Quantum Gases and Quantum Coherence

669. WE-Heraeus-Seminar

April 15 - 18, 2018
at the Physikzentrum Bad Honnef/Germany

WILHELM UND ELSE
HERAEUS-STIFTUNG

Introduction

The Wilhelm und Else Heraeus-Stiftung is a private foundation which supports research and education in science, especially in physics. A major activity is the organization of seminars. By German physicists the foundation is recognized as the most important private funding institution in their fields. Some activities of the foundation are carried out in cooperation with the German Physical Society (Deutsche Physikalische Gesellschaft).

Aims and scope of the 669. WE-Heraeus-Seminar:

This conference brings together a broad community of senior and junior scientists to address the most recent developments in the emerging cross-disciplinary research field involing ultracold atoms, quantum many-body physics, quantum simulation and quantum information.

The main themes of this edition will be:

- Non-equilibrium physics and dynamics
- Artificial gauge fields
- Topological phases
- Strongly correlated systems
- Ultracold atoms and quantum technologies
- From few to many-body physics

Scientific Organizers:

Prof. Corinna Kollath	Universität Bonn / Germany E-mail: corinna.kollath@uni-bonn.de
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Program

Program

Sunday, April 15, 2018

11:00 – 21:00	Registration	
12:30 – 14:00	*LUNCH*	
14:30 – 14:40	Scientific organizers	**Welcome words**
Session I:	*Non-equilibrium & dynamics*	
14:40 – 15:40	Christian Gross	**Microscopic studies of many-body localization in two dimensions**
15:40 – 16:10	Zala Lenarčič	**Time-dependent generalized Gibbs ensembles in open quantum systems**
16:10 – 16:40	*COFFEE BREAK*	
16:40 – 17:10	Jean-Sébastien Bernier	**Propagation of correlations in dissipative systems: ballistic, diffusive, rare event and aging dynamics**
17:10-17:40	Russell Bisset	**Dynamics and interactions of quantum vortices in Bose-Einstein condensates**
17:40 – 18:10	Jean-Loup Ville	**Sound propagation in a superfluid two-dimensional Bose gas**
18:10 – 18:20	**Conference Photo** (in the front of the lecture hall)	
19:00	*DINNER*	

Program

Monday, April 16, 2018

08:00	*BREAKFAST*	
Session II:	*From few to many-body physics*	
09:00 – 10:00	Frank Pollmann	**Efficient simulation of quantum thermalization dynamics**
10:00 – 10:30	Nicola Wurz	**Coherent manipulation of spin correlations in the 2D Fermi Hubbard model**
10:30 – 11:00	*COFFEE BREAK*	
11:00 – 11:30	Tommaso Comparin	**Itinerant ferromagnetism for two-dimensional dipolar fermions**
11:30 – 12:00	Francesco Scazza	**Time-resolved probing of repulsive many-body states in ultracold Fermi gases**
12:00 – 12:30	Markus Heyl	**Dynamical quantum phase transitions**
12:30	*LUNCH*	

Program

Monday, April 16, 2018

<u>Session III:</u> *<u>Gauge fields & topology</u>*

14:30 – 15:30	Klaus Sengstock	**Topology in floquet engineered optical lattices**
15:30 – 16:00	Samuel Lellouch	**Parametric instabilities in shaken atomic gases**
16:00 – 16:30	*COFFEE BREAK*	
16:30 – 17:00	Alexandre Dauphin	**Topological characterization of chiral models through their long time dynamics**
17:00 – 17:30	Leonardo Mazza	**Laughlin-like physics in bosonic and fermionic atomic synthetic ladders**
17:30 – 18:00	Giacomo Cappellini	**Engineering synthetic gauge fields with ultracold two-electron atoms**
19:00	*DINNER*	
20:30 – 21:30	Cristiane de Morais-Smith	**Colloquium:** **There is plenty of room at the bottom... but even more in a fractal**

