Australasian Workshop on Emergent Quantum Matter 2014

http://www.physics.uq.edu.au/people/mdavis/Straddie2014/

Book of Abstracts (final version)

Photo: view south from Point Lookout of Main Beach (Jan Zill)

Photo: view west of Cylinder Beach (Simon Haine)

Photo: Blue Lake (Tyler Neely)

Monday 24 November - Friday 28 November 2014

Moreton Bay Research Station, The University of Queensland

Dunwich, North Stradbroke Island, Queensland, Australia.

Program committee: Matthew Davis (UQ), Kris Helmerson (Monash), Elena Ostrovskaya (ANU), Ben Powell (UQ), Chris Vale (Swinburne), Andy Martin (Melbourne), Michael Fuhrer (Monash), Alex Hamilton (UNSW)

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THE UNIVERSITY OF QUEENSLAND AUSTRALIA

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An Australian workshop of ICAM-I2CAM

Institute for Complex Adaptive Matter: http://icam-i2cam.org/

ICAM-I2CAM Institute for Complex Adaptive Matter

We welcome you to Minjerribah (North Stradbroke Island) in Queensland, Australia for this Australasian Workshop on Emergent Quantum Matter 2014. The indigenous Australians of this area are the Quandamooka people and we show our respect and acknowledge the traditional custodians of this land, of their elders past and present, on which this event takes place. North Stradbroke Island is home to rare and endangered flora and fauna, and we ask that you take care of it especially when sightseeing. There are 18 species of native land mammals on the island as well as reptiles that include some poisonous snakes. Sharks are known to live in the surrounding ocean waters. **Maps and more information can be found in the workshop information booklet.**

Contents

Timetable: Keynote talks (45 + 15 mins) and Invited talks (25 + 10 mins)

	Mon 24	Tue 25	Wed 26	Thu 27	Fri 28
9:00	Arrival	**K2: Galitski**	**K4: Fraser**	**K5: Lobb**	**K7: Zuelicke**
10:00		Coffee	Coffee	Coffee	Coffee
11:00		**ITu1: Dyke**	**IW1: Hamilton**	**ITh1: Poletti**	**IF1: Stace**
11:35		**ITu2: Liu**	**IW2: Whitlock**	**ITh2: Jacko**	Discussion: What *did* we achieve?
12:00	Lunch	Lunch, free time	Lunch, free time	Lunch, free time	Lunch, free time
1:00 1:50	**Induction to MBRS** Opening remarks				
2:00	**K1: McKenzie**	**K3: Brand**	Free afternoon / trip to Point Lookout	**K6: Gangardt**	Departure
3:00	Coffee	Coffee		Coffee	
4:00	**IM1: Eckel**	**ITu3: Simula**		**ITh3: Frydman**	
4:35	**IM2: Fuhrer**	**ITu4: Martin**		**ITh4: Shah**	
5:10	**IM3: Doherty**	**ITu5: Bowen**		**ITh5: Powell**	
5:45	Free time	Free time	6:00pm start: Workshop dinner	Free time	
6:30	Dinner	Dinner		Dinner	
7:30	Reception/Discussion What *will* we achieve?	Poster Session A		Poster Session B	

Talk titles at a glance

Monday

2:00 pm K1: McKenzie	Ross McKenzie	UQ	*An emergent perspective on quantum matter*
4:00 pm IM1: Eckel	Stephen Eckel	NIST	*Experiments with Superfluid Atom Circuits*
4.35 pm IM2: Fuhrer	Michael S Fuhrer	Monash	*Controlling the Surfaces of Atomically Thin Materials to Create New Electronic Phases*
5.10 pm IM3: Doherty	Andrew Doherty	Sydney	*Quantum information processing in many-body systems*

Tuesday

9:00 am K2: Galitski	Victor Galitski	Maryland/Monash	*Moving solitons in a fermionic superfluid*
11:00 am ITu1: Dyke	Paul Dyke	Swinburne	*When is an interacting 2D Fermi gas kinematically 2D*
11:35 am ITu2: Liu	Xia-Ji Liu	Swinburne	*Strongly interacting Fermi and Bose gases in the quasi-repulsive regime*
2:00 pm K3: Brand	Joachim Brand	Massey	*What can be learned about quantum gases from observing solitary wave dynamics?*
4:00 pm ITu3: Simula	Tapio Simula	Monash	*Quantum turbulence and order*
4:35 pm ITu4: Martin	Andy Martin	Melbourne	*Vortices and Vortex Lattices in Quantum Ferrorfluids*
5:10 pm ITu5: Bowen	Warwick Bowen	UQ	*Laser cooling and control of superfluid excitations*

Wednesday

9:00 am K4: Fraser	Michael Fraser	RIKEN	*Realizing exotic states of condensed matter with exciton-polaritons*
11:00 am IW1: Hamilton	Alex Hamilton	UNSW	*Excitonic superfluidity in electron-hole bilayer systems*
11:35 am IW2: Whitlock	Shannon Whitlock	Heidelberg	*Long-range interactions and spin transport with Rydberg dressed atoms*

Thursday

9:00 am K5: Lobb	Christopher Lobb	Maryland	*Ohm's Law for Atom Circuits*
11:00 am ITh1: Poletti	Dario Poletti	Singapore U.T.D.	*Exploring exotic Hamiltonians and quantum phases using fast periodic modulations*
11:35 am ITh2: Jacko	Anthony Jacko	UQ	*Designer Hamiltonians: Using molecular crystals to control strong correlations*
2:00 pm K6: Gangardt	Dimitri M Gangardt	Birmingham	*Mobile impurities in 1D ultracold gases: a simple yet rich many-body problem*
4:00 pm ITh3: Frydman	Aviad Frydman	Bar Ilan	*New developments of the "Superconductor-Insulator-Transition"*
4:35 pm ITh4: Shah	Nayana Shah	Cincinnati	*Majorana zero-bias anomaly: A microscopic non-equilibrium study*
5:10 pm ITh5: Powell	Ben Powell	UQ	*Emergent spins in ring molecules - an alternative route to quantum spin liquids*

Friday

9:00 am K7: Zuelicke	Ulrich Zuelicke	Victoria U.W.	*Emergent electromagnetism in materials*
11:00 am IF1: Stace	Thomas Stace	UQ	*What do we know about stable phases of quantum matter?*

Poster session A - Tuesday

1. Danny Baillie - University of Otago - *Anisotropic number fluctuations of a dipolar Bose-Einstein condensate*
2. Mark Baker – The University of Queensland – *A BEC apparatus for rotation sensing and atom interferometry*
3. Samuel Bladwell - University of New South Wales - *Spin splitting of heavy holes in magnetic focussing*
4. Carlos J. Bolech - University of Cincinnati - *Expansion dynamics of 1D systems and connections to integrability*
5. Chris Bradly - University of Melbourne - *Few-body problems as a route to investigating the many-body Fermi gas*
6. Michael Bromley – The University of Queensland - *Born-Oppenheimer approach to generating many-vortex superfluids*
7. David Cavanagh – The University of Queensland - *The Kadowaki-Woods ratio in arbitrary band structures and two-dimensional graphene*
8. Cinthya Valeska Chianca Da Silva – *The University of Queensland - Engineering of topological structures in wavefunctions*
9. Jayson Cosme - Massey University - *Thermalization in closed quantum systems: semiclassical approach* (Joint poster with Oleksandr Fialko)
10. Oleksandr Fialko - Massey University - *Fate of the false vacuum: Towards realization with cold atoms*
11. Brenton Hall – Swinburne - *RF-induced association of ultracold molecules in* ^{87}Rb
12. Sascha Hoinka – Swinburne University of Technology - *Low-momentum Bragg spectroscopy of a strongly interacting Fermi gas*
13. Hui Hu - Swinburne University of Technology - *Gapless topological Fulde-Ferrell superfluidity in spin-orbit coupled atomic Fermi gases*
14. Pekko Kuopanportti - Monash University - *Ground-state multiquantum vortices in two-species superfluids*

