THE HAMBURG CENTRE FOR ULTRAFAST IMAGING

CUI young researchers workshop

From few- to many body physics in cold atomic quantum matter

June 27 - 29, 2016

Center for Optical Quantum Technologies

University of Hamburg

Schedule

Monday 27/6

8:30 am *Registration*

8:50 am *Welcome and introduction to the workshop*

9:00 am **Javed Akram**
A single Cs impurity in a Rb Bose-Einstein condensate

10:00 am *Coffee Break*

10:30 am **Paula Ostmann**
Single particle dynamics in an ultracold environment:
From superfluidity to finite site reheating

11:30 am **Bernhard Ruff**
Local Ionization of Ultracold Bosonic Gases

12:30 am *Lunch*

2:00 pm **Robert Höppner**
Semiclassical simulation of many-body ultra-cold atoms systems

3:00 pm *Coffee Break*

3:30 pm **Christian Fey**
Geometry of triatomic ultralong-range Rydberg molecules

4:30 pm **Kathrin S. Kleinbach**
A single Rydberg excitation in a Bose-Einstein Condensate

5:30 pm *BBQ & Poster session*

Tuesday 28/6

9:00 am **Sven Krönke**
Natural orbitals of ultracold many-body systems: from experimental reconstruction to correlation analysis in coordinate and energy space

10:00 am *Coffee Break*

10:30 am **Manfred J. Mark**
Quantum simulation 2.0: Quench dynamics and long-range extensions in the Bose-Hubbard model

11:30 am ***Simeon I. Mistakidis***
Dynamics of interaction quenched ultracold bosons in periodically driven finite lattices

12:30 am *Lunch*

2:00 pm **Niklas Luick**
Local Probing of Phase Coherence in a Strongly Interacting 2D Quantum Gas

3:00 pm *Coffee Break*

3:30 pm **Thomas Niederprüm**
Rydberg molecules: From spin-flips to butterflies

4:30 pm **Mathew T. Eiles**
Polyatomic Rydberg molecules in a high density environment

5:30 pm ***Helmut Strobel***
Spin dynamics out of equilibrium: Fisher information of entangled non-Gaussian states and scaling of dynamics in quenched quantum gases

Wednesday 29/6

9:00 am **Rasmus S. Christensen**
The Bose Polaron: Theory & Experiments

10:00 am *Coffee Break*

10:30 am **Johannes M. Schurer**
Impurity ion immersed in bosonic ultracold atoms

11:30 am **Gerhard Zürn**
Quantum magnetism with few cold atoms

12:30 am *Lunch*

8:30 am - 8:50 am ***Registration***

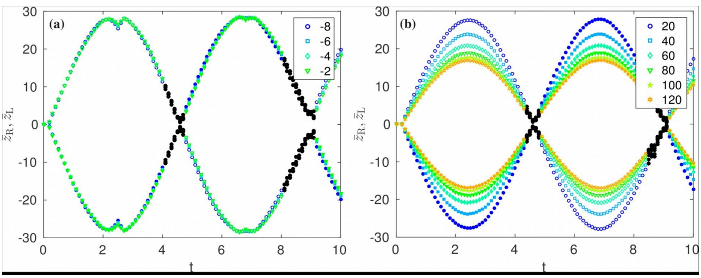
8:50 am - 9:00 am ***Welcome and introduction to the workshop***

9:00 am – 10:00 am

Javed Akram
Axel Pelster
Institute für Theoretische Physik, Freie Universität Berlin

A single Cs impurity in a Rb Bose-Einstein condensate

Motivated by recent experiment [Phys. Rev. Lett. 109, 235301 (2012)], we investigate a single Cs impurity in the center of a trapped Rb Bose-Einstein condensate (BEC). Within a zero-temperature mean-field description we provide a one-dimensional physical intuitive model which involves two coupled differential equations for the condensate and the impurity wave function, which we solve numerically. With this we determine within the equilibrium phase diagram spanned by the intra- and interspecies coupling strength whether the impurity is localized at the trap center or expelled to the condensate border. In the former case we find that the impurity induces a bump or dip on the condensate for an attractive or a repulsive Rb-Cs interaction strength, respectively. Conversely, the condensate environment leads to an effective mass of the impurity which increases quadratically for small interspecies interaction strength. Afterwards, we investigate how the impurity imprint upon the condensate wave function evolves for two quench scenarios. At first we consider the case that the harmonic confinement is



released. During the resulting time-of-flight expansion it turns out that the impurity-induced bump in the condensate wave function starts decaying marginally, whereas the dip decays with a characteristic time scale which decreases with increasing repulsive impurity-BEC interaction strength. Second, once the attractive or repulsive interspecies coupling constant is switched off, we find that white-shock waves or bi-solitons emerge which both oscillate within the harmonic confinement with a characteristic frequency as shown in Fig.

