AIP Summer Meeting 2019

Abstract Book

RMIT University, Melbourne, Australia

4th – 6th December 2019

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AUSTRALIAN INSTITUTE OF PHYSICS

aip SUMMER MEETING

Welcome to Melbourne and the 2nd Australian Institute of Physics Summer Meeting 2019, which follows the previous meeting in Sydney (2017).

The AIP summer meeting was established in 2017 as the biennial meeting of the physics community in Australia. The AIP summer meeting takes place in odd-numbered years and focusses on the recent trends and developments of Australian physics research.

The AIP Summer Meeting is equally targeted at professional scientists, academics, post-doctoral researchers and PhD students. By comparison, the AIP Congress takes place in even-numbered years and features many keynote and plenary talks given by overseas speakers, with participation by ~ 800 delegates.

The field of physics is diverse and there are many societies catering to sub-fields of physics such as optics and astrophysics. The goal of a general physics conference is to bring all those fields together and to allow physicists to wander into sessions and talks they may not encounter on a daily basis.

I invite you all to explore the wonderful field of physics, in all its forms and hope that you learn something new not just in your specialised area, but in others.

I hope that you have an enjoyable and productive meeting.

With best wishes,
Gail Iles

AUSTRALIAN INSTITUTE OF PHYSICS aip SUMMER MEETING

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Chair

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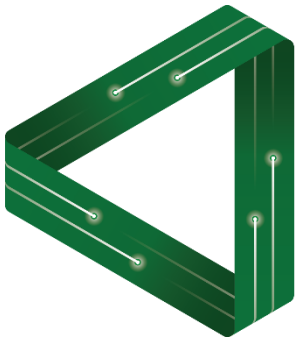

FLEET

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Conference Dinner

On the evening of Thursday 5th December 2019 delegates are invited to join the conference group at the Zinc restaurant at Federation Square, near Flinders train station, Melbourne.

Dinner is a two-course meal beginning with a drinks reception overlooking the Yarra river. Dress code is formal or smart business.

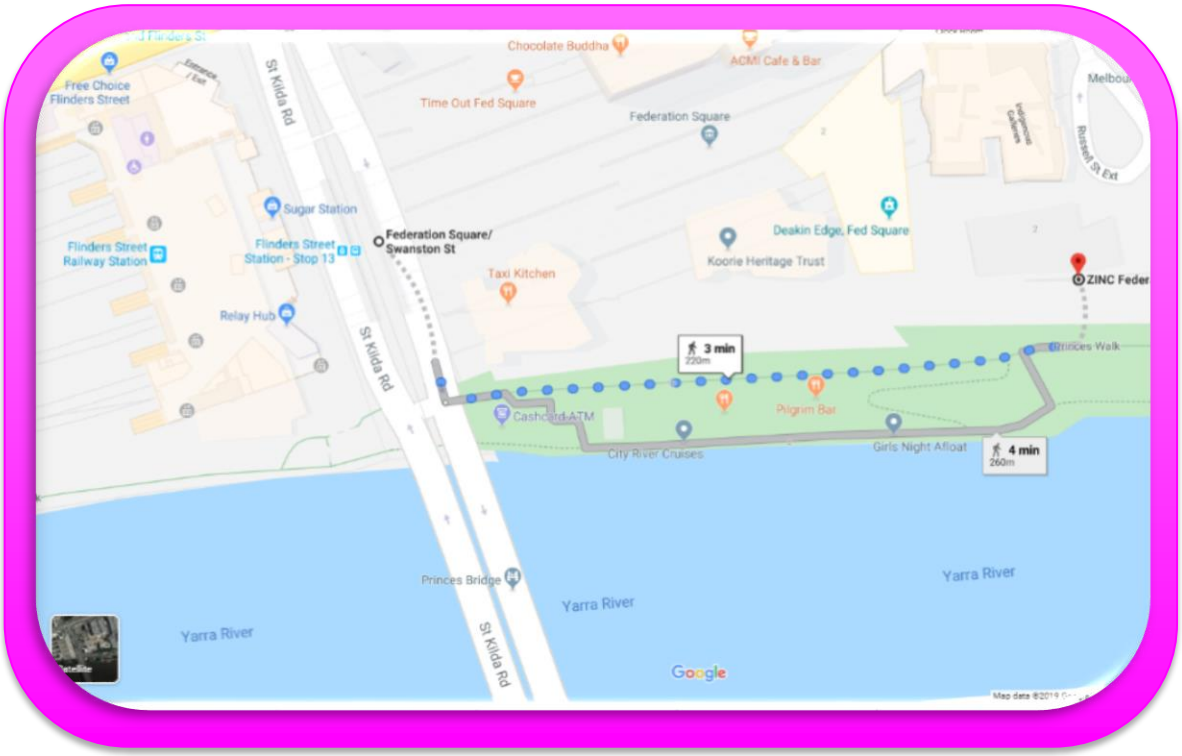
ZINC FED SQ

Itinerary for the evening

17:00 Conference day 2 ends

18:30 Drinks reception

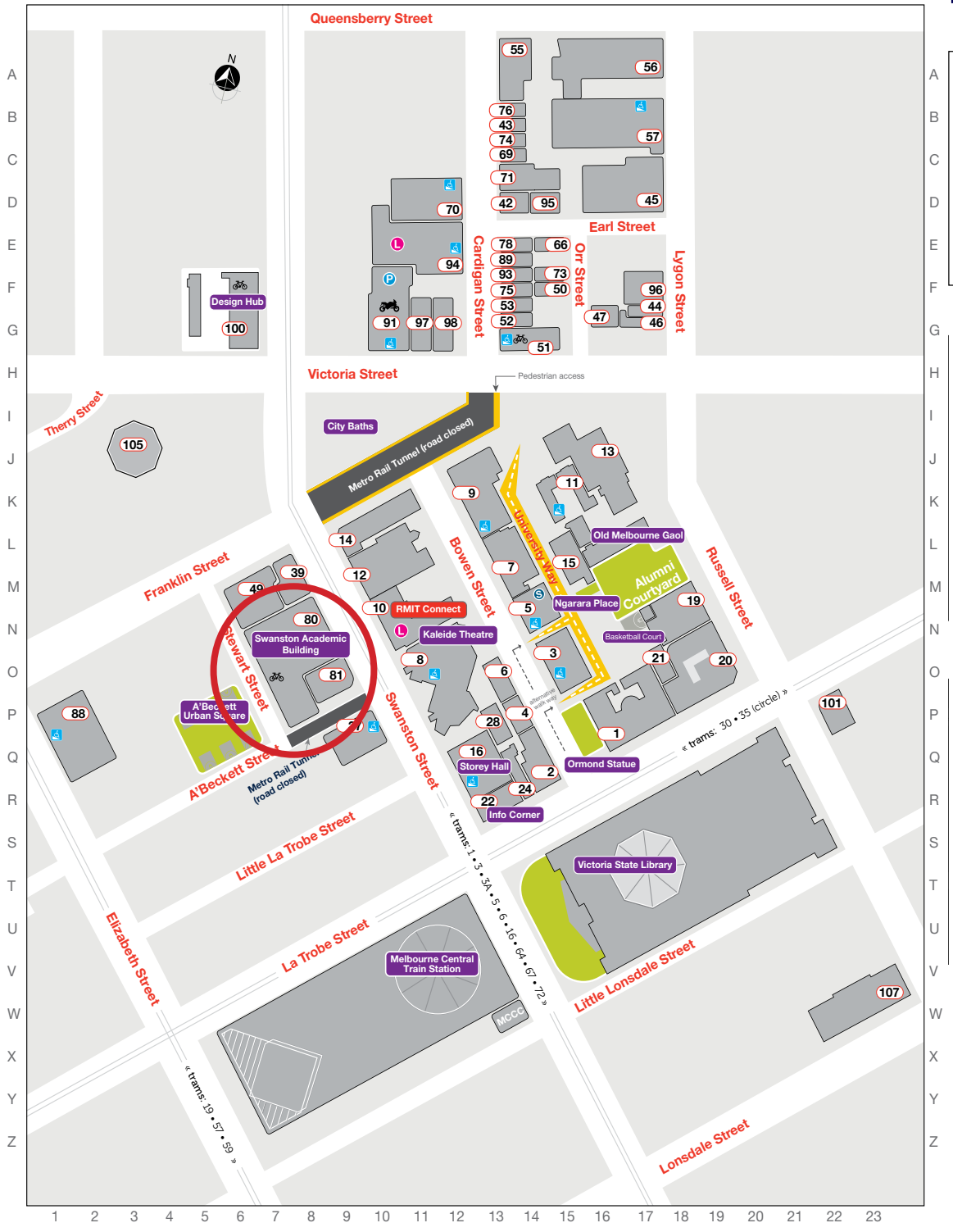
19:00 Dinner



Getting there

Travel on Melbourne city centre trams is free. The first tram stop inside the free tram zone is outside the Victoria State Library (NOT RMIT!). Alight at Flinders Street Strain Station and walk a short distance along Princes Walk to the restaurant.

City campus



AIP Summer Meeting 2019 4 -6 December 2019

RMIT University
Swanston Academic Building
Building 80, level 2
445 Swanston St, Melbourne VIC

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RMIT UNIVERSITY

Programme of Events

Wednesday 4th – Friday 6th December 2019

Wednesday 4th December 2019

8:00	*09:00*	REGISTRATION		
9:00	*9:30*	OPENING CEREMONY		
9:30	*10:30*	Plenary	Allan MacDonald	
10:30	*11:00*	Morning Tea		
Session I		***I.1***	***I.2***	***I.3***
	Theme	**Condensed Matter**	**Astrophysics**	**Medical Physics**
	Chair	*Oleg Tretiakov*	*Glenn Kacprzak*	*Suzie Sheehy*
11:00	*11:15*	Amie Khosla	Hannah Middleton	Werner Ruehm
11:15	*11:30*			
11:30	*11:45*	Karel	Kgoadi	Asfia
11:45	*12:00*	Vaitkus	Newton	Eyou
12:00	*12:15*	Rachel	Carlin	Peiris
12:15	*12:30*	Y. Lee	Hon	Zhang
12:30	*13:30*	Lunch		
Session II		***II.1***	***II.2***	***II.3***
	Theme	**Condensed Matter**	**Atomic, Molecular, Optical**	**Physics Education**
	Chair	*Julie Karel*	*Paul Dyke*	*Maria Parapilly*
13:30	*13:45*	Daniel Creedon	Sean Hodgman	Joanna Turner
13:45	*14:00*			
14:00	*14:15*	Tsai	Weyland	Angstmann
14:15	*14:30*	Edalati	Dalton	Dixon
14:30	*14:45*	Johnson	Cheng	Lazendic-Galloway
14:45	*15:00*	Lew	Kirk	Wait
15:00	*15:30*	Afternoon Tea		
Session III		***III.1***	***III.2***	***III.3***
	Theme	**Condensed Matter**	**Particle Physics**	**Quantum Computing**
	Chair	*Allan MacDonald*	*Martin Sevior*	*Charles Hill*
15:30	*15:45*	Oleg Tretiakov	Peter Skands	Campaioli
15:45	*16:00*			Pollock
16:00	*16:15*	Yick	Kumar	Alexander
16:15	*16:30*	Mikhail	Wray	Pantaleoni
16:30	*16:45*	Booth		Walshe
16:45	*17:00*			Baragiola

17:00 *19:00* **DRINKS RECEPTION AND POSTER SESSION**

ID	Presenter	Abstract title
CM-1	Jamie Booth	Optical Properties of Perovskites with Large Spin-Orbit Coupling from First Principles
CM-2	Tyler Gardener	Unconventional superconducting states on the honeycomb lattice
CM-3	Alexander Nguyen	Achieving Aluminum Liftoff for Fabricating a Spin Hall Effect Device
CM-4	Mason Paxevanos	High Frequency Vibrational Energy Harvesting Using [011] Mn-PMN-PZT Relaxor Ferroelectric Single Crystals
CM-5	Roberto Munoz	Causal state analysis of blinking quantum dots
CM-6	Amani Alruwaili	Structure and dynamics in charged colloidal suspensions
CM-7	Samir Eldemrdash	The colloidal properties of detonation nanodiamonds in water
CM-8	Antony Jones	Large scale defects for pinning modification of YBCO thin films
CM-9	Zhaojin Liu	Single Crystal Diamond Thin Film for Dosimeter Applications
CM10	Nicholas Collins	Surface Defect Effects for Deterministic Doping in Diamond
CM11	Alex Healey	Comparison of different methods of spin defect creation in diamond for quantum microscopy
CM12	Harish Vallury	The Promise of Superconducting Boron Doped CVD Diamond Devices Fabricated by Ion Beam Techniques
CM13	Sam Scholten	Cryogenic widefield nitrogen-vacancy microscopy – set-up and application
CM14	Emma Gill	Growth Mechanisms and Interfacial Properties of Iron Nanoparticles Electrodeposited to Carbon Nanotubes
CM15	Ryan Parker	Erbium and defect luminescence in SiC nano-pillars
CM16	Liam Thomas	Towards a scalable silicon based quantum computer
QC-1	Graeme Berk	Resource Theories of Multi-Time Processes: A Window Into Non-Markovianity
QC-2	Aidan Dang	Tensor Networks for Quantum Circuit Simulation
QC-3	Pedro Figueroa Romero	Typicality and equilibration on general quantum processes
QC-4	Taylor Kearney	Measuring the Complexity of Open Quantum Dynamics
QC-5	Alexander Jakob	Deterministic Implantation of Donor Qubits in Si with Nanometer Precision
QC-6	Zehai Pang	Heavy-Molecule Ion Implantation for Qubit Architectures in Silicon
QC-7	Amanda Seedhouse	Readout of Silicon Spin Qubits Beyond the Singlet-Triplet Blockade
QC-8	Gregory White	Efficient drift-robust improvement of two-qubit entangling gates
PP-1	Md. Shahinur Rahman	Investigation of Viton O-ring performance for the SABRE dark matter experiment
SP-1	Nicholas Florent	Ferrofluid-based electrospray thrusters in nanosatellites for short-range, lightweight propulsion
ED-1	Aesha Bhansali	Measuring Students' Emotional Engagement with Physics Lectures
AMO1	Patrick Adams	Spectroptychography of Iron Oxide/CNT Composite Materials for Battery Technologies
AMO2	Paul Jnr Di Pasquale	Structural Distortions in Fluorescence EXAFS Due To Spectral Flattening
AMO3	Samira Falahatdoost	Photoinduced Zeta Potential Changes of Semiconducting Nanoparticles
AMO4	Trey Guest	Evaluation of an Undulator Soft X-ray Beamline for the Study of 6.x nm Interference Lithography
AMO5	Abbas Hussein	Bose Einstein condensates of metastable Helium loaded into an optical lattice

Thursday 5th December 2019

9:00	9:45	Keynote 1	Sven Rogge		
9:45	10:30	Keynote 2	Virginia Kilborn		
10:30	11:00	Morning Tea			
	Session IV	**IV.1**	**IV.2**	**IV.3**	
	Theme	**Condensed Matter**	**Astrophysics**	**Biophysics**	
	Chair	*Stephan Rachel*	*Virginia Kilborn*	*Brian Abbey*	
11:00	11:15	Eric Mascot	Strang	Kaye Morgan	
11:15	11:30		Venville		
11:30	11:45	Pan	Williams	Kozlov	
11:45	12:00	Wolf	Balkenhol	Qazi	
12:00	12:15	Crawford	Patil	Barzegaramiriolya	
12:15	12:30	Bartolo		Stamp	
12:30	13:30	Lunch			
	Session V	**V.1**	**V.2**	**V.3**	
	Theme	**Condensed Matter**	**Particle Physics**	**Physics Education**	
	Chair	*Jared Cole*	*Peter Skands*	*Jasmina Galloway*	
13:30	13:45	Charlotte Petersen	Martin Sevior	Maria Parapilly	
13:45	14:00				
14:00	14:15	Martin	Krohn	Smith	
14:15	14:30	Hinsley	Ferlewicz	Kota	
14:30	14:45	Bryant	Pham	Hughes	
14:45	15:00	Zhu	MacQueen		
15:00	15:30	Afternoon Tea			
	Session VI	**VI.1**	**VI.2**	**VI.3**	
	Theme	**Condensed Matter**	**Quantum Computing**	**Atomic, Molecular, Optical**	
	Chair	*Anton Tadich*	*Sven Rogge*	*Sean Hodgman*	
15:30	15:45	J-P Tetienne	Charles Hill	Paul Dyke	
15:45	16:00		Buchs		
16:00	16:15	Cole	Berkman	Kim	
16:15	16:30	Lillie	Tonetto	Anda	
16:30	16:45	Dontshuk	Mooney	Yazmaciyan	
16:45	17:00	Moss	Kargi	Sullivan	

18:30	21:30	**CONFERENCE DINNER**

Friday 6th December 2019

9:00	*9:45*	Keynote 3	Christine Charles	
9:45	*10:30*	Keynote 4	Deb Kane	
10:30	*11:00*	Morning Tea		
Session VII		***VII.1***	***VII.2***	***VII.3***
	Theme	**Condensed Matter**	**Particle Physics**	**Quantum Computing**
	Chair	*Jennifer MacLeod*	*Nick Menicucci*	*Gilles Buchs*
11:00	*11:15*	Peter Jacobson	Nick Menicucci	Henriques
11:15	*11:30*			van Geleuken
11:30	*11:45*	Cyster	Virgato	Robson
11:45	*12:00*	Grant	Amintaheri	Holmes
12:00	*12:15*	J. Smith	Sanderson	Usman
12:15	*12:30*	Klymenko	Bigaran	Mensen
12:30	*13:30*	Lunch		
Session VIII		***VIII.1***	***VIII.2***	***VIII.3***
	Theme	**Condensed Matter**	**Biophysics**	**Space Physics**
	Chair	*Peter Jacobson*	*Alex Kozlov*	*Gail Iles*
13:30	*13:45*	Jennifer MacLeod	Brian Abbey	Daniel Liang
13:45	*14:00*			
14:00	*14:15*	Raeber	Lou	Iles
14:15	*14:30*	Wong	Solano	Moshovelis
14:30	*14:45*	Hochstetter	Su	
14:45	*15:00*	Valani		

15:00	*15:30*	**CLOSING CEREMONY**

Strong Correlation Physics in Moiré Superlattices formed in Two-Dimensional Crystals

A.H. MacDonald[a],

[a] *Physics Department, University of Texas at Austin 78712 USA*

Moiré patterns are ubiquitous in layered van der Waals materials and can now be fabricated with considerable control by combining mechanical exfoliation of van der Waals layers with tear and stack device fabrication techniques. I will explain why the electronic and optical properties of two-dimensional semiconductors and semimetals are strongly altered in long-period moiré superlattices, focusing in particular on the remarkable example of twisted bilayer graphene.

When twisted to a magic [1] relative orientation angle near 1 degree the moiré superlattice minibands of bilayer graphene become extremely narrow and electronic correlations become strong. Experimental studies [2] of magic-angle twisted bilayer graphene (MATBG) have demonstrated that the electronic ground state can be a superconductor, a metal, or an insulator, depending on the filling of the magic angle flat bands. Insulating states occur close to most integer values of the number of electrons per moiré superlattice period, whereas superconducting states are common at fractional moiré band filling factors. In some cases, the insulating states are purely orbital ferromagnets that exhibit a quantum anomalous Hall effect and have superlattice bands with non-zero topological Chern indices *C*. I will discuss progress that has been made toward understanding these remarkable properties

[1] Moire bands in twisted double-layer graphene, R. Bistritzer and A.H. MacDonald, PNAS **108**, 12233 (2011).

[2] Magic-angle graphene superlattices: a new platform for unconventional superconductivity, Y. Cao *et al.* Nature (2018).

Spin Molecular Orbital Coupling in Organometallic Complexes- A new approach

A. L. Khosla[a], A. C. Jacko[a], J. Merino[b] and B. J. Powell[a]

[a]*School of Mathematics and Physics, The University of Queensland, Brisbane, Queensland 4072, Australia*

[b]*Departamento de Fsica Terica de la Materia Condensada, Condensed Matter Physics Center (IFIMAC) and Instituto Nicols Cabrera, Universidad Autnoma de Madrid 28049, Spain*

Spin-orbit coupling (SOC) is a relativistic effect that entangles orbital and spin degrees of freedom such that neither remain good quantum numbers. It splits otherwise degenerate sets of orbitals. The combination of SOC and strong electronic correlations can lead to a variety of novel phases such as topological Mott insulators and quantum spin liquids. To date much of this research has been largely focused on inorganic atomic crystals with partially filled d-orbitals, in particular transition metal oxides. In these systems the SOC is essentially atomic and increases with atomic number. Molecular crystals provide a novel playground for understanding the combined effect of strong SOC and electron correlations - due to the tunability of these organic and organometallic systems.

Calculating the exact form of the SOC is a difficult task. Thus SOC is often treated by only attributing its effects to the heaviest atoms in the molecule and assuming that the spherically symmetry of a single atom remains. In this work we present a new approach to determining the form of the SOC for organometallic systems and present the emergence of a Spin Molecular Orbital Coupling (SMOC) that is unlike what might be expected.

I will discuss ongoing work on deriving the SOC Hamiltonians for all 32 Point Groups, starting with the simplest case of cyclic symmetry [1] and moving on to the larger groups of higher symmetry. We invoke group theoretical techniques to derive the exact form of the SOC Hamiltonian. We make use of not only the geometric symmetry of the system but also time reversal symmetry. This method does not allow us to determine terms in the Hamiltonian are allowed to exist based on the symmetry alone, without the need for atomistic calculations.

[1] A. L. Khosla, A. C. Jacko, J. Merino, and B. J. Powell, *Phys. Rev. B* **95**, 115109 (2017)

Large Anomalous Hall Effect in Amorphous $Fe_{1-y}Co_ySi$ Thin Films

S. Bennett[a], D. S. Bouma[b,c], A. Nguyen[a], J. Karel[a,d], F. Hellman[b,c]

[a] *Department of Materials Science and Engineering, Monash University, Clayton, Victoria 3800, Australia*

[b] *Materials Science Division, Lawrence Berkeley National Lab, Berkeley, CA, USA*

[c] *Physics Department, University of California Berkeley, Berkeley, CA USA*

[d] *ARC Centre of Excellence in Future Low-Energy Electronics Technologies, Monash University, Clayton, Victoria 3800, Australia*

Magnetoresistive random access memory (MRAM) utilizing spin orbit torque (SOT) based switching has emerged as a promising non-volatile memory candidate, and amorphous materials offer a unique prospect with respect to this technology. They lack long range order, and theory has predicted that disorder may lead to an enhancement in spin orbit torques.[1,2] Moreover, amorphous materials are extremely tolerant to defects, meaning less stringent manufacturing requirements and thus lower costs.

This work will present a study of the anomalous Hall effect (AHE) in a series of amorphous $Fe_{1-y}Co_ySi$ ($0<y<1$) thin films. The mechanisms used to describe the spin Hall effect (SHE) borrow directly from the physics of the AHE; therefore, a large AHE may point to a large SHE and a potential application in SOT-MRAM. A large AHE was found in amorphous $Fe_{1-y}Co_ySi$ thin films with y = 0-0.3. The magnitude of the Hall resistivity is larger than previously reported in the bulk crystalline analogue (e.g. $Fe_{0.9}Co_{0.1}Si$ ~2μΩcm at 5K).[3] This large effect persists up to room temperature. The magnetic moment is also larger than previously reported in bulk crystalline $Fe_{1-y}Co_ySi$ (e.g. y=0.1 M_s ~50 emu/cm^3).[3] Similar enhancements in magnetization have been reported in amorphous Fe_xSi_{1-x} ($0.45<x<0.65$) thin films in comparison to the crystalline analogue.[4] The origins of this large AHE will be discussed. Specifically, we will show that the results suggest the intrinsic mechanism (e.g. non-zero Berry curvature) may play an important role. In these amorphous materials, the possible dependence of the AHE on the intrinsic mechanism is remarkable because it indicates a local atomic level description of a Berry phase in a system that lacks lattice periodicity.

[1] I. A. Ado, O. A. Tretiakov, *et al.*, *Phys. Rev B* **95**, 094401 (2017)

[2] O. A. Tretiakov, *et al.,* Phys. Rev Lett **119**, 077203 (2017)

[3] N. Manyala, *et al., Nature Materials* **3** 255 (2004)

[4] J. Karel, *et al., Europhysics Letters* **114** 57004 (2016)

Disruption of helical edge states in topological insulators by magnetic impurities

J. A. Vaitkus†, S. A. Wilkinson, and J. H Cole
Chemical and Quantum Physics and ARC Centre for Future Low-Energy Electronics Technologies, School of Science, RMIT University 3000, Melbourne, Australia

Topological insulators (Tis) are a promising candidate for future low-energy electronics technologies, and the 2D or quantum spin hall (QSH) insulator [1] has attracted much attention for its $2e^2/h$ conductance regardless of width. This conductance is characterised by two helical edge states that have correlated spin polarization and momenta [2]. This correlation acts to explicitly prevent backscatter, as a spin-flip is required to scatter into the opposite momentum state. Introduction of magnetic defects break time reversal symmetry and allows for such a flip. Therefore, a bath of nuclear spins coupling to the transport electron spins via the hyperfine interaction will disrupt the pristine helical flow. Alternatively, this effect may prove useful, enabling electrical polarization of the bath spins [3].

We use the Non-Equilibrium Green's function (NEGF) formalism to explicitly model transport in a QSH model [1]. This method allows for arbitrary defect placement, and full energetic dependency on current, charge and spin densities. A nuclear spin bath is introduced using a first principles derived self-energy [4], modified to work as Büttiker probes [5]. We observe the redistribution of spin polarization mediated by a spin-bath, presented in Figure 1.

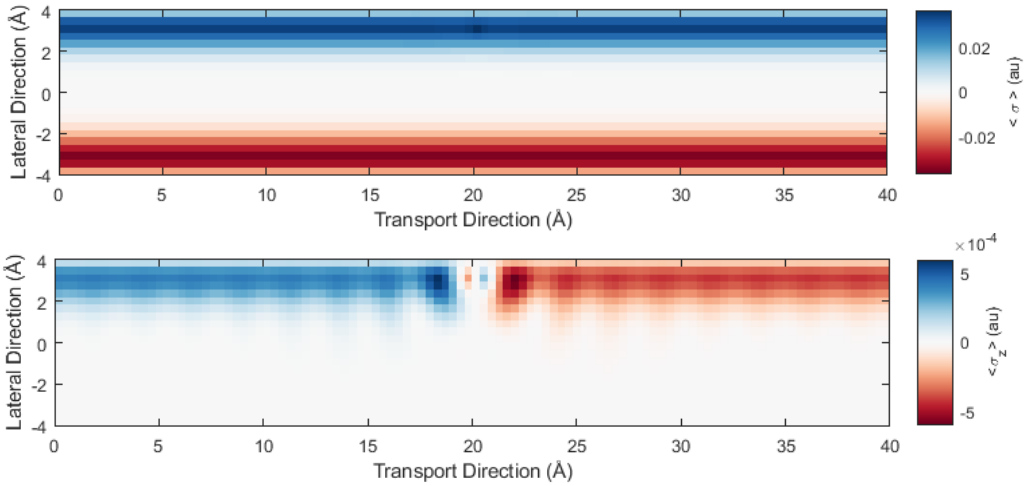

Fig. 1. (Top) Total spin density for a helical edge state for conduction from right to left, showing the correlation between momentum and spin direction. (Bottom) Partial current contribution introduced by spin scattering due to an unpolarised nuclear spin positioned close to the top edge. The induced spin current propagates with opposite spin in each direction.

