Book of Abstracts

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Contents

Abstracts of talks

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University of Luxembourg

Control of open quantum systems with engineered dephasing

Control techniques such as shortcuts to adiabaticity (STA) have been mainly limited to isolated systems. Extending such techniques to open systems is highly desirable in view of applications to cooling, and more generally, in finite-time thermodynamics. I will present a universal scheme for the control of open systems, defining a trajectory-based equation of motion that allows for the control of any arbitrary dynamics [1]. Its application will be given for controlling the temperature of squeezed thermal state in a harmonic trap [2], and in a trapped ion [3]. In addition, this physically motivated equation of motion leads to an entropy-based definition of heat and work, that asks to reconsider the standard model and extends these notions to open quantum systems [4].

1. S. Alipour, A. Chenu, A. Rezakhani, A. del Campo. Shortcuts to Adiabaticity in Driven Open Quantum Systems: Balanced Gain and Loss and Non-Markovian Evolution. Quantum, 4:336 (2020)
2. L. Dupays, I. L. Egusquiza, A. del Campo, and A. Chenu. Superadiabatic thermalization of a quantum oscillator by engineered dephasing , Phys. Rev. Res. 2:033178 (2020)
3. L. Dupays and A. Chenu, Quantum, 5:449 (2021)

Sabrina Patsch

Free University of Berlin

Optimal control of high-dimensional Hilbert spaces

The precise engineering of quantum states is a basic prerequisite for technologies such as quantum-enhanced sensing, a task which becomes more challenging with increasing dimension of the system Hilbert space. Here, we use quantum optimal control theory to derive shaped radio-frequency pulses to navigate the Stark manifold of a Rydberg atom and discuss the fundamental quantum speed limit for circularisation when lifting the experimental constraints. We demonstrate that optimal control, beyond improving the fidelity of an existing protocol, also enables us to accurately generate a non-classical superposition state that cannot be prepared with reasonable fidelity using standard techniques.

Andreas Ruschhaupt

University College Cork

Enhanced Shortcuts to Adiabaticity

The preparation and control of quantum states in a fast and robust way is of the utmost importance for current and future quantum technologies. One class of quantum control schemes are "Shortcuts to Adiabaticity" (STA) [1, 2]. They are quantum control protocols motivated by adiabatic processes and mainly derived using analytical techniques. First, I will first give a brief overview of STA. However, there are still quantum systems where these STA techniques cannot be applied. Therefore, I will then present a new technique for such scenarios, called "Enhanced Shortcuts to Adiabaticity" [3, 4]. These new method works for previously intractable Hamiltonians by providing an analytical correction to existing STA protocols. This correction can be easily calculated and the resulting protocols are outside the class of STA schemes. Finally, I will also give an outlook towards Shortcut-Enhanced Quantum Thermodynamics [5,6].

1. E. Torrontegui et. al, Adv. At. Mol. Opt. Phys. 62 (2013), 117
2. D. Guery-Odelin et. al., Rev. Mod. Phys. 91 (2019) 045001
3. C. Whitty, A. Kiely, and A. Ruschhaupt, Phys. Rev. Research 2, 023360 (2020)
4. C. Whitty, A. Kiely, and A. Ruschhaupt, "Robustness of Enhanced Shortcuts to Adiabaticity in Lattice Transport", in preparation
5. https://www.ucc.ie/quantumcontrol/
6. https://www.ucc.ie/quantumcontrol/sfifrontiersforthefutureprojectseqt/

Paul Eastham

Trinity College Dublin

Optimal control beyond the weak-coupling and Markovian regimes: efficient simulation of families of open quantum systems with differing Hamiltonians

Optimal control of quantum systems allows the discovery of protocols for state preparation and other tasks in quantum technology. However, it rests on the ability to accurately compute the dynamics of a quantum system under the action of its environment. This is generally only straightforward for simple systems which are weakly coupled to Markovian environments. Here we show how optimal control protocols can be found without these assumptions. We use a recently developed method in which a matrix product representation is used to efficiently encode the effect of the environment as a process tensor to rapidly compute the dynamics of an open quantum system for many different control fields. We describe this approach and illustrate its application to quantum control problems by identifying non-trivial pulses for state preparation in qubits coupled to baths with structured spectral densities [1]. We show that the gradients of the target functional, with respect to the control parameters, can be efficiently calculated using a form of backpropagation. This enables sensitivity analyses, and opens the way for optimal control studies of non-Markovian systems with extremely large numbers of control parameters.

