INTERNATIONAL SCHOOL

OPEN QUANTUM MANY-BODY SYSTEMS

Tutzing, Germany

February 20 – 23, 2023

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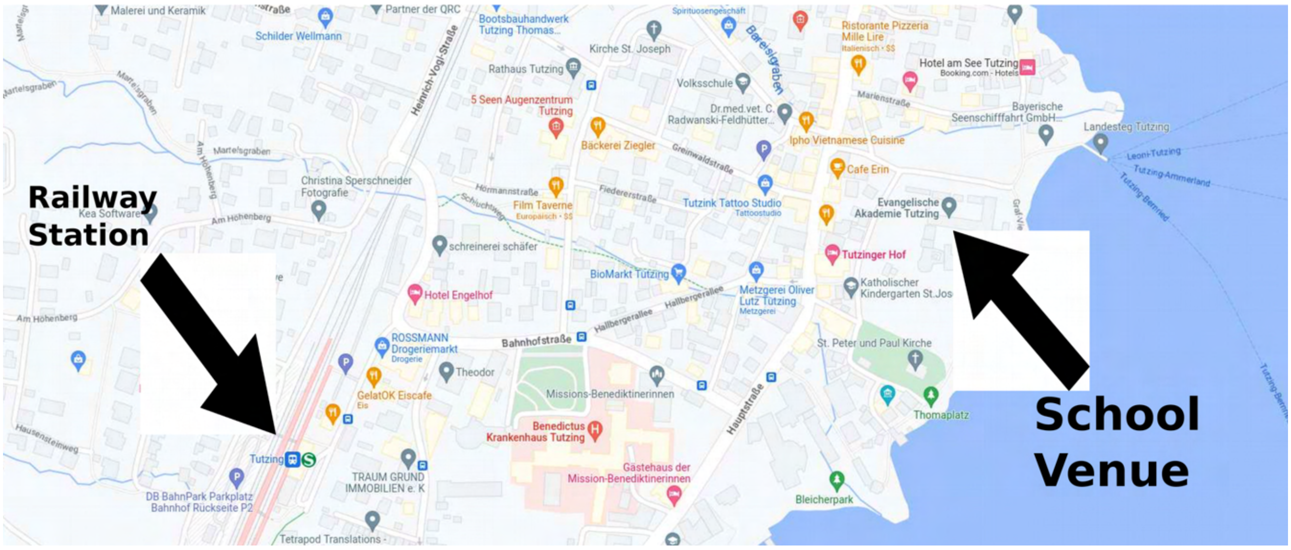







Preface

The Collaborative Research Center *Open System Control of Atomic and Photonic Matter (OSCAR)*

https://www.physik.uni-kl.de/oscar

explores the physics of open quantum many-body systems across different experimental platforms. Apart from basic research in this field the integrated young reseacher training program i-OSCAR guarantees education of the highest quality standards for the involved doctoral students and early postdocs. As a particular educational measure our SFB organizes an International Winter School on *Open Quantum Many-Body Systems*, which takes place in the Evangelische Adademie in Tutzing (Germany), in the period February 20-23, 2023. The lectures focus on three research areas, which are of central importance of OSCAR and will be discussed from both the experimental and the theoretical point of view:

1) BEC-BCS Crossover:

a) Taira Kawamura (Yokohama, Japan): *Non-equilibrium BCS-BEC crossover in a strongly interacting driven-dissipative Fermi gas*

b) Henning Moritz (Hamburg, Germany): *Comparing fermionic superfluids in two and three dimensions*

2) Hybrid Quantum Systems:

a) Michael Thorwart (Hamburg, Germany): *Nonequilibrium quantum phase transitions in hybrid atom-optomechanical systems*

b) Philipp Treutlein (Basel, Switzerland): Light-mediated interactions in atomic and optomechanical systems

3) Topology:

a) Alexander Altland (Cologne, Germany): *Topological quantum matter*

b) Christoph Weitenberg (Hamburg, Germany): *Detecting topology with ultracold atoms*

Program

OSCAR School
Tutzing, Germany
February 20-23, 2023

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Monday, Februatry 20

14.00-15:30	Reception
15:30-16:30	Alexander Altland (Cologne, Germany):
	T*opological quantum matter*
16:30-17:00	Coffee Break
17:00-18:00	Henning Moritz (Hamburg, Germany):
	Comparing fermionic superfluids in two and three dimensions
18:30-20:00	Dinner
20:00-22:00	Socializing

Tuesday, February 21

09:00-10:00	*Alexander Altland (Cologne, Germany):*
	Topological quantum matter
10:00-10:30	Coffee Break
10:30-11:30	Henning Moritz (Hamburg, Germany):
	Comparing fermionic superfluids in two and three dimensions
12:00-13:30	Lunch
13:30-15:00	*Discussion Groups 1*
15:00-15:30	Coffee Break
15:30-16:30	Christof Weitenberg (Hamburg, Germany):
	Detecting topology with ultracold atoms
16:30-17:00	Coffee Break
17:00-18:00	Taira Kawamura (Yokohama, Japan):
	Non-equilibrium BCS-BEC crossover
	in a strongly interacting driven-dissipative Fermi gas
18:30-20:00	Dinner
20:00-21:00	*Poster Session 1*

OSCAR School
Tutzing, Germany
February 20-23, 2023

SFB/TR 185

Wednesday, February 22

09:00-10:00	Christof Weitenberg (Hamburg, Germany):
	Detecting topology with ultracold atoms
10:00-10:30	Coffee Break
10:30-11:30	Taira Kawamura (Yokohama, Japan):
	Non-equilibrium BCS-BEC crossover
	in a strongly interacting driven-dissipative Fermi gas
12:00-13:30	Lunch
13:30-15:00	*Discussion Groups 2*
15:00-15:30	Coffee Break
15:30-16:30	Philipp Treutlein (Basel, Switzerland):
	Light-mediated interactions in atomic and optomechanical systems
16:30-17:00	Coffee Break
17:00-18:00	Michael Thorwart (Hamburg, Germany):
	Nonequilibrium quantum phase transitions
	in hybrid atom optomechanical systems
18:30-20:00	Dinner
20:00-21:00	*Poster Session 2*

