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Conference on

"Quantum Paths in Low Dimensions: Theory and Experiment"

of the programme "Quantum Paths"

April 9 – 13, 2018

Abstracts

- **Monday, April 9, 2018**

Ignacio Cirac
Tensor networks: fundamental theorems and applications

Frank Verstraete
Continuous variational matrix product states for quantum field theories

Jens Eisert
Quantum simulators probing the non-equilibrium

Quantum systems out of equilibrium pose some of the most intriguing problems of the study of interacting quantum matter. In this talk - quite in the spirit of the Quantum Paths Programme - we will start from discussing foundational aspects of quench dynamics, related to equilibration and Gaussification. We will then take a pragmatic stance and explore to what extent those questions can be probed with cold atomic systems that constitute quantum simulators. Specifically, we will discuss new results on equilibration, experimental Gaussification, a new tomographic procedure for cold atomic simulators, offering a new window into quantum simulators, and a testbed for many-body localisation, based on an intuition arising from tensor networks. If time allows, the talk will be ended with a discussion on how cold atomic quantum simulators may be an excellent platform to show a much sought after quantum advantage.

Markus Oberthaler
Spin-1 many-body system: Einstein Podolsky Rosen Correlations & Universal Time Dynamics

Condensates of dilute Bose-gases with internal degrees of freedom offer a unique experimental platform for studying quantum correlation and longtime dynamics. I will give an introduction into the experimental capability of this system and discuss two explicit examples studied. The versatile control allows the access of conjugate variables a prerequisite for detecting Einstein-Podolsky Rosen correlations. Our results confirm that in an expanding condensate these correlations survive. This quantum resource allow for three way steering as well as witnessing genuine five-partite entanglement [1]. The long life time of this system also allows for the study of quantum dynamics in a new regime. I will discuss our results obtained in our study of the time dynamics in the transient regime between instability driven dynamics and the approach of thermal equilibrium. We find scaling behavior in this transient regime and with that confirm for the first time that universality in far-from-equilibrium dynamics experimentally.

[1] Spatially distributed multipartite entanglement enables Einstein-Podolsky-Rosen steering of atomic clouds, P. Kunkel et al., arXiv:1708.02407

- **Tuesday, April 10, 2018**

Dan Stamper-Kurn
Interacting bosonic atoms in triangular lattices with varying geometry

Interacting ultracold atoms in optical lattice potentials offer a means to study fundamental ideas emerging from condensed-matter physics in an idealized experimental form. To realize this scientific potential, we have developed means to characterize precisely and to drastically vary the geometry of optical lattice potentials. I will present studies of ultracold bosonic atoms trapped within two-dimensional bichromatic optical lattice potentials, focusing on three main results: (1) The realization of a kagome-geometry optical lattice, (2) a precise test of a scaling hypothesis for the equation of state of the Bose-Hubbard system, and (3) recent measurements of the geometric structure of correlations in an inversion-symmetry-broken kagome lattice.

Jürgen Berges
Universality far from equilibrium and entanglement entropy

Andreas Läuchli
Quantum Criticality in iMPS & iPEPS Tensor Network Methods

Francesca Ferlaino
Observation of Roton Modes in an Erbium Dipolar quantum gas

Discovered in liquid helium about 80 years ago, superfluidity is a counterintuitive phenomenon, in which quantum physics and particle-wave duality manifest at the macroscopic level. Since then, it has yielded many advances in understanding quantum matter, yet leaving mysterious some of its features. A hallmark of superfluidity is the existence of so-called quasi-particles, i.e. elementary excitations dressed by interactions. Laudau predicted two type of quasi-particles. The first ones are the phonon modes, the well-known long-wavelength sound-wave quanta. The second ones, much more bizarre and intriguing, are massive quasi-particles named rotons. They have large momenta, and, contrarily to the common (quasi)particles for which the energy increases with the momentum, the roton dispersion relation exhibits a minimum at a finite momentum, called roton momentum. This unusual behavior expresses the tendency of the fluids to build up short-wavelength density modulation in space, precursor of a crystallization instability. In 2003, theoreticians suggested that a similar rotonic excitation might also occur in dipolar Bose-Einstein condensates because of the special properties of the long-rang and anisotropic dipole-dipole interaction. We here report on the first observation of roton quasiparticles in a dipolar gas of high magnetic Er atoms.