Program

Tuesday, April 17, 2018

08:00	*BREAKFAST*	
<u>*Session IV:*</u>	<u>*Strongly correlated systems*</u>	
09:00 – 10:00	Leticia Tarruell	**Quantum liquid droplets in a mixture of Bose-Einstein condensates**
10 :00 – 10:30	Andrea Bergschneider	**Detection of entanglement in a Fermi-Hubbard dimer**
10:30 – 11:00	*COFFEE BREAK*	
11:00 – 11:30	Cecile Repellin	**Creating a bosonic fractional quantum Hall state by pairing fermions**
11:30 – 12:00	Jean Decamp	**Correlations and symmetries in one-dimensional quantum gases**
12:00 – 12:30	Guillame Salomon	**Direct observation of incommensurate spin correlations in Hubbard chains**
12:30	*LUNCH*	
14:30 – 18:00	**Poster session with 2-minute presentations off the posters and**	
16:00	*COFFEE BREAK*	
19:00	*HERAEUS DINNER* *(social event with cold & warm buffet with complimentary drinks)*	

Program

Wednesday, April 18, 2018

08:00	*BREAKFAST*	
Session V:	*Quantum technologies & cold atoms*	
09:00 – 10 :00	Giovanna Morigi	**Collective dynamics of atomic ensembles confined within high-finesse optical cavities**
10 :00 – 10:30	Benoit Vermersch	**Measuring entanglement and scrambling via random unitaries**
10:30 – 11:00	*COFFEE BREAK*	
11:00 – 11:30	Philipp Hauke	**Many-body entanglement witnessed through the quantum Fisher information**
11:30– 12:00	Irénée Frérot	**Probing quantum superpositions in equilibrium many-body systems close to quantum and thermal critical points**
12:00 – 12:30	Daniel Barredo	**Quantum simulation of spin models with individual Rydberg atoms in arbitrary geometries**
12:30 – 12:45	Scientific organizers	**Closing words**
12:45	*LUNCH*	

End of the seminar and departure

NO DINNER for participants leaving on Thursday morning

Posters

Posters

Adriano Angelone	**Superglass phase of interaction-blockaded gases on a triangular lattice**
Lisa Arndt	**Dual Shapiro steps of a phase-slip junction in the presence of a parasitic capacitance**
Cosetta Baroni	**Interactions in a tunable Bose-Fermi mixture of ^{41}K and ^{6}Li: phase separation and spin transport**
Gianluca Bertaina	**Quantum critical behavior of one-dimensional soft bosons in the continuum**
Guillaume Berthet	**Non linear scattering of atomic bright solitons in disorder**
Thomas Bland	**Quantum ferrofluid turbulence**
Anton Buyskikh	**Spin model for 2-site resonant tunneling dynamics of bosons in a tilted optical superlattice**
Josep Cabedo Bru	**A three-mode treatment of spin-1 Bose-Einstein condensates with spin-orbit coupling**
Cecile Carcy	**Single-atom-resolved probing of lattice gases in momentum space**
Agnieszka Cichy	**Reentrant Fulde-Ferrell-Larkin-Ovchinnikov superfluidity in the honeycomb lattice**
Ricardo Costa de Almeida	**Measurement of multipartite entanglement in many-body systems using temporal fluctuations**

Posters

Marco Di Liberto	**Particle-hole character of Higgs and Goldstone modes in strongly interacting lattice bosons**
Arturo Farolfi	**Towards the study of many-body effects in resonantly coupled spinor BECs**
Serena Fazzini	**Non-local orders and SPT phases in Hubbard-Heisenberg models**
Wojciech Górecki	**Roton in a many-body dipolar system**
Piotr Grochowski	**Ferromagnetic instability in a dynamical system of a repulsive two-component Fermi gas**
Michael Hagemann	**Production of a molecular Lithium BEC in a single-chamber setup**
Catalin-Mihai Halati	**Cavity-induced artificial gauge field in a Bose-Hubbard ladder**
Yi-Ping Huang	**Dynamical quantum phase transitions in the particle-antiparticle production of a lattice gauge theory**
Dariusz Kajtoch	**Spin-squeezed atomic crystals**
Andreas Kerkmann	**Gray molasses laser cooling of fermionic Lithium**
Antonia Klein	**Towards quantum state assembly**
Thomas Kohlert	**Exploring the single-particle mobility edge and many-body localized phase in a 1D quasiperiodic optical lattice with ultracold atoms**