[1] Bernevig, Hughes, Zhang, 2006, *Science* **314**(5806), 1757.
[2] Qi, Zhang, 2011, *Reviews of Modern Physics* **83**(4), 1057.
[3] Bozkurt, Pekerten, Adagideli, 2018, *Physical Review B* **97**(24), 245414.
[4] Yanik, Klimeck, Datta, 2007, *Physical Review B*, **76**(4), 045213.
[5] Vaitkus, Cole, 2018, *Physical Review B* **97**(8), 085149.
†jesse.vaitkus@rmit.edu.au

Impurity bound states as detectors of first and higher-order topological insulators

Seydou-Samba Diop[a,b], Matthias Vojta[c] and Stephan Rachel[a]

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[b]*Département des Sciences de la Matière, ENS de Lyon, 69007 Lyon, France*

[c]*Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany*

Band structures of topological insulators are characterized by non-local topological invariants. As a consequence, proposals for the experimental detection using local probes are rare. A recent paper has argued, based on theoretical results for a particular class of models, that topologically trivial and non-trivial band structures in two space dimensions display a qualitatively different response to point-like impurities. Here we present a comprehensive investigation of the impurity response of different models of non-interacting electrons on the honeycomb lattice, driven insulating by either broken inversion, broken time reversal, broken C_3, or broken translation symmetry, or by applied magnetic field. Amongst these models are several higher-order topological insulators. Our results confirm that for translation-invariant host systems, the response to a single impurity can indeed distinguish between cases of trivial and non-trivial topology (albeit not between weak and strong topological phases). However, for modulated or inhomogeneous host systems, this distinction fails.

Transport properties of a two-dimensional electron gas with spin-orbit coupling

Y. K. Lee[a], Jackson S. Smith[a], Jared H. Cole[a]
[a] *Chemical and Quantum Physics, School of Science, RMIT University, Melbourne, Australia*

Given current power consumption trends, improvements in the energy efficiency of modern electronic devices are sorely needed. Spintronics, where spin manipulation replaces charge manipulation, is a promising way to achieve this improvement. However, it is difficult to design such nanoscale devices because at these length scales their electrical transport properties are influenced by quantum effects. One example of a nanoscale device is the two-dimensional electron gas (2DEG). In such a system, spin-orbit coupling (for example via the Rashba effect) leads to a coupling between the spin and momentum of conduction electrons. Furthermore, if an external magnetic field is applied, the Zeeman effect results in a coupling between the spin of the electrons and the external magnetic field. The interaction of these two effects leads to interesting topological phenomena such as the anomalous Hall effect and edge states. The interplay of the Zeeman and Rashba effects allows for an important hurdle in spintronics to be overcome, namely, the spatial separation of electrons with different spins. By applying an out-of-plane magnetic field to a 2DEG, the electrons curve in a cyclotron motion and, due to the Rashba effect, electrons of different spins will have different Larmor radii (Fig. 1). This technique is called transverse magnetic focusing (TMF) and has been shown to be a viable way to separate electron spins. We investigate the transport properties of a TMF system in a 2DEG using the non-equilibrium Green's functions (NEGF) formalism, combined with a tight-binding model of the 2DEG. In doing so we analyze the effects of varying conditions such as spin-orbit coupling, magnetic field, device geometry, and disorder strength.

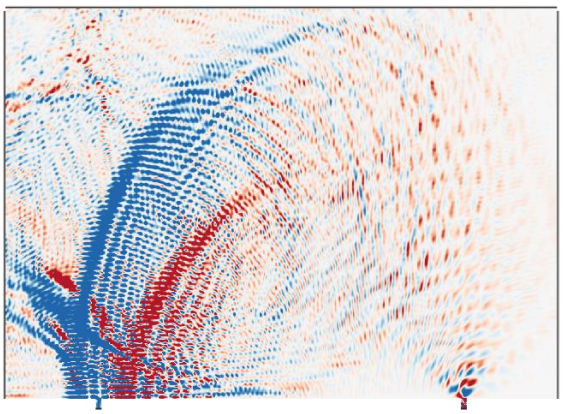

Fig. 1. *Electron density for a 2DEG with an out-of-plane magnetic field (B_z) applied. Electrons are injected on the bottom right, and collected on the bottom left. The electrons are shown to separate into two paths, each corresponding to a different spin.*

Searching for continuous gravitational waves from low mass X-ray binaries with known rotation frequencies

Hannah Middleton[a,b], Patrick Clearwater[a,b,c], Andrew Melatos[a,b] and Liam Dunn[a,b]

[a]*School of Physics, University of Melbourne, Parkville, VIC 3010, Australia*

[b]*OzGrav-Melbourne, Australian Research Council Centre of Excellence for Gravitational Wave Discovery*

[c] *Data61, Commonwealth Scientific and Industrial Research Organisation Corner Vimiera & Pembroke Roads, Marsfield NSW 2122, Australia*

Ground-based gravitational wave observatories are searching for continuous gravitational waves (persistent periodic signals) from rotating neutron stars. Neutron stars in low mass X-ray binaries (LMXB) are prime continuous wave targets. Traditional continuous wave LMXB targets, such as Scorpius X-1 have been subject to thorough searches, but these searches are hampered by a lack of electromagnetic observation of the neutron star rotation frequency (e.g. [1]). This work describes a search for a number of other LMXBs that have high-precision measurements of rotation frequency (and also orbital parameters), allowing a finely targeted search with a modest computational cost. One challenge addressed is that the the rotation frequency itself may not be monochromatic and in fact wanders unpredictably on a timescale (~ 10 days) which may be shorter than the electromagnetic observation cadence. A hidden Markov model [2] can be used to search for just such a wandering frequency. In this work we search data from the second observing run of Advanced LIGO (Laser Interferometer Gravitational-wave Observatory [3]).

[1] The LIGO Scientific Collaboration and The Virgo Collaboration, *Search for gravitational waves from Scorpius X-1 in the second Advanced LIGO observing run with an improved hidden Markov model*, preprint: 1906.12040 (2019)

[2] S. Suvorova, P. Clearwater, A. Melatos, L. Sun, W. Moran, R. J. Evans, *Hidden Markov model tracking of continuous gravitational waves from a binary neutron star with wandering spin. II. Binary orbital phase tracking*, PRD 96 10 (2017)

[3] J. Aasi et al., *Advanced LIGO*, CQG 32 074001 (2015)

Classification of full-length K2 mission light curves using ensemble methods

R. Kgoadi[a], A. Tkachenko[b], I. Whittingham[a] and C. Engelbrecht[c]

[a]*College of Science and Engineering, James Cook University, Townsville Queensland, 4810, Australia*

[b]*Instituut voor Sterrenkunde, KU Leuven, Celestijnenlaan 200D, B-3001 Leuven, Belgium*

[c]*Physics Department, Faculty of Science, University of Johannesburg, Johannesburg, 2006, South Africa*

The K2 mission observed at least 500,000 objects over a period of four years. However, a significant number of these have not been classified. In this study, we aim to classify stellar light curves from the K2 mission using stellar light curves. In this presentation, we will propose a method to generate a full-length K2 cataloque and present preliminary results. Ensemble methods consisting of extreme gradient boosted tress (`xgb`) and Artificial Neural Networks (ANNs) will be utilised to classify stars. Classifiers will be trained on previously labelled stars from the mission using a subset of features derived from light curves and colour magnitudes from photometry.

26AL SLR production and its impact on planetary habitability

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To build habitable planets we must start with understanding the make-up of their protoplanetary nebula. This nebula will have some intrinsic chemical make-up, but can also become "enriched" by elements shed from nearby massive stars via OB stellar winds or supernova explosions. Particularly important in this context are the short-lived radionuclides (SLRs), such as 26Al. They are a major heat source responsible for the planetesimal melting and differentiation in the early Solar system. Residual heating provided by SLRs is potentially crucial in forming iron-rich planetary cores, as well as sustaining them in liquid form, which then produces protective magnetic fields. We will present a summary of our project on habitable planets, looking into distribution and accumulative yield of 26Al in stellar clusters, and their effect on nearby planetesimals.

Stress-release modelling as applied to pulsar glitches

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Many physical systems boil down to stress steadily building up and being released in sudden, stochastic events. Avalanches, bush fires, solar flares, and pulsar glitches fall into this category. We have developed a generic meta-model which tracks the stress in such systems, allowing specific, precise, *falsifiable* predictions to be made regarding the long-term statistical behaviour of the system.

In particular, we apply the meta-model to pulsar glitches: events which abruptly spin up a neutron star, interrupting the star's steady spin-down. As the number of observed rotational glitches in pulsars grows it is useful to consider the time-ordered nature of these sudden events. The shape of waiting time and glitch size distributions, cross-correlations, and autocorrelations are all avenues that can test the applicability of the meta-model. Reconciling observations with the meta-model leads to implications as to which physical mechanism may be causing glitches in pulsars.

Changing Look Active Galactic Nuclei in the Southern Sky

2019

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Active Galactic Nuclei (AGN) with extreme optical/UV continuum and broad line emission variation are classified as Changing Look AGN (CLAGN). The short timescale of these variations challenges the accepted models of the AGN physics, thus offering insight to new AGN dynamics. In particular binary black hole systems are of interest in explaining the observed changes. With still less than 100 classified CLAGN [1], searching for more is highly beneficial. We present our work on 7 CLAGN found in the Southern Sky. These are sources among the 6dFGS spectral database with optical variation relative to the Skymapper Southern Sky Survey photometry. Spectral verification of CLAGN changes are from the Australian National University 2.3m WiFeS instrument. Based on our first study of the metrics used for CLAGN searches, we can infer that present searches are highly incomplete implying that there are more to be discovered.

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Activities of the European Radiation Dosimetry Group (EURADOS)

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The European Radiation Dosimetry Group (EURADOS) is a self-sustainable network of more than 60 European institutions including about 600 scientists active in the field of dosimetry of ionising radiation. The mission of the network includes promotion of European cooperation in research and development in the dosimetry of ionizing radiation and its implementation in routine practice. EURADOS Working Groups are active in various dosimetric fields and cover a wide range of dosimetric applications. Working Group topics include harmonization of individual monitoring, environmental dosimetry, computational dosimetry, internal dosimetry, dosimetry for medical applications (diagnostics and therapy), retrospective dosimetry, and dosimetry in high-energy radiation fields. Education and training are also important activities for EURADOS.

As a major topic across all Working Groups, EURADOS has recently published a Strategic Research Agenda "Visions on Dosimetry of Ionising Radiation" which is used by the European Commission to identify future research needs in radiation dosimetry in Europe. Currently this Strategic Research Agenda is being updated by a cross-cutting effort involving all EURADOS Working Groups.

The present paper introduces the network and presents strategic views on the future of dosimetry in Europe including medical applications. More details can be found on the EURADOS website (www.eurados.org).

Skin Dose Measurement of 3D-printed Materials for Radiation Therapy Immobilisation Masks

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Increased or unknown skin dose is considered as one of the disadvantages of radiation therapy fixation devices as materials used have a bolus effect which increase the radiation dose on the patient's skin.

This work aims at investigating the influence of infill pattern, infill density and print orientation of the 3D print materials on the change in the surface dose.

Sixty samples were printed using fused filament fabrication (FFF) technique (Flashforge Creator Pro 3D printer) with dimensions 100 mm × 100 mm × 3mm for skin dose measurement. These tests were performed using a 6MV X-ray beam from a Varian Trubeam linear accelerator. Acrylonitrile butadiene styrene (ABS) was used as the print material. The samples were printed with 10 different infill patterns which each of them was printed with 4 different infill density including 15%, 30%, 50% and 80%. The samples were also printed in two print orientation (vertically and horizontally).

For the horizontally printed samples, the sample with 50% infill density and Star pattern had the least surface dose, however, the sample with 3D Honey comb pattern and 80% infill density had the highest surface dose. In the vertically printed samples, the Hilbert curve pattern with 15% density had the least surface dose while Honey combe with 80% density had the highest surface dose. The infill pattern and infill density with the least surface dose would be selected for printing an immobilisation mask for our future work.

Complete Elimination of the Beam Hardening Effect in Quantitative Absorption Tomography Using Polychromatic X-rays with Single-Component Specimens

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Absorption tomography has been a unique technique for 3D imaging in many scientific research and applications. However, the use of polychromatic x-ray sources for quantitative tomography has been limited due to the well-known beam hardening effect. In this presentation, we will describe the theoretical details of a new technique for quantitative tomography using polychromatic x-rays. The technique incorporates the full spectral information of the incident beam into the tomographic reconstruction process. Consequently, beam hardening effects are eliminated and the result is quantitative. We will also demonstrate the technique experimentally using a single-component specimen. This technique promises great opportunities for laboratory-based x-ray sources to be used in quantitative applications.

AIP Abstract: Robust, affordable radiotherapy accelerators for challenging environments

One of the greatest barriers to cancer treatment in Low and Middle-Income Countries (LMICs) is the access to Radiotherapy Linacs. Not only are these machines expensive, the harsh environment of LMICs cause frequent breakdowns, resulting in downtimes ranging from days to months. From recent research done into downtime and failure modes, many of the faults are linked to inconsistent power supply and insufficient preventative maintenance, along with inaccessible spare parts and expertise. Little is being done in the accelerator components to improve these machines. This project aims to propose alternatives to the current generation Linacs, by looking first at modelling the electron beam parameters, studying possibilities for of replacing the electromagnet with permanent magnets or removing it all together as well as introducing a simpler collimation system in conjunction with electron beam manipulation. The ultimate goal is to simplify these machines to achieve less frequent downtimes and greater quality cancer care in LMICs.

Comparison of future hadron therapy synchrotron and beam delivery options

The Next Ion Medical Machine Study (NIMMS) project led by CERN aims to design the next generation hadron therapy system including a compact synchrotron and an efficient beam delivery method suitable for future clinical use. This project synergises with the Australian initiative to build the first hadron therapy centres in the country. As a first step in collaboration with CERN, this work compares different synchrotron designs used in existing hadron therapy facilities worldwide. A systematic scan of the design parameters was performed with considerations of design requirements for the beam intensity, magnet strength and compactness. We also outline future work including a feasibility study for a permanent magnet beam delivery system.

Anisotropic 3D weak localization in nitrogen incorporated ultra-nanocrystalline diamond films

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We present a study of the structural and electronic properties of ultra-nanocrystalline diamond films that were modified by adding nitrogen to the gas mixture during chemical vapour deposition growth. Hall bar devices were fabricated from the resulting films to investigate their electrical conduction as a function of both temperature and magnetic field. Through cryogenic magnetoresistance measurements, we present strong evidence that the dominant conduction mechanism in these films can be explained by a combination of 3D weak localization (3DWL) and thermally activated hopping at higher temperatures. An anisotropic 3DWL model is then applied to extract the phase-coherence time as function of temperature, which shows evidence of a power law dependence in good agreement with theory.

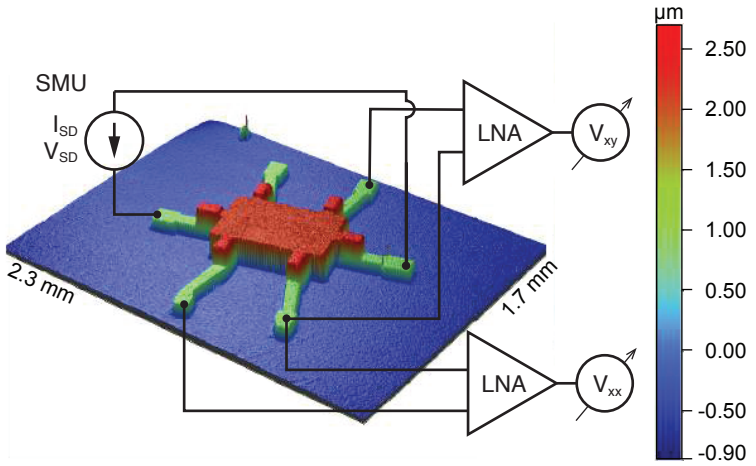

Figure 1: Schematic of the electrical measurement setup overlaid on a false-color 3D optical profilometer image of an N-UNCD Hall bar device

Heteroepitaxial Growth of SiC on Diamond

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Diamond is a wide-bandgap semiconductor with a high thermal conductivity and significant interest as it is a promising host material for novel solid-state quantum and high power electronic devices [1]. However, utilising diamond in a heterostructure is difficult due to its small lattice parameter which limits coherent heterojunction formation with other materials. The lattice mismatch between materials can result in screw dislocations, threading faults, and twinned growth which form to relieve interfacial strain and detract from heterostructure performance [2].

The work presented here shows the formation of a localised coherent interface between diamond and silicon carbide with minimal strain. These materials have a mismatch $f \approx 20\%$, significantly beyond the expected range of coherent junction formation. We propose a surface reconstruction model that accounts for this surprising lack of misfit dislocations. An advantage associated with such a junction is the superior capabilities of diamond to cool high power SiC devices. In addition, novel applications in quantum devices as well as viable pn-junctions indicate a yet to be explored range of possibilities that could be achieved.

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Improve the wetting of Gold-ABA filler on micromachined diamond by using nano-metallic layers via vacuum brazing technique

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With approximately 200 million people suffering from degenerative retina conditions, development of vision prostheses, such as the Bionic Eye, are of significant interest in biomedical research. Such medical devices contain sophisticated electronic circuits. Therefore, biocompatible, durable and hermetic packaging are required to protect the electronic circuitry of the implant from the harsh environment inside the human body. Diamond as a material exhibits outstanding biochemical stability, chemical inertness and mechanical stability. Combined with Gold-ABA, which can be used to generated low impedance feedthroughs, suitable for data and power transfer to internal electronics [1], these materials are excellent choices for implantable devices. However, Au-ABA is unable to wet bare diamond surface due to their inertness and adhesion layers are required. We previously showed [2] that silver-ABA can improved wetting of Au braze but only enough for to yield <10% success rate and is likely to receive scrutiny by regulators owing to silver's established toxicity and propensity to degrade, in vivo. The principle aim of the present work is to improve the wettability of Au-ABA braze on diamond by applying nano-metallic interlayers. The diamond surfaces were milled by laser. Prior to the brazing, either Mo, Nb or Mo/Nb bilayer thin films ranging from (10nm-1μm) were sputtered onto the samples. Brazing experiments was performed in a brazing furnace at 1100°C for 30 minutes under vacuum. Surface and cross-sectional microstructure of braze-diamond interfaces were observed by either optical microscopy, scanning electron microscopy or Energy dispersive X-ray spectroscopy. Also, helium leak test was conducted to test the hermeticity. Using Mo and Nb bilayer, excellent wettability was obtained, with the braze completely filling the holes and leaving no gaps. We have thus shown that biocompatible metallic interlayers such as Mo and Nb can replace the Ag based brazes. The results bode well for the use of diamond encapsulation in biomedical devices.

Acknowledgement

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SiC/SiO_2 interface related quantum emitters

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Silicon carbide (SiC) has attracted considerable attention for use in high-power, high-temperature and high-frequency device applications. However, major improvements in device performance are still urgently required since transistor mobilities remain low (typically < 20 $cm^2V^{-1}s^{-1}$). This is attributed to the high SiC/SiO_2 interface defect density.

In this work, we investigate the optical properties of defects that reside near the SiC/SiO_2 interface. These defects form a continuum of states in the band gap and display photoluminescence over a broad range of wavelengths from about 500 to 700 nm. By tuning an excitation laser appropriately, single defects can be addressed individually [1]. This allows the defect density to be quantified directly and quickly within a specific optical energy window in a non-destructive manner without the need for test device fabrication. Here, the effect of various interface passivation and surface modification procedures are considered [2].

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Electrically Detected Magnetic Resonance Study of Intrinsic Defects in SiC PN Junction Devices

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We report on the development of a compact room temperature low and high field electrically detected magnetic resonance (EDMR) spectrometer recently established at the University of Melbourne. The system is being used to spectroscopically investigate the transport mechanisms and spin properties of atomic-scale paramagnetic defects in SiC. Deep level defects in SiC have recently drawn significant interest as promising candidates for quantum applications as it has been shown that some defects have coherence times comparable to the nitrogen-vacancy centers (NV) in diamond [1,2]. In addition to being a material more amenable to electrical device fabrication than diamond, CMOS-compatible SiC has a range of polytypes available which allow the properties of a particular defect to be tuned.

We have recently demonstrated successful implementation of our custom-built EDMR spectrometer on a fully fabricated 6H-SiC pn junction at low magnetic fields by observing a continuous wave spin resonance signal following the Zeeman condition via spin-dependent recombination (SDR). An additional signal situated at zero field was also observed even in the absence of RF excitation. This was previously ascribed to the transition between degenerate triplet and singlet states at zero magnetic field [3]. The EDMR spectrum was studied as a function of the lock-in modulation source, bias across junction, and RF excitation power. Once optimized, a large signal amplitude and high signal-to-noise ratio (SNR) was measured from a single EDMR scan, which has immediate potential for applications in magnetometry [4].

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Higher-Order Ghost Imaging with Ultracold He* Atoms

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Ghost imaging is a quantum optics technique where correlations between two beams are used to reconstruct an image from photons that never interact with the object being imaged. The correlated nature of ghost imaging means that it can yield improved performance in certain imaging applications, such as for weakly absorbing objects, at low light levels or where imaging may cause damage to the target. While pairwise (second-order) correlations are usually used to form the ghost image, higher-order correlations can be employed and have been shown to improve imaging performance.

We have demonstrated higher-order atomic ghost imaging [1], following on from our previous demonstration of ghost imaging using atoms [2], the first such demonstration with massive particles. Both experiments used entangled [3] pairs of ultracold metastable helium atoms from an s-wave collision halo formed by colliding two Bose-Einstein condensates. We are able to create higher-order ghost images (up to fifth order) and show that using higher-order correlations can improve the visibility of the images at no detriment to the imaging resolution. This is the first demonstration of higher-order ghost imaging with massive particles. It is also the first higher-order ghost imaging experimental protocol of any type to use a quantum source (i.e. quantum correlated pairs of particles generated in analogy to spontaneous parametic down conversion, rather than the intensity fluctuations or correlations used in previous optical experiments).

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Photoassociation dynamics of two atoms

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Optical tweezers provide a rapidly advancing platform for control and manipulation of individual atoms. We can now use these tweezers to build individual molecules using a process known as photoassociation [1, 2]. This process of molecule formation has been studied in many-atom ensembles for several decades [3, 4], but the ability to isolate indivudial reactions allows a much higher degree of control over the process and the created molecule. Our goal is to investigate the dynamics and determine if there is a fundamental limit for the time it takes to form a molecule in the two-atom case.

We prepare single ^{85}Rb atoms in seperate optical tweezers in particular internal quantum states [5]. Merging two such tweezers ensures that we hold exactly two atoms in a single tweezer from which we can build a molecule.

Photoassociating the two atoms in the optical tweezer reveals more complex dynamics than those observed in many-atom ensembles. We find that the single photoassociation rate which is found in many-atom ensembles is insufficient to describe the observed dynamics of just two atoms. Instead, two different timescales for photoassociation - a fast one and a significantly slower one - are necessary to describe our observations. The dynamics originate from the 2-atom system being non-chaotic and the time to form a molecule depending on the initially populated state. These additional dynamics are unique to the two-body system and vanish when we introduce a third atom to the system.

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Grassmann Phase Space Theory for Fermions: Stochastic Field Equations for Temperature Evolution

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Recent developments [1, 2] show that the behavior of fermions in cold atom and condensed matter physics may be treated using Grassmann phase space theory (GSPT), in which annihilation and creation operators are represented by Grassmann variables (rather than c-numbers as for bosons), with the density operator equivalent to a distribution function of these variables. Treatments based on both [3] separate modes and on fields have been formulated, and applications [4,5] of Grassmann phase space theory have been carried out.

Grassmann phase space theory enables the calculation of quantum correlation functions (QCF) as stochastic averages of products of stochastic Grassmann phase space variables or fields. Using the B distribution [4], Fokker-Planck equations for the distribution function are obtained from the density operator's evolution equation, and here the drift vector and diffusion matrix depend linearly and bilinearly (respectively) on the Grassmann variables or fields. Ito stochastic equations can then be obtained with the evolved Grassmann quantities depending linearly on their initial values via stochastic transformation matrices only involving c-numbers. QCF can hence be calculated numerically without representing Grassmann quantities on the computer.

Previous work [2,3,5] dealt with time evolution. Here we show how GPST can be applied to treat temperature evolution based on Matsubara equations for the equilibrium density operator.

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Ground-state energy of a quasi-free positron in liquid helium

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Understanding the propagation of electrons and positrons through dense media is important for many applications, including plasma medicine, PET scans and liquid particle detectors. One of the essential elements of the transport properties of the electrons and positrons is the ground-state energy they have in liquids (V_0) [1, 2]. Compared to the particles in the gaseous systems, the ones in the liquid systems behave more quantum mechanically and classical models are not sufficient to describe them. This poses a challenge for the calculation in liquid systems [3]. The current project is an attempt to provide an accurate ab initio method to calculate V_0 values for electrons and positrons in liquids.

We have developed a numerical method to explore the density dependence of the ground-state energy of a quasi-free positron in non-polar liquids. This method generates the V_0 values by numerically solving the scattering equation of the positron in a liquid. We use the Wigner-Seitz model [2] and the polarised orbital method [4] to describe the liquid structure and potential, and we obtain the pair correlator through molecular dynamics simulations. We have applied our method to calculate V_0 for positrons in several noble-gas liquids and will discuss our results for positrons in liquid helium.

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Critical measurement of the phase fine structures across the copper K-edge

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Current applications of X-ray Absorption Fine Structure to low absorbing samples such as ultra-thin films in semiconductor and nano-devices have been limited. This is expected to not be the case for the phase component of the fine structure as it is generally orders of magnitude larger than the absorption component in the x-ray regime. We will present details of an experimental measurement to retrieve the phase and absorption components of a copper thin film simultaneously at the XFM beamline of the Australian Synchrotron by applying the HERALDO technique across the copper K-edge. The results provide critical experimental benchmark for further theoretical development and has potential to delve into the phase equivalent of the XAFS technique.

Ultraviolet radiation, Art and Science Outreach – Physics Education activities expanded with the cyanotype.