10:00 am - 10:30 am ***Coffee Break***

10:30 am - 11:30 am

Paula Ostmann
Walter Strunz
Institut für Theoretische Physik, Technische Universität Dresden

Single particle dynamics in an ultracold environment: From superfluidity to finite site reheating

We study the quantum dynamics of a single trapped ion which is in contact with a Bose-Einstein condensate. The ultracold environment acts as a refrigerator, and thus, the influence on the motion of the ion is dissipative. For a theoretical description of the damped quantum dynamics, simple phenomeno-logical master equation approaches are widely used. But instead of calculating the particle dynamics itself, our focus lies on a more detailed description of the environment and the particle-environment interaction. Rather than using a simple damping rate, we aim to describe the effective dynamics of the damped particle using the full bath correlation function. In this way we gain a more thorough theoretical understanding of properties of quantum matter, such as superfluidity, when acting as an environment.
We find that we can divide the dynamical effect of the BEC on the ion into two parts: The initial energy loss and the return of energy to the ion dynamics. By considering just the initial decay we effectively study an ion coupled to an infinitely large environment and are able to identify a Landau Criterion for a quantum particle in a harmonic trap. On the other hand we see that the finite size of the condensate causes a return of energy, which results in a periodically reheating of the ion. Interestingly the system can be tuned such that this effect can lead to an additional cooling mechanism.

11:30 am - 12:30 am

Bernhard Ruff
Institut für Laser-Physik, Universität Hamburg
The Hamburg Centre for Ultrafast Imaging, Universität Hamburg,

Local Ionization of Ultracold Bosonic Gases

The combination of ultracold atomic systems and ultrafast laser pulses promises insight into the coherence properties of macroscopic dissipative quantum targets and enables preparing hybrid quantum systems via local ionization of atoms in strong laser fields.
We report on the investigation of ultracold 87 Rb gases exposed to femtosecond laser pulses at 515 nm wavelength and 290 fs pulse duration. The light pulses ionize atoms of the atomic cloud within the focal region (7 µm waist) of the beam by simultaneous absorption of two photons. The number of generated ions can be controlled by tuning the intensity or the wavelength of the laser. Remaining atoms are detected by resonant absorption imaging either in-situ or after time of flight.
Atomic losses evident as void in the trapped cloud are evaluated and show a non-linear increase with respect to the pulse energy demonstrating the generation of ions in a multiphoton process. Additionally, recent results on the dynamics of the atomic sample after a femto-second pulse will be discussed for thermal as well as degenerated gases.
Further perspectives on the direct detection of ionization fragments will be presented.

12:30 pm - 2:00 pm ***Lunch***

2:00 pm - 3:00 pm

Robert Höppner
University of Hamburg, Centre for Optical Quantum Technologies

Semiclassical simulation of many-body ultra-cold atoms systems

I'll talk about how to simulate many-body ultracold atom systems in the semiclassical approximation. The semiclassical approximation replaces an many-body quantum system that occupies an impossibly large Hilbert space with an ensemble of coupled classical oscillators whose characterization only requires a rather small classical configuration space. The system is initialized with classical Metropolis Monte-Carlo, time-dependent problems (driving, quenches) are simulated by propagating the Hamilton equations of motion using an ODE integrator. As an example I take an experiment carried out in the Sengstock group (ILP, Uni Hamburg). The experiment was an implementation of a frustrated coupled Ising-XY model. In the first part of this talk, I'll explain the relevant physics of this model, then I'll discuss the experiment and finally conclude by commenting on the semiclassical simulation of such experiment with a computer.

