To standardise grades, the examiners will refer to these criteria:

- 0 – 64 Fail. Unacceptable effort.
- 65 – 69 Hons III. Minimum acceptable to pass Honours.
- 70 – 74 Hons II.2. Capable of proceeding to MSc in some circumstances, but further postgraduate study would depend on an assessment at the end of the 1st year of MSc.
- 75 – 79 Hons II.1. Certainly capable of MSc; probably PhD.
- 80 – 90 Hons I. High standard of work and undoubted research capability. Evidence of independent thought and dedication abd is certainly acceptable directly into a PhD program.
- 91 – 100 Hons I and possible University Medal. An outstanding student showing exceptional achievement. Some conditions apply regarding eligibility for an award of a Medal.

3. Projects available in 2007

A short description of the work carried out by the different Research Groups is now given, followed by a listing of project titles, supervisor contact details and a paragraph desribing each of the projects. The titles represent only some of the opportunities available for research projects and you are welcome to explore other possibilities in your field of interest with potential supervisors in the School of Physics.

It is very important to choose a project and supervisor to suit your interests and skills. You are strongly encouraged to have discussions with several possible supervisors before making a decision. Speaking to current Honours and postgraduate students will also give you valuable feedback. The Web of Science, accessible from the Library website, will give you information on the research activity of the School's academics. You should also read the Research pages on the School's website (http://www.physics.usyd.edu.au/research.html) for more information on the different areas that are currently being researched.

Students should decide upon projects as early as possible — well before the start of their first semester of project work. You should aim to start 3 weeks *before* the start of lectures. This will enable you to get your project under way before lectures and assignments compete for your time.

Students should make certain that their proposed supervisor will not be absent for protracted periods during semester, unless an associate supervisor is also involved. These issues will need to be formally settled when you submit your Research Plan, two weeks after the start of your first Semester as an Honours student.

Honours students are expected to continue working in their Research Groups during the normal undergraduate vacation periods, except for the designated rest period for students commencing in the July Semester (see Important Dates section).

Overview of Research Areas

APPLIED & PLASMA PHYSICS:

(1) Biomaterials and Materials Processing with Plasmas

Name	Room	Phone	email
Prof Marcela Bilek	407	9351 6079	m.bilek@physics.usyd.edu.au
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Dr Dixon Kwok	367	9351 5972	d.kwok@physics.usyd.edu.au
Dr Sunnie Lim		9351 3311	shnlim@physics.usyd.edu.au
Dr Nigel Marks	357	9351 8167	n.marks@physics.usyd.edu.au
Prof David McKenzie	441	9351 5986	mckenzie@physics.usyd.edu.au
Dr Richard Morrow		9351 5984	r.morrow@physics.usyd.edu.au
Dr Kostya Ostrikov	569	9351 7688	K.Ostrikov@physics.usyd.edu.au
Dr Richard Tarrant	366	9351 5970	r.tarrant@physics.usyd.edu.au
Dr Kostya Ostrikov	569	9351 7688	K.Ostrikov@physics.usyd.edu.au
Dr Yongbai Yin	438	9351 4756	yyin@physics.usyd.edu.au

Plasmas are being developed for specific tasks in the processing of materials. Plasmas offer a source of ions and electrons whose flux and energy can be tailored by applying voltages to the workpieces. We are applying this technique to produce specific modifications of surfaces with applications in medicine and engineering. We have developed and patented a plasma technology utilising high energy ions for activating polymer surfaces to attach proteins and retain their activity.The attachment of bioactive proteins to surfaces underpins the development of biosensors and diagnostic arrays for detecting disease. There are a number of student projects available, all of which will allow the student to learn about the physics governing the response of protein molecules to surfaces and to become familiar with one or more analysis methods.

(2) Centre for Quantum Computer Technology

Name	Room	Phone	email
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Dr Nigel Marks	357	9351 8167	n.marks@physics.usyd.edu.au
Dr Oliver Warschkow	433A	9036 9085	O.Warschkow@physics.usyd.edu.au

The Centre for Quantum Computer Technology is an Australian multi-university collaboration undertaking research on the fundamental physics and technology of building, at the atomic level, a solid state quantum computer in silicon together with other high potential implementations. The objective is underpinned by a vigorous semiconductor research program that includes a sophisticated quantum measurement capability at ultra-low temperatures. The School of Physics at the University of Sydney is a Node of the Centre providing support for the experimental programs through atomistic modelling.

Established in January 2000 through funds from the Australian Research Council and participating institutions, the Centre has nodes at the following institutions, in addition to the University of Sydney; University of New South Wales, University of Queensland, University of Melbourne, UNSW@ADFA, Department of Defence, Griffith University and Macquarie University. The nodes maintain an important collaboration on this project with Los Alamos National Laboratory in the United States. The Centre encompasses major research infrastructure at each of the eight nodes, including an extensive semiconductor nanofabrication facility, crystal growth, ion implantation, surface analysis, laser physics, high magnetic fields/low temperatures, and has substantial theoretical support including advanced atomistic modelling.

(3) Complex Plasmas

Name	Room	Phone	email
A/Prof Brian James	214	9351 2537	james@physics.usyd.edu.au
Dr Kostya (Ken) Ostrikov	569	9351 7688	K.Ostrikov@physics.usyd.edu.au
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Dr Sergey Vladimirov	458	9351 5770	S.Vladimirov@physics.usyd.edu.au

The complex plasma, so called in analogy with complex fluids, consists of a suspension of highly charged particles in background plasma of ions and electrons and confined by external electric fields. Complex plasmas are similar to aqueous colloidal suspensions but have damping rates and volume fractions which are smaller by a factor of up to 10^5. The ambient plasma plays several roles: it sustains a negative charge on the particles, it provides a Debye shielding in the vicinity of the particles, and it provides an inward long-range electric force that confines the mutually repulsive particles in a stable suspension. The suspension is characterized by direct measurements of the particle locations which yield structural, such as topological defect statistics, as well as dynamical information. A dust in a plasma acquire electric charge by collecting electrons and ions, and this charge can be extremely high (say 103 - 104 electron charges for a micron - sized particle). This high charge causes the particles to interact as a strongly coupled component. The Coulomb interaction between the dust particles leads to ordered structures formation including liquid- and solid-like forms of matter, where the particles are arranged just as atoms are in actual condensed matter. Ordered structures formed in complex plasma called Coulomb (dusty plasma) crystals. Currently there is strong interest in the dynamical behaviour and stability of these Coulomb crystals and a better understanding of the particle dynamics may make it possible to control the dust particles as a group or one by one. If successful, this knowledge could be used in a wide range of applications from everyday life as well as for specific future needs for industry.

For more information, please visit our website at:
http://www.physics.usyd.edu.au/plasma/complex/

(4) Fusion Studies

Name	Room	Phone	email
Dr Joe Khachan	363	9351 2713	khachan@physics.usyd.edu.au

The Centre for Fusion Studies draws together an experimental effort in Electrostatic Ion Confinement, fusion theory and basic plasma physics. The current research activities of the fusion studies group are: compact fusion sources, plasma spectroscopy, plasma modelling and theory, spacecraft ion thrusters. Members of the research group have affiliation with the Applied and Plasm Physics Research Group, the Space and Solar Physics group, the National fusion facility in Canberra, and the U.K. Atomic Energy Authority.

(5) Solar Energy

Name	Room	Phone	email
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Dr Yongbai Yin	438	9351 4756	Y.Yin@physics.usyd.edu.au

The solar energy group undertakes experimental research and modelling aimed at developing new and improved methods of converting sun light to more useful forms of energy. At present, work is proceeding on solar selective surfaces for thermal collectors, advanced semiconductor research for the next generation of photovoltaic solar cells and new types of optical systems for harvesting sunlight on a large scale. The School has experimental facilities including a solar concentrator, thin film deposition equipment, optical and electrical characterisation equipment. The group has strong links with other leading solar energy laboratories and industrial manufacturers worldwide.

More information at: http://www.physics.usyd.edu.au/app/solar/

ASTROPHYSICS:

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A/Prof Anne Green	564	9351 2727	agreen@physics.usyd.edu.au
Prof Bryan Gaensler	556	9351 6053	bgaensler@usyd.edu.au
Prof Dick Hunstead	567	9351 3871	rwh@physics.usyd.edu.au
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Dr Qinghuan Luo	318	9351 2546	luo@physics.usyd.edu.au
Prof Don Melrose	454	9351 4234	melrose@physics.usyd.edu.au
Dr Tara Murphy	565	9351 3041	tara@physics.usyd.edu.au
Dr John O'Byrne	568	9351 3184	j.obyrne@physics.usyd.edu.au
Dr Gordon Robertson	562	9351 2825	jgr@physics.usyd.edu.au
Prof Elaine Sadler	555	9351 2622	ems@physics.usyd.edu.au
Dr Peter Tuthill	566	9351 3679	p.tuthill@physics.usyd.edu.au
Dr Paul Watson	455	9351 2934	watson@physics.usyd.edu.au
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(1) Galactic & Extragalactic Astronomy

The Astrophysics research group is involved in research on a wide range of astronomical frontiers, ranging from neutron stars and pulsars to the ecology of our Galaxy, the Milky Way, to external galaxies, clusters of galaxies and quasars. The research spans the full electromagnetic spectrum, from radio to X-ray wavelengths. The group operates the Molonglo Observatory Synthesis Telescope (MOST) at a site 40 km east of Canberra; this is one of the major radio telescopes in the southern hemisphere and it is currently surveying the southern sky at unprecednted sensitivity. Data from this instrument are used in some of the proposed projects, often in conjunction with data at other wavelengths obtained using other telescopes. There is also a strong theoretical astrophysics group working on black holes, neutron stars and other exotic sources.

(2) Stellar Astrophysics & Asteroseismology

A detailed understanding of star formation is still one of the major unsolved problems in astrophysics. While much has been learned in the last decade about how Sun-like (ie low-mass) stars form in isolation, many aspects of more massive star formation, which form in large clusters in Giant Molecular Clouds, are a complete mystery. With the recent advent of mm-capability for the Australia Telescope Compact Array, we now have a high-resolution facility and many new discoveries are likely. Asteroseismology is a new and exciting field of stellar astrophysics, using the oscillations of stars or "starquakes" to measure some fundamental internal properties.

(3) Theoretical Astrophysics

There is a strong theoretical astrophysics group working on topics including black holes, neutron stars, scintillation effects, pulsar radiation mechanisms and the properties of other exotic sources, and solar flares. Enquiries about projects in this group should be directed to Prof Don Melrose.

(4) Instrumentation

Australian optical astronomers have a strong tradition of building instruments. The SUSI (stellar interferometer) is a prime example. Another example is narrow-band filter-based imaging, using the Anglo-Australian telescope, which has centred around the use of the Taurus Tunable Filter (TTF - http://www.aao.gov.au/ttf/). The TTF allows for narrowband imaging anywhere in the wavelength range 370 to 1000 nm through a bandpass that can be tuned to resolving powers of 100 to 1000. Novel modes of using the CD detector allows differential imaging between bands while minimising the effects of atmospheric seeing. Researchers involved are Dr Joss Bland-Hawthorn (TTF instrument scientist from the AAO) and Dr John O'Byrne.

BIOPHYSICS:

Name	Room	Phone	email
Dr Serdar Kuyucak	351	9036 5306	serdar@physics.usyd.edu.au

Biophysics is a rapidly developing research area that employs experimental and theoretical methods of physics to study biological systems. During the last two decades, structures of many molecular machines that control biological processes have been determined, and the current challenge is to understand the dynamics of their operation, i.e. uncover the structure-function relationships. Physicist have a lot to contribute to this frontier area that requires modeling of biological systems at different time scales using quantum, classical and stochastic dynamics. A few sample projects are listed. More can be found in the Biophysics web page: http://www.physics.usyd.edu.au/biophys/

COMPLEX SYSTEMS:

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Prof Sergey Vladimirov	458	9351 5770	S.Vladimirov@physics.usyd.edu.au
Prof Iver Cairns	457	9351 3961	cairns@physics.usyd.edu.au
Dr Zdenka Kuncic	464	9351 3162	Z.Kuncic@physics.usyd.edu.au

(1) Brain Dynamics

The dynamics and information processing pathways in the brain are of intense research interest worldwide. The cerebral cortex exhibits waves of activity ("brain waves") that are detected electrically by electrodes on the s calp, or via magnetic resonance imaging. We have developed a model of how these waves are related to the underlying structure of the cortex, which is made of around 100 billion neurons. This model yields excellent agreement with experiment and is enabling a new range of diagnostics to be implemented. It reproduces many wave properties, including spectra and several types of nonlinear seizure, and was recently awarded a Eureka Prize. There is much yet to be done in areas ranging from pure theory to data analysis and experiment, often in conjunction with psychologists, medical staff, and the Brain Resource Company, whose Brain Resource International Database is accessible by us. Some possible projects are listed below, but more are likely to become available.

They also form part of Federation-Fellowship and other research programs recently funded by the Australian Research Council. Projects in this area almost invariably lead to publication of one or more papers in scientific journals. (Prof Peter Robinson – primary contact)

(2) Nanoscience, Nanotechnology, Surface Science and Plasma Applications

Nanoscience is one of the most dynamically developing area of truly interdisciplinary research. Several breakthrough discoveries in the last few years such as nanotubes and fullerens have demonstrated a great potential for applications of nanosized objects. Now, when we can manipulate the individual nano-objects and even atoms on the surface, we face a new global task of inventing ways and methods for manipulating multi-billion ensembles of nano-objects. The most, possibly, remarkable feature of the nano-world is not a nano-size of specific "building blocks", but actually an enormous number of the blocks to be moved, processed and controlled. It is clear that the classical methods of building nano-world in the "atom-by-atom" way are inefficient, since nobody can control selectively an enormous number of individual nano-objects (just for example, 10 billion of quantum dots per square cm). The nano-world lives by its own rules, and can be controlled only by methods that respect and obey the rules. This situation resembles assembling a huge brick building, so huge that we cannot even dream of laying individual bricks one by one. What could we do in this situation? The only way is to affect our huge heap of bricks in the way to get them self-arrange to create the building on their own, without our help. This is not possible in our real macroworld but it is possible in a nanoworld! This sounds like a magic, but the nature really goes this way. From molecules to stars, everywhere we see how a myriad of "bricks" self-organizing into really very complex systems. Thus our task is to "guide" the Nature to assemble the nano-structures by using guided self-assembly. We have developed a range of complex models that enable us to reveal the main self-assembly rules and to invent the tools to control atomic scale processes on the surface. Our research group, which is a lead team of the International Network for Deterministic Plasma-Aided Nanofabrication, works on this problem in a close cooperation with several world-leading universities of the USA, Japan, Singapore, Germany, China and other countries. This is an extremely HOT TOPIC (just see recent citation reports in Physics published in Nature!) and any of our projects (with virtually unlimited number of projects owing to a great variety of exotic nanostructures!) will guarantee numerous publications in prestigious scientific journals and a competitive edge for future career. Mid-year (July) commencement is also welcome. (Dr Ken Ostrikov – primary contact).

(3) Space Physics/ Plasma Theory/ Astrophysics

Processes in plasmas in space and the laboratory are usually nonuniform, often with random (i.e., stochastic) and nonlinear effects dominating the dynamics. Important research topics include particle acceleration, generation of plasma waves and radio emissions, shock waves, and multiple specific space phenomena. The Space Physics Group researches these topics, often combining them into quantitative theories for multiple solar system phenomena, and are experts in comparing theory and observations. These projects form part of Federation Fellowship, Professorial Fellowship, and other research programs funded by the Australian Research Council. Some of the work supports our participation in NASA's twin-spacecraft STEREO mission, to be launched in mid to late 2006. Projects in space physics almost invariably lead to publication of one or more papers in scientific journals. Additional projects to those listed below are possible. (Prof Iver Cairns, Prof Peter Robinson, Prof Sergey Vladimirov, Dr Zdenka Kuncic – primary contacts)

CONDENSED MATTER PHYSICS:

Name	Room	Phone	email
Prof Catherine Stampfl	343	9351 5901	stampfl@physics.usyd.edu.au
Dr Damien Carter	361	9036 5389	carter@physics.usyd.edu.au
Dr Carl (Xiangyuan) Cui	344	9036 5301	carlc@physics.usyd.edu.au
Dr Mira Todorova	361	9036 6039	m.torodova@physics.usyd.edu.au

Condensed matter physics is concerned with understanding the properties of solids and liquids and is the largest field of contemporary physics. In the condensed matter theory group, fundamental research is carried out on the basis of first-principles theory calculations, into the energetics, atomic, electronic, and magnetic properties of polyatomic systems. Such calculations can significantly contribute to the understanding, engineering, and design of complex materials; for example, catalysts with greater selectivity and efficiency, and new electronic devices. Research in this field forms part of the Federation Fellowship of Prof Catherine Stampfl.