Thursday, February 23

09:00-10:00	Philipp Treutlein (Basel, Switzerland):
	Light-mediated interactions in atomic and optomechanical systems
10:00-10:30	Coffee Break
10:30-11:30	Michael Thorwart (Hamburg, Germany):
	Nonequilibrium quantum phase transitions
	in hybrid atom optomechanical systems
12:00-13:30	Lunch

Poster Overview

1 **Lukas Ahlheit**
Rydberg superatoms for waveguide QED

2 **Ivan Ashkarin**
Toffoli gate based on a three-body Förster resonance in Rydberg atoms

3 **Alaa Bayazeed**
Implementation of interactions in 3D photonic quantum simulators through nonlinearity

4 **Shrestha Biswas**
Towards ultracold tetramers and dipolar BEC-BCS crossover

5 **Martin Bonkhoff**
Statistically suppressed coherence in the anyon-Hubbard dimer

6 **Marco Decker**
Ultracold Bose gases in temporally and spatially modulated potentials

7 **Marcos dos Santos Filho**
Incompressible energy spectrum from wave turbulence

8 **Andris Erglis**
Nested open quantum systems approach to photonic Bose-Einstein condensation

9 **Alexander Guthmann**
Theoretical study of radio-frequency induced Floquet Feshbach resonances in ultracold Lithium-6 gases

10 **Eugene Kogan**
The kinks, the solitons and the shocks in series-connected discrete Josephson transmission lines

11 **Franco Lisandrini**
Majorana edge-modes in a spinful particle conserving model

12 **Leon Mixa**
Strong sub-Ohmic quantum fluctuations in ultracold atom gases in a cavity

13 **Carole Peiffer**
Realization of an optical accordion for ultracold atoms

14 **Axel Pelster**
Quantum mechanical description of thermo-optic interaction in photon BEC

15 **Milan Radonjić**
Out of equilibrium dynamical properties of Bose-Einstein condensates in ramped up weak disorder

16 **Sayak Ray**
Equilibrium phases and non-equilibrium dynamics of ultracold atoms in an optical cavity

17 **Marvin Röhrle**
Experimental observation of a first-order dissipative phase transition in a many-body system

18 **Abel Rojo-Francàs**
Few distinguishable fermions in a one-dimensional harmonic trap

19 **Aleksandr Sazhin**
Open-system dynamics and fluctuation-dissipation relation in a photon Bose-Einstein condensate

20 **Anna Sidorenko**
Effect of disorder on directional transport in plasmonic waveguide arrays

21 **Michael Turaev**
Floquet drive of Kondo lattice systems

22 **Damian Włodzyński**
New approach to a small Fermi-polaron system in a harmonic trap

23 **Sejung Yong and Nikolai Kaschewski**
BEC-BCS crossover: Mean-field theories and beyond

Abstracts of Invited Talks

Topological quantum matter

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The physics of topological matter is governed by the presence of integer valued topological invariants whose values do not change under local perturbations or system deformations. If present, such invariants define a powerful principle of universality with far reaching phenomenological consequences. In these two talks, we will discuss introductory concepts of topological quantum matter – topological foundations, classification, entanglement properties, approximation methods, and phenomenological signatures – on two case studies: the SSH topological quantum wire, and Kitaev's toric code. No previous familiarity with topological quantum matter is assumed.

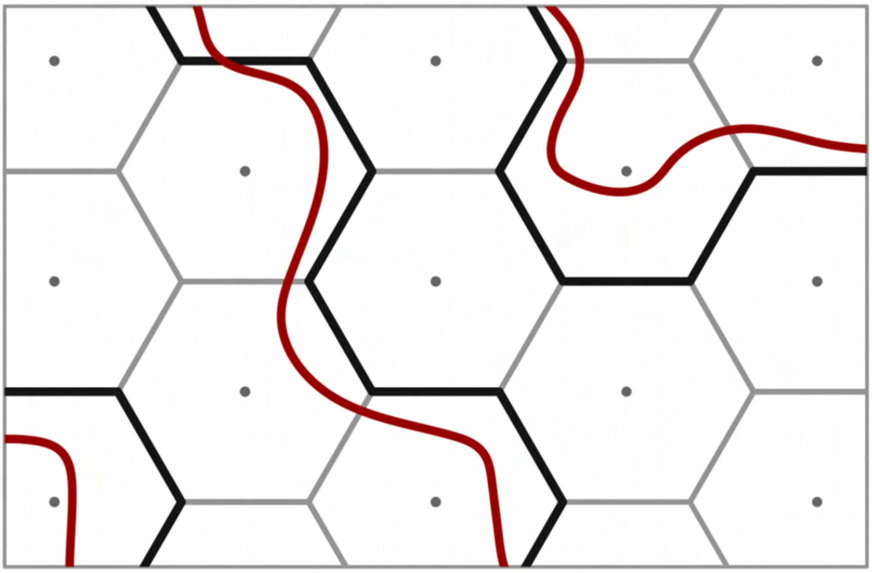

Figure: Schematic image of a topological tensor network configuration [1].

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Non-equilibrium BCS-BEC crossover in a strongly interacting driven-dissipative Fermi gas

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The study of driven-dissipative quantum many-body systems is currently a rapidly evolving field, both experimentally and theoretically in various platforms, such as superconducting circuits, exciton polaritons, strongly correlated photons, and cold atoms. In these systems, exotic quantum many-body states, that have not been realized/discussed/known in the thermal equilibrium case, can emerge due to non-equilibrium and nonlinear effects.

In these two talks, as a paradigmatic example, we will discuss non-equilibrium quantum many-body properties of the model of a driven-dissipative two-component Fermi gas with a tunable *s*-wave pairing interaction [1,2]. As the chemical potential bias applied by two reservoirs increases, a highly non-thermal Fermi momentum distribution with a two-step structure is realized (see the pop-up in the Figure). We will explain that the combination of this non-equilibrium Fermi momentum distribution and the strong pairing interaction gives rise to non-equilibrium quantum many-body phenomena beyond the conventional BCS-BEC crossover physics [3].

