they surround in dicotyledonous leaves are consistent with a honeycomb lattice with six-sided symmetry. Monocot leaf networks however, appear more like rectangular lattices. We will compare the scaling of leaf vein networks in monocot leaves with the null expectations emerging from a null rectangular lattice model.

g) Plant branching architecture:

Several recent models have suggested that plant branching architecture is consistent with a fractal model. However, this has little direct empirical support. Thus to determine if a fractal model is a reasonable approximation for plant branching networks, we will collect and analyse data on the geometry and topology of herbaceous and/or woody plant branching networks.

h) Leaf shape and vein network geometry and topology:

The relationship between leaf shape and vein network architecture is evident to anyone who has held leaves up to the light. However, there have been no systematic attempts to quantify how the descriptive statistics of leaf vein networks depend on leaf shape. We will select leaves of similar shape from different species and explore how leaf shape influences whole leaf vein geometry and topology.

i) Rigorous simulation of random media as focussing elements

Light scattering in biological tissue has traditionally been considered the arch enemy of biomedical optical imaging and microscopy. Recently, however, researchers in the field have begun to harness scattering to perform high resolution imaging. It has been shown that a random medium can be characterised and thus manipulated to perform imaging with a higher spatial resolution than is possible without such a medium. I am interested in rigorously modelling this phenomenon in order to gain further insight into this effect. I have thus run a large number of simulations of light scattering by using the finite difference time domain method, a rigorous electromagnetic scattering solver. I am thus looking for someone interested in analysing this data. This will entail simulating optimisation procedures used by researchers in the field to characterise the random media. Then, the properties of this technique, such as the spatial resolution which can be achieved, signal to noise ratio, light efficiency and the effect of using broadband light will be probed. This project is an open book full of rich results awaiting to be discovered.

You will learn some of the principles of numerical electromagnetic methods, rigorous optical modelling and optimisation techniques. Knowledge of a high level programming language such as Matlab is desirable, or the desire to learn it. This project is suited to student of physics, electrical engineering or applied mathematics.

Supervisor: Asst/Prof Peter Munro (Optical & Biomedical Engineering Laboratory)
j) Understanding the scale dependency of leaf vein measurements

Leaf vein density is an important parameter with ramifications for physiology, ecology and evolution of land plants. It is thus the subject of considerable attention from researchers, who use a variety of means to measure it. One way of measuring leaf vein density is to digitally image leaves, which have been stained to highlight veins, with a wide field microscope. These images are then subjected to a sequence of image processing steps before applying an algorithm which estimates leaf vein density. Recently, in research led by Asst/Prof Price, it was shown that existing methods for measuring leaf vein density are not robust. In particular, it was shown that the imaging parameters such as magnification, resolution and field of view effect the measurement of leaf vein density. We propose to further investigate this effect by developing a mathematical model of the entire measurement process in order to further probe this phenomenon.

This project is quantitative and so familiarity with a high level programming language such as Matlab is desirable. A background in image processing, mathematics of optics is also desirable. You will learn about mathematically modelling of microscopes, image processing and applied mathematics.

Contact: charles.price@uwa.edu.au/peter.munro@uwa.edu.au

12. Associate Professor Duncan A Wild, Chemistry

Photoelectron spectroscopy of gas phase anion-molecule complexes

This project will be undertaken in the research group of Dr Duncan Wild and involves spectroscopy of gas phase anion-molecule complexes. The rate and direction of chemical reactions are determined by the potential energy surface governing the interactions between the species. Using photoelectron spectroscopy of gas phase anion-molecule complexes allows us to probe the neutral potential energy surface. In this project, you will be involved with studies of fundamental species with Nitrogen and Sulfur containing molecules attached to an anion. These species have relevance for the chemistry occurring in our atmosphere, and that of distant celestial bodies. This project is flexible in that you can choose the systems to investigate! The idea behind the experiments is:

1) Create exotic gas phase anion-molecule clusters.
2) Mass select a specific cluster using TOF mass spectrometry
3) Record a photoelectron spectrum using laser radiation.

We have built up our own spectrometer which incorporates a mass spectrometer (time of flight) and a magnetic bottle photoelectron spectrometer, and you will be able to work on this apparatus alongside other students in the group. You can also be involved with quantum chemical calculations on the experimental targets.

Please look to our group website for more information, or Facebook page.  
http://laser.scb.uwa.edu.au  
https://www.facebook.com/UWALaserSpectroscopyGroup

Required skills: Good basis in Chemistry, Physics, Mathematics.
Computational and Theoretical Chemistry

During the past decade, computational chemistry has had an increasingly important impact on almost all branches of chemistry as a powerful approach for solving chemical problems at the molecular level. The increasing computational power provided by supercomputers and the emergence of highly accurate theoretical procedures make contemporary computational chemistry one of the most detailed “microscopes” currently available for examining the atomic and electronic details of molecular processes. In my lab we use supercomputers in conjunction with very accurate theoretical methods to elucidate the reaction paths, kinetics, and the mechanisms in salient organic, organometallic and enzymatic systems.

Projects:

a) Computational Antioxidant Design

Oxidative damage to DNA and proteins is a major cause of many chronic inflammatory diseases including conditions such as cancer, arthritis and cardiovascular disease. In recent work, we elucidated the molecular mechanism by which the potent endogenous antioxidant carnosine operates (Fig. 1). We showed that a unique structural relationship between three adjacent functional groups (imidazole, carboxylic acid and terminal amine) enables carnosine to work via a novel two-step mechanism. Initial chlorination occurs at the imidazole nitrogen (the kinetically favoured site), followed by an intramolecular Cl transfer in which the Cl is transferred to the terminal primary amino nitrogen (the thermodynamically favoured site) effectively trapping the chlorine. This bifunctional mechanism is illustrated schematically in Fig 2. Based on this discovery of carnosine’s two-step mechanism, we designed improved bifunctional antioxidants against HOCl-mediated oxidative damage. The bioinspired antioxidant trap the noxious chlorine atom at rates several orders of magnitude faster than carnosine. This work opens the way for further computational design of potent bifunctional antioxidants that selectively target strong HOX oxidising agents. The aim of this project is to provide an innovative basis for the development of new antioxidants to alleviate or circumvent the damage resulting from HOX-induced oxidative stress. The project will decipher the reaction mechanisms by which HOX oxidise biologically important purine bases (e.g. guanine, cytosine, thymine, uracil), and other biomolecules incorporating nitrogen-heterocycle functionalities (e.g. substituted imidazole, pyrazole, diazines). These biomolecules are ideal candidates to serve as “kinetic traps” in bifunctional antioxidants; e.g. carnosine uses an imidazole ring as the kinetically preferred site (Fig. 2). These heterocycles have multiple N–H sites that are prone to oxidation. The project will address questions such as (i) which sites are kinetically
favoured and which are thermodynamically favoured, (ii) what are the rate-determining steps, and (iii) can we control the outcome by changing the reaction conditions (e.g. temperature, solvent, etc.)?

b) Computational Chemistry in Outer Space

A recent study, based on data collected from NASA’s Kepler space telescope, shows that roughly 20% of the Sun-like stars in the Milky Way galaxy have an Earth-like planet orbiting around it in the so-called ‘goldilocks’ zone, i.e. at distances from the star that produce the right temperature for surface liquid water. According to this study there are as much as 40 billion such planets that could potentially support life in the Milky Way galaxy alone. This raises the fundamental question (which is also relevant to our Earth): which complex organic molecules can be synthesized in the interstellar medium, and can they be delivered to these planetary systems? (see Fig. 3). This project will elucidate the reaction mechanisms by which prototypical organic molecules are synthesized in space, using composite quantum chemical theories to determine the main mechanistic aspects underlying molecular formation in the gas phase under interstellar conditions. This will involve such issues as locating the (i) preferred chemical routes for the formation of prototypical molecules that have been observed in the interstellar medium (e.g. methanol, formaldehyde, and formamide), (ii) expected products of subsequent reactants (e.g. hydrogenation and oxidation processes), (iii) pathways by which the observed products may react to give more complex organic molecules (e.g. small PAHs and biologically-relevant molecules such as amino acids and carbohydrates), (iv) reaction pathways by which unstable complex species may decompose to give simple products, and (v) the effect of temperature on these processes.

**PREREQUISITES**

Students should have:

1) A strong background in organic and physical chemistry
2) Familiarity with UNIX/LINUX environment
3) Previous experience with quantum chemical software (e.g. Gaussian, Molpro, ORCA, GAMESS, Q-Chem, or any other quantum chemistry software) is an advantage
4) The ability to write scripts (e.g. in bash, tcsh, perl, or Fortran) is an advantage

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**Figure 3.** A schematic representation of the four phases in the life cycle of the interstellar medium (ISM): (a) molecules are injected to the ISM from stars, (b and c) material in the ISM circulates between diffuse phases and molecular clouds, and (d) molecular clouds become gravitationally unstable and form new stars and planetary systems. [Tielens, AGGM Rev Mod Phys 2013, 85, 1021]
a) Magnetisation dynamics in nanostructured magnetic films for microwave applications (experimental)

Magnonics [1,2] and spintronics [3] are two emerging fields of electronics which exploit electron spin rather than electron charge. Worldwide research in these fields is hoped to result in faster, more compact and more power efficient electronic devices for applications ranging from microwave signal processing to bio- and chemical sensing. The functionality of spintronic and magnonic devices is generally based on high frequency magnetic excitations such as magnetic waves, or "spin waves", which exist in a frequency range from 10MHz to 50 GHz and have sub-micrometre wave lengths.

Experimental opportunities in our group will involve the study of spin-waves and other high frequency magnetisation dynamics in various magnetic nanostructures. Experimental techniques available in our laboratory, such as ferromagnetic resonance and travelling spin wave spectroscopy will be utilised in this project. To take the measurements the student will utilise an extremely high-sensitivity microwave receiver we recently developed for studying these materials. The student will also have possibility to participate in characterisation of static magnetic properties of these materials using Superconducting Quantum Interferometer Device (SQUID) and Magneto-Optical Kerr Effect.


b) Magnetisation dynamics in magnetic multi-layers and superlattices (theoretical and computational)

Spintronics is an emerging field of electronics which exploit electron spin rather than electron charge. Many spintronic phenomena, such as Spin Transfer Torque [1] and Spin Hall Effect [2] are dynamic effects involving microwave oscillations (0.5-50GHz) and waves (called spin waves) in magnetic nanostructures and multilayers. Microwave signal processing is an area important for applications in mobile telephony, satellite communications and radiolocation. Microwave devices are still bulky and new physical approaches are urgently needed to decrease the sizes of microwave gear.

In parallel to microwave spintronic effects, the metallic magnetic multi-layers and nanostructures exhibit a number of very interesting effects related to microwave conductivity. One of them is “the perfect microwave shielding” [3]. In real-life experiment the effects of microwave conductivity combine with spintronic effects and make the observed dynamics complicated. Therefore it is very important to distinguish between the two classes of the physical effects.

The student will be involved in construction of an improved theoretical model for calculating the microwave response of metallic magnetic multilayers and superlattices with nanoscale thicknesses. This model will be used to identify the microwave conductivity effects in the experiments. It is anticipated that the theory which will follow from this work will allow designing a number of novel nanoscale devices for microwave signal processing in the future. If the student wishes to, he/she will also have a possibility to measure these effects experimentally and compare the obtained experimental results with the calculations he/she will carry out with the constructed theory.