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In recent years, a resurgence of interest in the cyanotype has occurred. The cyanotype was developed by John Herschel as a method of photography and was made famous by female botanist Anna Atkins, considered the first producer of a book utilising "photography" to provide scientific images. Today the cyanotype is of particular interest to artists curious about alternative photography methods, however the technique is also extremely useful to the scientist as well. The method produces images resulting in a palette of incredible azure blue (better known as "Prussian blue") although variations in the chemical reactions and pre- and post-treatments to the printing can vary the colour significantly. It is also a common experiment in the chemistry lab, but it has been found to be particularly useful for physics experiments that may be otherwise difficult to explain to certain age groups. Using the paper version of the technique, physicists can visually demonstrate effects of ultraviolet (UV) radiation, demonstrate absorbance of chemicals and efficacy of sunscreen at blocking UV radiation, and just generally be an all-round fun activity for any age group. Applications of further experiments include investigating scattered radiation, and creating calibration curves for dose response measurement. This presentation will review the current knowledge on the technique from a physics education point of view, and present new activities and research in order to expand student understanding and knowledge of physical processes through practical application. In particular the activities are able to show participants changes directly resulting from exposure to UV radiation, with minimal UV exposure to the participant. The activities are suitable for teachers, researchers and anyone interested in this area of public awareness.

Addressing the shortage of trained physics teachers in Australia

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There is an acknowledged shortage of physics trained school teachers in Australia, over 60% do not have a physics major [1]. A recent report [2] found that 20% of physics classes were taught by teachers teaching out-of-field. In 2019 the requirement to be an accredited physics teacher in NSW changed to require accredited physics teachers to have completed four university level physics courses so this shortage is only going to get worse if not addressed. There is no shortage of science teachers, the shortage is specifically in physics [2].

UNSW has recently introduced a graduate certificate in physics for science teachers. It consists of four university level physics courses. The program is aimed at science teachers as they have already completed teaching methods courses in science education and are currently working as biology or chemistry teachers. In Australia 30-40% of teachers leave teaching in their first five years [3], as such training established teachers may produce a larger impact.

The degree is delivered online to cater for rural teachers and provide flexibility for currently employed teachers. The courses have been designed to promote active engagement as much as possible [4]. Throughout the course students are encouraged to share ideas of how they could teach this material to their students. Where possible predict-observe-explain has been used for demonstrations with teachers entering their predictions, observations, and explanations into the online platform. While the courses are physics courses rather than teaching method courses there are references made to the literature on physics teaching throughout the course.

Feedback from teachers has been very positive, the third cohort of students are just starting with numbers increasing year on year.

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Datamining of online quizzes: student study patterns and outcomes

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The relationship between student outcomes on different assessments and conceptual instruments holds potential for considerable insight into student study processes. At the University of New South Wales, introductory physics students complete online quizzes that cumulatively comprise 10% of their final grade. The quizzes are completed fornightly and students are allowed unlimited attempts with no penalty: this is to encourage the quizzes utility as a method of formative assessment. In addition, each student completes two midterm examinations of an identical format in an invigilated computer-exam room, each worth 10%. The high course enrolment (N=1115) and comprehensive logging available for the quiz platform present this data as an attractive opportunity for exploratory analysis.

In this talk, we present results of an extensive datamining of student quiz data, including score progressions, attempt time, total number of attempts and question dwell time. We combine these metrics with Force Concept Inventory (FCI) scores, attitudes-and-conceptions surveys and final examination scores to paint a comprehensive picture of student effort and outcomes in introductory physics. We examine the relationship between time spent on online quizzes and assessment results and discuss correlations between students self-reported study processes and actual practice. Finally, we make recommendations for implementation and analysis of similar online quiz systems based on our experience and insight.

Compering your answers with that of an expert: using self-reflections in learning physics

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Assessment in physics courses usually consists of formative assessment (e.g. labs, homework), where students form and practice application of their new knowledge and summative assessment, (e.g., tests, exams) where they can demonstrate their level of mastery. Besides teaching physics content and skills, we also aim to provide our students with transferable skills, such as critical thinking, problem-solving and communication skills. Assessment and feedback are the vital part of this learning experience, yet research indicates their roles vary, and that assessment is too often used as a measurement tool or for grade justification rather than for learning purposes [1]. However, our goal as educators is to equip students to understand and incorporate feedback from others, and to teach them ability for self-assessment in order to identify learning needs throughout their career [2]. I will present an introduction of an assessment in my 1st year physics course that use the principles of constructive alignment, where the course assessment is driven by the learning outcomes and incorporates students' reflection on their learning achievements in order to build students' lifelong learning skills.

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Stellar misconceptions: student understanding of astronomical scale

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Astronomy tends to generate excitement among students of all ages, and as such is valuable both as a discipline of knowledge and as a way of creating interest in science learning [1,2]. Tools facilitating astronomy education research are therefore highly relevant. The Introductory Astronomy Questionnaire (IAQ) asks students to, among other things, rank astronomical objects (up to 10 at a time) by size and distance [3]. This provides a unique opportunity to acquire detailed information about students' knowledge of astronomical scale [3].

Data collected in Norway gave surprising results: both before *and* after instruction, over 40% of middle school students believed planets to be larger than stars, and over 60% believed Polaris to be within our solar system [3]. We wanted to see whether these misconceptions are widespread across countries, ages and contexts. We will present results from a study of N = 211 first year undergraduate students at the University of New Mexico enrolled in an introductory astronomy course for non-majors. Persistent misconceptions regarding the distance to, and size of, various astronomical objects will be discussed. For instance, 29% of respondents believed planets to be larger than stars, and 54% believed the star Polaris to be within our solar system. The results show significant and contextually invariant misconceptions in students' knowledge of astronomical scale, which we, as educators and scientists, should seek to address. Future research directions will be discussed.

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Antiferromagnetic Spintronics with Topological Solitons

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Magnetic skyrmions are topologically protected spin solitons, which may be used in spintronic devices for information storage and processing. However, skyrmions in ferromagnets have some intrinsic difficulties, which must be overcome to use them for spintronic applications, such as the inability to move along electric current due to skyrmion Hall effect [1]. I will discuss how to work around this problem by using instead of skyrmions different anisotropic topological solitons – antiskyrmions, recently observed in systems with anisotropic Dzyaloshinskii-Moriya interaction [2]. I will explain their current-driven dynamics in both ferromagnets and antiferromagnets based on the transformation between skyrmion and antiskyrmion. Yet as another solution to eliminate the skyrmion Hall effect, I will also talk about skyrmions in antiferromagnetic materials [3]. We demonstrate how they can be stabilized [4] and manipulated at finite temperatures [3]. An antiferromagnetic skyrmion is a composite topological object with a similar but of opposite sign spin texture on each sublattice, which results in a complete cancellation of the Magnus force and as a result absence of skyrmion Hall effect. However, the topological spin Hall effect of antiferromagnetic skyrmion texture is nonzero and enhances the spin transfer torques acting on skyrmions [5]. Finally, I will describe the existence in antiferromagnets of bimerons [6], a pair of two merons that can be understood as the in-plane magnetized version of a skyrmion [7].

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Probing the Dynamics of Skyrmions in Cu_2OSeO_3

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Magentic skyrmions are topologically protected particle-like textures consisting of spin rotations with a diameter of ~50 nm, typically forming 2D hexagonal structures perpendicular to an applied magnetic field. This ordering can be induced in chiral magnets due to the interplay between Dzyaloshinskii-Moriya and ferromagnetic exchange interactions.

Cu_2OSeO_3 is an insulating chiral-lattice magnet which allows the skyrmion dynamics to be controlled via an external electric field [1]. Such direct control through a non-dissipative method would offer technological benefits for low energy devices. Therefore, there are strong interests in understanding the underlying mechanism governing such magnetic features.

Skymrions can be detected by neutron scattering and Lorentz microscopy. Furthermore, competing spin interactions induce different magnetic phases. In this work, using a combination of Small Angle Neutron Scattering (SANS), Lorentz TEM and SQUID magnetization measurement, we probed the dynamic of the skyrmions and explain the underlying mechanism that stabilizes this magnetic order.

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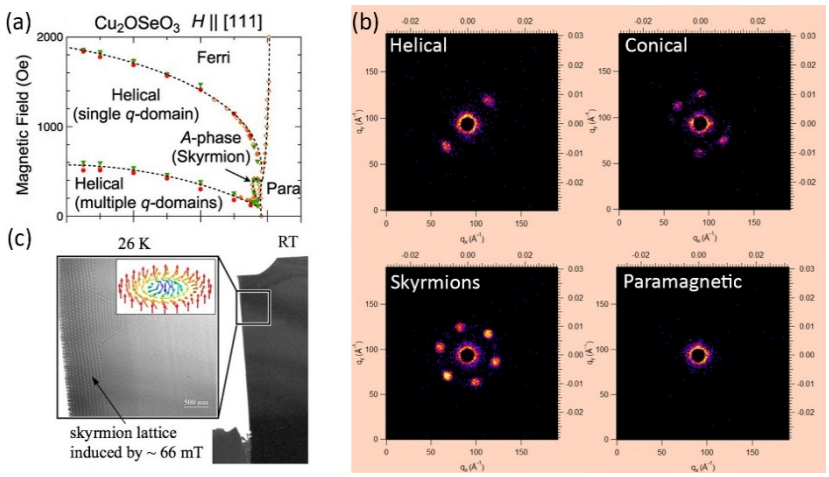

Figure 1: (a) Phase diagram of Cu_2OSeO_3 from [1]. (b) Different patterns of Bragg spots corresponding to various magnetic structures as observed in SANS. (c) Micrograph depicting the skyrmion lattice.

Quantum multicritical behavior and emergent symmetry in (2+1)-dimensional Dirac systems

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In this work, we investigate multicriticality in Dirac materials with focus on the (2+1)-dimensional case of graphene. Embedded in the framework of the Gross-Neveu-Yukawa theory, we perform a perturbative RG analysis in the presence of N_f massless fermions coupled with two order parameters. The particular choice of the description is motivated by the introduction of interactions on the honeycomb lattice, leading to various orderings. In this context we present a new method to derive the RG flow equations, based on a few constraints obtained from symmetry considerations, topological aspects of Feynman diagrams and the limits of the model. This technique is less error-prone than usual approaches since neither regularization of UV-integrals, nor bookkeeping of combinatorical prefactors is needed. From these beta functions the fixed points are evaluated and their stability properties are analyzed leading to the determination of the multicritical points controlling the quantum phase transitions. Subsequently, the results are compared to the critical properties of the purely bosonic O(N_1)$\oplus$O(N_2) model. We find that the presence of chiral Dirac fermions changes the critical behavior qualitatively.

While no isotropic O(N) multicritical point occurs in the traditional Landau-Ginzburg-Wilson paradigm for $N_1 + N_2 > 2$, the gapless Dirac-fermion fluctuations stabilize such symmetry enhancement for compatible order parameters with anticommuting mass operators.

A Mathematical Description of Phase Transitions at Strong Coupling

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Over the course of the last century tremendous progress has been made in describing the physics of materials using first quantum mechanics, and subsequently ideas and machinery from Quantum Field Field Theory. However, despite this progress, and the huge effort which has been poured into this search for understanding, precise descriptions of certain phenomena have remained stubbornly intractable. This is most often due to the presence of strong coupling; amplitudes for certain processes to occur approach unity and prohibit the use of perturbation theory. One such problem is a mathematical description of the metal-insulator-structural phase transition of vanadium dioxide. VO_2 is a $3d^1$ system which exists in a metallic, tetragonal structure above $\sim$ 340 K, and when pure or unstrained adopts a monoclinic $P2_1/c$ structure (usually called "M_1") below T_c (see Figure 1).

In this work the formalism of lattice QCD[1] is adapted to give a non-perturbative description of crystal lattices and their fluctuations [2] to describe crystal structure transformations which are accompanied by spin ordering and metal-insulator transitions, in which strong coupling is easily incorporated.

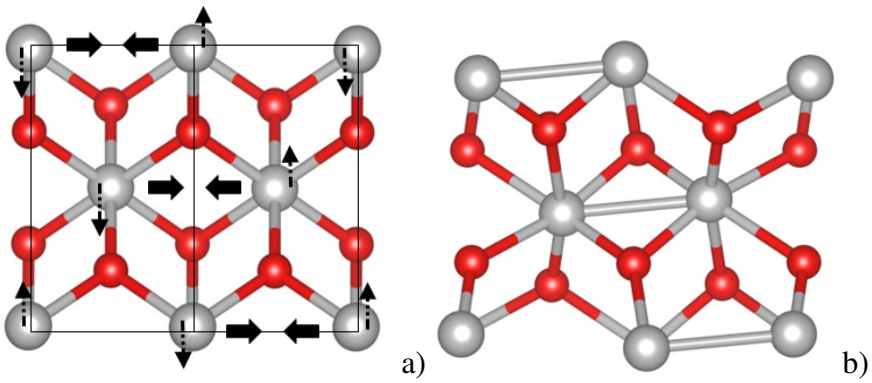

Figure 1: a) Pattern of atomic displacements in the tetragonal phase of VO_2 which give rise to the monoclinic structure in b)

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Top Physics and Colour

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Production and decays of top quark pairs are among the most intensely studied processes at the LHC, with flagship measurements of the top quark mass approaching per-mille level precision. Among Standard-Model particles, the top quark enjoys pride of place not only as the heaviest particle but also as the only coloured "resonance". In new-physics scenarios, final states with top quarks often appear as signals and always as backgrounds. Top pair production can also serve as an experimentally accessible template example of more general realisations of coloured resonances. In short, top quarks are highly relevant – and interesting – to study. I will discuss interference effects arising from the finite life-time and coloured nature of the top quark, and how these are (not) implemented in current Monte Carlo models of top quark physics. I will describe a new coherent treatment of radiation in top quark production and decays that we have developed [1], highlight differences with existing approaches, and give an outlook to future applications.

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Effect of Nucleon Dressing on the Triton Binding Energy

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It has long been established that standard non-relativistic three-body (Faddeev) descriptions of the three-nucleon system, underestimate the triton binding energy by an amount ranging from 0.5 to 1.5 MeV, when the only interactions included are accurately constructed two-nucleon forces. Much effort has been devoted in trying to explain this discrepancy in terms of three-body forces [1], delta resonance components [2], and relativistic effects [3]. Yet all this while there has been an "elephant in the room", namely the neglect of nucleon dressing in all the models describing the triton. This is especially surprising given the significance of three-body forces which are modelled in terms of pion exchanges between the nucleons: if pions can be exchanged between nucleons, they can also be re-absorbed by the same nucleon.

That nucleon dressing by pions has not been previously considered in the context of the triton binding energy may be due to the perceived difficulty of including all such dressings in the framework of non-relativistic time-ordered perturbation theory. Yet the framework for such an inclusion was provided by two of us in Ref. [4], and consisted of a specific use of convolution integrals.

We have used the convolution approach of Ref. [4] to develop three-nucleon equations where all three-body forces are neglected, but where all nucleon dressing terms (consistent with the neglect of three-body forces) are retained. By using the same two-body input in standard three-nucleon Faddeev equations and in the three-nucleon equations of the convolution approach, we can deduce the effect of nucleon dressing on the binding energy of the triton. Using separable forms of the Paris, Bonn, and a variety of other nucleon-nucleon potentials, we find that the effect of including nucleon dressing is to increase the triton binding energy by about 0.6 MeV.

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Convolution Approach to the πNN System

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An outstanding problem in the theoretical formulation of the πNN system, where pion production and absorption is included, has been obtaining the simultaneous dressing of both nucleons in the framework of time-order perturbation theory. The technical difficulty of including such dressing has led to approximations, such as Hilbert space truncation to states of no more than one pion, which resulted in an inadequate description of a number of observables [1].

A solution to this problem has been proposed through the use of convolution integrals to sum all possible time-ordered dressing diagrams, thereby successfully dressing both nucleons at the same time [2]. This innovation has led to the formulation of new equations for the πNN system, where the only approximation made is the neglect of connected three-body forces [3]. However, some of the neglected three-body forces contain contributions to nucleon dressing, and this has given rise to a concern regarding the new theory's accuracy [4].

To address this concern, we have formulated new equations of NN scattering, still in the framework of time-ordered perturbation theory, but that retain all nucleon dressings. These equations are four-dimensional, and retain all dressing diagrams, including those corresponding to connected three-body forces. By comparing our three-dimensional and four-dimensional equations, we are able to determine the significance of neglecting connected three-body forces and whether the πNN system can be effectively represented by these three-dimensional equations. For the first time, numerical results have been obtained, and suggest that convolution integrals might just be the long, sought-after solution to the problems of the πNN system.

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Operational Interpretation of Time-Energy Uncertainty Relations

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Quantum mechanics allows us to access, manipulate, and exploit the vast amount of information carried by physical processes, that would otherwise be lost with a classical description. Technology is progressively making use of such information, with paradigm changing visualization methods such as scanning tunneling microscopes and magnetic resonance imaging (MRI), cryptography protocols such as quantum key distribution, and information processing with the quest towards universal and fault tolerant quantum computers.

A ubiquitous challenge in the development of quantum technology is to protect the performance of those components that are highly sensitive to the many sources of noise, which often impose extremely short time windows to operate. It thus becomes necessary to optimise the delicate balance between resources and time available to perform tasks such as implementing a logic gate. This balance is fundamentally limited by time-energy uncertainty relations, which can be interpreted as fundamental bounds on the minimal time for the evolution of systems governed by the laws of quantum mechanics. Besides their fundamental relevance, time-energy uncertainty relations are applied as a benchmarking tool to study the performance of information processing, metrology protocols, and thermodynamics in the quantum regime, while revealing new ways to improve the performance of existing methods.

The primary focus of my research is the derivation of bounds on the minimal time of evolution of quantum systems, also known as quantum speed limits. In order to be useful, such bounds have to be easy to compute and to measure, while being as tight and robust as possible. The secondary objective of my research is to use these bounds to study the limits on the performance of quantum technology, learn how to implement methods that can saturate the speed limits imposed by Nature, and achieve a deeper understanding of these trade-off relations using visual methods and physical interpretations.

Quantum Markov order, memory strength and reconstruction of quantum stochastic processes

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Nontrivial dependence of a system's evolution on its history is a hallmark of complex stochastic processes. Such non-Markovian memory effects are important in classical processes ranging from share prices to soft matter dynamics, and it is becoming increasingly recognised that the same is true in the quantum setting. Understanding how to characterise and exploit the structure of memory in stochastic processes is crucial to classifying, simulating and manipulating them. However, there is a fundamental difficulty in even describing quantum stochastic processes, in that observing them necessarily disturbs their evolution. Moreover, this disturbance depends on the way in which they are observed.

Here, I will show how a recently developed formalism for operationally characterising quantum processes can be used to meaningfully extend notions of non-Markovianity and Markov order beyond the classical regime [1, 2]. I will present the surprising result that no non-Markovian quantum process can have a finite Markov order with respect to all observations, and will present examples of exotic memory structures with no classical analogue [3]. Finally, I will show how memory strength can be meaningfully quantified in quantum stochastic processes, and how this leads to a new prescription for efficiently reconstructing processes with limited memory effects [4].

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Quantum-Computing Architecture based on Large-Scale Multi-Dimensional Continuous-Variable Cluster States in a Scalable Photonic Platform

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Quantum computing is a disruptive paradigm for solving problems that are intractable for classical computers. Here we present a quantum computing architecture based on large-scale continuous-variable cluster states in a scalable quantum-photonic platform [1]. Recent implementations have demonstrated the viability of generating 2D resource states of this type in bulk optical implementations [2]. In this new proposed architecture, we combine compact generation techniques pioneered in bulk optics with photonic-chip technology, yielding a proposal for a compact, robust, and mass producible quantum-photonic platform capable of operating at room temperature. Our architecture tackles the connectivity challenge of quantum computing by proposing a method for generating highly connected 3D cluster states comprised of hundreds of spectral modes and an unlimited number of temporal modes. The Kerr soliton microcombs offer simultaneous access to all spectral modes, an elusive and long sought-after feature in bulk-optics cluster-state platforms. Squeezing requirements for fault-tolerance can be lowered by using recent topological error correction techniques requiring 3D Gaussian entangled states and robust bosonic qubits. Though the latter have recently been demonstrated experimentally, the former has been thus far limited to 2D. We give the first explicit scalable generation method for generating 3D continuous-variable cluster states, thereby providing a crucial ingredient for fault-tolerant quantum computation.

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Modular Bosonic Subsystem Codes

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We introduce a formalism for encoding a qubit into a bosonic mode as a discrete subsystem. Using a modular decomposition of the position operator [1, 3], we divide the bosonic mode into two subsystems: a logical qubit and a gauge mode. This formalism enables the analysis of continuous-variable quantum information using standard qubit-based quantum information tools. We apply the formalism to approximate Gottesman-Kitaev-Preskill (GKP) [2] states and show that the logical qubit experiences decoherence due to entanglement with the gauge mode. We also identify and disentangle a qubit cluster state hidden inside of a Gaussian continuous-variable cluster state.

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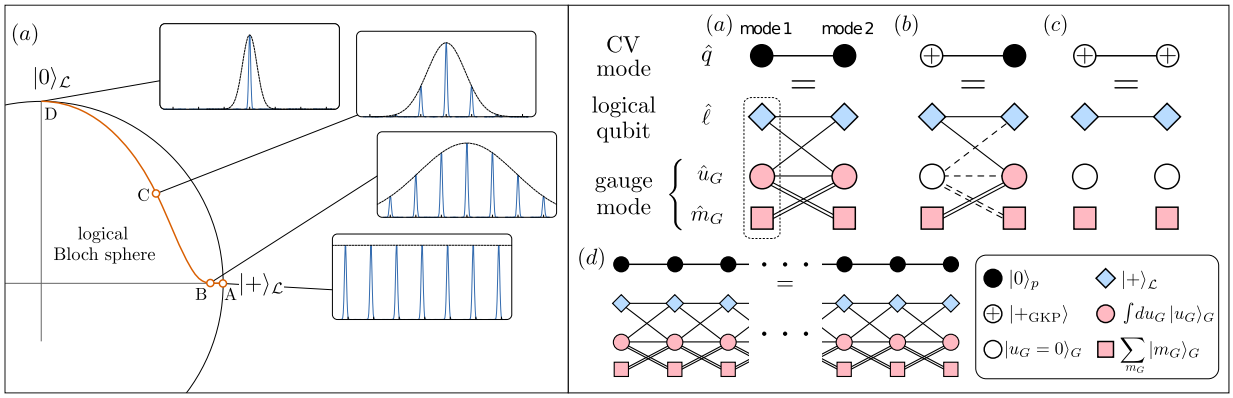

Figure 1: Left: Quality of approximate square-lattice GKP states. Right: Graphical representations of pure states in the subsystem decomposition. (a) Logical-gauge entanglement structure for an infinitely squeezed two-mode squeezed state.

Robust fault tolerance for continuous-variable cluster states with excess anti-squeezing

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Measurement-based quantum computing (MBQC) utilizes highly entangled resource states known as cluster states as a substrate for quantum computation. Large 1- and 2-dimensional continuous-variable cluster states have been constructed deterministically using temporal modes of light [1,2]. The MBQC scheme is fault tolerant when using pure resource states and along with specially prepared ancilla modes (in GKP states) for error correction [3].

One hurdle to overcome in continuous-variable MBQC is the noise inherent in any continuous-variable system. We address the case where the cluster-state resource is built from impure states that contain additional variance in the anti-squeezed quadrature compared to squeezed vacuum states [4]. Our results show that (1) position measurements on the cluster state nodes, (2) implementing single- and two-qubit logical Clifford gates, and (3) preparing magic states are all robust to the presence of this additional anti-squeezing. In other words, the fault-tolerance established by [3], including the squeezing threshold, is also applicable to impure resource states. This is an important simplification for experimentalists who now do not need to fully characterize their input states because as long as the measured squeezing is below a predefined threshold, fault tolerance is possible.

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All-Gaussian fault-tolerant universality with the Gottesman-Kitaev-Preskill code

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1. Introduction

The promise of a quantum computer lies in its ability to dramatically outpace classical computers for certain tasks. A promising candidate for qubits are *bosonic codes*, which embed discrete quantum information into continuous-variable (CV) systems, such as quantum harmonic oscillators. Bosonic codes map CV noise into effective logical noise acting on the encoded qubits. A particular bosonic code, the Gottesman-Kitaev-Preskill (GKP) code [1], is particularly appealing for quantum computing because of its error-correcting properties, and moreover because the entire set of GKP Clifford operations can be performed by Gaussian operations. In general, Clifford operations allow error correction but must be supplemented with additional resources to achieve universality.

2. Results

In order to achieve fault-tolerant, universal quantum computation with the GKP code, one needs a fault-tolerant way to perform a non-Clifford operation. Until now, this required an *additional* non-Gaussian element—a cubic phase gate, cubic phase state, or logical magic state—beyond a (non-Gaussian) logical-GKP Pauli eigenstate itself. We show that none of these is necessary [2]. High-quality GKP magic states (used to implement non-Clifford gates) can be produced by applying GKP error correction to trivial Gaussian states: vacuum or low-temperature thermal states. The result is that Gaussian operations and just one type of non-Gaussian resource—a high-quality GKP Pauli eigenstate—suffice for both universality and fault tolerance.

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Building quantum matter atom by atom

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This talk focuses on single dopant atom placement in the context of engineered matter for quantum simulation and computation. Silicon offers an interesting platform for engineered quantum matter because when isotopically purified it acts as a "semiconductor vacuum" for spins. After a general introduction of quantum simulation and computation a first step towards engineered Hamiltonians for Fermionic systems in the form of atomic chains will be presented. Here strongly interacting dopants were employed to simulate a two-site Hubbard Hamiltonian at low effective temperatures with single-site resolution which allows the quantification of the entanglement entropy and Hubbard interaction strengths. To scale this approach to larger systems complex in-situ multi-electrode devices have been fabricated by a scanning probe hydrogen depassivation and decoration technique and spatially resolved gated single-electron spectroscopy maps obtained in ultra-high vacuum will be presented. Such quantum-state images of two-donor devices led to a donor based two qubit gate design that is robust in regard to variability in dopant placement. In addition to the work on donors I will also present work on single defects in silicon with a spin-orbit interaction for electrical manipulation and coupling. This includes coherence times for holes bound to boron in isotopically enriched silicon rivalling the best results for donors and quantum dots.

Probing galaxy formation and evolution with next generation radio telescope surveys

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We are currently undergoing a revolution in galaxy evolution studies through new instruments and technologies allowing us to map more galaxies, in multiple wavelengths. This allows for deep studies of the evolution of galaxies over time, which when comparing with galaxy evolution modelling is enabling the picture of galaxy evolution to emerge.

In particular, neutral atomic hydrogen (HI) is an excellent tracer of interactions and physical processes occurring in galaxies, enabling us to observe first-hand events such as gas-stripping, tidal interactions, and hydro-dynamical processes that are acting on the gas. When combined with other indicators such as star formation rate, this can elucidate how galaxies are transformed in different environments. Next generation telescopes such as the Australian SKA Pathfinder [1] will provide thousands of resolved maps of the HI distribution galaxies in the local universe. I will outline the state-of-the-art research in this area, and how next generation telescopes will help us to untangle the physical processes acting on galaxies in the local universe.