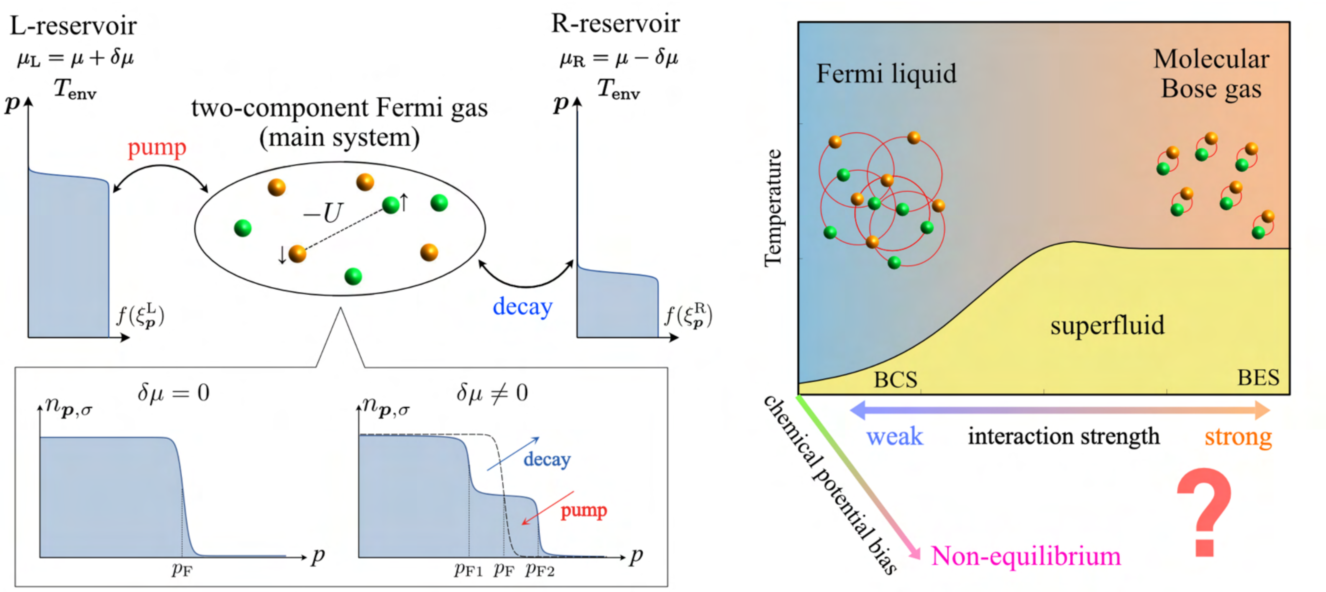

Figure: Model of a non-equilibrium driven-dissipative two-component Fermi gas with a tunable *s*-wave pairing interaction -*U*. The fusion of quantum many-body effects and non-equilibrium effects causes a variety of novel phenomena in the non-equilibrium BCS-BEC crossover regime.

References

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Comparing fermionic superfluids in two and three dimensions

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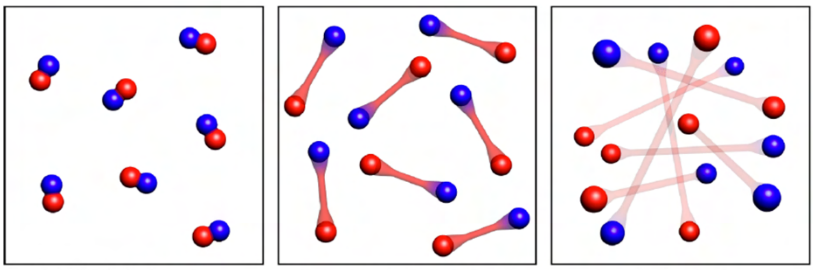
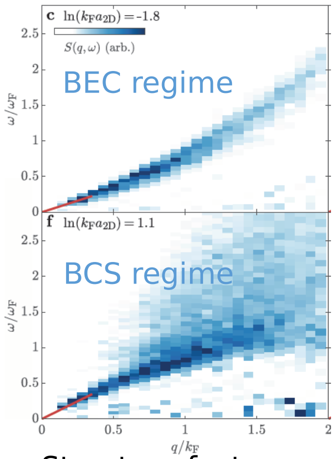
Understanding the origins of unconventional superconductivity has been a major focus of condensed matter physics and experiments have found the highest critical temperatures in layered 2D materials. However, to what extent their remarkable stability is affected by their reduced dimensionality is still an open question. Here, I will discuss influence of dimensionality on the stability of strongly interacting fermionic superfluids.

I will introduce fermionic superfluidity in ultracold atoms, where Cooper pairs form. Their pair size can be continuously tuned from the Bardeen-Cooper-Schrieffer (BCS) regime of loosely bound pairs to the BEC regime of very tightly bound pairs [1]. I will introduce the critical velocity v_c and the pairing gap Δ and review milestone experiments performed on superfluid 3D Fermi gases [2]. After explaining how to determine v_c and Δ using Bragg spectroscopy I will discuss our recent intriguing results comparing superfluidity in 2D and 3D [3-5]. We find that the superfluid gap follows the same universal function of the interaction strength regardless of dimensionality, which suggests that there is no inherent difference in the stability of 2D and 3D.



BEC of Molecules | Crossover Superfluid | BCS state



Structure factor

References

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Nonequilibrium quantum phase transitions in hybrid atom-optomechanical systems

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Hybrid quantum systems combine complementary fields of physics, such as condensed matter physics, quantum optics, and atomic physics, in one setup. One realization consists of a single mechanical mode of a nanomembrane which is placed inside an optical cavity and which is optically coupled to a far distant cloud of cold atoms residing in the optical potential of the out-coupled standing wave of the cavity light. This system shows fascinating effects, such as a nonequilibrium quantum phase transition at a critical atom-membrane interaction from a localized symmetric state of the atom cloud to a shifted symmetry-broken state [1]. The energy of the lowest collective excitation vanishes, and a strong atom-membrane entanglement arises. Also, internal atomic states can be involved in the hybrid coupling [2,3].

