## Conference Programme

## Tuesday-7 May / Seaside House

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|---|---|
| 14:00 – | **Arrival and Registration** |
| 19:00 – 21:00 | **Dinner** |

## Wednesday-8 May / Seaside House

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|---|---|
| 07:00 – 08:45 | **Breakfast** |
| 08:45 – 09:00 | **Opening Speech by President Jonathan Dorfan** |
| 09:00 – 09:45 | **Klaus Mølmer**<br>*"Needles in hay stacks - quantum memories with inhomogeneous spin ensembles"* |
| 09:45 – 10:15 | **Emi Yukawa**<br>*"SU(3) spin-nematic squeezing in a collective spin-1 atomic system"* |
| 10:15 – 10:45 | **Pietro Massignan**<br>*"Synthetic gauge fields for ultracold atoms in synthetic dimensions"* |
| 10:45 – 11:15 | **Coffee Break** |
| 11:15 – 12:30 | **Poster Preview** |
| 12:30 – 14:30 | **Lunch**<br>13:45 Nabi-chan visits C3QS!<br>(*Nabi-chan is a mascot representing Onna village) |
| 14:30 – 15:15 | **Hidetoshi Katori**<br>*"Precise Frequency Comparisons of Optical Lattice Clocks"* |
| 15:15 – 16:30 | **Poster Preview** |
| 16:30 – 17:15 | **Tea Break** |
| 17:15 – 18:00 | **Hideo Mabuchi**<br>*"Coherent feedback and quantum photonic circuit theory"* |
| 18:00 – 19:00 | **Poster Session** |
| 19:00 – 21:00 | **Dinner** |

## Thursday-9 May / OIST Campus (Lectures@B250)

07:00 – 08:15 **Breakfast**

**(OIST Campus)**

09:00 – 09:45 **Eugene Polzik**
*"Quantum teleportation with macroscopic material objects"*

09:45 – 10:15 **Veronica Ahufinger**
*"Single-site addressing of ultracold atoms in an optical lattice via position dependent adiabatic passage"*

10:15 – 10:45 **Alexander Badrutdinov**
*"Electrons on helium: towards quantum engineering"*

10:45 – 11:15 **Coffee Break**

11:15 – 12:00 **Vlatko Vedral**
*"Extracting quantum work statistics and fluctuation theorems by single qubit interferometry"*

12:00 – 13:00 **OIST Campus Tour**

13:00 – 14:00 **Lunch**

14:00 – **Excursion**

19:10 – 21:00 **Dinner at Renaissance Hotel**
**(The bus departure time - 21:30)**

## Friday-10 May / Seaside House

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|---|---|
| 07:00 – 09:00 | **Breakfast** |
| 09:00 – 09:45 | **Yasunobu Nakamura**<br>*"Driven artificial atoms in circuit quantum electrodynamics"* |
| 09:45 – 10:15 | **Michèle Heurs**<br>*"Exploring coherent feed-forward control for quantum noise cancellation in interferometric gravitational wave detectors"* |
| 10:15 – 10:45 | **Chandrashekar Madaiah**<br>*"Secured Quantum Memory by Induced Localization"* |
| 10:45 – 11:15 | **Coffee Break** |
| 11:15 – 12:00 | **Christiane Koch**<br>*"Optimal control theory for quantum gates in open quantum systems"* |
| 12:00 – 12:30 | **Wei Cui**<br>*"Quantum Feedback Control of Rabi Oscillation in Circuit QED"* |
| 12:30 – 14:30 | **Lunch** |
| 14:30 – 15:15 | **Masahito Ueda**<br>*"Information thermodynamics and fluctuation theorems"* |
| 15:15 – 15:45 | **Cecilia Cormick**<br>*"Dissipative preparation of steady-state multipartite entanglement"* |
| 15:45 – 16:30 | **Ite Yu**<br>*"Interaction between Two Stopped Light Pulses"* |
| 16:30 – 17:15 | **Tea Break** |
| 17:15 – 18:00 | **Tilman Pfau**<br>*"Trilobites and other molecular animals: How Rydberg-electrons catch ground state atoms"* |
| 18:00 – 19:00 | **Poster Session** |
| 19:00 – 21:00 | **Dinner** |

## Saturday-11 May / Seaside House

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|---|---|
| 07:00 – 09:00 | **Breakfast** |
| 09:00 – 09:30 | **Adriana Marais**<br>*"Decoherence-assisted transport in quantum networks"* |
| 09:30 – 10:00 | **Andreas Ruschhaupt**<br>*"Shortcuts to adiabaticity"* |
| 10:00 – 10:30 | **Florian Mintert**<br>*"Optimal control of quantum coherence in disordered composite quantum systems"* |
| 10:30 – 11:15 | **Coffee Break** |
| 11:15 – 12:00 | **Kae Nemoto**<br>*"Precise control of NV Centers in Diamond for Quantum Networks"* |
| 12:00 – 12:30 | **Gary Wolfowicz**<br>*"Atomic clock transitions in silicon-based spin qubits"* |
| 12:30 – 14:30 | **Lunch** |
| 14:30 – 15:15 | **Yuimaru Kubo**<br>*"Hybrid Quantum Circuit with a Superconducting Qubit and an Electron Spin Ensemble"* |
| 15:15 – 15:45 | **Mikio Nakahara**<br>*"Concatenated Composite Pulses: Toward High-Precision Quantum Gate Implementation"* |
| 15:45 – 16:30 | **Yoshiro Takahashi**<br>*"Ultracold Ytterbium Atoms in an Optical Lattice"* |
| 16:30 – 17:15 | **Tea Break** |
| 17:15 – 18:00 | **Christian Kurtsiefer**<br>*"Coupling single photons to single atoms"* |
| 18:00 – 19:00 | **Panel Discussion** |
| 19:00 - | **BBQ Dinner** |

## Sunday-12 May / Seaside House

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|---|---|
| 07:00 – 09:00 | **Breakfast** |
| | **Departure** |

# Needles in hay stacks - quantum memories with inhomogeneous spin ensembles

**Klaus Mølmer**
*University of Aarhus, Aarhus, Denmark*

A recent proposal to implement multi-bit quantum memories in large spin ensembles will be reviewed. The long lifetimes achievable in spin systems and the strong interactions and fast processing in circuit cavity quantum electrodynamics are combined into a hybrid quantum computing device. Rather than storing the qubit information in individual spins, every qubit is stored collectively as a spin wave. This amplifies the weak single spin interaction with the cavity field by many orders of magnitude, but the scheme is prone to decoherence due to inhomogeneities in the spin coupling strengths and transition frequencies. New theoretical analyses will be presented, which address the imperfections and losses in the system and which show that inhomogeneous broadening can be refocused and is, indeed, a useful property of the spin system.

# SU(3) spin-nematic squeezing in a collective spin-1 atomic system

**Emi Yukawa**
*National Institute of Informatics, Tokyo, Japan*

Bose-Einstein condensates (BECs) are considered to be among the excellent resources applicable to quantum meteorology due to their macroscopic quantum nature and controllability in the inter-atomic interactions. Spin squeezing in spinor BECs is expected to be instrumental in improving the precision of atomic clocks and interferometers beyond the standard quantum limit. The properties of spin squeezing are well understood [1]; however, squeezing originating from spin degrees of freedom is not necessarily confined to the SU(2) manifold of the spin vector. In general, magnetic multipole moments can also take part in squeezing in spinor BEC systems in addition to the spin vector. In the case of a spinor BEC with spin quantum number 1, we may expect some trade-off relations in squeezing between the spin vector and the quadrupolar moment (nematic tensor), which together obey the SU(3) algebra. By analogy with the flavors of quarks, properties of spin-nematic squeezing in an SU(2) subgroup involving the isospin have been investigated [2]. However, a more comprehensive classification of squeezing in a spin-1 BEC remains to be formulated, and the optimization of the general spin-nematic squeezing, which is crucial for precision measurement, has yet to be developed.

We find that arbitrary SU(2) sets of the spin vector and the nematic tensor can be categorized into two classes according to their structure constants of the underlying Lie algebras, which implies that two qualitatively different types of squeezing can occur in a spin-1 BEC system: one is a spin-nematic squeezing with the structure constant of 1 (type 1), and the other is characterized by the structure constant of 2 (type 2), which is equivalent to isospin squeezing [2-4] and has recently been observed experimentally [4]. We show that both types of squeezed states in these SU(2) subspaces can be realized through one-axis twisting. We construct a Hamiltonian for one-axis twisting with respect to each SU(2) manifold and show that minimized fluctuations in both types of squeezing asymptotically approach O(N1/3) in the limit of large number of particles N. Furthermore, we find that the minimized fluctuation of type 1 is about a quarter of that of type 2 due to the difference in their structure constants.

[1] M. Kitagawa and M. Ueda, Phys. Rev. A 47, 5138 (1993).
[2] Ö. E. Müstecapıǒglu, et. al., Phys. Rev. A 66, 033611 (2002).
[3] J. D. Sau et. al. New J. Phys. 12, 085011 (2010).
[4] C. D. Hamley et. al., Nature Phys. 8, 305 (2012).

# Synthetic gauge fields for ultracold atoms in synthetic dimensions

**Pietro Massignan**
*The Institute of Photonic Sciences, Barcelona, Spain*

It has been recently proposed that an internal or local degree of freedom (such as the spin state of a particle) may be used as an extra-dimension, which is generally discrete and compact. Moreover, boundary conditions in the extra-dimension may be left open, or may be closed to become periodic, or even twisted with an arbitrary phase to simulate, e.g., Moebius strips. Here we demonstrate that by employing atoms on an optical lattice with two-photon Raman-assisted tunnelings in the "spin dimension" (which effectively yield a synthetic spin-orbit coupling), one is able to create optical lattices pierced by a constant, non-staggered synthetic magnetic flux. With this system, we discuss prospects to investigate quantum Hall physics and Hofstadter-type butterfly spectra.