3:00 pm - 3:30 pm ***Coffee Break***

3:30 pm - 4:30 pm

Christian Fey
University of Hamburg, Centre for Optical Quantum Technologies

Geometry of triatomic ultralong-range Rydberg molecules

Ultralong-range Rydberg molecules (ULRM) are giant molecules consisting of a Rydberg atom whose valence electron binds one or more polarizable ground state atoms by low-energy scattering. In contrast to common covalent molecules ULRM possess oscillatory potential surfaces (PES) supporting several equilibrium configurations with huge bond lengths of thousands of Bohr radii.
Besides these exotic properties they are an interesting system for studying few- to many-body phenomena: Having control over the principal quantum number n of the Rydberg electron and over the density of ground state atoms allows to switch experimentally from few-body states, like triatomic or tetratomic ULRM, to regimes where one Rydberg electron interacts with thousands of ground state atoms.
In the talk we will briefly discuss the existing theoretical models to describe these systems and present then our recent results on the structure of triatomic ULRM which were obtained by following the typical Born-Oppenheimer approach. As calculating the potential energy surfaces for polyatomic ULRM in general is computationally demanding we demonstrate how the finite basis set representation of the unperturbed Rydberg electron Green's function can be employed to reduce numerical efforts. The remaining vibrational problem is solved by separating the vibrational bending and stretching dynamics adiabatically. This procedure yields information on the radial and angular arrangement of the nuclei which are not captured by the previously mentioned alternative methods.

4:30 pm - 5:30 pm

Kathrin Kleinbach
Tilman Pfau
5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart

A single Rydberg excitation in a Bose-Einstein Condensate

A single Rydberg excitation in the high density and low temperature environment of a Bose-Einstein condensate (BEC) leads to a fascinating testbed of low-energy electron-neutral and ion-neutral scattering. For a Rydberg state with a principal quantum number of 100, thousands of ground-state atoms reside inside the Kepler orbit of the Rydberg atom. The Rydberg blockade allows for the spectroscopy of exactly a single Rydberg atom within a BEC. The emerging line shapes unveil many details of the underlying pair potentials especially in the presence of a scattering resonance admixing additional states. Therefore, the interaction potential energy curves of the Rydberg electron scatterer with the neutral atom perturber is reviewed. Additionally not only elastic collisions are observed, but also chemical reactions leading to state changing collisions or the production of molecules. We have studied these processes, happening on the μs scale, time and energy resolved over a large range of quantum states.

5:30 pm – 8:00 pm ***BBQ and poster session***

Tuesday 28/6

9:00 am - 10:00 am

Sven Krönke
Zentrum für Optische Quantentechnologien, Universität Hamburg
The Hamburg Centre for Ultrafast Imaging, Universität Hamburg,

Natural orbitals of ultracold many-body systems: from experimental reconstruction to correlation analysis in coordinate and energy space

Deep insights into the structure of a many-body state can often be inferred from its natural orbitals (eigenvectors of the reduced one-body density operator) and their populations. In this talk, various aspects of this theoretical concept will be discussed in the context of ultracold bosonic atoms: First, I will consider the decay of dark solitons due to dynamical quantum depletion as an example for how a natural-orbital analysis can help unravelling complex many-body processes and intriguing aspects of local correlations. Secondly, it will be shown how two-body correlation measurements can in turn be utilized for reconstructing the natural-orbital densities for a certain class of many-body states. Finally, I will discuss in the context of binary bosonic mixtures how the interplay between inter-species correlations and excitation transfer can be made transparent by applying the natural-orbital analysis generalized to a whole species.

10:00 am - 10:30 am ***Coffee Break***

10:30 am - 11:30 am

Manfred J. Mark
Institute for experimental physics, University of Innsbruck.

Quantum simulation 2.0: Quench dynamics and long-range extensions in the Bose-Hubbard model

Cold atoms confined in optical lattice potentials offer unique access to study and simulate condensed matter Hamiltonians, e.g. the bosonic Hubbard model. In a first set of experiments bosonic Cs atoms, which offer a high tunability of the contact interaction via magnetic Feshbach resonances, are used to investigate correlated tunneling dynamics after a quantum quench [1]. We report significant modification of the tunneling rate induced by interactions [2] and show clear evidence for collective effects in the oscillatory response. Further, we observe higher-order tunneling processes that occur over up to 5 lattice sites [3]. In a second setup we use bosonic erbium, which possesses a large magnetic moment of 7 Bohr magneton, to study extended Bose-Hubbard models with long-range, anisotropic interactions. Here we present the first study on the superfluid-to-Mott insulator transition with dipole-dipole interactions (DDI) and evidence of the nearest-neighbour interaction (NNI) between the atoms [4]. This opens the doors for the investigation of exotic quantum phases like supersolid- or checkerboard-phases.