In these two talks, I will show how to describe such nonequilibrium hybrid quantum-many body systems theoretically, starting from their different constituents. An effective Hamiltonian to be derived will allow us to obtain generalized Gross-Pitaevskii equations. On the basis of generalized variational perturbation theory, we will be able to identify nonequilibrium quantum phase transitions and entanglement properties of the combined membrane-atom gas state [2,3]. A second part will involve also internal atomic states [2,3], such that the order of phase transition can be tuned.

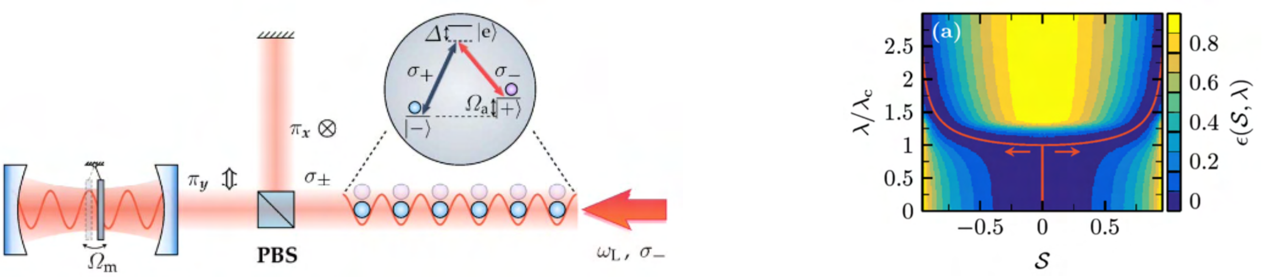

Figure: Left: Scheme of hybrid atom-optomechanical quantum system with internal atomic states. Right: Effective potential energy surface for varying control parameters, illustrating the location of the nonequilibrium quantum phase transition (red line).

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Light-mediated interactions in atomic and optomechanical systems

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Many of the breakthroughs in quantum science and technology rely on engineering strong Hamiltonian interactions between quantum systems. Typically, strong coupling relies on short-range forces or on placing the systems in high-quality electromagnetic resonators, which restricts the range of the coupling to short distances. In these lectures I will show how a loop of laser light can generate Hamiltonian coupling over a distance [1] and report experiments using this approach to strongly couple a nanomechanical membrane oscillator and an atomic spin ensemble across one meter in a room-temperature environment [2]. We observe spin-membrane normal mode splitting, coherent energy exchange oscillations, two-mode thermal noise squeezing, and dissipative coupling with exceptional points [2]. We furthermore realize an optical coherent feedback loop and use it for cooling of the membrane vibrations [3,4]. Our experiments demonstrate the versatility and flexibility of light-mediated interactions, a powerful tool for quantum science that offers many further possibilities and is readily applicable to a variety of different systems.

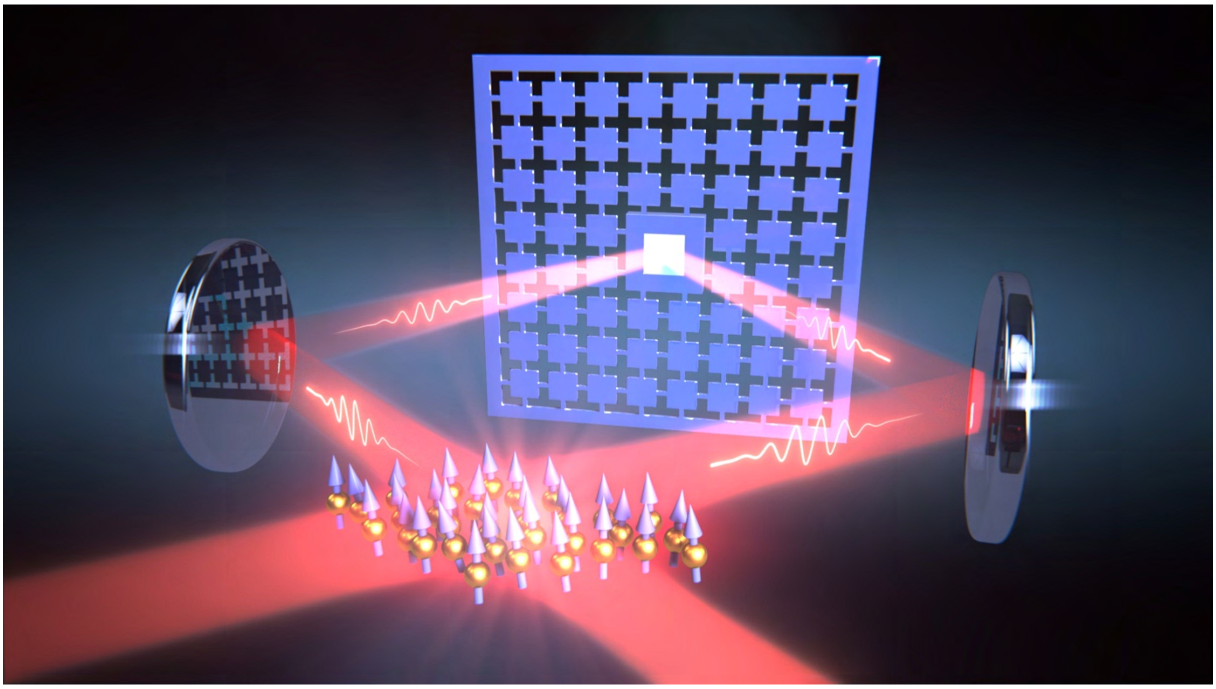

Figure: A loop of laser light couples the vibrations of a nanomechanical membrane to the spin of a cloud of atoms.