CUDOS:

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Prof Martijn de Sterke	307	9351 2906	desterke@physics.usyd.edu.au
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Dr Libin Fu	218	9036 5206	libin@physics.usyd.edu.au
Dr Christian Grillet	303B	9036 9430	grillet@physics.usyd.edu.au
Dr Boris Kuhlmey	303B	9036 9430	borisk@physics.usyd.edu.au
Dr Ian Littler	218	9036 5206	littler@physics.usyd.edu.au
Dr Erik Magi	218	9036 5206	magi@physics.usyd.edu.au
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Dr Mike Steel	304B	9351 6061	mike@rsoftdesign.com
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Dr Eduard Tsoy	314	9351 3953	etsoy@physics.usyd.edu.au

An underlying theme of the CUDOS research is the "processing" of short pulses of light (down to 100's of femtoseconds). One aspect of this research is that electronics cannot cope with such fast processes and thus only way for this processing to occur is all-optically, *i.e.*, using other light! Now in standard, linear optics, two different light beams do not interact with each other and so the optical processing of light is impossible. That's why we use *nonlinear optics*, by which one beam of light can change the phase of another, new frequencies can be generated, or solitons can form, to name just a few examples. Though much of our work involves standard glass, it is one of the least nonlinear materials known, and so nonlinear processes requires high intensities (100's of $\mathrm{MW/cm^2}$ to $\mathrm{GW/cm^2}$. This is the reason why we are also working with chalcogenide glasses, which contain elements like sulphur or selenium, since nonlinear effects in these materials are about 1000 times stronger than in ordinary glass.

We want the processing of light to occur in small volumes so that they are fast and efficient. This is why *photonic crystals* and *photonic crystal fibres* are amongst our research interests. In these structures the refractive index varies periodically with position, which in practice is usually achieved by the inclusion of periodically spaced air holes in the structure. The periodicity gives rise to a photonic band structure with photonic band gaps, where light cannot propagate through the structure, leading to the ability to manipulate light to an unprecedented degree. A particularly dramatic example of this is the manipulation of the spontaneous emission of an atom. Much of our research aims to clarify the properties of these structures.

ELECTRON MICROSCOPE UNIT:

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Dr. P. Thordarson	EMU	9351 7548	palli@emu.usyd.edu.au

The Electron Microscope Unit is the premier research and teaching centre for electron microscopy in Australia and offers our students direct access to world-class facilities and resources. We are part of a larger collaborative network of universities, research institutes and industry providing access to other off-campus instrumentation. Incorporated in the EMU are the Australian Key Centre for Microscopy and Microanalysis (AKCMM), the Nanostructural Analysis Network Organisation (NANO) Major National Research Facility (NANO-MNRF) and the Macintosh Centre for Quaternary Dating. Research conducted In the EMU covers a wide variety of subjects reflecting the diverse backgrounds of our academic staff and the projects below reflect the some of the current research in the physical sciences. Additional projects in the biological and archaeological sciences are also available. For more information about the staff and facilities of the EMU please visit www.emu.usyd.edu.au or for information about a particular project contact the named supervisor directly.

HIGH ENERGY PHYSICS:

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Dr. Reza Hashemi-Nezhad	354	9351 5964	reza@physics.usyd.edu.au

High Energy, or Particle, physics involves the study of the world of subatomic particles and the forces via which they interact.

(1) The Belle Experiment

Belle is an exciting experiment taking place now at the National High Energy Physics Laboratory KEK in Japan, studying, amongst other things, the violation of CP symmetry. C (the charge conjugation operation) is the process of interchange of particles and antiparticles in a given system, and P (the parity operation) is the process of reflection of the system through the origin – effectively a mirror reflection. Belle studies CP using the weak interactions of B mesons (heavy mesons containing the "bottom" quark). The results from Belle may well give us some insight into why we live in a matter rather than an antimatter universe, as weak interactions of this type had a pivotal role in shaping the Universe in its very earliest stages of formation. The Sydney High Energy group is actively involved in this frontier experiment. Data taking commenced in northern summer 1999 and is ongoing. So far, some 500 million $B\overline{B}$ pairs have been collected, and positive results on CP violation in the B system have been obtained. Large samples of $e^+e^- \rightarrow q\bar{q}$ continuum, tau-pair and other kinds of events are also available. The projects described later are examples of those that can be offered on Belle – it is not meant to be an exhaustive list. See also http://www.physics.usyd.edu.au/hienergy/4thyear_projects_current.html

(2) The ATLAS Experiment

ATLAS is one of the detectors under construction for the LHC (Large Hadron Collider) situated at the European Laboratory for Particle Physics. When completed in 2007, the LHC will be the highest energy accelerator in the world, colliding protons on protons with a centre of mass energy of 14 TeV. The primary physics goal of ATLAS is to search for the Higgs boson. In addition it will provide a rich environment to study many aspects of particle physics such as CP violation in B meson decays, top physics and QCD. Searches for new physics beyond the Standard Model such as supersymmetry and extra dimensions will be a major activity. An international collaboration composed of more than 1700 physicists from approximately 150 different institutes and universities all over

the world are involved in the building (and soon running) of the ATLAS detector. Again, the projects described later are examples of those that can be offered on ATLAS – it is not meant to be an exhaustive list. See also
http://www.physics.usyd.edu.au/hienergy/4thyear_projects_current.html

MEDICAL PHYSICS:

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Medical Physics is the field in which physical scientists apply their knowledge and training in many different areas of medicine including the treatment of cancer, medical imaging, physiological monitoring and medical electronics. In the application of the physical sciences to the treatment of cancer, for instance, the aim is to develop new and more effective methods for administering radiotherapy and to assist radiation oncologists in studying the medical impact of new radiotherapy technology. To this end, research focuses on calculating, measuring, and verifying radiation dose (the amount of energy deposited per unit mass of tissue) to ensure that an accurate amount is delivered to a well-defined treatment volume. The fundamental physical laws of external electron, photon and proton radiation beams are explored to research treatment techniques, treatment apparatuses, radiation measurement devices, quality assurance methods, dose calculation methods, and methods of predicting the effects of radiation on tissue. In medical imaging applications, physicists apply their skills to the development of instrumentation (for imaging x-rays, gamma rays and non-ionising radiation), image reconstruction algorithms, models of photon transport and detection, and models of the underlying physiological processes. The broad aim of this field of research is to improve the resolution, signal-to-noise ratio and quantitative accuracy of non-invasive imaging techniques, within the constraints of radiation dose to the subject and duration of the procedure. This area of medical physics is undergoing rapid growth as functional imaging techniques such as PET and SPECT become increasingly used as a tool for basic biomedical research as well as a routine clinical procedure.

OPTIC FIBRE TECHNOLOGY CENTRE:

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Dr Maryanne Large	OFTC	9351 1923	m.large@oftc.usyd.edu.au
Dr Pam McNamara	OFTC	9351 1921	p.mcnamara@oftc.usyd.edu.au
Dr Leon Poladian	713	9351 2049	l.poladian@maths.usyd.edu.au
Dr Martijn van Eijkelenborg	OFTC	9351 1941	m.eijekelnborg@oftc.usyd.edu.au

The Optical Fibre Technology Centre [http://www.oftc.usyd.edu.au/] is an interdisiplinary research department of the University, located in the Australian Technology Park, next to Redfern station. OFTC students come from a large range of disciplines, including physics, mathematics, chemistry, engineering, and biomedical sciences. The Centre encompasses both experimental and theoretical research, and is also one of the few centres in the world which can fabricate optical fibre to order for academic research. A particular speciality is microstructured, or photonic crystal fibres. It was the first group to make these fibres in polymer, and is now the world leader in this area. It also has a leading role in the development of both developing new algorithms to model microstructured fibres, and to address the complex task of inverse design. Much of this design work has been biologically inspired, using techniques such as genetic algorithms, embryogeny and cellular automata. A related activity we have pursued is biomimetics, in which we try to exploit designs that have emerged from nature.

The projects listed in the next section are intended to be indicative only. Students interested in these areas should contact the academics concerned well before the projects are to start, and could be redefined in the light of the interests and abilities of the students. Students are also encouraged to see the OFTC website for further details, where publications and other details can be downloaded.

QUANTUM INFORMATION THEORY:

Name	Room	Phone	email
Dr Stephen Bartlett	317	9351 3169	bartlett@physics.usyd.edu.au

Recent years have seen a remarkable synergy between quantum physics and information processing. It has been demonstrated that the rules of quantum physics can protect the distribution of secret cryptographic keys, allowing for unconditionally secure communication between distant parties. Also, there is strong evidence that a quantum computer operating according to quantum physics could change the rules of computer science, solving problems that are intractable on any current computing device. These observations, which promise great future technological advances based on quantum information processing, have gone hand-in-hand with remarkable scientific breakthroughs in our understanding of quantum physics.

What then are the physical limits on transmitting, storing, and processing quantum information? The answer will have implications for both future technologies and fundamental quantum physics and is the topic of the exciting new interdisciplinary field of Quantum Information Theory.

In the Quantum Information Theory group, we explore these questions and more, developing insights into quantum physics and the laws of the universe. This new research group has close collaborative links with the Quantum Information Science Initiative and the Quantum Technology Lab at the University of Queensland, the Perimeter Institute for Theoretical Physics in Canada, and the University of Cambridge and Imperial College London in the UK.

SYDNEY UNVERSITY PHYSICS EDUCATION RESEARCH (SUPER):

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Physics education research (PER) provides an opportunity to investigate how physics is learnt. In the process you learn the intricacies of physics, as well as understand and critically analyze research involving people. Physics is considered a complex knowledge domain and investigations of how physics is learnt has the potential to inform theories and practices in a wide range of areas. However, not much research has been done on how complex physical phenomena is learnt as one needs physics knowledge to investigate such issues. This is the significance of projects undertaken by the SUPER group.

You will find that you learn about learning, and indeed, do learn a lot of physics while deciphering the complex and intricate processes. The research is discipline specific and is done within the physics department. The projects provided represent a flavour of possible projects. We invite you to bring forward your ideas of what intrigues you - a physics concept, a model, unifying ideas, demonstrations, learning experiences etc.

Research Projects in Applied and Plasma Physics

(1) Biomaterials and Materials Processing with Plasmas

SURFACES FOR ATTACHMENT OF BIOMOLECULES

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This topic includes a number of different project areas. The attachment of bioactive proteins to surfaces underpins the development of biosensors and diagnostic arrays for detecting disease. We have developed and patented a plasma technology utilising high energy ions for activating polymer surfaces to attach proteins and retain their activity. We have demonstrated the technology with three enzymes and developed a theory for the chemical and physical mechanisms responsible for their enhanced attachment. In the next phase of the project we seek to test our theory by studying the effects of modifications to the surface chemistry on interactions with a new set of proteins and molecules. The interactions of the proteins with the new surfaces will be examined using a range of methods including surface plasmon resonance, ellipsometry, neutron reflectometry and biological activity assays. There are a number of student projects available, all of which will allow the student to learn about the physics governing the response of protein molecules to surfaces and to become familiar with one or more analysis methods. In the course of the project students will interact directly with our research partners in biochemistry, anatomy, CSIRO and ANSTO and learn the research skills required to function effectively in a vibrant, multidisciplinary research environment.

PLASMONIC METHODS FOR PROTEIN DETECTION

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Proteins are polymer macromolecules folded into an approximately spherical shape. The area of physics that is concerned with the behaviour of matter of this type is ”soft condensed matter physics”. Proteins carry out the functions that enable a living cell to carry on its activities. Certain proteins are characteristic of disease states and detection of these is useful for medical diagnosis. Antibodies exist to each protein which ”recognize” the protein by a binding process to a specific binding site. We are developing an ”on chip” medical diagnostic by creating surfaces suitable for attachment of antibodies to produce antibodies arrays. Crucial to the functioning of such an diagnostic device is the readout mechanism, ie the capability to detect the antigens bound to surface attached proteins. In this project we will develop a sensitive spectroscopic method to detect the attachment of a protein in body fluid simulating solution to its antibody and to a surface.

The methods to be developed can be termed ellipsometric surface plasmon resonance. The phenomenon of surface plasmon resonance, which has spawned the field of plasmonics, is based on the absorption of light by resonances of oscillating free electrons in nanostructured metals. These resonant frequencies are highly sensitive to changes in refractive index, as would be caused by the attachment of a macromolecule, near to the metal surface. Ellipsometry allows phase changes as well as changes in intensity of light reflected from the system to be measured. We will test a new methods of increasing the sensitivity of surface plasmon resonance by incorporating the phase information of ellispometric monitoring and by the use of island metal films to enhance the signal.

DEVELOPING AND TESTING MODELS FOR PLASMONIC MONITORING

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In this project we will use optical theory of thin film multilayers to test the sensitivity of the surface plasmon resonance to the detailed structure of protein rich layers next to the metal surface, and to the nature of the metal surface (smooth or textured). Both the phase and the amplitude information available in ellipsometry will be used. We will predict the effect of protein attachment density and protein orientation (in the case of proteins that are non spherical). The effect of an electric field on the protein solution will also be predicted. The electric field causes a sudden change in the ionic concentrations which may be detectable by monitoring the plasmon. The results of the theoretical predictions will be tested wherever possible using the state of the art ellipsometer in the School and a prism coupling system. The results of this project will be of direct application to the sensing of protein attachment.

SURFACE TREATMENT OF COMPLEX SHAPES FOR MEDICAL IMPLANTS

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Plasma Immmersion Ion Implantation (PIII) is a convenient practical method of modifying the surface of objects using ion impacts. A conducting object is treated by immersing it in a plasma and applying a pulsed negative voltage to it. A problem arises in practice when objects of complex geometries are treated because the dynamics of the plasma sheath can result in a non uniform ion fluence around sharp points and deep hollows. In addition, insulating objects cannot be treated in the same way. Even if a conducting electrode can be placed behind the insulator, surface charge can build up and modify the fluence locally. These are major limitations that are hampering the treatment of prosthetic devices such as artificial joints and arterial implants. A mesh approximately conforming to the shape but not in contact with the surface could provide a way of modifying the dose distribution by refocusing ion trajectories using curved surfaces and by masking. This project aims to understand the ion focusing effects of various mesh topographies. The experimental results will be compared with existing calculations of the dose from simulations of the plasma as a collection of positive and negative particles. Meshes for two particular cases of practical importance will be designed using the physical principles developed. One is to treat a pattern of circles on a polymer sheet, for medical diagnostic arrays, the other is to treat the inside of a cylindrical object to form an arterial graft.

UNFOLDING PROTEINS USING ULTRA-FAST LASER PULSES

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We have developed a technique for applying ultrafast temperature pulses to proteins. The importance of this is that it enables theories for the unfolding of proteins to be tested. We have found for two common proteins that the Arrhenius formula for the rate of a chemical reaction applies to some common proteins over twelve orders of magnitude in unfolding rate. This surprising result has recently been published by us as a letter in a high impact journal. The implications of the result are still being evaluated as it implies that the protein has only two forms, folded and non functional or misfolded, for the purposes of the reaction rate. In order to confirm that the simple Arrheius relation applies to other proteins, we need to carry out further experiments of a similar type. Green fluorescent protein is a relatively recently discovered protein that produces green fluorescence when it is in its normal or ”native” state. When it is unfolded, the fluorescence strongly decreases. In this project, we will subject the green fluorescent protein to the same temperature regime as we have done for the other proteins, but covering a wider range of temperatures. The fluorescence will be monitored post exposure. We will also study the behaviour of an enzyme, with well known thermal unfolding behaviour, known as glucose oxidase. The aim is to confirm whether or not the Arrhenius relation applies.

CHARACTERISATION OF A NOVEL HIGH DENSITY PLASMA SOURCE

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The Applied and Plasma group has recently developed and commissioned a high current (1-5 kA) pulsed cathodic arc plasma source. This source is the only one of its kind in the world and produces a much higher instantaneous ion flux than any other deposition system currently available. The range of parameters which can be accessed make it an ideal instrument for investigating the basic physics of plasma transport in magnetic and electric fields. This project will utilize high-tech plasma diagnostic equipment, such as time resolved Langmuir probes, microwave and laser interferometry and tomography, and CIS spectroscopy) developed in collaboration with the fusion research group at the ANU, Canberra, on a two million dollar ARC infrastructure grant awarded to the consortium. The questions to be investigated include the identification of instabilities associated with transport of a high density fully ionized drifting plasma in magnetic fields, the development of enhanced charged states in the rapidly expanding plasma region of the high current cathodic arc and the effect of transport through a magnetic filter on ion charge and energy distributions. Recent simulation work has predicted that the charge state distribution is coupled to the energy distribution in a specific way and we are now in a unique position to test this. There are two to three separate projects available in this general area.