Poster session B - Thursday

15. Rob McDonald - University of Otago - *Quench-Induced Winding in a Bose-Einstein Condensate: Energy and Number Damping in C-Field Theory*
16. Nathan McMahon – University of Queensland - *AdS/CFT conjecture through a Multi-scale Entanglement Renormalisation Anzats (MERA) tensor network*
17. Brendan Mulkerin - Swinburne University - *Thermodynamic properties of strongly interacting two-dimensional Fermi gases*
18. Tyler Neely - UQ - *Dual Component* ^{87}Rb *and* ^{41}K *Bose-Einstein condensates in configurable optical potentials**
19. Nandan Pakhira - The University of Queensland - *Are there quantum limits to diffusion in quantum many-body systems?*
20. Kris Roberts - University of Otago - *Micromanaging Ultracold Atoms on a Macroscopic Scale**
21. Seyed Nariman Saadatmand – The University of Queensland - *Novel Quantum Phases in Triangular J1-J2 Heisenberg Magnets on a Cylinder*
22. Harley David Scammell - The University of New South Wales - *Violation of the Spin Statistics Theorem and the Bose-Einstein Condensation of Particles with Half Integer Spin*
23. Sophie Samira-Shamailov - Massey University - *Quasiparticles of widely tunable effective mass: The dispersion relation of atomic Josephson vortices*
24. Shih-Wei Su – Taiwan **-** *Position-dependent spin-orbit coupling for ultracold atoms*
25. Stuart Szigeti – The University of Queensland - *Realisable supersolid, Haldane insulating and charge-density wave phases in 1-D Josephson junction arrays*
26. Lewis Alexander Williamson - University of Otago - *Coarsening dynamics of a quenched spin-1 ferromagnetic condensate*
27. Matthew Davis – The University of Queensland - *Emergence of order from turbulence in an isolated planar superfluid*
28. Jan Zill – The University of Queensland - *Quench across a quantum phase transition in a one-dimensional Bose gas*

ABSTRACTS – Keynote talks (in alphabetical order)

Joachim Brand - Massey University - *What can be learned about quantum gases from observing solitary wave dynamics?*

Solitary wave dynamics probe the properties of a fluid at mesoscopic length scales and beyond the hydrodynamic paradigm. By virtue of their particle-like properties, they provide access to experimentally accessible characteristic parameters like the effective and physical mass. Beyond providing a challenge for theory to calculate these properties, the question arises how much we can learn about the mesoscopic physics beyond hydrodynamics. Is it possible to measure and observe deviations from mean-field theory predictions and what would they tell us about the microscopic physics? With these questions as a lead, I will review recent developments in the understanding of dark solitons in the superfluid Fermi gas, multi-dimensional solitons, Josephson vortices, and solitons in spin-orbit coupled Bose-Einstein condensates.

Michael Fraser – RIKEN – *Realizing exotic states of condensed matter with exciton-polaritons*

Microcavity exciton-polaritons, mixed light-matter semiconductor quasi-particles, have emerged as a highly promising system for revealing novel condensed matter phases, notably the recently explored polariton Bose-Einstein condensate (BEC). Polaritons have the unique ability to posses properties ranging between photonic-like and atomic-like by virtue of the relative mixture of the composing exciton and photon states, and as such, can exhibit behaviour from strongly non-equilibrium to roughly equilibrium dynamics. This ability to engineer the properties of the polaritons themselves over a wide parameter space can thus be used to drive the transition to a desired condensed matter state. In this presentation I will discuss how the properties of the microcavity polariton system, in particular open-dissipation, determine the presentation of BEC and superfluidity and their excitations, noting the differences withthe atomic BEC system. Further, I will introduce the recent technological advances in fabrication and processing of polariton microcavities that have led to deep trapping profiles capable of facilitating almost arbitrary complex band-structure engineering for the polariton condensate. I will describehow this progress and the great flexibility of the polariton system uniquely places it as capable of realizing various low-dimensional, topological and spinor states of condensed matter.

Victor Galitski - University of Maryland and Monash University - *Moving solitons in a fermionic superfluid*

Solitons are fascinating non-linear phenomena that occur in a diverse array of classical and quantum systems. In particular, they are known to exist in quantum superfluids, and have been demonstrated experimentally in Bose-Einstein condensates using phase imprinting and other methods. More recently, an anomalously heavy soliton-like excitation was observed in a fermionic superfluid [T. Yefsah et al., Nature 499, 426, (2013)]. In this talk, I will present an exact solution to the problem of a moving soliton in a one-dimensional fermionic superfluid. Connections to the inverse scattering method and supersymmetric quantum mechanics will be emphasized. Using these exact methods, the full soliton spectrum will be derived along with its “inertial” and “gravitational” masses. The former will be shown to be orders of magnitude larger than the latter. This results in slow oscillations of the soliton in a harmonic trap, consistent with recent experiment.

ABSTRACTS – Keynote talks contd. (in alphabetical order)

Dimitri M Gangardt - University of Birmingham - *Mobile impurities in 1D ultracold gases: a simple yet rich many-body problem*

Recent experiments with ultra cold atoms possessing several hyperfine states made possible studies of statics and dynamics of mobile impurities - atoms in a hyperfine state different from the rest. The physics of these objects becomes very interesting in one spatial dimension due to enhanced role of interactions leading to strong renormalisation of impurity's dispersion and resulting in intricate dynamic response. In this talk I will show that the physics of mobile impurities can be understood in terms of an universal phenomenological model and what dynamical effects can be expected from this universality.

Christopher Lobb - University of Maryland - *Ohm's Law for Atom Circuits*

Atomtronics is an emerging interdisciplinary field that is creating new devices and circuits where ultracold atoms, often superfluids, have a role analogous to that of electrons in electronics. After giving a brief overview of some experimental neutral atom-circuit results, I will show how these results can be described by lumped-element models analogous to those used in electronics. Resistance, capacitance and inductance can be defined for neutral-atom circuits, and they are analogous to the Sharvin resistance (in the non-superfluid case), quantum capacitance, and kinetic inductance, respectively, in electronic circuits. In the superfluid case, resistance must include different channels of dissipation, and thus is not just a Sharvin resistance. In collaboration with R. B. Blakestad, G. K. Campbell, C. W. Clark, S. Eckel, M. Edwards, K. Helmerson, W. T. Hill, III, F. Jendrzejewski, J. G. Lee, B. J. McIlvain, S. R. Muniz, N. Murray, W. D. Phillips, A. Ramanathan, K. C. Wright, and M. Zelan.

Ross McKenzie - University of Queensland - *An emergent perspective on quantum matter*

When a system is composed of many interacting components new properties can emerge that are qualitatively different from the properties of the individual components. Such emergent phenomena lead to a stratification of reality and of scientific disciplines. Emergence can be particularly striking and challenging to understand for quantum matter, which is composed of macroscopic numbers of particles that obey quantum statistics, such as electrons. Important examples of emergent states of quantum matter include superfluidity, superconductivity, and the fractional quantum Hall effect. I will introduce some of the organising principles for describing such phenomena: quasi-particles, spontaneously broken symmetry, and effective Hamiltonians. I will briefly describe how these ideas undergird some of my own theoretical research on complex molecular materials such as superconducting organic charge transfer salts, fluorescent proteins, and hydrogen bonded complexes. The interplay of emergence and reductionism raises issues in philosophy and as to the best scientific strategy for describing complex systems.

