10th Workshop on Principles and Applications of Control in Quantum Systems (PRACQSYS)
Sydney, July 20-24, 2015

I. Workshop Schedule

All workshop talks will be held in Gallery 1 of the Scientia Building, and the poster session will be held in Gallery 2 of the Scientia Building.

Monday, July 20 (8 speakers)

8:30 am–8:50 am : Morning coffee

9:00 am–9:10 am : Opening by Prof. Mark Hoffman, Dean of the Faculty of Engineering, UNSW Australia

9:10 am -9:15 am : Introduction to the workshop by Dr Hendra Nurdin

Session 1
9:20 am–10:00 am : Matthew James (Australian National University)  
On the design of quantum feedback systems
10:00 am–10:40 am : Andrew Doherty (University of Sydney)  
Supressing qubit dephasing using real-time Hamiltonian estimation

10:40 am–10:55 am : Coffee break

Session 2
11:00 am–11:40 am : Matthew Sellars (Australian National University)  
Rare earth-doped crystals and their application to quantum information processing
11:40 am–12:20 pm : Guofeng Zhang (Hong Kong Polytechnic University)  
Input-output analysis of quantum finite-level systems in response to single photon states

12:20 pm–2:00 pm : Lunch break

Session 3
2:00 pm–2:40 pm : Mankei Tsang (National University of Singapore)  
Quantum spectroscopy
2:40 pm–3:20 pm : Hsi-Sheng Goan (National Taiwan University)  
Quantum optimal control for quantum information processing

3:20 pm–3:35 pm : Coffee break

Session 4
3:40 pm–4:20 pm : Symeon Grivopoulos (UNSW Canberra)  
A new realization method for linear quantum stochastic systems

4:20 pm–5:00 pm : Yu Pan (Australian National University)  
The nonlinear dynamics of two-photon states in interaction with quantum two-level systems
**Tuesday, July 21 (6 speakers)**

8:30 am–8:50 am  : Morning coffee

**Session 1**
9:00 am–9:40 am  : Hideo Mabuchi (Stanford University)  
*Coherent feedback in photonic signal processing and computation*
9:40 am–10:20 am  : Michael Biercuk (University of Sydney)  
*Predicting the future of noisy qubits*

10:20 am–10:35 am  : Coffee break

**Session 2**
10:40 am–11:20 am  : Herschel Rabitz (Princeton University)  
*Theoretical and experimental aspects of controlled quantum dynamics*
11:20 am–12:00 pm  : Takahiro Sagawa (University of Tokyo)  
*Nonequilibrium thermodynamics of quantum information processing*

12:00 pm–2:00 pm  : Lunch break

**Session 3**
2:00 pm–2:40 pm  : John Teufel (NIST)  
*Engineering quantum interactions in microwave optomechanical circuits*
2:40 pm–3:20 pm  : Naoki Yamamoto (Keio University)  
*Quantum feedback amplification*

**Poster Session**
3:20 pm–5:00 pm  : Poster session and 1 hour cocktail function (3:30 pm–5:00 pm)

**Wednesday, July 22 (4 speakers)**

8:30 am–8:50 am  : Morning coffee

**Session 1**
9:00 am–9:40 am  : Andrew Dzurak (UNSW Australia)  
*Spin-based quantum computing in silicon*
9:40 am–10:20 am  : Robert Kosut (SC Solutions)  
*The role of convex optimization in quantum control design and quantum tomography*

10:20 am–10:35 am  : Coffee break

**Session 2**
10:40 am–11:20 am  : Haixing Miao (University of Birmingham)  
*Increasing measurement bandwidth with unstable filters*
11:20 am–12:00 pm  : David Reilly (University of Sydney)  
*TBA*

12:00 pm–6:30 pm  : Free time

6:30 pm–9:30 pm  : Workshop banquet at Tyree Room, Scientia Building
Thursday, July 23 (8 speakers)

8:30 am–8:50 am : Morning coffee

Session 1
9:00 am–9:40 am : Jörg Schmidmayer (Technical University of Vienna)  
Controlling quantum states of a many body system
9:40 am–10:20 am : Pierre Rouchon (MINES ParisTech)  
Quantum state tomography including measurement duration, imperfections and decoherence

10:20 am–10:35 am : Coffee break

Session 2
10:40 am–11:20 am : Poul Jessen (University of Arizona)  
Accurate and robust unitary control in a high-dimensional Hilbert space

11:20 am–12:00 pm : Paola Cappellaro (MIT)  
Fast control by a quantum actuator

12:00 pm–2:00 pm : Lunch break

Session 3
2:00 pm–2:40 pm : Jun-ichi Yoshikawa (University of Tokyo)  
Continuous-variable quantum optical experiments with conditional non-Gaussian states
2:40 pm–3:20 pm : Hendra Nurdin (UNSW Australia)  
On the cascade realization of the transfer function of linear quantum systems

3:20 pm–3:35 pm : Coffee break

Session 4
3:40 pm–4:20 pm : Madalin Guta (University of Nottingham)  
Estimation of stationary quantum input-output dynamics
4:20 pm–5:00 pm : Alessio Serafini (University College London)  
Open and closed-loop control of bosonic Gaussian states: recent findings and open problems

Friday, July 24 (4 speakers)

8:30 am–8:50 am : Morning coffee

Session 1
9:00 am–9:40 am : Joshua Combes (IQC and Perimeter Institute)  
Characterizing time dependent sources and gates

9:40 am–10:20 am : Keisuke Fujii (Kyoto University)  
Measurement-free topological protection with dissipative feedback

10:20 am–10:35 am : Coffee break

(Friday schedule continued to the next page)
Session 2
10:40 am–11:20 am: Chuan-Feng Li (University of Science and Technology of China)
Quantum control and quantum simulation with linear optics

11:20 am–12:00 pm: Arne Grimsmo (Université de Sherbrooke)
Time-delayed coherent quantum feedback control

12:00 pm–6:00 pm: Free time

6:00 pm–8:00 pm: Closing reception at Oceans Bar, Crowne Plaza Coogee Beach
II. Talk Abstracts

Monday, July 20

Session 1
Matthew James (Australian National University)
*On the design of quantum feedback systems*

Abstract: The purpose of this talk is two-fold: (i) to discuss the importance of dynamics in feedback systems, and (ii) to present some recent results concerning the use of dynamical observers in the design of coherent quantum feedback controllers. The talk begins with a review of the use of dynamics in classical feedback systems, and indeed highlights to need for feedback in uncertain and noisy environments. We then discuss in general terms how dynamics, both classical and quantum, may be included in quantum feedback systems. With this background in place, we describe how coherent observers may be used for pole placement in quantum feedback systems. The talk concludes with some general remarks.

