Many-body quantum chaos of ultracold atoms in a quantum ratchet

Lincoln Carr
Colorado School of Mines

Thursday, 14:00-14:50 (invited talk)

There are now over 200 quantum simulators on at least 8 separate architectures with long coherence times and controlled dynamics. These experimental systems have generated tremendous excitement about driven interacting quantum systems resulting in physics ranging from time crystals to dynamical many-body localization. The quantum ratchet adds a new feature to periodic driving: a preferred direction in both time and space, i.e., parity and time-reversal symmetry-breaking. By studying weakly interacting ultracold bosons in a quantum ratchet on a ring in position, momentum, and Floquet representations, we demonstrate the limits of known measures of quantum chaos in a system with a clearly defined and rather famous semiclassical or mean-field limit, and moreover supporting experiments. We show that the usual Wigner-Dyson statistics used to identify chaos are smeared out as we couple non-resonant modes into the drive. In contrast, the entropy of entanglement, condensate depletion, and inverse participation ratio all serve as accurate alternate identifiers for the chaotic regime in which the current on the ring flip-flops with a positive Lyapunov exponent in the mean-field limit. The dimension of the strange attractor is found to depend on the local vs. global nature of the observables. Moreover, the growth of depletion indicates mean field theory breaks down at realistic experimental times scaling polynomially as N^(0.18±0.004) in the chaotic regime. This study opens the door to beyond single-frequency many-body Floquet physics showing many surprises and subtleties in both the quantum many-body dynamics and the mean-field limit (or lack thereof). Our prediction of a concrete time at which depletion grows is experimentally observable via an interference experiment. The dynamics and emergent structure of higher order correlators remains an especially intriguing avenue of exploration as we find that, contrary to oft-stated popular opinion, chaos, at least in the quantum ratchet, does not lead to high entanglement.

References:

[1] M. Heimsoth, C. E. Creffield, L. D. Carr, and F. Sols, "Orbital Josephson effect and interactions in driven atom condensates on a ring," New J. Phys. 14, 075023 (2012).
[2] M. Heimsoth, D. Hochstuhl, C. E. Creffield, L. D. Carr, and F. Sols, "Effective Josephson dynamics in resonantly driven Bose-Einstein condensates," New J. Phys., New J. Phys. 15, 103006 (2013).
[3] M. A. Valdez, G. Shchedrin, M. Heimsoth, C. E. Creffield, F. Sols, and L. D. Carr, "Many-body Quantum Chaos and Entanglement in a Quantum Ratchet," Phys. Rev. Lett., under review (2016).
[4] M. A. Valdez, G. Shchedrin, F. Sols, and L. D. Carr, "Layered Chaos in Mean-field and Quantum Many-body Dynamics," to be submitted (2017).

Observation of Roton Mode Population in a Dipolar Quantum Gas

Daniel Petter
University of Innsbruck

Thursday, 14:50-15:15

Dipolar Bose-Einstein condensates (dBECs) offer an ideal playground for investigating novel aspects of many-body phenomena in the presence of dipole-dipole interactions (DDI). A seminal work in 2003 [1] predicted the existence of a roton mode (a minimum in the dispersion relation at a finite momentum k_{rot} and with an energy E_{rot}) in the excitation spectrum of a dBEC, similar to the roton mode in superfluid He II. In contrast to He II, the roton mode in a dBEC does not require strong interactions, but rather arises from the momentum dependence of the DDI. In our experiment, we use dBECs of 166Er, confined in a cigar-shaped trap. In order to investigate the roton mode, we employ a Feshbach resonance to quench down the scattering length a_s into a regime, where E_{rot} vanishes and eventually becomes imaginary. At this point, the roton mode population starts to grow with time. We probe the roton mode in the momentum distribution of the atomic cloud and observe two distinct peaks at k_{rot} appearing, when quenching below a critical a_s. From the time-resolved population we directly extract the imaginary E_{rot}. By repeating the measurements in different configurations, we experimentally probe the characteristic scalings of the roton mode with l_z and a_s. We compare our results with an analytical model and full real-time simulations, and unambiguously confirm the roton nature of the observed mode [2].

References:
[1] L Santos et. al., PRL 90, 250403 (2003).
[2] L. Chomaz, et. al., arXiv 1705.06914 (2017).

Photonic simulation of open quantum systems with various exchange statistics

Milan Radonjic
University of Vienna

Thursday, 15:15-15:40

Photonic quantum technology has reached a point where it is almost viable to use photonic setups to simulate the behavior of other quantum systems. Realistic quantum systems are inevitably influenced by the external environment: they are open. When the environment introduces pronounced memory effects, one speaks of non-Markovianity. The need to understand and the possibility of exploiting this phenomenon as a potential resource for quantum information tasks has spurred an increasing interest in generating and manipulating non-Markovian quantum dynamics using various experimental platforms, including photonic setups.