[1] *Quantum Quench in an Atomic One-Dimensional Ising Chain*, F. Meinert et al., Phys. Rev. Lett. 111, 053003 (2013)
[2] *Observation of Density-Induced Tunneling*, O. Jürgensen et al., Phys. Rev. Lett. 113, 193003 (2014)
[3] *Observation of many-body dynamics in long-range tunneling after a quantum quench*, F. Meinert et al., Science 344, 1259-1262 (2014)
[4] *Extended Bose-Hubbard Models with Ultracold Magnetic Atoms*, S. Baier et al., Science 352, 201 (2016)

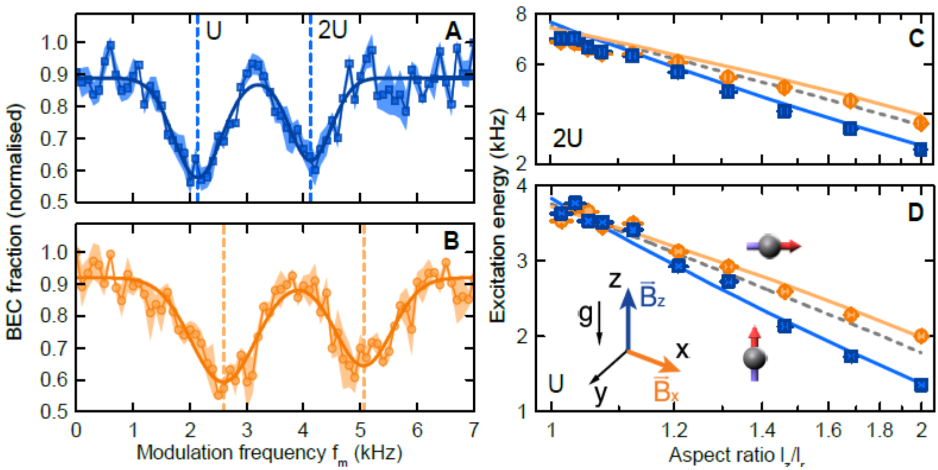


Figure: **A)** Excitation spectrum of the Mott insulator with dipoles oriented along the Z axis. Solid lines are double gaussian fits to the data. **B)** Same as A), but for dipoles oriented along the X axis. **C)** Onsite interaction energy 2U for the two dipole orientations as a function of the onsite trap aspect ratio out of double gaussian fits from spectra as seen in A) and B). Solid lines are theoretical predictions including contact interactions and DDI. Dashed lines are theoretical predictions without DDI. **D)** Same as C) but for the onsite interaction energy U.

11:30 am - 12:30 am

Simeon I. Mistakidis
University of Hamburg, Centre for Optical Quantum Technologies

Dynamics of interaction quenched ultracold bosons in periodically driven finite lattices

The out-of-equilibrium dynamics of ultracold bosons following an interaction quench upon either a static or a periodically driven optical lattice is investigated. It is shown that a quench on the interparticle repulsion of ultracold bosons confined in a static optical lattice triggers the inter-well tunneling dynamics, while for the intra-well dynamics breathing and cradle like processes can be generated [1,2]. In particular, the occurrence of a resonance between the cradle and the tunneling modes with varying quench amplitude is revealed [1]. Next, the dynamics caused exclusively by a periodically driven lattice (hereby, a vibration) is presented and the induced low-lying modes are introduced. The employed periodic driving enforces the bosons in the outer wells of the finite lattice to exhibit out-of-phase dipole-like modes, while in the central well the atomic cloud experiences a local breathing mode. The dynamical behavior is investigated with varying driving frequency, revealing a resonant-like behavior of the intra-well dynamics [3,4]. Furthermore, an interaction quench in the periodically driven lattice gives rise to admixtures of different excitations in the outer wells, an enhanced breathing in the center and an amplification of the tunneling dynamics. We observe then multiple resonances [4] between the inter- and intra-well dynamics at different quench amplitudes, with the position of the resonances being tunable e.g. via the driving frequency or the atom number manifesting their many-body nature. The evolution of the system is investigated in the framework of the Multiconfiguration Time-Dependent Hartree Method for bosons. Our results pave the way for future investigations on the use of combined driving protocols in order to excite different inter- and intra-well modes and to subsequently control them at will.