[1] https://www.csiro.au/en/Research/Facilities/A TNF/ASKAP

Magnetic Skyrmion Induced Topological Superconductivity

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Magnetic skyrmions are a stable topological spin texture found in magnetic materials with Dzyaloshinskii-Moriya interactions. These skyrmions are highly controllable and can be written and deleted using spin polarized currents [1], driven at speeds exceeding 100 m/s with short current pulses [2], or dragged by a magnetic tip [3]. The size can range from 1 nm to 100 nm [4], which can be controlled by material properties such as thickness or doping [5]. Nakosai, et. al. demonstrated that a lattice of skyrmions coupled to an s-wave superconductor induces a $p_x + ip_y$-wave like state [6]. Yang, et. al. demonstrated that a skyrmion with even vorticity hosts a Majorana bound state in the skyrmion core that can be braided to perform quantum computation [7]. Here, we investigate magnet-superconductor heterostructures with a skyrmion lattice spin texture, and the Chern number of these systems. We demonstrate that systems can be tuned to various topological phases by the size of the skyrmions, the magnetic exchange coupling, and the chemical potential.

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Tailored design of vortex behavior and its visualization

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The only method of abstract submission is electronically, using this template. If you simply type into this template there should be no need to worry about the page layout, font size and/or spacing. Nevertheless, here are the critical details:

Controlling the critical current density in superconducting thin films have always been the research focus with the expected impact in electronics and wires. The current-carrying ability can be effectively enhanced by introducing certain defects within the material (via multilayering [1], doping, patterning [2,3]). Controlled patterning can also give rise to other practically and scientifically appealing effects, such as current rectification, flux quantum filtering, and noise reduction in SQUIDs, etc. Different non-uniform arrays of large antidots are designed in high quality pulsed-laser deposited YBa2Cu3O7 (YBCO) superconducting thin films [1] and compared by examining the improvements in the critical current density Jc they produced over a large magnetic field range [2]. All types of non-uniform arrays were found to enhance Jc over a broad temperature and magnetic field range (~20% increase).
The corresponding vortex pinning model is based on the non-Bean-like magnetic flux penetration in the arraypatterned films. It indicates a large potential by optimising antidot and pattern parameters. The ratcheting effect on large antidot arrays investigated is marginal. However, it is simulated for individual vortices, exhibiting vortex diode or vortex pump properties. Individual vortices are visualised to form a glass-like state with an unlikely reproducible vortex configurations in static magnetic fields comparable to the Earth field [4]. The dynamics of transient current distributions in YBCO thin films during and immediately following magnetic field penetration are further explored employing high-speed Magneto-Optical Video and calculation of corresponding dynamic current profiles [5]. As a result, a number of qualitatively unique and previously unobserved features are seen in the evolution of supercurrent in these films. The most prominent behavior is that the current peaks are exceeding the critical current densities normally observed for the equilibrium measurements [6]. These dynamic peak values indicate that the superconducting critical state may be more robust for the dynamic applications.

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Spin-orbit coupled superconductivity on the square lattice

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In the last 10 years topological insulators attracted much attention among physicists and chemists, among experimentalists and theorists. One of the main ingredients of topological insulators is the strong spin-orbit coupling (SOC) in these systems. Another class of topological materials featuring strong SOC are the more recently discovered Weyl semimetals (sometimes also considered as gapless topological insulators). Some of these materials have been reported to also show superconductivity at low temperatures. Since phonon mediated pairing is suppressed by the strong SOC, these superconducting states are naturally unconventional. The weak coupling renormalization group (WCRG) is a promising method to be able to study the properties of the arising superconducting states in these topological materials.

In order to benchmark the WCRG method for spin-orbit coupled systems, we consider the paradigmatic case of the square lattice and study the arising superconducting instabilities in the presence of strong SOC. Among our findings are mixed singlet and triplet superconducting states, which is only possible due to the inversion symmetry breaking stemming from the Rashba SOC term.

High Temperature Majorana Fermions

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Chiral p-wave superconductors have attracted interest in recent years because they can host Majorana fermions at vortex cores or at the sample boundaries. These Majorana quasiparticles have potential application as qubits for topological, i.e. fault-tolerant, quantum computing. Chiral p-wave superconductors can be engineered in heterostructures based on conventional s-wave superconductors. These devices require very low temperatures and so it is desirable to find an alternative design based on high-temperature superconductors. Here we show that topological superconductors can be engineered from iron-based and other high-Tc superconductors, providing a pathway to experimentally access Majorana fermions at high temperatures.

Interplay of Aharonov-Bohm interference and signatures of Majorana fermions

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Majorana fermions (MFs) are a theoretical particle which, unlike conventional fermions, act as their own antiparticle. A condensed matter realisation of these particles was suggested by Kitaev whereby MFs would exist at the ends of superconducting nanowires[1]. Encoding information in such a system would be topologically protected from noise, as a global perturbation would be required to destroy the stored information.

The primary signature of the existence of MFs in superconducting nanowires is a zero bias conductance (ZBC) feature in the transport response of the wires. There have thus far been several experiments which produce signatures of Majorana bound states (MBS)[2]. However there are several alternative explanations for such a feature which can cast doubt over the origin of the ZBC observed in experiment. It is therefore important to devise a method of distinguishing systems which definitively contain MBS from other topologically trivial effects[2]. To this end we explore circuit geometries which are capable of hosting Majorana fermions at the superconducting/normal interfaces within the circuit.

We begin by simulating a ring comprised of two Kitaev chains with a normal conducting links between them, where the MFs form at the interfaces. We compute transport signatures as a function of ring dimensions to study how MFs in this geometry interact. Further, an applied magnetic field induces Aharonov-Bohm interference due to path differences around the ring. This allows for an analysis of signatures of MFs as a function of the magnitude and direction of an applied magnetic field. This computational model can inform future experiments which probe the topological properties of Majorana fermions.

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Supernova remnant-like X-ray plateaux in short Gamma-Ray Bursts

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Many short Gamma-Ray Bursts (sGRBs) have an extended afterglow in the X-ray spectrum lasting up to tens of thousands of seconds, commonly referred to as X-ray plateaux. It is well established that neutron star collisions cause at least some sGRBs. However, the compact remnant from such a collision remains uncertain and is dependent upon the neutron star equation of state.

One natural candidate for the driver behind plateaux is a long-lived millisecond magnetar. We develop a simple analytic model which naturally produces X-ray plateaux. Our model leverages well-established descriptions of young supernova remnants, in which the rotational energy of a millisecond magnetar is extracted via the pulsar wind. The wind fuels an adiabatically expanding bubble of electrons, which radiates X-rays via synchrotron radiation.

Previous work on such models has either neglected the physical mechanism for the radiation or focused on descriptions of emission from the merger ejecta. Our plerion model for sGRB plateaux reproduces key observational features, opening the door to tantalizing possibilities in multimessenger astronomy and neutron star physics.

Massive Galaxies in the EAGLE simulation: investigating the relation between dark matter halo mass and observable properties

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The assembly history of a galaxy is influenced by its dark matter halo [1], as the halo determines the accretion rate and the temperature of accreting gas, as well as the rate of galaxy mergers. The parameterized stellar-to-halo mass relation, however, is observed to have a large scatter: the stellar mass of a galaxy is insufficient information to facilitate even order of magnitude constraints on the halo mass of the galaxy. I will utilize the EAGLE simulations [2, 3] to address whether this scatter is irreducible, or if the dark matter halo determines other properties of the central galaxy in addition to its stellar mass. Furthermore, I will seek to answer the query: what combination of observable quantities is the best predictor of halo mass?

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Singular Behaviours and New Morphologies in Rayleigh Taylor Instability

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Rayleigh Taylor Instability is a fluid instability that forms when fluids of different densities are accelerated against one another. It is ubiquitous, with applications in inertial confinement fusion, supernovae evolution and formation and even cellular dynamics. Rayleigh-Taylor instability is studied for a flat interface with a spatially periodic perturbation under a time varying acceleration using group theoretic methods. For the first time, traditional bubble focused analyses are extended to include the so-called "spike" structures that emerge along the interface. The behaviour of these spikes is found to be singular in finite time. This singular behaviour is investigated and found to be physically appropriate for the system. The singular behaviour is also found to be in close agreement with previous theoretical treatments of Rayleigh Taylor Instability. The parameters affecting the behaviour of both bubble and spikes are discussed, including interfacial shearing, which is shown to have a profound effect on the long term behaviour of both bubbles and spikes. The applications of these findings in benchmarking numerical simulations and experiment design are also discussed.

Preparing Next-Generation CMB Experiments for Big Data Challenges Using Extreme Digitisation

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Cosmic Microwave Background (CMB) observations are a cornerstone of modern cosmology. Exciting science questions in astrophysics, cosmology, and particle physics are within reach of next-generation ground-based CMB experiments. However, the sheer size of time-ordered-data these experiments will collect leads to new challenges in mission planning, hardware requirements, and analysis. In particular leading Antarctica-based experiments, which transmit part of their data via satellite links, must explore how to maximise scientific gain within the bandwidth available.

We present extreme, i.e. few-bit, digitisation as a means of targeting these arising challenges by reducing the volume of time-ordered-data aggressively. Unlike lossless compression, extreme digitisation sacrifices information: it introduces additional noise. We present an optimal 3-bit digitisation scheme with a marginal (percent-level), scale-independent noise penalty. Such compression works equally well for temperature and polarisation observations and is independent of the noise profile of the experiment. Importantly, this type of digitisation reduces the data volume by an order of magnitude relative to 32-bit floats, making it a promising strategy for upcoming experiments.

An improved measurement of the secondary cosmic microwave background anisotropies using data from South Pole Telescope survey.

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Measurements of the primary cosmic microwave background (CMB) anisotropies have proven to be one of the most powerful and robust probes of cosmology [1, 2]. In addition to the primary anisotropies, the secondary anisotropies in CMB also provide a wealth of cosmological information. The secondary anisotropies are produced due to the interaction between the CMB photons and the intervening matter. The measurement of secondary CMB anisotropies provide powerful constraints on the growth of structure and the reionisation history of the Universe [3]. In this talk, I will report the improved measurement of the secondary anisotropy using the data from the South Pole Telescope(SPT)-SZ survey and SPTpol survey.

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Capturing three X-ray imaging modalities with a single exposure; Techniques and Applications

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Conventional X-ray imaging has relied upon the attenuation of x-rays by dense materials to create image contrast. This has limited the application of x-ray imaging to only those samples that provide strong attenuation. In recent decades, novel approaches have been demonstrated that capture how the x-ray wavefield phase is altered by weakly-attenuating samples, and how sub-pixel structures can scatter the x-ray wavefield. These emerging x-ray imaging modalities, known as phase-contrast and dark-field respectively, are equipping a range of new applications, in particular in biomedical research.

There are a range of approaches to capturing these three image modalities, typically utilising multiple images captured with different optical configurations to isolate the three effects. This is difficult to achieve in some applications, in particular when the sample is moving, as seen when imaging living beings. This talk will describe the development of a single-exposure approach [1-2], and recent experimental [3] and theory-based progress [4-5]. Finally, applications in biomedical research will be described [6], with a focus on respiratory imaging as a result of the strong phase and dark-field effects seen from air/tissue interfaces.

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Induced structural changes in proteins imaged with X-ray free electron lasers.

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The fundamental limit imposed by radiation damage on protein structure determination using X-ray crystallography techniques at synchrotron sources can be overcome by utilizing X-ray pulses generated by free electron lasers (XFELs). The latter pulses can be as short as 10 femtoseconds, but are at least 10^5 times brighter than those generated by modern synchrotron sources. Even on such short time scales rapid ionization causes heavier atoms, such as iron and sulfur, to substantially move inside the protein during the pulse. Furthermore, for these elements the motion is correlated through the micro-crystal [1, 2]. However, recent time-resolved X-ray pump and probe experiments indicate that the dissociation of disulfide bridges in lysozyme and thaumatin occurs much slower than expected from their ionization dynamics [3].

We have developed a theoretical model capable of explaining and accurately predicting the dissociation of heavy element bonds in time-resolved XFEL experiments. The model utilizes a time-dependent simulation of the ion dynamics treating the ejected electrons as a continuum. The continuum treatment of electron plasma has significant computational advantages over the existing treatment of ejected electrons as classical point particles, enabling simulations of large protein crystals. An addition of residual bonding between atoms and ions, screened by trapped electron plasma, yields the bond distance between sulfur atoms as a function of the time delay between pump and probe pulses that accurately reproduces the experimental observations. Future work will be focused on adapting the proposed model to solving an inverse problem – refinement of the local structure in the vicinity of heavy element clusters in protein imaged by means of serial micro-crystallography at XFEL facilities.

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Real-time detection and identification of organic pollutants

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Polycyclic aromatic hydrocarbons (PAHs) are a major class of hazardous organic pollutants, with two or more fused benzene rings that can cause carcinogenic and mutagenic effects in living organisms [1]. Conventional methods for their detection include gas chromatography and high-performance liquid chromatography, but these methods are time-consuming and labor intensive [2].

In this report a novel method has been investigated for determination of PAHs using confocal microscope. This method involves detection and identification of PAHs by exploiting their intrinsic fluorescence characteristics. The fluorescence in PAHs is attributed to delocalized pi bonds in their arrangement [1]. Fluorescent techniques are promising due to their simplicity, higher sensitivity and appropriateness for either laboratory based or portable instrumentation [2]. PAHs are investigated in this study using home-built confocal microscope. The Supercontinuum pulse laser (Fiannium,WhiteLase SC400, λ=532 nm) was used, and the sample was focused by 100×0.9 NA objective lens. Phenanthrene, pyrene and naphthalene confocal image is shown in Figure 1(a).

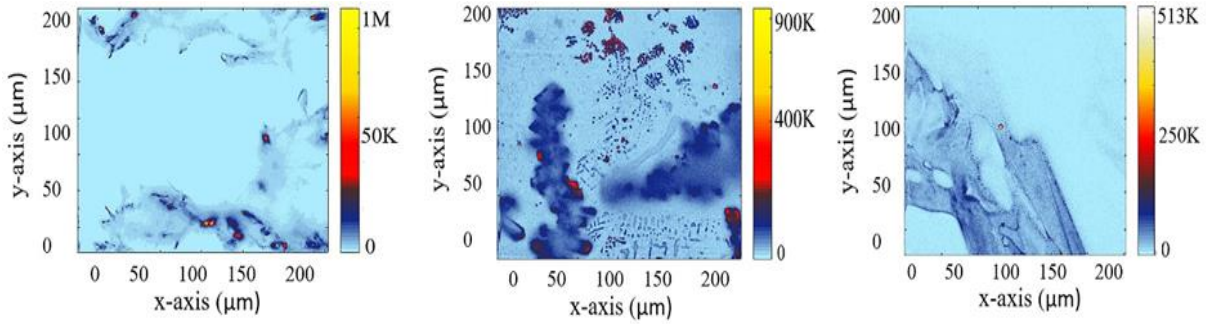

Figure 1 (a): Scanning confocal fluorescence 200 µm x 200 µm image of *Phenanthrene, Pyrene and Naphthalene*

These images show they are fluorescent without usage of tags and dyes. They can easily be tracked in the water and in soil due to their fluorescence properties. Our research opens new avenues for real time detection of pollutants without any limitation of concentration or type of pollutants on the contaminated site.

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Toward Detection of Free radicals in Living cells Using a Single-Spin Nanodiamond Probe

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Nanometer-sized diamonds (ND) containing nitrogen-vacancy defect centers (NV) are promising quantum nanosensors in biological environments. NV centres are defects in ND that generate when two adjacent carbon atoms are substituted by an empty lattice site and a nitrogen atom. These centres are ideal as biological sensors because they are photostable, biocompatible, non-toxic and can be placed in close contact with living cells and cultures. The NV defect is also responsible for diamond's red/near-infrared fluorescence and the intensity of the light emitted by these colour centres changes with the local magnetic field, enabling them to detect even very weak magnetic fields emanating from single cells, molecules, or organisms. Here we report on the detection of free radicals including hydroxyl and superoxide radicals in living cells using magnetic noise induced by the spin trap molecule attached covalently to the surface of the ND. 5,5-dimethyl-1-pryrroline N-oxide (DMPO) type molecules are the most reliable spin traps that can readily react with hydroxyl and superoxide radicals and form nitroxide radical and the influence of nitroxide single spin on the spin properties of single NV centers in NDs can be detected and quantified. This interaction leads to shortening of both the NV spin coherence time T2 and relaxation time T1, when compared to the values for noncoated NDs.

To implement biosensing of free radicals, NDs 100 and 50 nm size were aminated through modified procedure according to the protocols from Kruger et al,[1] Zhang et al.[2] The DMPO molecule terminated with carboxylic acid (CMPO) was synthesized and peptide-coupled to aminated ND in the presence of 1-ethyl-3-[3-(dimethylamino)propyl] carbodiimide hydrochloride (EDC) and N-hydroxysuccinimide (NHS), yielding ND−CMPO. The T1 and T2 relaxation time for the NV centres were measured using widefield imaging. We have observed a significant reduction of both coherence and relaxation time due to the presence of free radical on the surface of ND.

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A 3D diamond electrode array for high acuity stimulation in retinas

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People with retinal degenerative diseases, e.g. retinitis pigmentosa (RP) and age-related macular degeneration (AMD), suffer from a loss of photoreceptors, while a significant number of retinal ganglion cells (RGC) remain viable. Prognoses are indicating that 2020 worldwide, around 196 million people will develop AMD and several million suffering from RP. Here is, where retinal prostheses come of use. A visual image is captured by an external camera and transferred to an implant placed either in front (epiretinal) or behind (subretinal) the retina. This visual signal is then translated into an electric stimulation of the retinal neurons. Retinal prostheses have been around for decades, including first human trials in 2002 [1]. However, the visual acuity is below the threshold for functional vision, mainly due to the limited spatial resolution. For a natural vision, each neuron would have to be stimulated individually - a difficult task with over 1.5 million RGC.

In this work, we present a new design of 3D nanostructured diamond electrodes, integrated within polycrystalline diamond housing, offering a high electrode density and count, which simultaneously satisfies biocompatibility concerns. This electrode array consists of 25 pillars of nitrogen-doped ultra-nanocrystalline diamond (NUNCD) with 80μm in diameter and a 150μm pitch, hexagonal aligned. Hermetic feedthrough holes filled with silver braze are connecting the NUNCD tip with a circuit board on the backside. A holistic characterization of the electrodes has been performed, and the device tested in whole retinas with various pulse durations. Impedances have been measured with 10-20kOhm, and RGCs stimulation with ultrashort pulses of 33μs have been conducted indicating that stimulation is confined to a small area around the individual electrodes.

This new design of 3D electrodes for retinal prosthesis provides a stimulating device for local RGC activation and at the same time minimizing stimulation of the surrounding cells. Thus, leading to a higher acuity to restore vision to the blind.

[1] L. Yue, J. et al, “Retinal stimulation strategies to restore vision: Fundamentals and systems,” Prog. Retin. Eye Res., vol. 53, pp. 21–47, 2016.

Effects of quasi-confinement on a fluid

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Confined liquids display complicated and counter-intuitive phase and transport properties, whose relationship to the liquid's structure is not obvious. For liquids confined between two parallel walls, this structure is characterized by two particularly apparent features. The first is an inhomogeneous density profile caused by layering at the walls. The second is a non-monotonic dependence of the particle correlations on the confinement length.

Here, we disentangle these effects by confining a fluid through the use of periodic boundary conditions, such that one dimension of the system is very small. This can be thought of as a fluid confined to the surface of a torus or long cylinder. We quantify correlations in the fluid by calculating the static structure factor with both hard-sphere molecular dynamics simulations and the Percus-Yevick closure in liquid state theory [1]. We observe that the particle correlations exhibit a similar non-monotonic behavior to a liquid confined between two walls, even though the density profile is homogeneous. This indicates that these two measures of liquid structure may not be intrinsically connected in real confined fluids.

[1] C. F. Petersen, L. Schrack and T. Franosch, *J. Stat. Mech.* **8**, 083216 (2019).

Probing disordered nanostructure in 3D with X-ray free-electron lasers

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Fluctuation scattering is an emerging technique for solution scattering of single particles and for examining local structures in disordered materials [1]. We have developed a method for extracting 3D three- and four-body real space correlations from fluctuation scattering data [2]. This is a natural generalisation of the two-body statistics (i.e. pair or radial distribution function) well known in small-angle x-ray scattering or powder diffraction techniques. The multi-body correlations have angular information missing from pair statistics and greatly increased sensitivity to local structural information.

X-ray free-electron laser sources offer two key advantages for fluctuation scattering: i) the high intensity XFEL pulses can overcome noise limitations to push for atomic resolution studies of bulk disordered materials and ii) they outrun atomic diffusion times allowing studies of liquids and dynamical processes via an ensemble of snapshot diffraction patterns. XFEL sources have a potentially unique capacity for fluctuation studies of phase transitions and atomic resolution structures of liquids.

We will present some early results of XFEL and synchrotron experiments applying our 3D real-space technique to self-assembled lipid phases, protein crystallisation and liquids. The studies of self-assembled lipid phases are motivated by membrane protein crystallisation and we have shown that the fluctuation methods are sensitive to lattice lipid composition and lattice disorder. The progress on the analysis of XFEL diffraction data of liquids will also be presented.

[1] Kurta, R.P. et al. *Structural Analysis by X-ray Intensity Angular Cross Correlations* in Advances in Chemical Physics. John Wiley & Sons, Ltd. 2016, 1-39.

[2] Martin, A.V. *Orientational order of liquids and glasses via fluctuation diffraction*. IUCrJ, 4, 23-36 (2017)

Visualisation of dynamic processes using multidimensional coherent X-ray imaging

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Coherent imaging methods, such as Scanning X-ray Diffraction Microscopy (SXDM), have a growing interest for multidimensional imaging applications due to the high spatial resolution at which quantitative information can be obtained, as well as the ability to apply it simultaneously with complimentary techniques such as X-ray Absorption Spectroscopy and X-ray Fluorescence Microscopy [1]. Despite growing interest in the application of SXDM to the study of dynamic processes, the achievable temporal resolution is limited by the detector performance and the degree of redundancy in the diffraction data that must be acquired to reliably reconstruct real-space images using iterative algorithms. Approaches to resolving this problem based on the introduction of a constraint in the temporal domain have recently been proposed [2,3]. However, these methods impose limits on the object or illumination and require *a priori* knowledge of the location of time-invariant regions of the object, making them incompatible with scanning methods such as SXDM. Here we show the current progress of overcoming these limitations for *in situ* dynamic imaging using a state-of-the-art photon counting detector at the XFM beamline of the Australian Synchrotron. We also show that a spatiotemporal constraint in the image reconstruction algorithm that requires no *a priori* knowledge allows data redundancy requirements to be relaxed. The potential to improve the temporal resolution of SXDM and to characterise dynamic behavior is demonstrated through simulation of moving nanoparticles and thin-film crack propagation.

This work was performed in part at the Melbourne Centre for Nanofabrication (MCN) in the Victorian Node of the Australian National Fabrication Facility (ANFF). This research was undertaken on the XFM beamline at the Australian Synchrotron, part of ANSTO.

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[2] Y. H. Lo et al., "In situ coherent diffractive imaging," Nat. Commun., 9, 1826 (2018)

[3] X. Tao et al., "Spatially correlated coherent diffractive imaging method," Appl. Opt., 57, 6527 (2018).

Understanding dynamics in complex suspensions using Light Scattering and Differential Dynamic Microscopy.

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Dynamic light scattering (DLS) is a well established technique for measuring dynamics in colloidal suspensions, and is routinely employed for particle sizing to complement imaging techniques such as electron microscopy. However, there are a range of challenging systems that are difficult to study with DLS, including: non-spherical particles; concentrated (turbid) suspensions, and active colloids such as bacteria. Differential Dynamic Microscopy (DDM) is a relatively new technique that uses white light microscopy to measure dynamics by Fourier transformation of subtracted frames (see figure 1), and has some advantages over DLS for such systems.

In this talk we will explain the principles behind the techniques, and present novel application of both DLS and DDM to three systems: particle sizing in turbid colloidal suspensions; the measurement of dynamics of nanorods, and the characterization of bacterial motility. We discuss the advantages and disadvantages of each of the techniques.

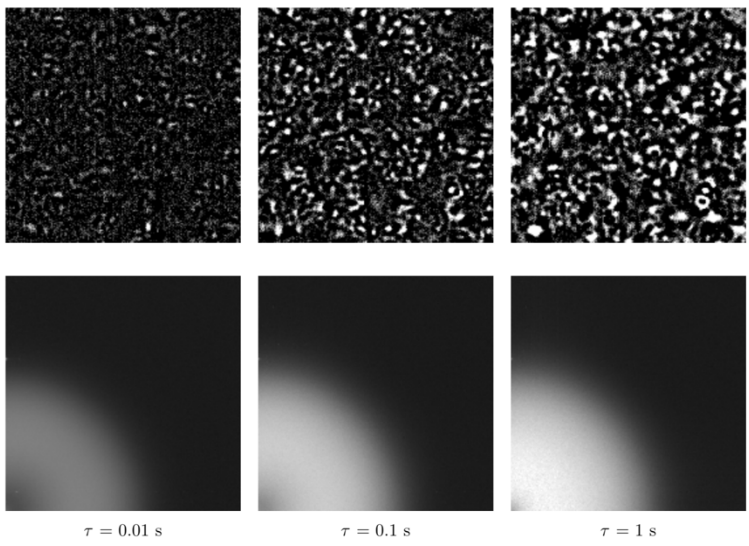

Figure 1: Principle of DDM. (Top row) Frames of increasing delay time subtracted from the same reference frame. The noise increases with delay time due to further particle displacement. Negative numbers are treated as black (0) and intensity is scaled for visualisation purposes. (Bottom row) Image structure function calculated from 2000 frame subtractions for the corresponding τ. The more noise in the difference image relates to higher energy content in the structure function.

Signal Transduction and Information Dynamics in Neuromorphic Nanowire Networks

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The rise of atomic switch nanotechnology brings artificial intelligence into a new regime. Not only because they respond to electrical stimuli in the same way as biological synapses [1]. But also because they exhibit brain-like properties such as non-linear power law dynamics and brain-like memories that cannot be readily implemented in software [2]. Upon the achievement of the physical realization of a self-organized atomic switch network with neuromorphic structure, spatially distributed memory and activation of feed-back and feed-forward sub-networks are observed [3]. Recent studies showed that such networks demonstrate cognitive memory and learning ability [4].

One effective approach to analyze these networks is through their intrinsic electrical signal transduction and information dynamics, specifically at the activation stage. Internal signal transduction is investigated and its effect on rest of the network is observed. Activation of atomic switch networks depends on external voltage bias as well as internal topology. With voltage bias close to activation threshold, the first signal pathway forms at the topological shortest distance from source to drain. Electric signal is propagated along the first pathway and also from this pathway to the rest of the network. Meanwhile, study of information dynamics on ASNs shows how information is stored locally at individual switches and also how information is exchanged when signals are propagating.