# Precise Frequency Comparisons of Optical Lattice Clocks

**Hidetoshi Katori**
*The University of Tokyo, Tokyo, Japan*

The performance of clocks is described in terms of accuracy and stability. While single-ion optical clocks demonstrate supreme frequency uncertainty [1] of 0.8×10-17, the necessary averaging time of about 105 s is limited by the quantum projection noise (QPN). The clocks' stability, therefore, becomes a serious experimental concern when further reducing the clock uncertainty down to 1×10-18. An optical lattice clock improves the clock stability as 1/√N by interrogating a large number N of atoms. By rejecting the Dick effect [2], the Allan standard deviation of 4×10-16/√τ/s was demonstrated [3] to allow exploring 1×10-17 uncertainty in τ ≈ 1,600 s, which corresponded to the QPN limit for N ≈ 1,000 atoms. Currently, the blackbody radiation (BBR) shift is one of the most serious sources of uncertainties for Sr and Yb based optical lattice clocks in achieving 10-17 uncertainty. We are developing cryogenic clocks, in which the interrogated atoms are shielded by 70-K-cold walls, to dramatically reduce the BBR shift. On the other hand, an appropriate choice of atomic species, such as Hg, effectively reduces the BBR shift. We will report the current status of the clock comparison comprising of Sr (x2) and Hg (x2) clocks, both of which we expect to be operated without dead time in the future. We also discuss possible impacts of frequency comparison of two clocks operated in distant places [4], which may allow relativistic geodesy.

References

[1] C. W. Chou, et al. Phys. Rev. Lett. 104, 070802 (2010).

[2] G. J. Dick, J. D. Prestage, C. A. Greenhall, and L. Maleki, in 22nd PTTI Applications and Planning Meeting, 1990), p. 487.

[3] M. Takamoto, T. Takano, and H. Katori, Nature Photon. 5, 288 (2011).

[4] A. Yamaguchi, et al., Appl. Phys. Exp. 4, 082203 (2011).

# Coherent feedback and quantum photonic circuit theory

**Hideo Mabuchi**
*Stanford University, Stanford, California, USA*

Methods being developed for the analysis of coherent feedback in quantum control provide an important new foundation for quantum photonic circuit theory. In this talk I will review basic ideas of coherent feedback analysis and paint a picture of how contemporary approaches in electrical engineering can be expanded to accommodate quantum coherence, fluctuations, and entanglement in complex photonic circuits. I will mention motivating applications both in ultra-low power classical information processing and in quantum information processing, show some related experimental results in cavity QED, and present some new ideas about high-level circuit architectures that are well matched to the physics of nanophotonics and quantum optics.

# Quantum teleportation with macroscopic material objects

**Eugene Polzik**
*University of Copenhagen, Copenhagen, Denmark*

The recent experiment on quantum teleportation between macroscopic spin oscillators will be described [1]. The deterministic teleportation allows for the better-than-classical transmission of dynamically evolving sequence of spin states from one location to another. The extension of the idea of an oscillator with a negative frequency from spin ensembles to entanglement and measurements beyond the standard quantum limit with mechanical oscillators will be introduced. Finally, quantum optical interface with the electronic radio-frequency oscillator via strong electro-mechanical coupling will be reported.

References

[1] H. Krauter et al. To appear in Nature Physics. arXiv:1212.6746.

# Single-site addressing of ultracold atoms in an optical lattice via position dependent adiabatic passage

**Veronica Ahufinger**
*Universitat Autonoma de Barcelona, Bellaterra (Barcelona), Spain*

Authors: D. Viscor et al

Ultracold neutral atoms in an optical lattice with single-atom and single-site resolution constitute an ideal physical system to investigate strongly correlated quantum phases which, in turn, has interesting applications in quantum optics, quantum simulation and quantum information processing among others. Unfortunately, for typical lattice spacings of strongly correlated systems, the diffraction limit imposes severe restrictions on the addressability of individual lattice sites. To overcome this limitation different techniques have been investigated like the generation of position dependent energy shifts on the atom by spatially dependent electric and magnetic fields, the use of a scanning electron microscopy system to remove atoms from individual sites with a focused electron beam or the implementation of high resolution fluorescence imaging techniques, that make use of an optical system with high numerical aperture [1,2].

In this context, we propose [3] a single-site addressing implementation based on the sub-wavelength localization via adiabatic passage (SLAP) technique [4]. We consider a sample of ultracold neutral atoms loaded into a two-dimensional optical lattice with one atom per site. The internal degrees of freedom of each atom are modeled as a three-level system in interaction with a pump and a Stokes laser pulse with Gaussian shaped spatial distributions. The pump field presents a node centered at the lattice site that we want to address. Assuming that all the atoms in the optical lattice are initially in the same internal ground state and applying the standard counterintuitive temporal sequence of the light pulses required in adiabatic passage techniques, we show that it is possible to adiabatically transfer all the atoms, except the one at the node of the pump field, to an auxiliary ground state. This technique allows for the preparation, manipulation, and detection of atoms with a better spatial resolution than the one expected within the diffraction limit, which either relaxes the requirements on the optical setup used or extends the achievable spatial resolution to lattice spacings smaller than accessible to date. Specifically, we show that this process is performed with higher efficiency and yields better spatial resolution than the coherent

population based techniques [5]. Also, we demonstrate that our addressing technique requires shorter times than in the adiabatic spin-flip technique discussed in [2], and that larger addressing resolutions can be achieved using similar focusing of the addressing fields. Moreover, our technique has the additional advantage that it can be applied between two degenerated ground-state levels. Analytic expressions for the achievable addressing resolution and efficiency are derived and compared to numerical simulations for 87Rb atoms in state-of-the-art optical lattices.

References

[1] M. Lewenstein, A. Sanpera and V. Ahufinger, "Ultracold atoms in optical lattices. Simulating quantum many-body systems". Oxford University Press (2012).
[2] C. Zhang, S. L. Rolston, and S. Das Sarma, Phys. Rev. A 74, 042316 (2006); C. Weitenberg, M. Endres, J. F. Sherson, M. Cheneau, P. Schauss, T. Fukuhara, I. Bloch, and S. Kuhr, Nature 471, 319 (2011).
[3] D. Viscor, J. L. Rubio, G. Birkl, J. Mompart, and V. Ahufinger, Phys. Rev. A 86, 063409 (2012).
[4] J. Mompart, V. Ahufinger, and G. Birkl, Phys. Rev. A 79, 053638 (2009).
[5] G. S. Agarwal, and K. T. Kapale, J. Phys. B: At. Mol. Opt. Phys. 39, 3437 (2006).

# Electrons on helium: towards quantum engineering

**Alexander Badrutdinov**
*Okinawa Institute of Science and Technology, Okinawa, Japan*

Electrons floating on the surface of liquid helium are an example of a physical system with unique parameters. Confined in vacuum, in close vicinity of the helium surface in a potential well, electrons form a two-dimensional (2D) non-degenerate electron liquid, where an effective electron mass is equal to the bare electron mass. In contrast to 2D-electron gases in semiconductor heterostructures, the interactions between electrons on helium are essentially unscreened, as a result, strong correlation effects are present. The absence of host material and, hence, defects and impurities, results in an exceptionally high mobility of electrons on helium up to 108 cm2/V s, which is much higher than the typical mobility of semiconductor-based 2D-electron gases (order of 106 cm2/V s). The only interactions, which limit the mobility, are scattering from a few helium vapor atoms and from surface capillary waves (ripplons). It has been predicted that isolation of surface electrons from the environment will result in long coherence time of electron states, and a number of proposals to employ electrons on helium for the quantum computation were made. As a candidate for a qubit, they considered surface states of electrons, as well as spin states, and, more recently, hybrid architectures, in which the lateral motion and the spin state of an electron are coupled to a superconducting cavity. Experimentally, single electron confinement and detection has already been demonstrated, suggesting the feasibility of electrons-on-helium qubit, though much remains to be done. The aim of this presentation is to give an introduction to the electrons-on-helium system, and to review a recent progress in the field, focusing on quantum computational prospects.

# Extracting quantum work statistics and fluctuation theorems by single qubit interferometry

**Vlatko Vedral**
*University of Oxford, Oxford, UK / National University of Singapore, Singapore*

I will first introduce the quantum version of the Jarzynski equality coming from non-equilibrium statistical mechanics. I will then describe an experimental scheme to verify the Jarzynski relations using current technology. Specifically, I will show that the characteristic function of the work distribution for a non-equilibrium quench of a general quantum system can be extracted from Ramsey interferometry of a single probe qubit. I will argue that this scheme paves the way for the full characterisation of non-equilibrium processes in a variety of complex quantum systems ranging from single particles to many-body atomic systems and spin chains. I intend to discuss this work within the context of the Second Law of thermodynamics and the (apparent) irreversibiltiy of natural phenomena.

# Driven artificial atoms in circuit quantum electrodynamics

**Yasunobu Nakamura**
*The University of Tokyo, Tokyo, Japan*

Circuit quantum electrodynamics has proved to be a key concept in quantum information processing in superconducting circuits. We have investigated dynamical response of a superconducting flux qubit coupled to a coplanar waveguide resonator. The qubit is read out through a dispersive frequency shift of the resonator, and the signal is amplified by a Josephson parametric amplifier, which allows continuous nondemolition measurement of the qubit evolution. Under a resonant driving field of the qubit, an effective Delta-system is realized in the dressed states, in which we engineer quantum optical functions in the microwave domain.