Ulrich Zuelicke - Victoria University of Wellington - *Emergent electromagnetism in materials*

Classical electrodynamics, as formalised by Maxwell's equations, relates electromagnetic fields to their sources and to each other. With some generalisations and augmented by appropriate constitutive relations, Maxwell's theory can also be used to describe electromagnetism of ordinary materials. However, unconventional electromagnetic properties can arise in systems having broken symmetries and/or strong correlations. Intriguing examples for this are the magneto-electric materials, which exhibit untypical relationships between sources and fields that mimic those expected in the presence of the putative axion elementary particle. Also, in a complex system, fictitious gauge fields can emerge that cause physical effects usually associated with electromagnetism even in the absence of any conventional fields. I am going to give an overview of emergent electromagnetic phenomena that are currently attracting interest and discuss the unusual electromagnetism of electrons in bilayer graphene as a specific example.

ABSTRACTS – Invited talks (in alphabetical order)

Warwick Bowen – The University of Queensland - *Laser cooling and control of superfluid excitations*

Emergent quantum phenomena such as superconductivity, quantum magnetism, and superfluidity arise due to elementary excitations and the strong interactions that occur between them in condensed matter systems. In superfluids, the elementary excitations are phonons and rotons, as famously postulated by Landau. Experimentally, techniques such as neutron and light scattering have been used to probe the behaviour of phonon's and roton's since the 1950's. However, quite generally, such techniques have been limited to collective measurements of many modes of excitation, or to observations of the driven response of a single mode far out of equilibrium. Here, we apply techniques from cavity optomechanics to directly probe the equilibrium dynamics of a single superfluid mode of excitation. Specifically, we observe the thermomechanical dynamics of third sound phonon resonances in a nanoscale think superfluid film. Detuned laser driving allows laser cooling and heating, while optical driving allows the non-linear interactions between phonons to be probed. This research could enable direct measurements of correlations induced by phonon-phonon interactions in equilibrium superfluids, an important property in any microscopic understanding of their behaviour; as well as new approaches cavity optomechanics, new methods to probe quantum vortices and 2D quantum systems, and applications in inertial sensing and gyroscopy.

Andrew Doherty – University of Sydney - *Quantum information processing in many-body systems*

One of the most interesting approaches to manipulating quantum information is so-called "measurement-based quantum computation", where the computation proceeds by making local measurements on some many-body entangled state that is independent of the specific computation that is to be performed. Recent work at Sydney has attempted to understand what classes of states allow for measurement-based quantum computation. I will describe one key result which shows that the ground states of Hamiltonians that display so-called "symmetry-protected topological order" are useful for measurement based quantum computation regardless of the details of the wave-function. The most well-known examples of such systems are one-dimensional spin-1 anti-ferromagnets in the Haldane phase. This is one of several interesting developments in quantum information that are closely related to physical concepts from condensed matter physics. I will give some brief overview and context of the current state of research in this area.

ABSTRACTS – Invited talks contd. (in alphabetical order)

Paul Dyke - Swinburne University of Technology - *When is an interacting 2D Fermi gas kinematically 2D*

Ultracold gases of fermionic atoms provide a versatile tool for studying many-body quantum phenomena. One example is a two-component 2D ultracold Fermi gas with tunable interactions, which is anticipated to provide new insight into questions encompassing the crossover from BCS to BKT superfluidity and 2D spin-orbit coupled systems. To effectively investigate these areas we need to establish the conditions for which an interacting Fermi gas subject to tight transverse confinement is kinematically 2D. We have begun addressing this using an atomic gas of Li-6 with tunable interactions in a region where reliable theoretical predictions are not available. By answering this question we can then investigate the 2D equation of state (EoS) when atoms are confined to the transverse ground state. For this we will adapt a scheme based on model independent thermometry to the study of 2D systems. Our experiments will focus on the search for thermodynamic signatures of the superfluid transition. Another topic we are investigating is spin-orbit coupled 2D Fermi gases, which may lead to new topological superfluids. To date however, heating by near resonant Raman lasers has been a limitation so we plan to investigate alternative schemes that may offer a means to avoid this.

Stephen Eckel – NIST - *Experiments with Superfluid Atom Circuits*

Bose-Einstein condensates in ring geometries are essential ingredients to the ongoing effort at JQI of building increasingly complex superfluid circuits. A repulsive optical barrier across one side of the ring creates a tunable weak link in the condensate circuit and can be used to control the current around the loop. By rotating the weak link, we have observed phase slips between well-defined persistent current states, which are analogous to transitions between flux states in an rf-superconducting quantum interference device (SQUID). Importantly, we have demonstrated that these transitions are hysteretic, a characteristic of many common electronic circuits like memory, digital noise filters, and, indeed, the rf-SQUID. More recently, we have realized a geometry similar to a dc-SQUID using two weak links. In this case, we can move these weak links relative to each other and observe resistive flow when the current exceeds the critical current. This observation of resistive flow is an important step to realizing the atomtronic analog of the dc-SQUID. Lastly, we have developed techniques of measuring the current flow around the ring which allows us to measure the current-phase relationship of our weak link.

Aviad Frydman - Bar Ilan University, Israel - New developments of the “Superconductor-Insulator-Transition”

The interplay between disorder and superconductivity gives rise to a disorder-induced superconductor-insulator-transition (SIT). Though this is a rather old topic, it gained renewed interest lately because of two reasons. One is the realization that this is a unique prototype of a quantum-phase-transition in which quantum rather than thermal fluctuations drive the transition at zero temperature. The second is a set of dramatic experimental features that were observed near the SIT and cannot be explained by current theories. These include a huge peak in the magneto-resistance, peculiar I-V characteristics, and traces of superconductivity at temperatures above Tc and in the insulating state. In this talk some recent developments in the field will be reviewed including possible experimental detection of the “Higgs mode” in superconductors and vortex dynamics in the vicinity of the transition.

ABSTRACTS – Invited talks contd. (in alphabetical order)

Michael S Fuhrer - School of Physics, Monash University - *Controlling the Surfaces of Atomically Thin Materials to Create New Electronic Phases*

The last decade has seen a revolution in two-dimensional electronic systems. Atomically thin materials such as graphene and transition-metal dichalcogenides host two-dimensional electron systems with novel electronic properties. Strong topological insulators and topological crystalline insulators have metallic surface states with Dirac dispersions and spin-momentum locking. In each case, the electronic conduction happens in an atomically-thin layer at the material surface. Modification of the surface can be used to dope the materials, tune the electron-electron and electron-impurity interactions (through the dielectric background), add magnetic moments, change spin-orbit coupling, break symmetries, and more. Theoretical proposals for adatom-modified two-dimensional materials include quantum spin Hall and quantum anomalous Hall phases, chiral d-wave superconductivity through electron interactions, and ecitonic superfluidity. I will describe the development of new experimental tools to achieve control over the surfaces of atomically thin materials, and characterize the modified surfaces at the both the nano- and macro-scales.