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[2] T. Ohno, T. Hasegawa, T. Tsuruoka, K. Terabe, J. K. Gimzewski, and M. Aono, *Nature Materials,*, vol. 10, no. 8, p. 591, 2011.

[3] A. V. Avizienis, H. O. Sillin, C. Martin-Olmos, H. H. Shieh, M. Aono, A. Z. Steig, and J. K. Gimzewski, *PLoS One*, vol. 7. no. 8, p. e43772, 2012.

[4] K. S. Scharnhorst, J. P. Carbajal, R. C. Aguilera, E. J. Sandouk, M. Aono, A. Z. Steig, and J. K. Gimzewski, *Japanese Journal of Applied Physics*, vol. 57, no. 3S2, p. 03ED02, 2019.

Prospects for discovering New Physics at the Belle II experiment

The Belle II experiment collides electrons at 7 GeV with positrons at 4 GeV at the SuperKEKB accelerator at the KEK laboratory in Japan. The goal of the experiment is to collect 50 times more data than its predecessor experiment, Belle with the goal make precision measurements of decays of B-Mesons, Charmed mesons, tau-leptons with the aim to discover the effects of new physics via discrepancies with Standard Model (SM) calculations. In addition the vast increase in data enables the direct search for dark matter particles.

Belle II data collection started in earnest in 2019 and the luminosity of SuperKEKB is rapidly increasing. There are number of known anomalies between current measurements of B-meson decay properties and SM calculations. We do not yet know if these discrepancies are the result of statistical fluctuations in measurements or are the result of new physics contributions not accounted in the SM calculations. This presentation will describe the Belle II experiment, it's specific capabilities and the prospects for discovering New Physics with a particular emphasis on the anomalous measurements.

Particle decay vertex resolution studies with the Belle II Detector

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Particle vertex fitting techniques are widely used in particle and nuclear physics. Beyond the suppression of background, applications range from the improvement of particle momentum resolution (under the assumption they originate from some vertex point), to the determination of the presence of intermediate particles, and the precision determination of decay vertex positions. One can, for example, combine the measurements of two charged pion tracks originating from the decay of a K^0_S-meson to extract the decay vertex position, flight length, and four-vector and their uncertainties. By performing a kinematically constrained fit, one obtains an improvement of the pion track momenta and can use the χ^2 probability of the fit result to suppress background.

The Belle II experiment takes place in Tsukuba, Japan. It employs an implementation of Ref. [1] for global vertex fitting. The first data with the full Belle II vertex detector was taken in 2019, this presentation will present results based on these data.

[1] J.F. Krohn, et al. *Global Decay Chain Vertex Fitting at B-Factories*, arXiv:1901.11198

Measuring $|V_{cb}|$ using fits to $B^0 \to D^{*-}\ell^+\nu$ decays at Belle

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The Cabbibo-Kobayashi-Maskawa matrix element $|V_{cb}|$ is the magnitude of the coupling between b and c quarks in weak interactions within the Standard Model, which affects the rate at which $b \to c$ quark transitions occur. Its value is a free parameter in the Standard Model and is therefore determined from measurements of B-meson decays. Unlike with inclusive $B \to X_c\ell\nu$ decays, measuring yields exclusively in one mode requires taking hadronic currents into account using form factors and lattice QCD calculations. There exists a long standing tension between the values of $|V_{cb}|$ obtained from inclusive and exclusive methods and previous results have suggested that a model-dependent approach of parameterising form factors may create a bias in measurements and be the cause of this tension.

The data sample from the Belle experiment contains $(772 \pm 11) \times 10^6$ $B\overline{B}$ meson pairs and the 2018 analysis of $B^0 \to D^{*-}\ell^+\nu$ decays over this sample published the most precise measurements of $|V_{cb}|$ and relevant form factor constants to date [1]. These results showed agreement between the model-dependent parameterisation and a model-independent parameterisation, which implies that the tension between inclusive and exclusive measurements remains.

The analysis used a χ^2 minimisation approach to fit to the data. We show that using the provided systematic correlation matrix in a naive way will cause a bias in fit results and we avoid this by using a Cholesky decomposition of the covariance matrix. With this method, we explore how different numbers of free parameters and lattice QCD constraints in both the model-dependent and model-independent approaches affect the obtained central values and uncertainties of $|V_{cb}|$ and form factor distributions.

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Hadronic B decay reconstruction in Phase 3 data at Belle II

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The Belle II Experiment is the successor to the Belle Experiment that ran from 1998 to 2010. Belle produced 752×10^6 $B\bar{B}$ pairs at the $\Upsilon(4S)$ resonance with the KEKB e^+e^- collider. Belle II is designed to reach a peak luminosity forty times higher and is expected to collect 50 times more data with SuperKEKB. The Belle detector has also been significantly upgraded to handle the increased luminosity.

After almost a decade of upgrades, the full Belle II detector has started its first period of collision-data taking on March 11, 2019 in a period conventionally dubbed "Phase III". It is essential to validate and benchmark the detector and reconstruction performance against Monte Carlo simulation. The reconstruction of hadronic B decays in a variety of $B \to Dh$ decays as well as the double charm decay $B^+ \to D_s^+ D^0$ is used to show evidence of solid performance and to get a consistent global picture. In addition, we also report the discovery of the first double charm signal at Belle II and employ this to investigate our understanding of detector performance in hadronic final-state reconstruction.

A Flavour Search for Axion-Like Particles in e^+e^- Collisions at the Belle Experiment

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There is ample evidence for the existence of dark matter — the interactions and constituents of dark matter, however, remain a mystery. If dark matter is not a Weakly Interacting Massive Particle (WIMP), we must search for a portal between the visible and dark sectors. One such portal involves the introduction of an Axion-Like Particle (ALP) mediator which would couple to the gauge bosons of the SM and could present itself in electroweak penguin (EWP) decays — the so-called *axiflavon*.

A search for the axiflavon, a', is explored at Belle, which is attached to the asymmetric-energy KEKB collider in Tsukuba, Japan. KEKB is an e^+e^- collider which operates at the $\Upsilon(4S)$ resonance and is nominally a *B-factory*, having produced nearly 775×10^6 $B\bar{B}$ pairs (corresponding to a time-integrated luminosity of $L_{int} = 710$ fb^{-1}). This search proceeds via six different flavour physics channels: $B^{\pm} \to K^{\pm}a'$ and $B^0 \to \bar{D}^0 a'$ where $a' \to \gamma\gamma$, gg, or *invisible*. The reach of the Belle experiment for axiflavon searches is emphasized and the branching fraction sensitivities for each mode are revealed.

STEM Enrichment: A Program to Enhance Year Nine Students' Interest in Physics

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With women underrepresented in STEM disciplines, there is a focus on encouraging females to pursue careers in STEM fields [1], such as Physics. Research suggests that enrichment programs enhance interest in pursuing a STEM career [1], however knowledge on the most effective enrichment method is limited. The aim of this project is to investigate the effectiveness of different enrichment methods on female year nine students' interest in physics.

The project involves three enrichment programs run through Flinders University; Real Science Enrichment Days focussed on core STEM areas (Physics/ Chemistry/Engineering), a Design & Technology Enrichment Series, and a 3-day STEM Enrichment Conference. The effectiveness of enrichment on student attitudes towards STEM, in particular physics, was evaluated by experiment using modified validated pre- and post- surveys [2].

Findings show that enrichment methods help to take the negativity out of students, who found Science less challenging after enrichment. After the Real Science Enrichment Day focussed on 'Physics' an increase in interest towards physics and related careers was observed. These findings will be beneficial in designing more efficient programs to inspire girls about physics.

We seek to discuss Enrichments that involved students in hands-on activities on various Physics concepts and usefulness of such programs in increasing student's interest in Physics.

[1] Wayne, K. (2018). *Keeping Them in the STEM Pipeline: A Phenomenology Exploring the Experiences of Young Women and Underrepresented Minorities in a Long-Term STEM Enrichment Program*. Ed.D. Drake University

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The Graviton: where GR meets QFT

Paul T. Smith

Australian Institute of Physics.

In the teaching of physics, general relativity (GR) and quantum field theory (QFT) are usually treated as two separate, parallel subjects. It occurs because the mathematics and concepts of each are distinctly different. The partitioning in this way of the two pillars of modern physics, leads to long term difficulties for the student and research. This presentation works through improvements that can be used to teach these subjects to undergraduate students. The graviton is the quantum field particle which naturally becomes the subject because it is at the interface between these two theories. The student will gain fresh insights from the teaching method that will be detailed in this presentation.

Integrating technology with model-based inquiry in undergraduate physics experiment on waves

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Waves is a standard topic in first-year undergraduate physics courses with laboratory experiments used to aid student understanding of waves. Research has shown that utilising modelling and inquiry (Coll & Lajium, 2011) can potentially improve students' learning through experiments. Here, we present how technology and inquiry was integrated when designing an experiment for modelling waves on a rope. Furthermore, we investigated how do students engage with the new experiment? The experiment was designed in an iterative manner using design-based research (DBR) methodology. It had three features, (1) qualitative description and kinesthetic feel of waves being created on ropes, (2) taking measurements using video analysis software, and (3) a whole class display and comparison of experimental and theoretical values using a pre-designed EXCEL spreadsheet. There was one tutor training session in which tutors trialled and gave feedback. The near-final experimental was run with tutors to obtain final feedback but also train them with the notion of modelling in this experiment. The sample includes 501 students. Data were of three types, observational, survey from 406 students, logbooks & interviews. Tutors were also surveyed, with 24 surveys returned. Preliminary results indicate that the experiment fostered teamwork, video analysis was interesting and required appropriate investment of mental effort. The data demonstrated that the experiment did engage students in a meaningful manner. Results from the study show that the integration of digital technologies and inquiry resulted in higher levels of engagement with the experiment and good student engagement with the content.

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Moving clocks do not run slow

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This talk follows on from an article [1] which discussed the use of the phrase "moving clocks run slow" in teaching Special Relativity. The magazine received significant feedback from AIP members in relation to the article. Given the limitations of length and format for the article, this talk provides the author a chance to offer further perspectives on the topic, and an opportunity for people to ask questions, and discuss viewpoints, in person.

[1] T. Hughes, *Moving clocks do not run slow*, Australian Physics. Vol 56, No. 1, p11 (2019).

Magnetic imaging of 2D materials with a nitrogen-vacancy microscope

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Diamond nitrogen-vacancy (NV) microscopy has emerged as a promising tool to study the magnetic properties of ultrathin materials including van der Waals ferromagnets [1-3] but has been typically limited to room temperature operation or small fields of view (a few μm). Here we report on the realization of a widefield NV microscope operating over the range 4-300 K while offering a field of view of 120 μm with a near-diffraction-limited spatial resolution of ≈500 nm. We use this microscope to perform magnetic imaging of a range of freestanding ultrathin materials including flakes of van der Waals materials. Our quantitative magnetic field measurements allow us to infer the absolute magnetization of individual flakes, the anisotropy axis, the Curie temperature and the coercive field.

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[2] J.-P. Tetienne et al, *Science Advances* **3**, e1602429 (2017).

[3] L. Thiel et al, *Science* **364**, 973 (2019).

Quantum Phase Slips and Electromagnetic Duality in Quantum Circuits

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In a Josephson junction, two pieces of superconducting metal are separated by a ultra-thin region of insulator. Alternatively, if two regions of superconducting material are linked via a nanoscale constriction (for example a nanowire) then similar relationships between current and voltage hold, however the roles of charge and phase are interchanged [1]. Such a device is termed a quantum phase slip (QPS) element and is the dual of a Josephson junction (see Fig. 1). Realising quantum circuits based on QPS elements has proven challenging due to the disorder inherent in thin superconducting films with sufficiently large kinetic inductance [2].

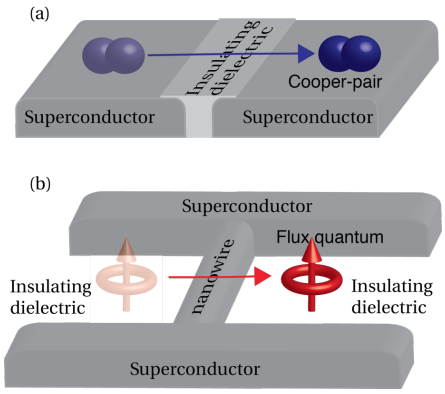

Figure 1. (a) A Josephson junction is a thin insulating barrier between two regions of superconductor, through which Cooper-pairs can tunnel. (b) Two regions of superconducting material connected via a nanoscale constriction forms a barrier for magnetic flux quanta. This is a quantum phase slip element.

Motivated by recent work on anharmonic oscillators based on QPS elements made from granular aluminium oxide films [3], we perform numerical simulations to understand the relationship between electrical response and film morphology and structure. We use effective models as well as atomistic approaches to understand the conduction properties of both the metallic and insulating regions of these films. The resulting network models can then be analysed using quasicharge [4,5] and Green's function [6] techniques to provide a detailed understanding of how current flows through a typical device.

Constructing detailed computational models of nanowires fabricated from thin film granular superconductors allows us to optimise the fabrication process, resulting in more efficient and reliable circuits for quantum computing and sensing applications.

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Laser modulation of superconductivity in a cryogenic widefield nitrogen-vacancy microscope

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Microscopic imaging based on nitrogen-vacancy (NV) centres in diamond, a tool routinely used for room-temperature studies of condensed matter systems, has recently been extended to cryogenic conditions [1-3]. However, achieving a wide field of view while maintaining a low base temperature remains a challenge due to the laser power requirements inherent to the technique. We realise a widefield NV microscope with a field of view of 100 μm and a base temperature of 4.0 K, and use it to image Abrikosov vortices and transport currents in a superconducting Nb film. We observe the disappearance of vortices upon increasing the laser power, and clustering around hot spots upon decreasing, indicating that laser powers as low as 1 mW (4 orders of magnitude below the NV saturation) are sufficient to locally quench the superconductivity of the film ($T_c = 9$ K without laser). This significant local heating is confirmed by resistance measurements, which reveal the presence of large temperature gradients (several K) across the film. We then investigate the effect of such gradients on transport currents, where the current path is seen to correlate with the temperature profile even in the fully superconducting phase. This work informs future studies employing NV microscopy at cryogenic temperatures and highlights the role of temperature inhomogeneities in superconductivity phenomena.

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[3] L. Thiel, et al., *Science* **364**, 973 (2019).

Probing the electronic nature of the diamond surface

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The electronic nature of the diamond surface strongly effects the performance of diamond material in the advanced applications of quantum sensing and high power/energy electronics. The room temperature quantum sensing nitrogen vacancy defects (NV-) in diamond is known to be strongly affected by the surface induced spin noise and charge instability. Electronic interfaces with diamond are typically hard to control, often exhibiting unexpected rectifying behaviour and Fermi level pinning.

Here we present a range of works in characterising some of these surface effects [1-3]. We performed optical detected magnetic resonance via the NV- defect to directly measure unexpectedly large electric fields at the diamond surface independent of the atomic termination. We explain these fields as a result of a previously unidentified surface acceptor defect. This defect was identified to be a protected graphitic-like carbon double bond with soft x-ray spectroscopy techniques performed at the Australian Synchrotron. The proposed atomistic nature of the defect was confirmed to be a stable surface acceptor by density function theory modelling. Including this defect in band alignment calculations showed good agreement with the measured surface fields.

Furthermore, we utilise the charge state response of NV- to image electric field modulation at titanium carbide electronic contacts to conductive hydrogen terminated diamond surfaces. We observe a complex interface that exhibits a negative capacitance and directly image the back to back Schottky diode band alignment that occurs despite the ohmic contact behaviour measured in DC.

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Relaxor Ferroelectric Single Crystals for Defence Applications

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Relaxor ferroelectric single crystals, including PMN-PT binary and PIN-PMN-PT ternary systems, are evolving as promising materials for the design of next generation transducers owing to their outstanding electromechanical properties. These materials possess a high energy-transformation efficiency due to their giant piezoelectric coefficients and large electromechanical coupling factors, which can be harnessed for use in:

- Electrical to mechanical energy transducers (actuators) for active sensing systems such as acousto-ultrasonic detection of structural damage in high-value military platforms, sonar projector in the maritime domain, and for adaptive structures [1]
- Mechanical to electrical energy transducers (sensors) for use in applications such as vibration energy harvesting and acoustic/ultrasonic sensing, i.e. hydrophone [2].

The Australian Defence Science and Technology Group's relaxor ferroelectrics work program is focused in the Defence priority areas of materials and advanced sensors, leveraging multinational effort to accelerate local manufacturing, characterisation, and assessment processes (e.g. macro properties, transmission electron microscopy, high energy diffraction at the Australian Synchrotron) of these materials for Defence applications [3, 4]. Relaxor ferroelectric single crystals, although *International Traffic in Arms Regulations* (ITAR) approved, are difficult to obtain from overseas suppliers due to limited production runs, uneven batch quality, and large demand from both the military and medical industries. Ultimately, a local crystal supply with a capacity to optimise electromechanical properties, will ensure that Australia has a sovereign capability to field Defence technologies based on these strategic materials.

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Measurement based quantum computation algorithms on IBM Q devices

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The dawn of the quantum information revolution is being heralded by nascent quantum computing devices, which are both noisy and have a limited number of qubits (NISQ devices [1]). While these devices are not yet able to carry out large-scale quantum algorithms, they are useful proving grounds for the application of quantum information and quantum computing protocols. Measurement based quantum computation (MBQC) is a method whereby an initially highly entangled state is used as a resource, and then only local measurements and feed-forward are used to implement quantum algorithms [2]. In this work we present an application of Measurement Based Quantum Computation to IBM Q devices carried out in the IBM Q Hub at the University of Melbourne. We demonstrated fundamental operations required for MBQC including single and two qubit operations, and the teleportation of quantum state down a chain of entangled qubits. Using these fundamental building blocks we then demonstrate the operation of small quantum algorithms in the MBQC framework. This serves not only as a demonstration of a novel application of quantum computing principles and entanglement, but also as a benchmark test for the quality and controllability of quantum systems.

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Quantum Simulation with Donor Qubits in Silicon

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A challenge to address in the context of many-body quantum systems is the characterization of the interactions and correlations within a quantum architecture, as well as the certification of its evolution. Donors in silicon are promising candidates for quantum computation and simulation [1,2]. They hold the ability to engineer quantum devices with a high level of control of the tunneling and exchange interactions between the dopants using the atomic precision of scanning tunneling microscope (STM) lithography [3]. These interactions can be measured by mapping out the wavefunction of coupled states at low temperature [2]. We have developed a platform to enable both the fabrication of STM donor devices and the spatially resolved spectroscopy of the interacting states, starting with a single and double quantum dots [4]. We extend these results to the local spectroscopy of STM-based complex donor structures to evidence non-trivial states arising in Fermi-Hubbard many-body systems.

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Integrating High Efficiency Single Infrared Photon Detectors with Fast Reset Times

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The past decade has seen an astonishing increase in interest in superconducting nanowire single photon detector technologies with a system detection efficiency (including optical coupling losses) of at least 90% for 1550 nm and sub-nanosecond reset times [1-3]. Besides single-photon detectors being one of the key elements in quantum optics experiments, a major drive of the current research into achieving a high efficiency performance is the rapid growth of the field of quantum-information science [4-7]. Furthermore, faster reset times would enable future experiments that require the detection of rapid subsequent photons [4].

We report the progress on fabricating a fibre-coupled single-photon detection integrated system that uses superconducting nanowire single-photon detectors and silicon nanoelectronic devices for the quantum state readout. The ability to fabricate these detectors on chip allows us to integrate the single-photon detectors in nanoelectronic devices to detect single photons emitted from ions in silicon. In addition, cryogenic amplifiers allow us to shorten the reset time and improve signal to noise.

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Quantum Factoring on IBM Q devices using the Quantum Approximate Optimization Algorithm

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One of the most important and influential quantum algorithms is Shor's algorithm for integer factorization. However, it requires fault-tolerance and a number of qubits beyond the scope of today's noisy intermediate-scale quantum (NISQ) computers [1]. An alternative approach to integer factorization which could be run on NISQ computers is known as variational quantum factoring [2, 3], which reformulates the problem of integer factorization as an energy minimization problem. Once posed as an energy minimization problem, it is amenable to being solved by various methods, notably Quantum Annealing [4], but also more recently, the Quantum Approximate Optimization Algorithm (QAOA) [5], a hybrid quantum/classical algorithm that uses a parameterized quantum circuit to create an ansatz wavefunction, and a classical optimizer to update its parameters in order to minimize the expectation value of energy. We experimentally investigate the factorization of various integers on IBM Q devices [6], as well as discussing a systematic classical pre-processing method that can be applied to reduce the number of qubits necessary.

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Entanglement in a 20-Qubit Superconducting Quantum Computer

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A critical milestone for quantum computing systems is the ability to prepare many-qubit entangled states [1] with full individual qubit control. In this work [2], we investigate entanglement of a graph state prepared on the 20-qubit superconducting quantum computer *IBM Q Poughkeepsie* [3]. The graph state was prepared along a path consisting of all twenty qubits in the device and full quantum state tomography was performed on all groups of four connected qubits along this path. Each pair of connected qubits was determined to be inseparable and hence the prepared state was entangled. Additionally, we measured a genuine multipartite entanglement witness [4] along all qubit sub-paths of the graph state and found genuine multipartite entanglement in 3-qubit chains. These results represent a demonstration of full entanglement in one of the largest solid-state qubit arrays to date and indicate the positive direction of progress towards the goal of performing complex quantum algorithms relying on such effects.

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Discretisation Effects in Circuit-QED-Based Digital Quantum Simulators

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In digital quantum simulations (DQS), complex Hamiltonian evolution that cannot be directly realised on a simulator can be approximated by breaking it up into sequential steps of simpler dynamics that can be implemented directly. In the most common approach, known as Trotterisation, time discretisation introduces unavoidable simulation error.

Recent numerical studies [1,2] show that rigorous generic error bounds may significantly overestimate the errors in physically interesting observables, and suggest errors display threshold behaviours in discretisation time that separate the simulated dynamics into stable and quantum chaotic regimes. In this work, we explore these Trotterisation effects in more detail in the context of circuit-QED based digital quantum simulators, beginning with a recently demonstrated protocol for simulating ultrastrong light-matter interactions [3]. Using numerical results, we attempt to identify and categorise effects leading to the breakdown of simulation accuracy in DQS.

We observe threshold behaviours in the system dynamics and look for measurable signatures of quantum chaos. We also show that discretisation causes aliasing effects, which limit the range of parameters that can be accurately simulated.

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Exploring many-body physics in two and three-dimensional strongly interacting Fermi gases

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The ability to tune the interactions and dimensionality in ultracold gases of fermionic atoms provides a versatile test bed for studying quantum many-body phenomena; unlocking new ways to study condensed matter physics in an environment free of defects. We study strongly interacting Fermi gases in both two and three-dimensions. In three-dimensions we present measurements of the excitation spectra of strongly interacting Fermi gases using focused beam Bragg spectroscopy. At high momentum, Bragg spectroscopy allows the determination of Tan's universal contact parameter and the internal energy via the application of sum-rules. These allow us to map the temperature dependence of the contact and energy for gases at unitarity [1]. By changing the shape of the confining potential we can tune the dimensionality from 3D to 2D, which dramatically alters the scattering properties and enhances two-body pair formation. We present an experimental study of collective oscillations in strongly interacting Fermi gases in the crossover from two to three dimensions [2]. By measuring the frequency of the radial breathing mode, we map the evolution between the known 2D and 3D limits due to the different polytropic equations of state. Furthermore, in 2D, the Hamiltonian for a gas with delta-function interactions is classically scale invariant. However, renormalisation in a quantum treatment introduces a length scale which breaks scale invariance leading to a so-called quantum anomaly. Our measurements of the collective mode frequency in the 2D regime lie above the scale-invariant classical prediction for a range interaction strengths, consistent with the existence of the quantum anomaly.

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Generalized Homodyne Detectors for Quantum Optics

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Optical quantum technologies are increasingly attractive due to their potential high speed and scalability [1,2]. Across the board, these technologies, including quantum computing [3] and communication, require high-quality optical measurements. However, our current set of measurements in quantum optics is quite limited, with a key measurement device being the homodyne detector. Typically, homodyne detectors allow high precision phase-dependent electric-field measurements [4]. A homodyne detector's measurement characteristics depend on one of its inputs, called the *local oscillator* (LO). By modifying a standard homodyne detector—specifically, replacing the local oscillator with a nonclassical state of light—we can engineer new measurements of the quantum electromagnetic field. This has many uses including non-Gaussian state preparation, efficient quantum tomography, and low-power quadrature measurements for integration into optical chips.

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Explicit simulation of 2D spectroscopies: Contrasting heterodyne-detected and fluorescence-detected signals

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Two-Dimensional Electronic Spectroscopy (2DES) is by now a well-established method in the study of the third-order response of a quantum system to an electric field. Traditionally, phase matching is employed to spatially separate the third-order signal, which is then heterodyne-detected (HD) by a local oscillator. On the theory side, the double-sided Feynman diagrams provide a simple way of modelling the spectra. Although the method targets optical electronic transitions, there can be concurrent vibrational transitions followed by a coevolution of the electrovibrational system. We have previously studied the effect of anharmonic vibrational potentials on linear absorption, fluorescence and HD-2DES. [1,2]

Recently, Fluorescence-Detected Two-Dimensional Electronic Spectroscopy (FD-2DES) has been emerging as an interesting alternative to the conventional Heterodyne-Detected Two-Dimensional Electronic Spectroscopy (HD-2DES). The sensitivity of FD-2DES is vastly superior to that of HD-2DES, but more importantly, the method is not limited to an ensemble measurement, meaning that it is capable of observing in situ ultrafast dynamics down to the single-molecule limit.

Whereas FD-2DES and HD-2DES share many similarities in the spectral evolution and the experimental setup, there are also fundamental differences. How these differences manifest in the measured spectra are not fully understood. In this work we go beyond the double-sided Feynman diagrams and simulate the different experimental realisations non-perturbatively to learn how the spectral evolution is affected by the detection scheme.

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Cavity Enhanced Organic Photodiodes with Charge Collection Narrowing

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Colour discrimination in photodetection is conventionally achieved using broadband-absorbing inorganic semiconductors with passive optical filters.[1] Organic semiconductors have shown promise to deliver narrowband spectral responses due to their tunable optical properties. While achieving narrow-absorbing organic semiconductors is an ongoing endeavour in the synthetic chemistry community, charge collection narrowing has been introduced as a 'material-agnostic' technique to realize narrowband spectral responses using broadband absorbers such as blends of organic semiconductors, inorganic nanocrystals and perovskites in a photodiode architecture. Charge collection narrowing in organic semiconductors demands photo-active junction thicknesses on the order of few microns causing fabrication difficulties and limitations in device metrics such as frequency bandwidth.