Dimitry Abanin
Quantum many-body scars: a new mechanism of ergodicity breaking

- **Wednesday, April 11, 2018**

Ulrich Schneider
Ultracold atoms in low-dimensional quasi-periodic potentials

The out-of-equilibrium dynamics of interacting many-body systems presents one of the most challenging problems in quantum physics with implications ranging from thermalization over transport properties to novel transient effects and the formation of order. Traditionally, however, out-of-equilibrium dynamics was mostly confined to short transients, since typical systems would ultimately relax back into well-understood thermal states.
One major exception is Many-Body Localization (MBL) — the interacting extension of Anderson lo-

calization — where particles are localized by the presence of a disordered potential and therefore never relax to a thermal state. In this talk, I will first present our experimental realization of MBL of interacting fermions in the presence of quasi-periodic disorder in 1D and 2D, and then discuss extensions to 2D quasicrystals with high rotational symmetries.
Quasicrystals are a novel form of condensed matter that is non-periodic, but long-range ordered. They give rise to diffraction patterns consisting of sharp Bragg peaks, similar to periodic crystals, but with rotational symmetries that are forbidden for periodic structures. Quasicrystals can be described by fractal aperiodic tilings with more than one unit cell, similar to the celebrated Penrose tiling. Even though they are long-range ordered, many foundational concepts of periodic condensed matter systems such as Blochwaves or Brillouin zones are not applicable, thereby giving rise to new physics.

Eugene Demler
Quench and Floquet dynamics in solid state systems and ultracold atoms

I will discuss surprising electro-magnetic properties of the photoinduced superconducting state in K3C60 and show how they arise from the non-equilibrium dynamics of electron-phonon systems. In particular I will explain the phenomenon of the Higgs lasing. I will also discuss how experiments with ultracold atoms can provide new insight into the paradigmatic problems of quantum optics and field theories, such as the dynamic Casimir effect.

Bruno Bertini
Transport in Closed One-Dimensional Systems: Integrable Models and Universality at Low Temperatures

Adam Nahum
Emergent statistical mechanics of entanglement in random unitary circuits

Jean-Sebastien Caux
Quench, Hydro and Floquet dynamics in solvable many-body quantum systems

- **Thursday, April 12, 2018**

Hanns-Christoph Nägerl
Impurity dynamics in 1D for strong interactions: Bloch oscillations in the absence of a lattice

We experimentally study the dynamics of strongly-correlated quantum many-body systems of ultracold atoms with particular focus on bosons confined to one-dimensional geometry. We have investigated the quantum motion of an impurity atom that is immersed in a strongly interacting Bose liquid and is subject to an external force [1]. We find that the momentum distribution of the impurity exhibits characteristic Bragg reflections at the edge of an emergent Brillouin zone. While Bragg reflections are typically associated with lattice structures, in our strongly correlated quantum liquid they result from the interplay of short-range crystalline order and kinematic constraints on the many-body scattering processes in the one-dimensional system. As a consequence, the impurity exhibits periodic dynamics that we interpret as Bloch oscillations. These arise even though the quantum liquid is translationally invariant. Our observations are supported by large-scale numerical simulations.

[1] F. Meinert et al., Bloch oscillations in the absence of a lattice, Science 356, 945 (2017)

Rosario Fazio
Finite frequency criticality and time-crystals

Denis Bernard
Curiosities in monitoring quantum systems (in or out-of-equilibrium)

Lukasz Fidkowski
Fermionic symmetry protected phases via 2+1d bosonization

Robert Konik
Rare States and Anomalous Thermalization in the 1D and 2D Quantum Ising Model

We show that confinement in the Ising model leads to rare atypical (nonthermal) eigenstates, in both continuum and lattice theories, in both one (1D) and two dimensions (2D). In the ordered phase, the presence of a confining longitudinal field leads to a profound restructuring of the excitation spectrum, with the low-energy two-particle continuum being replaced by discrete meson modes (linearly confined pairs of domain walls). These modes are atypical, in the sense that expectation values in the state with energy E do not agree with the microcanonical (thermal) ensemble constructed at the same energy. Single meson states persist above the two meson threshold, due to a surprising lack of hybridization with the continuum that can be understood from analytical calculations. The presence of such states in the spectrum is revealed in anomalous post-quench dynamics, such as the lack of a light cone and the suppression of the growth of entanglement entropy.