Alex Hamilton – University of New South Wales - *Excitonic superfluidity in electron-hole bilayer systems*

Exciton bound states in solids between electrons and holes have been predicted to form a superfluid at high temperatures. The challenge is to confine the electrons and holes into two separate layers spaced close enough that the excitonic superfluid forms under experimentally accessible conditions, but not so close that the electrons and holes rapidly recombine. We theoretically study electron hole systems in three different heterostructures: (i) GaAs/AlGaAs double quantum wells, (ii) double bilayer graphene, and (iii) hybrid graphene–GaAs quantum well structures. We find that in the GaAs and bilayer graphene systems the sample parameters necessary to generate equilibrium superfluidity of the electron-hole pairs are close to values already achieved in experiments. Our results indicate that the superfluid transition temperatures should be above liquid helium in both cases. For the hybrid bilayer graphene–GaAs quantum well structure, we obtain chiral superfluid states with phase coherence across the graphene–GaAs interface. A key controversy in performing such calculations is how to treat screening of the attractive Coulomb interaction between electrons and holes. In the past mean-field theories using different screening approximations have come to wildly different conclusions, with predictions of the superfluid transition temperature varying by more than 6 orders of magnitude for the same system. We resolve this issue by testing these different screening approximations against essentially exact recent diffusion quantum Monte Carlo results. Our results will allow calculations to be extended to complicated lattices at finite temperatures, and non-equilibrium situations, impractical in Monte Carlo.

ABSTRACTS – Invited talks contd. (in alphabetical order)

Anthony Jacko – The University of Queensland - *Designer Hamiltonians: Using molecular crystals to control strong correlations*

Molecular crystals provide a novel approach to controlling strong correlations and implementing designer Hamiltonians. Molecular crystals (periodic arrays of molecules) allow us unprecedented control over both inter- and intra-molecular interactions by fine tuning their chemical structure. Organometallic molecules allow us to introduce significant correlations into the model, opening the door to the rational design of materials along the whole spectrum of strongly correlated phases. In addition, it is easy to achieve very low effective temperatures T/T_F in molecular crystals. However, there is a huge theoretical challenge in connecting their molecular and crystal structure with a model Hamiltonian and vice versa. This is in contrast with other approaches to Hamiltonian engineering, such as Fermi gases in optical lattices, where the connection between system and Hamiltonian is clearer, but the effective temperatures are higher. I will discuss ongoing work on organometallic molecular crystals: understanding how their chemistry and external pressure effect the parameters of the model, and the emergence of a spin-orbit coupling interaction unlike the spin-orbit coupling one might expect. This understanding will lead to the ability to design other forms of electronic interactions, including those one might not expect to see in simple materials.

Xia-Ji Liu - CQOS, Swinburne University - *Strongly interacting Fermi and Bose gases in the quasi-repulsive regime*

Recent advances in rapidly quenched ultracold atomic Fermi gases near a Feshbach resonance arise a number of interesting problems, in the context of observing the long-sought Stoner ferromagnetic phase transition. The possibility of experimentally obtaining a “quasirepulsive” regime in the upper branch of the energy spectrum due to the rapid quench is currently debated and theoretically, the Stoner transition has mainly been investigated at zero temperature or high polarization, due to the limited theoretical approaches in the strongly repulsive regime. Here, we develop a nonperturbative large-N expansion theory for a quasirepulsive Fermi gas near resonance and present a finite temperature phase diagram for its Stoner instability. Our results agree well with the known quantum Monte-Carlo simulations at zero temperature and recover the virial expansion prediction at high temperature for arbitrary interaction strengths. At resonance, we find that the unitary Fermi gas undergoes the Stoner transition at about 1.5TF, where is the Fermi degeneracy temperature. Within the same framework of large-N expansion we also investigate the equation of state and Tan’s contact of a strongly interacting Bose gas.

Andy Martin – University of Melbourne - *Vortices and Vortex Lattices in Quantum Ferrorfluids*

In this talk I will consider the properties of vortices in dipolar condensates. Initially the talk will focus on how long-range dipolar interactions can lead to striking modifications of vortex-vortex dynamics [PRL 111, 170402 (2013)]. I will then move on to consider how dipolar interactions can play a significant role in the structure of vortex lattices. Specifically, this work will show how it is possible to use, both the strength and orientation of dipolar interactions to switch between triangular, square and stripe vortex lattice phases in rapidly rotating quantum ferrrofluids.

Dario Poletti - Singapore University of Technology and Design - *Exploring exotic Hamiltonians and quantum phases using fast periodic modulations*

Recent years have seen a tremendous growth of interest in the field of Hamiltonian engineering via fast periodic modulations, with fascinating theoretical and experimental results. We first present an overview of this field from the perspective of the ultracold atoms community. We then show how to engineer density-dependent synthetic gauge fields by combining periodically modulated interactions and Raman-assisted hopping in spin-dependent optical lattices. These density-dependent synthetic gauge fields lead to density-dependent shifts of the momentum distribution, cause anomalous correlations and induce superfluid to Mott-insulator transitions (even at fractional filling). Last we show that modulating both the lattice and the interaction allows to explore a much broader class of Hamiltonians compared to a single modulation. In particular Hubbard models with asymmetric hopping, which present insulating phases with both parity and string order, and lattice models in unconventional parameter regimes, illustrated by the case of the spin 1/2 Fermi-Hubbard model with correlated hopping. Our papers on the topic are:
S. Greschner, G. Sun, D. Poletti, L. Santos, Density dependent synthetic gauge fields using periodically modulated interactions, arxiv:1311.3150
S. Greschner, L. Santos, D. Poletti, Exploring unconventional Hubbard models with doubly-modulated lattice gases, arxiv:1407.6196"

Ben Powell – The University of Queensland - *Emergent spins in ring molecules - an alternative route to quantum spin liquids*

Quantum spin-liquids are one of the most fascinating emergent quantum many-body effects. The best understood cases are in one (spatial) dimension. In 1D integer spin and half-integer spin systems behave very differently. Furthermore, it has also been suggested that charge fluctuations will destroy the topological Haldane spin liquid phase in spin-1 systems. But in crystals we are dealing with electronic spins and inevitably charge fluctuations; nevertheless there is good evidence for Haldane physics in some 1D materials. This talk will begin with a discussion of topological spin liquids and symmetry protected topological spin liquids and why they are interesting. I will discuss how one might use ring like molecules to achieve large integer spins. To do so I will demonstrate a relationship between some (recent) exact results for the Hubbard model and Hund's rules. This allows us to view molecules as controllable “artificial atoms”. I will then show that chains of such molecules support the Haldane spin-liquid phase even when the charge fluctuations are large.

Nayana Shah - University of Cincinnati - *Majorana zero-bias anomaly: A microscopic non-equilibrium study*

Recently there has been a lot of excitement generated by the possibility of realizing and detecting Majorana fermions within the arena of condensed matter physics and its potential implication for topological quantum computing. In the pursuit of identifying and understanding the signatures of Majorana fermions in realistic systems, we go beyond the low-energy effective-model descriptions of Majorana bound states to derive non-equilibrium transport properties of a topological superconducting wire in the presence of arbitrarily large applied voltages. By virtue of a microscopic calculation we are able to model the tunnel coupling between the superconducting wire and the metallic leads realistically, study the role of high-energy non-topological excitations, predict how the behavior compares for an increasing number of odd versus even number of sites, and study the evolution across the topological quantum phase transition. We consider the Kitaev model as well as its specific realization in terms of a semiconductor-superconductor hybrid structures. Our results have concrete implications for the experimental search and study of Majorana fermions.

ABSTRACTS – Invited talks contd. (in alphabetical order)

Tapio Simula - Monash University - *Quantum turbulence and order*

Turbulence is likely necessary for the existence of life. Increasing knowledge in one may improve the understanding of the other. Rapid growth in international activity is currently taking place in the experimental and theoretical study of two-dimensional turbulence in superfluids. One of the key theory predictions for such systems is the emergence of ordered vortex structures out of the chaotic superfluid dynamics. This talk aims to provide a general introduction to the problem of quantum turbulence and to emergent phenomena in such chaotic dynamical systems. Major open problems will be discussed, including questions whether large scale supervortex structures in two-dimensional quantum turbulence or noncommutative quantum turbulence in vector superfluids be realized in quantum gas laboratories? Do absolute negative temperature states really exist and what is their relation to the concept of non-thermal fixed points? What happens to turbulence when the system dimensionality crosses-over from 2D to 3D? The talk will be concluded by considering how studying such problems may help increase knowledge also in other cross-disciplinary systems.