SYNTHESIS OF MAX PHASES USING A HIGH POWERED PULSED PLASMA

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The MAX phases are made up of an early transition metal M, an element from the A groups, usually IIIA and IVA, and a third element, X, which is either nitrogen or carbon, in the composition Mn+1AXn, where n is 1, 2 or 3. The MAX phases represent a new class of compounds which have unique properties that can be related to their layered (nanolaminate) crystal structure. They have high thermal and electrical conductivities and are machineable like metals, but are also highly resistant to oxidation and thermal shock like ceramics. To fabricate a thermodynamically stable MAX phase material it is necessary to obtain the correct stoichiometry and so a means of combining elements with high degree of accuracy is required. This project aims to fabricate Ti2AlC and Ti3AlC2, and possibly also V2AlC, and Cr2AlC, using the high current pulsed cathodic arc in the School of Physics. This is a unique deposition tool allowing highly reproducible, sub- monolayer quantities of material to be ablated into a plasma during each pulse. A ternary cathode source has been built, calibrated , and interfaced with control software. The plasma parameters and film properties will be measured and correlated to develop an understanding of the synthesis process.

DEPOSITION OF NEW TRANSPARENT CONDUCTING OXIDE MATERIALS

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The recent growth of information technology and the need for energy efficiency have significantly increased the demand for optically transparent, electrically conducting coatings. Indium tin oxide (ITO) is currently the most popular transparent conducting oxide (TCO). However, limited reserves of indium mean that ITO cannot continue to meet the growing demand. Furthermore, the range of substrates on which indium tin oxide can be used is limited due to its brittleness and the need for high deposition temperatures. In this project we aim to synthesis new binary and ternary conductive metal oxide alloys with a particular emphasis on developing methods to synthesize good quality TCOs at low temperature. The synthesis methods to be used are cathodic arc and sputtering, both of which allow the manipulation of ion energy and flux with magnetic and electric fields. The effects of energetic ion bombardment on the crystallinity and mobility of charge carriers in the films will be studied with an aim to developing deposition strategies which achieve films of quality comparable to ITO. Transparency will be assessed using UV-Vis-NIR spectrophotometry and the nature of electrical conductivity will be studied using four point probe and Hall measurements. The stoichiometry of the deposited films will be determined by SNMS (secondary neutral mass spectroscopy) and their structure determined using electron microscopy methods.

REACTIVE DEPOSITION OF THIN FILMS FROM A PULSED CATHODIC ARC PLASMA

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To make ceramics such as metal oxides and nitrides using a cathodic arc plasma, it is necessary to operate the arc in a background pressure of the gas. The gas is then ionised by its interaction with the metallic cathodic arc plasma. This interaction varies with gas pressure, flow rate and injection point in the vacuum chamber. In a pulsed cathodic arc the interaction also varies as a function of time throughout the pulse. Depending on the time between pulses cathode poisoning or total gettering of the gas molecules can occur blocking completely the metal plasma from reaching the substrate. This complex system of dependencies means that the stoichiometry of films deposited in the reactive mode is difficult to control. This project will utilise a mass selective energy analyser, time resolved Langmuir probes and other plasma diagnostic methods to map the parameter space associated with the reactive mode. The use of a secondary ion source to pre-ionise the gas will also be explored. The stoichiometry of deposited films will be determined by SNMS (secondary neutral mass spectroscopy) and optimum deposition conditions for ceramic materials will be identified.

PREDICTION OF NEW TRANSPARENT CONDUCTING OXIDE MATERIALS USING SIMULATIONS

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The recent growth of information technology and the need for energy efficiency have significantly increased the demand for optically transparent, electrically conducting coatings. Indium tin oxide (ITO) is currently the most popular transparent conducting oxide (TCO). However, limited reserves of indium mean that ITO cannot continue to meet the growing demand. Furthermore, the range of substrates on which indium tin oxide can be used is limited due to its brittleness and the need for high deposition temperatures. In this project, we aim to use ab-initio computer simulations to determine the structural, energetic and electronic effects of dopant incorporation into a number of transparent oxide material (such as CdO and ZnO). For a given concentration of dopant, calculations will be used to determine the most energetically favourable incorporation sites. First principles electronic structure calculations will then be used to determine the electronic structure changes caused by the dopants. Molecular dynamics will be used to investigate the mobility of the dopant atoms in the matrix and to determine the effect of temperature on the structure to assess the material's stability at elevated temperatures.

COMPUTER SIMULATION OF STRESS AND PREFERRED CRYSTALLOGRAPHIC ORIENTATION

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A number of theories based on different physics are proposed to explain the formation of preferred crystallographic orientation in microcrystalline thin film materials. The competing ideas are based on energy minimization on the one hand and dynamic effects associated with energetic ions during the growth process on the other. Although a lot of experimental data exists showing how various plasma parameters used during the growth phase affect the preferred orientation of the resulting materials, the data on elastic constants which determine the minimum energy orientation in a biaxial stress field are is scant. In this project the student will use quantum mechanical computational methods to determine the anisotropic elastic constant tensor for a number of well studied materials and using this data calculate the orientation minimizing the elastic energy for each phase. The results will be compared to the experimental data to assess the two prevailing theories and hopefully resolve the prevailing controversy. A definitive resolution of the controversy will certainly result in a landmark publication.

MONTE CARLO MODELLING OF CERENKOV RADIATION IN OPTICAL FIBRES

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Cerenkov radiation is produced when a high energy electron passes through a medium faster than the speed of light in that medium. This radiation creates a large unwanted background signal in optical fibres used in radiation therapy dosimetry. The purpose of this project is to design and write a function of the Egs4 Monte Carlo program to calculate the path of electrons through an optical fibre when exposed to a high energy electron or photon beam. This will help to explain the observed Cerenkov radiation and be used to optimise the design of radiation detectors that use an optical fibre.

RELIABLE AND HIGH PRECISION UV LIGHT-EMITTING SOURCE FOR APPLICATIONS IN FIBRE OPTIC RADIOTHERAPY DOSIMETRY

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One of the most important research topics in radiation therapy clinical practice is to monitor radiation dose in vivo with high precision in order to provide optimal treatment without introducing damage that may cause serious side effects and compromise the patient's quality of life. A new technology, called in vivo fibre optic dosimetry (FOD), was developed in this School in collaboration with Royal Prince Alfred Hospital. The FOD uses radiation sensitive scintillator to produce optical emission in the visible wavelength region. The emitted light then is recorded using a highly sensitive photon detector. In order to improve further the accuracy and repeatability of the FOD in a wide range of environmental conditions, an ultra violet light source was introduced to provide a tool for real time calibration. This project aims to understand the mechanisms that govern the stability and repeatability of the ultra violet source, namely, a light emitting diode for a wide range of environmental conditions, such as temperature, humidity, and electromagnetic field. Simulation, analysis design, and characterisation will be carried out in this research project. The student will work alongside the experts both in this School and in the collaborating laboratories.

Research Projects in Astrophysics

(1) Galactic and Extragalactic Astronomy

YOUNG NEUTRON STARS AND THEIR WINDS

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A young neutron star (sometimes known as a ”pulsar”) usually generates a relativistic outflowing wind. When this wind expands into its surroundings, the resulting shock wave accelerates electrons up to ultra-relativistic energies, and a synchrotron-emitting ”pulsar wind nebula” (PWN) results. In this project, a student will make a detailed study of two young neutron stars and their PWNs, using new radio, X-ray and infra-red data. The results of this analysis can then be used to trace the process through which neutron stars transfer energy to their environment.

STRANGE SUPERNOVA REMNANTS

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Supernova remnants (SNRs) are the expanding clouds of debris left behind by the explosions of massive stars. After decades of intensive effort, we now have a mature understanding of the interplay between SNRs and their environments. Detailed investigations of bright SNRs in uncluttered environments have led to sophisticated theories to explain nucleosynthesis, shock heating and particle acceleration. However, these bright and well-behaved SNRs are not representative of the general population. Many SNRs expand into complex environments shaped by molecular clouds and by the strong winds from nearby stars. If our understanding of SNRs is to progress further, we must also study more typical, complicated systems. In this project, a student will analyse radio, X-ray and millimetre data on several unusual SNRs, and will use the results of these measurements to develop an understanding of the interaction of supernova explosions with their surroundings.

MAGNETIC TURBULENCE IN THE LARGE MAGELLANIC CLOUD

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Large fluctuations in electron density and magnetic fields are seen on parsec scales in the Milky Way, but the origin of this turbulence is unknown. Recent measurements of radio polarisation have shown that a similar phenomenon must be occurring in the Large Magellanic Cloud (LMC). The presence of this effect in a region at known distance and of low optical extinction provides a unique opportunity to directly measure the scale and strength of these fluctuations, and to separate out the contributions due to density and to magnetic fields. In this project, a student will analyse high-resolution radio observations of galaxies behind the LMC. Spatially resolved Faraday rotation seen against these sources can then directly yield the characteristics of parsec-scale magnetic turbulence in the interstellar medium.

THE EVOLUTION OF GALAXY MORPHOLOGIES

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The shapes of galaxies in the nearby universe are dominated by well-defined spiral and elliptical structures, smooth and continuous, with a small contribution from dwarf and irregular systems. At very early times, though, galaxies looked remarkably different, with irregular, amorphous shapes being dominant. At some point these young galaxies developed into the structures we see today, and understanding how this change occurred is a fundamental question in observational astronomy. We can make use of the fact that galaxies appear different at different wavelengths, corresponding to how different underlying physical processes produce or affect the emission, to connect the measured morphologies of galaxies to these underlying processes. We are interested in star-formation in particular as it is the distribution of stars in a galaxy which dominate the morphology we see. In the past decade observational astronomy has undergone a rapid evolution. We now live in an era when many large astronomical surveys provide publicly available archives. This provides a wealth of imaging data with which to quantitatively explore galaxy evolution. This project will make use of two such archives, the Sloan Digital Sky Survey (SDSS, a large survey of relatively nearby galaxies) and the Great Observatories Origins Deep Survey (GOODS, a high-sensitivity survey using the Hubble Space Telescope of very distant galaxies). The aim of this project will be to measure and compare the morphologies of galaxies in these two surveys, to get a direct and quantitative understanding of how galaxy shapes have changed, and to explore the connections with star-formation processes in these systems.

EXTREME AND UNUSUAL RADIO GALAXIES

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Radio galaxy spectral shape has traditionally been used to differentiate between two broad populations: (1) steep spectrum objects, often the extended lobes of radio jets, and (2) flat spectrum objects, often an active nucleus at the core of a radio galaxy. In particular, galaxies with very steep radio spectra (so-called ultra-steep-spectrum, or USS, sources) are important as a large fraction of these lie at very high redshift. Such high redshift radio galaxies are among the most massive systems in the very early universe, are relatively rare, and place strong constraints on cosmological models and models of galaxy evolution. The radio spectral slopes for several hundred radio galaxies in a survey called the Phoenix Deep Survey have recently been measured, and a sample of 20-30 objects are confirmed as being very extreme examples of such steep spectral index sources, even more steep than the USS sources pre-selected for high redshift object searches. The sample from Phoenix will be extended by using two additional large sky surveys, the NVSS and

SUMSS surveys. The aim of this project will be to explore the nature of these objects. The Phoenix Deep Survey project has a wealth of complementary data available, including imaging at optical and near-infrared wavelengths, and optical spectroscopy, providing redshifts for most of the bright optical counterparts to the radio galaxies. Similar, but shallower, imaging resources are available for the large sky surveys. The nature and properties of radio sources with extreme spectral indices will be explored in the context of their optical colours, redshifts where available, as well as optical galaxy morphologies.

WHERE DO STARS FORM WITHIN GALAXIES?

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Galaxies are made up of billions of stars, and their distribution gives a galaxy its shape. Stars have different colours, depending on their temperature, with very hot stars being blue and cool stars being red. The hot-blue stars are also very massive and short-lived, while the cool-red stars are low-mass and have lifetimes comparable to the age of the universe. Mapping out the colour-distribution across a galaxy, therefore, gives us insight into the range of stellar populations that are present at different locations within a galaxy, and in turn into the star formation history of these different regions. Exploring where stars are forming in galaxies, and how this is related to or influenced by other galaxy properties, such as the environment they live in, can shed some light on the process of galaxy evolution. This project will make use of data from the Sloan Digital Sky Survey (SDSS) and an analysis of galaxy images from the SDSS using a tool called pixel-z. Pixel-z provides spatially-distributed measurements of star formation rate, stellar ages, heavy element abundance and obscuration throughout a galaxy. These estimates will be analysed in the context of the environment and morphology of the galaxies in order to explore the connection between these and the underlying star formation properties.

WHAT TRIGGERS A QUASAR?

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Its recently become apparent that most galaxies in our Universe contain super-massive black holes with masses a million to a billion times that of the Sun (this includes our own Milky Way). In local galaxies these black holes are largely inactive, but at earlier epochs they grew rapidly via accretion of gas and stars. Black holes with high accretion rates are highly luminous and are observed in our universe as quasars. The triggering mechanism for the high accretion phase of black holes is far from clear, one possible mechanism is galaxy mergers. In this project the student will analyse data just obtained from the 8m Very Large Telescope in Chile to shed light on this issue. Spatially resolved spectroscopy of the host galaxies of quasars, in combination with Hubble Space Telescope imaging data, will be used to search for dynamical evidence of merger events as well as determine the mass of the black holes contained within the galaxies.

FINDING & MEASURING THE LARGEST STRUCTURES IN THE UNIVERSE

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Large quasar groups are the biggest coherent 3-dimensional structures found in our Universe and can be up to 200 Megaparsecs on a side. All previous work on these has focused on a small number of known groups, in relatively small areas, leading to great uncertainties as to the true number of such groups and whether their presence is consistent with the currently favoured cosmological models. The advent of massive quasar surveys allows this question to be addressed properly. In this project the student will use the large database of 23000 quasars from the 2dF quasar survey to find large structures and measure their properties (size, shape, density). They will then compare these to identical measurements from cosmological simulations as a test of the current world model.

MEASURING THE STRUCTURE OF QUASAR EMISSION REGIONS

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The standard describing active galactic nuclei (AGN) has fast moving gas orbiting the central black hole at radii of light days to months. This is the so called "broad line region" from which the characteristic broad emission lines in quasar spectra are emitted. The detailed structure of these gas clouds is largely unknown. The aim of this project is to use time variations in the spectra of quasars to place constraints on the physical structure of the broad line region. The student will examine a large database of quasar spectra taken over a period of approximately a decade and extract multiple repeat observations to test for variations in the emission lines. Any such line variations found will be compared to the most recent models of the structure of the broad line region.

PHYSICAL PROCESSES AND STRUCTURE IN THE GALAXY

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Looking into the plane of our galaxy we can see many interesting objects, from compact objects such as pulsars to diffuse supernova remnants and HII regions. Each tell us different things about the evolution of stars, and the physical processes taking place within our galaxy. The Sydney University Molonglo Synthesis Telescope has produced high quality radio continuum images of the Galactic plane at 843 MHz. To fully utilise these maps it is necessary to identify and characterise the wide variety of sources detected. Some of these sources will be present in existing catalogues, but others will be new 'undiscovered' objects.

In this project you will use data at other wavelengths (infrared and high radio frequency) to determine the physical processes involved, looking especially for signposts to objects at the extreme ends of the stellar lifecycle – the youngest and the most recently exploded. You will also use multi-resolution techniques such as wavelet analysis to characterise these sources, eventually producing a catalogue. The aim of the project is to understand how Galactic sources influence each other. The catalogue will be an important resource for future Galactic Plane studies.

GRAVITATIONAL MICROLENSING OF QUASARS

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Gravitational microlensing has proven to be a powerful astrophysical tool, revealing detailed structure within the heart of quasars. In this project, the student will make uses of 'ray-tracing' to model the action of gravitational microlensing; caused by individual stars, this can introduce dramatic brightness flares in distant sources. This will be coupled with the recent models for the distribution of emission of radiation in the vicinity of supermassive black holes to predict the expected brightness fluctuations of microlensed quasars, and determine what kind of information can be derived from a quasar light curve.

THE ADVENTURES OF THE ROCKETEER: ACCELERATED TRAVEL IN AN EXPANDING UNIVERSE

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If we could travel at a constant acceleration, suitable for human existance, just how far can we get in the Universe in a typical lifespan? In this project, you will work with the equations of general relativity, looking at accelerated motion through the expanding spacetime of the Universe. While learning the underlying framework of relativity, you will also employ numerical techniques to solve the equations of motion to calculate how far you can travel.