1. Efficient Exploration of Hamiltonian Parameter Space for Optimal Control of Non-Markovian Open Quantum Systems, Gerald E. Fux, Eoin P. Butler, Paul R. Eastham, Brendon W. Lovett, and Jonathan Keeling, Phys. Rev. Lett. 126, 200401 (2021).

Qiongyuan Wu

Queen's University Belfast

Non-equilibrium thermodynamics of a levitated nanoparticle in a controllable time-varying potential

Many advanced quantum techniques feature non-Gaussian dynamics, and the ability to manipulate the system in that domain is the next-stage focus to many experimentalists. One example of meaningful non-Gaussian dynamics is the one with a double-well potential. Here we study the dynamics of a Gaussian-to-Double-Well potential in a realistic setting, subjecting to both thermalising and localising dissipations. Effects of these dissipations are illustrated with a spin-S system, and by comparison, a quantum oscillator with the Gaussian-to-double-well potential. We characterise these dynamics from a thermodynamic point-of-view, investigating the dynamics with its the Wehrl entropy production. For the Gaussian-to-Double-Well potential, we investigate contributions of higher order terms in the potential by applying to it the Taylor expansion. The effects and the competition of two dissipators onto the system are demonstrated, and we found that thermalisation has a more severe impact than the localisation. We quantify the requirements for conducting a bonafide experiment with the presence of the environment, and discuss the experimental interpretations of our results in the end.

Gabriele de Chiara

Queen's University Belfast

Control of quantum critical systems

In the first part, I will show that a bang-bang protocol, consisting of a time evolution under two different values of an externally tunable parameter, allows for a high-fidelity fast ground state preparation [1]. We benchmark the performance through the Landau-Zener and the Lipkin-Meshkov-Glick models. Remarkably, the critical ground state of the latter model can be prepared with a high fidelity in a total evolution time that scales slower than the inverse of the vanishing energy gap. In the second part, I will show how to harness excitations produced by crossing a quantum critical point for applications in quantum thermodynamics, e.g. battery charging, and quantum information tasks, e.g. metrology and sensing [2].

1. L. Innocenti, G. De Chiara, M. Paternostro, R. Puebla, New J. Phys. 22, 093050 (2020)
2. O. Abah, G. De Chiara, M. Paternostro, R. Puebla, arXiv:2105.00362

Ulrich Schneider

University of Cambridge

Controlling the character of a quantum phase transition in a driven optical lattice

Phase transitions and critical phenomena have been at the heart of quantum simulations with cold atoms from the beginning. While almost all phase transitions in cold atoms systems are continuous, there is a renewed interest in discontinuous (first-order) phase transitions and the associated metastable states, whose relativistic analogues are believed to play an important role in early-universe cosmology (false vacuum decay).
We experimentally demonstrate a novel level of control over a quantum phase transition by combining an optical lattice with resonant Floquet engineering. Contrary to most applications of periodic driving, where the drive frequency is selected to avoid all resonances, we resonantly couple the lowest two bands of a lattice. By controlling drive parameters, we can not only induce the superfluid to Mott insulator transition but are furthermore able to control its character and turn the Mott transition from a continuous into a discontinuous transition. Our observations of the associated metastability and hysteresis agree with numerical simulations and pave the way for exploring the crucial role of quantum fluctuations in discontinuous transitions.