Thomas Stace – The University of Queensland - *What do we know about stable phases of quantum matter?*

There is great interest in the existence of phases of matter that stably preserve quantum superpositions. Apart from representing a fundamentally new kind of phase of matter, these would find applications in quantum information and engineered quantum systems. I will present a survey of what is known about such phases, including some results in 2D and 4D systems, along with some open questions, particularly pertaining to 3D.

Shannon Whitlock - University of Heidelberg - *Long-range interactions and spin transport with Rydberg dressed atoms*

Ultracold Rydberg atoms, with their exceptionally large dipole moments, offer the exciting prospect to create and study new types of strongly-interacting quantum systems in which the strength, anisotropy, range and character of the interaction potential can be controlled at will. In particular, state-changing interactions between Rydberg atoms are similar to those found in complex molecules, but can be orders of magnitude stronger and extend over micrometer distances, far beyond nearest neighbours. We experimentally and theoretically study the dipole-mediated transport of Rydberg impurities through a surrounding gas of atoms coupled via an electromagnetically induced transparency (EIT) resonance. This system can be mapped onto an effective spin-1/2 model for the impurity Rydberg state and the laser dressed atoms. Using the background gas as an amplifier we monitor the migration of electronic excitations with high time and spatial resolution. Through precise control of interactions and the coupling to the environment via the laser fields, we find different regimes ranging from coherent exciton motion to classical diffusive transport and a collective regime in which a new length scale emerges. Finally I will discuss the possibility to exploit the extreme properties of Rydberg-dressed atoms to create novel types of long-range interacting quantum fluids.

ABSTRACTS – Posters Session A (in alphabetical order)

(Posters 1-13 are in poster session A)

1. Danny Baillie - University of Otago - *Anisotropic number fluctuations of a dipolar Bose-Einstein condensate*

We present a theory for the number fluctuations of a quasi-two-dimensional dipolar Bose-Einstein condensate measured with finite resolution cells. We show that when the dipoles are tilted to have a component parallel to the plane of the trap, the number fluctuations become anisotropic, i.e. depend on the in-plane orientation of the measurement cell. We develop analytic results for the quantum and thermal fluctuations applicable to the cell sizes accessible in experiments. We show that as cell size is increased the thermodynamic fluctuation result is approached much more slowly than in condensates with short range interactions, so experiments would not require high numerical aperture imaging to observe the predicted effect.

2. Mark Baker – The University of Queensland – *A BEC apparatus for rotation sensing and atom interferometry*

Bose-Einstein condensates of dilute gases are promising candidates for next generation inertial sensors and atom interferometry. To this end, we have developed a new ^{87}Rb BEC apparatus, that makes use of time averaged optical potentials. The time averaged potentials are formed by a rapidly scanned far detuned dipole beam, allowing versatile optical potentials to be generated, but in particular ring shaped potentials which act as a waveguide for cold atoms. Our new apparatus makes use of a hybrid magnetic trap and optical dipole trap, combining the advantages of the respective trapping techniques, with large initial capture volume and simplicity of RF evaporation provided by the magnetic trap, and final fast evaporation stage in the dipole trap. We report here details of progress with this new experimental setup, and first experiments in condensing atoms into the ring shaped potential.

3. Samuel Bladwell - University of New South Wales - *Spin splitting of heavy holes in magnetic focussing*

We investigate theoretically magnetic focusing of heavy holes in a zinc-blende 2D semiconductor heterostructure. For this system the spin-orbit interaction and in particular Rashba spin-orbit interaction is very strong, a significant fraction of Fermi energy. In the magnetic focusing experiment a weak focusing magnetic field is applied perpendicular to the heterostructure. The spin-orbit interaction results in a double focusing peak. An additional strong magnetic field of several Teslas applied in the plane heterostructure significantly influences the spin-orbit interaction and allows for both the suppression and enhancement of the double focusing. From this analysis we present predictions for experiment.

4. Carlos J. Bolech - University of Cincinnati - *Expansion dynamics of 1D systems and connections to integrability*

We study the sudden expansion of ultra-cold lattice bosons and fermions with repulsive and attractive interactions in one dimension after turning off the longitudinal confining potential. We show that the momentum distribution functions of majority and minority fermions approach stationary values quickly, and make predictions for the cloud expansion velocity. Furthermore, we argue that these quantities can be understood by relating them to the integrals of motion in this (quasi)-integrable quantum systems.

ABSTRACTS – Posters Session A contd. (in alphabetical order)

5. Chris Bradly - University of Melbourne - *Few-body problems as a route to investigating the many-body Fermi gas*

Ultracold two-component Fermi gases are ideal systems for exploring fundamental properties of condensed matter. Few-body problems provide an effective route for investigating the many-body system, especially in the strongly-interacting regime where perturbative techniques fail. Based on the dominance of two-particle collisions at low temperatures, we investigate two avenues of analysis. Firstly, exact solutions to the problem of two trapped fermions subject to a synthetic magnetic field are used, via the quantum virial expansion, to calculate thermodynamic properties of the many-body gas. We find a new universality class with respect to the synthetic magnetic field when the interactions are in the strong regime. Secondly, we develop a coupled-pair approach to tackle the N-body problem in a strongly-interacting two-component Fermi system. In accordance with the variational principle, we calculate an upper bound to the ground state energy of up to 8 particles. This result is the first using exact diagonalisation and is also lower than any other variational method. We also calculate structural properties of the 8 system to investigate the transition from few-body to many-body systems.

6. Michael Bromley – The University of Queensland - *Born-Oppenheimer approach to generating many-vortex superfluids*

The computational engineering of complicated phase and amplitude structures into wavefunctions is interesting for fundamental reasons such as understanding turbulent flow in the non-linear dynamics of superfluids, but also for a range of applications such as orbital angular momentum-based laser tweezers. We present a computational algorithm that can imprint various phase and amplitude structures into wavefunctions and then smooth them out to remove any unwanted excitations. By varying the distance between these structures that we impose we are able to adiabatically map out a Born-Oppenheimer-like energy landscape. We use calculations of the non-linear Schroedinger equation to show that we are able to locate, and generate, Ince-Gaussian-like eigenstates in Bose-Einstein condensates consisting of multiple vortices. Applications of the method to exploring out-of-equilibrium, eg. rotating, several-vortex systems will be presented. I will also present laser-based spatial-light-modulator experiments demonstrating both the production and dynamics of up to 25 vortices in the wavefunction of a propagating laser beam, as a useful tool for optical tweezers, but also a necessary precursor to being able to directly imprint these smooth wavefunctions into a Bose-Einstein condensate.

