ZOQ Workshop on

"Bose-Einstein Condensates in Waveguides - Curvature meets Nonlinearity and Nonlocality"

May 14 - 16, 2014
Center for Optical Quantum Technologies
University of Hamburg

ZOQ Zentrum für Optische Quantentechnologien

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

Körber-STIFTUNG
Forum für Impulse

9:30 am - 9:55 am ***Registration***

9:55 am - 10:00 am ***Welcome and introduction to the workshop***

10:00 am - 11:00 am

S. M. Reimann
Mathematical Physics, LTH, Lund University

Quantum gases in a low-dimensional confinement – from few-body properties to the thermodynamic limit

The talk will review our recent work on bosonic or fermionic quantum gases in a low-dimensional confinement, setting emphasis on the transition from the few-body limit to the mean-field regime. For a weakly interacting Bose gas rotating in a harmonic trap, we relate the properties of small systems to the "thermodynamic" limit. The exact quantum states obtained for small particle numbers reveal significant structure not captured by the Gross-Pitaevskii approximation, providing deepened insight into the beyond-mean-field properties of bosonic systems. Intriguingly, the lowest-energy state and the low-lying excitations show exponential convergence into the exact solution with increasing system size [1]. In the rotational response of (dipolar) Bose-Einstein condensates confined in an annular potential, we identify certain phases associated with different vortex configurations, and analyse the stability of persistent currents [2]. The cold-atom analogue of a quasi one-dimensional quantum wire exhibits new scenario for the quantum transport: Attractive interactions may lead to a total current blockade, i.e., a complete suppression of current in the low-bias range. We demonstrate this effect for the example of ultra-cold quantum gases with dipolar interactions [3]. An outlook is furthermore given on the possible realization of one-dimensional quantum magnetism in cold gases, discussing our very recent work on the probing of few-body spin states [4].

[1] J. C. Cremon, G. M. Kavoulakis, B. R. Mottelson, and S. M. Reimann, Phys. Rev. A **87**, 053615 (2013); J.C. Cremon, A. Jackson, E. Karabulut, G.M. Kavoulakis, B.R. Mottelson, and S.M. Reimann, to be published (2014).

[2] E. Ö. Karabulut, F. Malet, G. M. Kavoulakis, and S. M. Reimann, Phys. Rev. A **87**, 033615 (2013); F. Malet, G. M. Kavoulakis, and S. M. Reimann, Phys. Rev. A **84**, 043626 (2011).

[3] L. H. Kristinsdóttir, O. Karlström, J. Bjerlin, J. C. Cremon, P. Schlagheck, A. Wacker, and S. M. Reimann, Phys. Rev. Lett. **110**, 085303 (2013).

[4] F. Deuretzbacher, D. Becker, J. Bjerlin, S. M. Reimann, and L. Santos, arXiv:1310.3705.

11:00 am - 11:30 am ***Coffee***

11:30 am - 12:30 pm

G. Pupillo
IPCMS and ISIS, Université de Strasbourg and CNRS, Strasbourg

Dynamics of blockaded Rydberg gases in low dimension

We discuss the quantum phases and dynamics of a gas of two-dimensional Bosons with finite-range soft-core interactions. For low densities, the system is shown to form a solid in which superfluidity is provided by delocalized zero-point defects. This provides the first example of continuous-space supersolidity consistent with the Andreev-Lifshitz-Chester scenario. We further discuss the connection between quantum mechanical supersolid behaviour and a novel mechanism for a glass formation.

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

2:30 pm - 3:30 pm

K. Sengstock
Institut für Laserphysik and Zentrum für Optische Quantentechnologien, Universität Hamburg

Quantum gases in lower dimensions: solitons and 2D lattice structures

The talk will discuss two very different regimes of quantum gas physics: Solitary structures in Bose-Einstein condensates in nearly one-dimensional trap geometries and the emulation of magnetic like interactions in a two-dimensional triangular lattice structure.