Graham Kells

Dublin Institute for Advanced Studies

Weak measurement, quantum trajectories, and topological order

The idea of continuous or weak-measurement has been used in recent years to motivate and explore what are called entanglement transitions in quantum trajectory dynamics. Here I will discuss our analysis of a system that employs different types of continuous/weak monitoring together with free-fermion hopping to generate distinct area- and volume-law phases. Crucially, one of the area-law phases has non-trivial topological properties. I will outline how phase diagram can be understood in terms of a non-Hermitian Hamiltonian derived using the notion of post-selected measurement, and propose a general experimental setup that could be used to support such a system.

Emma Minarelli

University College Dublin

Pseudogap charge Kondo effect in graphene quantum dots

Historically, the roots of the Kondo effect [1] are associated with anomalous transport properties of metals such as Au or Ag at low temperatures due to quantum magnetic impurities. At small energy scales, the Kondo effect describes the formation of singlet state by magnetic local moments strongly interacting with the surrounding conduction sea of electrons. In fact, Kondo effects characterize the general class of quantum impurity problems, where the impurity is a few degrees of freedom system with local interactions that are coupled to a larger non-interacting electronic bath. A rather complete physical picture was provided theoretically by the Numerical Renormalization Group (NRG) invented by K. Wilson [2]. In recent years, experimental results have probed the Kondo effect from magnetic impurities or defects in graphene. Here we consider the two-channel charge-Kondo quantum dot paradigm of K.A. Matveev [3], but now with a graphene dot and graphene leads, realizing a variant of the two-channel linear Kondo model with pseudogap density of states. In particular, we discuss the crucial role of doping, which is needed in the large graphene dot to realize a charge pseudospin, and note the suppression of Kondo effect as charge neutrality is approached. NRG results for thermodynamics property as entropy and quantum transport as electrical conductance are presented. Acknowledgements: Irish Research Council through grant EPSPG/2017/343.

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3. K.A. Matveev. 1991, Soviet physics, JETP, 72(5), pp.892-899; A. Furusaki and K.A. Matveev, Phys. Rev. B, 52(23), p.16676, (1995)

Felix Binder

Trinity College Dublin

Quantum predictive modelling: unitary simulation and dimension reduction

Stochastic processes with memory are as ubiquitous throughout the quantitative sciences as they are notorious for being difficult to simulate and predict. Weather patterns, stock prices, and biological evolution are just some of the most prominent examples. In the last decades an information-theoretic framework, called 'computational mechanics', has been developed that studies the complexity of such non-Markovian processes in terms of the minimal memory required for their simulation. More recently, it was discovered that this memory requirement for simulation may be further reduced by using a quantum instead of a classical memory substrate. Based on these results, we have developed a generic method for constructing unitary quantum simulators for a large class of stochastic processes, which can yield an unbounded scaling advantage.

In this talk I will give a brief an introduction to computational mechanics and statistical complexity as well as their extension to quantum memory. I will then describe a proposal for the construction of a unitary quantum simulator which is applicable to a large class of stochastic processes. Finally, I will highlight some of the implications of the results, and in particular, unbounded dimension reduction of the memory.

Ahsan Nazir

University of Manchester

Heat and work statistics in adiabatic quantum systems with strong reservoir coupling

We study the heat and work full counting statistics for a slowly driven quantum system that is strongly-coupled to its surrounding environment. We employ a polaron approach to derive a master equation for the work and heat characteristic functions beyond the weak-coupling limit, valid in the adiabatic regime of slow time-dependent system control. We show how the resulting work and heat probability distributions vary from the weak-coupling approach and outline potential applications in driven quantum dots.

