School of Physics
The University of Melbourne
Honours research projects offered in 2008

These are not expected to be complete

Please consult the individual supervisors for additional details and information about particular or alternate topics as well as consult the website at http://www.ph.unimelb.edu.au/honours/ for updated information

ALLEN, ASSOC PROF LES. J.
Theoretical Condensed Matter Physics
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- Quantum mechanical inverse scattering problems.
- Inelastic scattering of electrons in crystals: Scattering of fast electrons in condensed matter; phonon excitation; applications to atomic resolution imaging and spectroscopy; development of confocal scanning transmission electron microscopy at atomic resolution (with Oxford Materials).
- Phase retrieval in atomic resolution imaging.

BELL, DR NICOLE
Theoretical Particle Physics
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- Neutrino astrophysics
- Indirect detection of dark matter

BARBERIO, DR ELISABETTA
Experimental Particle Physics
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- Astro-particle physics with the ATLAS detector
- Search for extra-dimention and Super-symmetry at LHC
- Derivation of the cosmological constant for Super-symmetry at LHC
- Search for the Higgs particle at LHC
- Studies of matter anti-matter asymmetry in the Universe with the Belle detector

CHANTLER, ASSOC. PROF. CHRIS
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- **Atomic & condensed matter experiments**: X-ray measurement of atomic form factors f and the refractive index RI: Our international measurements are two orders of magnitude more accurate than previous literature. How does Quantum Mechanics work in practice? This has opened up a new field and initiated questions about relativistic, and QED contributions to observed interactions.
- **Quantum Electrodynamics**: Development and design of X-ray spectrometers for high-precision measurement in X-ray physics and QED. We have made the highest precision test of QED for Vanadium using an Electron Beam Ion Trap and new tests of excited state and two-electron QED. This requires new detector technology.

- **Atomic form factor theory**: scattering of X-rays, diffraction & atomic structure. Particular questions relate to high-energy limits, analytic formulations, S-matrix quantum field theory and correlated perturbation theory.
- **X-ray Absorption Fine Structure theory & experiment**: Isolated Particle Approximation models, XAFS and near-edge structure (scattering, atomic structure & crystals). Anomalies in current experimental data from synchrotron research.
- **Synchrotron techniques** for new understanding in atomic, molecular, condensed matter and biophysical systems
- **Biophysics** of X-ray irradiation, biological structures and catalysts.
- **Investigation of X-ray scattering and fluorescence distributions**. These investigate the real component of the atomic form factor, and the radial electron density in atomic systems. The relativistic component of f has never been accurately measured.
- **Dynamical diffraction from curved crystals (diffraction / mosaicity).** Synchrotrons use advanced X-ray optics and need advanced theory to calibrate and predict results. Developments of theory of mosaicity and mosaic diffraction of X-rays is necessary in high-efficiency diffraction experiments in the X-ray regime.
- **X-ray source distributions (experiment and computation)**: X-ray sources produce spectra which are relied on around the world; theory is unable to predict experimental observed distributions
- **Experiments in reflectivity.** Details of reflectivity profiles test dynamical diffraction theory and investigate surface roughness in materials.

HOLLENBERG, PROF. LLOYD
Theoretical Particle Physics/Centre for Quantum Computer Technology
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- **Quantum Computing Project Areas (CQCT)**

  Quantum algorithms/circuits: simulations and implementation: developing code to simulate a quantum computer running specific quantum algorithms, using the QCV supercomputing facilities.
- **Theoretical quantum computation, quantum error correction, fault-tolerant thresholds:** deriving the equations which govern how errors arising in the operation of a quantum computer (normally fatal for reliable operation) are correctable using quantum error correction protocols. Ultimately, the maximum error threshold for fault-tolerant operation is computed for a given quantum computer architecture.
- **Quantum control and feedback:** quantum mechanics allows for remarkable and non-intuitive ways of controlling qubit(s) system(s), which are just now coming to light. Robust pulsing which protects the qubit system against /unknown /errors is of particular interest.
- **Entanglement generation:** entanglement is the fragile resource of Nature that powers quantum information processing. Understanding its generation, classification and use continues to define the cutting-edge of quantum mechanics research.
- **Condensed matter theory of solid-state quantum computer architectures:** underpinning the most advanced silicon-based quantum computer architectures developed within the CQCT, are detailed condensed matter models describing the individual qubits and their quantum logic gate operations. Linking these descriptions to the quantum information theoretic considerations is of primary importance.
- **Device modeling:** nanoelectronic gate structures and quantum gate operations linking experiments to quantum computer design.
- **Decoherence and fidelity of quantum operations:** accurate models of how the environment "decoheres" the quantum computer operation informs the analysis of fault-tolerant threshold and operation.
- **New proposals for quantum devices:**quantum entanglement and coherent evolution offers a host of new and exciting ideas for devices and applications from quantum imaging, quantum

lithography, to efficient quantum chemistry calculations

Quantum Communication Project Areas (QCV) [with Dr. Shane Huntington, Dr. Brant Gibson, Dr. Faruque Hossain]