SEARCHING FOR RADIO SUPERNOVAE

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Supernovae which arise from the explosion of massive stars are sometimes extremely strong radio sources which can be detected at distances well beyond our own Galaxy Their radio emission typically peaks a few years after the supernova explodes, and appears to arise from the interaction of the supernova shock with a dense stellar wind shed by the progenitor star. Several radio-loud supernovae have been found by chance in nearby spiral galaxies, and it is possible that such objects are common. This project will use data from the University's Molonglo radio telescope to measure the radio supernova rate in nearby galaxies, and to determine how many of these supernova are obscured by dust which would make them invisible to optical telescopes.

LOOKING FOR RANDOM TRANSIENTS IN THE GALAXY

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The most well-known transients are pulsars, which are the super-dense remains of exploded massive stars. Once found, the rotation period of pulsars can be extremely accurately measured and many astrophysical parameters calculated. However, there are many sources, such as soft gamma-ray repeaters (SGRs) and X-ray binary systems, which sporadically emit bursts of radio emission, often in response to an accretion event. There is also likely to be other transient behaviour in radio sources on a weeks/months time-scale which has not yet been well-studied, principally because it is so hard to predict the outbursts. As part of a southern sky survey being undertaken currently with the Molonglo Observatory Synthesis Telescope (MOST), we are monitoring on a regular basis two fields to gain an understanding of long-term transient behaviour. Both fields contain known transients which will help calibrate the results. The aim of this project is to investigate this possible long period variability, which may be a new phenomenon. Analysis of the images will require a study of how to measure reliably unexpected variations in some sources when the remainder of the image stays constant over a period of some years. Consulting the MOST archives to check against earlier observations will be part of the project.

RADIO-SOURCE POPULATIONS AT 20GHZ

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The radio sky is still largely unexplored at frequencies above 5 GHz. Most radio telescopes have a small field of view at these high frequencies, making it extremely time-consuming to image large areas of sky. However, measuring and understanding the high-frequency properties of extragalactic radio sources is crucial for interpreting the high-sensitivity and high-resolution maps of the Cosmic Microwave Background (CMB).

In this project, you will work with a team of astronomers who are using the Australia Telescope at Narrabri to carry out the first radio imaging survey of the entire southern sky at 20 GHz. The brightest radio sources at this frequency are expected to be blazars and quasars, but the survey is also likely to discover rare and unexpected classes of radio sources. Your role will be to match radio sources detected at 20 GHz with optical spectra from the recently-completed 6dF Galaxy Survey to measure the distances and physical properties of a subset of high-frequency radio sources.

IDENTIFYING & STUDYING BRIGHT X-RAY SOURCES IN THE SOUTHERN SKY

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In this project, you will combine data from recent surveys of the southern sky at X-ray, radio and optical wavelengths to identify and study the astrophysical objects which are the brightest southern X-ray sources. These are expected to include (i) nearby spiral galaxies whose X-ray emission is powered by stars and stellar remnants, (ii) elliptical galaxies and galaxy clusters which are surrounded by enormous haloes of very hot gas, and (iii) quasars and active galactic nuclei, where the X-ray emission arises from processes related to accretion of gas onto a central, supermassive black hole.

STAR FORMATION IN NEARBY GALAXIES

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This project involves the identification and study of star forming regions in nearby galaxies, using their hydrogen emission. Comparison of the strength of emission in several spectral lines allows an estimation of how much light escapes the gas and dust of the star forming regions and thereby the true rates of star formation across the galaxy. Results so far suggest interesting star formation histories, asymmetrically placed in some galaxies.

C2D: A DETAILED STUDY OF LOW-MASS STAR FORMATION WITH THE MOPRA AND SPITZER TELESCOPES

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Recent theoretical progress has given us a general paradigm for the formation of low-mass (Sun-like) stars, but there are still many details of this model that need to be explored. The Spitzer Legacy Project "c2d: From Cores to Disks" is conducting a uniform, unbiased survey across the electromagnetic spectrum, of conditions in around 100 nearby low-mass star-forming regions. This comprehensive survey will allow us to study many of these details for the first time. As part of this ambitious project, we have obtained a large amount of data from ATNF's Mopra dish of all the southern sources in this survey. The Mopra data consist of maps of each source in several molecular transitions at 3mm wavelength, and will allow us to examine the chemical signatures in the cold molecular gas of protostellar evolution, revealing important clues to how Sun-like stars and their solar systems form. For example, although the species N_2H^+ and CS are both excited under similar physical conditions ($n \sim 10^5 H_2$ molecules/cm^{-3}, T ~ 10 K), their very different distributions in maps of dense cores show that chemical evolution in the gas plays an important role, and that different species trace different regimes in the dense gas.

In this project you will analyse the Mopra data and compare the molecular emission with images from other tracers and other telescopes. You will compile a systematic and uniform database of the physical, chemical, and dynamical conditions in dense molecular clouds before, during, and after star formation. Depending on your interests and abilities, you will also construct theoretical or numerical models of the emission seen, based on the underlying structure of the gas. You will collaborate in these areas with colleagues in the c2d project from around the world.

CHaMP: DENSE GAS AND MASSIVE STAR FORMATION IN THE CARINA SPIRAL ARM OF THE MILKY WAY

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Like c2d (see above), CHaMP (a Census of High- and Medium-mass Protostars) is collecting a large database of properties of medium- and high-mass star formation throughout the Milky Way by looking at several tracers of dense interstellar gas, using the Mopra dish of the Australia Telescope. In collaboration with colleagues from Japan, for the first time we are building a reliable picture of the typical evolution of these rare but powerful engines of galactic ecology, where even a general paradigm has yet to be defined, unlike the case for low-mass star formation. First results include the extreme rapidity of gravitational collapse in massive protostars, and a turbulent structure in the protostellar clouds which is apparently at odds with some current theory. We also see effects of astrochemistry in the images of different molecular species, showing that chemical evolution plays an important role in massive star formation, as it does in low-mass star formation.

We are also surveying these same regions at various infrared wavelengths, using both the Anglo-Australian Telescope and archival astronomy satellite data, in order to characterise the result of the star formation activity we see in the dense molecular gas. In this project, you will analyse all these data and identify the physical, chemical, and dynamical conditions in molecular gas that are required for massive star formation. You will also systematically identify what evolutionary stages can be seen in these regions, derive appropriate timescales for these stages, and compare these results with a number of competing theories.

(2) Stellar Astrophysics & Asteroseismology

ASTEROSEISMOLOGY: PROBING INSIDE STARS USING STELLAR OSCILLATIONS

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Asteroseismology involves using the oscillation frequencies of a star to measure its internal properties. Measuring stellar oscillations is a beautiful physics experiment: a star is a gaseous sphere and will oscillate in many different modes when suitably excited. The frequencies of these oscillations depend on the sound speed inside the star, which in turn depends on density, temperature, gas motion and other properties of the stellar interior. This analysis, called asteroseismology, yields information such as composition, age, mixing and internal rotation that cannot be obtained in any other way and is completely analogous to the seismological study of the interior of the Earth.

Many stars, including the Sun, are observed to oscillate. Asteroseismology is a new and rapidly developing field and there are several possible Honours projects, depending on the preference of the student. These range from using observations of red giants taken over many decades by amateur astronomers, to obtaining high-precision Doppler measurements of sun-like stars with large telescopes such as the AAT and the VLT.

SWIRLING GAS AROUND A BLACK HOLE

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A0620−00 is a binary star system consisting of a normal star orbiting around a black hole, one of a class of objects known as low-mass X-ray binaries. The normal star is feeding gas into the black hole via an accretion disk, which produces bright emission lines which we can detect with optical telescopes. A0620−00 last had a major outburst in 1975, at which time it was the brightest X-ray source ever seen. Since then it has been quiescent. It is still producing X-rays at a vastly reduced rate, and these X-rays are illuminating the disk and producing the emission lines we see in our spectra. However, the details of the emission mechanism are not understood.

In this project, you will analyse optical spectra from the ANU 2.3m telescope at Siding Spring Observatory to uncover the physical mechanism(s) producing the emission lines in A0620−00 and other low-mass X-ray binaries. There is also a possibility of the honours student observing with the 2.3m telescope to obtain new spectra, which would be reduced and analysed as part of this project.

WIND COLLISION IN MASSIVE WOLF-RAYET BINARIES: THE PINWHEEL NEBULAE

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Wolf-Rayet stars are the last stable phase in the lives of blue supergiants before they are annihilated in a supernova explosion. They have long fascinated astronomers with their unique emission-line spectra which originate in fast (1000 km/sec) stellar winds. In a binary system, these winds can produce dramatic fireworks: a small number of colliding-wind binaries studied at extremely high angular resolution show elegant dust plumes with an intuitive geometry: that of an Archimedian spiral. This is a classic 'lawnsprinkler' spiral produced with a rotating flow injection into a radially divergent flow. A great deal of fundamental information on the binary and the winds is encoded in these structures, ultimately teaching us about dust formation and wind-wind collision zones in these fascinating systems. The project consists of analysis, modeling and interpretation of data from the Keck telescope (near infrared and mid infrared data; both interferometry and adaptive optics) in addition to radio observations with the Australia Telescope Compact Array.

More information can be found at http://www.physics.usyd.edu.au/∼gekko

(3) Theoretical Astrophysics

ELECTRON CYCLOTRON MASER

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Electron cyclotron maser emission (ECME) is the emission mechanism for very bright emission from the Earth below 500 kHz (called AKR), from Jupiter below 40 MHz (called DAM), for certain solar bursts (called spike bursts), and for very bright radio emission from flare stars. An older theory, based on ECME from a loss-cone distribution, was successful in explaining some features of DAM and AKR, and also of the solar and stellar emissions, but with a major proviso: it is unclear how the radiation can escape due to stop band and absorption bands encountered along the escape path. A more recent theory, based on ECME from a ring distribution, can explain important aspects of AKR, but with a similar proviso: the emission can escape only if there is essentially no cold plasma in the emission region or along the escape path.

This project will involve reviewing the existing theory, concerning ECME due to both types of distribution, comparing and contrasting them, together with a critical analysis of the conditions under which the emission can escape for AKR; DAM and the solar and stellar forms of ECME.

Interested students must have a strong mathematical background and a willingness to learn the necessary plasma dispersion theory.

BUILDING A SHOT-NOISE SOLAR CORONA

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Solar flares are large explosions in which magnetic energy is liberated in the solar corona, the extended outer atmosphere of the Sun. The solar corona is at a temperature of around two million Kelvin, the high temperature being maintained by an unknown heating mechanism. It is appealing to link these two processes. It is possible that coronal heating is due to the continual occurrence of small, spatially unresolved flares (nanoflares), as argued by Parker and others. Although this idea has been pursued in a number of ways, the consequences for observed statistics of coronal X-ray emission have not been considered in detail. If coronal heating is due to nanoflares, the observed emission should represent the random superposition of basic structures (flare time histories), and hence should have shot-noise statistics. Simple models for shot noise are available. In this project we will consider the application of these models, and infer properties of the elementary flares from coronal X-ray observations. The work will involve analytic calculation as well as numerical simulation and data analysis.

HIGH ENERGY EMISSION FROM MAGNETARS

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Soft-gamma ray repeaters (SGR) and anomalous X-ray pulsars (AXP) are thought to be magnetars, which are rotating neutron stars with an extremely strong magnetic field ($\sim 10^{11}$ T). This special class of pulsars is very different from normal radio pulsars. Radiation from normal pulsars is driven by the star's rotation energy, while high energy emission from magnetars are predominantly powered by decay of the magnetic field. This project will study how the magnetic energy is dissipated in the magnetar and how this dissipation leads to X-ray emission.

Research Projects in Biophysics

SIMULATING PROTEIN UNFOLDING AT HIGH TEMPERATURE

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Proteins are produced in a string form in cells and fold to their 3-dimensional native states within seconds. How this happens is one the most interesting problems in biophysics today. While it is still beyond our reach to simulate the folding process in the native environment of a cell, we can learn from the reverse process of unfolding by speeding it up using higher temperatures than the body temperature. The project involves molecular dynamics simulations of some functionally important proteins at several different temperatures and analysing their structural properties to assess the degree of unfolding.

POLARIZABLE FORCE FIELDS IN MOLECULAR DYNAMICS SIMULATIONS

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Practically all the force fields employed in molecular dynamics simulations of biomolecules neglect polarization interactions among the atoms. Computational expense used to be the main reason for this approximation but this is no more an excuse. Nevertheless lack of compelling evidence showing the importance of polarization effects is hindering development of polarizable force fields. One area where one may find such evidence is the temperature dependence of the transport coefficients of ions (conductance and diffusion), which are grossly underestimated by the traditional force fields. The project involves calculation of the transport coefficients of ions using a polarizable force field at several temperatures. An improved agreement with the experimental data will provide a clear signal for the importance of polarization effects and thus will help to stimulate development of polarizable force fields.

BROWNIAN DYNAMICS OF TOXIN BINDING TO ION CHANNELS

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Computer simulations of biomolecular reactions provide complementary, dynamic information on biological processes that often cannot be accessed by experiments. So far most simulation studies of biomolecules have been carried out using molecular dynamics (MD). MD provides an atomic resolution description of a system but it is limited to the nanosecond time domain. Hence it is not very useful for biomolecular reactions that take place over much longer periods. In contrast, in Brownian dynamics (BD) only the trajectories of the interacting molecules are followed, which allows orders of magnitude longer simulation times compared to MD. The aim of this project is thus to develop the

BD formalism in the relatively simple setting of a toxin binding to a potassium ion channel, whose molecular structure has recently been determined. Toxins and drugs interfere with normal channel operation with sometimes lethal consequences. Therefore, a detailed understanding of their interactions with ion channels would also have important ramifications for drug development.

ION PERMEATION IN CARBON NANOTUBES

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Carbon nanotubes have many potential applications in biotechnology, medicine, electronics and materials science. An interesting question that may have important ramifications in biotechnology and medicine is whether they can be made to function like ion channels. The project will investigate the permeation properties of carbon nanotubes using molecular dynamics simulations. Steered MD simulations and/or umbrella sampling method will be used to calculate the free energy profiles of ions crossing a nanotube. Issues to be addressed include: size (radius and length of the nanotube) dependence of ion conduction and modification of the nanotube structure so as to make it charge selective.

UNDERSTANDING THE ROLE OF P2X7 RECEPTOR IN DEATH OF IMMUNE CELLS

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The nucleotide ATP has a profound effect on the T cells of the immune system – when present in sufficient concentrations, it eventually leads to death of T cells. The membrane protein P2X7 receptor forms a cation conducting channel in T cells that opens upon binding of ATP. Prolonged exposure to ATP, however, turns this channel into a large pore that conducts all types of ions as well as fairly large molecules. This loss of selectivity is the main cause of cell death. The mechanism of pore formation in T cells have been the focus of many physiological studies recently. These studies suggest that presence of ATP does not cause dilation of a single P2X7 receptor but rather leads to an aggregation of several P2X7 molecules that form a large hole in the membrane wall. The aim of this project is to construct a simplified model of P2X7 receptor and study their behaviour in membrane using stochastic dynamics. Comparison of results with and without ATP binding will provide important clues on the pore formation process in T cells. P2X7 receptor has also been found on all synaptic terminals in the brain so far investigated. Thus the mechanism studied in this project may also be implicated on the onset of neurological diseases.

Research Projects in Complex Systems

(1) Brain Dynamics

STATISTICAL PROPERTIES OF THE EEG

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Electroencephalographic signals show a large degree of randomness. However, litt le work has been done on the statistical properties of EEG potentials, which can reveal such features as nonlinearities in the underlying dynamics. Of particular interest is the possibi lity of obtaining an EEG "standard candle" to allow calibration of brain-level potent ials from scalp-level recordings, something never achieved to date. Using insights from sl eep research and cellular-level biophysics, we hope to formulate such self-calibration methods , based on statistical properties of the EEG. This would remove one large source of uncerta inty that has persisted for decades in EEG measurements.

NEURODYNAMIC DRIVE OF THE BOLD RESPONSE

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When a region of the brain is active, its metabolism increases, burning oxygen and increasing demand for blood flow. Resulting changes can be observed using magnetic resonance imaging (MRI) to obtain functional MRI images. Much remains to be understood about the relationship between these images, the neural activity, and the underlying stimuli. This project will extend our work on blood-flow (hemodynamic) modeling to understand spatial aspects of fMRI, which have been largely neglected so far, but which are expected to be critical to a full understanding of what fMRI images really mean. Some interpretation of fMRI experiments carried out at Westmead Hospital may also be involved.