UWA is internationally recognized as developing the world’s best microwave sapphire oscillators, which have found broad application in areas ranging from commercial products to laboratory tests of fundamental physics. Because frequency is the most sensitive experimental parameter that can be measured, it is crucial to continually develop and improve frequency standards, or “clocks”, which generate extremely stable and spectrally pure signals. In this way, exquisite measurement precision can be achieved in any area of science if an experiment can be designed to measure the effect in terms of a frequency shift. This is particularly important in physics because many theorists predict that violations of physics as we currently understand it may occur, with the magnitude of the effect being extremely weak. Research groups worldwide are engaged in tests of fundamental physics - for example, extremely precise tests of Einstein’s theories, the principles of Lorentz invariance, and measurements of whether fundamental “constants” like the speed of light or the fine structure constant may actually drift over time.

Our research group has a long history of success in this area, in particular with a modern Michelson-Morley type experiment that relies on a pair of extremely stable devices known as Cryogenic Sapphire Oscillators (CSOs). CSOs were invented and developed by our group over the past couple of decades, and are currently the worlds most stable oscillator, or equivalently the worlds “best clock”, for short integration times (less than 100 seconds). In addition, they are deployed in metrological laboratories worldwide, acting as flywheel oscillators that allow cold atom fountain clocks to achieve their ultimate performance at the quantum projection noise limit.

Recently, in collaboration with a French research group, we have developed a novel frequency standard similar to the CSO called an ‘Atomic Oscillator’. The device is a maser (microwave laser) which is based on electron spin resonance of paramagnetic iron ions in a large sapphire crystal. Results so far have been promising, with the stability of the maser approaching parts in $10^{15}$ in a free-running configuration. This project aims to improve the performance of the atomic oscillator technology, with the next generation having the potential to outperform the current world-leading CSOs by a factor of 10.

We will first attempt to improve the maser performance by building a stabilised loop oscillator. Currently, the maser is pumped in a free-running configuration using a microwave synthesizer at 31 GHz, corresponding to a spin transition for the iron ions in the crystal. To achieve maximum stability, we will build a loop oscillator locked to a whispering gallery mode coincident with the iron spin transition frequency, as well as introduce power stabilization. The potential improvements of these techniques are clear when we consider that a Cryogenic
Sapphire Oscillator operating in a free-running configuration can typically only achieve frequency stability of parts in $10^{13}$, two orders of magnitude worse than a free-running Atomic Oscillator. With the introduction of feedback loops and operating at the Schawlow-Townes thermal noise limit, which we have achieved previously in collaboration with our French collaborators, we calculate a potential measurement precision of 1 part in $10^{16}$ for the next generation of Atomic Oscillator, a value that is truly unsurpassed by any other system.

Whilst the system currently operates entirely at microwave frequencies, it has now been theoretically predicted that it is possible to excite maser oscillation by illuminating the sapphire with visible laser light at a particular wavelength (see Fig. 1). As well as developing the atomic oscillator to its full potential as a microwave frequency standard, work related to optical pumping of the maser will be undertaken as basic research to understand the potential of the new technique. We hope to demonstrate maser operation at 31 GHz for the first time using an optical pump laser, enabling optical to microwave coupling through spins in sapphire.

The success of this project will contribute a new type of ultra-stable oscillator to the clock ensemble at UWA, which is hosting the only southern hemisphere ground station for upcoming European Space Agency ‘Atomic Clock Ensemble in Space’ mission (launching 2016). Comparisons between the clock proposed in this project, and those soon to be launched aboard the International Space Station can be performed, which will allow its ultimate performance to be determined.

The student undertaking this project will develop skills in:
- Cryogenic techniques (from 7 mK to ~10 K using pulse tube cryocoolers and a dilution refrigerator)
- Vacuum techniques
- Microwave engineering
- Precision measurement
- Characterisation of noise and stability of clocks and oscillators
- Measurement of paramagnetic spins in crystals

Further reading:


b) Parametric cooling of bulk acoustic modes of quartz resonators using qubit-phonon non-linear coupling

Coupling of acoustic resonators to superconductive qubits on Josephson junctions is known to be a way towards preparation of acoustic phonons in ground or more exotic quantum states. However, due to high transition frequencies of contemporary qubits (~ few GHz) direct coupling with mechanical oscillations is hindered by a lack of high-Q mechanical resonators at these frequencies. In this project we aim to investigate the possibility to use intrinsic nonlinearity of qubit to render strong parametric coupling with relatively low-frequency (~100 MHz) piezoelectric quartz resonator and cool the latter down to its ground state.

Reaching oscillator's ground state is the first step towards observation of non-classical effects with mechanical objects that has wide application in quantum communication and quantum memory. The far reaching goals of the project include contriving novel schemes for preparation of robust non-classical mechanical quantum states for fundamental tests of quantum mechanics and various quantum and semiclassical gravity theories.

The student will work under joint theoretical (Dr. S. Danilishin) and experimental (W/Prof. M.Tobar, Dr. M.Goryachev) guidance to deliver experimentally feasible scheme that can be directly implemented on the experimental base of Frequency and Quantum Metrology group. Help with numerical modelling of quantum dynamics of qubit-phonon coupled quantum system by solving numerically stochastic master equation (SME) on Python, C, C++ and CUDA is expected from potential student. Theoretical knowledge of quantum mechanics is preferable.

**Supervisors:** Dr. S. Danilishin, Dr. M. Goryachev, W/Prof. M.Tobar

c) Utilising Spins in low-loss single crystal hosts as a quantum memory

In this work we will investigate spins in solids at low temperature that have not yet been investigated. Crystal hosts under consideration include sapphire, rutile, strontium titanate and diamond. First, the student will undertake spectroscopy with the use of our seven Tesla superconducting magnet, which operates using our cryogen free cooling systems down to below 4 K in one system and down to 10 mK in another system.

We have only just recently discovered that paramagnetic ions in sapphire at very low concentrations manifest a Kerr type non-linearity with only 100 ppb levels of concentration, with some recent high impact publication just published [1–3]. This project will look at ways of exploiting this non-linearity. We will aim to build novel devices like:
- Making a low noise parametric amplifier.
- Designing a quantum memory.
- Understanding if the non-linearity can mean a sapphire resonator may be used as a qubit.