3:30 pm - 4:30 pm

D. Guéry-Odelin
Laboratoire de Collisions Agrégats Réactivé, CNRS, IRSAMC, Université de Toulouse (UPS)

Guided atom optics

In this talk, I will describe some recent results obtained in our group. First, I will explain the experimental techniques that allow for the realization of a transversally monomode guided atom laser. These systems are the equivalent for matter waves of monomode fibers in optics. Second, I will discuss the interest of such systems for matter wave scattering and I will in particular comment on their energy resolution depending on the role of atomic interactions. Third, I will present our realization of a distributed Bragg reflector for matter waves where the succession of layers is provided by here by a finite size optical lattice. I will explain how the interaction between the matter wave and the optical lattice with an inhomogeneous envelope can be described in terms of transmission through effective thin tunnel barriers (spatial gaps), and comment about the applications of such engineered tunnel barriers. I will also describe the scattering on an amplitude modulated optical lattice which provide a new method to engineer the momentum distribution of the matter wave and to realize, for instance, ultra selective velocity filters. In the last part of the talk, I will detail other experiments where the transverse of degrees of freedom in the guide play an important role. We will give an example with the interaction of an off-center defect that can trigger a transition to chaos in this system. Another example will be discussed on the very first experiments dealing with the realization of a guided matter wave beam splitter. These systems may provide an interesting testbed for the study of classical versus quantum chaos

4:30 pm - 5:00 pm ***Coffee***

5:00 pm ***Lab tours***

9:00 am - 10:00 am

A. Rauschenbeutel
Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien

Nanofiber-Based Trapping of Cold Neutral Atoms

In the first part of my talk, I will briefly present a selection of our experimental results on trapping and optically interfacing laser-cooled cesium atoms using optical nanofibers, i.e., cylindrical silica waveguides with a sub-wavelength diameter. The evanescent field surrounding such nanofibers allows one to trap the atoms at typical distances of 100 - 200 nm from the nanofiber surface while still maintaining ground state coherence times in the range of milliseconds. At the same time, the atoms are efficiently detected and interrogated with light which is sent through the nanofiber. The use of nanofibers for atom trapping allows one to straightforwardly realize interesting trapping geometries and trapping mechanisms which are not easily accessible with freely propagating laser beams and which I will present in the second part of my talk. These comprise one-dimensional optical lattices, straight, helical, and toroidal atomic waveguides, traps that enable stable Kepler orbits around the nanofiber, and traps that exploit the strong fictitious magnetic field gradients that are generated by the complex polarization pattern of the evanescent field. Finally, I will sketch our efforts towards loading nanofiber-based traps with a Bose-Einstein condensate of rubidium atoms and touch on the interesting dynamics that may occur in such a system.

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

10:30 am - 11:30 am

J. Stockhofe
Zentrum für Optische Quantentechnologien, Universität Hamburg

Ultracold atoms in curved quantum waveguides

I will present our recent results on the quantum dynamics of a single particle moving inside a curved waveguide of spatially varying cross-section. We perform a transverse-mode decomposition and examine the adiabatic structure of the problem and nonadiabatic couplings. The exact multimode matrix Hamiltonian is taken as the natural starting point for few-mode approximations. The quantum waveguide Hamiltonian is recast into a form that clearly illustrates how it generalizes the Born-Oppenheimer Hamiltonian encountered in molecular physics. In analogy to the latter, I will discuss the local gauge structure inherent to the quantum waveguide problem and suggest the usefulness of diabatic states, giving an explicit construction of the adiabatic-to-diabatic basis transformation.
In the second part of the talk, I will briefly introduce and discuss a Bose-Hubbard model on a lattice of helical geometry, exhibiting an effective nonlocal hopping term. Within the mean-field discrete nonlinear Schrödinger framework, I will show some first results concerning plane wave stability and the existence of localized breathers in this model.