In this work we show that electrical inversion can result in charge collection narrowing in organic photodiodes with active layer thicknesses on the order of 100s of nanometers and hence much easier to achieve *via* high throughput solution processing techniques. Additionally, we show that an indium tin oxide/gold electrode with modified work function acts as a cavity mirror further narrowing the spectral response and at the same time delivering an extremely selective cathode suppressing the dark current dramatically. Nearly voltage independent detectivities of 10^{13} Jones are achieved with an active sensing area of 0.2 cm^2.[2]

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Electronic transitions in quantum dot molecules mediated by light carrying angular momentum

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An electromagnetic field may be endowed with orbital angular momentum (OAM) by the twisting of the beam's phase. The OAM of a photon may take any integer multiple of ħ (Allen *et al.* 1992). Electromagnetic fields imbued with OAM are commonly referred to as *twisted light*. Circularly polarised light additionally contributes spin angular momentum (SAM).

When quantum dots (QDs) are arranged in close proximity they support delocalised states. The specific arrangements that we consider are N QDs placed on a ring of radius, r_0, at the angles which are multiples of $2\pi/N$. This system we refer to as a quantum dot molecule (QDM). The delocalised, or 'molecular', states are excitons which can have a meaningful value of angular momentum. Light endowed with SAM or OAM may be used to create these excitons (Müller *et al.* 2012; Williams *et al.* 2013). We wish to explore a scheme where particular pulses of twisted light may selectively create angular momentum carrying excitons. A similar scheme has already been examined where a magnetic field threads a sheet of triple quantum dot molecules, providing it with the chirality to selectively absorb angular momentum carrying light (Kotetes 2014).

The magnitude of the transition matrix elements and the lifetime of the excitons will determine whether this scheme is feasible. The optical transitions depend on QDM properties as well as the light beam's properties. To this end we have employed a semi-classical model to derive the transition matrix elements between the excitonic states in QDMs when they are irradiated with twisted light. The specific light profiles we utilise are the well-studied, Laguerre-Gauss modes in the paraxial approximation.

Numerical simulations are performed for standard QD materials whilst varying other parameters. We investigate effective selection rules for these quantum systems. Furthermore, we demonstrate the optimal geometries of the QDMs and light beam profiles for achieving the aforementioned scheme. This approach combined with recent developments in QDM fabrication (Harris 2016) may provide the basis for a meta-material capable of angular momentum up-conversion.

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Space plasma physics applied to smartphones, satellite propulsion and space debris removal

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Harnessing the plasma state on Earth has allowed the development of increasingly performant integrated circuits and sensors such as those found in smartphones. Similarly, progress in satellite technologies is ongoing and eventually finds applications back on Earth. Electric propulsion has been an innovative or complementary solution in a number of space missions but its scalability remains a challenge especially when considering standardised nano-satellite platforms such as CubeSats. The low-cost Pocket Rocket electrothermal radio frequency plasma thruster has now reached Technology Readiness Level 7 and uses a compact, efficient and less expensive power supply with pulsed operation and "instant on" capabilities. Thousands of CubeSats satellites are expected to be launched over the next decade, many in constellations. While most of these will be positioned in low earth orbit with a short lifetime and complete burn on re-entry, the emerging space sector is faced with the problematic issue of space debris mitigation. Space debris removal from Earth orbit by using a satellite is an emergent technological challenge for sustainable human activities in space. In order to de-orbit debris it is necessary to impart a force to decelerate it, resulting in its atmospheric re-entry. A satellite using an energetic plasma beam directed at the debris will need to eject plasma in the opposite direction in a controlled manner in order to maintain a constant distance between it and the debris during the deorbiting mission. By employing a magnetic nozzle plasma thruster (such as the Helicon Double Layer Thruster or the Helicon Thruster) having two open source exits, bi-directional plasma ejection can be achieved using a single electric propulsion device. Paving a path to space heritage for these new propulsion concepts while addressing the fundamental physics of out-of-equilibrium expanding magnetised plasmas is an exciting challenge. The Australian Space Agency was born in 2018 and a complete end-to-end small satellite industry --- "Lab to Launch" --- may now be envisaged within the Trans Australasian Pacific region, thanks to the recent demonstration of *Rocket Lab*'s access to orbit and successful commercial launches from New Zealand with the *Electron* Rocket.

Optical Surface Profiling at Micro/Nanoscopic Scale

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It is well known that standard compound microscopy has a fundamental lateral resolution limited by the wavelength of the light. Hence a lateral resolution of better than 200 nm cannot be achieved by a standard compound microscope. The innovations in techniques to overcome this limit has led to super-resolution microscopy which has enabled a burst of discovery, and has been recognized in the 2014 Nobel Prize in chemistry. What is less well known is that depth resolution at the nanometer scale is possible using interference microscopy – optical surface profiling. Two generations of Optical Surface Profiler have been established at Macquarie University through multi-institution ARC Linkage Infrastructure and Equipment funding. From the early plan to use this instrument to measure 3-dimensional data of microscopic single-laser-pulse/photonic materials interaction sites [1], we have gone on to research such things as ways to measure the diameter of semiconductor nanowires [2] and size nanoparticles [3]; explain unexpected spectral results in VUV spectroscopy [4]; study spider silks from several different species, with relevance to the likely visibility of the silks to insects; and uncovering unexpected systematics in laser processing of mineral muscovite [5]. Overall, this will be a tour of what we can learn and discover by embracing the third dimension in microscopy.

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Conformations and Trapping of Unidirectional Molecular Motors on TiO_2 (110)

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Motorized molecules, where an external stimulus is converted controlled motion, are envisioned as cargo carriers at the nanoscale. In Feringa type motors, ultraviolet light triggers a sequence of isomerization and helical inversion steps leading to the unidirectional rotation of the motor. When incorporated into larger molecules, these motors are a potential source of unidirectional translation at surfaces. Scanning tunneling microscopy (STM) is an ideal tool to investigate the single molecule dynamics of these molecular machines, but commonly used metal substrates have drawbacks, such as the quenching of excited states by conduction electrons. An alternate approach is to deposit them on semiconducting substrates, thereby reducing the adsorption strength of the molecule on the surface and removing a potential path for quenching. Here, I will present initial results on a unidirectional molecular motor adsorbed on a wide band gap semiconductor, TiO_2 (110). STM imaging at 77K reveals multiple adsorption configurations and, critically, motion. Finally, I will show how hydroxyl groups influence the motion of these motors.

Simulating the electrical response of aluminium oxide tunnel junctions in three dimensions: how atomic disorder leads to localised conduction channels

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Aluminium oxide (AlOx) tunnel junctions are fundamental components in superconducting quantum computers being developed around the world [1]. Variability in tunnel junctions is often interpreted using 1D models that average over the details of the atomic structure [2]. However experimental investigations of Al/AlOx/Al junctions show a distribution of barrier thicknesses at nanometre length scales that cause the majority of the current to flow through the thinnest regions of the oxide layer [3].

We perform numerical simulations to probe the electrical properties of these devices at even smaller length scales to improve our understanding of how the atomic structure affects conduction. Al/AlOx/Al junction models were developed in 3D with molecular dynamics simulations. Electronic properties were calculated with the non-equilibrium Green's function (NEGF) formalism by computing the electrostatic potential in the junction from the final positions and charges [4].

By performing an end-to-end 3D calculation, we study how the structure of the oxide and the Al/AlOx interfaces affects conduction. Exponential changes in the junction resistance as a function of oxide thickness and density are observed. We find that the local structure at the Al/AlOx interface causes spatial variation in the current density. Due to the exponential nature of the tunnelling current, small variations in the effective barrier thickness as a function of position lead to significant variation in the tunnelling probability causing the majority of the current to flows through localised channels.

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A Quantum-Based Nanoscale Sensor for Improved Detection of Ferritin-Bound Iron

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The iron storage protein ferritin, capable of storing between 0-4500 Fe^{3+} ions, is the main serum parameter used to inform clinical diagnosis regarding iron status. However, the standard detection method—immunoassay—is only sensitive to protein concentration and is therefore an indirect measure of iron. This leads to cases wherein interpretation is ambiguous, especially in the presence of other confounding pathologies. Here we extend upon previous work [1] [2] [3] using the nitrogen-vacancy defect in diamond to directly detect the iron present in ferritin through sensing of the superparamagnetic magnetisation fluctuations of the core. Development of a standard curve of nominally fully loaded ferritin of varying concentrations has yielded a current detection limit of 0.2 µg/mL, at the upper end of the physiological range. Current work aims to improve this limit, and create a similar standard curve for varying iron loads at a constant concentration. Successful development of this technique will provide a clinically viable technique for direct measurement of the iron load of ferritin, enriching the information available during diagnosis.

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Models for electron transport in the two-dimensional allotropes of bismuth

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In two-dimensional (2D) materials with honeycomb lattices, such as graphene, large spin-orbit coupling strengths are predicted to cause the existence of edge states. The 2D allotropes of bismuth are no exception to this prediction as they exhibit properties that are topologically non-trivial [1, 2]. In this work, we calculate the band structure of the 2D allotropes of bismuth using density-functional theory (DFT) and then develop tight-binding models of these materials by fitting their energy bands with a basis of maximally-localised Wannier functions. We do this for bismuthene and the (111) and (110) bismuth bilayers. Accurate TB models for the 2D allotropes of bismuth are needed to simulate electron transport in these systems and thereby determine their suitability for device applications in the field of low energy electronics technologies.

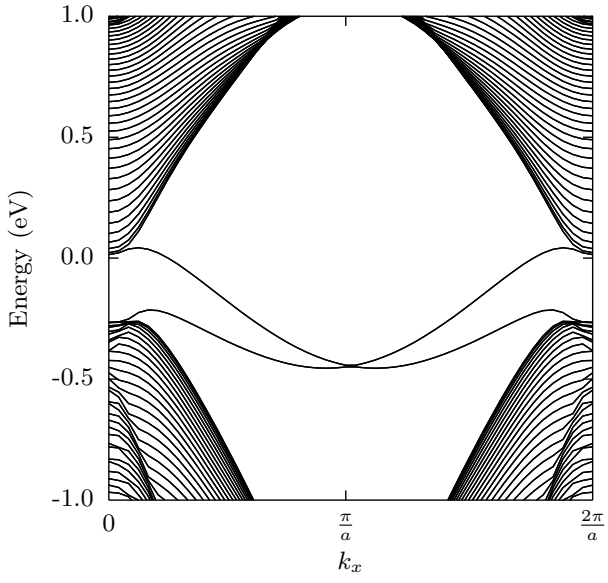

Figure 1: Band structure of a bismuth (111) nanoribbon that is 17 nm wide and has armchair edge termination. The bands of two edge states cross the gap between the valence and conduction bands.

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Probing charge transfer across HIOS interface by nanowire conductance spectroscopy

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Understanding the mechanism of charge and exciton transfer across the hybrid inorganic-organic semiconductor (HIOS) interface is crucial for designing novel third generation photovoltaic devices [1]. In this work, we study electron transport processes in a silicon nanowire covered by an organic semiconductor [2]. We propose a mathematical model that estimates the effect of charge transfer across the interface on the conductance of the nanowire. The model is based on the non-equilibrium Green's function approach [3] with the semi-empirical $sp^3d^5s^*$ tight-binding model for the electronic structure of the nanowire [4]. The scattering potential has been computed using a combination of the polarizable continuum model and density functional theory with the range-separated exchange-correlation functional for organic molecules [5].

Moving charge carriers in the organic semiconductor perturb the electrostatic environment of the nanowire, introducing an additional source of elastic scatterings that suppresses the coherent transport of electrons. The conductance change caused by scattering on a single molecule both for positive and negative charge carriers has been computed for a range of Fermi energies. A steady-state injection of charge carriers into the nanowire from the organic semiconductor has been also considered. It redefines the quasi-equilibrium thermodynamic variables such as temperature and Fermi energy level that leads to the increase of the conductance. Thus, the movement of charge carriers in tetracene reduces the conductance of the nanowire introducing an additional source of scatterings, while the charge transfer across the interface enhances it. Both effects can be quantified from experimental measurement of the conductance.

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Detectors in Bandlimited Quantum Field Theory

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It has been known for decades that quantum field theory exhibits mathematical pathologies at very small scales. This is why an ultraviolet (high-energy) cutoff is assumed to exist, although its details are often left unspecified. The standard approach to this problem is to employ renormalisation, which seeks to model low-energy behaviour for field theories whose high-energy details are unspecified. In this work, we take a different approach, inspired by information theory: *Bandlimited quantum field theory* [1] is an approach to quantum fields that allows them to simultaneously be described as both continuous and discrete. This eliminates the need for renormalisation and leads to new detectable artefacts of the bandlimit.

In this work, we analyse the behaviour of quantum detectors interacting with bandlimited quantum fields. For the analysis, we employ Unruh-Dewitt detectors [2], which are a useful toy model of the atom-field interaction. First, we study the response of a single detector, discovering a modification to its spontaneous emission rate as a function of the bandlimit. Second, we examine how the bandlimit affects the ability of two detectors to harvest entanglement from the quantum field, and we find that the bandlimit enhances this ability. The value of this work is in explaining how a fundamental bandlimit changes the behaviour of quantum detectors and in offering an operational means to detect a fundamental bandlimit via entanglement harvesting.

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Neutron Star Heating via the Capture, Thermalisation and Annihilation of Dark Matter

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Particle Dark matter is expected to scatter in neutron stars and become gravitationally captured. It may then undergo further scattering interactions to thermalise with the star, and eventually self annihilate within the star's core. The energy transferred through these processes will heat neutron stars to temperatures that can be observed by upcoming infra-red telescopes. Using an effective field theory framework, we examine the capture, thermalisation and annihilation of dark matter, correctly accounting for the effect of Pauli blocking in the highly degenerate neutron star media. This allows us to place limits on dark matter-neutron cross section that, in some cases, are significantly stronger than current experimental limits. This is particularly so for momentum dependent interactions, which are highly suppressed in direct detection experiments, and for dark matter masses below approximately 1 GeV, for which the signals in nuclear recoil experiments are below threshold.

Electroweak Dark Matter

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In the absence of any hints of new physics in LHC, the TeV dark matter candidates interacting through electroweak force (EWDM) are highly motivated. We extend the Standard Model by adding an arbitrary fermionic / scalar dark matter (DM) multiplet in non-chiral representation [1]. In addition to the real representation, by including a higher dimensional mass-splitting operator, the complex DM candidate survive the current direct detection constraints.

Since the masses of gauge mediators are light compared to the dark particles, Sommerfeld effect is dominant and affects the annihilation cross-sections in both the early universe and current time. This means that perturbative quantum field breaks down, and we need to make use of non-relativistic effective Electroweak theory to account for non-perturbative effects while computing the annihilation cross sections for the two-body states of the dark matter [2].

We computed DM relic abundance through freeze-out mechanism in order to determine its mass. Gamma ray spectrum resulting from the fragmentation and Bremsstrahlung phenomena turn out to be an interesting tool to probe EWDM theory.

We confronted different representations of the model with the latest HESS observations [3]. The model is not ruled out according to the current data, and it is accessible to future observations.

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Abstract Preparation Instructions and Template for AIP Summer Meeting 2019

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In conventional dark matter direct detection experiments, we assume some interaction between dark matter and nucleons. Such an interaction, however, will also lead to dark matter accumulating in the Sun, and eventually annihilating. For dark sectors with a mediator that is very weakly coupled to the Standard Model, such as a "dark photon", the dark matter may annihilate into these long-lived mediators, which can then escape the Sun before decaying to charged particles and photons. The recent measurements of the HAWC observatory provide strong bounds on very high energy solar gamma rays, providing more sensitive constraints on very heavy dark matter than typical direct detection experiments.

A near-minimal leptoquark model for reconciling flavour anomalies and generating radiative neutrino masses

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We introduce two scalar leptoquarks, the $\mathrm{SU}(2)_L$ isosinglet denoted $\phi \sim (\mathbf{3}, \mathbf{1}, -1/3)$ and the isotriplet $\varphi \sim (\mathbf{3}, \mathbf{3}, -1/3)$, to explain observed deviations from the standard model in semi-leptonic B-meson decays. We explore the regions of parameter space in which this model accommodates the persistent tensions in the decay observables $R_{D^{(*)}}$, $R_{K^{(*)}}$, and angular observables in $b \to s\mu\mu$ transitions. Additionally, we exploit the role of these exotics in existing models for one-loop neutrino mass generation derived from $\Delta L = 2$ effective operators. Introducing the vector-like quark $\chi \sim (\mathbf{3}, \mathbf{2}, -5/6)$ necessary for lepton-number violation, we consider the contribution of both leptoquarks to the generation of radiative neutrino mass. We find that constraints permit simultaneously accommodating the flavour anomalies while also explaining the relative smallness of neutrino mass without the need for cancellation between leptoquark contributions. A characteristic prediction of our model is a rate of muon–electron conversion in nuclei fixed by the anomalies in $b \to s\mu\mu$ and neutrino mass; the COMET and Mu2e experiments will thus test and potentially falsify our scenario. The model also predicts signatures that will be tested at the LHC and Belle II. Presentation based on Ref. [1].

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Digital simulation of the quantum Rabi model phase transition in circuit QED

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The Quantum Rabi model, which describes a two-level system coupled to a single-mode cavity field, is the most fundamental description of quantum light-matter interactions. Despite its simplicity, it predicts exotic phenomena such as ground-state entanglement in the ultrastrong and deep-strong coupling regimes. It is even possible to define a thermodynamical limit where a quantum phase transition can be observed between localised and delocalised phases [1]. The latter is characterized by photon build up and state degeneracy. If the system is tuned dynamically through the critical point, the inevitable non-adiabaticity that results from closing energy gaps results in excitations described by the Kibble-Zurek mechanism [2]. In this work, we investigate the suitability of a circuit-QED-based digital quantum Rabi simulator (DQRS) [3] for observing both equilibrium and dynamical signatures of the quantum Rabi phase transition. We numerically model the DQRS to explore its performance in the extreme parameter ranges required to realise an effective thermodynamic limit and explore the effects of digitisation and digitisation errors on experimentally measurable signatures of the quantum phase transition.

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Decoherence and Localisation at the Wavefunction Level through Conditional Wave Theory

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We present a conditional wave theory formulation of quantum decoherence based on the exact-factorisation methods developed in molecular physics. In the presence of environmental interactions, we show that the marginal wavefunction obeys a non-linear wave equation. This nonlinearity enters through the gauge fields and is proportional to the long-wavelength decoherence rate. We explore the behaviour of Gaussian wave-packets under this Schrodinger-like equation and show good agreement with the full master equation solution. By evolving a non-linear wave equation rather than a density matrix, conditional wave theory may lead to computationally efficient descriptions of decoherence.

Low-energy Single Ion Detection for a Si:P Quantum Computing Architecture

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The quantum states of donors within a semiconductor medium provide a promising platform for a qubit. The long-lived electronic and nuclear spin states of single ^{31}P donors in an ^{28}Si "spin vacuum" make phosphorus-in-silicon (Si:P) architectures particularly attractive. Prototype devices have demonstrated reliable high-fidelity control and readout of single donor-qubit spins, with a record nuclear $T_2 > 30$ s [1]. In addition, the emergence of an innovative flip-flop Si:P architecture [2] allows relaxation of the previously restrictive donor-qubit placement precision to several tens of nanometres. Industry-standard ion implantation at low energies meets these constraints, thus representing a promising tool for large-scale quantum architecture fabrication.

Through the use of the ion beam induced charge method and an active ulta-low noise detection substrate, electron-hole pairs created by each ion impact are detected [3]. We present single ion detection benchmarks from a new detector generation specifically developed for the flip-flop Si:P architecture, including the first successful demonstration of 14 keV P^+ ions detected with 90% fidelity at room temperature. Further energy reduction yielding P ion placement to within 10 nm of the surface with comparable detection fidelties is also shown. Furthermore, the adaptation of the detection setup for use with high-resolution Rutherford backscattering spectroscopy is presented within the context of ^{28}Si isotopic purification of the substrate [4]. For a compact solid-state detector in the coventional $\sim 170^\circ$ backscattering orientation, a ground-breaking 7 keV energy resolution is presented, sufficient to resolve the isotopes of silicon at MeV probe energies.

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Electrically Detected Magnetic Resonance of P in ^{28}Si Isotopically Enriched by High Fluence Ion Implantation

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The electron and nuclear spins of donors in ^{28}Si are promising qubit candidates due to their long coherence times [1]. Control and readout of donor spins using surface nano-circuitry requires a donor depth of ~ 20 nm in Si; achievable using ion implantation. The activation of Bi donors implanted 20 nm deep in ^{nat}Si has been shown using electron spin resonance [2]. However, the surrounding ^{29}Si nuclei in ^{nat}Si cause donor decoherence by spectral diffusion. We present a method of isotopic enrichment of ^{28}Si by high fluence ion implantation. Implanting 42 keV ^{28}Si ions results in a sputter yield of 1 and a ~ 120 nm thick layer depleted in ^{29}Si nuclei. Successful recrystallisation of this enriched layer by solid phase epitaxy has been demonstrated, indicating that the concentration of impurities introduced during processing is relatively low.

Measuring the quantum environment of P donors implanted into this ^{28}Si layer is challenging due to the thickness of the enriched layer and low P concentration required to limit donor-donor interactions. Electrically detected magnetic resonance (EDMR) offers a more sensitive alternative to conventional electron spin resonance. At a particular microwave frequency and magnetic field where the P electrons are on resonance, a change in substrate conductivity occurs; measurable via a photocurrent [3]. The EDMR peak linewidth of P implanted into the enriched ^{28}Si layer will be compared with ^{nat}Si to show the effect of the depletion of ^{29}Si on the P donor environment. An EDMR device fabricated on a Si:P substrate is shown in Figure 1.

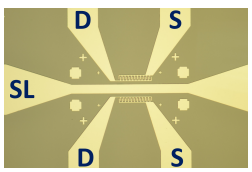

Figure 1: An EDMR device with a microwave stripline (SL) and interdigitated source (S) and drain (D).

We acknowledge the ARC Centre of Excellence CQC2T (Grant no. CE170100012) and the AFAiiR node of the NCRIS Heavy Ion Capability.

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Characterization of atomic qubits in silicon by machine learning

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Of the leading platforms for the implementation of quantum computer architectures, atomic qubits in silicon are attractive candidates given the nexus with nanoelectronics engineering and the long coherence times [1-3]. The characterization and control, even at the level of a few qubits, are formidable tasks. As the number of qubits in quantum devices are expected to increase in the coming years, the characterization by direct quantum measurements may become increasingly onerous, and therefore a fast, reliable, and autonomous methodology would play a crucial role in the scale-up process. Here, we report an autonomous characterization scheme for the donor spin qubits in silicon by integrating the multi-million-atom tight-binding simulations and the scanning tunneling microscope (STM) images of the donor wave functions with machine learning techniques. The spatially resolved STM images of the electron wave function confined on individual impurity atoms have opened new avenues for high-precision characterization [4-6]. By coupling large-scale atomistic wave function simulations with the Bardeen's tunneling formalism, we have established a theoretical framework to compute the STM images with an unprecedented accuracy, leading to the world's first spatial metrology of impurities in silicon with a single atom precision [5]. A machine learning framework is formulated by training a convolutional neural network (CNN) based on the 100,000 simulated STM images, which are pre-processed by feature-detection and feature-averaging schemes to reduce the computational complexity [7]. The trained CNN performs qubit characterization with fidelities above 95% over 17600 test images which included blurring and asymmetry noise commensurate with the measurements. The method established here will enable a high-precision post-fabrication characterization of dopant qubits in silicon, with high-throughput potentially alleviating the requirements on the level of resource required for quantum-based characterization, which may be otherwise a challenge in the context of large qubit arrays for universal quantum computing.

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Error correction in phase space for bosonically encoded qubits

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In 2001, Gottesman, Kitaev and Preskill (GKP) proposed a method to encode an error-correctable qubit within a bosonic mode (such as a quantum harmonic oscillator) based on discrete translation symmetry [1]. The GKP encoding has been shown to be particularly resilient to both phase-space displacements and pure loss [2].

We present a comprehensive, phase-space description of quantum computing with the GKP code including error correction. A key advantage to this approach is that under physical circumstances GKP-encoded states are not pure due to preparation errors and decoherence, and thus a wavefunction description is inadequate. Moreover, the GKP encoding benefits from the fact that the full set of encoded Clifford operations—all that is needed for error correction—is performed by Gaussian operations on the underlying mode. These processes have a particularly simple treatment in phase space, where Gaussian operations are implemented by linear coordinate transformations on Wigner functions [3]. Further, important noise channels on a mode, such as pure loss, the Gaussian displacement channel, and thermal heating are also Gaussian. Our construction accommodates not only ideal GKP encodings but also approximate, finite-energy encodings, which are crucial for describing physical implementations.

Using this phase-space construction, I will discuss GKP error correction in the context of fault-tolerant computation in the presence of preparation errors and decoherence. I will also describe how GKP error correction can be used to produce magic states as a resource for universal quantum computation [4].

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Assemblies and reactions of small carboxylated molecules on metal surfaces

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In the pursuit of applications-targeted materials, the reaction of small molecular precursors on a surface is emerging as an attractive route towards designing 1D and 2D materials with well-defined chemical and structural properties. For example, the use of extended molecular scaffolds has led to unprecedented control over the growth of graphene nanoribbons on surfaces.[1]

Taking a similar approach, we have been systematically studying the use of small, single-ring aromatic precursor molecules as candidates for on-surface materials synthesis. Ironically, these simple molecules exhibit surprisingly complex behaviour under reaction conditions on metal surfaces. Here, I will discuss what we have learned by studying a range of di- and tri-carboxylated pyridine and benzene-based molecules on copper and silver single crystals. Through thermal annealing, we initiate first deprotonation, then decarboxylation of the molecules. We find that the adsorption geometry of the molecules changes significantly as they undergo successive reactions,[2] that molecules in different chemical states can assemble into complex structural motifs,[3] and that maintaining the pyridine ring integrity during decarboxylation may be difficult.[4] We have studied these systems using a range of surface science techniques including photoelectron spectroscopy, near-edge x-ray absorption fine structure and scanning tunnelling microscopy. When combined with density functional theory calculations, these measurements give us well-rounded insight into the challenges inherent in predictive control of on-surface synthesis using small precursor molecules.

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Amorphous Carbon-based Resistive Switching Devices for Neuromorphic Applications

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Resistive switching devices are being used as the building blocks for future technologies such as non-volatile memory and data storage, neuromorphic computing and as the basis for next generation sensing applications. Amorphous carbon-based resistive switching devices have gained attention through their recent addition to the International Technology Roadmap for Semiconductors [1].

In this work, we investigate multilayer amorphous carbon-based resistive switching devices fabricated using physical vapor deposition techniques. A series of elemental and oxygenated carbon-based resistive layers were deposited using a filtered cathodic vacuum arc. The films were chemically and microstructurally characterised using transmission electron microscopy, electron energy loss spectroscopy and X-ray photoelectron spectroscopy.

Electrical testing revealed unipolar and bipolar switching modes in the bilayer amorphous carbon devices. Combining these two modes enabled a 3-state memory system. Neurological functions including paired-pulse facilitation (PPF) and paired-pulse inhibition (PPI) were successfully emulated. Additionally, the devices exhibited sensitivity to both temperature and photonic stimulation. The neuromorphic traits and sensitivity to various external stimuli suggest that the applications for these carbon-based devices can extend beyond simple memory to more advanced neuromorphic ‘smart’ sensors.