Janet Anders

University of Exeter/ University of Potsdam

Quantum Brownian Motion for Magnets

Spin precession in magnetic materials is commonly modelled with the classical phenomenological Landau-Lifshitz-Gilbert (LLG) equation. Evidence is mounting that generalisations of this equation are required to describe dynamics on ultrashort time scales. In my talk I will discuss a much more general quantum spin dynamics equation that describes three-dimensional precession and damping, and consistently accounts for effects arising from memory, coloured noise and quantum statistics. The derivation is based on a system+bath Hamiltonian, similar to the Caldeira-Leggett and spin-boson models. The LLG equation is recovered as a classical, Ohmic approximation. We further introduce resonant Lorentzian system–reservoir couplings that allow a systematic comparison of dynamics between Ohmic and non–Ohmic regimes. Finally, we simulate the full non-Markovian dynamics of a spin in the semi–classical limit. The above three ingredients - the 3D quantum equation, Lorentzian couplings, and our method for numerical simulation - provide a powerful framework to explore general three-dimensional dissipation in quantum thermodynamics.

1. arxiv 2009.00600v2, J.Anders, C.R.J. Sait, S.A.R. Horsley.

Mark Mitchison

Trinity College Dublin

Thermometry by decoherence with impurity qubits

The precise measurement of temperature is a crucial prerequisite for the coherent control of cold quantum systems. In this talk, I will describe how temperature can be inferred by monitoring the decoherence of a qubit embedded within the system of interest [1,2,3]. This approach can be implemented in ultracold atomic gases [4], for example, and has several interesting advantages compared to standard thermometry schemes. Surveying some of our recent results in this direction, I will first present a proposal for thermometry by decoherence in a single-component Fermi gas [1]. I will then describe how this idea can be extended to generic, strongly interacting systems, which may even be prepared in a pure quantum state [2]. Finally, I will discuss the general thermodynamics of decoherence [5], which shows that such measurements come at a fundamental energetic cost in the form of heat dissipation.

1. M. T. Mitchison, T. Fogarty, G. Guarnieri, S. Campbell, T. Busch, and J. Goold, Phys. Rev. Lett. 125, 080402 (2020)

2. M. T. Mitchison, A. Purkayastha, M. Brenes, A. Silva, and J. Goold, arXiv:2103.16601 [quant-ph] (2021)

3. T. H. Johnson, F. Cosco, M. T. Mitchison, D. Jaksch, and S. R. Clark, Phys. Rev. A 93, 053619 (2016)

4. D. Adam, Q. Bouton, J. Nettersheim, S. Burgardt, A. Widera, arXiv:2105.03331 [quant-ph] (2021)

5. Maria Popovic, Mark T. Mitchison, John Goold, arXiv:2107.14216 [quant-ph] (2021)

Heather Leitch

Queen's University Belfast

Thermodynamics of Driven Quantum Harmonic Oscillators

The study of quantum thermodynamics is key to the development of quantum thermal machines. I present a system of parametrically driven quantum harmonic oscillators coupled to heat baths via a collision model. From a thermodynamically consistent local master equation, I shall derive the heat flows and work power from the working device which can operate as an engine, refrigerator, or heat pump. Studying both slow and fast driving of the system, it is found that an increased driving frequency can lead to a change of operation to an accelerator.

Eoin Carolan
University College Dublin

Counterdiabatic Control in the Impulse Regime

Coherent control of complex many-body systems is critical to the development of useful quantum devices. Fast perfect state transfer can be exactly achieved through additional counterdiabatic fields. We show how the added energetic overhead associated with this can be reduced while still maintaining high fidelities. This is done by only implementing control fields during the critical impulse regime as identified from the Kibble-Zurek mechanism. Restrictions to local interactions are also investigated. We demonstrate our results for the Landau-Zener model and the Transverse Field Ising model.