Posters

Johannes Kombe	**Observation of the Higgs mode in the superfluid BEC-BCS crossover in Fermi gases**
Arkadiusz Kosior	**Dynamical quantum phase transitions in discrete time crystals**
Avinash Kumar	**Producing superfluid circulation states using phase imprinting**
Alessio Lerose	**Chaotic dynamical phase induced by non-equilibrium quantum fluctuations**
Elia Macaluso	**Observing anyonic statistics via time-of-flight measurements**
Alfonso Maiellaro	**Topological phases of a two-leg Kitaev ladder**
Giovanni I. Martone	**Quantum depletion and coherence of an ultracold boson vapor after a quench**
Leonardo Masi	**Self-bound quantum droplets in atomic mixtures**
Paolo P. Mazza	**Non equilibrium dynamics and transport in non-integrable systems**
Raphal Menu	**Quench spectroscopy of unconventional excitations in Rydberg quantum simulators**
Silvia Musolino	**Dynamics of few-body correlations in a quenched unitarity Bose gas**
Aurélien Perrin	**Magnetic transport of cold atoms in a quadrupole trap**

Posters

Michele Pini	**Comparative study of many-body t-matrix theories for a Fermi gas through the BCS-BEC crossover**
Lukas Rammelmüller	**Spin and mass imbalance in strongly interacting Fermi gases**
Arko Roy	**Design and characterization of a quantum heat pump in a driven quantum gas**
Angelo Russomanno	**Dynamical localization and delocalization in a system of coupled kicked rotors**
Grazia Salerno	**Topological two-body bound states in the interacting Haldane model**
Peter Schauss	**Quantum gas microscopy of many-body dynamics in Fermi-Hubbard and Ising systems**
Thomas Secker	**Efimov physics for narrow Feshbach resonances**
Jasper Smits	**Faraday waves in Bose-Einstein condensates**
Andrzej Syrwid	**Time crystal behavior of excited eigenstate**
Konrad Szymański	**Spin self-rephasing in the system of several atoms**
Jérôme Thibaut	**Entanglement properties of lattice bosons from a variational wave function**
Roberto Verdel Aranda	**Quantum dynamics with artificial neural networks**
Nicolas Victorin	**Bosonic double lattice ring under a gauge field**

Posters

Botao Wang	**Floquet engineering of optical solenoids and quantized charge pumping along tailored paths in two-dimensional Chern insulators**
Yibo Wang	**Q-Walker: a fully-programmable quantum dynamics simulator with Rydberg-dressed atoms**
Zhi-Yuan Wei	**Directly measuring the degree of quantum coherence using interference fringes**
Stefan Wolff	**Dissipative dynamics of spin-1/2 chains by tensor network algorithms**
Hepeng Yao	**Full scaling function of the Tan contact for trapped Lieb-Liniger gases at finite temperature**
Henrik Zahn	**3D image reconstruction using symmetries applied to cold Rydberg gases**
Klaudia Zaremba-Kopczyk	**Magnetically tunable Feshbach resonances in an ultracold gas of europium atoms and a mixture of europium and alkali-metal atoms**

Abstracts of Talks

(in chronological order)

Microscopic Studies of Many-Body Localization in Two Dimensions

C.Gross[1]

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The breakdown of the thermalization of a generic isolated quantum system is one consequence of many-body localization. This aspect can be probed experimentally in systems of ultracold lattice atoms by the measurement of the long-time remaining traces of an initially prepared far from equilibrium distribution of the atomic density. We summarize our experiments performed in this spirit and report on recent progress on the characterization of the system in the seemingly localized phase, including the study of the stability of the localization when coupling to a well controlled atomic bath.