NONLINEAR SLEEP DYNAMICS

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No-one knows exactly why we sleep. In part, sleep onset is governed by a balance between driving by the day-night (circadian) cycle, and the need to remove metabolic byproducts that have built up during the day. This project will extend and test a nonlinear model being dev eloped for these processes and their action on the brain in order to better understand the dynamics of the sleep cycle, and its disorders, including effects like jetlag and sleep deprivation. Potential applications also exist in alertness prediction and monitoring.

SYNCHRONIZATION OF NEURONS IN BRAIN

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Synchrony of neurons in brain has been studied to explore brain diseases such as Parkinson's and eppilepsy, which generally show excessively synchronized behaviors. For example, Tass modeled the neurons as phase oscillators and suggested several methods to therapeutically desynchronize the neurons. Although he qualitatively described many phenomena successfully, his method still needs some improvement. We thus propose a new method that replaces the abstract phase-oscillator variable by a dynamical variable that can be physiologically measured. We will use a physiology-based brain model to describe the dynamics of this variable. Conditions for achieving synchrony will be investigated and related to electroencephalography measurements.

IMAGING THE FUNCTIONING BRAIN: TEMPORAL DELAY IN BOLD RESPONSE

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In order to understand the functioning of the brain it is important to be able to measure and image its neural activity changes. Such an imaging technique should be noninvasive; i.e., not involve having to cut into the skull. Active neurons are known to have increased oxygen consumption, and thus regions of increased brain activity show local deoxygenation of their blood supply. In an MRI scanner it is possible to measure this local deoxygenation via the so called Blood Oxygen Level Dependent (BOLD) MRI signal. Thus BOLD measurement is an indirect probe of neural activity and the brain's functioning. BOLD imaging is very widely used by neuroscientists to understand brain function due to its fine spatial resolution. However, to properly understand the significance of BOLD measurements it is necessary to link the measured BOLD signal to the underlying activity of neurons. This is an area of extremely active research as models of this link between neural activity and BOLD response are necessary to allow better interpretation of studies of brain function based on BOLD imaging.

Recently, we have analyzed a widely used temporal BOLD response model (the Friston-Obata model) and have been developing the first detailed spatial/temporal BOLD response model. Other researchers have proposed an additional time delayed BOLD response to account for inadequacies in the Friston-Obata model. The aim of this project is to explore and analyze numerically and analytically the delayed BOLD response and to estimate bounds for the size of delay effects from existing published experimental data. An extension of the project to include proposing delay terms for the spatial/temporal BOLD response model may be possible if time permits.

MECHANISMS OF NEURAL ADAPTATION

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When the two eyes view conflicting or incompatible images the visual system is thrown into oscillations, so that first the image from one eye is visible, followed by the image from the other eye. This response is often provoked by presenting horizontal stripes to one eye and vertical stripes to the other, for example, and is termed binocular rivalry. An important ingredient of these oscillations is thought to include spike-rate adaptation, a process whereby neurons responding to one eye become highly active for a characteristic time before tiring, allowing neurons responding to the other eye to dominate in turn. Adaptation is also thought to be important for functions such as short-term memory, contrast sensitivity, neuronal plasticity, and attention.

Recently, we have modeled adaptation using a mean-field model of brain activity by including negative feedback over large timescales. The aim of this project is to investigate adaptation using two different mechanisms of negative feedback acting simultaneously on a single population of neurons. Limit cycle oscillations are expected to occur, and more complicated behavior may also be possible. Extension of the project to include two different populations of neurons may be possible if time permits. The emphasis will be on understanding how this phenomenon contributes to binocular rivalry.

(2) Nanotechnology/Nanoscience, Surface Science & Plasma Applications

ORIGIN OF SYMMETRY & SELF-ORGANISATION IN SUB-NANO LARGE-SCALE PATTERNS

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The behavior of ultra-nanosized objects, that consist of just several atoms, determine in a great extend the further development of the whole ensemble; that is why it is so important to set a proper control and direct the system to the “proper” way at the ultra-nano stage. This project is aimed to the development of the model and simulation code able to describe the origin of order and symmetry in the ensembles of sub-nano Quantum Dots Nuclei (QDN) consisting of 10..100 atoms. At this stage, the QDNs still can move about the surface, yet not so fast as the adatoms. The QDNs stage should be modeled in terms of “affected diffusion”, i.e. QDNs diffusion that causes origination of the long-scale order. The diffusion mobility of the QDNs is relatively large, this outlines a set of physical phenomena involved: stochastic diffusion of sub-nano QDNs consisting of 5..20 atoms, interchange of energy between the sub-nano QDNs via evaporating/attaching adatoms, diffusion of sub-nano QDNs by the surface strain, diffusion of sub-nano QDNs by non-uniform growth in the adatom field. We plan to find several triggering keys that enables as to start an effective self-ordering process in the QDN ensemble, and get eventually a perfect self-ordered pattern.

SELF-ORGANIZED LARGE-SCALE QUANTUM DOT PATTERNS

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The project is aimed to the development of the model and simulation code able to describe the development of order and symmetry in the large (10^{10} nano-objects) ensemble of Quantum Dots (QDs) which consist of 100...10000 atoms. At this stage of the ordering, the QDs cannot move directly about the surface, and their displacement is caused by the following phenomena: displacement by the surface strain, displacement by non-uniform growth in the non-uniform adatom field, displacement by reshaping under affect of surface strain, and displacement by the reshaping under affect of electric field. We are planning to find, by the large-scale numerical simulation, the conditions for the effective self-assembly that is a versatile present-day nanotool. Specifically, we plan to investigate an influence of the key parameters on the self-ordering process, determine the range of the effectiveness, and eventually build an "own" self-ordered pattern. This project can be ideally suited for someone particularly interested in visualizing and animating physical phenomena.

COMPUTER SIMULATION OF PLASMA-ASSISTED FABRICATION OF NANOSTRUCTURED HYDROXYAPATITE BIOCERAMICS FOR APPLICATIONS IN ORTHOPAEDICS & DENTISTRY

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Hydroxyapatite (HA) coatings find numerous applications in orthopaedics and dentistry owing to their excellent ability to promote stronger implant fixation and faster bone tissue ingrowth and remodelling. Thermal plasma spray and other plasma-assisted techniques have recently been used to synthesize various calcium phosphate-based bioceramics. However, the existing techniques fall short to meet the coating requirements imposed by biomedical industry. Recently, an advanced plasma-assisted concurrent sputtering deposition technique of high-performance biocompatible HA coatings on Ti6Al4V implant alloy has been proposed and tested. The plasma-assisted Rf magnetron co-sputtering deposition method allows one to simultaneously achieve most of the desired attributes of the biomimetic material and overcome the problems peculiar to other existing methods. The project will use advanced computer simulations to reveal the optimal conditions when the plasma-generated reactive species can be deposited on the surface and thus take part in the bioceramic fabrication process.

PLASMA-AIDED NANOFABRICATION: ONE STEP CLOSER VIA NUMERICAL SIMULATION

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The aim of this project is to develop the physical principles of nano-scale assembly processes in laboratory, space and astrophysical plasmas. Advanced numerical simulations is a powerful tool to develop novel approaches for tailoring the plasma-grown building blocks in various self-organization processes at nanoscales. Examples of applications of such approaches include but are not limited to plasma-aided nanofabrication of nanodevices, nanostructured films, nanoassemblies with intricate architecture and exotic properties, deposition of ordered nanoparticle arrays on nanopatterned solids, and origin and self-organization of dusty matter in the Universe. The project will contribute to elucidation of fundamentals of the multi-scale dynamic processes in various plasma-solid systems in laboratory and space. This will ultimately lead to the improvement of the existing and the emergence of new techniques for plasma-aided fabrication of new nano- and biomaterials and electronic/photonic devices, as well as global understanding of nanoassembly processes in the Universe. The expected outcomes are highly relevant for the nano-materials and optoelectronic technologies, rapidly emerging areas of high-tech industries worldwide.

CONTROLLED SYNTHESIS OF ION-FOCUSING NANOSTRUCTURES: IMPROVING PREDICTABILITY

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Plasma-aided nanofabrication is an emerging research area at the cutting edge of the physics of plasmas and gas discharges, nanoscience and nanotechnology, materials science and engineering, and structural chemistry [Rev. Mod. Phys. **77**, 489-511 (2005)]. The existing approaches to fabricating exotic nanostructures and functional nanofilms are mostly process-specific and suffer from cost-inefficient “trial and error practices. One of the reasons is that the ability to control in the plasma phase the generation, transport, deposition, and structural incorporation of the building units of such films and structures, still remains elusive. This project will challenge one of the previously intractable problems of how to manipulate the ionic building units in the non-neutral layer of space charge that separates the plasma and solid surfaces. The major aim of this project is to explore, by means of advanced computer simulation, the microscopic topology of ion fluxes in the vicinity of selected functional nanostructures and the arrangement of adsorbed species into nanopatterns on solid surfaces.

NANOSCALE SELF-ORGANIZATION IN PLASMAS OR UNCOVERING NATURE’S MASTERY

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The two major existing approaches to nanoassembly are based on nanomanipulation of individual building units by external means, such as a sharp tip of a Scanning Tunneling Microscope or via self-assembly of subnanometre building units (such as atoms and simple molecules) into nanometre patterns (self-organization). It is commonly known that 99% of the matter in the Universe is in the plasma state. On the other hand, we are not aware of any extraterrestrial intelligence-driven ”manipulator arms” that assemble solid matter in the Universe, which leaves the only one viable, the self-organization, pathway. The project is to reveal, via numerical modeling, how the Nature’s mastery works in the self-assembly of nanometre-sized dust particles in the Universe and of exotic nanoassemblies in laboratory plasmas.

(3) Space Physics/Plasma Theory/ Astrophysics

NEW SCIENCE WITH STEREO

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NASA's two STEREO spacecraft will observe radio emissions generated in the solar corona and interplanetary medium, as well as in situ plasma waves. Multiple unanswered questions exist concerning type II and III radio bursts and the generation of Langmuir and ion sound waves. A number of projects are available to address these questions, ranging from more observational to more theoretical projects.

WAVE GROWTH BELOW THE ELECTRON PLASMA FREQUENCY

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Electron beams drive Langmuir waves just above the electron plasma frequency. Observations also often show waves well above and below the plasma frequency that cannot be in the Langmuir mode. A recent theory suggests that this wave growth can be due to electrons with a loss cone distribution rather than a beam distribution. Observations and recent simulations show loss cone and other localized features on the electron distribution that might drive waves. This project involves analytic and numerical calculations of the wave dispersion equation, as well as some comparisons with spacecraft data, in order to determine whether this theory is quantitatively viable.

PROPAGATION OF RADIATION IN THE OUTER HELIOSPHERE

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The Voyager 1 and 2 spacecraft sometimes observe intense bursts of 2–3 kHz radio waves that appear to be coming from beyond the heliopause, the outer boundary of our solar system which separates solar wind plasma from interstellar plasma. The aim of this project is to develop a quantitative theoretical model, based on a ray tracing code, for the radiation's propagation from the predicted source region into the inner solar system. This project will primarily involve analytic theory and computational work, followed by comparisons with Voyager data.

RADIATION FROM ASTROSPHERES AND SUPERNOVAE

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Shock waves propagating from the Sun to the outskirts of the solar system generate intense radio emissions observed by the Voyager spacecraft. A theory developed at U. Sydney predicts the levels and frequency of the emission quite well. Similar emission is expected from other stars (astropspheres) and from supernova shocks. This project involves applying the existing theory to supernova shocks and to other astrospheres, in order to assess whether they should produce observable emission and contribute to the low frequency radiation (3–100 kHz) observed from the galaxy.

ASTROPHYSICAL ACCRETION

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Accretion is arguably the most prevalent physical process in the Universe. It is important in the birth and death of not just individual stars, but of entire galaxies. In the special case of accretion onto a black hole, the energy conversion efficiency surpasses any other mechanism known in nature. Various projects concerned with accretion onto black holes are on offer. These include:

1. calculating the emission spectrum of a relativistic, magnetised black hole accretion disk and comparing with observational data
2. magnetohydrodynamic turbulence in accretion disks
3. calculating the emission spectrum of relativistic jets coupled to an accretion disk

STOCHASTIC DEPOLARIZATION

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Random wave growth in turbulent plasmas generates waves that scatter off turbulent fluctuations and must random-walk out of their source region. This leads to extended emission tails that persist long after wave generation ceases. Another expected effect is that each scattering should partly depolarize the radiation. This project will calculate this effect and compare it with polarization observations. The results are expected to give better insight into how radio emissions escape their sources to reach space- and ground-based detectors.

ELECTROMAGNETIC STRONG TURBULENCE

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When plasma wave intensities become large, they change the properties of the plasma itself, leading to self-focusing of intense wave packets, which can then collapse to short scales, before dissipating. If such waves are pumped by an energy source, a statistically steady state of *strong plasma turbulence* can develop, comprising intense packets amid a sea of low level incoherent waves. Turbulence consisting of electrostatic waves has been studied for over 20 years, but electromagnetic strong turbulence (EMST) is little understood. This project would involve exploring the properties of two-dimensional EMST using both analytic techniques and numerical simulations. A student with strong programming skills could adapt our codes to do the first ever 3D EMST simulations.

NONLINEAR WAVE INTERACTIONS AND TURBULENCE

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The key to the character of the wave turbulence is in nonlinear interactions of waves. While the three-wave interactions tend to increase chaos in the system, the higher-order four-wave interactions can lead to the self-organization of coherent structures in the developed turbulence. Thus an interesting feature of the four-wave interactions is that due to development of the modulational instability, a reverse process (i.e., from random- phase to coherent) may take place, which is qualitatively different from what is observed for three-wave interactions when the coherence decreases. This project is to explore how four-wave interactions, including modulational processes, change the character of the plasma turbulence and lead to formation of coherent structures (such as solitons in the one-dimensional case). The work involves theoretical analysis of the wave equations complemented by numerical simulations.

ENERGY CONVERSION IN TYPE III SOLAR RADIO BURSTS

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Type III solar radio bursts are produced via energetic electrons which are accelerated locally in solar flares and then ejected as beams into the solar atmosphere. The beams then propagate through the solar atmosphere and persist far into interplanetary space, where they generate plasma waves and type III radio emissions. Understanding of type III bursts from the theoretical viewpoint has been advanced significantly in recent years. However, the nature of type III bursts at the microscopic level is not clear. The aim of this project is to study energy transfer from the beam to plasma waves and electromagnetic radiation from the microphysics viewpoint. The project involves using an existing numerical simulation code to study conversion efficiencies of beam energy into different wave modes participating in type III bursts, and comparison of numerical results with type III emission theory and observational data.

REFORMATION OF SUPERCRITICAL COLLISIONLESS SHOCKS

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Numerical simulations have revealed a strongly nonstationary behavior of shock waves with parameters relevant in heliospheric and astrophysical contexts. This behavior is characterized by cyclical reformation on the spatio-temperal scales of the upstream ion gyroperiod and convected ion gyroradius. The aim of this project is to discover the dependences of shock reformation on background plasma parameters. It will use an existing parallel simulation code on supercomputers, and involve running the code, analysis of simulation data, and use of linear instability theory to interpret the simulation results.

Research Projects in Condensed Matter Physics

NANOSCALE BUILDING BLOCKS FOR THE FUTURE: SEMICONDUCTOR NANOWIRES & QUANTUM DOTS

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Recent reports of successful fabrication of high quality semiconductor nanostructures such as quantum dots, nanocrystallites and nanowires open the door to their potential role as important nanoscale building blocks for future optoelectronic, high-temperature/power and spintronic device applications. While holding exciting potential, little is presently known about the properties of these structures and of the behaviour of defects and dopants in them. Clearly to understand and design the function of such materials, a detailed microscopic knowledge of their atomic and electronic structure is crucial. Using quantum mechanical calculations, various nanostructures will be studied to determine the effect of size and dimensionality, as well as the influence of defects and dopants, on the electronic (and magnetic) properties.

CONDENSED MATTER THEORY OF NANOCATALYSIS: UNDERSTANDING THE THERMODYNAMICS OF OXIDATION

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Iridium, like other late transition metals, shows a wide variety of potential applications as a heterogeneous catalyst in technologically important reactions. Bridging the recent advancement of nanotechnology and heterogeneous catalysis, it is of enormous interest to survey the interface between material and gas-phase, acquiring knowledge of the involved catalytically-active surfaces. Iridium-based materials are potentially important for hydrogen-carbon bond activation, a central reaction step for fuel cell-related applications. In order to exploit this material as an efficient catalyst, it is crucial to obtain an accurate microscopic understanding of the structure and thermodynamics in the appropriate technical environment. This will be achieved through state-of-the-art quantum mechanical calculations to describe the subnano-scale activity in an oxygen-rich environment.