11:30 am - 12:30 pm

A. V. Zampetaki
Zentrum für Optische Quantentechnologien, Universität Hamburg

Charged particles confined on 1D helical manifolds: Classical few body dynamics and equilibrium properties

The confinement of identical charged particles on a helical manifold induces, despite the repulsive character of the interactions, a tunable number of bound states depending on the helix parameters [1]. We present the two-body dynamics of such particles confined on an inhomogeneous helix. In this case [2] the center of mass motion couples to the relative one, leading, for certain initial conditions, to the dissociation of initially bound states. Due to the time reversal symmetry this equally corresponds to a binding of particles out of the scattering continuum. An analysis of the Poincare surfaces of section allows furthermore for identification of totally bound states within the inhomogeneity.
When more than two charged particles are confined on a helix, the number of stable equilibrium configurations increases exponentially, resembling the potential energy landscape of glassy systems. For a finite confining manifold, the ground state configuration changes varying the parameters of the helix, and bifurcations as well as energy level crossings can be observed, depending on the commensurability of the number of windings with the number of particles.

[1] P. Schmelcher, Europhys. Lett. **95**, 50005 (2011).
[2] A. V. Zampetaki, J. Stockhofe, S. Krönke and P. Schmelcher, Phys. Rev. E **88**, 043202 (2013).

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

2:30 pm - 3:30 pm

N. T. Zinner
Department of Physics and Astronomy, Aarhus University

Classical and quantum particles in helical geometries

We study particles confined to move in a one-dimensional geometry describe by a helix with short- and long-range interactions. For dipolar particles on a single constant curvature helix we see chain formation in the classical regime (large dipole moments) driven by the competition between repulsive side-by-side and attractive head-to-tail interactions. In the quantum regime we study bound states of two- and three-body systems with either dipolar or repulsive zero-range interactions on the helix and also in more general geometries with non-constant curvature.

3:30 pm - 4:30 pm

M. G. Boshier
Physics Division, Los Alamos National Laboratory

Experiments with BECs in a Painted Potential

The Painted Potential is a time-averaged optical dipole potential which is able to create arbitrary and dynamic two dimensional potentials for Bose Einstein condensates (BECs). We will discuss some recent experiments performed using this technique. First, we have realized the dc atom SQUID geometry of a BEC in a toroidal trap with two Josephson junctions. We observed Josephson effects, measured the critical current of the junctions, and found dynamic behavior that is in good agreement with the simple Josephson equations for a tunnel junction with the ideal sinusoidal current-phase relation expected for the parameters of the experiment. Second, we have observed quantized circulation in a toroidal BEC and used free expansion of a rotating toroidal BEC to create matter wave Bessel beams. Third, we have realized the basic circuit elements necessary to create complex matter wave circuits. We launch BECs at arbitrary velocity along straight waveguides, propagate them around curved waveguides and stadium-shaped waveguide traps, and split them coherently at y-junctions that can also act as switches. We will also discuss some of the challenges associated with propagating matter waves around bends with minimal excitation and reflection.

4:30 pm - 5:00 pm ***Coffee***

5:00 pm - 6:00 pm

D. J. Frantzeskakis
Department of Physics, University of Athens

Ring dark solitons: from optics to superfluids

Ring dark solitons, namely annular "troughs" with a phase jump across their density minimum, have been studied in optics, Bose-Einstein condensates and polariton superfluids. We study basic properies of these structures, as well as their dynamics and stability. Both stationary and non-stationary forms of ring solitons are studied by means of various models and analytical techniques. Connection of theoretical results with earlier and recent experiments is provided.

6:15 pm ***Departure for conference dinner***

9:00 am - 10:00 am

F. Jendrzejewski
Joint Quantum Institute, National Institute of Standards and Technology and University of Maryland

Experiments with superfluid atom circuits

Bose-Einstein condensates in ring geometries are essential ingredients to the ongoing effort of building increasingly complex superfluid circuits. Such circuits have previously allowed for the observation of persistent currents and hysteresis. Here we report on two new experiments that increase our abilities further. First, we report the observation of resistive flow through a weak link in a weakly interacting atomic Bose-Einstein condensate. We use two weak links to separate our ring-shaped superfluid circuit into two distinct regions, a source and a drain. At a critical value of the weak link velocity, we observe a transition from superfluid flow to superfluid plus resistive flow. Second, we demonstrate a new technique to directly observe the current-phase relationship through such weak links. By interfering our ring with a phase reference (formed as a disk), we show that we can measure the phase of the BEC around the ring and the average current.