Time-dependent generalized Gibbs ensembles in open quantum systems

Z. Lenarčič, F. Lange, and A. Rosch

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Generalized Gibbs ensembles have been used as powerful tools to describe the steady state of integrable many-particle quantum systems after a sudden change of the Hamiltonian. Our work shows that their time-dependent version can be used for a much broader class of problems. I will consider integrable systems in the presence of integrability breaking driving terms due to coupling to a non-equilibrium environment, using the one-dimensional Heisenberg model with perturbations described by Lindblad operators or Floquet unitary driving as an example. I will show that the dynamics is fundamentally different from that with static perturbations. As demonstrated in quantum quench protocols, static integrability breaking terms always lead to simple thermalization. Our numerical results show that driving reactivates conserved quantities of the underlying integrable model, promoting features inherited from the integrability to be much more robust and experimentally observable. We show that dynamics is accurately captured by a time-dependent generalized Gibbs ensemble with steady state Lagrange parameters determined by the perturbations. This result significantly extends the application of the concept of generalized Gibbs ensembles.

References

[1] F. Lange, Z. Lenarčič, and A. Rosch, Nat. Comm. **8**, 15767 (2017)
[2] Z. Lenarčič, F. Lange, and A. Rosch, Phys. Rev. B **97**, 024302 (2018)
[3] F. Lange, Z. Lenarčič, and A. Rosch, arXiv:1801.07646 (2018)

Propagation of correlations in dissipative systems: ballistic, diffusive, rare event and aging dynamics

Jean-Sébastien Bernier

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In recent years, considerable experimental efforts have been devoted to dynamically generate complex states and monitor their evolution. Despite remarkable advances, the theoretical principles behind the non-equilibrium dynamics of strongly correlated quantum matter are still far from being fully understood. In particular, very few studies have sought to clarify the influence of environmental couplings on the propagation of correlations. We attempt here to fill this gap. As a first step, we consider an interaction quench in the Bose-Hubbard model under the effect of dephasing, and observe that dissipation effectively speeds up the propagation of single-particle correlations while reducing their coherence. In contrast, for two-point density correlations, the initial ballistic propagation regime gives way to diffusion at intermediate times. As a second step, we consider the evolution of two-time correlations in the XXZ spin-1/2 model in contact with a similar environment. We find this system to display rare event and aging dynamics. The latter dynamical regime is characterized by a breakdown of time-translation invariance, a slow non-exponential relaxation of two-time correlations and the presence of dynamical scaling.

Dynamics and interactions of quantum vortices in Bose-Einstein condensates

R. N. Bisset, S. Serafini, L. Galantucci, E. Iseni, T Bienaimé, M. Barbiero, C. F. Barenghi, G. Lamporesi, G. Ferrari, F. Dalfovo

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Boundaries strongly affect the behavior of quantized vortices in Bose-Einstein condensates, a phenomenon particularly evident in elongated cigar-shaped traps where vortices tend to orient along a short direction to minimize energy. Remarkably, contributions to the angular momentum of such vortices are tightly confined to the region surrounding the core, in stark contrast to untrapped condensates where every atom would contribute hbar. We theoretically and experimentally (using real-time imaging) explore the intriguing consequences. On the one hand, we demonstrate that such localized vortices precess in a manner analogous to a classical spinning top [1]. On the other hand, the elongated nature of the condensate allows us to channel two vortices towards one another. The local character of the vortices means that the ensuing collisions occur within a well-defined interaction region [2].

References

[1] R. N. Bisset, S. Serafini, E. Iseni, M. Barbiero, T. Bienaimé, G. Lamporesi, G. Ferrari, and F. Dalfovo, Phys. Rev. A **96**, 053605 (2017)

[2] S. Serafini, L. Galantucci, E. Iseni, T. Bienaimé, R. N. Bisset, C. F. Barenghi, F. Dalfovo, G. Lamporesi, and G. Ferrari Phys. Rev. X **7**, 021031 (2017)

Abstracts of Posters

(in alphabetical order)

Superglass phase of interaction-blockaded gases on a triangular lattice

Adriano Angelone[1,2], Fabio Mezzacapo[3] and Guido Pupillo[1,2]

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[3]Laboratoire de Physique de l'ENS Lyon
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The search for phases showing coexistence of different physical phenomena in systems of experimental interest is an active direction of research in condensed matter physics. Such scenarios include supersolids or superglasses, where macroscopic quantum phenomena coexist with a crystalline structure or glassy phenomena, respectively. In particular, superglasses have been predicted to appear in several numerical and theoretical studies, but without any conclusive experimental realization.