This work is important for the next generation of qubit and quantum measurement at microwave frequencies. The UWA technology is unique and this will be the first attempt to use this technology for quantum measurement.

**Supervisors:** From the ARC Centre of Excellence in Engineered Quantum Systems

For more information contact: Michael Tobar email: michael.tobar@uwa.edu.au
16. Assoc/Prof Danail Obreschkow & Assoc/Prof Chris Power

**Cosmic Structure Formation & Exotic Dark Matter**

This project tackles a crucial problem in computational cosmology, namely to provide robust reliable predictions for the properties of cosmic structure in exotic dark matter models.

The standard cosmological model assumes that most (~85%) of the matter in the Universe is in the form of exotic "cold" dark matter (CDM), quite unlike the ordinary matter (i.e. protons, neutrons and electrons) of everyday experience, and the consequences of this assumption for cosmic structure formation have been studied exhaustively using supercomputer simulations over the last three decades. The CDM model has had mixed success, providing an excellent description of the Universe on large scales, but struggling on small scales. However, our understanding of cosmic structure formation in alternatives to the CDM model is limited by the robustness and reliability of supercomputer simulations, whose results appear to be blighted by numerical artefacts.

The objective of this project is to explore and assess systematically novel approaches developed by the supervisors for setting up dark matter simulations to overcome this problem of numerical artefacts, and to use these simulations to make more reliable and robust predictions for the structure of the dark matter cosmic web and the abundance of dark matter haloes than has been possible previously. The student will develop expertise in cosmological simulations and supercomputing, and they will have unique opportunities to collaborate with world class scientists at UWA and collaborators in Switzerland and in the UK. The project is likely to result in publications, as in the case with our previous exchange students from USTC.

17. A/Professor Eric Howell

**The Rate and Luminosity Function of Gamma-ray Bursts**

The study of gamma rays is a rapidly emerging area, advanced in recent years by observations from the Swift Gamma-Ray Burst Satellite. A key objective of the Swift mission was to obtain an accurate determination of the GRB luminosity function (LF). Although Swift has obtained over 200 redshifts, for long duration gamma-ray bursts (LGRBs), the data is still insufficient to determine the LF accurately; additionally, the redshift distribution has been plagued by various selection effects which must be fully understood to gain an accurate representation of the data. Many studies have examined the LF using the more abundant higher energy data via the brightness distribution in peak flux (e.g. log $N$-log $P$). However, a mixing of the LF and rate evolution and other factors (e.g. cosmic metallicity dependence or an evolving LF) can introduce a degeneracy that must be confronted. Using well-constructed data sets (see for example the sample at [http://www.ejhowell.com/data/](http://www.ejhowell.com/data/)) this project examines different methods that can untangle the various contributions of a brightness distribution (e.g. see for example Howell & Coward 2012 [arXiv:1206.4151](http://arxiv.org/abs/1206.4151)). It also addresses methods to place constraints on the smaller sample of short duration bursts (SGRBs). This work is relevant to a number of topical questions: how often do GRBs occur; does the LF evolve with...
cosmic time; if the LF evolves, what effect will this have on the high energy correlations such as those proposed by Amarti or Yonetoku; how strong is the effect of cosmic metallicity dependence.

18. Professor David Coward, Physics

a) Gamma ray bursts as probes to the distant Universe.

Gamma ray bursts are the brightest explosions in the Universe and there is growing evidence that there are several types of bursts that relate to their progenitors. There is still many outstanding questions that remain unsolved. The project will investigate various observed correlations between the optical and high energy emissions of gamma ray bursts. This could lead to confirmation of models that predict some GRBs are related to the merger of massive stars as opposed to the collapse of single stars.

Experience: background in astrophysics and computational modelling and a keen interest to explore new ideas.

b) Searching for hazardous Near Earth Asteroids and other exotic transients using the UWA Zadko Telescope

The UWA Zadko Telescope is a 1-m fully robotic (automated) optical telescope. In 2013, more than a dozen new asteroids were discovered using the Zadko Telescope. The student will learn to schedule, manage and analyse image data, focusing on the search for hazardous Near Earth Asteroids. Because the Zadko Telescope is directly linked to NASA satellites, the student will also have the opportunity to work on analyzing gamma ray burst optical afterglows using nearly real-time data from the Zadko Telescope.

Experience: A keen interest to learn new skills in robotic astronomy and image analysis, with the aim of making unique discoveries.

19. A/Prof. Robert McLaughlin

Image processing techniques to detect blood flow in optical coherence tomography images

Optical coherence tomography (OCT) is a rapidly developing imaging technique capable of acquiring extremely high resolution images of blood vessels. This is important in many diseases, where the size and density of the blood vessels can indicate how well tissue is repairing. A recent paper by Lee [1] described a technique to automatically detect blood flow in OCT scans. In this project, you will implement the computer algorithm from this paper in Matlab, and use it to detect blood vessels in OCT scans from human patients.

Prerequisite: The student must have extensive experience in the Matlab programming language. They should have a major in Computer Science or Mathematics.

The following two projects are available:

**a) Nano-structural Characteristics of Soot from Compression Ignition Engines Fuelled with Biodiesel**

Soot is a key component of the atmospheric aerosols, with fossil fuel and biomass combustion being the major sources. Soot particles emitted from compression ignition (CI) engines normally exhibit branched and irregular chain-like structures, varying widely in size. As a promising alternative fuel, biodiesel is attracting the researchers’ major interests for its direct application in diesel engines. It has shown that neat/blended biodiesel combustion generates less carbon monoxide (CO), unburned hydrocarbons (UHC) and soot emissions. However, the nanostructure of soot particles emitted from biodiesel combustion in CI engines is rarely reported in the literature and therefore is the focus of the present research. Studies on soot nanostructures can provide valuable insights into the understanding of soot formation and oxidation, and serve as evidences for assessing their toxicity, chemical and deposition characteristics. Another aspect of this proposed study is to investigate the effect of a ferrous picrate combustion catalyst (FPC), which has shown to be effective in improving fuel combustion efficiency and reducing soot emissions from CI engines, on the nano-structural characteristics of soot from the combustion of biodiesel fuels.