[1] S.I. Mistakidis, L. Cao, and P. Schmelcher, Interaction quench induced multimode dynamics of finite atomic ensembles. J. Phys. B: Atomic, Molecular and Optical Physics, 47, 225303 (2014).

[2] S.I. Mistakidis, L. Cao, and P. Schmelcher, Negative-quench-induced excitation dynamics for ultracold bosons in one-dimensional lattices, Phys. Rev. A, 91, 033611 (2015).

[3] S.I. Mistakidis, T. Wulf, A. Negretti, and P. Schmelcher, Resonant quantum dynamics of few ultracold bosons in periodically driven finite lattices, J. Phys. B: Atomic, Molecular and Optical Physics, 48, 244004 (2015).

[4] S.I. Mistakidis, and P. Schmelcher, Mode coupling of interaction quenched ultracold few-boson ensembles in periodically driven lattices, arXiv preprint arXiv:1604.02976 (2016).

12:30 pm - 2:00 pm ***Lunch***

2:00 pm - 3:00 pm

Niklas Luik
Jonas Siegl, Klaus Hueck, Kai Morgener, Thomas Lompe, Wolf Weimer, Henning Moritz
Institut für Laser-Physik, Universität Hamburg

Local Probing of Phase Coherence in a Strongly Interacting 2D Quantum Gas

The dimensionality of a quantum system has a profound impact on its coherence and superfluid properties. In 3D superfluids, bosonic atoms or Cooper pairs condense into a macroscopic wave function exhibiting long-range phase coherence. Meanwhile, 2D superfluids show a strikingly different behavior: True long-range coherence is precluded by thermal fluctuations, nevertheless Berezinskii-Kosterlitz-Thouless (BKT) theory predicts that 2D systems can still become superfluid. The superfluid state is characterized by an algebraic decay of phase correlations $g_1(r) \propto r^{-\tau/4}$, where the decay exponent τ is directly related to the superfluid density ns according to $\tau=4/(n_s\lambda^2_{dB})$. I will present local coherence measurements in a strongly interacting 2D gas of diatomic ^{6}Li molecules. A self-interference technique allows us to locally extract the algebraic decay exponent and to reconstruct the superfluid density. We determine the scaling of the decay exponent with phase space density to provide a benchmark for studies of 2D superfluids in the strongly interacting regime.

3:00 pm - 3:30 pm ***Coffee Break***

3:30 pm - 4:30 pm

Thomas Niederprüm
Herwig Ott
Research Center OPTIMAS, Technische Universität Kaiserslautern

Rydberg molecules: From spin-flips to butterflies

An ever increasing interest in the interaction of Rydberg atoms with surrounding ground state atoms of ultracold samples was triggered by the first experimental proof of Rydberg molecules. These peculiar molecules are bound by a previously unknown type of chemical bond that relies on the scattering between the Rydberg electron and a ground state perturber inside the Rydberg wave
function. Apart from the already observed ultra-long range Rydberg molecules that arise in the well- separated low-l states also the very exotic so-called trilobite and butterfly states are predicted to exist in rubidium. Whereas indications of the former have already been seen experimentally evidence for the latter was so far missing.
Summarizing our recent experiments I will report on ultra-long range Rydberg molecules and exotic butterfly Rydberg molecules. I will highlight the role of the hyperfine interaction in the perturber atom and how the molecular coupling can be used to change the hyperfine state upon excitation. Furthermore I will show that such molecular states can be a useful probe for many-body properties and how they can be used to study the superfluid to Mott insulator transition in optical lattices. Extending the topic to the exotic high-l molecules I will present the first experimental proof of the existence of butterfly Rydberg molecules and highlight their unique properties, such as a tunable bond length, the availability of multiple vibrational ground states and giant dipole moments of hundreds of Debye. Contrary to previous studies we are able to resolve the rotational structure of the Rydberg molecules and observe pendular states with an unprecedented degree of orientation in small electric fields. This allows us to precisely extract the bond length and to map out the radial nodes of Rydberg P-state wave function.