# Exploring coherent feed-forward control for quantum noise cancellation in interferometric gravitational wave detectors

**Michèle Heurs**
*Albert-Einstein-Institut Hannover, Hannover, Germany*
*Leibniz Universität Hannover, Hannover, Germany*

Quantum noise provides the limit to measurement precision in various physical systems ranging from atomic spin measurements, via displacement sensing in micro-optomechanical setups to gravitational wave detectors (GWD). Currently operating interferometric GWDs are already limited by quantum noise (the photon statistics causing shot noise) for high measurement frequencies, and the next generation of GWDs – currently under construction – will additionally be limited by radiation pressure noise (the „flip side" of photon statistics) at intermediate measurement frequencies. In such quantum noise limited systems there is a fundamental problem with traditional measurement based control as measurement destroys information. Coherent control on the other hand avoids this limitation: the goal of quantum state preparation, manipulation or readout is achieved by appropriately designed interference effects. This has been successfully demonstrated in the work on linear quantum stochastic control theory by M. James, H. Nurdin and I. Petersen [1] and in H. Mabuchi's experimental follow-up [2]. The latter is a pioneering demonstration of the principle of coherent control applied to a basic quantum optical system. Recent proposals by M. Tsang and C. Caves [3,4] put forward the idea of coherent control for quantum noise cancellation in optomechanical systems to avoid the need for measurement and thereby evade the ensuing backaction and disturbance of the system.
I will present our ongoing work on investigating QNC techniques in quantum optics and interferometry using coherent control to exploit its advantages for systems exhibiting noise at the quantum limit. In contrast to the pioneering work by H. Mabuchi which employs coherent feedback control we are working on a first experimental realisation of coherent feed-forward control for backaction cancellation in an optomechnical system (as proposed by M. Tsang [3]). The research we are performing is aimed at (but not limited to) enhancing the sensitivity of next generation interferometric gravitational wave detectors.

References

[1] M. James, H. Nurdin and I. Petersen., IEEE Trans. Autom. Control, Vol. 53, Iss. 8, 1787 (2008)
[2] H. Mabuchi, Phys. Rev. A 78, 032323 (2008)
[3] M. Tsang, Phys. Rev. Lett. 102 250403 (2009)
[4] M. Tsang and C. M. Caves, Phys. Rev. Lett. 105, 123601 (2010)

# Secured Quantum Memory by Induced Localization

**Chandrashekar Madaiah**
*Okinawa Institute of Science and Technology, Okinawa, Japan*

Storing and transferring quantum states efficiently between nodes of an information processing network is of paramount importance for scalable quantum computing. With a brief introduction to the topic, my talk will present a new protocol for perfect storage and retrieval of quantum state by combining the protocols for localizing the quantum state using disordered quantum walks and perfect state transfer.
This protocol can store and transfer arbitrary quantum state with high fidelity without giving chance for the eavesdropper to retrieve any useful information in the process. In addition, this can find a potential application in quantum cryptography.

# Optimal control theory for quantum gates in open quantum systems

**Christiane Koch**
*University of Kassel, Kassel, Germany*

The standard approach to gate optimization for open quantum systems requires propagation of a full operator basis to evaluate the gate fidelity. We show that the time evolution of three states,irrespective of the dimension of Hilbert space, is sufficient to assess how well a desired unitary is implemented and reconstruct the unitary close to a given open system evolution. This observation also allows for defining an efficient protocol for quantum device characterization.
We apply quantum gate optimization to two transmon qubits that interact via a cavity.

# Quantum Feedback Control of Rabi Oscillation in Circuit QED

**Wei Cui**
*Digital Materials Laboratory, RIKEN, Saitama, Japan*

We present a theoretical study of quantum feedback control for a superconducting qubit which is coupled to a microwave cavity. We design the error based feedback controller to compensate the uncertainties and optimal stabilize the Rabi oscillations.   It is shown that there exist well-defined ranges of parameters for which Rabi oscillations persist indefinitely.

In particular, we demonstrate clear that feedback control remarkably increases the state fidelity and fight against measurement induced noises.

# Information thermodynamics and fluctuation theorems

**Masahito Ueda**
*The University of Tokyo, Tokyo, Japan*

The second law of thermodynamics presupposes a clear-cut distinction between the controllable and uncontrollable degrees of freedom by means of macroscopic operations. The cutting-edge technologies in quantum information and nanoscience seem to require us to abondon such a working hypothesis in favor of the distinction between the accessible and inaccessible degrees of freedom. In this talk, I will talk about the fundamentals of such information thermodynamics together with the related new results on fluctuation theorems.

# Dissipative preparation of steady-state multipartite entanglement

**Cecilia Cormick**
*Institute of Theoretical Physics, Ulm University, Ulm, Germany*

We propose a method to create multipartite-entangled states of spin systems by means of engineered dissipative processes. The model we consider consists of a spin chain along which excitations are allowed to hop, while the on-site energy can be shifted by the coupling to a harmonic oscillator. We show that for small chains, by damping the harmonic oscillator the system can be driven towards an entangled asymptotic state which corresponds to the ground state of an XX-spin chain with transverse field. We discuss the role of non-Markovianity of the environment and propose an implementation using ions in a linear trap.

# Interaction between Two Stopped Light Pulses

**Ite Yu**
*National Tsing Hua University, Hsinchu, Taiwan*

The efficiency of a nonlinear optical process is equal to the product of the transition rate and interaction time. If the interaction time can be maximized, it is possible to achieve high efficiency even below single-photon level. Here, we report the experi-mental demonstration that two light pulses were made motionless and interacted with each other through a medium. To demonstrate the enhancement of optical nonlinear efficiency, we used the process of one optical pulse switched by another. A light pulse was stopped as the atomic excitation [1] and another is stopped in the form of the electromagnetic wave [2]. The stored atomic excitation is switched by the stationary electromagnetic wave. Because the two light pulses are motionless, a very long inter-action time of 7 μs was achieved. This interaction time makes our system analogous to the scheme of trapping light pulses by an optical cavity with a very high Q factor of approximately 10^10. Our result shows that motionless light pulses can activate switching at 0.56 photons per atomic absorption cross section [3]. The great potential of the scheme is that the switching efficiency is not limited to the present result but can be further improved by increasing the optical density of the medium. This work advances the technology of low-light-level nonlinear optics and quantum information manipulation utilizing photons.

# Trilobites and other molecular animals: How Rydberg-electrons catch ground state atoms

**Tilman Pfau**
*University of Stuttgart, Stuttgart, Germany*

We report on laser spectroscopy results obtained in a dense and frozen Rydberg gas. Novel molecular bonds resulting in ultralong-range Rydberg dimers were predicted [1] and dimers as well as trimers in different vibrational states were found [2]. Some of these states are predicted to be bound by quantum reflection. Lifetime measurements confirm this prediction. Coherent superposition between free and bound states have been investigated [3]. Recently we have also confirmed that in an electric field these homonuclear molecules develop a permanent dipole moment [4]. We recently extended these studies to very large Rydberg bound clusters in a Bose-Einstein Condensate, which also cause mechanical effects in quantum gases once the frozen gas limit is left.

References

[1] C. H. Greene, A. S. Dickinson, and H. R. Sadeghpour, Phys. Rev. Lett. 85, 2458 (2000).

[2] V. Bendkowsky, B. Butscher, J. Nipper, J. P. Shaffer, R. Löw, T. Pfau, Nature 458, 1005 (2009); V. Bendkowsky, B. Butscher, J. Nipper, J. Balewski, J. P. Shaffer, R. Löw, T. Pfau, W. Li, J. Stanojevic, T. Pohl, and J. M. Rost, Phys. Rev. Lett. 105, 163201 (2010).

[3] B. Butscher, J. Nipper, J. B. Balewski, L. Kukota, V. Bendkowsky, R. Löw, and T. Pfau Nature Physics 6, 970–974 (2010).

[4] W. Li, T. Pohl, J. M. Rost, Seth T. Rittenhouse, H. R. Sadeghpour, J. Nipper, B. Butscher, J. B. Balewski, V. Bendkowsky, R. Löw, T. Pfau, Science 334, 1110 (2011).

# Decoherence-assisted transport in quantum networks

**Adriana Marais**
*University of KwaZulu-Natal, Durban, South Africa*

While vast scale separation has meant a traditional distinction between quantum mechanics and biology, recently evidence of quantum coherence in highly efficient photosynthetic light-harvesting complexes at physiological temperatures has raised the intriguing question of whether non-trivial quantum effects play a role in living systems. Many models of environment-assisted quantum transport have been proposed, typically within approximate spin-boson models of the system.

We show, however, that interaction with a finite spin bath can also assist quantum efficiency. Our system is a fully connected network of qubits with equal coupling strengths and site energies. The dynamics of a single excitation in the symmetric network are compared with the case where the symmetries that prevent distinguishing sites are removed via a pure dephasing interaction between each site and a spin environment at zero temperature. We show analytically that the maximum probability of transfer through the network can be increased by decoherence-induced site energy shifts, and that there are cases where transfer can be guaranteed.

Furthermore, we show that these effects persist at physiological temperatures, i.e. that near perfect transfer can be achieved for biologically relevant parameter regimes. Applying this model to the Fenna–Matthews–Olson photosynthetic antenna complex, we show numerically that energy transfer is significantly assisted by a decoherent interaction between each network site and a respective spin environment at 300 K. These results motivate further study of the degree to which a spin bath can provide a sufficiently realistic model for the environment of photosynthetic complexes and biological systems in general.

# Shortcuts to adiabaticity

**Andreas Ruschhaupt**
*University College Cork Cork Ireland*

Quantum adiabatic processes -that keep constant the populations in the instantaneous eigenbasis of a time-dependent Hamiltonian- are very useful to prepare and manipulate states, but take typically a long time. This is often problematic because decoherence and noise may spoil the desired final state, or because some applications require many repetitions. ""Shortcuts to adiabaticity"" are alternative fast processes which reproduce the same final populations, or even the same final state, as the adiabatic process in a finite, shorter time. We present such ""shortcuts to adiabaticity"" for the manipulation of the motional state of atoms or a condensate in a harmonic trap. Especially, we show the stability of the shortcuts concerning different types of errors like noise errors and systematic errors. Moreover, we present shortcuts to adiabatic passage from one internal atomic state to another. Again we especially study and compare the stability of different schemes concerning different types of errors.