The experiments will be conducted on a laboratory diesel engine under various engine load and speed conditions and fuelled with biodiesel/diesel mixtures in varying blending ratios, with or without the FPC treatment. At each condition, soot from the combustion of the fuel mixtures will be collected by a thermophoretic sampling device and subject to a set of analyses, including transmission electron microscopy (TEM), scanning electron microscopy (SEM), X-ray energy dispersive spectroscopy (EDS) and electron energy loss spectroscopy (EELS), for their particle sizes and distributions, elemental and morphological properties.

We are looking for a student with a major in chemical/mechanical engineering or related disciplines, basic data analysis skills and a working knowledge of electron microscopy. The candidate with some knowledge or experience in CI engine combustion is preferred.

**b) Flammability limits and flame propagation speeds of combustible gas mixtures: measurements and modeling**

Flammability limit and flame propagation speed are important parameters of a combustible gas mixture. Understanding of flammability limit and flame propagation speed can prevent unwanted fires and gas explosions and the knowledge of these two parameters is desirable for the design of a combustor. Over the last few decades, there has been increasing interests in burning syngas, a gas mixture from gasification and pyrolysis of coal and biomass, in many practical applications for heat and power generation such as internal combustion engines and gas turbines. Therefore, it is necessary and important to know the flammability limits and flame propagation speeds and other combustion behaviours of syngas.

The objective of this project is to study the flammability limits and flame propagation speeds of various gas mixtures, with the composition representing real syngas. Both experimental and kinetic modelling techniques will be used to achieve this objective. The experiments will be carried out using a flat flame burner at the Centre for Energy. The flammability limits and flame propagation speeds will be measured as a function of the composition of gas mixtures, equivalence ratio, and gas inlet temperature. Kinetic modelling will be performed using a commercial software Chemkin-Pro to simulate the corresponding experimental work. The model results will be validated by the experimental results, providing an insight into the reaction mechanisms of the syngas studied.
We are looking for a student with a major in chemical engineering or mechanical engineering or related discipline. The candidate should have a keen interest in reaction engineering, heat and mass transfer, transport phenomena and fluid dynamics as well as combustion science and technology and in using Chemkin-Pro.

21. Dr Pilar Blancafort

**Targeted silencing of the SOX2 oncogene using engineering zinc finger proteins fused to DNMT3A and UHRF1**

A current obstacle in the treatment of aggressive cancers is the inability to effectively target and repress transcription factors (TFs), which are responsible for the maintenance of the tumorigenic phenotype in a subpopulation of cells within the tumor, named cancer stem cells. Notably, triple-negative breast cancers (TNBC) and serious ovarian cancers are refractory to current treatment regimens such as anti-oestrogens and chemotherapy, due to their lack of small molecule binding pockets (Stolzenberg et al., 2012). It has been demonstrated that many TFs are over-expressed in poorly differentiated TNBCs and ovarian cancer cells (Blancafort et al., 2011). Therefore there is a need to develop novel and more effective strategies to target the TFs in these poorly differentiated and treatment-resistant carcinomas.

Cancer cells not only exhibit changes in DNA sequence relative to normal tissue. In the last few years it has been demonstrated that alterations in the epigenetic code highly contribute and predispose the genome to cancer initiation and progression (Blancafort et al., 2011). Epigenetics refers to changes in the genome, which do not involve alterations in the DNA sequence per se. Epigenetic modifications are chemical modifications occurring at level of DNA and histone post-transcriptional modifications, for example DNA methylation, histone methylation and histone acetylation. These chemical modifications act as marks that modify the packaging of the DNA and proteins in chromatin, whereby changing gene expression (Bronner et al., 2010). For example, DNA methylation and Histone 3 (H3) methylation at lysine 9 (H3K9me) act to promote chromatin condensation, referred as heterochromatin (inactive or silenced chromatin). One important aspect of the epigenetic modifications, in particular DNA methylation, is that they are transferred over cell divisions via the endogenous enzymes that recognise (read) and transfer (write) these marks during cell replication.

Epigenetic aberrations in cancer include both abnormal silencing of tumour suppressor genes and reactivation of silenced oncogenes. The oncogene SOX2 encodes a TF belonging to the high-mobility group (HMG) family. SOX2 expression is critical for the maintenance of self-renewal in stem cells and progenitor cells. While SOX2 is highly transcribed in self-renewal conditions, its promoter undergoes epigenetic silencing during the onset of differentiation of stem cells (Stolzenberg et al., 2012). A study by Rodriguez-Pinilla et al. (2007) showed that SOX2 was found over-expressed in 28% of all invasive breast carcinomas and in 43% of basal-like TNBCs, suggesting the involvement of SOX2 in tumour initiation and progression and in the maintenance of a poorly differentiated state.

Previously our laboratory has generated sequence-specific, artificial Zinc Finger (ZF) proteins fused with DNA methyltransferase 3a (DNMT3a), to epigenetically suppress the expression of SOX2 in breast cancer cells. Importantly, this suppressive effect persisted for 48 days, even when the expression of the artificial methyltransferase was not longer detected in the cells (Rivenbark et al., 2012). Similarly, Stolzenburg et al. (2012) showed that targeted repression of SOX2 using a 6ZF attached to the Kruppel Associated Box (KRAB) repressor domain achieved a 95% repression of the oncogene in two breast cancer cell lines.