7. David Cavanagh – The University of Queensland - *The Kadowaki-Woods ratio in arbitrary band structures and two-dimensional graphene*

The Kadowaki-Woods ratio (KWR), defined as the ratio between a material's resistivity and heat capacity at low temperatures, gives important insights into the emergent physics of strongly correlated many-electron systems. In its dimensionless form, the KWR is constant in a wide range of materials described by Fermi liquid theory and therefore the KWR can be used as a test of the Fermi liquid nature of a material. This previous theory of the KWR is based on toy models of electronic band structure. We will present a generalisation of the universal KWR for arbitrary band structures. In particular, we show that there are significant changes in the KWR when multiple bands cross the Fermi surface. As an example, we calculate the generalised multi-band Kadowaki-Woods ratio of graphene, a material of significant interest, which displays a number of unusual properties, including multiple bands and a massless electron dispersion"

8. Cinthya Valeska Chianca Da Silva – The University of Queensland - Engineering of topological structures in wavefunctions

We present in detail the design and implementation of a computational algorithm that can imprint desired phase and amplitude excitations into wavefunctions and then smooth the wavefunctions out to remove undesirable excitations. We simulate a harmonically trapped BEC containing one or more vortices precessing with the Gross-Pitaevskii equation (GPE) to explore the dynamics of vortices in BECs. To generate the initial conditions of the GPE with vortices we used the algorithm to pin the vortices with a internal grid-based boundary condition where psi(x,y) = 0 and then use an unkinking algorithm at each imaginary time step to remove any resulting kinks in the wavefunction. In particular, we have investigated how one simple system, a single vortex in a wavefunction, responds to rotation i.e. an out of equilibrium situation. We map out an energy landscape of this system by varying the distance between the centre of the harmonic trap and the vortices. As first application, we have performed laser-based spatial-light-modulator experiments demonstrating both the production and dynamics of up to 4 spatially rotating vortices in the wavefunction of a propagating laser beam, as a useful tool for optical tweezers. Here, we can completely engineer the topological structure of the wavefunction.

9. Jayson Cosme - Massey University - *Thermalization in closed quantum systems: semiclassical approach* (Joint poster with Oleksandr Fialko)

Thermalization in closed quantum systems can be explained either by means of the eigenstate thermalization hypothesis or the concept of canonical typicality. Both concepts are based on quantum mechanical formalism such as spectral properties of the eigenstates or entanglement between subsystems respectively. Here we study the onset of thermalization of Bose particles in a two-band double well potential using the truncated Wigner approximation. This allows us to use the familiar classical formalism to explain quantum thermalization in this system. In particular, we demonstrate that sampling of an initial quantum state plays the role of a statistical mechanical ensemble, while subsequent chaotic classical evolution turns the initial quantum state into the thermal state.

10. Oleksandr Fialko - Massey University - *Fate of the false vacuum: Towards realization with cold atoms*

Quantum decay of a relativistic scalar field from a false vacuum is a fundamental idea in quantum field theory. It is relevant to models of the early Universe, where the nucleation of bubbles gives rise to an inflationary universe and the creation of matter. We propose a laboratory test using an experimental model of an ultra-cold spinor Bose gas. A false vacuum for the relative phase of two spin components, serving as the unstable scalar field, is generated by means of a modulated radio-frequency coupling of the spin components. Numerical simulations demonstrate the spontaneous formation of true vacuum bubbles with realistic parameters and time-scales.

11. Brenton Hall – Swinburne - *RF-induced association of ultracold molecules in ^{87}Rb*

Radiofrequency spectroscopy of molecular binding energy can be a powerful tool for extracting interaction properties of ultracold atoms, parameters of molecular potentials, ultracold chemistry and testing variations of fundamental constants. Using powerful RF radiation we couple pairs of ultracold colliding atoms to five highest molecular states at a variable DC magnetic field, measure the binding energy of three hyperfine molecular states with 0.01% precision and observe RF-induced Feshbach resonances [1, 2]. Molecular binding energies and scattering properties are closely related and our measurements add new data for improving the simulations of BEC dynamics and for the determination of the long-range parameters of the ^{87}Rb molecular potential.

[1] T.M. Hanna et al. New J. Physics 12, 083031 (2010). [2] T.V. Tscherbul et al. Phys. Rev. A 81, 050701 (2010).

12. Sascha Hoinka – Swinburne University of Technology - *Low-momentum Bragg spectroscopy of a strongly interacting Fermi gas*

We report on the progress towards low-momentum Bragg spectroscopy of a strongly interacting Fermi gas. At low momentum, Bragg scattering probes the long-wavelength or collective excitations of the gas, closely related to the superfluid order parameter. We therefore expect to observe a clear signature for macroscopic coherence in the form of a discrete peak in the Bragg spectrum at low excitation energies, the so-called Goldstone (Bogoliubov-Anderson) mode. Also, the onset of single-particle excitations in the spectrum at higher energies should provide a direct measure of the pairing gap. To discriminate between collective and single-particle excitations, we shine two tightly focussed laser beams into the centre region of an optically trapped cloud of (lithium-6) atoms, where the density is nearly uniform, to directly probe the homogenous response. As the setup is located far from the atom cloud (outside the vacuum glass cell), high mechanical stability on the micrometer scale is required. Such a setup may also allow measurement of the superfluid fraction in the atomic cloud across the entire BCS-BEC crossover.

13. Hui Hu - Swinburne University of Technology - *Gapless topological Fulde-Ferrell superfluidity in spin-orbit coupled atomic Fermi gases*

Topological superfluids are recently discovered quantum matters that host topologically protected gapless edge states known as Majorana fermions – exotic quantum particles that act as their own anti-particles and obey nontrivial non-Abelian statistics. Their realisations are widely believed to lie at the heart of future technologies such as fault-tolerant quantum computation. To date, the most efficient scheme to create topological superfluids is based on the model proposed by Sau, Lutchyn, Tewari and Das Sarma (SLTD) in 2010, where the topological transition is driven by an out-of-plane Zeeman field perpendicular to the plane of spin-orbit coupling. The resulting topological superfluid is gapped in the bulk, behaving similar to the well-known p-wave superfluid.

14. Pekko Kuopanportti - Monash University - *Ground-state multiquantum vortices in two-species superfluids*

We show that rotating, harmonically trapped mixtures of two Bose-Einstein-condensed superfluids can - contrary to their single-species counterparts - contain multiply quantized vortices in the ground state. These vortices can exist as solitary structures without any accompanying single-quantum vortices, and they may either be coreless or have genuinely empty cores depending on whether the interspecies interaction is repulsive or attractive, respectively. Our mean-field Gross-Pitaevskii simulations demonstrate that the multiquantum vortices can be readily realized in the two-species Bose-Einstein condensate of Rb-87 and K-41 using available experimental techniques. The discovered states not only provide a rare example of a thermodynamically stable, solitary multiquantum vortex in a rotating superfluid but also reveal new physics stemming from the coexistence of multiple, separately phase-coherent, and mass-imbalanced condensates in one system.

(end of poster session A)

ABSTRACTS – Posters Session B (in alphabetical order)
(Posters 15-28 are in poster session B)

15. Rob McDonald - University of Otago - *Quench-Induced Winding in a Bose-Einstein Condensate: Energy and Number Damping in C-Field Theory*

Previous works testing the predictions of the Kibble-Zurek mechanism in Bose gases have typically utilised the simple growth sub-theory of the Stochastic Projected Gross-Pitaevskii equation (SPGPE). This description neglects terms representing energy-damping number-conserving interactions between the condensate and thermal cloud. The full theory can be simplified by dimensional reduction for systems that are highly 1D or 2D in nature, making inclusion of the energy-damping terms more numerically efficient. We simulate quenches of chemical potential across the Bose-Einstein condensation transition in a toroidally trapped quasi-1D Bose gas using the 1D SPGPE, with and without the energy-damping terms. We investigate how inclusion of the energy-damping terms affects the winding of the superfluid with respect to the quench rate, and compare to the predictions of the Kibble-Zurek mechanism. We also examine the coherence length of the gas at the boundaries of the so-called impulse regime for both the simple-growth sub-theory and the full SPGPE.