References

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Detecting topology with ultracold atoms

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Topological phases of matter are a central topic of modern physics. They can be realized with ultracold atoms in optical lattices in the spirit of quantum simulation by means of Floquet engineering [1]. An important goal of these efforts is to combine topological phases with interactions, which can be independently controlled in cold atoms. But already in the non-interacting context, experiments with ultracold atoms can help to shed new light on the fundamental concepts of topology, because they allow to directly access Berry phase and Berry curvature [2], cyclotron and skipping orbits as well as new exotic observables such as linking numbers in quench dynamics [3]. In these two lectures, I will revisit theses basic topological concepts along with their experimental demonstration with ultracold atoms.

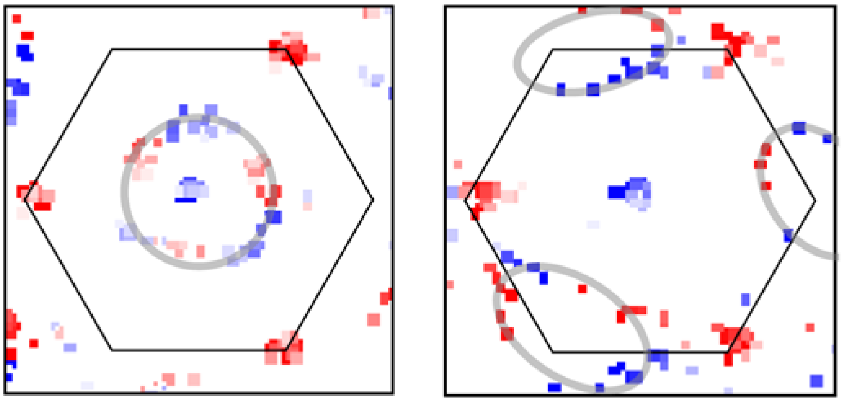

Figure: Pseudospin vortices in momentum space from quench dynamics in the Haldane model forming closed paths with a linking number reflecting the underlying topological invariant [3].

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Abstracts of Posters

Rydberg superatoms for waveguide QED

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Waveguide-systems, where quantum emitters are strongly coupled to a single propagating light mode, offer an interesting platform for quantum nonlinear optics. We work towards realizing a cascaded system in free space by using Rydberg superatoms - single Rydberg excitations in individual atomic ensembles smaller than the Rydberg blockade-volume - as directional effective two-level systems. On this poster we show our setup implementing a one-dimensional chain of Rydberg superatoms with low internal dephasing. We employ a double magic-wavelength optical lattice to pin atoms during optical experiments using Rydberg states and thus reduce motional dephasing of the collective excitation. We further show our interferometer setup for obtaining phase information about the photons to perform full state tomography of outgoing multi-photon pulses to characterize the effective photon-photon interaction mediated by the superatom chain.

Toffoli gate based on a three-body Förster resonance in Rydberg atoms

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We have developed an improved scheme of a three-qubit Toffoli gate based on a fine-structure-state-changing three-body Stark-tuned Rydberg interaction. This scheme is a substantial improvement of our previous proposal [1]. Due to the use of a different type of three-body Förster resonance we substantially simplified the scheme of laser excitation and phase dynamics of collective three-body states. This type of Förster resonance exists only in systems with more than two atoms, while the two-body resonance is absent. We reduced the sensitivity of the gate fidelity to fluctuations of external electric field and eliminated the necessity to use external magnetic field for fine-tuning of the resonant electric-field value, compared to the previous scheme of Toffoli gate based on Rydberg atoms. A gate fidelity of >99% was demonstrated in the calculations.

References:

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Implementation of interactions in 3D photonic quantum simulators through nonlinearity

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The paraxial Helmholtz equation, which governs the propagation of light within a waveguide, is mathematically equivalent to the Schrödinger equation that describes the behavior of electrons in condensed matter systems. This relationship provides a unique opportunity to study the behavior of electronic systems in periodic potentials by utilizing arrays of evanescently coupled waveguides. For the fabrication of such waveguide systems, 3D micro-printing is a powerful tool. After printing the inverse of a waveguide lattice, the structures consist of an array of holes (Figure 1a) that are subsequently infiltrated to transform them into functional waveguides. The ability to control the geometry, and the type of photoresist infiltrated into the structure allow to create systems with non-trivial topology and effective interactions between photons. Since photons do not usually interact with each other, we use the nonlinear Kerr effect to introduce effective interactions on a mean-field level. The system can then be described by the discrete nonlinear Schrödinger equation, analogous to the Gross-Pitaevskii equation

$$i\hbar\frac{\partial}{\partial t}\psi(x,y,t) = -\left[H + g|\psi(x,y,t)|^2\right]\psi(x,y,t),$$

which describes the behavior of Bose-Einstein condensates. The emergence of spatial solitons (wavepackets that retain their transverse profile during propagation) is a result of the introduced effective nonlinearity (Figure 1b). One potential method for incorporating nonlinear molecules is through the use of the newly developed material DDMEBT, which can be mixed into the photoresist and infiltrated into the structure. In a first step, we plan to observe of spatial solitons in experiments to verify the sucessful inclusion of nonlinearity.

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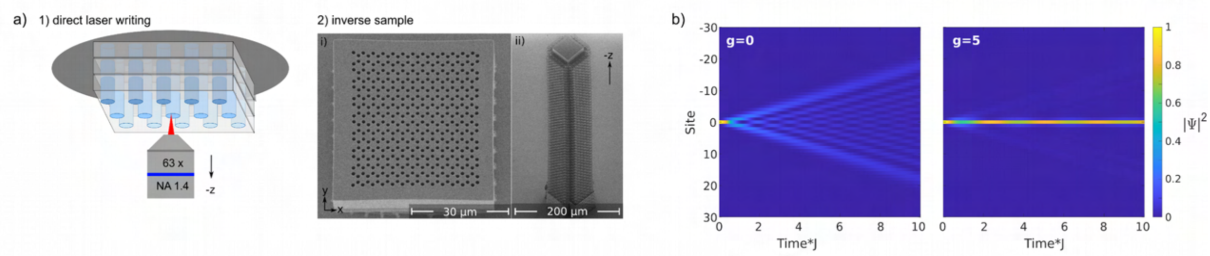

Figure 1: (a) Fabrication process of waveguide structures. (b) Simulation results of Gross-Pitaevskii equation in a 1D array of equally spaced evanescently coupled waveguides for the linear case (g = 0) and the nonlinear case (g = 5).