THE ROLE OF INTERFACES IN SUPERHARD NANOCOMPOSITE MATERIALS

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There has been considerable effort in recent years in identifying and developing new and improved super- and ultra-hard materials. Such structures clearly have huge potential technological and industrial applications, but are also of fundamental interest with regard to understanding the mechanisms responsible for the enhanced hardness. In particular, a most challenging quest, to find a material harder than diamond, with superior properties, is proving elusive. One strategy, however, that has lead to promising results is based upon a generic design concept involving self-organized spinodal phase segregation, leading to a nanocomposite, with strong, sharp interfaces between nanocrystalline regions and thin amorphous layers. Clearly, it is of significant importance to understand the origin and extent of the superstrengthening effect and theoretical evidence is needed to verify and understand reported results. This project will involve application of quantum mechanical calculations to investigate the atomic, electronic, and mechanical properties of nanocomposites in order to shed light on the role interfaces play.

PLAYING CHESS WITH ATOMS: USING THE LATTICE GAS HAMILTONIAN & STATISTICAL MECHANICS TO DETERMINE SURFACE ATOMIC STRUCTURES AND PHASE TRANSITIONS

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We are surrounded by surfaces and interfaces. Their properties, and the atomic and molecular processes occurring on them, is crucial to our way of life. A fundamental question in this context is identifying stable and metastable surface adsorption sites and structures, and associated phase transitions. By constructing a Lattice-Gas Hamiltonian, on the basis of quantum mechanical calculations, together with statistical mechanical methods, such as Monte Carlo simulations, such structures and phase transitions can be predicted without recourse to experimental input. This approach will be developed and applied to the adsorption of Xe atoms on the Pb(111) surface, for which there exists interesting and detailed experimental results with which to compare, and will provide an explanation and understanding of the observed behaviour.

MITIGATING CARBON EMIMSSIONS: A COMPUTATIONAL STUDY

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Carbon dioxide (CO_2) is a greenhouse gas that is released to the environment during the use of fossil fuels. The capture and separation of CO_2, being the prior step to storage, is one of the main focuses of the relatively new field of carbon sequestration science. Recycling or reuse of CO_2 from energy systems would be an attractive alternative to the storage of CO_2. One promising pathway would be the use of alkaline-earth oxides such as magnesium oxide and calcium oxide. As an example of the potential of this study, the Department of Energy has reported that the entire global emissions of carbon in 1990 could be contained as magnesium carbonate in a space of 10 km by 10 km by 150 m. The goal of this project is to investigate the conversion of CO_2 into products that are inert and long-lived or stable solid compounds. State-of-the-art quantum mechanics will be used in this study to probe the interface between the oxide and carbonate in a CO_2 rich environment at high temperatures and pressures. This will provide us a microscopic understanding of carbonate formation on these oxide surfaces, affording a first step to better management of carbon emissions.

Research Projects in CUDOS

www.physics.usyd.edu.au/cudos
http://www.physics.usyd.edu.au/cudos/positions/pgrad_prospectus.pdf

EXTREME PHOTOSENSITIVITY IN CHALCOGENIDE WAVEGUIDES

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Chalcogenide glasses have very strong photosensitivity meaning that the refractive index can be permanently increased when exposed to visible light. This property is very useful as it allows for the fabrication of a range of photonic structures in these glasses that form the basis of photonic integrated circuits – the photonic chip. Although very promising for this application, some of the key properties of chalcogenide photosensitivity are not well understood. This will project will investigate experimentally and through phenomenological models, elucidate photosensitivity in chalcogenide waveguides and exploit this extremely large photosensitivity to create very strong Bragg reflectors and other structures.

MID-INFRARED MICROPHOTONICS

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The mid-infrared spectral region is becoming increasingly important for a range of application including astronomy, biological, environmental sensing and defense applications. It is particularly significant for mid-infrared astronomy since it offers the ability to probe the physical conditions and chemistry of heavily dust-obscured regions of the universe, such as super-massive black holes at the centres of galaxies. CUDOS is developing photonic integrated circuits for next generation optical communication systems based on chalcogenide glasses, which are completely transparent at mid-infrared wavelengths. They are thus very well suited for developing mid-infrared integrated components, including optical fibres, diffraction gratings for spectral analysis, splitters and couplers. This project will investigate integrated structures in chalcogenide waveguides for application in mid-infrared wavelengths, specifically the fabrication of optical gratings at mid-infrared wavelengths and initial testing of devices.

OPTICAL TWEEZER ACTUATION OF MICROPHOTONIC ELEMENTS

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This project will exploit the optical tweezer principle, whereby a laser beam can trap and actuate micron-sized objects, to manipulate and control microphotonic structures. While optical tweezers have many biological applications, the aim of this project is to conduct experiments that will investigate different trapping architectures to optimize the trapping efficiency. Trapping measurements will be compared with theoretical calculations that will be carried out using commercial software. Experiments will be performed in the CUDOS Nanophotonics laboratory.

RAMAN GAIN IN HIGHLY NONLINEAR PLANAR WAVEGUIDES

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Light traveling through optical fibres can excite vibrational levels (phonons) in the glass host to produce light with a lower frequency, with the frequency difference corresponding to the phonon frequency – the Raman shift. Because there is a spectrum of phonon energies, the Raman spectrum is quite broad, typically a few hundred nanometers, and it is shifted several hundred nanometers from the wavelength of the incident light. This process is of interest because it is nonlinear: the strength of the Raman interaction grows with pump intensity, so that at high intensities a large fraction of the incident light can be shifted. In this project, you will experimentally investigate Raman scattering in highly nonlinear planar waveguides using ultra-fast, high power modelocked lasers and high-speed detection equipment. This work should lead to the demonstration of a highly efficient broad band Raman source.

GENERATION, PROPAGATION & DETECTION OF 320 Gb/s OPTICAL SIGNAL

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This project will investigate novel schemes based on nonlinear optics for generating ultra-high capacities for transmission in optical fibre communication systems. The challenge in these systems is that the electronic switching required to detected optical signals is limited to bandwidths of less than 40 Gb/s. Detection at higher bit-rates requires principles based on nonlinear optics. This project will utilize the CUDOS Bit-Error-Rate system. State of the art optical transmission test-bed, unique to Australia.

EFFICIENT FOUR-WAVE MIXING & PARAMETRIC AMPLIFICATION IN HIGHLY NONLINEAR CHALCOGENIDE NANOWIRES

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At high light intensities, materials such as glass respond *nonlinearily,* which means that the refractive index depends on intensity. Nonlinear processes also generate light at completely new frequencies. This project will investigate nonlinear processes in highly nonlinear chalcogenide optical fibres that have been tapered to very small (below a micrometer) dimensions. In the waist of this tapered fibre, extremely high nonlinearities can be achieved, leading to a range of fascinating and very useful processes. Furthermore, the tapering allows us to engineer the group velocity dispersion, which means that new frequencies can be generated very efficiently. This project will investigate this process theoretically, using analytic equations and nonlinear simulations, and will perform experiments using such tapers.

MONITORING NOISE IN ULTRA-HIGH BANDWIDHT 160 Gb/s OPTICAL TRANSMISSION SYSTEMS

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This project will investigate schemes that can monitor noise in ultra-high bandwidth optical communication systems, specifically in-band noise, which limits the distances that data can be transmitted. The problem is that at 160 Gb/s, which involves light pulses that are only a few picoseconds long, electronics cannot process the information sufficiently fast. CUDOS is pioneering all-optical methods to monitor noise in such optical communication systems. It relies on nonlinear processes occurring in a waveguide, so that very fast signal fluctuations, i.e. noise, can be monitored using a slow, and thus cheap, detector. This project will investigate new schemes at 160 Gb/s on our newly established facility. We will analyze simple designs using theory and simulations, which will subsequently be tested on the facility.

PARABOLIC PULSES IN HIGHLY NONLINEAR FIBRES

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Under certain conditions *parabolic* optical pulses (known as similaritons) can propagate without changing shape in spite of strong dispersive effects. These pulses require a careful interplay between dispersion, nonlinearity and gain which is difficult to obtain in conventional optical fibres. CUDOS is pioneering a new class of optical fibre based on a highly nonlinear material known as chalcogenide that possesses the properties to generate and propagate parabolic pulses. This project will investigate theoretically and experimentally the propagation of parabolic pulses through highly nonlinear chalcogenide fibres. Sophisticated experiments will be performed using ultra-fast picosecond pulsed lasers and pulse diagnostics.

ULTRA-LONG SILICA PHOTONIC NANOWIRE TAPERS

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Conventional optical fibres guide light in their core, which is 8 to 10 micrometers in diameter. Intuitively we may think of the core needing to be larger than the optical wavelength to guide light effectively. However, recent experiments have demonstrated that optical fibres, when tapered to sub-micrometer dimensions (nanowires) can still guide light effectively. This surprising discovery, and possible applications of it, will be investigated in this project. You will use beam-propagation method techniques to simulate the process, and explore the subtleties of light propagation in nanowires. You will also use existing CUDOS facilities to fabricate nanowires, reducing their optical loss and investigating their potential for a range of applications including environmental sensing.

OPTICAL SWITCHING INTEGRATED IN CHALCOGENIDE LONG PERIOD GRATINGS

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Optical grating structures have been studied extensively in nonlinear optics as the basis of all-optical switching schemes. In these schemes, the nonlinear refractive index is exploited to suppress coupling between different modes, manifesting in intensity dependent transmission and optical switching. One particularly elegant embodiment of these types of structures are long-period gratings, which resonantly couple from the core mode of a single-mode waveguide to higher order modes. Chalcogenide glass-based optical waveguides offers new opportunities for fundamentals studies of nonlinear optical process and applications in optical switching and optical signal processing. These glasses are attractive because of the large nonlinearity, low losses, and a response time of less than 100 fs. The high nonlinearity promises to lower the switching threshold of these devices by several orders of magnitude, opening new applications in optical signal processing, for example in mode locked fibre lasers. This project will investigate optical switching experiments in chalcogenide waveguide gratings. Experimental results will be compared to detailed numerical simulations.

COUPLING LIGHT INTO ULTRA-SMALL PHOTONIC CRYSTAL NANOCAVITIES

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This project will investigate schemes for inserting light from an optical fibre into ultra-small photonic crystal nanocavities. By using the optical nonlinearity of the photonic crystal material, the cavity can be switched from a low to a high-transmission state. The method we use is to suspend an optical fiber a distance about a micrometer above the photonic crystal, which causes the light to couple into the structure. This project will focus on designing sophisticated optical fiber nanowires, which are made by tapering optical fibres and inserting light into the nanocavities. This is achieved by heating the fibre and stretching it gently. Experiments will be performed in the CUDOS clean room nanophotonics laboratory.

MODELLING OF EVANESCENT COUPLING OF LIGHT INTO PHOTONIC CRYSTAL SLABS

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The aim of the previous project is the coupling of light into a photonic crystal slab using a nanowire. The aim of the present project is the modeling of this process, so that we know how to optimize it. The modeling will make use of two different methods: the first of these is an analytic method that is valid when the nanowire is not too close to the photonic crystal. However, this is not the regime in which we wish to work. We therefore also use a second method, which is purely numerical, but can model the process to arbitrary accuracy irrespective of the distance between the photonic crystal and the nanowire. The combination of these two methods is very powerful indeed, and should help us understand the coupling process, thereby optimizing the optical switching.

SUPERCONTINUUM GENERATION ENHANCED BY TUNABLE GRATINGS

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Supercontinuum generation represents a spectacular nonlinear process that generates bright white light in specially designed optical fibres when excited by short intense optical pulses. CUDOS researchers have recently shown that the supercontinuum spectrum can be tailored and enhanced by sending the continuum through a resonant filter, for example an optical grating. This insight suggests that we can modify the spectral enhancement by introducing gratings into the fibres, and even tune the spectrum if we can tune the grating, for example its pitch. This project will investigate experimentally innovative schemes for enhancing and tuning the supercontiuum spectra in different optical fibres using tunable long-period gratings that can be imposed in the core of the fibre. Long-period gratings will be induced acoustically, or via microbends, and will be tuned to optimize the supercontinuum enhancement.

ENHANCED NONLINEAR INTERACTIONS USING SLOW LIGHT

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We have become accustomed to thinking of the speed of light as a constant. In the past few years, scientists have introduced new tools that can make the group velocity of the light higher or lower, or even to stop it completely. This concept is having a profound impact on the optics community from a fundamental science point of view. However, it can also be used in the next generation of communication systems. One key attribute of slow light is that the interaction of light with the underlying medium can be enhanced, simply due to the reduced group velocity. This enhanced interaction can enhance nonlinear interactions, and thus offers an mechanism for reducing switching threshold in optical switching devices. Similarly, the enhanced interaction will enhance efficiencies of modulators. CUDOS researchers has developed highly innovative schemes for slowing light in photonic crystal structures based on propagation of solitons. This project will investigate theoretically and experimentally the potential for exploiting gap soliton slow light schemes for developing ultra-low threshold optical switching structures and other optical signal processing elements.

NOVEL HETEROSTRUCTURES IN PHOTOSENSITIVE PHOTONIC CRYSTALS

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Photonic crystals are structures with a periodic variation of the refractive index. They have many applications, ranging from lasers with very low threshold, to optical switches. The key to many of these applications is the presence of a cavity, a region where the field can be confined by reflection, leading to high intensities. In this project you will devise new ways to achieve such light confinement in photonic crystals using *photosensitivity:* the property that the refractive index of a material can be changed permanently by irradiation of light if suitable wavelength. The project will not only develop new ways to generate and/or tune defects, but these nanoscale structures also offer great promise for research into fundamental physical laws that rule light behaviour.

SLOW GAP SOLITONS IN RANDOM MEDIA

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Periodic structures, like photonic crystals and fiber Bragg gratings, are key elements of optical computing and signal processing. High-intensity light can propagate in such periodic structures as gap solitons, stable and robust pulses that can travel at any velocity between 0 and the speed of light. In recent experiments we observed speeds as low as c/6 in a glass fibre with refractive index below 1.5. Gap solitons can therefore be used as a basic carrier of information in optical systems. However, material imperfections and peculiarities of the technological processes always introduce randomness of the parameters of photonic structures. The aim of the project is to study theoretically and numerically the formation and dynamics of gap solitons in random periodic media. We will also analyze how the nonlinear switching of light in periodic structures is affected by the randomness.

LOCAL DENSITY OF STATES OF FINITE CLUSTERS OF NON-CIRCULAR CYLINDERS

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One of the exciting properties of photonic crystals (PCs) is their ability to modify the radiation properties of atoms placed inside them. Whereas an ensemble of atoms in free space spontaneously emit photons at a given rate, in a PC the rate of emission can be drastically enhanced or suppressed. This property holds the promise of useful applications such as highly efficient LEDs and ultra-low threshold lasers. Formally, the emission rate is described by the Local Density of States (LDOS) which is just the number of electromagnetic states that exist at a particular site in the crystal. We have developed analytic and numerical procedures for calculating the LDOS for photonic crystals and have found that the LDOS depends sensitively on the overall shape. In this project we will investigate the underlying reasons for this sensitivity and how it may be exploited in future devices.

PROBING "HEAVY MASSLESS" PHOTONS IN SLAB PHOTONIC STRUCTURES

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One of the most exciting phenomena in photonic crystals physics is the slowing down of light propagation through an astute management of multiple scattering. In this slow-light regime the electromagnetic energy density can be huge, and therefore, optical non-linear effects are greatly enhanced. However, because slow-light tends to be associated with the electromagnetic modes of an infinite crystal, confining slow-light photons to a particular region of the crystal can be a challenge. The main objective of this research project is to understand the confinement and scattering properties of slow-light in photonic crystal slabs. A combination of analytical and numerical tools will be used to study the interaction of slow photons with their environment. We will "poke and probe" at slow photons to assess how sensitive or immune they are to defects and disorder. The knowledge and tools developed in the course of this project will lead to a better understanding of enhanced nonlinear optics associated with slow-light in a photonic crystal structure.