16. Nathan McMahon – University of Queensland - *AdS/CFT conjecture through a Multi-scale Entanglement Renormalisation Anzats (MERA) tensor network*

One idea about how to approach quantum gravity is the theory of gravitational holography, inspired by black hole thermodynamics. While it is only a conjecture it has been shown in terms of the AdS/CFT correspondence in string theory. Recently Brian Swingle has proposed a generalised notion of holography can be found through renormalisation techniques and later expanded this conjecture to Multi-scale Entanglement Renormalisation Anzats (MERA) and the AdS/CFT correspondence. One of the most obvious connections is the entanglement entropy on the boundary CFT (a spin chain for MERA) can be connected to the geodesic path length in the bulk Anti-de-Sitter (AdS) space. We have been investigating the decoupling limit of AdS/CFT where in the large N limit we get a decoupling of components representing Gauge theories and geometry. Exploiting internal symmetries, we numerically investigated how this may appear in the MERA analogy. In addition we also consider a method of generating geodesic path lengths in the discrete space AdS analogy in a similar way to the one proposed for continuous MERA by Takayinagi.

17. Brendan Mulkerin - Swinburne University - *Thermodynamic properties of strongly interacting two-dimensional Fermi gases*

We present a calculation of the normal phase properties of a two-dimensional strongly interacting Fermi gas. Understanding fermionic superfluidity, its thermodynamic properties and the formation of fermion pairs is an important area of research, elucidating our understanding of high temperature superconductors. In lower dimensions quantum fluctuations are expected to play a more important role, thus in this project we aim to better understand strongly-interacting two-dimensional Fermi gases. The interaction strength can be parametrised through the bound state energy and controlled via Feshbach resonances allowing us to examine the crossover regime, i.e. from a weakly interacting BEC gas to a weakly interacting BCS gas. We determine the thermodynamic properties and the spectral function through a self-consistent T-matrix calculation over the crossover regime for several different choices of the self-consistent theory; a fully self-consistent GG scheme, partially self-consistent GG_0 scheme and non-self consistent Nozieres-Schmitt Rink scheme. The transition temperature to superfluidity are calculated in the crossover regime for a finite system and the compressibility and pressure of the gas is calculated and compared for the different schemes.

18. Tyler Neely - UQ - *Dual Component ^{87}Rb and ^{41}K Bose-Einstein condensates in configurable optical potentials**

Multi-component Bose-Einstein condensates (BECs), whether composed of spin mixtures or different atomic species, present features not seen in single component gases. In particular, interactions between the components allow for more diverse superfluid behaviour. These interactions are tuneable via Feschbach resonances, enabling a host of rich behaviour to be studied [1]. We present our ongoing development of a two-component BEC, consisting of ^{87}Rb and sympathetically cooled ^{41}K, loaded into configurable optical potentials. By utilising a digital micromirror device (DMD) and high-resolution imaging system combined with a vertically confining light sheet, a wide range of precise 2D potentials can be created. We propose to first use this system to study the coarsening dynamics of the miscible-immiscible superfluid transition in a flattened optical trap.

[1] G. Thalhammer et al. Phys. Rev. Lett. 100, 210402 (2008).

* with Nicholas McKay-Parry, Isaac Lenton, Matthew Davis, and Halina Rubinsztein-Dunlop

19. Nandan Pakhira - The University of Queensland - Are there quantum limits to diffusion in quantum many-body systems?

Good metals like copper and gold show a high optical reflectivity (shiny), electrical and thermal conductivity. Good metals are characterised by diffusive transport of coherent quasi-particle states and the resistivity (<< milli-Ohm-cm) in these materials is well within the Mott-Ioffe-Regel (MIR) limit, ha/e^2 (where a is the lattice constant). But in a wide range of strongly correlated materials and most notably in the strange metal regime of doped cuprates (high T_c superconductor) the resistivity exceeds the MIR limit and the picture of coherent quasi-particle based transport breaks down.

20. Kris Roberts - University of Otago - *Micromanaging Ultracold Atoms on a Macroscopic Scale**

We present our implementation of an optical tweezer system for controlled transport of ultra-cold atoms. The tweezer system [1] uses fast acousto-optic deflectors for two-dimensional control over the position of crossed-beam dipole traps. This system is capable of micrometer precision across a macroscopic distance up to 6 mm. Our system can independently track multiple clouds with time-shared tweezer beams which we use to demonstrate sequential binary splitting of an ultracold ^{87}Rb cloud into 25 clouds. The tweezers are readily applied to the production of multi-BECs [2] and to studying atomic collisions [3].

[1] K. O. Roberts, T. McKellar, J. Fekete, A. Rakonjac, A. B. Deb, and N. Kjaergaard, Steerable optical tweezers for ultracold atom studies, Opt. Lett. 39, 2012 (2014).
[2] A. B. Deb, T. McKellar and N. Kjaergaard, Optical runaway evaporation for multi-BEC production, arXiv:1409.4502
[3] A. Rakonjac, A. B. Deb, S. Hoinka, D. Hudson, B. J. Sawyer, and N. Kjaergaard, Laser based accelerator for ultracold atoms, Opt. Lett. 37, 1085 (2012)."

* with R. Thomas, T. McKellar, A.B. Deb, and N. Kjaergaard.

ABSTRACTS – Posters Session B contd. (in alphabetical order)

21. Seyed Nariman Saadatmand – The University of Queensland - *Novel Quantum Phases in Triangular J1-J2 Heisenberg Magnets on a Cylinder*

The recent discoveries about unique properties of novel magnetic materials like spin liquids and topological insulators led to a need for detailed reviewing of 2D spin many-body systems, and especially Antiferromagnetism (AFM). Most importantly are the nature of the ground-state and its properties of symmetry breaking. One of the widely considered models to study these behaviours is the Heisenberg model. In 1973 P. W. Anderson inferred that the Resonating-Valence-Bond (RVB) picture could play a pivotal role in the description of these new kinds of materials, and he conjectured that the ground-state of the Heisenberg model on a triangular lattice would be such an RVB state. However studies of this model have failed to find an RVB state and the evidence is very strong that the ground-state is a 120^o magnetically ordered state. If the RVB is to be realized on the triangular lattice, then additional interaction effects must be considered. A natural choice for this additional interaction is simply considering next-to-nearest-neighbour (NNN) couplings in frustrated systems. So in this project we studied the spin-1/2 isotropic J1-J2 model on a triangular lattice. We studied l×3 cylinders. This model contains a deep theoretical foundation to simulate frustrated magnets and could also describe some properties of real organic materials like κ-(BEDT-TTF)2Cu2(CN)3, Me3EtP[Pd(dmit)2]2, also some quasi-two-dimensional lattices like Cs2CuCl4, Cs2CuBr4, and RbFe(MoO4)2. We have performed numerical simulations of this model at zero temperature by employing the state-of-the-art Density Matrix Renormalization Group algorithm. Our comprehensive study of exchange interactions has led to find the complete phase diagram of the model, ground state properties, and some previously undescribed phases, such as long-range non-planar 120^o order and a Valance-Bond-Crystal.

22. Harley David Scammell - The University of New South Wales - *Violation of the Spin Statistics Theorem and the Bose-Einstein Condensation of Particles with Half Integer Spin*

We consider the Bose condensation of particles with spin 1/2. The condensation is driven by an external magnetic field. Our work is motivated by ideas of quantum critical deconfinement and bosonic spinons in spin liquid states. We show that both the nature of the novel Bose condensate and the excitation spectrum are fundamentally different from that in the usual integer spin case. We predict two massive (“Higgs”) excitations and two massless Goldstone excitations. One of the Goldstone excitations has a linear excitation spectrum and another has quadratic spectrum. This implies that the Bose condensate does not support superfluidity, the Landau criterion is essentially violated. We formulate a “smoking gun” criterion for searches of the novel Bose condensation.