We investigate the quantum phases of monodispersed bosons on a triangular lattice and interacting via soft-shoulder potentials. Using exact Path Integral Monte Carlo simulations, we determine the equilibrium phases of the model to be a superfluid, a supersolid, and a crystal for weak, intermediate, and strong interactions, respectively. Simulated temperature quenches result in the appearance of out-of-equilibrium glass and superglass regions, for strong and intermediate values of the interaction strength, respectively. The investigated Hamiltonian is free of external frustration sources, usually employed to engender glassy phenomena, and the interactions of choice are relevant for experiments with Rydberg-dressed atoms in optical lattices, making our prediction of a superglass state of direct experimental interest.

Dual Shapiro steps of a phase-slip junction in the presence of a parasitic capacitance

L. Arndt, A. Roy, and F. Hassler

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Bloch oscillations in a single Josephson junction in the phase-slip regime relate current to frequency. They can be measured by applying a periodic drive to a DC-biased, small Josephson junction. Phase-locking between the periodic drive and the Bloch oscillations then gives rise to steps at constant current in the I–V curves, also known as dual Shapiro steps. Unlike conventional Shapiro steps, a measurement of these dual Shapiro steps is impeded by the presence of a parasitic capacitance. This capacitance shunts the junction resulting in a suppression of the amplitude of the Bloch oscillations. This detrimental effect of the parasitic capacitance can be remedied by an on-chip superinductance. Additionally, we introduce a large off-chip resistance to provide the necessary dissipation. We investigate the resulting system by a set of analytical and numerical methods. In particular, we obtain an explicit analytical expression for the height of dual Shapiro steps as a function of the ratio of the parasitic capacitance to the superinductance. Using this result, we provide a quantitative estimate of the dual Shapiro step height. Our calculations reveal that even in the presence of a parasitic capacitance, it should be possible to observe Bloch oscillations with realistic experimental parameters.

References

[1] L. Arndt, A. Roy, and F. Hassler, arXiv:1802.08123 (2018)

Interactions in a tunable Bose-Fermi mixture of ^{41}K and ^{6}Li: phase separation and spin transport

Cosetta Baroni[1], Isabella Fritsche[1,2], Tanner Grogan[1], Bo Huang[1], Emil Kirilov[2], Rianne S. Lous[1,2] and Rudolf Grimm[1,2]

[1] *Institut für Quantenoptik und Quanteninformation (IQOQI), Österreichische Akademie der Wissenschaften, Austria*
[2] *Institut für Experimentalphysik, Universität Innsbruck, Austria*

We investigate the interaction properties of a ^{41}K Bose-Einstein condensate (BEC) immersed in a degenerate ^{6}Li Fermi sea. The scattering length between the lowest Zeeman spin states of the two species can be tuned in a precise controlled way by using a Feshbach resonance near 335 G. We observed the onset of a phase separation between the two species for sufficiently strong repulsive inter-species interaction, by investigating the spatial overlap thanks to K-K-Li three-body loss rate of the mixture[1]. Oscillations of a small BEC surrounded by a Fermi sea in the phase-separated regime can be theoretically studied by solving the hydrodynamic equations for the BEC and the Vlasov-Boltzmann equations for the fermions[2] and are now experimentally under investigation in our group. Our forthcoming goal is the characterization of non-equilibrium spin transport in a two-component spin-imbalanced Fermi sea caused by the presence of a small BEC that interacts solely with one fermionic component.