LIGHT FORCES IN CLOAKING METAMATERIALS

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There has been much recent excitement in physics around metamaterials, structured materials especially designed to have extraordinary optical properties. For example, light can be refracted in a left-handed or negative way, meaning the refracted ray is on the same side of the normal as the incident wave, rather than the opposite side. This enables a slab of suitable material with flat sides to behave like a perfect lens. During 2006, a second exciting application has started to be investigated: their use in cloaking, the hiding of objects from a probing electromagnetic wave, or, in other words: making them invisible. Sir John Pendry, a colleague from the UK, has proposed cloaking using a layer with effective refractive index of zero, which excludes electromagnetic rays from the space inside the layer. One of us recently proposed a method in which a coated cylinder acts as a resonant system and cancels out the response of any polarizable molecule sufficiently close to it. In this project, you will consider the trajectory of a polarizable particle moving close to one of these resonant cloaking cylinders, and calculate the forces acting on the particle. You will also consider interactions between several particles, vying to cloak each other. The project will involve both analysis and numerical simulations.

IMPEDANCE OF PHOTONIC CRYSTALS AND WAVEGUIDES

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Impedance is a useful concept can be applied to a large variety of physical structures, including photonic crystals. It condenses the properties of a structure on one side of an interface into a single (complex) number. We recently succeeded in defining the impedance of a photonic crystal in a rigorous fashion and now wish to put this method to good use. We want to study the properties of inhomogeneous waveguides inside photonic crystals, and to the describe the properties of entire surfaces, where the impedance gives the reflectivity of incident light. We then use the impedance to design these surfaces, in particular the terminations, to design and analyze photonic crystals with minimal reflection at the interface so that the light can be coupled in efficiently.

ANTI-RESONANT REFLECTION PHOTONIC CRYSTAL FIBRES WITH LIQUID CRYSTAL INCLUSIONS

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Photonic crystal fibres exist in a range of different classes. Most attention has focused on fibers with air holes, both solid core and air core, resulting in unusual dispersion, very-high or very-low nonlinearity, and remarkably low loss. In another class of fibers the light is confined in a low index core by a lattice of surrounding high index inclusions by a subtle anti-resonant reflection effect. The inclusions are created by inserting fluids into the air holes of a standard fibre. Aside from the intrinsically interesting guidance mechanism, these fibers show strong potential through the large range of materials that may be inserted into the holes. We want to exploit the peculiar optical properties of liquid crystals. Anti-resonant reflecting fibres with liquid crystals should display useful dispersion and a high degree of tunability. This project would commence with a theoretical study of the mode properties, but could also involve a significant experimental component.

AN ANALYTIC ROUTE TO ARROW FIBRES

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Photonic crystal fibres (PCF) are a new kind of optical fibre in which light is guided by microscopic air holes running along the fibre. Compared to conventional optical fibres they offer exciting properties, most of which still remain to be explored. Of particular interest, notably for sensing, are so-called ARROW fibres, PCFs in which the holes are infiltrated by liquids. The way ARROW fibres guide light depends on the optical properties of each hole taken separately, but also on how putting holes next to each other modifies these properties (coupling of holes). While the properties of a single hole are well understood, the effects of the coupling of the holes remains largely unexplored. This project will aim at studying analytically and numerically the coupling between holes and how they affect the hole's properties, yielding a much better understanding of the guidance mechanisms of light in PCFs.

BULLETS OF LIGHT IN FLUID FILLED FIBRES

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When light propagates in a homogeneous medium, it diffracts, meaning that any beam expands laterally while it propagates. For example if one takes the best laser beam, which looks like completely parallel rays of light when it comes out of the laser, and points it to the moon, the spot size on the moon will be of several kilometres in diameter. This is a fundamental physical phenomenon, linked to the Heisenberg uncertainty principle, and cannot be avoided. However, when very intense light propagates in some materials, it can change the properties of matter to a point where the material will act as a lens, compensating the natural diffraction. In such a case, light doesn't expand anymore, and forms "bullets" called spatial solitons. Solitons are immensely interesting in fundamental physics as well as for all-optical signal processing. Solitons come in different forms and shapes, but some of the most interesting ones are those found in waveguide arrays. So far experiments on solitons in waveguide arrays involved very complicated experimental setups with numerous well adjusted lasers. This project will aim at demonstrating spatial soliton propagation with a much simpler setup, using fluid filled photonic crystal fibres to create the required waveguide array.

Research Projects in the Electron Microscope Unit (EMU)

ANALYSIS OF ELECTRON DIFFRACTION PATTERNS

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Crystal structure is a fundamental parameter in designing or characterising the microstructure of engineering materials. The process of structure determination involves the identification of the crystal system, the lattice parameters and the assignment of point and lattice-space symmetry. These parameters have direct significance on the misfit, orientation, crystallographic form and stability of second phases such as precipitate particles. It is noteworthy that the technology underlying applications involving a wide range of high strength low alloy steels and aluminium alloys depends on the presence of nanoscale phases possessing critical values of these parameters. Conventional methods of measurement of electron diffraction patterns have, under usual operating conditions, limiting accuracies of 1.5 – 2%. The Electron Microscope Unit possesses a digital image acquisition system on various instruments for analytical scanning transmission electron microscope. This allows the digital acquisition of selected area and convergent beam electron diffraction patterns. This type of attachment remains rather new and the recent networking of these facilities has improved the ease of image handling, analysis and archiving. In addition to providing engineers with opportunities to extract information easier and faster than conventional (film based) methods, this attachment may also represent an opportunity to extend the usual range of accuracy possible in the measurement of the geometry of electron diffraction patterns. This project will involve the development of methods for the analysis of digitally acquired electron diffraction patterns and the application of these methods to the solution of several critical crystallographic problems from a variety of technologically significant alloys, where there is current interest to distinguish the lattice parameter of precipitate phases to ¡ 1%. An approach involving the calibration of the ultimate accuracy of a range of analysis methods with standard crystal structures will be explored. The student will develop an appreciation of the engineering significance of the alloy systems and the phases under study, skills in electron microscopy and image acquisition and analysis.

METALLOGRAPHY OF TEMPER EMBRITTLEMENT

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Temper embrittlement is associated with an increase in the fracture appearance transition temperature (FATT) when alloy steels are heated in, or cooled slowly through the critical temperature range $345 - 540°$ C. The degradation on mechanical properties is related to a co-operative segregation of impurity elements such as Sn, P, Sb and alloying elements such as Mn, Si, Ni and Cr to grain boundaries. The segregation is not uniform, presumably because of variations in grain boundary structure and energy. Variations in the degree of segregation and therefore embrittlement exist between matrix phases, (notably between tempered martensite and tempered bainite), variations in grain size and the presence of precipitates; (i.e.) temper embrittlement is highly sensitive to microstructure. A sample-set from an ex-service power generation turbine rotor steel is available for this project. The samples exhibit a wide range of FATT's induced through variations in service conditions and through heat treatments which accelerate the embrittlement process. These samples will serve as the basis of a metallographic investigation involving light-optical microscopy and electron probe microanalysis using wavelength dispersive X-ray spectroscopy. It is intended to relate the etched microstructure to the results of microanalysis so as to relate microstructure, solute distribution and impact strength in this important class of steels.

MODELLING OF HEATER TUBE DAMAGE IN PETRO-REFINING PLANT

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Low carbon-manganese steels are widely used as heater tubes in the Australian petrorefining industry. These tubes carry oils and unprocessed hydrocarbons at elevated temperatures and are therefore susceptible to the degradation process known as coking. This involves the formation of carbon (coke) on the inside of the heater tube and results in a deterioration of the heat transfer properties of the steel. The tube areas adjacent to the coking regions heat up resulting in spheroidisation of the pearlitic carbides. Materials Scientists and Engineers seek to assess the structural integrity and remaining life of these components through an assessment of their microstructure, since the degree of spheroidisation during elevated temperature service acts as an internal timetemperature recorder. The present project aims to extend work started in 1997 to develop a tempering parameter which will relate details of the structure and chemistry of the ferrite-pearlite microstructure to the effective service heat treatment and, therefore, the structural integrity. This project will involve mainly an examination and refinement of models for the spheroidisation process and their application to an ASTM A106 grade B carbon steel, which is widely used as heater tube material. In doing so, the student will utilise a systematic set of microstructural data recently acquired for this steel. The project will also involve light optical and analytical scanning electron microscopy and liaison with industrial colleagues at HRL Technology Pty. Ltd.

GENERAL CALIBRATON OF AN ENERGY DISPERSIVE X-RAY SPECTROMETER

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The technology of many engineering materials depends on the stability of nanoscale precipitate dispersions. This stability is directly linked to the precipitate microchemistry and the solute distribution near the precipitate/matrix interface. A quantification of these vital engineering parameters requires analytical scanning transmission electron microscopy (ASTEM). The aim of this project is perform a general calibration of the energy dispersive X-ray spectrometer attached to the VG STEM in the Electron Microscope Unit. It is intended to assemble a viable range of standards and describe the K, L and M emissions over the energy range covering $1 - 20$ keV of the detector. The applications component of this project involves the preparation of extraction replicas and the analysis of precipitate particles in a Cr-Mo pressure vessel steel, where damage due to creep and embrittlement during elevated temperature service are concomitant with subtle changes in the chemistry of precipitate particles. Since the precipitate chemistry may act as an internal timetemperature recorder of the component, quantitative microanalysis can provide engineers with a predictive capability for the remaining life of in-service components.

CHARACTERISATION OF WELDED PIPING FOR PETRO-REFINING PLANT

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Steels alloyed with Cr and Mo are widely used as heat exchangers and pressure vessels in the Australian petro-refining industry. Engineers often seek to assess the structural integrity and remaining life of these components through an assessment of their microstructure, since the degree of microstructural damage during elevated temperature service acts as an internal time-temperature recorder. The present project aims to apply advanced analytical electron microscopy to characterise an ex-service 1.25Cr-0.5Mo (wt.%) piping steel. It is intended to determine the primary damage mechanisms that operated during service, to examine the effect on microstructure of repair welding on selected sections and to use mechanical testing to compare the structural properties of the heat affected zone to the bulk alloy microstructure. This work will be partially sponsored by BP (Bulwer Island).

TELEPRESENCE (WEB-BASED) MICROSCOPY

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Previously the motorisation of microscopes was as simple dumb fittings with minimal direct computer integration. The new generation of light microscopes however have introduced the concept that the motorised microscope can be controlled by computers that are internet aware. This allows both the image acquisition and the control of the microscope functionality to be handled by the same computer interface. Whilst this increases the ease of use of the microscope in on-site applications a logical extension of this increased functionality is to facilitate off-site control via Telepresence microscopy. This research project aims to establish a working telepresence platform so that technical issues regarding such external access can be elucidated and addressed. Students with a background in computer science or engineering would be particularly well suited to this project however students from any discipline with an interest in microscopy and web interface programming are encouraged to apply.

THREE-DIMENSIONAL IMAGE ANALYSIS TECHNIQUES

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Three-dimensional microscopy is emerging as one of the most powerful tools of the new century. With the development of new modes of microscopy 3D imaging has also undergone considerable growth and application. This is particularly the case for light microscopy where confocal microscopy continues to expand its range of application, but is also a feature of new techniques such as tomographic cryo-electron microscopy and nanoscale ion probe technologies. To date the vast majority of 3D imaging that has been applied in microscopy was directed towards visualisation and modelling. This elucidates structure and form relationships and presents then in a manner which makes vast amounts of data accessible to visual interpretation, but in general does not allow quantitative analysis of the visualized structure. This project has as its aim the development of software tools which overcome this limitation, with an underlying thesis that such tools will provide new insights into the structure and integrity of three-dimensional microscope derived data sets. In specific terms the project will:

1. Develop an interactive interface for probing of 3D visualizations with simple measurement tools for volume estimation, surface area estimation, 3D point-to-point distance metrics, geodesic distance metrics, angular alignments, surface curvature parameters and surface energy estimation.

2. More complex measurement tools will then be added to the platform. Development of these tools will have as a foundation the concept that the measured parameter must relate to the three-dimensional nature of the data set. This could include such parameters as:

- Surface continuity (ie. Are there breaks in a surface, and if so at what frequency are they likely to occur, with reference to both specified directions and random interaction with this surface).
- Surface roughness or energy
- Space filling density (ie. Fractalness)
- Three-dimensional co-occurrence
- Data pruning and model fitting to reveal structural primitives and base components
- Volume density variability (ie how homogeneous are one or more classes of object distributed within a three-dimensional region of interest).

This leads naturally to defining measures of such things as ”layeredness” or ”clumpyness” in volumetric spaces. Application of these measurement tools will be made to specific data sets to determine if it is possible to make quantitative statements regarding either natural or induced conformational changes in the objects visualized. This project will develop a much needed microscope resource whilst providing students with opportunities to develop skills in 3D image analysis, system development and computational science and engineering.

SPM vs. TEM FOR CONDUCTIVE MOLECULES

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Scanning probe microscopy (SPM) techniques such as STM and AFM have caused a revolution in chemistry and physics since their invention in the 1980's and are often hailed as the single most important tools of the emerging field of nanotechnology. Unfortunately, these techniques are not very tolerant in terms of the samples and substrates that can used, greatly limiting their usefulness. The development of conductive molecules requires detailed knowledge about their structure and properties on a given surface if molecular electronics devices based on these compounds are to become reality. Recently, we started working with a novel ”phase-imaging” transmission electron microscopy (TEM) technique that is much more tolerant in regards to the sample/substrate problem than SPM. The idea behind this project is to take (and possibly synthesise) several conductive molecules and compare SPM techniques with ”phase-imaging” TEM to obtain a clearer picture of the properties of these molecules. See also: http://www.chem.usyd.edu.au/thordap

Research Projects in High Energy Physics

NEUTRINO DETECTION IN BELLE

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Belle is an excellent detector for identifying most of the charged and neutral particles that are produced in the electron-positron collisions that we study. Neutrinos, however, are a different proposition; they interact so weakly with matter that they leave the detector (and usually the galaxy) unseen. Many important decays that are studied with Belle produce neutrinos, so this is a problem. What can be done, however, is to use all of the particles that are detected, and knowledge of the incoming beam energies, to try to reconstruct the neutrino. This project will study the problem of neutrino reconstruction in Belle in a systematic way and try to devise ways to improve it, building on a considerable amount of work already done within the group on this topic. It will involve the study of real and simulated data and will be computer analysis oriented, so some programming skills and knowledge (or desire to gain knowledge) of the C++ programming language would be helpful.

FULLY RECONSTRUCTED B MESON DECAYS

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Searching for B meson decays to a particular final state involves selecting the correct particles from the B in amongst all the particles observed in the event. The complications are that two B mesons (a particle-antiparticle pair) are produced and one does not know a priori which particles came from which B. There is also the problem of eliminating backgrounds from events in which no B mesons were produced at all. If we have found a candidate B decay, we can try to see if the remaining particles in the event are consistent with coming from a corresponding antiparticle B meson, thus fully reconstructing the event. Whilst this is likely to be possible only in a small fraction of cases, such a sample of events is essentially background free.

This project will investigate ways of improving the efficiency of this technique, and use it to look for selected rare decays of B mesons. It will involve the study of real and simulated data and will be computer analysis oriented. Some programming skills and knowledge (or desire to gain knowledge) of the C++ programming language would be helpful.

RARE THREE BODY DECAYS OF B MESONS TO SPINLESS FINAL STATES

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Belle has studied CP violation in the B meson system using a number of different final states which are CP eigenstates, accessible to the decay of both B and its antiparticle. The results to date are consistent with the Standard Model predictions. B mesons decay in a large number of ways, and because Belle has a huge set of data, some of the rarer decay modes (at the level of 1 in a million probability or smaller) are now starting to be observed. Rare decays to CP eigenstates are of great interest for further investigation of the phenomenon of CP violation, since the effects of new physics will be easier to see. There are a number of such decays to neutral final states which can be searched for in this project, and we can build on work which was performed in an honours project in 2004. Some programming skills and knowledge (or desire to gain knowledge) of the C++ programming language would be helpful.

SPECTROSCOPY USING INITIAL STATE RADIATION EVENTS AT BELLE

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Some of the most interesting particle physics results in recent years have been observations of new charmonium-like states, some of them unexpected. The Belle collaboration has taken a leading role, with the discovery of the $\eta_c(2S)$, the $\chi_{c2}(2P)$, the $X(3940)$ and the $X(3872)$: the last of these may be a bound state of a D^{*0} and a $\overline{D}^0$ meson, the first object of this kind to be seen. The $Y(4260)$, recently discovered by the BaBar collaboration, may be a so-called hybrid meson ($c\bar{c}g$), likewise the first such state to be observed.