The essentially distinct dynamical behavior of quantum entities obeying different exchange statistics (e.g., bosonic, fermionic or anyonic) has to leave a marked signature on non-Markovianity. We will talk about the project that ultimately aims to emphasize and to explore theoretically the versatility of photonic setups for simulating and studying the interplay between various exchange statistics and quantum non-Markovianity, with the ultimate goal of identifying and experimentally validating the benefits for quantum information applications.

Universal Dynamics across a Many-Body Localization Phase Transition

Maksym Serbyn
IST Austria

Friday, 16:20-17:10 (invited)

Many-body localization allows quantum systems to evade thermalization owing to the emergence of extensive number of local conserved quantities. Many-body localized (MBL) systems exhibit universal dynamics, qualitatively distinct from dynamics in ergodic systems. In this talk I will discuss recent progress in understanding the properties of the MBL phase, which follow from the picture of local conserved quantities. In particular, I will discuss the experimentally observable signatures of the MBL phase dynamics which include fluctuations of local observables, modification of spin-echo protocols, and Loschmidt echo. In the second part of my talk, I will discuss the delocalization transition which can be probed by characterizing the breakdown of local conservation laws. Using energy structure of matrix elements, I will extract the many-body Thouless energy which sets the inverse relaxation timescale. This allows to identify the critical region where Thouless energy becomes smaller than the level spacing. In this region matrix elements show critical dependence on the energy difference and exhibit strong multifractality. I will conclude by discussing experimental implications and open questions.

Ion Crystal Reconfiguration on a Planar Paul Trap

Martin van Mourik
University of Innsbruck

Thursday, 17:10-17:35

Trapped ion-based qubits provide a promising platform for quantum computation. These systems have already demonstrated a universal set of quantum gates necessary for performing arbitrary quantum algorithms. In our architecture, qubits are encoded in the electronic states of individual ions, confined in a single harmonic potential. Ion interactions are mediated through their shared coulomb coupling. To achieve full control of large-scale systems, two obstacles are present: (i) most of current ion trapping architectures are limited to containing tens of qubits, as opposed to the hundreds needed to outperform classical computers, and (ii) large-scale computing requires the implementation of quantum error correction protocols. In this

presentation, I introduce the eQual project, which uses an in-cryostat chip-based trapping architecture to demonstrate quantum computation in a fully scalable fashion. Our trap manifests scalability by allowing for multiple trapping regions. Furthermore, the trap provides the ability to replace demanding quantum operations, as used in quantum error correction, with physical manipulation of ion strings, such as shuttling, chain splitting, and ion position swapping. I focus on our investigations regarding ion swapping, in particular rotating two confined 40Ca+ ions around each other. We attain rotations preserving 98% coherence, and less than 1 phonon heating in both the common and stretch modes along the axis of the ion chain. As an outlook to future experiments, I show results of dual-species swapping and discuss the challenges present therein.

Cooperative Effects in Closely Packed Quantum Emitters with Collective Dephasing

Prasanna Venkatesh Bala
IQOQI Innsbruck

Thursday, 17:35-18:00

In a closely packed ensemble of quantum emitters, cooperative effects are typically suppressed due to the dephasing induced by the dipole-dipole interactions. Here, we show that by adding sufficiently strong collective dephasing cooperative effects can be restored. In particular, we show that the dipole force on a closely packed ensemble of strongly driven two-level quantum emitters, which collectively dephase, is enhanced in comparison to the dipole force on an independent non-interacting ensemble. Our results are relevant to solid-state systems with embedded quantum emitters such as colour centers in diamond and superconducting qubits in microwave cavities and waveguides.

Spinor Condensates: Nonlocal Entanglement & Universal Time Dynamics

Markus Oberthaler
University of Heidelberg

Friday, 09:30-10:20 (invited)

Bose condensates with spin degree of freedom offer a unique platform for questions about entanglement in ultracold gases. The precise measurement of the spin degree of freedom combined with the weak loss rates makes F=1 rubidium condensates a versatile system, also opening up a route for the study of longtime dynamics. I will present our recent results on the generation of nonlocal entanglement, which has been detected by explicit demonstration of EPR steering. The realized resource also allows for three way steering. Based on the strength of Einstein-Podolsky-Rosen steering we construct a witness, which testifies up to genuine five-partite entanglement. As second topic I will touch on the first observation of universal time dynamics after a quench. We have observed scaling of the spin-spin correlation function in time, the smoking gun signal for the presence of a non-thermal fixed point.