Towards ultracold tetramers and dipolar BEC-BCS crossover

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Fermionic molecules with anisotropic long-range interaction open opportunities to explore p-wave superfluidity, extended Fermi-Hubbard model, and long-range spin models. To observe these novel phenomena degenerate fermionic ground-state molecules are necessary.

Because of sticky collision of molecules, whenever two molecules are in short range, the process becomes inelastic. Evaporative cooling was impossible due to the low elastic-to-inelastic ratio of collisions. We solve the problem by microwave shielding, which induces repulsive intermolecular potential, restricting inelastic collisions. The intermolecular potential of microwave-shielded molecules can be modified by the polarization and the Rabi frequency of the microwave field. Recently, we have observed shape resonances in collisions of molecules induced by external field. In analogy to a Feshbach resonance between atoms, it offers control knobs over molecular interactions. As we can produce loosely bound molecules ramping over the Feshbach resonance, a natural next step is to create tetarmers, a bound state of two polar molecules, by ramping over the shape resonances. I will present our recent effort towards this and the BEC-BCS crossover.

Statistically suppressed coherence in the anyon-Hubbard dimer

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One-dimensional anyonic models of the Hubbard type show intriguing ground-state properties in gapless phases, effectively transmuting between Bose-Einstein and Fermi-Dirac statistics [1]. Recent progress in the experimental realization of such type of anyons via density-dependent gauge-phases [2] makes thereby a deeper theoretical understanding of such non-standard interactions inevitable. The simplest model that one can investigate is an anyonic version of the bosonic Josephson junction, the anyon-Hubbard dimer [3]. In the following we find an exact solution to the problem by a duality relation to the Bethe-solvable Bose-Hubbard dimer [4]. The duality transformation is well known from quantum optics and information theory, with interesting connections to spin squeezing and entangled coherent states [5,6]. Conversely, the anyonic Hubbard dimer provides a new experimental platform in the realm of cold-atoms, whose non-trivial coherence properties are interpreted in the terminology of quantum optics and are discussed by further analytical approximations to the exact solution.

References

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Ultracold Bose gases in temporally and spatially modulated potentials

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We investigate Bose-Einstein condensates in spatially and temporally modulated potentials. This allows us to study quantum transport phenomena and quantum scattering problems. To extend discrete models to continuum physics, we shift from lattice potentials to localized potentials in an optical trap. The potentials are projected onto the atoms with an objective inside the vacuum chamber, which is also used for absorption imaging. The atomic cloud can additionally be imaged via an electron column with high spatial resolution. Additionally, implementing two blue-detuned light sheets, we can furthermore change the trap geometry from 3D to quasi 2D. Future studies will include time-dependent barriers and local dissipation via the electron column.

Incompressible energy spectrum from wave turbulence

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Bose-Einstein condensates with their superfluidity property provide an interesting parallel to classical fluids. Due to the Kolmogorov spectrum of homogeneous turbulence the statistics of the incompressible velocity field is of great interest, but in superfluids obtaining quantities such as the statistics of the velocity field from the macroscopic wavefunction turns out be a complicated task; therefore, most of the work up to now has been numerical in nature. We made use of the Weak Wave Turbulence (WWT) theory, which provides the statistics of the macroscopic wavefunction, to obtain the statistics of the velocity field, which allowed us to produce a semi analytical procedure for extracting the incompressible energy spectrum in the WWT regime. This is done by introducing an auxiliary wavefunction that preserves the relevant statistical and hydrodynamical properties of the condensate but with a homogeneous density thus allowing for a simpler description of the velocity field.

Nested open quantum systems approach to photonic Bose-Einstein condensation

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The photonic Bose–Einstein condensate is a macroscopic state of light forming in thermal equilibrium with a sharply peaked ground mode occupation. We rigorously investigate the condensation using nested open quantum systems and macroscopic quantum electrodynamics [1]. We calculate all necessary constants in terms of the Green tensor.

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Theoretical study of radio-frequency induced Floquet Feshbach resonances in ultracold Lithium-6 gases

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Feshbach resonances are an indispensable tool in the research of ultracold atoms. The position of magnetic Feshbach resonances is determined by the magnetic field value where the energy of a dimer bound state crosses the asymptotic atomic threshold. By applying an oscillating magnetic field in the radio frequency regime, the colliding atom pair can be coupled to the dimer state, and new Feshbach resonances at different magnetic field values can be produced. Using techniques of Floquet theory, we convert the time-dependent problem into an equivalent time-independent problem, and derive a Hamiltonian which can be used for coupled-channel calculations. We use the example of Lithium-6 featuring an unusually broad s-wave resonance at 832 G caused by a weakly bound halo state. Results from coupled-channel calculations show that this halo state allows the creation of RF-induced resonances with large widths and tunability at technically achievable modulation strengths. These theoretical investigations will be presented, and the possibilities of experimental observation and associated technical challenges will be discussed.

The kinks, the solitons and the shocks in series-connected discrete Josephson transmission lines

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We analytically study the localized running waves in the discrete Josephson transmission lines (JTL), constructed from Josephson junctions (JJ) and capacitors. The quasi-continuum approximation reduces calculation of the running wave properties to the problem of equilibrium of an elastic rod in the potential field. Making additional approximation, we reduce the problem to the motion of the fictitious Newtonian particle in the potential well. We show that there exist running waves in the form of supersonic kinks and solitons and calculate their velocities and profiles. We show that the nonstationary smooth waves, which are small perturbations on the homogeneous non-zero background, are described by Korteweg-de Vries equation, and those on zero background – by modified Korteweg-de Vries equation. We also study the effect of dissipation on the running waves in JTL and find that in the presence of the resistors, shunting the JJ and/or in series with the ground capacitors, the only possible stationary running waves are the shock waves, whose profiles are also found. Finally in the framework of Stocks expansion we study the nonlinear dispersion and modulation stability in the discrete JTL.