References

[1] Xi Chen, A. Ruschhaupt, S. Schmidt, A. del Campo, D. Guéry-Odelin and J. G. Muga, Phys. Rev. Lett. 104, 063002 (2010)
[2] Xi Chen, I. Lizuain, A. Ruschhaupt, D. Guéry-Odelin and J. G. Muga, Phys. Rev. Lett. 105, 123003 (2010)
[3] S. Ibáñez, Xi Chen, E. Torrontegui, J. G. Muga and A. Ruschhaupt, Phys. Rev. Lett. 109, 100403 (2012)
[4] E. Torrontegui, S. Ibáñez, S. Martínez-Garaot, M. Modugno, A. del Campo, D. Guéry-Odelin, A. Ruschhaupt, Xi Chen and J. G. Muga, Adv. At. Mol. Opt. Phys. (2013), in press

# Optimal control of quantum coherence in disordered composite quantum systems

**Florian Mintert**
*Freiburg Insitute for Advanced Studies, Albert-Ludwigs University of Freiburg, Freiburg, Germany*

We present pulse shaping techniques that allow us to control quantum systems with external time-dependent fields that contain only a few predefined frequency components. By doing this, we respond to experimental challenges in implementing the broad band pulses typically generated with existing optimal control algorithms.

With our approach we target the design of control pulses for the manipulation of ensembles of NV centers and the interaction of such ensembles with microwave cavities. We construct high fidelity pulses that cope with inhomogeneous broadening in the ensemble as well as inhomogeneity in the control field itself.

In a similar fashion also interaction mechanisms can be modified through suitably shaped driving.

We investigate which driving yields the best approximation to the dynamics induced by a desired effective Hamiltonian. The viability of our approach is proven for the simple example of a driven three-level Lambda system and shall ultimately help to improve the precision of quantum simulations.

# Precise control of NV Centers in Diamond for Quantum Networks

**Kae Nemoto**
*National Institute of Informatics, Tokyo, Japan*

In recent years, NV centers in diamond has attracted significant attention as a candidate for quantum information devices. The negatively charged NV center, in particular, has been intensely investigated [1-3]. NV- centers host both an electron spin qubit and an nitrogen nuclear spin, in our case a nuclear spin-1/2 of 15N is imbedded. The ground state of the electron spin qubit has a long coherence time and an optical transition at 637nm. The nuclear spins may be considered as a long-lived quantum memory, which has been experimentally demonstrated [2]. Because of these preferable quantum properties, NV centers have been considered as a good candidate for implementation of quantum information processing and there has been a number of theoretically propose designs for quantum information processing [3]. Despite of the promising nature of NV diamond, the recent theoretical and experimental developments reveal challenges to achieve the gate fidelity to realize quantum information processing. For instance, there are phonon-involved transitions and state mixing in NV centers. Even though these events might occur with relatively small possibilities, these could lead the whole quantum information system to be catastrophic failure. In this presentation, we discuss these physical imperfections and how we can control them to achieve the accuracy for the information task at hand.

References

[1] Michael Trupke, William J. Munro, Kae Nemoto and Jörg Schmiedmayer, Progress in informatics, No.8, pp. 33-37,(2011), and also see the references in this article.

[2] E. Togan, Y. Chu, A. S. Trifonov, L. Jiang, J. Maze, L. Childress, M. V. G. Dutt, A. Sorensen, P. Hemmer, A. S. Zibrov, and M. D. Lukin, Nature (London) 466, 730 (2010)

[3] N. Y. Yao, L. Jiang, A. V. Gorshkov, Z. X. Gong, A. Zhai, L. M. Duan, I. Cirac and M. D. Lukin., Phys. Rev. Lett. 106, 040505, (2010).

# Atomic clock transitions in silicon-based spin qubits

**Gary Wolfowicz**
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*London Centre for Nanotechnology, University College London, London, UK*

A major challenge in using spins in the solid state for quantum technologies is protecting them from sources of decoherence. This can be addressed, to varying degrees, by improving material purity or isotopic composition for example, or active error suppression methods such as dynamic decoupling or even combinations of the two. However, a powerful method applied to trapped ions in the context of frequency standards and atomic clocks, is the use of particular spin transitions which are inherently robust to external perturbations.

Here we show that such `clock transitions' (CTs) can be observed for electron spins in the solid state, in particular using bismuth donors in silicon, leading to dramatic enhancements in the electron spin coherence time. We find that electron spin qubits based on CT become less sensitive to the local magnetic environment, including the presence of 29Si nuclear spins as found in natural silicon. We probed such sensitivity from that of a pure electron to the CT, allowing us to understand the various decoherence mechanisms involved. We expect the use of such CTs will be of additional importance for donor spins in future devices, mitigating the effects of magnetic or electric field noise arising from nearby interfaces.

# Hybrid Quantum Circuit with a Superconducting Qubit and an Electron Spin Ensemble

**Yuimaru Kubo**
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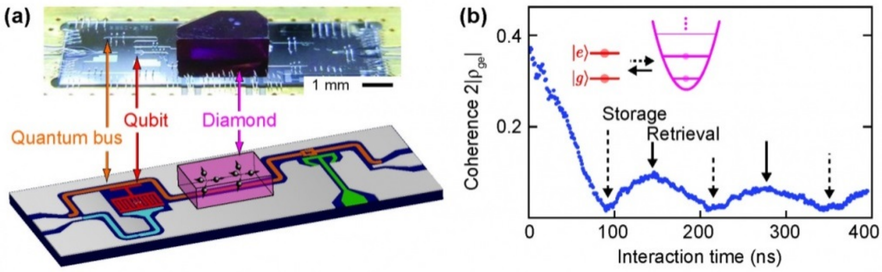
We report the experimental realization of a hybrid quantum circuit combining a superconducting qubit and an ensemble of electronic spins (Fig. a). The qubit, of the transmon type, is coherently coupled to the spin ensemble consisting of nitrogen-vacancy (NV) centers in a diamond crystal via a frequency-tunable superconducting resonator acting as a quantum bus[1,2]. Using this circuit, we prepare arbitrary superpositions of the qubit states that we store into collective excitations of the spin ensemble and retrieve back into the qubit later on (Fig. b) [3]. These results constitute a first proof of concept of spin-ensemble based quantum memory for superconducting qubits.We also report a new method for detecting the magnetic resonance of electronic spins at low temperature with a qubit using the hybrid quantum circuit [4].




References

[1] Y. Kubo et al., Phys. Rev. Lett., 105, 140502 (2010).

[2] Y. Kubo et al., Phys. Rev. A, 85, 012333 (2012).

[3] Y. Kubo et al., Phys. Rev. Lett., 107, 220501 (2011).

[4] Y. Kubo et al., Phys. Rev. B, 86, 064514 (2012).

# Concatenated Composite Pulses: Toward High-Precision Quantum Gate Implementation

**Mikio Nakahara**
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Pulse sequences called composite pulses have been developed in NMR to suppress one of two dominant errors; a pulse length error and an off-resonance error. These composite pulses implement high-precision gates out of low-fidelity gates in quantum information processing. We develop a general prescription to design a single-qubit ConCatenated Composite Pulse (CCCP) that is robust against both types of errors simultaneously. We introduce a criterion called the residual error preserving" property, which is satisfied by some composite pulses and is a sufficient condition to be a constituent of a CCCP. Then we introduce a general method to design CCCPs with reduced execution time and less number of pulses.
We implemented our CCCPs with an NMR quantum computer and demonstrated the high precision of the gates experimentally.

This contribution is based on Phys. Rev. A 84 (2011) 062311 and J. Phys. Soc. Jpn. 82 (2013) 014004.
This is a joint work with Masamitsu Bando, Tsubasa Ichikawa and Yasushi Kondo.

# Ultracold Ytterbium Atoms in an Optical Lattice

**Yoshiro Takahashi**
*Kyoto University, Kyoto, Japan*

I will report our recent experiments using quantum degenerate ytterbium (Yb) atoms loaded in an optical lattice. We have successfully created Bose-Einstein Condensates of 3 isotopes, and Fermi degeneracies of 2 isotopes, and a Bose-Bose mixture, and two Bose-Fermi mixtures, as well as Fermi-Fermi mixture with spin degrees of freedom. The created Yb quantum gases were loaded into a 3D optical lattice and were studied in several experiments.

Recently we successfully performed the high-resolution laser spectroscopy of bosonic Yb atoms in an optical lattice, which reveals the details of the superfluid-Mott insulator transition.

A Mott insulator state of fermions with SU(6) symmetry is also successfully created owing to the enhanced Pomeranchuk cooling[1]. In addition, we recently discovered magnetic Feshbach resonance between the ground state and the metastable state[2], which will open the possibility for realizing the Cooper pairing of atoms with different electronic states. I will discuss the prospect of topological superfluid by implementing spin-orbit interaction with this system.

*Talk _Sat 11 May 2013*

# Coupling single photons to single atoms


## Christian Kurtsiefer

*Centre for Quantum Technologies, National University of Singapore, Singapore*



A common combination of physical systems that allows a scaling up from single qubit demonstrations to more complex structures for quantum information purposes requires efficient bidirectional atom-light interfaces. While the transfer from atomic states to light is efficiently taken care of by a spontaneus emission process, the reverse part is practically much more challenging, since typical light sources that generate simple entangled states or even single photon states are not necessarily compatible with atomic transitions.