Belle has collected the world's largest sample of e^+e^- annihilation data, running at the $\Upsilon(4S)$ resonance ($10.58\,\mathrm{GeV/c^2}$), and has taken an unique dataset at the $\Upsilon(5S)$ ($10.86\,\mathrm{GeV/c^2}$), an order of magnitude larger than any other experiment. Both samples are well-suited to studies of charmonium and "hidden beauty" states using initial state radiation events, both directly (such as the $Y(4260)$) and via decay from other states (such as $\Upsilon(3S) \to \gamma\chi_b(2P)$, $\chi_b(2P) \to \gamma\Upsilon(1D)$). An analysis of the $Y(4260)$ is already being performed at Sydney using Belle data, and tools and expertise are being developed to facilitate further studies. There is an opportunity for an interested student to study the properties of several known states (some of them still poorly-understood); to conduct a systematic search for new mesons; or to otherwise exploit this largely-unexplored data in innovative ways.

SIMULATION OF LOW ENERGY ELECTRONS IN THE ATLAS DETECTOR

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Monte Carlo simulation of events in the highly complex ATLAS detector is a extremely demanding in terms of computer resources, given the huge sets of events that are needed to match the staggering event rates of the real detector. Simulation is based on the GEANT4 package which is pervasive in particle physics research. The limiting factor is the time it takes to simulate electrons, which shower readily in material producing large numbers of secondary electrons and photons. We have been involved in the development of so-called *fast simulation* algorithms which replace the time-consuming conventional simulation technique in certain circumstances with a parametrisation of the shower shape in the calorimeters of ATLAS. The saving in simulation time is substantial.

However, there are issues with the fast simulation of low energy electrons. In particular, the current parameterisation breaks down at energies less than about 1 GeV. The simple method of dumping the energy in a spot degrades the accuracy of the fast simulation quite significantly. This project will aim to arrive at a better understanding of low energy electron shower development in the ATLAS detector, and development of improved, faster and more accurate, parameterisation techniques. Some programming skills and knowledge (or desire to gain knowledge) of the C++ programming language would be helpful.

THE W BOSON IN ATLAS

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The following project is an example of the sort of project that can be offered on ATLAS, which is one of the detectors under construction for the LHC (Large Hadron Collider) situated at the European Laboratory for Particle Physics (CERN). A more detailed description is in the Research Overview section.

The mass of the W boson is of course known, but only to a precision of about 30 to 40 MeV. If it is measured more precisely by ATLAS, say to a precision of 15 MeV, then in fact this allows the mass of the Higgs boson to be predicted to within about 25%. ATLAS will collect a lot of W bosons, about 60 million per year in early running. W bosons will be identified by their decay to a charged lepton (electron or muon) and a neutrino, the latter characterised by missing energy and momentum in the detector. This sample will also be very useful for calibration of the detector and understanding its performance.

We are involved here in Sydney with electron identification in ATLAS, particularly in the electromagnetic calorimeter. This project will examine new samples of simulated (Monte Carlo) events in ATLAS which have been produced with a full detector simulation, in order to better evaluate what our ability to reconstruct $W \to e\nu$ decays will be and how precisely the W mass will be able to be determined. The project will be computer analysis oriented. Some programming skills and knowledge (or desire to gain knowledge) of the C++ programming language would be helpful.

Research Projects in Medical Physics

BRACHYTHERAPY APPLICATIONS OF NORMOXIC POLYMER GEL DOSIMETERS USING VIBRATIONAL SPECTROSCOPY, MAGNETIC RESONANCE IMAGING AND X-RAY COMPUTER TOMOGRAPHY

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Novel radiation sensitive polymer gels are being developed for use in three-dimensional radiotherapy dosimetry. This project will explore aspects of these radiation sensitive polymer gels using vibrational spectroscopy, magnetic resonance imaging and x-ray computer tomography with the aim of understanding and optimising the dosimeter formulation. Brachytherapy is the clinical treatment of cancer using a sealed radioactive source that is placed inside or close to a tumour. The use of these radiation sensitive polymer gel dosimeters will be evaluated for clinical applications including brachytherapy.

INVESTIGATION OF THE RADIOBIOLOGICAL IMPACT OF MOTION WITH REGARD TO INTENSITY MODULATED RADIATON THERAPY, TARGET & NORMAL TISSUE VOLUMES

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IMRT provides us with the ability to tailor dose distributions achieving sharper dose distributions compared with previous treatment plans. This raises two questions firstly the difference in the dose per fraction delivered to the surrounding tissues and the ability to predict the impact of this considering the radiobiology, secondly the impact of the change in dose distribution when motion is considered. This is particularly important when the motion margins for the target and critical structures overlap. These will be investigated and a method for determining the impact established for individual patients based on measured motion data.

Research Projects in the Optical Fibre Technology Centre (OFTC)

INTRA-CAVITY GRATING CHARACTERISTICS OF AN AIR-CLAD FIBRE LASER

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Air-clad fibres are fibres that have a ring of air holes with bridge thicknesses <300nm to stop light leaking out. When an air-clad fibre is doped with a rare earth ion in the core, high power fibre lasers can be made. This project builds on recent innovations in air-clad photonic crystal fibre lasers and gratings within these structures and will focus on characterising the thermal heat load arising from pump absorption in these lasers. The main active medium to be used in these studies will be Yb3+ although other ions will be considered. The role of resonant nonlinearities found with Yb3+ ions in affecting index change, both permanent and transient, will be studied.

IMPACT OF HEAT AND ELECTRIC ARCING ON THE SUPERCONTINUUM PROCESS IN OPTICAL FIBRES

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Photonic crystal fibres with cores $< 2\mu$ m are used in a number of applications such as supercontinuum (”white light”) generation and sensing applications. In this project, such fibre made at the Optical Fibre Technology Centre will be characterised and its suitability for sensing applications explored. The generation of white light through pulsed excitation with a YAG laser will be studied. The relationship with blackbody radiation generated by plasma generation either with the laser or with an electric and finally in combination will also be explored.

UV TRANSMITTING PHOTONIC CRYSTAL FIBRES

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There is a pressing need for efficient UV transmitting fibres that can operate down to 193 nm. However, the ability to transform and radiation harden silica so that it transmits more and further into the UV requires an understanding of the origins of photodarkening, the structure of silica and the role of impurities in glass transmission properties. The need for such fibres is to a large extent driven by the adoption of 193nm as the semiconductor lithography wavelength for making smaller and smaller features. This project will focus on making highly efficient fibres that transmit UV light down to 193 nm using in-house developments in radiation hardening of glass, including variations of hypersensitisation.

NA APERTURE MEASUREMENT OF PHOTONIC CRYSTAL FIBRES AND WHAT IT MEANS

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A key feature of photonic crystal fibres and air-clad fibres is the large NA that is possible given the effective index contrast can be much larger than conventional fibres. Such fibres have applications in efficient light collection for biomedical and astronomical diagnostics, fibre lasers, and high power delivery. A critical parameter is the numerical aperture – unlike conventional optical fibres this parameter is sensitive to wavelength as a result of the bridges that exist between holes that permit light to leak out. For astronomical applications, other parameters such as aberration free transmission become important. Indeed, quite distinct properties are observed giving rise to new interpretations of the role of tunnelling in light leakage in highly multi-moded fibres.

SPUN PHOTONIC CRYSTAL FIBRE

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A new spinning unit will allow us to spin photonic crystal fibres of all sorts to generate helical waveguiding structures with pitches potentially <100 m. This opens up new opportunities in studying helical mode propagation, controlling polarisation, and creating new devices based on this structure. This project will involve fabrication and characterisation of such fibre as well as device implementation and physical understanding behind all of these.

MASTER OSCILLATOR POWER AMPLIFIER (MOPA) CONFIGURATION USING DFB FIBRE LASERS AND POLYMER CLAD AND AIR-CLAD POWER AMPLIFIERS

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Narrow linewidth sources of sufficient power are required for numerous applications in particular long range sensing and laser radar. DFB fibre lasers can achieve the long coherence length (narrow linewidth) but are often limited to only tens of milliwatts. On the other hand, air-clad lasers can reach hundreds of watts single mode but are limited in coherent (broad linewidth). In this project a narrow linewidth high power source will be constructed by combining the DFB laser resonator inside a photonic crystal fibre and using an air-clad high power amplifier to amplify the power from milliwatts to watts. An exploration of the nonlinear issues that arise with such narrow linewidths and high powers and an investigation into the linewidth measurement process itself will be undertaken.

CONTROLLING REDOX REACTIONS IN MCVD FABRICATION

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Depending on the atmosphere employed, certain species can be reduced or oxidised in a number of ways during preform fabrication of optical fibres. There has been no detailed study to date of the possibility of opening up new levels of control of the electronic state of species introduced into preforms which end up in the final optical fibre phase. This project will beginning the first steps to exploring these possibilities and determining in practice just how far one can control the valence state of a metal, for example, and whether this can be used to greatly increase the incorporation of such metals into optical fibre form. If this is possible a new host of doped optical fibres with specific functionality ranging from practical nonlinear effects and Faraday rotation become possible.

STUDYING THE NONLINEAR PROPERTIES OF PHOTONIC CRYSTAL FIBRES DOPED WITH PORPHYRINS

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Metallo-organic cages are an exciting medium for tailoring custom properties both in the electrical and optical domain. They form the basis for future molecular electro optics. Together with the School of Chemistry, University of Sydney, the OFTC was the first group in the world to combine photonic crystal fibre technologies with porphyrins. This project will explore specifically the nonlinear properties of these materials both in and outside the fibres using custom tailored porphyrin structures. Depending on the atmosphere employed, certain species can be reduced or oxidised in a number of ways during preform fabrication of optical fibres.

LASER TREATMENT OF WATER

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Water is one of our most precious resources and after years of sustained drought there is great interest in reclaiming water - in purification of ground water and river outfalls and in decontamination of waste water. A novel technique involving photo-catalysis and nano-sized catalyst particles has been proposed, but has yet to be demonstrated. From a thorough analysis of the physics of the proposed process, this project will arrive at an initial optimum design and preliminary feasibility study. Key issues are the laser illumination source (wavelength, power, tunability, pulsed or CW) and the technique for its delivery into a volume of flowing water. The optmium wavelength is determined by a combination of factors including the properties of the catalyst, contaminants and water, the feasibility of delivery schemes and the availability of suitable laser sources. Typically, photo-catalysed processes are more efficient at short wavelengths, however it is more difficult to generate and transport these wavelengths. The delivery will involve a novel optical fibre system, the design of which is in turn dependent on the laser and materials properties. This project will involve the analysis of several different inter-related aspects of the physics (laser properties, waveguiding, material properties, liquid flow) and will produce an optimised initial system design. These results will be an important first step towards a major project with industrial partner Janaton P/L and hopefully making a contribution to our country's water conservation and ecological sustainability. It is hoped to run this project as an inter-disciplinary collaboration with a Chemical Engineering Honours project considering aspects of the reactions, reactors, throughput and overall process issues.

DESIGN AND FABRICATION OF PHOTONIC BANDGAP FIBRES

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Photonic bandgap fibres have the unique ability of guiding light efficiently in a hollow core. The light is prevented from leaving the core by a surrounding structure which has a photonic bandgap at certain wavelengths and thus reflects the light back into the core. This structure can be a Bragg reflector (a '1D' structure of concentric rings) or a photonic crystal (a 2D lattice of holes). Apart from air-guidance, these fibres offer many exciting opportunities such as guiding light in an aqueous solution with profound implications for biosensing. Surprisingly, there is still a fundamental argument as to the nature of the guidance mechanisms in such fibres and the processes that ultimately guide the light. Several qualitatively different structures have been experimentally demonstrated, but it is not clear whether they all satisfy the definition of a "bandgap fibre", whether the existing definition is itself appropriate or whether the fibres can even be grouped together in such a way. Another aspect of interest is the conditions the structure must satisfy to achieve bandgap guidance, such as regularity and periodicity. This project will have a theoretical aspect that will be considering these questions through numerical simulations on the existing structure designs, and will also investigate alternative designs and ways in which the bandgaps can be improved by modifying the structures, e.g. chirping. Existing numerical tools will need to be modified for this purpose. At the OFTC we have the unique facilities to fabricate such fibres using polymers, so the opportunity also exists for the fabrication and experimental testing of bandgap fibres.

MICROSTRUCTURED FIBRE LASERS AND GRATINGS

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Microstructured polymer optical fibres (mPOF) are a new type of fibre that use microscopic holes running the length of the fibre to guide the light. The properties of the fibre can be greatly modified by altering the details of the hole pattern, but with mPOF the opportunity also exists to change the properties of the polymer. In particular, we have developed a doping method by which laser dyes may be introduced into the polymer matrix. This method was used to demonstrate a polymer dye laser. This project will begin by building a simple dye laser and characterizing it and then can branch off in several ways. The hole pattern may be modified to change the properties, and more interestingly other dopants or polymers may be investigated, including inorganic dopants and ways of getting them into the polymer matrix. Fibre Bragg gratings can be inscribed into the fibres themselves to act as mirrors for the grating and these can utilize the flexibility of the polymer to make a tunable laser.

Research Projects in Quantum Information Theory

LINEAR OPTICS QUANTUM COMPUTING

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LOQC is a scheme to perform quantum computing with photons using linear optical elements to do the quantum gates. This is a very interesting subject at the moment, because the experiments are sufficiently advanced to do basic quantum information processing tasks that are of interest to a theorist. For example, measurement-based quantum computing schemes are being pursued first using photons. We work closely with the experimental LOQC group of Prof White at the University of Queensland, developing new protocols, gates, etc. which they can then do in experiments. A project in this area involves the investigation of schemes to construct massively-entangled ”spin lattices” of photons using LOQC technology, and to use these for measurement-based quantum computing.

QUANTUM CONTROL

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Noise usually destroys quantum effects, and if quantum technologies are going to be useful, they need to be robust against noise. In a classical world, complex systems (CD players, airplanes, etc.) are designed to function in noisy environments and with faulty parts by using ”feedback control,” i.e., continuously monitoring the system and correcting its state. (Think of the thermostat in your oven.) Complex quantum systems will also require control, but there is a catch: any measurements that we do on a quantum system will necessarily alter its state uncontrollably. If you look at a quantum system too closely, you completely collapse its state. So we’re developing new methods for feedback control of quantum systems, with a careful balance between acquiring information about the system but not disturbing it too much. A project in this area would be to analyse the fundamental limits imposed by quantum mechanics on some simple operational tasks in quantum theory, such as stabilizing a reference frame or maintaining quantum entanglement.

Research Projects in Sydney University Physics Education Research (SUPER)

MULTIMEDIA IN TEACHING AND LEARNING OF COMPLEX PHYSICS PROCESES

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Multimedia technology is increasingly used in educating people about the complex discoveries being made in science. But how effective is such technology for learning? Researchers continue to debate the merits of dynamic visual representations over static displays. In this project you will enter into this d ebate by exploring the relationships between "interactivity" and "learning" using various multimedia tools explaining process topics like the formation of electri cal storms.

UNDERSTANDING QUANTUM TUNNELLING

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Quantum tunnelling represents a milestone in understanding quantum phenomena as it brings together the myriad of representations fundamental to quantum mechanics. In this project you will interview learners and record how quantum tunnelling problems are solved and conceptualised by experts and novices. You will then compare and contrast "expert and novice strategies" and propose a model for bridging the gap.

GRAVITY, 'MICROGRAVITY' AND FREEFALL

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Various strategies can be used to explain facets of gravity and freefall. Preliminary phenomenographic analysis has provided a model of how gravity and freefall is understood. In this project you will investigate the effect of prior knowledge on the model. In a recent discussion in PHYSLRNR@LISTSERV.BOISESTATE.EDU, John L. Hubisz, President of the American Association of Physics Teachers said "I just finished a report on mistakes in Middle School physical science that shows these books riddled with errors" on, amongst other concepts, gravity and freefall.

APPROACHES TO LEARNING

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This project is an investigation of ”deep” and ”surface” approaches to learning physics and how the approaches relate to achievement. One would presume that a deep approach correlates with higher achievement. But how are deep approaches measured, and do they indeed correlate with higher achievement? If yes, shouldnt we be telling learners about this result?

STUDENT UNDERSTANDING OF BASIC CONCEPTS IN ASTRONOMY

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The Astronomy Diagnostic Test (ADT) is a survey developed in the US for undergraduate, non-science majors taking their first astronomy course. It is intended to test students’ knowledge of basic concepts of astronomy. The Southern Hemisphere Edition of the ADT has a small number of minor changes to words and images of the original ADT to permit its use in the southern hemisphere (see www.physics.usyd.edu.au/super/ADT.html).

The Southern Hemisphere Edition of the ADT has been used in the PHYS 1500 Astronomy introductory astronomy unit since 2000 as both a pre- and a post-course quiz. This spans the recent changes to the HSC. Some 2000 students have also been tested again in 2002. The test has also been used at several other universities around Australia.

This project will compare the available data sets, coordinate new data acquisition at other institutions in Australia, and formally validate the test in the Australian context.