4:30 pm - 5:30 pm

Mathew T. Eiles
Chris H. Greene
Department of Physics and Astronomy, Purdue University

Polyatomic Rydberg molecules in a high density environment

As experiments involving ultra-long-range Rydberg molecules are performed at greater densities and using higher principle quantum numbers, molecules consisting of more than two molecules are routinely formed and observed. Due to the unique nature of the electronic binding between the Rydberg atom and nearby ground state atoms, the spectroscopic characterization of these molecules involves several surprising considerations of the density, molecular geometry, and the Rydberg state involved. Hybridized diatomic states are capable of efficiently describing many of these effects. The dependence of the system's properties on the molecular geometry are studied through comparisons of the adiabatic potential curves and electronic structures for both symmetric and randomly configured molecular geometries. Results will be presented for a variety of atomic species to highlight some important distinctions, and some preliminary investigations of non-adiabatic vibronic-electronic couplings will be briefly discussed.

5:30 pm - 6:30 pm

Helmut Strobel
University of Heidelberg , Kirchhoff institute for physics

Spin dynamics out of equilibrium: Fisher information of entangled non-Gaussian states and scaling of dynamics in quenched quantum gases

In quantum metrology, entangled states are employed to enhance the performance of interferometers. Non-Gaussian spin states are particularly attractive for this task as they allow surpassing the performance of Gaussian (squeezed) states. Exploiting this resource in mesoscopic ensembles requires scalable methods for creation, verification and detection. We report on a general method to extract the Fisher information from experimental probability distributions of collective observables without the need for full quantum state tomography. We apply this method to non-Gaussian spin states generated via unstable fixed point dynamics in binary Bose-Einstein condensates in a single spatial mode. Our method reveals quantum states that are not spin squeezed but nevertheless entangled and useful for quantum enhanced metrology.

The emergence of an unstable fixed point in the internal degree of freedom of a single spatial mode is connected to a miscible-to-immiscible quantum phase transition for many spatial modes. We study the dynamics following a quench into the vicinity of the corresponding critical point in a spatially one-dimensional situation and find scaling of the characteristic length and time scales with the distance to the critical point in accordance with theoretical Bogoliubov predictions. The observed universality of the short-time quantum dynamics after the quench opens up a new path to study universal properties building on phase coherence in closed many-body systems out of equilibrium.

Wednesday 29/6

9:00 am - 10:00 am

Rasmus S. Christensen
Department of Physics and Astronomy, Aarhus University,

The Bose Polaron: Theory & Experiments

The behavior of a mobile impurity particle interacting with a quantum-mechanical medium is of fundamental importance in physics. Due to the great flexibility of atomic gases, our understanding of the impurity problem has improved dramatically since it was realized experimentally in a particularly pure form using degenerate Fermi gases. However, there has not been such a realization of the impurity problem in a bosonic reservoir so far.
We present the first experimental realisation of the Bose polaron, a well-defined quasiparticle state for an impurity interacting with a Bose-Einstein condensate (BEC). Along with the experiment we present our theoretical modelling, where we see excellent agreement between the experiment, a variational ansatz including 3-body Efimov correlations and a weak coupling perturbation theory for the Bose polaron.

10:00 am - 10:30 am ***Coffee Break***

10:30 am - 11:30 am

Johannes M. Schurer
Zentrum für Optische Quantentechnologien, Universität Hamburg
The Hamburg Centre for Ultrafast Imaging, Universität Hamburg,

Impurity ion immersed in bosonic ultracold atoms

In my presentation, I will show our theoretical predictions for ultracold hybrid atom-ion systems. Such systems recently attracted more and more interest since they allow for studying cold to ultracold atom-ion collisions and atom-ion chemistry, including the formation of molecules, and even have applications in quantum information science and condensed matter research. Those possibilities arise from the attractive and long-range atom-ion interaction which induced a new length scale to the ultracold gas. In our studies, we investigate the ground state and the dynamical behaviour of such systems in 1D from the few-body side in order to be able to capture all quantum correlation effects. This becomes possible by using the multilayer multiconfiguration time-dependent Hartree method for bosons, a variational ab-initio numerical exact method to study quantum many-body dynamics. Starting from the atom-ion scattering process, I will elucidate the behaviour of the bosonic ensemble in the presence of an ion by clearly distinguishing between mean-field and correlation-induced processes. Such analysis clearly reveals the presence of the additional length scale from the atom-ion interaction. Moreover, since this interaction is attractive and possess bound states, we studied the properties, such as critical size, of molecules formed by a single ion and many atoms. This allows us in the future to investigate the dynamics of such a molecular complex in a condensate in order to identify its polaron like properties as, e.g., its effective mass.