Andrew Doherty (University of Sydney)
*Supressing qubit dephasing using real-time Hamiltonian estimation*

Abstract: Semiconductor qubits, such as gate-defined quantum dots in GaAs, are a very promising experimental system for quantum information processing. In this system many theoretical ideas for quantum control can already be implemented in practice. For example, a lot of theoretical work has been done on various approaches to Hamiltonian parameter estimation in which one attempts to determine parameters of the Hamiltonian efficiently in terms of either the total time evolution required or the number of measurements that must be performed. I will describe an implementation of one approach to Hamiltonian parameter estimation for single qubits that is able to determine and compensate for the fluctuations of the magnetic field gradient between two quantum dots. Improvements of the qubit coherence time by a factor of 30 have been demonstrated in the laboratory. The approach is optimised for the fact that single-shot measurements of the qubit state, rather than the time taken for Hamiltonian evolution, dominate the time required for the estimation procedure. It is possible to monitor slow fluctuations of the magnetic field gradient in this way and thereby probe the dynamics of the magnetic field due to fluctuating nuclear spins. This work is in collaboration with M. D. Shulman, S. P. Harvey, J. M. Nichol, S. D. Bartlett, V. Umansky and A. Yacoby.

Session 2
Matthew Sellars (Australian National University)
*Rare earth-doped crystals and their application to quantum information processing*

Abstract: The unique properties of rare-earth optical centres in crystals offer great potential for a range of quantum information applications. The general strategies proposed to implement quantum information applications in rare-earth doped crystals will be described. I will highlight the innate advantages of rare-earth centers along with the fundamental material challenges in realizing practical applications. Developments in meeting some of these challenges will be discussed including advances in single site state readout, maximization of hyperfine and optical coherence times, reduction of ensemble inhomogeneity and the precise characterization of the interactions between rare-earth ions.
Guofeng Zhang (Hong Kong Polytechnic University)

Input-output analysis of quantum finite-level systems in response to single photon states

Abstract: Single photon states, which carry quantum information and coherently interact with quantum systems, are vital to the realization of all-optical quantum networks and quantum memory. In this paper we derive the conditions that enable an exact analysis of the response of passive quantum finite-level systems under the weak driving of single photon input. We show that when a class of finite level systems is driven by single photon inputs, expressions for the output states may be derived exactly using linear systems transfer functions. This removes the need for physical approximations such as weak excitation limit in the analysis of quantum nonlinear systems under single photon driving. We apply this theory to the analysis of a single photon switch. The input-output relations are consistent with the existing results in the study of few photon transport through finite-level systems.

Session 3

Mankei Tsang (National University of Singapore)

Quantum spectroscopy

Abstract: Many tasks in optomechanical force sensing and atomic magnetometry, such as thermometry, testing spontaneous collapse models, and stochastic-magnetic-field imaging, involve the estimation of power-spectral-density parameters via quantum sensors. Framing such problems as quantum spectral hyperparameter estimation, we derive a measurement-independent quantum limit to their accuracies in the form of a quantum Cramer-Rao bound. We illustrate our result in the context of the optical phase tracking experiment by Wheatley et al. and find that, while homodyne detection can get close to the quantum bound in a high-photon-flux regime, a coherent optical spectrometer can in principle saturate the bound for all parameters and beat homodyne detection by a significant margin in the low-photon-flux regime.

Hsi-Sheng Goan (National Taiwan University)

Quantum optimal control for quantum information processing

Abstract: We employ quantum optimal control theory (QOCT) based on the Krotov method to find control pulse sequences of fast and high-fidelity quantum gates, taking into account decoherence from dissipative environment, for various promising physical quantum systems, such as semiconductor-donor-based and NV-center-based spin-qubit systems and Josephson-junction-based superconducting-qubit systems. In this talk, we will discuss in some details for the system of the spins of nitrogen-vacancy (NV) centers in diamond, a promising solid-state candidate for quantum information processing due to the long coherence times of the spins and the reliability of quantum operations even at room temperatures. We model the surrounding spin environment in term of a small number of nearby noise qubits and a distant spin bath. We also consider the state leakage effect. The single-qubit and two-qubit gate fidelities we find through the QOCT are much better than what have been reported in the literature. Furthermore, we also apply QOCT to some exactly solvable models of non-Markovian open qubit systems to achieve and construct high-fidelity quantum gates for moderate qubit decaying parameters. Despite the broad applicability of the perturbative master equation, the approximations made in the derivation results in unwanted intrinsic error, which in turn contributes to the error in the constructed gate operations. With the help of the exact dynamics, we explore how the gate errors are corrected in the open qubit systems and determine the conditions for significant improvement.
Session 4
Symeon Grivopoulos (UNSW Canberra)
A new realization method for linear quantum stochastic systems

Abstract: In this talk we address the issue of realization of the (classical) transfer functions of linear quantum stochastic systems from a new point of view. In broad terms, we show how the transfer functions of such systems can be realized by combining simple quantum optical dynamical components (such as damped cavities, amplifiers, etc.) through a static feedback interconnection, preceded and followed by appropriate static networks (made up by phase shifters, beam splitters and static squeezers). The static networks through which the inputs enter the quantum system and its outputs exit the system, are determined through a Bogoliubov group singular value decomposition of the coupling matrix of the system. The static feedback interconnection is determined, in turn, by the requirement to produce the appropriate Hamiltonian matrix for the system from the block-diagonal Hamiltonian matrix of the concatenated simple dynamical components. We provide examples that demonstrate the general theory.

Yu Pan (Australian National University)
The nonlinear dynamics of two-photon states in interaction with quantum two-level systems

Abstract: We present the time-domain analysis of the two-photon input states in interaction with quantum two-level systems. Unlike linear systems, the quantum two-level system will respond to two-photon input non-linearly. We will introduce a method to model and calculate the nonlinear dynamics of this interaction in time domain, and then discuss its applications on pulse shaping and modelling quantum networks which are driven by photons.