Here, I present our efforts of mode matching of propatating photonic modes with atomic emission/absorption modes both spatially and temprorally for the atomic side, using a strong focusing approach and a rising exponential temporal profile of the photonic mode corresponding to time-reversed spontaneous emission solutions.

On the photon side, I present a bright correlated narrowband photon source based on parametric conversion in a cold atomic ensemble that is able to generate photon pair states which are spectrally compatible with atomic transitions. Due to the time scales involved, both homodyne measurements and a detection with photocounting detectors are possible, and we can show that such a source can generate heralded single photon pulses with a rising exponential envelope.

# Poster Presentation

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| 3 | Blackley, Caroline | Feshbach resonances in an ultracold mixture of 85Rb and 133Cs |
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| 16 | Hennessy, Tara | Tapered optical nanofibres as detectors for trapped atoms in a 1D optical lattice |
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*Poster Presentation-1*

# Two-qubits Non-Markovianity induced by a Common Dephasing Environment

**Carole Addis**
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Exploiting quantum correlations such as entanglement as a resource in quantum information tasks revolves around the major obstacle of preserving them from the detrimental interaction of the environment. For this reason we consider the simplest bipartite system, a system of two qubits, immersed in a non-Markovian structured environment. In such an environment, memory effects exist as a consequence of strong system-environment couplings as well as initial correlations between the two and as a result, quantum properties can be temporarily restored.

In order to quantify the capability of a system to regain quantum properties, it is important to unambiguously define and quantify non-Markovian behaviour for a given system. In this work we consider two measures of non-Markovianity. In more detail characterising non-Markovian behaviour as a backflow of information from the environment to the system and further by the mathematical property of the dynamical map known as divisibility. We consider a setting in which, by changing the distance between the qubits one can interpolate between independent reservoir and common reservoir scenarios. This allows us to demonstrate that non-Markovianity can be induced by the common reservoir and prove that, for the system considered, two-qubit non-Markovianity in terms of information flow coincides with divisibility. In addition we also discuss the pair of states maximising information flowback.

*Poster Presentation-2*

# Routes to Quantum Turbulence in Trapped Bose-Einstein Condensates

**Joy Allen**
*Joint Quantum Centre (JQC), Durham-Newcastle*
*School of Mathematics and Statistics, Newcastle University, Newcastle, UK*

Vortices are a hallmark signature of a turbulent flow. Quantum vortices differ from their classical counterparts because of the quantization of circulation in superfluid flow. This means that the rotational motion of a superfluid is constrained to discrete vortices which all have the same core structure. Turbulence in superfluid Helium has been the subject of many recent

experimental and theoretical investigations recently reviewed by Skrbek and Sreenivasan [1]. Recently, experimentalists have been able to visualise individual vortex lines and reconnection events using tracer particles [2]. Weakly interacting Bose-Einstein condensates present a unique opportunity to resolve the structure of vortices and in turn study the dynamics of a vortex tangle (as has recently been created in an atomic cloud [3]).

We investigate ways of generating turbulence in atomic systems by numerically stirring the condensate using a Gaussian 'spoon' (analogous to a laser beam in the experiments), and study the isotrophy of the resulting vortex tangle depending on whether the path the spoon stirs is circular or random. We model the system using the Gross-Pitaevskii Equation and extend our analysis to finite temperature using the Zaremba-Nikuni-Griffin (ZNG) formalism [4], whereby the full dynamics of the noncondensate atoms are described by a semiclassical Boltzmann equation.

[1] L. Skrbek and K.R. Sreenivasan, PoF 24, 011301 (2012)
[2] G.P. Bewley et al. PNAS 105, 13707 (2008).
[3] E.A.L. Henn et al. PRL 103, 04301 (2009).
[4] E. Zaremba, JLTP 116, 277 (1999).

# Feshbach resonances in an ultracold mixture of 85Rb and 133Cs

**Caroline Blackley**

*Joint Quantum Center DU/NE Department of Chemistry,Durham University, Durham, UK*

The creation of ultracold molecules is currently of great interest. They offer a wide range of applications including: studies of few-body quantum physics, high precision spectroscopy, quantum simulators for many-body phenomena and controlled chemistry [1]. One route to ultracold molecules is through the association of two ultracold atoms using a Feshbach resonance [2] followed by STIRAP to achieve ultracold ground state molecules. Here we present a detailed analysis of the resonance rich scattering length of 85Rb133Cs. We used potentials refined in ref. [3] to map the scattering length of the |2,+2> + |3+3> lowest hyperfine state and found 34 resonances of which 14 have been confirmed experimentally. We also predicted and confirmed several intraspecies resonances in various spin states of 85Rb. All calculations are preformed using typical coupled channel methods, in a fully decoupled basis set using the MOLSCAT [4] program with the additional BOUND and FIELD packages. Each set of calculations is performed with a set total angular momentum, which is the only good quantum number in an applied field, in each calculation this is the total angular momentum of the two separated atoms in their chosen channels.

References

[1] L. D. Carr, D. DeMille, R. V. Krems, and J. Ye, New J. Phys. 11, 055049 (2009)
[2] C. Chin, R. Grimm, E. Tiesinga, and P. S. Julienne, Rev. Mod. Phys. 82, 1225 (2010)
[3] T. Takekoshi, M. Debatin, R. Rameshan, F. Ferlaino, R. Grimm, H.-C. Nagerl, C. R. Le Sueur, J. M. Hutson, P. S. Julienne, S. Kotochigova, and E. Tiemann, Phys. Rev. A 85, 032506 (2012)
[4] J. M. Hutson and S. Green, MOLSCAT computer program, version 14 (CCP6, Daresbury, 1994)"

*Poster Presentation-4*

# Quantum State Tomography of a Single Polariton State of an Atomic Ensemble

**Eva Bookjans**
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Authors: E. Bookjans et al

We report on our experiment to create a single polariton state of an atomic ensemble and to detect it by performing quantum state tomography. The collective non-classical and non-Gaussian state of the ensemble is generated by the detection of a single forward scattered photon. Subsequently, the state is characterized by atomic state tomography and the non-classical and non-Gaussian nature is verified as described in S.L.Christensen et al. (New J. Phys. 15 015002). The atomic state tomography is performed using strong dispersive light-atom interaction followed by a homodyne measurement on the transmitted light, a method with projection noise limited sensitivity that is well suited for detecting a non-classical and non-Gaussian state of the mesoscopic atomic ensemble. This work represents the first attempt of hybrid discrete-continuous variable quantum state processing with atomic ensembles.

*Poster Presentation-5*

# Heisenberg limited atomic clocks in the presence of decoherence

**Johannes Borregaard**
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Some of the most precise measurements in physics are made with atomic clocks. Very accurate time measurements are used in anything from GPS-systems to gravitational wave detectors. Further improvements of atomic clocks are therefore of high interest and the use of entanglement to improve the resolution has been extensively studied. In Ref. [1] it was shown that spin squeezed ensembles of atoms can be used to improve the long-term stability of atomic clocks by a factor of N^(1/6) compared to uncorrelated ensembles, where N is the number of atoms. While this result highlights the possibility of enhancing the resolution, the improvement identified in Ref. [1] was rather limited due to the extra noise added by the spin squeezing. We show how the extra noise can be corrected for by an adaptive measurement protocol, which enables us to reach Heisenberg scaling of the long term stability. We base our adaptive measurement protocol on the protocol of Ref. [2] for estimating an unknown phase shift in an interferometer. With weak measurements we repeatedly estimate the collective spin state of the atoms and through a feedback we correct for the extra noise added by spin squeezing. This results in an improvement of using spin squeezed atoms compared to uncorrelated atoms that reaches a scaling of ~ N^(1/2) e.g. the Heisenberg limit. Furthermore this result is obtained in the presence of decoherence in the system.

References

[1] A. André, A. S. Sørensen and M. D. Lukin, Phys. Rev. Lett. 92, 230801 (2004)
[2] D. W. Berry and H. M. Wiseman, Phys. Rev. Lett. 85, 5098 (2000)

*Poster Presentation-6*

# Global correlations in finite-size spin chains

**Steve Campbell**
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Authors: S. Campbell et al

We perform an extensive study of the properties of global quantum correlations in finite-size one-dimensional quantum spin models at finite temperature. By adopting a recently proposed measure for global quantum correlations, called global discord, we show that critical points can be neatly detected even for many-body systems that are not in their ground state. We consider the transverse Ising model, the cluster-Ising model where three-body couplings compete with an Ising-like interaction, and the nearest-neighbor XX Hamiltonian in transverse magnetic field. These models embody our canonical examples showing the sensitivity of global quantum discord close to criticality. For the Ising model, we find a universal scaling of global discord with the critical exponents pertaining to the Ising universality class.

*Poster Presentation-7*

# Thermodynamic cost of acquiring information

**Céleri Lucas**
*Institute of Physics, Federal University of Goiás*

Connections between information theory and thermodynamics have proven to be very useful to establish bounding limits for physical processes. Ideas such as Landauer's erasure principle and in- formation assisted work extraction have greatly contributed not only to enlarge our understanding about the fundamental limits imposed by nature, but also to enlighten the path for practical imple- mentations of information processing devices. The intricate information-thermodynamics relation also entails a fundamental limit on parameter estimation, establishing a thermodynamic cost for information acquisition. We show that the amount of information that can be encoded in a physical system by means of any process is limited by the dissipated work during the implementation of the process. This includes a thermodynamic trade-off for information acquisition. Likewise, any information acquisition process is ultimately limited by the second law of thermodynamics. This trade-off for information acquisition may find applications in several areas of knowledge.