- **Quantum Key Distribution:** new protocols for quantum communication using single photon sources through fibre
- **Photonics:** simulation of the complete QKD diamond-fibre system using the QCV supercomputing facilities.
- **Condensed matter theory:** large scale density functional theory calculations using the QCV supercomputer facilities underpin the search for new colour centres in diamond.
- **Diamond cavity photonics:** the interaction between diamond colour centres and cavity QED is of great interest in defining new devices in quantum communication and computation.

JAMIESON, PROF. DAVID
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and

PRAWER, PROF. STEVEN
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- **Implanting single atoms for quantum devices: towards higher precision with avalanche detectors**: Fabrication of quantum devices that use single atoms as their function elements presents formidable challenges. Our method, based on the implantation of single ions into silicon, successfully meets this challenge. For the near future we must improve the accuracy of this method by reducing the ion energy. To do this we will need to improve the sensitivity of the single ion implantation detection system. One promising way of doing this is by raising the internal electric fields of the silicon substrate so that ion impact produce avalanches of electrons that can easily be detected. Numerical modelling with a large semiconductor device modelling code and experimental measurements are involved in this project.
- **Growth of nanodiamond on fibres**: Diamond has very promising optical properties which can be exploited for quantum information processing and transmission. To make this work, diamond must be integrated with conventional optical fibres. This project involves the use of our diamond reactor to grow nanodiamond crystals on the ends of optical fibres. Sophisticated machining with a focused ion beam microscope then allows the diamond to be configured for useful applications. Optical characterisation and modelling are also required.
- **Characterisation of single photon sources**: Colour centres in diamond have interesting properties that allow information to be stored as quantum states of excited electrons. Optical stimulation allows these quantum states to be programmed and read out. We seek new colour centres with wavelengths well matched to long distance signal transmission in silica fibres. This project involves measurement of the quantum states of colour centres in diamond to assess their suitability for information storage and transmission.
- **Arrays of single atoms for quantum computation**: We have demonstrated that silicon quantum devices containing a single pair of atoms can be fabricated and tested. We now need to move to the next step where this process is scaled up to larger scale arrays. This can be accomplished by several promising technologies involving scanned cantilevers containing precision apertures machined by a focused ion beam. This project involves experimental tests of this system for the fabrication of large scale arrays.
- **Fabrication of single colour centres in diamond**: Selected isotopes of some elements, when implanted into diamond, produce colour centres with useful properties. For example, 14N and 15N differ in their nuclear spin and quadrupole moment. This results in colour centres with different

quantum properties. For the construction of useful devices containing these colour centres, we need to reliably implant single atoms and read-out the characteristics of the resulting colour centre. This project combines ion implantation and optical characterisation to fabricate and study colour centres in diamond.

- **Ion beam lithography in diamond**: Using a novel combination of ion beams it is possible to machine microstructures in diamond. By fabrication of arrays of nano-scale holes it is possible to make an optical crystal which can capture the luminescence of embedded colour centres for useful applications. It is may also be possible to make micron-scale optical resonators that can process light in novel ways. Micromechanical devices fabricated with this method take advantage of the exceptional mechanical properties of diamond. This project involves the design, fabrication and test of novel nano-scale diamond optical and mechanical devices.

MARTIN, DR ANDREW
Theoretical Condensed Matter Physics
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- **Dynamics and Stability of Rotating Dilute Gas Bose-Einstein Condensates**. This project will investigate use analytical and numerical techniques to investigate the stability of rotating Bose-Einstein condensates.
- **Matter Wave Teleportation**. This project will use numerical and analytical methods to propose a new scheme to transport dilute gas Bose-Einstein condensates between two points, whilst never occupying the intervening region.
- **Bose-Fermi Mixtures**. This project will develop a methodology for understanding the properties of ultra cold Bose-Fermi mixtures, such that the interactions between the Bosons and Ferions can instigate a stable system.
- **Understanding rotating Black Holes through analogies with rotating Bose-Einstein Condensates**. This project will develop recent work on the analogies between the properties of rotating Black holes and rotating BECs. In particular the project will focus on showing how it is possible to design an experiment to measure super-radiation from a vortex in a BEC.