The general principle of artificial, DNA-sequence-specific targeting systems is the fusion of (a part of) an epigenetic enzyme to a DNA binding domain (DBD) to enforce the presence of this effector
domain on a particular DNA sequence (de Groote et al., 2012, Sera, 2009). Our objective is to develop a specific form of cancer treatment by engineering novel DNA binding proteins able to target specific, unique sequences of the cancer genome, by refining the existing 6ZF-DNMT3a protein construct to include the E3 ubiquitin ligase UHRF1 (Ubiquitin-like, containing PHD and RING finger domains 1), a unique chromatin effector protein that integrates both recognition of histone post-translational modifications (PTMs) and DNA methylation (Rothbart et al., 2013). UHRF1 has four unique structural domains that allow this concurrent recognition of histone modifications and methylated DNA: firstly the SET and RING-associated (SRA) domain which recognises hemimethylated DNA, and through its Ubiquitin-like (Ubl) domain recruits DNMT1 to facilitate faithful maintenance of DNA methylation (Bostick et al., 2007, Bronner et al., 2010). Rothbart et al. (2013) demonstrated that DNA methylation maintenance function by the UHRF1 is linked to its ability to engage H3K9 through its tandem tudor domain (TTD). The adjacent plant homeodomain (PHD) acts simultaneously by engaging histone deacetylases (HDACs), which contribute to histone post-translational modifications. This leads to silencing of genes (in particular the SOX2 oncogene) and normalisation of the epigenome.

Our approach consists of using this construct to downregulate SOX2, which is overexpressed in cancer stem cells but not normal cells, by restoring DNA methylation and normal epigenetic silencing of tumour cells.

**Hypotheses**

1. Our genetically-engineered construct with UHRF1 will be more efficient at silencing of SOX2 than existing constructs without UHRF1 due to its ability to recruit DNMT1, which maintains de novo methylation of SOX2, and other histone modifiers through its four domains
2. Epigenetic silencing will lead to to transcriptional silencing of the SOX2 oncogene and normalisation of the epigenome

**Aims and Methods**

1. To validate the expression of the full length of the UHRF1-6ZF-DNMT3a construct upon transfection of MDA-MB-453s breast cancer cells
   a. Carry out a Western Blot using anti-HA antibody and Immunofluorescence and compare the lengths of the construct versus controls
2. To investigate the capability of the construct to down-regulate SOX2 expression at the mRNA and protein level
   a. Measure SOX2 with qRT-PCR (mRNA)
   b. Measure SOX2 with Western Blot (protein)
3. Investigate DNA methylation and histone post-transcriptional modifications for epigenetic marks
   a. Chromatin immunoprecipitation (ChIP) assay
   b. DNA methylation assay (MassARRAY)

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Photothermal Optical Coherence Tomography

Optical Coherence Tomography (OCT) is a biomedical imaging technology which can detect tissue microstructure with high resolution. Conventional OCT systems cannot not provide information about the chemical composition of the tissue. However, it is possible to add this capability by injecting chemical substances called “markers” which will selectively bind to specific molecular targets in the biological tissue (e.g., it can bind to cancer cells in a tumor). These markers will absorb light from a pulsed laser source, thereby causing a periodic expansion and contraction of the tissue due to the heat generated by the absorbed light. This expansion and contraction can be detected with OCT.
OBEL has extensive know-how in OCT and several OCT systems are available in the lab. The intern student will build a proof-of-concept optical experimental setup (optics and electronics) to add photothermal excitation to an existing OCT system to reproduce results published in the literature. This will serve as a basis for further development of a photothermal OCT system at OBEL.

Required skills:
- Solid understanding of optics.
- Interested in hands-on experimental work.
- Some knowledge and experience in electronics will be useful.
- MATLAB programming experience required.

Supervisor: Dr. Dirk Lorenser, Optical + Biomedical Engineering Laboratory
dirk.lorenser@uwa.edu.au

Background reading: http://www.opticsinfobase.org/boe/abstract.cfm?uri=boe-3-11-2881

23. Associate Professor Ju Li

OMIT

Advanced interferometric gravitational wave detectors, e.g., the Advanced LIGO [1], are expected to be limited in sensitivity by the noise of quantum origin in most part of detection band. Further enhancement of these quantum-limited detectors requires manipulation of the optical field and the readout scheme at a quantum level. One approach suggested by Kimble et al. [2] is to inject frequency-dependent squeezed light into the interferometer, using a cascade of optical cavities to rotate the squeezing angle in a frequency-dependent way, such that the quantum noise is reduced over the entire detection band. The filter cavity bandwidth needs to be of the order of 100Hz. The scheme proposed is using relatively low-finesse cavities of kilometer scale, comparable to the size of the interferometer, an ambitious and costly plan.

We proposed to use tabletop scale cavity as a filter cavity but to narrow the filter cavity bandwidth via optomechanical induced transparency (OMIT). We have classically demonstrated feasibility of the scheme. The student working on this project will work together with a PhD student to optimize the scheme and to investigate other quantum measurement scheme using OMIT effects, such while light cavities.


24. Professor Linqing Weng

We are interested in students who are interested in detecting gravitational waves using ground-based interferometric detectors or using pulsar timing. The background requirements are:
- Physics/Astronomy background with interest in signal processing, computation, and source modelling
- Engineering/Computer/Mathematics background with interest in applications to gravitational wave detection problems
- We also prefer students who intend to pursue advanced degrees in physics or astronomy.

Three possible projects:
a) Use Pulsar Timing Array data to detect gravitational waves from supermassive black hole binaries. [http://www.ipta4gw.org/](http://www.ipta4gw.org/)

A passing gravitational wave will affect the local space-time metric on the travel path of a radio pulse from a fast spinning neutron star and can lead to observable fluctuations in its arrival time at Earth. There is an international effort in using pulsar timing arrays (PTAs) to detect gravitational waves. A direct detection of nanoHertz gravitational waves using PTAs is possible within this decades. The Parkes Pulsar Timing Array (PPTA) in Australia observes 20 millisecond pulsars at 2-3 weeks interval with regular monitoring commenced early 2005. PPTA offers the most regularly monitored millisecond pulsars among all efforts.

The student will have the opportunity to work with experts from the PPTA project and use data from the Parkes telescope to search for gravitational waves from binaries of supermassive black holes. The student can pick up a small project in the design of directional search methods for anisotropic gravitational wave background, optimal detections of individual gravitational wave sources, signal-based detection verification, parameter estimation including localization of detected individual sources, study of gravitational wave sources, or more hands-on projects on producing scientific output from pulsar data.