*Poster Presentation-8*

# Quantum coherence witness from Quantum Zeno dynamics

**Agata Checinska**
*Centre for Quantum Technologies, National University of Singapore*

We address the problem of assessing the coherent character of physical evolution. We take the quantum Zeno effect (QZE) as a characteristic trait of quantum dynamics, and derive relations among transfer rates as a function of the strength of a measurement. These relations support the intuition that only quantum dynamics is susceptible to QZE, and provide bounds on the magnitude of both classical (dissipative) and quantum (coherent) dynamics. Our results have potential application in assessing coherence of quantum transport in biological and other complex many-body systems.

*Poster Presentation-9*

# Optimizing fidelity in the electromagnetically-induced-transparency-based optical memory

**Yi-Hsin Chen**

*Department of Physics, National Tsing Hua University, Hsinchu, Taiwan*

Storing light based on the effect of electromagnetically induced transparency (EIT) provides a coherent way to realize light-to-matter or matter-to-light quantum state mapping. An important figure of merit of a quantum memory is the fidelity of the recalled pulse. Our phase measurement with the beat-note interferometer can minimize the two-photon detuning and magnetic field gradient in the experimental system, both of which can degrade the fidelity. Based on the systematic study of the phase of readout light pulses, we showed that the detuning induces a nonuniform phase variation during the pulse propagation and a time-dependent uniform phase shift during the light storage, and demonstrated that it can be reduced to below 10 kHz (or 1/600 of the excited-state natural linewidth). Furthermore, we showed that the field gradient results in a time-dependent nonuniform phase variation during the light storage, and demonstrated that it can be compensated to as low as 1 mG/cm. The fidelity of the readout pulse from the memory has been achieved to 0.94. This work provides the useful knowledge of EIT-related research, and makes practical applications of EIT-based quantum memory more feasible.

*Poster Presentation-10*

# Multi-Run Quantum Error Correction in Coupled Electron-Nuclear Systems

**Rahimi Darabad Robabeh**
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It has been a milestone in realizing quantum computing, to enhance our control over physical systems so that making quantum processors performing accurately and precisely in presence of environmental noise. For practical uses, quantum error correction should be employed in multi-run cycles in order to keep the encoded qubit, that is carrying the information, safe from noise. We have been working towards implementing multi-run quantum error correction in molecular systems that involve electron and nuclear spins. Electron spins of a molecular sample are used for pumping up the nuclear spin polarization, in addition to addressing and manipulating the nuclear spins. The required experimental conditions for having access to refreshable ancilla qubits are very much enhanced by a careful design of the molecular sample. We report the progress and prospects towards overcoming the experimental challenges in terms of irradiation imposed free electron samples, free radical molecular spin systems, and triplet state photoexcitable co-crystal samples.

*Poster Presentation-11*

# Resource estimation, control and optimization for topological quantum computing

**Simon Devitt**
*National Institute of Informatics, Tokyo, Japan*

The development of both theoretical and experimental techniques in quantum information and computation has lead to new and exciting architectures for large scale computing. These new architectures can arguably be considered complete as they include all requisite fault-tolerant error correction protocols and are designed in a manner to expand arbitrarily without significant changes to the underlying hardware configuration [1,2]. However, the control of these systems in order to implement fully error corrected quantum algorithms is a largely unexplored area of research. Decomposing the high level quantum algorithm into the appropriate set of control pulses applied to the quantum hardware is a complicated task requiring many different protocols. The ability of an algorithm to be implemented in a resource efficient manner (i.e. short computational times and a minimal number of physical qubits) requires careful estimates of what parts of a computation are resource intensive and what is the best approach for optimization [3].
In this work we will illustrate what a complete error corrected algorithm looks like in a topologically protected quantum architecture and exactly how a detailed resource estimate for a large scale quantum algorithm is made. Using a diamond based hardware design we will discuss the control aspects of quantum algorithms and the relevant feedback process that must occur due to algorithmic decomposition and error correction during computation.
The results of this work illustrate that the majority of resource savings that can be made with large scale computation is related to how the quantum computer is controlled, rather than the fundamental properties of the individual qubits. This work represents the first step in the development of a classical control package for large-scale, error corrected quantum computation [4].

References

[1] S.J. Devitt, A.G. Fowler, A.M. Stephens, A.D. Greentree, L.C.L. Hollenberg, W.J. Munro, and K. Nemoto. Architectural design for a topological cluster state quantum computer. New. J. Phys., 11:083032, 2009.

[2] N. Cody Jones, R. Van Meter, A.G. Fowler, P.L. McMahon, J. Kim, T.D. Ladd, and Y. Yamamoto. A Layered Architecture for Quantum Computing Using Quantum Dots. arxiv:1010.5022, 2010.

[3] S.J. Devitt, A.M. Stephens, W.J. Munro and K. Nemoto, Requirements for fault-tolerant factoring on an atom-optics quantum computer, arXiv:1212.4934 (2012).

[4] S.J. Devitt and K. Nemoto, Programming a Quantum Computer, Proc. ATS'12 (Niigata, Japan). arXiv:1209.1441 (2012).

*Poster Presentation-12*

# Creating N00N states in a free oscillation atom interferometer

**Thomás Fogarty**
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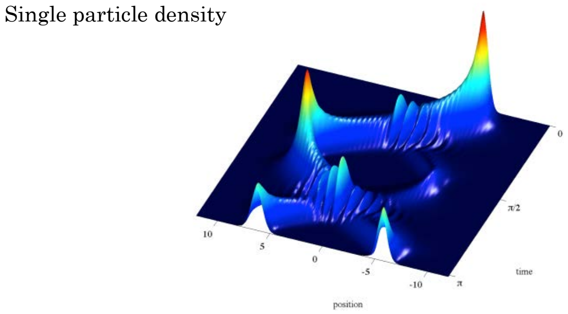
*University College Cork, Cork, Republic of Ireland*

Mesoscopic superposition states utilising ultracold atoms have recently become an exciting field when discussing atomic interferometry schemes. Unlike photons the finite mass of ultracold atoms can increase the sensitivity of the measurements of an unknown phase. Quantum correlations also play a key role in these measurements, and due to advances in manipulating single atoms and tuning interactions via feshbach resonances the creation of entanglement in ultracold gases is an achievable resource. The quantum fisher information (QFI) is a metric that allows us to estimate how accurately a given state can measure an unknown parameter. We assess the value of the states generated via the atomic interferometer in quantum metrology by calculating the QFI [1].

In this work I will present a simple model which incorporates the interferometry process in the dynamics of the harmonic oscillator. Based on the free oscillation atom interferometer [2], two interacting bosons in one dimension scatter off a delta function barrier acting as a beamsplitter. After one oscillation the scattered bosons scatter off the barrier again to complete the interferometry procedure. Through the one-dimensional scattering length the initial correlations of the atoms can be varied and the tunneling probabilities can be tuned by adjusting the delta barrier height. By varying these parameters a wide range of interesting and useful states can be easily generated, including the NOON state, which maximizes the QFI and is the foremost state in quantum metrology.




References:
[1] S. L. Braunstein, C. M. Caves, Phys. Rev. Lett. 72, 3439 (1994)
[2] R. P. Kafle, D. Z. Anderson, A. A. Zozulya, Phys. Rev. A. 84, 033639 (2011)

*Poster Presentation-13*

# Efficient Bayesian parameter inference from continuously monitored quantum systems

**Søren Gammelmark**
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We show that the stochastic master equations describing the dynamics of a quantum system subject to continuous observation using a definite set of measurements provide likelihood functions for unknown parameters in the system dynamics. We show that the asymptotic estimation error, given by the Fisher information, can also be identified by master equation simulations. For large parameter spaces we describe and illustrate the efficient use of Markov Chain Monte Carlo sampling of the Bayesian posterior distribution by a numerically efficient and stable calculation of the likelihood function.

*Poster Presentation-14*

# Tunneling, self trapping and manipulation of higher modes of a BEC in a double well

**Jérémie Gillet**
*Okinawa Institute of Science and Technology, Okinawa, Japan*

We study the semiclassical dynamical behavior of four modes of atomic Bose-Einstein condensates (BEC) trapped in a one dimensional double well trap. By considering different regimes of interaction, we find that the Josephson and self trapping dynamics for each energy levels can be influenced by the population in the other energy levels. We predict a shift in the stationary solutions of the system, show evidence of dissipation to the excited cloud and finally point at the possibility of chaotic behavior in the system.

*Poster Presentation-15*

# Dynamics of quasihole excitations as a detection tool for quantum Hall phases

**Tobias Grass**

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Existing techniques for synthesizing gauge fields are able to bring a two-dimensional cloud of harmonically trapped bosonic atoms into a regime where the occupied single-particle states are restricted to the lowest Landau level (LLL). Repulsive short-range interactions drive various transitions from fully condensed into strongly correlated states which feature interesting topological properties [1]. In these different phases we study the response of the system to quasihole excitations which can be induced by a laser beam. We find that in the Laughlin state the quasihole performs a coherent constant rotation around the center. This is distinct to any other regime with higher density, where the quasihole is found to decay. At a characteristic time, the decay process is reversed, and revivals of the quasihole can be observed in the density. This collapse-and-revival mechanism provides a spectroscopic tool to identify the strongly correlated phases by measuring the period and position of the revivals [2].

References

[1] B. Juliá-Díaz, T. Graß, N. Barberán, M. Lewenstein, New J. Phys. 14, 055003 (2012)

[2] T. Graß, B. Juliá-Díaz, and M. Lewenstein, Phys. Rev. A 86, 053629 (2012)

*Poster Presentation-16*

# Tapered optical nanofibres as detectors for trapped atoms in a 1D optical lattice

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Authors: T. Hennessy et al

We investigate the possibility of using a dark optical nano-fibre to detect and resolve the distribution of atoms trapped in a one-dimensional optical lattice arranged perpendicularly to the axis of the nano-fiber (see the schematic in Fig 1). This is an alternative to the recently constructed atom microscopes and an extension to the recently suggested use of nano-fibres to locally manipulate atoms in optical lattices[1].