Tuesday, July 21

Session 1
Hideo Mabuchi (Stanford University)
Coherent feedback in photonic signal processing and computation

Abstract: I will review our group's research on architectural principles for photonic signal processing and computation, with an emphasis on the role of coherent feedback.

Michael Biercuk (University of Sydney)
Predicting the future of noisy qubits

Abstract: The uncontrolled evolution of qubits in the presence of a noisy environment poses a major challenge to the development of quantum technologies. Nonetheless, similar circumstances are common in classical settings, and a wide range of techniques have been developed in the discipline of control theory to provide stability to dynamically unstable systems. We discuss experimental demonstrations using trapped ions of a suite of quantum-control theoretic techniques to predict and control the evolution of qubits subject to semiclassical decoherence. Our work builds on our recent development of generalized transfer functions permitting the prediction of a qubit’s ensemble-average evolution during an arbitrary operation. We integrate this formalism with concepts from optimal estimation to predict a qubit's future evolution due to stochastic decoherence processes, based on a time-stamped series of projective Ramsey measurements and limited knowledge of the noise power spectrum. This technique, closely related to Kalman filtering, permits us to perform feedforward compensation of
a stochastic process, providing enhanced stabilization against decoherence relative to traditional feedback. Finally, we describe how this suite of techniques can be made compatible with quantum computing control hardware, and touch on architectural impacts of our findings.

Session 2
Herschel Rabitz (Princeton University)
Theoretical and experimental aspects of controlled quantum dynamics

Abstract: Controlling quantum dynamics phenomena spans a wide range of applications and potential technologies. Although some experiments are far more demanding than others, the experiments are collectively proving to be remarkably successful considering all of the complexities involved in manipulating quantum coherence phenomena. The presentation will include experimental results ranging from NMR control of a few spins out to laser control of complex fragmentation channels of polyatomic molecules. Attention will be drawn to the explanation of the evident general ease of finding good controls by consideration of the theoretical principles underlying quantum control. These principles will particularly focus on the features of the underlying control landscape defined as the observable as a functional of the control. The landscapes have two key features categorized in terms of their topology and structure (i.e., the latter refers to all non-topological landscape “twists and turns”). The generally simple topological and structural features of quantum control landscapes will be argued as having independent physical origins, but both cooperatively conspire to provide a foundation for the observed relative ease of finding effective control fields. The practical significance of these findings will be discussed.

Takahiro Sagawa (University of Tokyo)
Nonequilibrium thermodynamics of quantum information processing

Abstract: Recently, "Maxwell’s demon" has attracted renewed attentions in both terms of theory and experiment [1]. The demon performs measurement and feedback control on nonequilibrium systems at the level of thermal and quantum fluctuations. In this talk, I will discuss our results on the generalized second law of thermodynamics with quantum information processing, where quantum information contents and thermodynamic quantities are treated on an equal footing. The generalized second law reveals the fundamental lower bound of the energy cost for quantum information processing.


Session 3
John Teufel (NIST)
Engineering quantum interactions in microwave optomechanical circuits

Abstract: By incorporating microfabricated mechanical resonators into superconducting circuits, we engineer interactions between microwave photons and radio-frequency “phonons.” The nature of the interaction Hamiltonian can be selected by choosing the amplitude and frequency of an applied pump field. While past work has demonstrated separately the "beam-splitter" and "dual-mode squeezing" interactions for coherent state exchange and entanglement, in this talk I will explore the consequences of combining multiple interactions simultaneously. These techniques clearly demonstrate that not only is the light measuring the motion, but the motion in turn measures the light. This interplay highlights the coherent feedback inherent to all optomechanical
interactions, and suggests ways in which we may engineer complex dynamics and steady-states of the system.

Naoki Yamamoto (Keio University)

Quantum feedback amplification

Abstract: Feedback control has several roles in practice; typically, as has been demonstrated in classical cases, it is used to gain robustness, to suppress noise, and to modify the system performance. In this talk I will show that the so-called coherent feedback has these fine properties for a class of quantum amplifiers.

Wednesday, July 22 (4 speakers)

Session 1
Andrew Dzurak (UNSW Australia)

Spin-based quantum computing in silicon

Abstract: Spin qubits in silicon are excellent candidates for scalable quantum information processing [1] due to their long coherence times and the enormous investment in silicon CMOS technology. While our Australian effort in Si QC has largely focused on spin qubits based upon phosphorus dopant atoms implanted in Si [2,3], we are also exploring spin qubits based on single electrons confined in SiMOS quantum dots [4]. Such qubits can have long spin lifetimes $T_1 = 2 \text{ s}$, while electric field tuning of the conduction-band valley splitting removes problems due to spin-valley mixing [5]. In isotopically enriched Si-28 these SiMOS qubits have a control fidelity of 99.6% [6], consistent with that required for fault-tolerant QC. By gate-voltage tuning the electron g*-factor, the ESR operation frequency can be Stark shifted by $> 10$ MHz [6], allowing individual addressability of many qubits. Most recently we have coupled two SiMOS qubits to realize CNOT gates [7] for which over 100 two-qubit gates can be performed within a two-qubit coherence time of 8 $\mu$s. I will conclude by discussing the prospects of scalability of this technology using traditional CMOS manufacturing.


Robert Kosut (SC Solutions)

The role of convex optimization in quantum control design and quantum tomography

Abstract: A number of quantum system design and estimation problems are, in part, well represented as a convex optimization, e.g., quantum state & process tomography,
quantum state detection, quantum error correction, and optimal experiment design. What makes this possible is the fact that a number of quantum objects naturally form convex sets, e.g., probability outcomes, density matrix, POVM, and the process matrix. Two problems that are generally not convex are Hamiltonian parameter estimation and quantum control design. For these, local solutions, often very good, can be found using iterative methods such as sequential convex programming. Many of the control problem solutions can provide a considerable robustness to anticipated uncertainties. Additionally, and surprisingly, they also provide robustness to unanticipated uncertainties. A possible explanation for this serendipity will be presented.