Several advanced ground-based interferometric gravitational-wave detectors are expected to be operational around 2015. Direct detections of gravitational waves from compact binaries of neutron stars and black holes are expected within this decade. An real-time search pipeline that uses newly developed time-domain search technology has been developed in our group in collaboration with Caltech, Perimeter institute, CITA and AEI. The aim is to detect gravitational waves in real-time in the advanced detector era and pass event triggers to conventional telescopes for prompt follow up observations. The pipeline has passed initial tests on existing detector data and on simulated online data from engineering runs for advanced detectors.

The student will have the opportunity to contribute to the on-going effort to further improve this search pipeline and use it to generate scientific outputs. This includes using Matlab or Mathematica to explore the potential of the new method to the extended parameter space of expected gravitational wave signals. The student will have access to real detector data from the past Science runs and simulated online data for future detectors for the testing. The student can work on the development of new search methods that optimally combine data from all gravitational wave detector, develop fast method to determine the sky direction of gravitational wave sources. The student can also study the astrophysical aspect of a joint gravitational wave-electromagnetic observation for advanced detectors and for a larger detector network.


We use the powerful cost-effective GPUs [http://www.nvidia.com/object/what-is-gpu-computing.html](http://www.nvidia.com/object/what-is-gpu-computing.html) together with CPUs to accelerate the gravitational wave signal processing. A GPU >accelerated search engine has been developed and a CPU-GPU hybrid pipeline has been developed for the real-time low-latency search mentioned above. We also look into the GPU application in industry, e.g., for resource exploration.

The student will have the opportunity to use the 96-node GPU cluster from iVEC/Pawsey Fornax cluster located at the UWA. This project requires students to have basic computational skills, e.g., C programming. Knowledge of GPU/CUDA programming will help.
Quantum information and computation is a rapidly evolving interdisciplinary field, which has attracted researchers from physics, computer science, mathematics, chemistry, and electronic engineering. Instead of brute-force miniaturization of basic electronic components, quantum computation utilizes entirely new design architecture and promises to solve problems that are intractable on conventional computers. Quantum information offers the prospect of harnessing nature at a much deeper level than ever before, as well as a wealth of new possibilities for communication and data processing.

Potential Projects:

**a) Quantum Walk Applications**

Quantum random walks display remarkably different properties from their classical counterparts, most notably their fast spreading characteristics and interference. For example, they were proven to provide an exponential algorithmic speedup for traversing a randomized glued-tree graph. However, despite such potentially superior efficiency in quantum random walks, they have yet to be applied to problems of significant practical importance. This project aims to develop useful quantum algorithms utilizing quantum interactions, interference and entanglement. Potential applications include relational quantum search, network characterization, graph isomorphism, and protein folding. Analytical and numerical methods will be developed to study the characteristics of the associated quantum walks and its computational complexity.

**b) Physical Implementation of Quantum Walks**

This project addresses key issues in the actual physical implementation of quantum walks in the laboratory. In particular, we need a quantum system that (1) exhibits discretized and addressable states representing the nodes and edges of graphs, (2) allows selective mixing of states to implement the coin superposition operator, (3) allows controlled quantum evolution to implement the conditional shift operator, and (4) permits accurate measurement of its quantum states. There have been several proposals using a variety of solid state as well as optical schemes. A detailed investigation will be carried out to examine the merits and shortcomings of these proposals.

**c) Quantum Simulation With Qubits**

Richard Feynman was among the first to note that simulating quantum dynamics using a classical computer was intrinsically hard due to the exponentially increasing Hilbert space occupied by a linearly increasing number of particles in the system. However, Feynman suggested that it was possible to construct a “quantum simulator”, which could be programmed to simulate the behaviour of other quantum systems of interest. For instance, a fairly complicated molecule may be modelled accurately by a quantum simulator with a small number of well-controlled qubits. To build such a quantum simulator would be a tremendous
step forward towards the eventual goal of achieving a general universal quantum computer. The aim of this project is to develop a theoretical model, which can be used to study the electronic structure of molecular systems by controlling the properties of quantum dot or photonic systems.

d) **Entanglement dynamics and chaos**

It is commonly accepted that there is no such thing as chaos in quantum systems. The Schrodiger’s equation is linear and the quantum evolution operator is unitary, which implies that small changes in the system’s initial conditions would not be magnified as the system evolves in time. In this sense, the sensitive dependence on initial conditions that defines classical chaos does not exist in quantum mechanics and thus quantum dynamics is strictly non-chaotic. What is interesting is the dynamics of quantum corrections between various parts of the system, which interact in a nonlinear fashion. In this project, we will examine the entanglement dynamics generated by interacting two-particle quantum walks on certain graphs, and carry out spectral analysis of the time-evolution of particle probability distributions, as well as the entanglement between particle pairs during their quantum walking on degree-regular and degree-irregular graphs.

e) **Quantum Compiler**

Quantum computing exploits the nature of the quantum world in a way that promises to solve problems that are intractable using conventional computers. At the heart of a quantum computer lies a set of qubits whose states are manipulated by a series of elementary quantum logic gates, namely a quantum circuit, to provide the ultimate computational results. In our earlier work, we have developed a general quantum computation compiler, which maps any given quantum algorithm to a quantum circuit consisting a sequential set of elementary quantum logic gates based on recursive cosine–sine decomposition. However, the resulting quantum circuits are often complex and contain large number of elementary quantum gates. This project aims to develop an optimization procedure to reduce the number of quantum gates as much as possible. One way is to search for an efficient transformation on the original unitary operation, which leads to a better quantum circuit overall. Another approach may involve finding the shortest path between two points in a certain curved geometry.

Email [jingbo.wang@uwa.edu.au](mailto:jingbo.wang@uwa.edu.au) for more information.