McCALLUM, DR JEFF
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- **Impurity activation during ultra-shallow junction formation in silicon:** This project will examine possible processes that can be used to electrically activate ion implanted impurities in the upcoming generations of silicon-chips. During thermal processing to activate implanted dopants there are a number of possible defect interactions that can influence the outcome. To identify which of these possible interactions dominates in any particular processing regime requires a combination of measurement of the active dopant profile at the end of the process and knowledge of the defects that are present at the start and during various stages of the processing. This project will combine atomic-force microscope-based techniques for measuring ultra-shallow dopant profiles and deep level transient spectroscopy identification of defects to study the activation process.
- **Ion implantation effects in metal-oxide semiconductor (MOS) devices:** Implantation of ions through a pre-existing silicon-dioxide layer on silicon is of increasing interest for development of devices including some in which quantum effects such as spin-based charge transport are to be utilized. Presently, there is insufficient knowledge of the damage caused to the oxide by the passage of the ions for us to be able to predict how best to thermally process the oxide to anneal or remove the damage or even for certain ion species/fluence combinations whether recovery can be achieved at all. This project will utilize electrical characterization measurements including capacitance-voltage and deep level transient spectroscopy to explore this problem.
- **Synthesis of Al_2SiO_5 in sapphire by ion implantation:** This project will examine the possible formation of Al_2SiO_5 in synthetic sapphire, Al_2O_3, by high-dose implantation of Si into sapphire at elevated temperatures. Formation of Al_2SiO_5 in sapphire is of interest for a number of reasons including the possible formation of new materials with useful optical properties and Al_2SiO_5 is an

important mineral in Geology so examination of possible formation mechanisms and influences on the particular phase of the mineral that forms are of interest. In this project X-ray diffraction and transmission electron microscopy will be key analysis tools.

MELATOS, DR. ANDREW
Astrophysics
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- Theory of gravitational waves radiated by neutron stars and black holes: new sources for LIGO
- Gravitational waves from supernova explosions
- Fundamental theory of rotating superfluids and quantum condensates
- Quantum vortices and superfluid turbulence in nuclear matter: the mystery of neutron star glitches
- Relativistic electron-positron winds and jets in supernova remnants
- Origin of magnetic fields in supernovae, neutron stars, black holes, and accretion disks
- Signal templates and algorithms for gravitational wave data analysis

NUGENT, PROF. KEITH
Optics
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- Physics with synchrotron sources and x-ray lasers
- Coherent x-ray science
- Biophysics
- Imaging and microscopy
- New methods for molecular imaging

RASSOOL, DR ROGER
Experimental Particle Physics
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- Super-allowed beta-decay studies
- X-ray imaging with Pilatus II
- Medical Imaging with PET: Positron Emission Tomography
- Antipersonnel land mine detection using neutrons

ROBERTS, ASSOC. PROF. ANN
Optics
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- Fabrication, characterisation and modelling of nanophotonic devices
- Characterisation of artworks using optical imaging techniques (with Centre for Cultural Materials Conservation)
- Quantum and classical imaging using correlated and entangled photons
- Characterisation of photonic devices using novel imaging techniques
- Applications of phase microscopy to cell physiology
- Determination of coherence properties of classical optical wavefields

SCHOLTEN, ASSOC PROF ROB
Optics
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- Squeezing light using laser-atom interactions
- Imaging ultra-cold atoms with “slow light”
- Ultracold plasma from photoionised laser-cooled atoms
- FAT atoms: making really big "Rydberg" atoms (diameter ~1μm) by photoexcitation of cold atoms
- Ghost imaging: using correlated and entangled photons to image an object that isn’t there
- Atomic clocks: locking lasers to coherent atomic states

SEVIOR, ASSOC. PROF. MARTIN E.
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- Measurement of CP violation with the Belle experiment
- Investigation of rare B-decays with the Belle detector

TAYLOR, PROF. GEOFFREY
Experimental Particle Physics
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- Searches for the Higgs Boson
- Searches for super symmetry and extra dimensions
- Silicon detectors for future experiments
- PET imaging array detectors

VOLKAS, PROF. RAY R.
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- Brane-world models and topological defects
- The early universe
- Extensions of the Standard Model of particle physics
- Neutrinos in particle physics, cosmology and astrophysics

WEBSTER, PROF. RACHEL
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- Gravitational Lensing
- Quasar Astrophysics
- Galaxy Formation
- Large-scale Structure and Cosmology
- Projects for Secondary Physics Students

WYITHE, DR. STUART
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- The First Sources in the Universe and Reionization
- Cosmological HII regions
- Evolution of Supermassive Black Holes
- Gravitational Lensing

- Earth-Shine (Earth as a Prototype Extra Solar Planet)