**Session 2**
Haixing Miao (University of Birmingham)

*Increasing measurement bandwidth with unstable filters*

Abstract: In phase-sensitive optical measurement devices, resonant cavities are often implemented to increase the measurement sensitivity by coherently amplifying small signals. However, when freely propagating inside the cavity, signals at different frequencies accumulate different phases. Such dispersion limits amplification only to signals that are around the cavity resonance frequency, leading to a tradeoff between the measurement bandwidth and peak sensitivity. In this presentation, we will talk about how to overcome such a limitation by embedding unstable optical filters inside the cavity and having the entire system stabilized via feedback control. Particularly, we will use the laser interferometric gravitational-wave detector as an example to illustrate this idea, and show how to realize such unstable filters with opto-mechanical devices operating in the instability regime. One can refer to arXiv: 1506.00117 for the technical detail of this example.

David Reilly (University of Sydney)

*TBA*

Abstract: TBA

**Thursday, July 23**

**Session 1**
Jörg Schmidmayer (Technical University of Vienna)

*Controlling quantum states of a many body system*

Abstract: Developing methods for the coherent control and manipulation of the external degrees of freedom of a many-body system has been a long-standing goal. In this talk I will give three examples of fast and efficient coherent manipulation of an interacting many-body system:

(1) We manipulate the motional states of a 1-dimensional Bose-Einstein Condensate. By “shaking” the trap using protocols obtained from optimal control theory. We transfer the entire BEC into the first excited state, and create thereby an highly non equilibrium situation that decays by emitting correlated atom pairs [1]. We have developed a two-pulse interferometry scheme acting on super positions of motional Fock states of a BEC trapped in a single anharmonic well [2] reminiscent of the Ramsey interferometers. The control sequence has to be fast compared to the intrinsic decay processes and dephasing effects.

(2) Adiabatic splitting a single well into a double well, can create large number squeezing and entanglement. We have developed control sequences that allow to speed up this process by nearly two orders of magnitude [3]. In first pilot experiments we
employed a simplified protocol of slow splitting with a fast final stage of decoupling and demonstrated strong number squeezing ($\sim -8$ dB), while keeping the sample highly coherent [4]. This leads to spin squeezing of $\sim -7.7$ dB, which is a witness to the large entanglement (typically 150 atom entanglement) between spatially separated Bose-Einstein condensates of about 500 atom each.

(3) We studied the effects of active manipulation of the external parameters of a 1d system and demonstrate scale invariant behaviour of the excitation spectrum [5]. This opened up the possibility to demonstrate that shortcuts to adiabaticity for the rapid expansion or compression of the gas do not induce additional heating.

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Pierre Rouchon (MINES ParisTech)
Quantum state tomography including measurement duration, imperfections and decoherence

Abstract: Tomography of a quantum-state is usually based on positive operator-valued measures (POVM) and on their experimental statistics. Among the available reconstruction techniques, the maximum-likelihood (MaxLike) algorithm is an efficient one. We propose here an extension of such MaxLike algorithm when the measurement process cannot be simply described by POVM. Here the reconstruction relies on a set of quantum trajectories and their measurement records. It includes the fact that, in practice, each measurement could take a finite among of time and could be corrupted by imperfections and decoherence. The proposed extension relies on effective matrices appearing in quantum smoothing and solutions of adjoint quantum filters. This extension is illustrated on experimental data of a superconducting qubit whose fluorescence field is measured using a heterodyne detector.

Session 2
Poul Jessen (University of Arizona)
Accurate and robust unitary control in a high-dimensional Hilbert space

Abstract: Quantum control in large Hilbert spaces is an essential part of quantum information processing. For closed systems the most general input-output maps are unitary transformations, and the fundamental challenge becomes how to implement these with high fidelity in the presence of experimental imperfections and decoherence. For two-level systems (qubits) most aspects of control are well understood, but for systems with Hilbert space dimension $d>2$ (qudits) questions remain regarding the design of control Hamiltonians and the feasibility of robust implementation in the laboratory. Over the past several years we have explored the use of optimal control theory and the performance of the resulting control Hamiltonians for tasks of varying complexity within a large ($d=16$) Hilbert space. In doing so, we have relied on a well-
developed test bed consisting of the electron and nuclear spins of individual 133-Cs atoms driven by radio-frequency and microwave magnetic fields. Our experiments show that the optimal control strategy is adaptable to a wide range of tasks, and that it can generate control Hamiltonians with excellent performance in the presence of both static and dynamic perturbations. Averaging over large samples of randomly chosen transformations, we reliably achieve fidelities from 0.982(2) for unitary maps to 0.995(1) for state-to-state maps. These results represent a significant advance in terms of control complexity and fidelity relative to state-of-the-art for other systems with similar sized-Hilbert spaces. Furthermore, given that the optimal control paradigm applies to any physical platform regardless of specifics, our work provides a useful template for similar advantages elsewhere. Most recently we have used our demonstrated capability for accurate qudit control as a resource for quantum tomography, and we hope to pursue applications in quantum metrology and analog quantum simulation in the future.

Paola Cappellaro (MIT)

Fast control by a quantum actuator

Abstract: Fast and high fidelity control of quantum systems is a key ingredient for quantum computation and sensing devices. The critical task is to reliably control a quantum system, while staying off decoherence, by keeping it isolated from any external influence. These requirements pose a contradiction: fast control implies a strong coupling to an external controlling system, but this entails an undesired interaction with the environment, leading to decoherence.

A strategy to overcome these issues is to use a hybrid system where a quantum actuator interfaces the quantum system of interest to the classical controller, thus allowing fast operations while preserving the system isolation and coherence. This indirect control is particularly appropriate for nuclear spin qubits, which only couple weakly to external fields, but often show strong interactions with nearby electronic spins. In this talk I will describe a strategy to achieve time-optimal indirect control of a nuclear spin qubit by an electronic spin quantum actuator. In particular, I will consider the specific case of the NV center in diamond with applications to both control and sensing.

Session 3
Jun-ichi Yoshikawa (University of Tokyo)

Continuous-variable quantum optical experiments with conditional non-Gaussian states

Abstract: In quantum optics, it is recently known to be beneficial to merge click-by-click discrete-variable technologies and continuous-wave continuous-variable technologies. I will talk about our recent experiments of creating various non-Gaussian states, conditioned by photon detection, which are compatible with wave-basis homodyne characterization. My talk will also include synchronization of conditional single photons by means of optical cavity storage, and continuous-variable quantum gates compatible with conditional non-Gaussian states.