Klaus Molmer
University of Aarhus

Coherent control in quantum networks: snowballs in Hell

Natalia Ares

University of Oxford

Quantum device control faster than human experts

Machine learning has been the enabler of well-known breakthroughs in computer science, such as the victory of AlphaGo over Go world champions and superhuman face recognition. This great potential can be directed to the real time control of quantum devices. Our algorithms harness bespoke machine learning techniques to allow for the very coarse to the very fine tuning and characterization of semiconductor devices [1]. One of these algorithms is based on deep reinforcement learning. In the same way as a Go player, carefully balancing short and long-term goals and devising actions accordingly, our algorithm devises efficient policies to find desired measurement features in real time. In this way, we are able to reduce the long characterization times required due to device variability. We also demonstrated efficient measurement and fine tuning of quantum devices using deep learning. Using Gaussian processes, we created an algorithm that can tune a 'virgin' quantum dot device to operation conditions in real time faster than human experts and without the need of specifying a device architecture. These approaches are widely applicable, opening the way to a completely automatic and efficient route to quantum device measurement and tuning, and thus taking a crucial step towards the scalability of quantum circuits.

1. N. Ares, Machine learning as an enabler of qubit scalability, Nature Reviews Materials (2021)

Pierpaolo Sgroi

Queen's University Belfast

Reinforcement learning approach to non-equilibrium quantum thermodynamics

The design and optimization of quantum thermal engines is one of the most active research strand in the burgeoning field of quantum thermodynamics. The quasi-static approximation that allows us to describe thermodynamic transformations with an equilibrium theory does not hold for real finite-time thermal engines, which operate in non-equilibrium conditions. This is even more true for quantum engines: in order to exploit the potential benefits of quantum coherences, such devices should operate within the coherence time of the platforms used for their embodiment, which might be very short. Therefore, the control of non-equilibrium quantum processes is an important goal to achieve to enhance the efficiency of quantum engines. A possible approach to this problem is the use of machine learning techniques currently employed in growing number of problems. In particular, problems of planning or control can be successfully addressed through reinforcement learning (RL). In this talk, I will show how a RL approach can be used to reduce entropy production in a closed quantum system brought out of equilibrium [1]. This approach bears no dependence on the quantitative tool chosen to characterize the degree of thermodynamic irreversibility induced by the dynamical process being considered, require little knowledge of the dynamics itself and does not necessarily need the tracking of the quantum state of the system during the evolution, thus embodying an experimentally non-demanding approach to the control of non-equilibrium quantum thermodynamics.

1. Pierpaolo Sgroi, G. Massimo Palma, and Mauro Paternostro, "Reinforcement learning approach to non-equilibrium quantum thermodynamics", Phys. Rev. Lett. 126, 020601 (2021)

Joseph Carthy
Equal1 Labs/ University College Dublin

Investigation into Entanglement in VQE Algorithms: By the example of Charge and Charge-Spin Models

Jing Li

University College Cork

A Feshbach engine on nonlinear coupled density-spin Bose-Einstein condensates

Firstly, I will introduce a thermodynamic cycle using a Bose–Einstein condensate (BEC) with nonlinear interactions as the working medium [1]. Exploiting Feshbach resonances to change the self-interaction strength of the BEC allows us to produce work by expanding and compressing the condensate. Then I investigate the effect of the shortcut to adiabaticity on the efficiency and power output of the engine and show that the tunable nonlinearity strength, modulated by Feshbach resonances, serves as a useful tool to enhance the system's performance. Furthermore, we would like to explore the thermodynamical characteristics on the coupled density-spin BEC driven by the quintic self-attraction in the same- and cross-spin channels [2]. We will analyse the stability diagram on the system. In addition, a novel quantum heat engine might be constructed by time-dependent tuning the strength of spin-orbit coupling and nonlinearity [3].

1. J. Li, T. Fogarty, S. Campbell , X. Chen and T. Busch, "An efficient nonlinear Feshbach engine" New J. Phys. 20, 015005 (2018)

2. J. Li, B. A Malomed, W. Li, X. Chen, E. Ya Sherman, "Coupled density-spin Bose–Einstein condensates dynamics and collapse in systems with quintic nonlinearity" Communications in Nonlinear Science and Numerical Simulation. 82, 105045 (2020).

3. J. Li, E. Ya Sherman and A. Ruschhaupt, in preparation