Programmable Superpositions of Ising Configurations

Wolfgang Lechner
University of Innsbruck

Friday, 10:20-10:45

In this talk I will present a framework to prepare superpositions of bit strings, i.e., many-body spin configurations, with deterministic programmable probabilities [1]. The spin configurations are encoded in the degenerate ground states of a lattice-gauge representation of an all-to-all connected Ising spin glass. In this model, the ground state manifold is invariant under variations of the gauge degrees of freedom, which take the form of four-body parity constraints. The protocol allows one to make use of these degrees of freedom to prepare programmable superpositions by quantum simulation of a transverse Ising model. The dynamics combines an adiabatic protocol with controlled diabatic transitions. I will present an effective model that allows one to determine the control parameters efficiently even for system sizes that cannot be simulated on a classical computer. Such a quantum RAM with O(N^2) qubits could serve as crucial ingredient for future quantum machine learning applications.

References:
[1] L. M. Sieberer and W. Lechner, arXiv:1708.02533 (2017).

Two Measurements are Sufficient for Certifying High-Dimensional Entanglement

Jessica Bavaresco
IQOQI Vienna

Friday, 10:45-11:10

High-dimensional encoding of quantum information provides a promising method of transcending current limitations in quantum communication. One of the central challenges in the pursuit of such an approach is the certification of high-dimensional entanglement. In particular, it is desirable to do so without resorting to inefficient full state tomography. Here, we show how carefully constructed measurements in two or more bases can be used to efficiently certify high-dimensional states and their entanglement under realistic conditions. We considerably improve upon existing criteria and introduce new entanglement dimensionality witnesses which we put to the test for photons entangled in their orbital angular momentum. In our experimental setup, we are able to verify 8-dimensional entanglement for 11-dimensional subspaces, at present the highest amount certified without assumptions on the state itself.

References:
[1] J. Bavaresco, N. Herrera Valencia, C. Klöckl, M. Pivoluska, N. Friis, M. Malik, and M. Huber, arXiv:1709.07344.

Measuring and Using Non-Markovianity

Carlos Pineda
IFUNAM

Friday, 11:40-12:05

We construct measures for the non-Markovianity of quantum evolution with a physically meaningful interpretation. We first provide a general setting in the framework of channel capacities and propose two families of meaningful quantitative measures, based on the largest revival of a channel capacity, avoiding some drawbacks of other non-Markovianity measures. We relate the proposed measures to the task of information screening. This shows that the non-Markovianity of a quantum process may be used as a resource. Under these considerations, we analyze two paradigmatic examples, a qubit in a quantum environment with classically mixed dynamics and the Jaynes-Cummings model.

Quantum Communications Uplink to a CubeSat

Sebastian Neumann
IQOQI Vienna

Friday, 12:05-12:30

Losses limit the maximum distance of ground based quantum communication to ~400 km. Satellites overcome this limitation. Till date there have been numerous feasibility studies and two successful, large-scale quantum communications satellite missions. Achieving similar performance with a tiny, low-cost CubeSat in the uplink scenario is a major challenge. Here we present a feasibility study for a fully functional 3U-CubeSat-based quantum receiver. The advantage of this scheme is twofold: first, the majority of complex and critical equipment is ground based; second, one satellite design is compatible with a variety of quantum optical experiments. We provide a complete link loss analysis, count rate estimations and preliminary design. Further we discuss solutions to key problems such as satellite pointing errors and measurement/detection issues. Using current technology, we show that the CubeSat is feasible and can be used to violate a Bell-like inequality over a free-space distance of 500 km.

Ground-State Cooling of Atoms Close to a Nanofiber

Alexandre Dareau
TU Wien

Friday, 12:30-12:55

The strong confinement of light in optical microtraps gives rise to strong fictitious magnetic field gradients. These fictitious magnetic fields arise naturally in nanofiber-based optical traps. They can be harnessed to perform degenerate Raman sideband cooling, which has been pioneered in optical lattices [1-2].

We have implemented degenerate Raman Cooling of atoms in a nanofiber-based optical trap. Remarkably, this scheme only requires a single fiber-guided optical field, which then provides three-dimensional cooling. We will show that continuously applying such cooling extends the lifetime of atoms in trap by one order of magnitude. The final temperature of the atoms, inferred from a fluorescence spectroscopy measurement [3], indicates three-dimensional ground state cooling of the atoms, only a few hundred of nanometers away from the hot nanofiber surface. This achievement sets an excellent starting point for the experimental study of light-induced crystal formation, of novel optical forces as well as precision measurements using waveguide-coupled ensembles of cold atoms.

References:

[1] S. E. Hamann et al., Phys. Rev. Lett. 80, 4149 (1998).
[2] A. J. Kerman et al., Phys. Rev. Lett. 84, 439 (2000).
[3] P. S. Jessen et al., Phys. Rev. Lett. 39, 49 (1992).