Hendra Nurdin (UNSW Australia)

On the cascade realization of the transfer function of linear quantum systems

Abstract: It is known that the transfer function of passive linear quantum systems that are commonly encountered in quantum optics, optomechanics, and related fields, have a purely cascade realization. That is, their transfer function can be realized by cascading of one degree of freedom linear quantum systems that are each also passive, without the need for any direct interaction between internal oscillators in the linear quantum
system. The question remains of whether active systems (that involve non-photon number conserving interactions between the oscillators or/and between oscillators and external fields) have a cascade realization, and when they have such a realization. This talk will present some new results on this problem.

**Session 4**
Madalin Guta (University of Nottingham)
*Estimation of stationary quantum input-output dynamics*

Abstract: This talk is focused on recent results on the identification of input-output systems in the stationary regime. The second part deals with the connection between dynamical phase transitions for open systems and the possibility to use the output state for quantum enhanced metrology of dynamical parameters. We show that for ergodic systems the dynamical parameters (Hamiltonians and jump operators) can be identified up to a unitary (“change of basis”) transformation and a shift of the Hamiltonian’s eigenvalues. We then identify the quantum Fisher information of the output state and show that it scales linearly in time, with rate equal to the Markov covariance of certain quantum stochastic integrals playing the role of generators for parameter changes. Moreover, asymptotically in time the output model converges to a Gaussian model consisting of coherent states of a continuous variable system whose phases space is that of the identifiable parameters. Finally, we show that if the system exhibits dynamical phase transitions (nearly degenerate stationary state) the quantum Fisher information has an initial quadratic increase in time for the duration of the correlation time. For degenerate stationary states, the quadratic scaling is valid for all time. This feature is illustrated with the example of phase estimation.

Alessio Serafini (University College London)
*Open and closed-loop control of bosonic Gaussian states: recent findings and open problems*

Abstract: After a very brief introduction to Gaussian states, symplectic operations - corresponding to unitaries generated by quadratic polynomials in the bosonic field operators - and general-dyne measurements, with references to practical implications in current experiments, we shall give an overview of results on the optimal (in terms of entropies, squeezing and entanglement) general-dyne filtering of Gaussian states, and on their application to quantum opto-mechanics. We will also show how, at finite temperatures, the optimal monitoring implies access to a purification of the state of the environment, and discuss the open problem of establishing optimality when such an access is ruled out. In the second part of the talk, we shall focus on the open-loop symplectic controllability problem in the algebraic framework, covering necessary and sufficient conditions for full symplectic controllability as well as the question of whether any multimode Gaussian state may be obtained from an uncorrelated state through the action of a single Hamiltonian (which is not trivial, since the most general symplectic operation cannot be generated by the exponentiation of a single Hamiltonian matrix).

**Friday, July 24**

**Session 1**
Joshua Combes (IQC and Perimeter Institute)
*Characterizing time dependent sources and gates*

Abstract: In state and process tomography one usually makes an assumption that the samples from the source or process are independent and identically distributed. Recent experimental results are suggesting that the noise present in sources and gates are not
accurately modeled as an independent and identically distributed process. Thus new characterization procedures are needed. In this talk I will describe two techniques to address this problem. The first technique that allows one to “coherently” measure the autocorrelation function of a quantum stochastic process. Then using the Wiener–Khinchin theorem one obtains the spectrum of a quantum stochastic process. The second technique extends quantum tomography so that dynamical tracking of the quantum state is possible. This has applications in QKD where dynamical reference frame tracking is a necessary calibration procedure.

Keisuke Fujii (Kyoto University)  
*Measurement-free topological protection with dissipative feedback*

Abstract: Protecting quantum information from decoherence due to environmental noise is vital for fault-tolerant quantum computation. To this end, standard quantum error correction employs parallel projective measurements of individual particles, which makes the system extremely complicated. Here, we propose measurement-free topological protection in two dimensions without any selective addressing of individual particles. We make use of engineered dissipative dynamics and feedback operations to reduce the entropy generated by decoherence in such a way that quantum information is topologically protected. We calculate an error threshold, below which quantum information is protected, without assuming selective addressing, projective measurements, or instantaneous classical processing. All physical operations are local and translationally invariant, and no parallel projective measurement is required, which implies high scalability. Furthermore, since the engineered dissipative dynamics we utilize has been well studied in quantum simulation, the proposed scheme can be a promising route progressing from quantum simulation to fault-tolerant quantum information processing.

**Session 2**

Chuan-Feng Li (University of Science and Technology of China)  
*Quantum control and quantum simulation with linear optics*

Abstract: Usually it is difficult to introduce Hamiltonian in linear optical system, therefore quantum simulation in this system is previously only state preparation process. In our experiment, we can introduce Hamiltonian via quantum control with an ancilla qubit and carry out some quantum simulation experiments, such as quantum Demon-like algorithmic cooling, quantum non-Abelian statistics etc. With this technique, we also observe wave-particle superposition state of single photon.

Arne Grimsmo (Université de Sherbrooke)  
*Time-delayed coherent quantum feedback control*

Abstract: In this talk I consider the problem of a quantum system subject to coherent feedback, mediated by a travelling quantum field. This type of feedback can be implemented in a variety of physical platforms, where remote quantum systems are coupled via waveguides. The conventional theoretical treatment of this type of feedback is to neglect any time-delays in the feedback loop, effectively assuming that the length of the feedback waveguide is zero. I will try to argue that going beyond this limit is both necessary and might open up for new possibilities for quantum feedback control. Using a so-called tensor network representation of the system+field time-propagator, I derive a tractable model for the reduced system dynamics. This model gives rise to a natural interpretation where the system is driven by past instances of itself, in a quantum cascaded fashion.
III. Poster Titles and Abstracts

Arash Khodaparastsichani (UNSW Canberra, Australia)

Parameterization of stabilizing linear coherent quantum controllers

Abstract: This poster is concerned with application of the classical Youla-Kucera parameterization to finding a set of linear coherent quantum controllers that stabilize a linear quantum plant. The plant and controller are assumed to represent open quantum harmonic oscillators modelled by linear quantum stochastic differential equations. The interconnections between the plant and the controller are assumed to be established through quantum bosonic fields. In this framework, conditions for the stabilization of a given linear quantum plant via linear coherent quantum feedback are addressed using a stable factorization approach. The class of stabilizing quantum controllers is parameterized in the frequency domain. Also, this approach is used in order to formulate coherent quantum weighted H2 and H∞ control problems for linear quantum systems in the frequency domain. Finally, a projected gradient descent scheme is proposed to solve the coherent quantum weighted H2 control problem.