11:30 am - 12:30 am

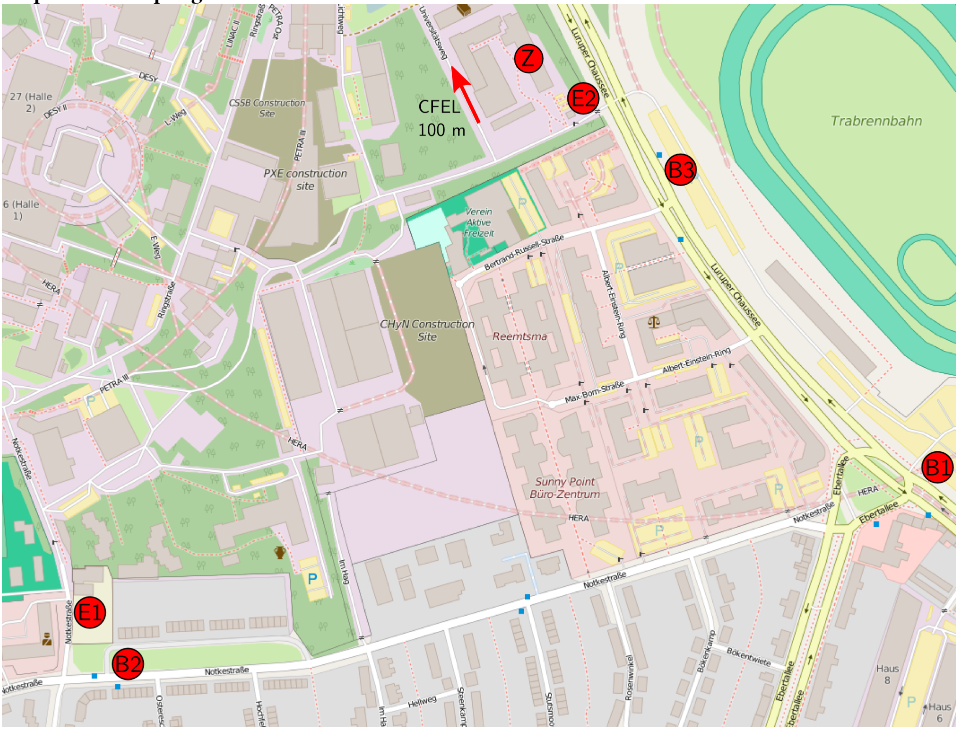
Gerhard Zürn
University of Heidelberg, Physikalisches Institut

Quantum magnetism with few cold atoms

Models describing quantum magnetism are of large interest as they can potentially shed light on exotic properties of matter. To study such models we have performed experiments with few point-like interacting fermions in a 1D environment. Strong repulsion leads to a Wigner-crystal-like state which can therefore be described by a spin-chain Hamiltonian. Using novel methods to probe the system we map out the spin correlations of the prepared antiferromagnetic state for up to four particles and directly observe quantum magnetism beyond two-particle correlations. In a different set of experiments we have introduced resonant dipolar exchange interactions by exciting atoms into Rydberg S-states which we then couple to close-by P-states using microwave fields. By recording the dynamics of the S- and P-state population we observe an interaction-induced reduction of contrast. We show that the system can be understood in terms of a dipolar XX-Heisenberg-like model, providing a benchmark for long-range interacting spins.

12:30 pm - 2:00 pm ***Lunch***

Directions



Z:Center for Optical Quantum Technologies (building 90, ZOQ), Luruper Chaussee 149, 22761 Hamburg
B1: Bus stop *Trabrennbahn Bahrenfeld*, lines 1,2,3
B2: Bus stop *Zum Hünengrab,* line 1
B3: Bus stop *Luruper Chaussee/DESY,* line 2
E1: Main entrance to the DESY campus
E2: Side entrance to the DESY campus
CFEL: Breakfast possibilities

Coming from the airport or Altona train station:
Take the train S1 to *Othmarschen* and then the bus 1 to *Zum Hünengrab* (B2). For more information on directions and the Hamburg public transport, please contact us or check www.hvv.de.

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Workshop homepage
http://photon.physnet.uni-hamburg.de/ilp/schmelcher/workshops/cui-young-reasearchers-workshop/

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