26. **Swaminathan Iyer K. L - BioNano Group**

The following projects are available:

a) **Magnetically guided migration of stem cells in-vivo**

*With Prof. Swaminatha-Iyer, Prof. Fiona Wood, Prof. Tim St. Pierre, Dr. Rob Woodward and Dr. Mark Fear*

Despite recent therapeutic advances, the mortality and morbidity from major burns remains high. Consequently, there is a pressing need to develop economical, efficient and widely-available therapeutic approaches to enhance the rate of wound re-epithelialization and restoration of the protective epithelial barrier. Skin, the largest organ of the human body, provides an essential protective barrier and serves several homeostatic/sensory functions vital to health and its functional recovery post burn injury remains the ultimate goal of wound healing research. The
ultimate goal of the treatment of acute burns and wounds is to restore the damaged skin both structurally and functionally to its original state. Recent research advances have shown the great potential of stem cells in improving the rate and quality of wound healing and regenerating the skin and its appendages. Using magnetically activated mesenchymal stem cells (MSCs), the project will explore the possibility of magnetic field guided migration of the cells to the injury sites. We will monitor migratory patterns of the cells in animals following administration in the presence and absence of a magnetic field, developing critical knowledge to advance stem cell based therapy in tissue engineering.

b) Designing polymeric nanoparticles and evaluating its transport across the Blood Brain Barrier for treating Neurotrauma

With Prof. Swaminatha-Iyer, Dr. Nicole Smith and Prof. Sarah Dunlop

Neurotrauma, such as traumatic brain or spinal cord injury, encompasses both acute damage induced by the primary injury and chronic progressive secondary degeneration of intact, but highly vulnerable, tissue, results in a drastic change in the cellular signalling pathways. Reactive oxygen and nitrogen species (ROS and RNS) are implicated to play a vital role in this, as their production is reported to exceed a cell's antioxidant capacity following injury. Drug based intervention currently is limited following trauma. The central nervous system, one of the most delicate microenvironments of the body, is protected by the blood-brain barrier (BBB) regulating its homeostasis. BBB is a highly complex structure that tightly regulates the movement of ions of a limited number of small molecules and of an even more restricted number of macromolecules from the blood to the brain, protecting it from injuries and diseases. However, the BBB also significantly precludes the delivery of drugs to the brain, thus, preventing the therapy of a number of neurological disorders. As a consequence, several strategies are currently being sought after to enhance the delivery of drugs across the BBB. Using partial optic nerve injury model, we will evaluate polymeric formulations to deliver drugs across the BBB over time.

c) Developing a nanoscale therapy to alleviate oxidative stress in placental-related diseases of pregnancy

With Prof. Swaminatha-Iyer, Prof. Jeff Keelan and Prof. Brendan Waddell.

Pregnancy is a state of oxidative stress arising from increased placental mitochondrial activity and production of reactive oxygen species (ROS), mainly superoxide anion. The placenta also produces other ROS including nitric oxide, carbon monoxide, and peroxynitrite which have pronounced effects on placental function including trophoblast proliferation and differentiation and vascular reactivity. Excessive production of ROS may occur at certain windows in placental development and in pathologic pregnancies, overpowering antioxidant defences with deleterious outcome. For example: miscarriage and pre-eclampsia are the most common disorders of human pregnancy. There is mounting evidence that oxidative stress or an imbalance in the oxidant/antioxidant activity in utero–placental tissues plays a pivotal role in the development of placental-related diseases. This project explores the application of magnetic nanoparticles as antioxidant delivery agents in placenta via a systematic approach.

d) Manipulating the shape of iron oxide nanoparticles as high performance magnetic resonance imaging contrast agents

With Prof. Swaminatha-Iyer, Prof. Tim St. Pierre, Dr. Mike House, Dr. Rob Woodward and Prof. Martin Saunders.

Spherical superparamagnetic iron oxide nanoparticles have been developed as T2-negative contrast agents for magnetic resonance imaging in clinical use because of their biocompatibility and ease of synthesis; however, they exhibit relatively low transverse relaxivity. Till date most of the literature has looked into size dependent effect of iron oxide nanoparticles in MRI contrast.
In this project we will explore the ability to manipulate the shape of iron oxide nanoparticles and its effect as contrast agents for magnetic resonance imaging. The project will involve High-Res Transmission Electron Microscopy, Magnetic Resonance Relaxometry and in-vitro analysis as contrast agents in PC12 cells.

27. W/Prof. Eric May, Assoc. Prof. Paul Stanwix

Group: Fluid Science & Resources Group, UWA Centre for Energy
Supervisor: Paul Stanwix (paul.stanwix@uwa.edu.au)
Web: www.fsr.ecm.uwa.edu.au

Raman Studies of Molecular Exchange in Hydrates for Clean Energy Production

The Fluid Science and Resources group at UWA conducts applied research aimed at advancing knowledge, maximising the value of resources produced, and minimising the environmental impact of their production. By investigating the underlying physical and thermodynamic phenomena we aim to develop a deeper scientific understanding of the complex fluids and solids that either comprise the natural resource or are used by engineers for extraction and processing.

One area of our research is natural gas hydrates. Natural gas hydrate is an ice-like substance in which gas, typically methane, is trapped inside a cage of water molecules. There are vast reserves of naturally occurring hydrate; it is estimated that they contain more hydrocarbon resource than all other conventional reserves. We are interested in studying the dynamics of how the trapped gas (methane) molecule can be driven to exchange with another molecule, such as carbon dioxide. This process would simultaneously release methane from the hydrate and sequester carbon dioxide in its place with the potential for clean energy production.

This project will use Raman Spectroscopy to study molecular exchange in hydrates at the microscopic level, with particular emphasis on identifying the mechanism by which the exchange occurs and how the efficiency of the exchange can be enhanced. We have recently acquired a high-performance Renishaw Raman Microscope that will be used in this work. The student will work with research staff in the group to build a library of gas hydrate Raman spectra and develop analytical software tools for processing and interpretation of data. Experience in Matlab or a similar programming environment is required. Familiarity with optical techniques will be useful.