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Shear-driven transformations in carbon under extreme pressure

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Diamonds are used in many industrial applications due to their extreme hardness, particularly for polishing, cutting, and pressure application. There has been an increasing interest in hexagonal diamond in recent years, largely due to its potential to be harder than diamond [1]. However, experimental hardness measurements for this technologically interesting material have yet to be reported due to the extreme temperature/pressure conditions required to form hexagonal diamond [2, 3] as well as the inability to form a phase-pure sample without cubic diamond inclusions [4]. Here, we report formation of pure hexagonal diamond at a record low temperature of 400°C that is proposed to be due to a shear-induced plastic flow. A region of pure hexagonal diamond was observed in an annular region around the central region containing a graphite-like structure. Transmission electron microscopy of lamellae containing both the graphite-like and diamond structures was examined to provide microstructural evidence for transformation mechanism. Within the graphitic regions, the graphitic layers are aligned perpendicular to the compression direction, with the amount of orientation within these sheets increasing with increasing shear. At regions of higher shear, these flowing graphitic sheets were observed to progressively "lock-into" hexagonal diamond within a mixed region where both structures were present. This is evidence for a step-wise transformation from the graphitic precursor to the hexagonal diamond structure due to a shear-induced flow mechanism.

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Emergent Collective Dynamics in Neuromorphic Nanowire Networks

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Inorganic nanowires can self-assemble into densely-connected, unorganised networks with a neural network like topology[1]. In networks of polymer-coated silver nanowires low resistance pathways form in response to application of electrical biases[2]. Individual nanowire-nanowire junctions display voltage-dependent non-linear resistive switching behaviour, mediated by electrochemical filament growth through insulating layers [3]. Networks display memory and characteristics of criticality, such as a scale-invariant power spectrum. Such properties indicate nanowire networks have potential for applications, such as neuromorphic computing.

A graph model was developed, representing nanowires as equipotential nodes and junctions as edges, with resistance dependent on filament growth state parameter. A threshold-type memristor model of junctions was modified to incorporate electron tunnelling and the effects on network response were studied by computational simulations. Spatio-temporal analysis of single switch dynamics during simulated DC network activation uncovered a collective switching mechanism. Networks self-organise into a state where the filament state of each switch along topologically shortest paths converges to the single path average, through avalanche-like variations in voltage across junctions. In this critical state the pathway collectively responds to external driving or perturbations, behaving like a single junction.

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Superwalking droplets *

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Abstract

In 2005, Yves Couder and colleagues showed that a droplet of silicone oil can be made to bounce and walk on the surface of an oscillating bath of the same fluid. These walking droplets or walkers are propelled by the standing waves they generate on each bounce and constitute a wave-particle entity. They have been shown to mimic several features that were previously thought to be intrinsic to the quantum regime. In this talk, I will present results for a new class of walking droplets that we have discovered in experiments. These droplets can be up to twice the size of a walker and walk at double the speed and hence we call them 'superwalkers'. Besides their size and speed, superwalkers are fundamentally different from normal walkers in their interactions with other walkers; they form tightly bound states from which droplets 'evaporate' on increasing the driving amplitude and behave like an 'ideal gas of particles' colliding with each other.

Keywords: bouncing droplets, quantum analog, fluid mechanics, chaos

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Quantitative biological and birefringent imaging via optical ptychography

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Label-free imaging of biological processes such as cell movement and death is of significant interest for the developing our understanding of the inner workings of cells. The role that mechanical forces play in these processes is currently an active area of research, however, non-destructively measuring stress in biological objects is challenging.

By developing new techniques for quantitatively mapping the birefringence of optically transparent objects we aim to address this critical issue. Recently we have successfully employed optical ptychography, a method for quantitatively recovering phase information, to reconstruct the stress tensor in samples subject to mechanical forces. Here we described our recent work in quantitative birefringent imaging [1] using photoelastic ptychography and discuss how this approach is being applied to investigate the fundamental mechanical properties of cells and tissues [2].

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Stepwise 53BP1 foci assembly in response to DNA double strand break.

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Abstract

Tumor suppressor p53-binding protein 1 (53BP1) is a DNA repair protein essential for the detection, assessment and resolution of DNA double strand breaks (DSBs). The presence of a DSB is signaled to 53BP1 via a bivalent histone modification - di-methylated lysine 20 of histone 4 (H4K20me2) and ubiquitinated lysine 15 of histone 2A (H2AK15ub) - to which 53BP1 dimers directly bind. While both elements of the DSB histone code are known biochemically to be necessary for 53BP1 recruitment to a DSB, it has never been shown in a living cell when or where 53BP1 dimerizes with respect to DSB induction or how H4K20me2 versus H2AK15ub differentially contribute to 53BP1 dimer retention at a DSB. Here in live cells we quantify the spatiotemporal order of events that underlie 53BP1 dimer recruitment and retention at DSBs by coupling fluorescence fluctuation spectroscopy (FFS) with the DSB inducible via AsiSI cell system (DIVA). From adopting a multiplexed approach to FFS, we find that pre-formed 53BP1 dimers are recruited to DSBs via a H2AK15ub dependent mechanism, and upon arrival, H4K20me20 is critical for immobilization, while H2AK15ub stimulates formation of higher order oligomers that lead to a mature DSB repair foci structure.

Mapping DNA target search in the nucleus of a living cell by pair correlation of molecular brightness microscopy

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Inside the nucleus at any given moment in time, thousands of molecules are diffusing throughout 3D genome organisation searching for a target DNA sequence. DNA repair machines look for sites of damage to prevent genetic mutations, and transcription factors undergo site specific DNA binding to maintain normal gene expression. The question is to what extent does nuclear architecture direct the diffusive route of molecules to these target destinations? Protein oligomerisation is known to modulate the exploration volume available to nuclear proteins and transcription factors routinely employ this fact to guide DNA target search. Thus, here we present a fluorescence microscopy method termed pCOMB (pair correlation of molecular brightness) that tracks the mobility of different oligomeric species within live cell nuclear architecture. pCOMB amplifies the signal from the brightest species present and filters the dynamics of the extracted oligomeric population based on the arrival time between two locations [1]. Here we use this method to quantify the dependence of signal transducer and activator of transcription 3 (STAT3) and tumor suppressor p53 mobility on oligomeric state. From application of the pCOMB approach to these two transcription factors we demonstrate the capacity of this method to map the impact oligomerisation has on transcription factor dynamics.

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A real-time dosimeter for DaRT Cancer Treatment

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Diffusing alpha-emitters Radiation Therapy (DaRT) is a new form of brachytherapy; it is currently undergoing several clinical trials [1]. DaRT inserts needles, coated with ^{224}Ra (half-life: 3.66 days), into solid tumors; which release by recoil short lived ^{220}Rn, ^{216}Po and ^{212}Pb atoms, that diffuse and convect into inter- and intra- cellular level with emitted destructive α-particles (energy between 5.67 and 8.79 MeV) and beta particles [2]. At present, however, dosimetry relies only on theoretical modelling [3]. For DaRT in vivo real time dosimetry, we propose an innovative dosimeter, called α-RAD, based on a metal-oxide-semiconductor field-effect-transistor (MOSFET). Preliminary characterization of the α-RAD (die size of 0.4mm x 0.6mm x 0.25mm) was performed with an ^{241}Am α-source (E=5.48 MeV) and MV electron beam. The α-RAD demonstrated a good linearity with dose and a good sensitivity (mV/Gy) to alpha radiation as shown in figure 1; our results were in agreement with earlier similar measurements [4]. Sensitivity to electron dose was about 5 times higher as expected. The α-RAD placed in a 1 mm diameter needle is promising for in vivo real time separating alpha and beta dosimetry for DaRT.

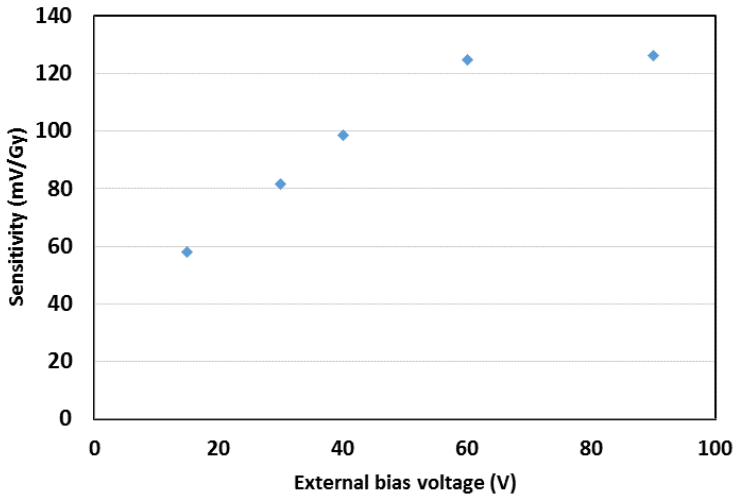

Figure 1. The sensitivity of the α -RAD as a function of external bias applied on the gate.

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Shape Memory Alloy Foils Used for Self-deployable Solar Arrays in Small Satellite Applications

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Shape memory alloy actuated components are lightweight and efficient mechanisms for retention, release and deployment of flexible solar arrays for small satellites such as CubeSats. The SMA foil is preferred over SMA rod or wire due to its large actuation force and fast response. CSIRO has been developing a near-net-shape casting process to produce thin Ni-Ti based SMA foils of 50-100μm thickness, which is of low cost, high production rate, and the foil length is continuous over several meters.

In this study, thermal and X-ray analysis were carried out on near-net-shape as-cast SMA foils to evaluate phase transformation as a function of temperature. Guided by the measured transformation temperature, a combination of heat treatment and deformation was explored to "train" the SMA foils to undergo 1-way or 2-way actuation. The combination of SMA foils and flexible solar arrays will also be explored and tested under the aerospace conditions. Preliminary findings of the study will be presented on the correlations between actuation behaviour, processing parameters, "training" conditions and integration of SMA foils with printable solar arrays that lead to demonstrate the potentials of the SMA foils for self-deployable solar panels in small satellites applications.

Space Physics projects at RMIT

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For the past 18 years humanity has maintained a constant human presence in space [1]. This time was spent in Low Earth Orbit (<450 km altitude) where there is still much protection from the sun's radiation by the Earth's magnetic field. With humanity's quest to continue exploring the solar system, the Artemis program planned for 2024 will see the next man and the first woman land at the South Pole of the Moon as a precursor to permanent bases on the Moon and Mars via the Lunar Orbital Gateway [2]. Without the protection of the Earth's magnetic field the radiation environment is significantly different in these new locations.

The Space Physics group at RMIT University is conducting a number of projects to solve propulsion [3] and radiation challenges associated with long-duration, long-distance space travel. Payloads can be tested using atmospheric sounding rockets as a microgravity platform whilst simulations, laboratory radiation sources and large user facilities provide specialized radiation beams. We present here designs of payloads currently under development for launch in 2019 and 2020 for a) radiation testing of the 30,000 – 60,000 feet regime of the atmosphere b) ferrofluid behaviour experiments; and c) initial results from simulations of the response to radiation by novel materials using GEANT-4 and the OLTARIS database [4] and d) radiation tests of active shielding prototypes in the laboratory.

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Shielding materials for protection of humans against radiation in Low-Earth Orbit and lunar orbit

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The first astronauts in Low Earth Orbit (<450 km altitude) wore personal dosimetry until it was discovered that their exposure was not significantly higher than that of commercial airline pilots [1]. The Artemis program planned for 2024 will see the next man and the first woman land at the South Pole of the Moon as a precursor to permanent bases on the Moon and Mars via the Lunar Orbital Gateway. Without the protection of the Earth's magnetic field the radiation environment is significantly different in these new locations [2]. Suitable materials for space transportation vehicles and planetary habitats to shield humans against solar particle events (SPEs) and excessive radiation will need to be developed. Shielding can either be passive [3] or active [4], however, any effective solution will need to remain lightweight and therefore affordable for launch. This project will involve modelling the response to radiation by novel polyethylene composite materials using GEANT-4 and the OLTARIS database [5] and constructing active shielding prototypes for radiation testing in the laboratory. Future work will involve using space radiation analogues [6] at the Australian Synchrotron and the Australian Nuclear Science and Technology Organisation to measure radiation responses of the prototypes.

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Poster Presentations

Wednesday 4th December 2019

Optical Properties of Perovskites with Large Spin-Orbit Coupling from First Principles

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Perovskite materials have been widely studied over the last few decades for a number of practical reasons, such as their utility in solar cells, and their exhibition of complex electronic phenomena such as high T_c superconductivity. Perovskites exhibiting large spin-orbit coupling, such as those based on Bismuth have potential for high performance solar cells due to their exceptional defect tolerance [1]. Due to increases in available computational power, methods for the calculation of optical properties based on approaches such as time-dependent Density Functional Theory (TDDFT) and solving the Bethe-Salpeter Equation (BSE) are now within reach for materials of practical interest. However, significant challenges still exist. While optical properties calculated from Density Functional Theory (DFT) in the Independent Particle Approximation can be performed with fine momentum space sampling which will accurately reproduce the optical transitions without electron-hole interactions, TDDFT and BSE methods must use much more coarse sampling while accounting for such interactions. In this work we compare DFT and TDDFT of over twenty Perovskites, and discuss the relative accuracies of these and the BSE approach.

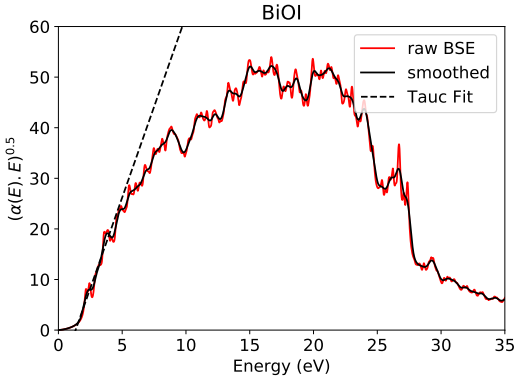

Figure 1: Tauc plot of the calculated Optical Absorption data of BiOI using the Bethe-Salpeter approach, the x-intercept is the optical gap: 1.35 eV.

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Unconventional superconducting states on the honeycomb lattice

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We investigate the unconventional superconducting ground states of the honeycomb lattice Hubbard model by means of the weak-coupling renormalization group method. We find topological superconducting phases of chiral singlet type as well as odd-parity states with f-wave symmetry. We calculate superconducting phase diagrams as a function of filling factor and discuss their stability. Our results suggest that the honeycomb lattice provides a promising platform to stabilize topological superconductivity.

Achieving Aluminum Liftoff for Fabricating a Spin Hall Effect Device

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Magnetoresistive random-access memory (MRAM) is a developing field of technology where bits of memory are stored using the orientation of ferromagnets [1]. Spin orbit torque-MRAM (SOT-MRAM) is an emerging non-volatile memory technology that is extensively studied since it offers the potential for lower energy consumption in comparison to other forms of MRAM. This energy efficiency is enabled by utilizing materials that exhibit a strong spin Hall effect (SHE). However, many of the currently well researched materials with a prominent SHE are quite rare and expensive [2]. This research endeavors to find a low cost, more abundant alternative by examining the SHE in amorphous Fe_xSi_{1-x} ($.35 < x < .5$), $Fe_{1-y}Co_ySi$ ($.1 < y < .3$), and CoSi. Specifically these materials will be used in nanoscale devices in order to measure their spin Hall angle.

The first step of this work was to optimise the fabrication process; the optimisation was done by creating aluminum test devices. Aluminum Hall bars (with arms 400 nm and 60 nm wide) were fabricated using electron beam lithography and liftoff. A major issue when fabricating aluminum structures is the re-deposition of aluminum back onto the substrate during the liftoff process. In order to achieve clean removal of excess aluminum, a new liftoff process was devised. After deposition of aluminum onto patterned PMMA, the devices were soaked in acetone for 10 minutes and then transferred to a new acetone bath while being sprayed with a fresh stream of acetone. This process was repeated another three times for a total of 5 baths. Finally the devices were soaked in one final bath of acetone for at least 8 hours. In addition to creating a new liftoff procedure it was found that lower aluminum deposition rates correlate with cleaner liftoffs. This result is likely due to the smaller grain size produced by reduced Al deposition rates [3].

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High Frequency Vibrational Energy Harvesting Using [011] Mn-PMN-PZT Relaxor Ferroelectric Single Crystals

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Failure of critical aircraft components, such helicopter main-rotor transmissions, can result in the loss of human life. Sensors and systems developed for the *Prognostic Health Monitoring* (PHM) of these components can significantly increase the safety of flight by detecting damage in its early stages. However, if these sensors are mounted at difficult to reach locations within an aircraft then they can require additional wiring systems and/or batteries, increasing the difficulty of routine maintenance and increasing the mass of the aircraft. The direct piezoelectric effect can be used to transform ambient mechanical energy into a local electrical energy source capable of powering PHM electronics, reducing the weight of wiring and the frequency of battery pack replacement [1]. For the current work, vibration energy harvesters were designed and optimised to generate energy from the mesh-frequency vibrations of a Bell 206B-1 helicopter main-rotor transmission, which is assumed to be operating at 80°C. Monolithic [011] poled Mn-PMN-PZT relaxor ferroelectric single crystals were selected as the transducer for each device, operating in the d_{32} transverse extentional mode. [011] poled Mn-PMN-PZT was selected due to its: (i) high transition temperature between the rhombohedral and tetragonal phases, $T_{RT} = 145°C$, (ii) large electromechanical quality factor, $Q_m = 1250$, (iii) high power density, 85.7 Watt/cm^3, and (iv) the high fracture toughness produced by Mn doping [2]. In addition, [011] poled material has a higher coercive electric field and stability compared with [001] poling [2]. Collectively, these properties make this material an appropriate choice for energy harvesting applications for use across a wide range of operational conditions.

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Causal state analysis of blinking quantum dots

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Quantum dots appear as a modern application for many new promising light-based electronic devices. However, their performance is limited by intermittent periods of luminescence known as *blinking* [1, 2]. Unlike the exponential behaviours of atomic emission lifetimes, quantum dot luminescence lifetimes obey power law distributions with no characteristic lifetime [2, 3, 4, 1]. Experiments seeking to use the blinking behaviour as a benchmark for quality control are limited to histogram distributions of *"on"* and *"off"* state lifetimes which may be approximately described by multi-exponential fits. This presents an issue for the case of single quantum dots entering physical configurations described by both multi-exponential statistics and power law statistics [5, 6]. Thus identifying the dot configuration that is present the data, is important. We avert this issue by using ϵ*-machines* [7], a tool developed from computational mechanics which can capture the multi-time correlations of photon trajectories that otherwise remain hidden to conventional analyses. A set of simulated ϵ-machine models characterising the known errors that may present themselves in an experimental setting are constructed, to which real data can be compared to. A distance measure between the ϵ-machines given by the simulations and data is then used to accept or reject an error hypothesis, thus pinning down the extant physical configuration in a given experiment. These findings establish a powerful tool for improved dot diagnostic practices, paving a faster roadmap for dot-based technologies.

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Structure and dynamics in charged colloidal suspensions

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Charged colloidal suspensions of Polymethylmethacrylate (PMMA) particles are prepared by maximally de-ionizing the suspensions using ion-exchange resins. The static structure factors *S(q)* and intermediate scattering functions (ISFs) are measured at various concentrations. The effect of the charge state on the structure and dynamics are compared with hard-sphere (HS) behaviour by rescaling the *S(q)* to determine an effective "HS-like" particle size (R_s) by assuming the *S(q)* peak is at qR =3.5. The normalized inverse short time diffusion coefficients (D_0/D_s) obtained from exponential fits to ISFs as a function of rescaled qR_s is shown in Fig.1. The *S(q)* and D_0/D_s, show similar trends as a function of qR and qR_s at several concentrations, in agreement with the HS-like colloidal system [1,2]. Our studies in charged colloidal system indicate the existence of similar correlation between structure and dynamics, irrespective of the interactions between the colloidal particles.

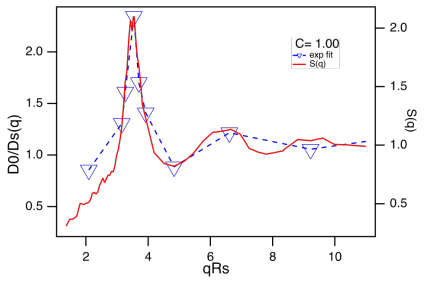

Fig.1 The D_0/D_s (data points) and the calculated S(q)(solid red line) as function of qR_s. The line connecting data points is a guide to the eye.

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The colloidal properties of detonation nanodiamonds in water

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Nanodiamonds have received significant attention from the scientific and engineering communities due to their unique physiochemical properties. These properties are exploited in many applications from drug delivery and biosensing to composite materials and abrasives.[1] Most particles are colloidally stable in water and many organic solvents without the need for stabilising ligand molecules. However, their colloidal properties and aggregation behaviour in simple and controlled aqueous environments remain largely unexplored and poorly understood. We report the dynamic aggregation of detonation nanodiamonds in water.

We demonstrate that charge-stabilised ~5 nm sized primary particles dynamically form elongated, chain-like structures in solution. We employ dynamic light scattering (DLS), small-angle X-ray scattering (SAXS) and cryogenic transmission electron microscopy (cryo-TEM) to show the presence of these structures in water at the nanoscale (TEM) and in ensemble measurements (light and X-ray scattering). We also investigate the effect of particle concentration and ionic strength on the dynamic aggregation behaviour. Our results suggest that the complex surface chemistry of detonation nanodiamonds leads to a unique form of dynamic aggregation and self-assembly in solution, paving the way towards an improved understanding of their colloidal properties and novel applications.

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Large scale defects for pinning modification of YBCO thin films

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Modification of the pinning mechanisms of YBCO thin films leads to new and interesting properties. Introducing artificial pinning centres may not only increase critical current density (J_c) but also create rectifying currents and reduce flux movement noise. Traditionally application of these defects has been between ~a few nm to ~a few hundred nms for YBCO which is suitable for single vortex pinning. However, by increasing the size of these defects means that technologically simpler and cheaper equipment, whilst potentially trapping tens to hundreds of vortices at once. Hence becoming an enticing prospect, but only if these large scale defects are as useful as their small scale counterparts. In this work, several different types of large scale defects (antidots, substrate engineering, and ramp type bridges) have been introduced to YBCO thin films to produce interesting and useful superconducting properties. This includes increasing the J_c by improving the pinning landscape, and rectifying the current by utilising asymmetrical pinning potentials [1, 2, 3].

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Single Crystal Diamond Thin Film for Dosimeter Applications

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Diamond is a material form of carbon and can be used in multiple areas, including medical and electronics. In my research project, thin diamond membrane (about 3 μm) detector with gold layers on both sides will be constructed. Diamond has the merits of wide-band gap (about 5.5 eV), high resistivity ($> 10^{10}\ \Omega \cdot$ cm) and low permittivity (about 5.7), which make sure the low noise of diamond detector and no need to worry about the impact of visible light. The detector will enable us to achieve high charge collection efficiency and can also be used in studying NV color center.

One application is using our membrane for hadron therapy [1]. Hadron therapy has many advantages, one is that it has an inverse depth dose distribution compared to the traditional photon therapy. Therefore, determining the dose of hadron delivered to the patient is of crucial significance. Since the effective atomic number of tissue of human is about 7.4, while the atomic number of diamond is 6. Though diamond has lower atomic number, it has higher density than the soft tissue, so it is almost the same to get the reduced dose for hadrons irradiated on the same mass of diamond and soft tissue. Therefore, using thin membrane diamond detector can determine the dose of hadron in hadron therapy.

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This work was performed in part at the Melbourne Centre for Nanofabrication (MCN) in the Victorian Node of the Australian National Fabrication Facility (ANFF).

Surface Defect Effects for Deterministic Doping in Diamond

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The ability to deterministically create colour centres in diamond would enable the engineering of ordered dopant arrays for advanced quantum sensing and imaging applications with room temperature compatibility.[1]

Ion implantation has been shown to be a reliable tool for scalable dopant introduction into diamond substrates for the creation of colour centres.[2] When an ion strikes into a diamond crystal its deceleration process causes the creation of electron-hole pairs, which can in turn be detected as a charge-proportional voltage pulse by means for surface electrodes ("single ion detector"). One key step involves the fabrication of a diamond single ion detector that does not suffer from bulk and surface defects in order to ensure a charge collection efficiency of 100% across its entire active area. Likewise, establishing ultra-low leakage and capacitance are crucial prerequisites for the reliable detection of low-energy ions (< 30 keV) upon implantation. Recent developments include the development of electronic grade diamond with ppb nitrogen content for a drastically reduced bulk defect density. While this has enabled the fabrication of devices with the required 100% charge collection efficiency, first generation devices still suffered from large leakage currents which affect the detector's noise performance and in turn rendering low-energy ion impact detection impossible.[3] We recently developed diamond detectors with improved surface leakage characteristics as well as a COMSOL finite element model, incorporating the effects of various surface defects.[4] Our combined experimental-computational work highlights the importance of understanding the complicated surface physics in diamond in order to produce a functional device for low-energy single ion detection.

This research is funded by the Australian Research Council Centre of Excellence for Quantum Computation and Communication Technology (Grant no. CE170100012). We acknowledge the AFAiiR node of the NCRIS Heavy Ion Capability for access to ion-implantation facilities.

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Comparison of different methods of spin defect creation in diamond for quantum microscopy

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The nitrogen-vacancy (NV) centre in diamond has emerged as an attractive quantum sensor due to its room temperature quantum stability and ease of optical readout. Its Hamiltonian is sensitive to magnetic, electric, stress, and strain fields, motivating the use of NV ensembles to facilitate widefield imaging of these fields. For these applications, an NV layer taking up 100 nm from the diamond surface is optimal, though the specific design of this layer is non-trivial. The desire for large signal and hence high NV density requires populating the layer with additional vacancies via an appropriate implantation procedure. Equally important in achieving optimal sensitivity, however, is maintaining good spin coherence properties, which will typically scale inversely with the degree of implantation and may also depend on the way in which the nitrogen was incorporated into the crystal. This study compares the available methods of nitrogen incorporation pre-vacancy creation: in situ delta doping during chemical vapour deposition (CVD), nitrogen implantation into a pure CVD substrate, and high-pressure high-temperature (HPHT) growth to determine the merits of each in producing samples that offer optimal sensitivity.

The Promise of Superconducting Boron Doped CVD Diamond Devices Fabricated by Ion Beam Techniques

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Heavily boron-doped diamond is a p-type semiconductor material which is remarkably shown to exhibit BCS superconductivity at temperatures up to 11 K [1, 2]. While diamond is well-known to have advantages such as mechanical and chemical robustness, its superconducting state boasts a notably high tolerance to external magnetic fields, and theoretical results even predict near room temperature superconductivity given sufficient boron incorporation [3, 4]. Diamond is already ubiquitous in quantum technology research, so the development of a superconducting device in this material is a step toward a monolithic controlled quantum system. We have recently observed suppression of superconductivity in boron-doped diamond via ion irradiation, when n-type donors compensate the p-type carriers [5]. We present some initial results from our use of ion beam fabrication techniques to modify superconductivity in boron doped diamond, toward the development of essential superconducting devices such as Josephson junctions, SQUIDS and single photon detectors.