Michael Hush (University of New South Wales at the Australian Defence Force Academy, Australia)

Spin Correlations as a probe of quantum synchronization in trapped ion phonon-lasers

Abstract: We investigate quantum synchronization theoretically in a system consisting of two cold ions in microtraps. The ions' motion is damped by a standing-wave laser whilst also being driven by a blue-detuned laser which results in self-oscillation. Working in a non-classical regime, where these oscillations contain only a few phonons and have a sub-Poissonian number variance, we explore how synchronization occurs when the two ions are weakly coupled using a probability distribution for the relative phase. We show that strong correlations arise between the spin and vibrational degrees of freedom within each ion and find that when two ions synchronize their spin degrees of freedom in turn become correlated. This allows one to indirectly infer the presence of synchronization by measuring the ions' internal state.

Haidong Yuan (Chinese University of Hong Kong, Hong Kong)

Ultimate precision limit and optimal input states in quantum metrology

Abstract: Measurement and estimation of parameters are essential for science and engineering, where the main quest is to find out the highest achievable precision with given resources and design schemes that attain that precision. We present a general framework for quantum metrology which relates the ultimate precision limit directly to the underlying dynamics. This provides efficient methods to compute the ultimate precision limit without making any assumptions, and it also provides efficient ways to obtain optimal input states that achieve the ultimate limit.

Yonghai Chen (Institute of Semiconductors, Chinese Academy of Sciences, China)

Spin depolarization under low electric fields at low temperatures in InGaAs/AlGaAs quantum well

Abstract: The spin polarization under low electric fields (<300 V/cm) at low temperatures has been studied in undoped InGaAs/AlGaAs multiple quantum well. The spin polarization was created by optical spin orientation using circularly polarized light, and the inverse spin-Hall effect was employed to measure the spin polarization current. We observed an obvious spin depolarization especially at lower temperatures (80–120
K). We ascribed the spin depolarization of the photoinduced electrons to the heating effect from the low electric fields (the low field regime 50–300 V/cm). This spin depolarization due to the heating effect is sensitive to temperature and electric field, suggesting a wide range of potential applications and devices.

Gerardo Andres Paz-Silva (Griffith University, Australia)

*Noise spectroscopy and targeted suppression*

Abstract: We present a general framework and methods capable of (i) characterizing the spectral properties of a classical or quantum noise source with minimal assumptions or knowledge of the underlying Hamiltonian, and, (ii) by exploiting the acquired information, of implementing a desired high quality operation on a quantum system suffering such noise. Our model independent approach and methods are applicable to all current quantum platforms.

Yongsheng Zhang (University of Science and Technology of China, China)

*Deterministic noiseless amplification of coherent states*

Abstract: A universal deterministic noiseless quantum amplifier has been shown to be impossible. However, probabilistic noiseless amplification of a certain set of states is physically permissible. Regarding quantum state amplification as quantum state transformation, we show that deterministic noiseless amplification of coherent states chosen from a proper set is possible. The relation between input coherent states and gain of amplification for deterministic noiseless amplification is thus derived. Besides, the potential applications of amplification of coherent states in quantum key distribution (QKD), noisy channel and non-ideal detection are also discussed. [arXiv:1503.03554]

Shibei Xue (UNSW Canberra at ADFA, Australia)

*Quantum filter for a class of non-Markovian quantum systems*

Abstract: In this paper we present a Markovian representation approach to constructing quantum filters for a class of non-Markovian quantum systems disturbed by Lorentzian noise. An ancillary system is introduced to convert white noise into Lorentzian noise which is injected into a principal system via a direct interaction. The resulting dynamics of the principal system are non-Markovian, which are driven by the Lorentzian noise. By probing the principal system, a quantum filter for the augmented system can be derived from standard theory, where the conditional state of the principal system can be obtained by tracing out the ancillary system. An example is provided to illustrate the non-Markovian dynamics of the principal system.

Shuang Cong (University of Science and Technology of China, China)

*Lyapunov-based control of a double quantum-dot system*

Abstract: The Lyapunov-based control strategy was designed in the manipulation of a single qubit in the two-level double quantum-dot (DQD) system. The control process is composed of three parts: firstly, a slope pulse takes the system from a positive detuning adiabatically to the anti-crossing point, which corresponds to the resonance state of the system; then, a Lyapunov-based control pulse drives the charge qubit transfer non-adiabatically; finally, another slope pulse takes the system away from the anti-crossing point to keep the system stable. The charge state probability and the curve of Lyapunov-based control pulse were studied under different control parameters. Simulation results showed that: the designed Lyapunov-based control pulse has a rise time ~ 100ps, which
is in the scope of the Agilent 81134A pulse generator for implement. The max-imum charge qubit probability can reach ~ 96%, and the stable probability can be ~ 86% for transition from the initial charge state to the desired target charge state.

Karsten Pyka (Quantum Control Lab, The University of Sydney, Australia)

*Experimental apparatus for quantum simulation with two-dimensional 9Be+ Coulomb crystals*

Abstract: We report on the development of a new experimental setup designed for Quantum Simulation studies at a computationally relevant scale using laser-cooled 9Be+ ion-crystals in a Penning trap. The trap geometry is optimized using numerical calculations for trapping large ion crystals with enhanced optical access and reduced anharmonic perturbations. Separate loading and spectroscopy zones prevent long term drifts of the trapping parameters due to contamination of the trap electrodes with Be deposits. Our customized superconducting magnet provides a homogenous (dB/B < 10-6) magnetic field at 3T required for ion trapping. Laser frequencies required for cooling/detection and spin-motion entanglement are generated from telecom wavelength fiber laser systems in the IR via nonlinear conversion. Our new approach employs high-efficiency telecom modulators and mode-selecting cavities to generate multiple beamlines from a single Sum-frequency-Generation step. Ultimately, this newly developed setup will allow for studies of many-body spin systems with tuneable interaction strength from infinite-range to nearest-neighbour type interaction.