- **Friday, April 13, 2018**

Zoran Hadzibabic
Bose gases quenched to unitarity

I will give an overview of our recent progress in trying to understand the dynamics and thermodynamics of a Bose gas quenched to unitarity. We have performed a series of experiments with both degenerate and thermal gases, and obtained measurements of the three-body contact, the universal scalings in the decay dynamics at unitarity, and most recently of the energy and quantum depletion of the degenerate unitary Bose gas.

Sandro Stringari
Propagation of sound in two-dimensional Bose gases

A recent experiment carried out in the team of Jean Dalibard at the College de France has revealed unexpected features concerning the propagation of sound in 2D weakly interacting Bose gases. In particular it has been shown that second sound can propagate also above the Berezinskii-Kosterlitz-Thouless transition, where superfluidity is absent, in contradiction with the predictions of Landau's two fluid hydrodynamics. In the talk I will report the results of a recent theoretical study, where the dynamics of the system is described in the collisionless regime and the resulting predictions well agree with the experimental findings.

Tin-Lun Ho
Monopoles and Instantons in Cold Atoms

Recent experiments on Yang Monopole show it is possible to engineer quantum manifolds with non-zero second Chern number. In this talk, I shall discuss (i) a method to construct quantum manifolds with non-zero n-th Chern-numbers, (ii) interaction effects on these manifolds, and (iii) the emergence of instantons in quench processes, and how they be used to determine topological transitions. Instantons are the topological structures of quantum manifolds in spacetime.

Jörg Schmiedmayer
Relaxation, (pre-) thermalization and revivals in (nearly) integrable systems: an experimental perspective?

The evolution of an isolated quantum system is unitary. This is simple to probe for small systems consi-

sting of few non-interacting particles. But what happens if the system becomes large and its constituents interact? In general, one will not be able to follow the evolution of the complex many body eigenstates.
Ultra-cold quantum gases are an ideal system to probe these aspects of many body quantum physics and the related quantum fields. Our pet systems are one-dimensional Bose-gases. Interfering two systems allows studying coherence between the two quantum fields and the full distribution functions and correlation functions give detailed insight into the many body states and their non-equilibrium evolution.
I will give an overview of our experiments, where we study how the coherence created between the two isolated one-dimensional quantum gases by coherent splitting slowly degrades by coupling to the many internal degrees of freedom available [1]. We find that a one-dimensional quantum system relaxes to a pre-thermalisatized quasi steady state [2] which emerges through a light cone like spreading of 'decoherence' [3]. The pre-thermalized state is described by a generalized Gibbs ensemble [4]. Finally, we investigate the further evolution away from the pre-thermalized state. On one hand, we show that by engineering the Quasiparticles we can create many body quantum revivals [5]. On the other hand, we point to two distinct ways for further relaxation towards a final state that appears indistinguishable from a thermally relaxed state. The system looks like two classically separated objects. This illustrates how classical physics can emerge from unitary evolution of a complex enough quantum system.
We conjecture that our experiments point to a universal way through which relaxation in isolated many body quantum systems proceeds if the low energy dynamics is dominated by scrambling of the eigenmodes of long lived excitations (quasi particles) [6].
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M. Gring et al., Science, 337, 1318 (2012); D. Adu Smith et al. NJP, 15, 075011 (2013).

T. Langen et al., Nature Physics, 9, 640643 (2013).

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B. Rauer et al. Science in print (2018); arXiv:1705. 08231.

T. Langen, T. Gasenzer, J. Schmiedmayer, J. Stat. Mech. 064009 (2016)