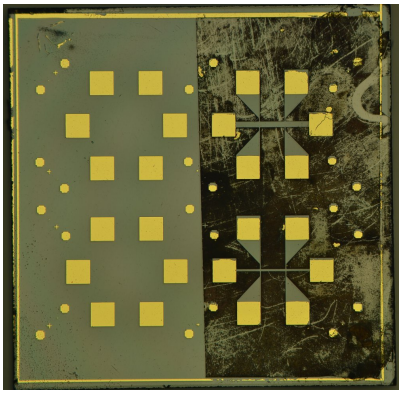

Figure 1: Hall bar structures etched into superconducting boron-doped diamond.

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Cryogenic widefield nitrogen-vacancy microscopy – set-up and application

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Diamond nitrogen-vacancy (NV) microscopy has emerged as a promising tool to study mesoscopic magnetic materials, devices and condensed matter systems [1, 2, 3] but has been typically limited to room temperature operation. Here we report on the realisation and application of a widefield NV microscope operating between 4 and 300 K with a 120 μm field of view and near-diffraction-limited ≈500 nm spatial resolution. To illustrate the versatility of this instrument two distinct applications are presented: 1) imaging of superconductor phenomena and 2) imaging of ultrathin van der Waals ferromagnets. Our microscope allows us to image Abrikosov vortices and transport currents in a superconducting Nb film as well as map the effect of the laser's inhomogeneous heating distribution on quenching local superconductance. Further, our quantitative magnetic field measurements allow us to infer the absolute magnetization of individual van der Waals flakes, their anisotropy axis, Curie temperature and coercive field.

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Growth Mechanisms and Interfacial Properties of Iron Nanoparticles Electrodeposited to Carbon Nanotubes

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Metallic Fe nanoparticles (NPs) were electrodeposited onto polished glassy carbon surfaces and ozone functionalized carbon nanotube (CNTs) films to produce ferromagnetic carbon nanomaterials [1,2]. Chemical and structural characterization of these nanomaterials, as a function of iron deposition parameters and substrate morphology, was related to the nanoparticle growth mechanisms. At short deposition times, individual NPs of 110nm were observed for flat glassy carbon surfaces, and NPs of 30nm were observed for CNT film surfaces, see figure 1. As electrodeposition continues, individual crystalline NPs began to overlap, and fine grain films were formed on both substrates. It is evident that the plating conditions and substrate influence nanoparticle formation and growth, and consequently film morphology and structure.

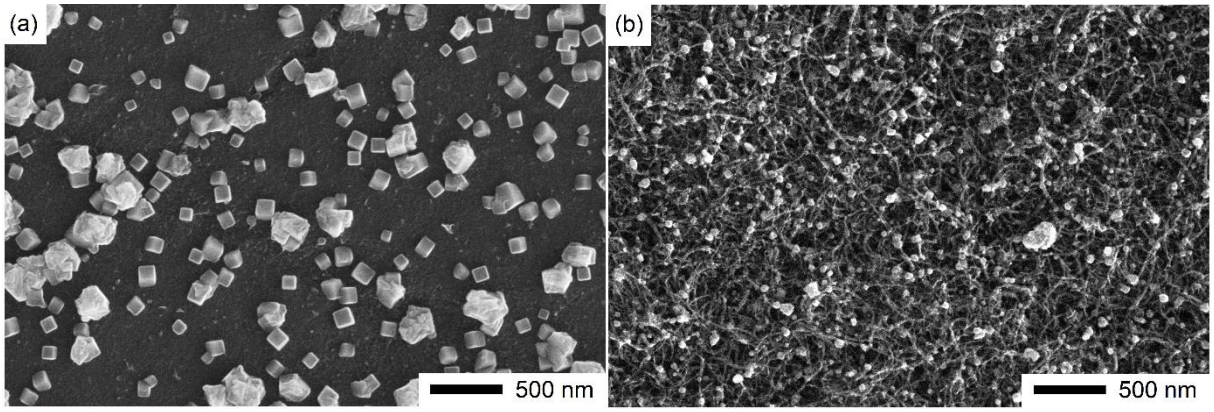

Figure 1: Iron nanoparticles pulsed electrodeposited under identical plating conditions onto (a) glassy carbon, and (b) carbon nanotubes. Early stages of fine grain growth are visible on the glassy carbon surface in (a), where iron nanoparticles have an average size of 110nm. Iron nanoparticles deposited onto the carbon nanotubes have an average size of 30nm.

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Erbium and defect luminescence in SiC nano-pillars

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Colour centres in optically amenable materials, such as SiC, have shown to be promising candidates for facilitating the development of photonic devices for quantum information processing [1-4]. Furthermore, with its wide band-gap, commercial availability and mature device fabrication protocols, 4H-SiC is a fantastic substrate to house such quantum systems. However, in order to realise many near-term optical quantum technologies such as single photon source generation, nuclear hyperpolarization and photonic quantum information processing, many hurdles remain, such as: identifying methods to enhance the photonic collection efficiency, selecting photons into only a few spatio-temporal modes and how to fabricate such a device so as to be commercially viable and scalable.

In this work we show that it is possible to incorporate Er colour centres into fabricated nano-structures in 4H-SiC to modify their luminescence properties and spontaneous emission lifetimes. It is also observed that there is a correlation between the photo-luminescence intensity of the Er colour centre and its substitutional fraction, which sheds light on the previously unknown atomic origin of the Er luminescence centre in SiC. Thus, by combining theoretical results, nano-scale fabrication and optical & materials characterisation of Er (and other) colour centres in 4H-SiC we are able to address some of the issues hindering photonic device development; moving us towards a scalable fabrication protocol to facilitate photonic quantum devices operating at telecommunication wavelengths.

This research is funded by the Australian Research Council Centre of Excellence for Quantum Computation and Communication Technology (Grant no. CE170100012). We acknowledge the AFAiiR node of the NCRIS Heavy Ion Capability for access to ion-implantation facilities.

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Towards a scalable silicon based quantum computer

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The work presented in the poster reviews the necessary steps required to build a flip flop donor spin qubit[1].
Crucial to the successful fabrication of such a qubit is the accurate implantation of Phosphorous donor ions in crystalline silicon wafers. In this poster we will present our findings on experimentally measured lateral straggle of arsenic in silicon, a similar ion to phosphorous, knowledge necessary for developing accurate implantation devices. The regions of crystal amorphisation and donor straggle were measured by cross sectional transmission electron microscopy and the results were compared to SRIM simulations. Vital to the realisation of the flip flop qubit is knowledge of the strength of the electron wavefunction overlap of two adjacent qubits. To this end we perform simulations of the electron wavefunction of two phosphorous atoms in silicon using the modelling software NEMO3D.

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Resource Theories of Multi-Time Processes: A Window Into Non-Markovianity

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An ever-present challenge in the development of quantum technologies is dealing with the fact that every real quantum system is exposed to a noisy background process. Efforts towards solving this problem have so far been focussed on reducing the amount of influence which the environment can exert over the system; these efforts include error correction, decoupling, or simply engineering cleaner quantum systems. We present a novel alternative solution: we seek to find ways in which an experimenter may harness properties of an uncontrollable background process to mitigate the ill effects of the environment. We focus on the property of certain types of environments which have some ability to 'remember' the system's past – a widely present phenomenon known as non-Markovianity. It has been suggested that non-Markovianity can be exploited as a resource to perform tasks which may be too difficult otherwise [1].

Our framework for resource theories of multi-time quantum processes [2] sheds light on which experimental scenarios – such as optimally manipulating a qubit, or performing cloud quantum computing – can benefit from non-Markovianity and other temporally complex phenomena. To demonstrate the power of our framework, we analyse a class of experimental scenarios with varying levels of control. In almost all of the corresponding resource theories, some form of temporally complex phenomena was found to be useful, including one where non-Markovianity is the precise quantity that aids the experimenter in achieving their goals.

Our newly developed framework may be used in the future to investigate other temporally complex phenomena, or to describe specific experiments. Furthermore, we expect that our work will be expanded on in the future to yield even more powerful descriptions of nature.

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Tensor Networks for Quantum Circuit Simulation

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Tensor networks are valuable computational tools in the areas of statistical and quantum many-body physics [1]. Originally used to perform variational optimisation [2], they have since been adapted for use in quantum circuit simulation [3] due to computational resource requirements which scale with entanglement. Classically simulating quantum circuits is important for the development of quantum algorithms and also for determining quantum supremacy for particular computational problems [4]. We detail two example uses of tensor networks for quantum circuit simulation. By examining the entangling properties of the circuit for Shor's quantum factoring algorithm and effectively mapping it across the one-dimensional structure of a matrix product state, we were able to simulate sampling measurements from a particular 60-qubit instance which would otherwise be infeasible [5]. Additionally, we show numerical results for sampling from one-dimensional random quantum circuits with depolarising noise via the use of matrix product density operators.

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Abstract for AIP Summer Meeting 2019

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A fundamental issue at the core of statistical mechanics is the search for a complete quantum mechanical understanding of how a system approaches equilibrium. In particular, questions regarding the emergence and robustness on the mechanism for equilibrium when a quantum system is repeatedly probed remains. In such case, not only do these interventions have to be taken into account, but also the memory effects (non-Markovianity) introduced therein that may propagate through an external environment.

Despite of open systems theory telling us that non-Markovian processes are the norm, with our poster I will elaborate on how, without resorting to the weak coupling assumption or making any approximations, we formally proved that typical processes are almost Markovian when the subsystem is sufficiently small compared to the remainder of the composite, as well as how it may not be possible to neglect non-Markovian effects when the process is allowed to continue for long enough. I will also discuss the standard approaches to equilibration and present the stronger version that takes into account multiple observations and memory effects. Finally, I will present our results and in particular highlight that temporally non-local observations can evade equilibration, along with the potential applications that this could entail.

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Measuring the Complexity of Open Quantum Dynamics

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Fault-tolerant universal quantum computers are expected to outperform their classical counterparts in a variety of tasks. However, the current generation of Noisy Intermediate-Scale Quantum (NISQ) devices have not yet achieved quantum supremacy. Despite this, NISQ devices may still be capable of outperforming their classical counterparts in select applications, with one of the most promising being the simulation of open quantum dynamics. In particular, NISQ devices – being open quantum systems themselves – have potential as analogue simulators of open systems. Here we build on the results of [1] and [2] to construct a method that allows us to measure the complexity of the dynamics of an open system. When applied to NISQ devices this result allows us to quantify the complexity of the open dynamics present in these devices. This in turn provides insight into whether NISQ devices have the potential to outperform classical computers in the simulation of open quantum dynamics.

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Deterministic Implantation of Donor Qubits in Si with Nanometer Precision

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The success in manipulating single P-donor spins ("qubits") in ^{28}Si [1,2] represents a milestone for the realisation of a quantum-computer. Inspired by these results, innovative quantum architectures such as the highly scalable flip-flop qubit configuration were recently proposed [3]. A robust long-range qubit entanglement over distances up to several hundreds of nanometers loosens the strict constraints on the donor-qubit placement precision.

This in turn makes ion implantation – a standard doping tool in semiconductor industry – a promising approach for the scalable engineering of ordered dopant architectures in silicon [4]. We present the latest developments of our implanter facility including a room-temperature-functional detector setup for the reliable sensing of single low-energy ions, in combination with a state-of-the-art nano-stencil scanning stage to enable precision placement. This system constitutes a major step towards upscale-compatible donor qubit array fabrication with sub-10nm spatial precision.

Our technology is being discussed within the context of near- and long-term demands on scalable top-down fabrication of donor-based silicon quantum devices.

This research is funded by the Australian Research Council Centre of Excellence for Quantum Computation and Communication Technology (Grant no. CE170100012). We acknowledge the AFAiiR node of the NCRIS Heavy Ion Capability for access to ion-implantation facilities.

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Heavy-Molecule Ion Implantation for Qubit Architectures in Silicon

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Silicon-based devices are promising candidates for hosting spin qubits, the building blocks of quantum computers. Remarkable progress on electron- and nuclear spin control and read-out of implanted P-donors in silicon has been demonstrated recently. Successful entanglement of ordered qubit arrays with sufficient ensemble coherence times remains a major challenge.

In order to enable multi-qubit scale-up in Si devices, reliable placement of single ion implanted atoms with high precision is required. In this work, we consider an alternative way to enhance the ion-induced signal itself. When an accelerated ion impacts silicon, electron-hole pairs are generated and swept towards the detector electrodes causing a detectable voltage pulse. As opposed to single P^+-ions, an increased number of electron-hole pairs can be generated using PF_x^+ molecule-ions instead, which in turn improves the detection signal and thus the dopant placement fidelity. After implantation, the sample is annealed at 1000^{o}C for 5s for dopant activation. Under these conditions the F-bystander atoms are expected to either diffuse away from the active quantum device volume or passivate oxide interface dangling bond defects. As with hydrogen, ^{19}F has a nuclear spin I=1/2 and may contribute to the spin bath flip-flops, leading to further qubit decoherence. F is also known to form a number of stable paramagnetic impurities in Si with vacancy clusters [2]. We therefore assess the suitability of this implantation method for quantum device engineering.

This research is funded by the Australian Research Council Centre of Excellence for Quantum Computation and Communication Technology (Grant no. CE170100012). We acknowledge the AFAiiR node of the NCRIS Heavy Ion Capability for access to ion-implantation facilities.

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Readout of Silicon Spin Qubits Beyond the Singlet-Triplet Blockade

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A major challenge for scalable quantum computer architectures based on spins in Silicon is to efficiently perform spin measurements in order to detect and correct noise-induced errors, in addition to reading the output of the calculation. Charge sensing readout of spin qubits based on spin-to-charge conversion can be conducted based on the Pauli exclusion principle. In practice, spin-orbit coupling, magnetic field gradients and the nuclear Overhauser field may cause the spin dynamics to detract from the idealised construct of the singlet-triplet blockade, mixing together states with a different total spin. These effects may be tuned in a MOS quantum dot in order to harness the spin dynamics for different spin readout schemes. We focus on the variability of the Zeeman energy among dots which, together with charge dephasing and relaxation, leads to the lifting of the T_0 triplet blockade. This effect was previously identified for GaAs-based qubits constructed from the singlet and triplet T_0 states in a doubly occupied double quantum dot in which case the lifted blockade is simply associated to a loss of readout. We demonstrate experimentally that single spin qubits can still be measured in purified Silicon after the T_0 triplet is unblocked. This means that only the parallel spin configurations will remain blockaded, which we refer to as *parity readout*. This model is able to interpret such experiments performed in two distinct double quantum dot devices. We also derive, within the Schrieffer-Wolff transformation, an analytical expression for the T_0 unblocking time as a function of the system parameters. Finally, we discuss the influence of the charge sensing integration time on the fidelity of the two readout schemes and their impact on the implementation of a surface code in Silicon MOS quantum computers.

Efficient drift-robust improvement of two-qubit entangling gates

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Characterisation techniques are highly important for the identification and mitigation of noise if the field of quantum computing is to continue to flourish, but can be expensive to repeatedly employ. A challenging aspect of maintaining quantum hardware is that parameters governing the performance of different operations tend to drift over time, and monitoring these is a difficult task. The most accurate current characterisation technique, gate set tomography (GST), provides a self-consistent estimate for the completely positive, trace-preserving (CPTP) maps for a complete set of gates, including preparation and measurement operators [1,2]. We develop a method which couples this powerful technique with a classical optimisation routine to achieve a consistent gate improvement in just a short number of steps on a given day. Because this method finds the best available gate operation given the hardware, it is robust to the effects of drift. To demonstrate the performance of this method on a real quantum computer, we map out the superconducting qubit operations of the *IBM Q Poughkeepsie* quantum device [3]. Under the restriction of logical-only control, we monitor the performance of the routine on a CNOT gate over a period of six weeks. In this time, we see a consistent improvement in gate fidelity, as measured by randomised benchmarking. This information is used to quantitatively study the change of the device's behavior over time. Finally, we also report the two-qubit GST estimates for six other CNOT pairs, as well as their in-principle improvements.

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Investigation of Viton O-ring performance for the SABRE dark matter experiment

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Viton O-rings will be used for critical seals of the liquid scintillator (LS) veto detector for the SABRE (Sodium-iodide with Active Background Rejection) dark matter experiment in Australia [1, 2]. These Viton O-rings have to maintain a leak-free seal under exposure to the LS for the 3-5-year operational life of the experiment.

In this study, the combined effects of elevated temperature, air and LAB (Linear Alkyl Benzene) scintillator exposure on physical properties of Viton O-rings were investigated over time using compression set and Young's modulus tests, ATR-FTIR spectroscopy, and the analysis of solvent induced swelling. The degradation of physical and mechanical properties of the Viton O-rings were found to be more pronounced in air under compression set conditions for the same temperature compared to the compression set tests in LAB scintillator. Results from both confirmed the increased value of the compression set (%) and change in Young's modulus. The ATR-FTIR results show that the effects of LAB scintillator on the changes of surface composition of the Viton O-rings were more significant than for exposure to air, but only at elevated temperature. Moreover, the excellent chemical and physical compatibility between Viton O-rings and LAB scintillator were observed based on the solvent swelling analysis. The overall conclusion is that the LAB scintillator will not degrade the Viton O-rings used more rapidly than normal lifetime under SABRE dark matter experiment conditions.

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Ferrofluid-based electrospray thrusters in nanosatellites for short-range, lightweight propulsion

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Nanosatellites, or nanosats, are satellites with a mass between 1 kg and 10 kg and are typically launched into a low earth orbit (LEO) between 100 km and 2000 km above the Earth's surface. They range in size from 0.25U to 27U where 1U is 10 cm × 10 cm × 10 cm [1]. As of January 2019, there have been 1116 nanosatellites launched, two of these being interplanetary. There are currently 564 of these nanosatellites still in operation. This rapid increase in the number of nanosatellites launched into space has promoted investigating an efficient propulsion system to maintain and correct the orbits of such satellites. Ionic liquid ferrofluids have been identified as possible liquids in electrospray thrusters [2]. When a ferrofluid is exposed to a magnetic field, multiple peaks known as Rosensweig instabilities form, however, the effects microgravity has on a ferrofluid have not been extensively investigated. We designed and built a scientific payload to observe the behaviour of a ferrofluid in microgravity whilst on board a model rocket [3]. Utilising a pair of magnetic solenoids with 280 windings each placed above and below a glass jar containing a ferrofluid, we imaged the behaviour of the ferrofluid with and without an applied magnetic field of 60 mT. During 30 seconds of microgravity, in situ photographs show while the magnetic field was applied, no Rosensweig instabilities were produced, however, in microgravity the ferrofluid formed spheres approximately 7 mm in diameter that joined to form chains. Similar results have been reported in the literature for nickel [4] and cobalt and therefore we conclude that the spheres are interacting via a dipole-dipole magnetic interaction.

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Measuring Students' Emotional Engagement with Physics Lectures

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The Physics is a discipline associated with diverse emotions. Yet, students' emotions when studying physics is under researched. This study adapts the Achievement Emotions Questionnaire (AEQ) to measure the emotions of students with first year physics undergraduate lectures. The aims of this research are to validate the questionnaire in our context and to probe students' emotions towards two lecture streams; the Control which is of standard format and the Intervention which incorporates colour and historical aspects seeking to produce positive emotions. Confirmatory Factor Analysis and descriptive statistics conducted with a sample of around 300 students. Priliminary analysis will be presented in the poster. We are set to generate more positive emotional engagement with our intervention and find the differences in emotions between the Control and Intervention to indicate that the AEQ-PhysPrac has utility in physics education. The findings from the questionnaire will be triangulated with observational field notes to further consolidate the findings.

Spectroptychography of Iron Oxide/CNT Composite Materials for Battery Technologies

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The incorporation of carbon nanotube (CNT) and iron oxide composites as anodic material in lithium ion batteries has the potential to decrease operating voltages, increase battery capacity, and improve manufacturing costs and general safety [1]. There is growing interest in the use of X-ray based *in situ* analysis of lithium ion battery electrode nanomaterials to create better performing batteries. The nanoscale resolution and chemical-state sensitivity of X-ray spectroptychography has been shown to provide particularly valuable insight into the *in situ* lithiation/delithiation performance of nanoparticles [2,3] and the electrochemical deposition of nanocomposite electrode films [4]. However, the preparation of suitable electrochemical sample environments remains challenging for most technologically relevant electrode materials. We have developed a framework for the *in situ* spectroptychography analysis of electro-deposited iron/iron oxide nanocrystals onto CNT/Au composite microelectrodes. As a proof-of-principle, samples prepared *ex situ* were analysed with this method to spatially resolve the location of iron nanocrystals and differentiate oxidation states of the iron. Spectroptychography was performed using a recently developed capability at the XFM beamline of the Australian Synchrotron [5]. We evaluate the potential of this approach by comparing the information it provides to X-ray fluorescence microscopy, X-ray photoelectron spectroscopy and electron microscopy.

This work was performed in part at the Melbourne Centre for Nanofabrication (MCN) in the Victorian Node of the Australian National Fabrication Facility (ANFF). This research was undertaken on the XFM beamline at the Australian Synchrotron, part of ANSTO.

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Structural Distortions in Fluorescence EXAFS Due To Spectral Flattening

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Extended X-ray Absorption Fine Structure (EXAFS) is a very powerful technique, capable of measuring the physical/chemical properties of a molecular structure. Despite the highly precise measurements the technique is unable to retrieve quantitative absorption results from a system with low concentration such as a thin film sample or a low-concentration dilute sample.

Fluorescence EXAFS provides a solution to this problem through measuring the fluorescent photons from a sample with a multi-element detector. This, while solving a major shortcoming, introduces a new problem. The resulting spectra from a measurement like this is known to show significant dispersion in relative absorption which has been attributed by many to self-absorption within the sample [1]. Until recently there has not been a full correction for this effect [2], where the current widely accepted solution is to apply an algorithm which reduces the dispersion to a flat state which is referred to as flattening. The application of flattening to a fluorescence spectrum introduces unknown systematic errors which, to the best of our knowledge, have not yet been fully quantified.

By comparing the complete self-absorption correction and a flattened correction on the same set of data we show that the introduction of these systematic uncertainties caused by flattening can modify the outcome of a structural fit, in which we observe variation in atomic distances up to the order of ~3σ.

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Photoinduced Zeta Potential Changes of Semiconducting Nanoparticles.

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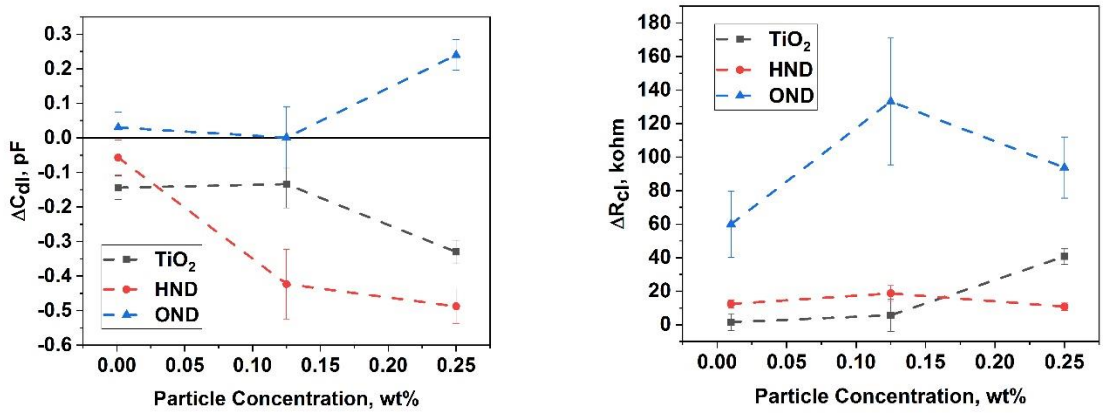
An electrokinetic chemical property of a particles surface/electrolyte interface is usually investigated by the electrokinetic potential, also known as the Zeta potential [1]. As the zeta potential introduces the driving force for electrostatic attraction and repulsion between the particle's surface and solution, the knowledge of the zeta potential is therefore required to predict the interaction of ions and other charged compounds with particles' surface[2]. In this work, we introduce a new technique for the investigation of photo-electrokinetic properties of aqueous semiconducting nanoparticles. Using 4-electrode Electrochemical Impedance Spectroscopy (EIS) technique, we investigate the effect of light on the Electric Double Layer (EDL) of particles with less interference. We investigated the changes in EDL capacitance of semiconducting materials after light illumination, TiO_2, Hydrogen terminated nanodiamond (HND), and Oxygen terminated nanodiamond (OND), below Figure. The Differential Dynamic Microscopy is also used as a complementary method to measure the light effect on the EDL of particles. This parallel experiment is utilized to explain and confirm the result of the 4-electrodes EIS measurement.



Changes of Capacitance (C_{dl}) (left) and Resistance (R_{dl}) (right) of the EDL around particle with light illumination.

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Evaluation of an Undulator Soft X-ray Beamline for the Study of 6.x nm Interference Lithography

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Photolithography is the primary vehicle for device scaling in the semiconductor industry [1]. The minimum achievable pattern can be extended to meet the requirements of the 3.5 nm technology node by further reducing the wavelength of the source [2]. The implementation of lithography with 6.x nm radiation is currently inhibited by the availability of suitable light sources and the complexities that arise from increased sensitivity to photomask defects at shorter wavelengths.

We have constructed and end-to-end computational model of the imaging branch of the Soft X-ray Spectroscopy beamline at the Australian Synchrotron used it evaluate the potential for using this facility for studying interference lithography processes with a partially coherent undulator light source at 6.x nm wavelengths. The model was implemented using a Gaussian-Schell model of the undulator light source and partially coherent wavefront propagation using the WPG framework [3]. We show that analysis of the simulated irradiance of the wavefield at the plane of the photoresist (the *aerial image*) provides insight into optimisation of the optical configuration of the beamline and mask design. We also use the model to evaluate the role of partial coherence on the aerial image formed using grating-based masks, and on the transfer of mask defects to the aerial image.

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Bose Einstein condensates of metastable Helium loaded into an optical lattice

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Much research has been devoted toward understanding quantum systems and many body physics. A Bose Einstein condensate (BEC) in an artificial optical lattice provides a promising approach toward emulation of many body quantum systems. Measuring high order correlation functions allows investigation of many systems such as the Bose Hubbard model and many body localization.

We demonstrate implementation of a hybrid trap to reach BEC with metastable Helium atoms [1,2]. Our setup is based on a combination of a quadrupole magnetic and crossed optical dipole trap. The individual metastable helium atoms are detectable for high resolution using a delay line detector. Therefore, correlation functions of high order can be measured [3]. A metastable helium BEC in a 3D optical lattice will enable us to conduct a wide range of experiments and investigate particle-particle correlation function in superfluid and Mott insulator phase.

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aip SUMMER MEETING

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