Ryan Hamerly (Stanford University, United States)

*Ising machines via OPO and free-carrier oscillations*

Abstract: The Ising problem is a common optimization problem that involves finding the ground state of a pairwise spin Hamiltonian. For a general coupling, this problem is NP hard, and classic NP problems such as MAX-CUT and 3-SAT can be recast as Ising problems. We are working on schemes to minimize the Ising potential that involve networks of optical oscillators. One scheme involves a time-multiplexed OPO with injection feedback. Another approach is based on oscillations in semiconductor microcavities driven by free-carrier dispersion.

Elica Kyoseva (Singapore University of Technology and Design, Singapore)

*Quantum control by composite pulses & quantum-optical analogies*

Abstract: We present analytical broadband, narrowband and passband composite pulses for quantum control of two-state quantum systems for QIP. We extend the composite pulses approach and design robust analytical composite Householder reflections in N-state quantum systems, which have broad applications in synthesis of unitary operations. Furthermore, we numerically develop a new type of composite pulses, which allow the robustness of the excitation to be maximized, given a certain level of the tolerated error. Lastly, we show how achromatic optical elements can be created based on an analogy with composite pulses.

Antti Vepsäläinen (Aalto University, Finland)

*Experimental realization of stimulated Raman adiabatic passage using a superconducting transmon qutrit*

Abstract: Stimulated Raman adiabatic passage (STIRAP) is a widely used technique for robust population transfer in multi-level systems. We experimentally demonstrate that this method can be also used in a circuit QED consisting of a three level transmon read
via a resonator, where the STIRAP is applied to transfer population from the ground state of the transmon to the second excited state. The main benefit of STIRAP is its robustness with respect to the timing of the control pulses, and that the small fluctuations or errors in the frequencies of the control signals do not significantly affect the transfer efficiency. As a result, we realize a high fidelity quantum gate which can realize arbitrary superposition states between the ground state and the second excited state.

Ian Petersen (UNSW, Canberra, Australia)

*Time averaged consensus in a direct coupled coherent quantum observer network for a single qubit finite level quantum system*

Abstract: This paper considers the problem of constructing a direct coupled quantum observer network for a single qubit quantum system. The proposed observer consists of a network of quantum harmonic oscillators and it is shown that the observer network output converges to a consensus in a time averaged sense in which each component of the observer estimates a specified output of the quantum plant.

Christopher Bentley (The Australian National University, Australia)

*Fast gates with trapped ions*

Abstract: Systems of trapped ions offer exceptional control opportunities via optical and magnetic fields. Adiabatic schemes are typically extremely robust, and are used for performing quantum gate operations on trapped ions. The disadvantage of an adiabatic process is that it is necessarily limited in speed. This forms a fundamental constraint in using trapped ions for quantum information processing, where the figure of merit is the number of gate operations per decoherence lifetime. We discuss the implementation of fast gates, highlighting experimental control restrictions and the requirements for scaling the gates to large numbers of ions.

Richard Taylor (Australian National University, Australia)

*Fast multi-qubit gates for quantum simulations in trapped ions*

Abstract: Quantum information processing, based on single and multi-qubit logic gates, promises a number of exciting possibilities beyond the capabilities of classical computation. A promising platform for the implementation of quantum information processing is the ion trap. Unfortunately, existing multi-qubit gates in these ion traps are slow, depending on the resolution of sideband excitations of single collective motional modes of the trap using long laser pulses.

Theoretical proposals for much faster two-qubit gates using laser pulses resonant to the internal state transition of an ion qubit have recently been made, relying on the excitation of all collective motional modes of the trap to produce an entangling gate. In this work I present progress towards extending these fast gates to perform a gate operation on more than two qubits. This has a particular application in improving the implementation of a recently-proposed scheme for digital quantum simulations of fermionic and bosonic systems using an ion trap, which presently relies on the slow Molmer-Sorensen gate and is thus not yet feasible.

Ryosuke Hata (Osaka Prefecture University, Japan)

*Population inversion and up-converted luminescence of a 2-level system coupled with an anharmonic auxiliary system*
Abstract: We theoretically study the population dynamics of a 2-level system coupled with an anharmonic auxiliary system such as the localized surface plasmon-polariton or LC circuit, driven by a strong Gaussian laser.

In our previous study, for a continuum wave laser as incident light, we have revealed that the population inversion of the 2-level system can be achieved by connecting it with an anharmonic auxiliary system even when the resonance energy of the 2-level system is far detuned from the incident energy (R. Hata, et. al., J. Phys. Soc. Jpn. 83, 093401 (2014)). Such system is expected to be promising for future applications for novel types of active light sources.

In the present contribution, we study the feasibility of such a light-source scheme for more realistic condition considering a short pulse as incident light. We assume that the eigenenergy of the 2-level system is resonant with a Mollow triplet sideband originated from the interaction between the field and anharmonic auxiliary system.

As a result, the population inversion is also achieved even for realistic parameters of the auxiliary system representing a light antenna sustaining localized surface plasmon-polaritons, and its dynamics shows faster decay than its spontaneous emission due to the Purcell effect. Further, we evaluate the photoemission activity of the 2-level system whose spectrum has a peak at bare resonance energy. Thus, both the population inversion and the up-conversion are simultaneously realized by using our system. These demonstrations show a great potential for a novel type of active up-converted device that can be realized by preparing an ensemble of such 2-level systems.

Takashi Kinoshita (Osaka Prefecture University, Japan)

*Ultrafast switching of light polarization by nondipole-type superradiance*

Abstract: We theoretically demonstrate an ultrafast switching of polarization of light by utilizing a ZnO thin film in which nondipole-type excitonic wavefunctions are confined. The submicron-order of coherence length of excitonic wavefunction realizes a large interaction volume with the electromagnetic (EM) field. In such a situation, the size-dependent nonlocal effect between excitons and EM field plays an important role on formation of mode structures in the light-exciton coupled system. Due to this effect, some particular modes monopolize the radiative self-energy corrections and exhibit radiative decay times reaching to several femto seconds (excitonic superradiance). In order to demonstrate an ultrafast switching of light at room temperature (RT), we focus on the optical Kerr response that is a typical third-order nonlinear and polarization rotation effect. Because the radiative decay times of the superradiant modes are much faster than the thermal dephasing, such modes are expected to exhibit a robust nonlinearity against temperature.