This scheme is very sensitive to different orientations of the atomic dipoles with maximal emission into the guided modes occurring with radial orientation [2,3]. We calculate the rate of emission into the guided modes of the fibre and show that the effectiveness of the scheme is dependent on the size of the fibre radius, the radiation wavelength, the spacing between the atoms and the perpendicular distance between the fibre and the row of atoms. We fully consider the van der Waals force when the fibre is brought very close to the atomic array.

Among the possible applications of such a scheme is the reading out of edge states for the realization of topological quantum states in cold-atom lattice systems, which offers an opportunity for exploring topological phases. It can also be used for measuring fidelity and detecting imperfections in Mott Insulator configurations or non-destructively detecting the presence of a single atom in an optical trap .

We also investigate optical dipole traps for cold neutral atoms based on the evanescent field around a dielectric nanofiber for a number of evanescent field shapes. We consider the combination of counter propagating red detuned HE11 modes with a blue detuned HE11 mode to form a potential minimum that spirals around the nanofiber. A potential geometry in the shape of four intertwined spirals can be formed by replacing the red detuned HE11 modes with HE21 modes which can be excited by coupling Laguerre Gaussian beams into the un-tapered region of the fiber. We investigate these potentials in the case of caesium atoms and we show that it is possible to transform the four thread potential into a rectangular lattice of traps.

References:

[1] T. Hennessy and Th. Busch, Phys. Rev. A 85, 053418 (2012).
[2] V.V. Klimnov and M. Ducloy, Phys. Rev. A 69, 013812 (2012).
[3] Fam Le Kien and K. Hakuta, Adv. Nat. Sci. : Nanosci. Nanotechnol. 3 (2012) 035001 (5pp).

*Poster Presentation-17*

# Ensemble magnetometry with Nitrogen-Vacancy centers in diamond

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Nitrogen-vacancy (NV) centers in diamond are promising candidates for quantum information processing, imaging on the nano- and micrometer scale, and quantum sensing. In particular, a magnetic field sensor based on NV centers in diamond can have a combination of high magnetic-field sensitivity and high spatial resolution [Nat. Phys. 4, 810 (2008)]. I will discuss different techniques for measuring magnetic fields with an ensemble of NV centers. Using a confocal microscope where the red fluorescence from the NV centers is detected, we optimize the shot-noise limited magnetic-field sensitivity which is found to be in the 100 pT/sqrt(Hz) range [arXiv:1210.5574]. Magnetic resonance can also be detected using absorption on a infra-red transition in the NV center [APL 97, 174104 (2010)]. In our experiment, the diamond has been placed in an optical cavity to enhance the absorption and the magnetic field sensitivity. Since a magnetometer based on absorption do not suffer from the low photon-detection efficiency inherent in fluorescence-based techniques, the sensitivity should be able to reach around 10 pT/sqrt(Hz) with the absorption-based sensor. Finally, I present results of a magnetic field sensor based on electro-magnetically induced transparancy (EIT) and discuss the prospects for storing quantum information in an ensemble of NV centers using EIT.

*Poster Presentation-18*

# Shortcut to adiabaticity for the fast production of spin-squeezed states in bosonic Josephson junctions

**Bruno Julia-Diaz**
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The controlled production of correlated states in many-body quantum physics plays an important role for any foreseeable application in future quantum technologies. An important class of correlated states which have been identified and studied recently are spin-squeezed states. Bosonic Josephson junctions, pioneered by the groups of Oberthaler (Heidelberg) and Steinhauer (Jerusalem), provide an important experimental realization of pseudo-spin Hamiltonians which ground states are pseudo-spin-squeezed many-body states.
First we will describe the mapping of the two-site Bose-Hubbard Hamiltonian to that of a single effective particle evolving according to a Schr¥"odinger-like equation in Fock space in the vicinity of two important coherent states. This framework will allow one to describe with simple analytical formulas the formation of squeezing in the early time evolution from a coherent state [1].
Then we describe methods for fast production of highly coherent-spin-squeezed many-body states in bosonic Josephson junctions [2]. Since, for repulsive interactions, the effective potential in Fock space is nearly parabolic, we extend recently derived protocols for shortcuts to adiabatic evolution in harmonic potentials to the many-body BH Hamiltonian. The results clearly confirm the possibility of short-cutting the adiabatic following of the ground state of the BJJ.

References

[1] B. Juliá-Díaz, T. Zibold, M. K. Oberthaler, M. Melé-Messeguer, J. Martorell, A. Polls
Phys. Rev. A 86, 023615 (2012)
[2] B. Juliá-Díaz, E. Torrontegui, J. Martorell, J. G. Muga, A. Polls
Phys. Rev. A 86, 063623 (2012)

*Poster Presentation-19*

# Coherence dynamics of kicked Bose-Hubbard dimers: Interferometric signatures of chaos

**Christine Khripkov**
*Ben-Gurion University of the Negev, Be'er-Sheva, Israel*

We study the coherence dynamics of a kicked two-mode Bose-Hubbard model starting with an arbitrary coherent spin preparation. For preparations in the chaotic regions of phase-space we find a generic behavior with Flouquet participation numbers that scale as the entire N-particle Hilbert space, leading to a rapid loss of single particle coherence. However, the chaotic behavior is not uniform throughout the chaotic sea, and unique statistics is found for preparations at the vicinity of hyperbolic points that are embedded in it. This is contrasted with the low log(N) participation that is responsible for the revivals at the vicinity of isolated hyperbolic instabilities.

*Poster Presentation-20*

# Single Neutral Impurity Atoms Immersed in an Ultracold Gas

**Farina Kindermann**
*Technische Universität Kaiserslautern, Kaiserslautern, Germany*

Recently hybrid systems immersing single atoms in a many body system have been a subject of intense interest. Here we present an example of controlled doping of an ultracold Rubidium cloud with single neutral Cesium impurity atoms. We observe thermalization of 'hot' Cs atoms by elastic interaction with an ultracold Rb gas, employing different schemes of measuring the impurities' energy distribution. Inelastic collisions are restricted to a single three-body recombination channel allowing us to precisely determine the three-body loss coefficient in good agreement with theory.
In addition we present a concept of a new setup, which is currently build, capable of breeding an all optical BEC in few seconds. Our setup will feature mechanisms for independently manipulating and imaging both single atoms and the BEC, thereby providing an unrivaled level of control over impurities in a quantum gas. Possible research directions include the investigation of coherent impurity physics and the creation and characterization of polarons in a BEC.

*Poster Presentation-21*

# Feedback control of coherent spin states in atomic interferometers

**Ralf Kohlhaas**

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Atomic sensors are primary examples of coherently controlled quantum systems with practical applications for the measurement of time, accelerations and magnetic fields. The key strategy in the operation of atomic interferometers consists in a series of coherent manipulations, an interrogation time and a final destructive measurement of the quantum system. We take here an alternative approach with the repeated nondestructive readout and feedback on the same quantum system. As a first experimental demonstration, we subject the internal state of an atomic cloud to synthetic collective noise and show that weak measurements of negligible back-action and feedback by coherent microwave operations can protect a superposition state against the induced decoherence process [1]. We follow then a recent proposal [2] to lock the phase of a local oscillator on the phase of an atomic quantum state, in contrast to the typical frequency lock in atomic clocks. We present preliminary experimental results and discuss the metrological gain of the atomic phase lock versus a conventional atomic clock.

[1] T. Vanderbruggen, R. Kohlhaas, A. Bertoldi, S. Bernon, A. Aspect, A. Landragin and P. Bouyer, arXiv:1207.3203.

[2] N. Shiga and M. Takeuchi, New J. Phys. 14, 023034 (2012).

*Poster Presentation-22*

# Two-Qubit Gate Operation Applied on Nearest Neighboring Qubits in a Neutral Atom Quantum Computer

**Elham Hosseini Lapasar**
*Osaka City University, Osaka, Japan*

We have discussed a design of a neutral atom quantum computer with an on-demand interaction [J. Phys. Soc. Jpn. 80, 114003 (2011)] . In this contribution, we propose a first feasible experiment towards a two-qubit gate operation that is less demanding than our original proposal, although the gate operation is limited between neighboring atoms. We evaluate the process of a two-qubit gate operation that is applied on a nearest neighboring trapped atoms and estimate the upper bound of the gate operation time and corresponding gate fidelity.

*Poster Presentation-23*

# Attractive atom-dimer interaction on the repulsive side of a 6Li-40K Feshbach resonance

**Jesper Levinsen**
*University of Cambridge, Cambridge, UK*

Mass imbalance in strongly interacting mixtures of ultracold fermions is predicted to lead to new pairing phenomena and quantum phases. We investigate a 6Li-40K Fermi-Fermi mixture in the regime of strong interactions on the repulsive side of an interspecies Feshbach resonance. We find that, for a sufficiently strong repulsive s-wave interaction, the 40K atoms and the 6Li40K dimers interact attractively, in strong contrast to the mass-balanced case. This surprising behavior is related to the existence of a trimer state in heteronuclear mixtures with a mass ratio above 8.2, which turns into a p-wave atom-dimer scattering resonance for lower mass ratios (e.g. 40K/6Li=6.64). Here we present our theoretical predictions on interactions in a resonantly interacting atom-dimer mixture and compare these with experimental results obtained using radio-frequency spectroscopy over a range of temperatures and interaction strengths. We confirm the presence of a strong attraction on the repulsive side of a Feshbach resonance, in good agreement with theory.