[1]R. Lous, I. Fritsche, M. Jag, F. Lehmann, E. Kirilov, B. Huang, R. Grimm; *arXiv:1802.01954* (2018)

[2]B. Van Schaeybroeck, A. Lazarides; *Phys. Rev. A* **79**, 033618 (2009)

Quantum Critical Behavior of One-Dimensional Soft Bosons in the Continuum

S. Rossotti[1], M. Teruzzi[1,2], D. Pini[1], D. E. Galli[1] and G. Bertaina[1]

[1]*Department of Physics, University of Milan, Italy*

[2]*Scuola Internazionale Superiore di Studi Avanzati, Trieste, Italy*

We consider a zero-temperature one-dimensional system of bosons interacting via the soft-shoulder potential in the continuum, typical of dressed Rydberg gases. We employ quantum Monte Carlo simulations, which allow for the exact calculation of imaginary-time correlations, and a stochastic analytic continuation method, to extract the dynamical structure factor. At finite densities, in the weakly interacting homogeneous regime, a rotonic spectrum marks the tendency to clustering. With strong interactions, we indeed observe cluster liquid phases emerging, characterized by the spectrum of a composite harmonic chain. Luttinger theory has to be adapted by changing the reference lattice density field. In both the liquid and cluster liquid phases, we find convincing evidence of a secondary mode, which becomes gapless only at the transition. In that region, we also measure the central charge and observe its increase towards c=3/2, as recently evaluated in a related extended Bose-Hubbard model, and we note a fast reduction of the Luttinger parameter. For two-particle clusters, we then interpret such observations in terms of the compresence of a Luttinger liquid and a critical transverse Ising model, related to the instability of the reference lattice density field towards coalescence of sites, typical of potentials which are flat at short distances. Even in the absence of a true lattice, we are able to evaluate the spatial correlation function of a suitable pseudospin operator, which manifests ferromagnetic order in the cluster liquid phase, exponential decay in the liquid phase, and algebraic order at criticality.

References

[1] S. Rossotti, M. Teruzzi, D. Pini, D. E. Galli, and G. Bertaina, Phys. Rev. Lett. **119**, 215301 (2017).

[2] M. Teruzzi, D. E. Galli, and G. Bertaina, J. Low Temp. Phys. **187**, 719 (2017).

Non linear scattering of atomic bright solitons in disorder

A. Boissé[1] and G. Berthet[1] and T. Bourdel[1]

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We observe nonlinear scattering of 39K atomic bright solitons [1] launched in a one-dimensional (1D) speckle disorder. We directly compare it with the scattering of non interacting particles in the same disorder. The atoms in the soliton tend to be collectively either reflected or transmitted, in contrast with the behavior of independent particles in the single scattering regime, thus demonstrating a clear nonlinear effect in scattering. The observed strong fluctuations in the reflected fraction, between zero and 100%, are interpreted as a consequence of the strong sensitivity of the system to the experimental conditions and in particular to the soliton velocity [2]. This behavior is reproduced in a mean-field framework by Gross Pitaevskii simulations, and mesoscopic quantum superpositions of the soliton being fully reflected and fully transmitted are not expected for our parameters. We discuss the conditions for observing such superpositions, which would find applications in atom interferometry beyond the standard quantum limit [3].

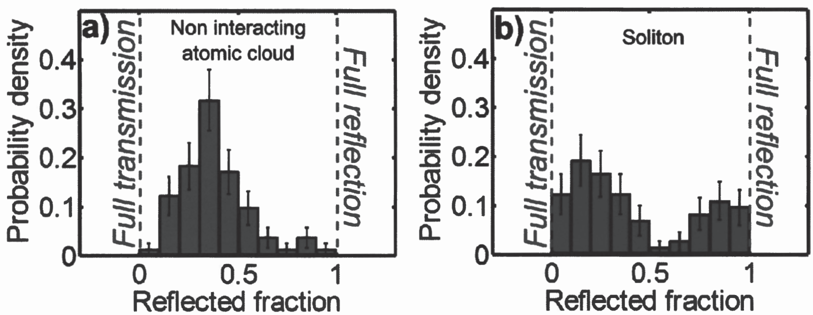

Figure 1: (Color online) Histograms of the experimentally measured reflected fractions of noninteracting atoms ((a) in blue) and solitons ((b) in red). The double-peak structure in (b) is a clear signature of nonlinear scattering.

References

[1] S. Lepoutre et.al, Phys. Rev. A **94**, 053626 (2016)

[2] A. Boissé et.al, EPL **117**, 10007 (2017)

[3] A. I. Streltsov et.al, Phys. Rev. A **80**, 043616 (2009)