As a result, we find that the efficiency of polarization rotation is not much reduced by dephasing even at RT if a sufficiently short input pulse is applied to cover the superradiant modes effectively. This result means that one can realize ultrafast and efficient switching of light polarization by utilizing excitonic superradiant modes in a ZnO thin film even at RT.

Tekle Setargew (Australian National University, Australia)

*Entanglement distribution in quantum networks*

Abstract: Quantum Relays and entangled quantum networks are key steps in developing technologies in Quantum Communication and Quantum Computation. This work investigates how different parameters affecting the entanglement between adjacent
nodes in a quantum network influence the final entanglement between the endpoints of the network.

Sam Needham (Australian National University, Australia)
Modelling a BEC Undergoing Feedback Control With a Gaussian Approximation

Abstract: BECs are useful for a huge variety of applications, from cold atom interferometry to tests of fundamental physics. Here a BEC is modelled numerically using a Gaussian approximation and compared with previous theoretical and experimental results. In theory, it should offer perfect agreement with mean-field approximations in regimes where they are valid, and offer some insight into the behaviour of systems where mean-field fails. Coherent evolution has been successfully modelled, and the next step is to introduce the measurement and feedback process.

Ruvindha Lakshan Lecamwasam (Australian National University, Australia)
A quantum light switch

Abstract: We outline a system with the potential to produce various photon states on demand, and protect them against decoherence. Such a device would have a variety of applications in experimental physics, as well as quantum computing and communication.

Jessica Eastman (Australian National University, Australia)
Generating efficient random quantum states with quantum trajectories

Abstract: Random quantum states are a useful resource in quantum information, unfortunately they are hard to generate and not very efficient. For some applications it suffices to share some of the "coarse" statistical features of truly random states. This work looks at efficiently generating quantum states using quantum measurements. We have developed a scheme that we believe will scale well as more qubits are added.

Shanon Leigh Vuglar (University of Melbourne, Australia)
The physical realizability of spectral density matrices describing non-markovian quantum noise

Abstract: We consider modeling non-Markovian quantum noise as the output of a physically realizable quantum system driven by Markovian quantum noise. In particular, we consider the class of spectral density matrices corresponding to non-Markovian quantum noises obtained in this way.

Paul Wigley (Australian National University, Australia)
Experimental application of online optimisation to a Bose Einstein Condensate

Abstract: Experiments often involve tedious manual optimisation unsuited to a human but ideal for computers. By providing the experimental goal to the computer, we can use online optimisation techniques to make these tedious apparatus optimisations simpler and faster. Machine learning provides further gains in speed by using all tested data to generate a model. This model can provide further insight into the system that may otherwise go unnoticed. Here we present machine learning successfully applied to the evaporation stage of Bose Einstein condensation.
Zhan Shi (UNSW Australia, Australia)

Entanglement in a linear coherent feedback chain of nondegenerate optical parametric amplifiers

Abstract: This work is concerned with linear quantum networks of $N$ nondegenerate optical parametric amplifiers (NOPAs), with $N$ up to 6, which are interconnected in a coherent feedback chain. Each network connects two communicating parties (Alice and Bob) over two transmission channels. This work aims to analyse stability, EPR entanglement between two outgoing fields of interest, and bipartite entanglement of two-mode Gaussian states of cavity modes of the N-NOPA networks under the effect of transmission and amplification losses, as well as considering the effect time delays in the output entanglement. It is numerically shown that, in the absence of losses and delays, the network with more NOPAs in the chain requires less total pump power to generate the same degree of EPR entanglement. Moreover, we report on the internal entanglement synchronization that occurs in the steady state between certain pairs of Gaussian oscillator modes inside the NOPA cavities of the networks.

Nedasadat Hosseinidehaj (UNSW Australia, Australia)

Gaussian versus non-Gaussian entanglement over atmospheric fading channels

Abstract: In this work distribution of quantum entanglement between a ground station and satellite over an atmospheric fading channel is analysed. We consider two cases; entangled states which are initially Gaussian in character, and entangled states which are initially non-Gaussian in character. The transmitted non-Gaussian states we discuss are obtained from Gaussian states via photon subtraction. We determine the total amount of final entanglement between the terrestrial station and the satellite after decoherence through the fading atmospheric channel is accounted for. We outline under which conditions the initially transmitted Gaussian states are more robust (relative to initially non-Gaussian states) in retaining their entanglement.

Zibo Miao (University of Melbourne, Australia)

Coherently tracking the covariance matrix of an open quantum system

Abstract: Coherent feedback control of quantum systems has demonstrable advantages over measurement-based control, but so far there has been little work done on coherent estimators and more specifically coherent observers. Coherent observers are input the coherent output of a specified quantum plant, and are designed such that some subset of the observer’s and plant’s expectation values converge in the asymptotic limit. We previously developed a class of mean tracking (MT) observers for open harmonic oscillators that only converged in mean position and momentum; Here we develop a class of covariance matrix tracking (CMT) coherent observers that track both the mean and covariance matrix of a quantum plant. We derive necessary and sufficient conditions for the existence of a CMT observer, and find there are more restrictions on a CMT observer than there are on a MT observer. We give examples where we demonstrate how to design a CMT observer and show it can be used to track properties like the entanglement of a plant. As the CMT observer provides more quantum information than a MT observer, we expect it will have greater application in future coherent feedback schemes mediated by coherent observers. Investigation of coherent quantum estimators and observers is important in the ongoing discussion of quantum measurement; As they provide estimation of a system’s quantum state without explicit use of the measurement postulate in their derivation.

Wei Zhang (UNSW Canberra, Australia)

Sampling-based robust control in synchronizing charge transfer collision
Abstract: This poster proposes that robust laser pulses can be obtained by the sampling-based method to achieve a desired charge transfer probability with a limited uncertainty in the arrival time of laser pulses taken into account.

Shi Wang (UNSW Canberra, Australia)

*Fault-Tolerant Control of Linear Quantum Stochastic Systems*

Abstract: In quantum engineering, faults may occur in a quantum control system, which will cause the quantum control system unstable or deteriorate other relevant performance of the system. This poster presents an estimator-based fault-tolerant control design approach for a class of linear quantum stochastic systems subject to fault signals. In this approach, the fault signals and some commutative components of the quantum system observables can be estimated, and a fault-tolerant controller can be designed to compensate the effect of the fault signals.