23. Sophie Samira-Shamailov - Massey University - *Quasiparticles of widely tunable effective mass: The dispersion relation of atomic Josephson vortices*

The problem of two coupled linear Bose-Einstein condensates is treated numerically. We extend the known zero-velocity Josephson vortex solutions to non-zero velocities, thus obtaining the full dispersion. The Josephson vortex branch exhibits a critical point at which the inertial mass at zero momentum changes sign by diverging to positive and negative infinity. Therefore, by tuning the coupling strength about this critical point, a large range of inertial masses is accessible. Moreover, we compare the full Gross-Pitaevskii equations at small coupling to the analytically-solvable Sine-Gorden model, and show that the correspondence between them is not asymptotic. Finally, for unequal and non-zero self- and cross-species non-linearities, we find a new excitation branch. Whenever it exists, dark solitons and Josephson vortices are both dynamically stable while the new excitations are unstable.

24. Shih-Wei Su – Taiwan - *Position-dependent spin-orbit coupling for ultracold atoms*

Recently several schemes have been proposed to create the spin-orbit coupling (SOC) of the Rashba-Dresselhaus type for ultracold atoms by illuminating them with several laser beams. This leads to a number of distinct phenomena, such as formation of non-conventional Bose-Einstein condensates (BECs) of ultracold atoms affected by the SOC. Here we explore effects due to the position-dependence of the SOC for atomic BECs. The position-dependence provides domains of the stripe phases with the stripes oriented in different directions. It is shown that non-trivial structures can be formed at the boundaries of these domains, such as defects or arrays of vortices and anti-vortices."

25. Stuart Szigeti – The University of Queensland - *Realisable supersolid, Haldane insulating and charge-density wave phases in 1-D Josephson junction arrays*

In recent years, there has been a great deal of research into strongly-correlated bosonic systems, with a particular focus on the Bose-Hubbard model. Much of this interest has been spurred by the experimental realisation of controllable bosonic systems, such as Bose-Einstein condensates and Josephson junction arrays (JJAs). Historically, theoretical investigations into strongly correlated bosonic systems have been restricted to approximate treatments, such as mean-field and perturbative approaches, which rarely give accurate quantitative insights. However, one-dimensional lattice systems can be numerically studied with great accuracy via density-matrix renormalisation group (DMRG) methods. Here, we present the results of a numerical DMRG analysis of the one-dimensional Bose-Hubbard model with exponentially decaying interactions. We report the ground state phase diagram for this model, which indicates the existence of charge-density wave, supersolid and Haldane insulating phases. This model is commonly used to describe one-dimensional JJAs, and so these results should be of assistance to the experiments within EQuS's Superconducting- Single Charge Device Laboratory at the University of New South Wales.

26. Lewis Alexander Williamson - University of Otago - *Coarsening dynamics of a quenched spin-1 ferromagnetic condensate*

We study the dynamics of spin domain formation and coarsening in a spin-1 Bose-Einstein condensate quenched across the phase transition between polar and ferromagnetic phases by a sudden change in the quadratic Zeeman energy. We present the results of classical field simulations as evidence that the long-time coarsening of the domains follows a universal scaling law. The universal regime emerges for domain sizes much larger than the spin healing length, and is demonstrated by the spin correlation function at different times collapsing onto a single function when the position argument is scaled by a characteristic length L(t). In accordance with phase ordering kinetics, we find that $L(t)\sim t^{\{1/z\}}$, where z is the dynamical critical exponent that can be determined from our simulations.

27. Matthew Davis – The University of Queensland - *Emergence of order from turbulence in an isolated planar superfluid*
(with Tapio Simula, Kris Helmerson)

We study the relaxation dynamics of an isolated zero temperature quasi-two-dimensional superfluid Bose-Einstein condensate (BEC) that is imprinted with a spatially random distribution of quantum vortices. Following a period of vortex annihilation, we find that the remaining vortices self-organise into two macroscopic coherent `Onsager vortex' clusters that are stable indefinitely. We demonstrate that this occurs due to a novel physical mechanism --- the evaporative heating of the vortices --- that results in a negative temperature phase transition in the vortex degrees of freedom. At the end of our simulations the system is trapped in a non-thermal state. Our computational results provide a pathway to observing Onsager vortex states in a superfluid Bose gas.

28. Jan Zill – The University of Queensland - *Quench across a quantum phase transition in a one-dimensional Bose gas*
The so-called Lieb-Liniger gas of bosonic particles subject to pair-wise contact interactions in one dimension is a comparatively transparent, prototypical example of the class of integrable quantum models. The well-studied ground-state and equilibrium correlations of this model reveal important paradigmatic phenomenology including fermionization of the gas at strong repulsive interaction strengths and a quantum phase transition to a symmetry-broken many-body bound state at a finite attractive interaction strength. In recent years, the nonequilibrium dynamics following an abrupt change (quantum quench) of the interparticle interaction strength from zero to a repulsive value have been investigated by a number of authors. Here, we investigate the dynamics that result from a quench of the interactions across the quantum phase transition to the symmetry-broken phase. We calculate correlations of the Bose field in this nonequilibrium scenario for small systems of at most five particles by symbolic evaluation of coordinate Bethe-ansatz expressions for operator matrix elements between Lieb–Liniger eigenstates. Contrasting our results to those obtained for quenches to repulsive interactions, we isolate the contributions of multi-particle bound states to the relaxation dynamics and identify remnants of the quantum phase transition in the nonthermal effective equilibrium state of the post-quench system.

List of other attendees

Yasar Atas – The University of Queensland
Guillaume Gauthier – The University of Queensland
Alexei Gilchrist – Macquarie University
Jake Glidden – The University of Queensland
Kris Helmerson – Monash University
Karen Kheruntsyan – The University of Queensland
Halina Rubinsztein-Dunlop – The University of Queensland
Chris Vale - Swinburne University of Technology

Accommodation details

Researcher house
Twin 1- Alex Hamilton
Ulrich Zuelicke
Twin 2- Chris Vale
Kris Helmerson
Twin 3- Aviad Frydman
Stephen Eckel
Queen- Halina Rubinsztein-Dunlop

Postgrad cabin
Twin 1- Joachim Brand
Ross McKenzie

Research station
Disabled- Dima Gangardt
Karen Kheruntsyan
Twin 1- Matthew Davis
Michael Fraser
Twin 2- Shannon Whitlock
Brenton Hall

Research station
Twin 3- Thomas Stace
Andrew Doherty
Twin 4- Ben Powell
Anthony Jacko
Twin 5- Oleksandr Fialko
Dario Poletti
Twin 6- Warwick Bowen
Alexei Gilchrist
Twin 7- Nandan Pakhira
Shih-Wei Su
Twin 8- Andy Martin
Tapio Simula
Twin 9- Sophie Samira Shamailov
Cinthya Valeska Chianca Da Silva
Twin 10-Paul Dyke
Danny Baillie

Research station
Quad 1- Caterers
Quad 2- Guillaume Gauthier
Nathan McMahon
Jake Glidden
David Cavanagh
Quad 3- Pekko Kuopanportti
Sascha Hoinka
Yasar Atas
Jan Zill
Quad 4- Chris Bradly
Brendan Mulkerin
Harley David Scammell
Samuel Bladwell
Quad 5- Lewis Alexander Williamson
Kris Roberts
Rob McDonald
Jayson Cosme

7 Rainbow Cres
Jaan Oitmaa
Mark Baker
Stuart Szigeti
Tyler Neely
Michael Bromley

35 Flinders Ave
Xia-Ji Liu
Hui Hu
Kevin (5)
Nayana Shah
Carlos J. Bolech
Romila

Point Lookout (own arrangements):
Seyed Nariman Saadatmand + wife
Michael S Fuhrer + family
Christopher Lobb
Victor Galitski + family