Majorana edge-modes in a spinful particle conserving model

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We show the presence of Majorana edge modes in an interacting fermionic ladder with spin in a number conserved setting. The interchain single particle hopping is suppressed and only a pair hopping is present between the different chains of the ladder. Additionally, the hopping along the chains is spin imbalanced and a transverse magnetic field is applied breaking time-reversal invariance. We study the robustness of the topological phase with respect to an on-site interaction between the spin-up and spin-down fermions and the spin dependent imbalance of the hopping. The main result of the present work is that the topological phase survives for a finite region in the parameter space in the presence of interactions. The localized Majorana edge modes seem to be more stable in the case when the on-site interaction is an attraction.

Strong sub-Ohmic quantum fluctuations in ultracold atom gases in a cavity

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Cavity BEC systems with strong coupling between the atomic and cavity sector provide extraordinary possibilities for observing details in their phase transition through the cavity loss channel. By microscopic derivation starting from the systems field Hamiltonian, we uncover the atomic quantum fluctuations around the condensate. The quantum fluctuations are then captured in exact fashion as the bath of a system bath description of the cavity-BEC. We present analytic expressions of the sub-Ohmic spectral densities governing the various Landau and Beliaev damping processes. We showcase the influence on the systems fluctuations and its Dicke phase transition with regards to the critical point, universality class and temperature dependence.

Realization of an optical accordion for ultracold atoms

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Optical lattices, created by the interference of two or more coherent and often far-detuned laser beams, are among the most established tools used to manipulate quantum gases. One special realization, the so-called optical 'accordion', promises enhanced flexibitlity: when changing the angle of the two interfering beams, the lattice constant changes, allowing control over the lattice spacings over a large range of values. We aim at realizing such an accordion setup using a beamsplitter, consisting of two custom Dove-prisms, glued together by a special UV-curing epoxy, in combination with a large focusing lens. When a single beam passes through the prism pair, it is split into two parallel rays, and their distance depends on the incidental beams. After focusing by the lens onto the atom's position, interference creates the lattice potential. I will report the planning and the construction of an ex-situ characterization of an optical accordion, which will be used to access lower dimensions in our setup with ultracold lithium-6 atoms.

Quantum mechanical description of thermo-optic interaction in photon BEC

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Photon Bose-Einstein condensates are created in a microcavity filled with a dye solution in which photons are trapped. The dye continually absorbs and re-emits these photons causing the photon gas to thermalise at room temperature and finally to form a Bose-Einstein condensate. Because of a non-ideal quantum efficiency, these cycles heat the dye solution, creating a medium in which effective photon-photon interaction takes place. However, a full Hamiltonian formulation of this process has yet to be derived.

In this poster, we focus on a Hamiltonian description of the effective photon-photon interaction that includes the thermal cloud and, thus, resembles a Hartree-Fock analogue theory for this kind of interaction [1]. Using an exact diagonalisation approach, we work out how the effective photon-photon interaction modifies the spectrum of the photon gas and how it affects the condensate width [2]. As a second case study, we apply our theory to the dimensional crossover from 2D to 1D. In this scenario, we focus on a comparison with a plain variational approach based on the Gross-Pitaevskii equation and explicitly work out the contribution of the thermal cloud.

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Out of equilibrium dynamical properties of Bose-Einstein condensates in ramped up weak disorder

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We investigate theoretically how the superfluid and the condensate deformation of a weakly interacting ultracold Bose gas evolve during the ramping up of an external weak disorder potential. Both resulting deformations turn out to consist of two distinct contributions, namely a reversible equilibrium one, already predicted by Huang and Meng in 1992 [1,2], as well as a non-equilibrium dynamical one, whose magnitude depends on the details of the ramping protocol [3]. For the specific case of the exponential ramping up protocol, we are able to derive analytic time-dependent expressions for the aforementioned quantities. After sufficiently long time, a steady state emerges that is generically out of equilibrium. We make the first step in examining its properties by studying the relaxation dynamics into it. Also, we investigate the two-time correlation function and elucidate its relation to the equilibrium and the dynamical part of the condensate deformation.

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Equilibrium phases and non-equilibrium dynamics of ultracold atoms in an optical cavity

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Open quantum systems are inherent in nature since no system can completely be isolated from the environment. In this work, we consider a driven dissipative system consisting of BECs loaded into a 2D optical lattice and coupled to a single mode of an optical cavity. The cavity field generates an effective long-range interaction between the atoms which, at zero temperature, gives rise to phases with a modulated atomic density such as density waves and supersolids which appear together with the Dicke superradiant state. At finite temperatures, we study the melting of these phases with increasing temperature, namely, the supersolid transits into a compressible solid with vanishing superfluid order, followed by a transition to normal fluid state with vanishing density order. To take into account the spatial correlation we use cluster mean-field theory and obtain phase diagrams both at zero and at finite temperature. Finally, we study the dissipative dynamics in presence of photon loss from the cavity using the Lindblad master equation. We analyze the steady states, particularly, the density modulated phases and the transitions between them with increasing rate of photon loss from the cavity.

Experimental observation of a first-order dissipative phase transition in a many-body system

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Phase transitions are a ubiquitous phenomenon, which can be encountered in many physical systems. Here we discuss a first-order dissipative phase transition in a 1D lattice of quasi-2D Bose-Einstein condensates and a central lattice site with dissipation. The system is experimentally investigated either by measuring the time evolution of two metastable states or by sweeps across the critical point.

The dissipation is realized by an electron beam which removes atoms from a single lattice site. Removed atoms are detected and used as the measurement signal. Neighboring lattice sites act as atom reservoirs. Due to the atomic motion being slower than the detection rate, we can look into the dynamics when the system switches between states.

Due to the nature of the phase transition, we can observe dynamic hysteresis, whose area scaling can be characterized and gives insight into the internal dynamics and fluctuations. This behavior can also be related to the Kibble-Zurek mechanism for scaling of system parameters by fast quenches over phase transitions.