*Poster Presentation-24*

# Non-Markovian probes in ultracold gases

**Suzanne McEndoo**
*Institute of Photonics and Quantum Sciences School of Engineering & Physical Sciences, Heriot-Watt University Edinburgh*

The study of open quantum systems largely concerns itself with the dynamics of a particular system of interest, usually a qubit or system of qubits, interacting with an environment, while tracing out the environment itself. This allows for the use of an environment to protect quantum information and to facilitate certain quantum protocols. However, one can also use these systems when the environment is the system of most interest. By considering the dynamics of a qubit under the influence of an environment, we can use the qubit as a probe for certain environmental parameters.

We present here a detailed investigation of the dynamics of two physically different qubit models, dephasing under the effect of an ultracold atomic gas in a Bose-Einstein condensed (BEC) state. We study the robustness of each qubit probe against environmental noise; even though the two models appear very similar at a first glance, we demonstrate that they decohere in a strikingly different way. This result holds signicance for studies of reservoir engineering as well as for using the qubits as quantum probes the ultracold gas. For each model we study whether and when, upon suitable manipulation of the BEC, the dynamics of the qubit can be described by a (non)Markovian process and consider the the effect of thermal fluctuations on the qubit dynamics. We show that such qubits can be used to detect both the interaction and dimensionality of the environment.

*Poster Presentation-25*

# Quantum cryptosystems to client-server applications

**Gabriela Mogos**
*Stefan Procopiu Technical College, Iasi, Romania*

Starting with bachelor's degrees in physics, a master degree in computer science, and continuing with a PhD in quantum cryptography, I have been working on understanding the computational power of quantum systems.

In the following I shall discuss my major contributions in the areas of quantum cryptography. During my research till now, I have been primarily interested in developing information theoretic tools and applying them in areas like quantum cryptography and quantum coding theory.

Using encryption techniques that are based on laws of quantum physics, I have proposed algorithmic solutions to current problems quantum encryption, and novel ways of integrating these solutions in high performance computing and next generation.

My postdoctoral research project, "Quantum cryptosystems to client-server applications", aims to replace classic techniques of client-server authentication and encryption key distribution existing Secure Sockets Layer - handshake protocol, with a quantum version. To encoding information, schemes will be used qubits and three-dimensional quantum systems - qutrits, which are not vulnerable to the cybernetic attacks, assure the correct authentication, and determine giving up the long row of authentication certifications used in the classical case for removing any suspicions.

*Poster Presentation-26*

# Simulating 3D atomic dynamics using a GPU accelerated split-operator method

**Lee O'Riordan**
*Okinawa Institute of Science and Technology. Okinawa, Japan*

Precise control over the external degrees of freedom of cold atomic systems for applications in quantum technologies often requires a fully three dimensional description. For numerical simulations this usually means large grids leading to long processing times, making highly scalable parallel approaches essential for obtaining results within useful timescales. We present a study into two sets of codes developed for the purpose of simulating the adiabatic dynamics of a single atom on a multi-waveguide atom chip. The first is a CPU approach utilising MPI and FFTW, and the second a modern GPU-based approach. We find that the GPU approach offers a large potential reduction in calculation time, making detailed simulations of even large structures realistic. The example we investigate aims to show Coherent Tunneling Adiabatic Passage (CTAP) in a system of waveguides on an atom chip. Due to the absence of Rabi oscillations in this process very large transfer fidelities can be achieved. All results we present closely mirror experimentally realisable systems and we present strategies we have developed to combat currently existing problems with other experimental approaches in order to fulfil the conditions necessary to observe CTAP. The developed algorithm is further extended to numerically solve the non-linear Schrodinger equation. A demonstration of preliminary results is given showing vorticity in Bose-Einstein condensates.

*Poster Presentation-27*

# Quantum coherence and sensitivity of avian magnetoreception

**Tomasz Paterek**
*School of Physical and Mathematical Sciences Nanyang Technological University*

Migratory birds and other species have the ability to navigate by sensing the geomagnetic field. Recent experiments indicate that the essential process in the navigation takes place in the bird's eye and uses chemical reaction involving molecular ions with unpaired electron spins (radical pair). Sensing is achieved via geomagnetic-dependent dynamics of the spins of the unpaired electrons. Here we utilize the results of two behavioral experiments conducted on European robins to argue that the average lifetime of the radical pair is of the order of a microsecond and therefore agrees with experimental estimations of this parameter for cryptochrome—a pigment believed to form the radical pairs. We also find a reasonable parameter regime where the sensitivity of the avian compass is enhanced by environmental noise, showing that long coherence time is not required for navigation and may even spoil it.

*Poster Presentation-28*

# Towards using atom chip technology to map and control solid-state devices

**Samanta Piano**
*University of Nottingham, Nottingham, UK*

Quantum technology, embracing a broad range of emerging technologies, has progressed rapidly in recent years, thanks to a steadily increasing degree of control of complex systems at the quantum level.

Solid-state devices are the most promising candidates for scalable implementation of quantum electronics. Systems of ultra-cold atoms constitute the most sensitive and robust laboratory means of studying and controlling coherent quantum dynamics. Cold atom systems find natural applications in quantum simulations and metrology.

Our proposed research aims to establish a two-way interface between cold atoms and solid-state systems in order to pursue a novel route towards hybrid quantum technology.

The microscopy system based on the Bose-Einstein Condensate (BEC) will be able to reach unprecedented levels of precision in the investigation of the magnetic domain structure of a wide range of magnetic materials (Co, Fe, Ni, etc..) operating at room and liquid helium temperature. Novel quantum chips incorporating thin, semiconducting magnetic films (like Ga,MnAs ) will be designed and fabricated at the University of Nottingham in order to trap cold atoms at submicron surface distance and to provide corresponding resolution. This will allow coupling of atomic and semiconducting electronic systems in a fully quantum interacting regime.

*Poster Presentation-29*

# Exciton-Polariton Condensation in High Excitation Density Regime

**Yutaka Shikano**
*Institute for Molecular Science, National Institutes of Natural Sciences, Aichi, Japan*

Exciton-polariton condensation has two interesting aspects: Bose-Einstein condensation (BEC) and laser by changing the excitation density and temperature. Exciton-polariton condensation has been expected to show a transition from the thermal-equilibrium BEC in a low excitation regime to a conventional photon lasing in a high excitation regime. However, our result shows a completely different behaviour from photon lasing in the high excitation density regime, which is up to over 400 times of the condensation threshold. The obtained PL of the negative branch is quantitatively consistent with the effect of the quantum depletion in the Bogoliubov theory dealing with weakly interacting BEC. Our result implies that the system is not in photon lasing regime but still is in strong coupling regime with electron-hole pair binding.
In this talk, we would like to discuss the specific behaviour of this system by temperature and excitation density.  This work is collaborated with NII/Stanford and Wurtzburg groups.

*Poster Presentation-30*

# Measures of turbulence in Bose-Einstein condensates

**Angela White**
*Newcastle University, Newcastle, UK*

Turbulence, a dynamically reconnecting tangle of vortices, is ubiquitous throughout nature and can be found in both classical and quantum fluids. Trapped atomic condensates are an ideal test-bed for investigating the small-scale properties of turbulent tangles of vortices, due to the simple quantized nature of vortices in quantum fluids and the experimental control over condensate dimensionality and vortex dynamics.The quest to understand and study quantum turbulence in trapped atomic Bose-Einstein condensates raises unique challenges. In particular, it is important to understand how to create and characterize turbulent tangles. We present some recent progress towards theoretically addressing these issues. Motivated by work in classical fluids, we investigate if methods that are known to efficiently mix classical fluids, known as pseudo-Anosov stirring protocols, also efficiently mix trapped atomic condensates. In order to characterize turbulence, we develop some measures that are experimentally accessible, based on the density and distribution of vortices in trapped atomic condensates. At scales larger than the vortex core size we describe how the momentum spectrum of vortices scales with vortex number. We also investigate velocity correlations as a measure of turbulence and vortex distribution in two-dimensional condensates.

*Poster Presentation-31*

# Exploring fundamental physics with optomechanics and matter-wave interferometry

**André Xuereb**

*Queen's University Belfast, UK*

Optomechanical systems provide a top-down approach to exploring the boundary between the quantum and classical regimes, whereas massive molecular matter-wave interferometry experiments provide a bottom-up approach. We combine these technologies to propose a coherent interface between matter- and electromagnetic waves. Such an interface facilitates the exploration of the behaviour of quantum mechanics on large mass scales, thereby making fundamental tests of quantum mechanics accessible. The scheme that we introduce paves the way to the coherent transfer of information to and from matter waves.

As a second topic, we investigate the collective optomechanics of an ensemble of scatterers inside a Fabry-Perot resonator and identify an optimised configuration where the ensemble is transmissive, in contrast with the usual reflective optomechanics approach. In this configuration, the optomechanical coupling of a specific collective mechanical mode can be several orders of magnitude larger than the single-element case, and long-range interactions can be generated between the different elements since light permeates throughout the array. This new regime should realistically allow for achieving strong single-photon optomechanical coupling with massive resonators, realising hybrid quantum interfaces, and exploiting collective long-range interactions in arrays of atoms or mechanical oscillators.

*Poster Presentation-32*

# Bose-Einstein condensates in spin-orbit coupled optical lattices

**Yongping Zhang**
*Okinawa Institute of Science and Technology, Okinawa, Japan*

Recently spin-orbit (SO)-coupled superfluids in free space or harmonic traps have been extensively studied, motivated by the recent experimental realization of SO coupling for Bose-Einstein condensates (BEC). However, the rich physics of SO-coupled BEC in optical lattices has been largely unexplored. Here, we show that in a suitable parameter region the lowest Bloch state forms an isolated flat band in a one-dimensional SO-coupled optical lattice, which thus provides an experimentally feasible platform for exploring the recently celebrated topological flatband physics in lattice systems. We show that the flat band is preserved even with the mean-field interaction in BEC. We investigate the superfluidity of the BEC in SO-coupled lattices through dynamical and Landau stability analysis, and show that the BEC is stable on the whole flat band.