Few distinguishable fermions in a one-dimensional harmonic trap

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We study systems of few particles trapped in a harmonic oscillator potential with short-range interactions, modeled by a delta potential. There are recent experimental [1] and theoretical [2] studies with these conditions. We provide a method to improve the results when one uses the exact diagonalization method, compared with exact results for the SU(N) symmetric case [3]. In addition, we deal with systems without symmetric interactions, paying special attention to an impurity configuration.

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Open-system dynamics and fluctuation-dissipation relation in a photon Bose-Einstein condensate

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The tuneable openness of optical quantum gases, as photon or polariton condensates in optical microcavities, enables the exploration of new system states and phases, which would not be accessible under closed system conditions. Here, we experimentally demonstrate a non-Hermitian phase transition in a photon Bose-Einstein condensate in an open dye-filled optical microcavity. The transition separates a phase of biexponential photon number correlations from both lasing and an intermediate, oscillatory regime, as characterised by the second-order correlation dynamics of the BEC [1]. By studying the magnitude of the condensate number fluctuations and relating them to a response function, we verify a fluctuation-dissipation relation for the BEC coupled to a molecular reservoir [2]. In more recent work, we have extended these studies to the time domain, establishing a connection between the fluctuation dynamics and the response of the condensate population to an external pulse-like perturbation of the molecular reservoir.

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Effect of disorder on directional transport in plasmonic waveguide arrays

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Evanescently coupled waveguides provide a convenient platform for the simulation of various quantum phenomena whose experimental realization in analogous condensed matter systems is otherwise difficult due to quantum optical analogy. In this poster, we present a comparative study of the robustness of directional transport in presence of disorder in two periodically driven plasmonic waveguides systems – ratchets and fast Thouless pumps. Directional transport in a ratchet requires fine-tuning of the driving parameters. In contrast, directional transport in Thouless pumping is a topological effect that can be achieved for a range of driving frequencies considering the closed cycle in parameter space. We analyze the effect of topological protection on directional transport by introducing identical disorder distributions to both systems.

Floquet drive of Kondo lattice systems

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In this work we study the effects of light irradiation on heavy-fermion systems. A typical model for such systems is the periodic Anderson model where interacting, localized electrons in the 4f shell of rare-earth ions hybridize with a sea of conduction electrons. The application of a time-periodic laser field induces a periodically time-dependent hybridization between the conduction and the 4f electrons due to the dipole selection rules. To be able to analyze such a scenario we use the dynamical mean field theory (DMFT) combined with the Floquet Green's function method. We obtain that for the single-impurity problem, weak periodic drive leads to Floquet replicas of the Kondo resonance at multiples of the driving frequency. However a strong drive can lead to an efficient suppression of the Kondo effect. In the lattice, the Kondo resonance induces the flat band and, therefore, the weak drive produces Floquet replicas of the flat band. When the driving strength is increased, the spectral weight of the flat band is reduced, and is most strongly suppressed for small momenta.

New approach to a small Fermi-polaron system in a harmonic trap

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The experimental realization of an ultracold mixture with a single impurity immersed in several fermions in a one-dimensional harmonic trap motivated theoretical studies of this system. The analysis is particularly challenging in the case of strong inter-component interactions. Methods used to solve this problem (such as an exact diagonalization) require an enormous amount of computational resources. Therefore they are limited to very small mixtures. I will present an alternative numerically exact approach in which the problem is simplified using an appropriately tailored canonical transformation. The method is especially effective in the case of heavy impurity, where the problem is reduced to a weakly interacting system.

BEC-BCS crossover: Mean-field theories and beyond

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The established theory for the BCS-BEC crossover is based on formulating the underlying many-body problem with the functional integral and on performing a Hubbard-Stratonovich transformation in the Bogoliubov channel [1,2]. A saddle-point approximation reveals then that the whole BCS-BEC crossover can only be described once Gaussian fluctuations around the saddle point are taken into account, which turns out to be numerically quite demanding. Here we tackle this many-body problem from another point of view. To this end we work out a variational approach for the underlying Hamilton operator in canonical field quantization, which includes not only the Bogoliubov but also the Hartree and the Fock channel.

In order to test the predictions of the resulting Hartree-Fock-Bogoliubov mean-field theory we combine it with a local density approximation and determine the density profiles in the BCS regime. A comparison with experimental density profiles [3] reveals that interaction effects are already relevant in the normal fluid phase in contrast to the Bogoliubov mean-field theory [1,2]. A direct theory-experiment comparison even suggests that the temperature in the BCS regime can be measured, which hitherto represents a delicate task. Namely, in the literature temperature measurements have so far been only suggested in an indirect way, where one sweeps isentropically from the BCS to the BEC limit [4,5].

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time	Mon. 20.03.	time	Tue. 21.03.	time	Wed. 22.03.	time	Thu. 23.03.
		09:00-10:00	Alexander Altland	09:00-10:00	Christof Weitenberg	09:00-10:00	Philipp Treutlein
		10:00-10:30	Coffee Break	10:00-10:30	Coffee Break	10:00-10:30	Coffee Break
		10:30-11:30	Henning Moritz	10:30-11:30	Taira Kawamura	10:30-11:30	Michael Thorwart
		12:00-13:30	Lunch	12:00-13:30	Lunch	12:00-13:30	Lunch
-14:00	Arrival	13:30-15:00	Discussion Groups 1	13:30-15:00	Discussion Groups 2	13:30-	Departure
14:00-15:30	Reception	15:00-15:30	Coffee Break	15:00-15:30	Coffee Break		
15:30-16:30	Alexander Altland	15:30-16:30	Christof Weitenberg	15:30-16:30	Philipp Treutlein		
16:30-17:00	Coffee Break	16:30-17:00	Coffee Break	16:30-17:00	Coffee Break		
17:00-18:00	Henning Moritz	17:00-18:00	Taira Kawamura	17:00-18:0	Michael Thorwart		
18:30-20:00	Dinner	18:30-20:00	Dinner	18:30-20:00	Dinner		
20:00-22:00	Socializing	20:00-21:00	Poster Session 1	20:00-21:00	Poster Session 2		