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

10:30 am - 11:30 am

A. Minguzzi
Université Grenoble-Alpes and CNRS, Laboratoire de Physique et Modélisation des Milieux Condensés, Grenoble

Optimal persistent currents for interacting bosons stirred on a ring

I will present our results on persistent currents for interacting bosons on a tight (quasi-one-dimensional) ring trap, subjected to an artificial gauge field induced by a rotating, localized barrier potential. By employing a combination of several analytical techniques (a soliton solution of the mean-field Gross-Pitaevskii equation, the low-energy Luttinger Liquid method, and the Tonks-Girardeau exact solution for impenetrable bosons), as well as the numerical DMRG method, we find that the persistent current response is maximal at intermediate interactions. This maximum is due to the competing effects of classical screening due to interactions in the mean-field regime and quantum fluctuations in the strong-interacting regime. In particular, we find that the effective barrier seen by the bosons strongly depends on the interaction regime, and interactions can turn a relatively strong barrier onto a weak one. Finally, I will present results for the time-of-flight images, making a direct link with possible experiments with ultracold atomic gases on mesoscopic rings.

11:30 am - 12:30 pm

P. G. Kevrekidis
Department of Mathematics and Statistics, University of Massachusetts

Dynamics of Vortices in BECs: some recent developments

In this talk, we'll summarize some recent developments in the theme of vortices in Bose-Einstein condensates. Motivated by experiments in the lab of D. Hall on vortex dipoles, but also co-rotating sets of 2-, 3-, 4- or more vortices, we discuss a particle model involving the precession and interaction of the vortices that enables a systematic analysis of the relevant stationary or co-rotating states of a few vortices. The stability of such states presents various surprises including symmetry breaking bifurcations and the formation of asymmetric states, features that appear to also be supported in the experiments. In addition, some further features are discussed including a systematic analysis of the stability of an N-vortex ring and a state with N+1 vortices (N forming a ring and one at the center). These configurations are especially relevant for a small number of vortices (N). The opposite limit of large N will also be touched upon (time permitting) and the distribution in that limit will by obtained by means of coarse-graining techniques. Lastly, yet another intriguing mathematical approach will be developed involving generating functions that will enable in a number of cases to connect the vortex locations (in stationary or co-rotating states) to the roots of classical polynomials such as the Hermite polynomials.

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

2:30 pm - 3:30 pm

A. Szameit
Institute of Applied Physics, Friedrich-Schiller-Universität Jena, Abbe Center of Photonics

Photonic Graphene: Ultrastrong magnetic fields and Floquet topological insulators

“Photonic graphene” – the optical version of the wonder material graphene, which consists of evanescently coupled waveguide in honeycomb geometry – offers a unique platform for the experimental analysis of graphene physics. On the basis of this new material, we were able to demonstrate various phenomena, such as optical tachyons, ultra-strong pseudo-magnetic fields and photonic Floquet topological insulators – a “superconductor for light”.

3:30 pm - 4:30 pm

B. A. Malomed
Department of Physical Electronics, School of Electrical Engineering, Faculty of Engineering, Tel Aviv University

Bright solitons in self-defocusing nonlinear waveguides

Recently, a new class of models was proposed for supporting bright fundamental and topological solitons, as well as their bound states, in waveguides with purely self-defocusing nonlinearity, whose local strength grows from the center to periphery at any rate faster than r^D, where r is the radial coordinate, and D the spatial dimension. Such nonlinearity structures can be created in optics and BEC. Curved nonlinear waveguides of this type support dynamical regimes in the form of Josephson oscillations. In addition to systematic numerical results, many results for these models are obtained in an analytical form, with very good accuracy, by means of the Thomas-Fermi and variational approximations.

4:30 pm - 5:00 pm ***Coffee***

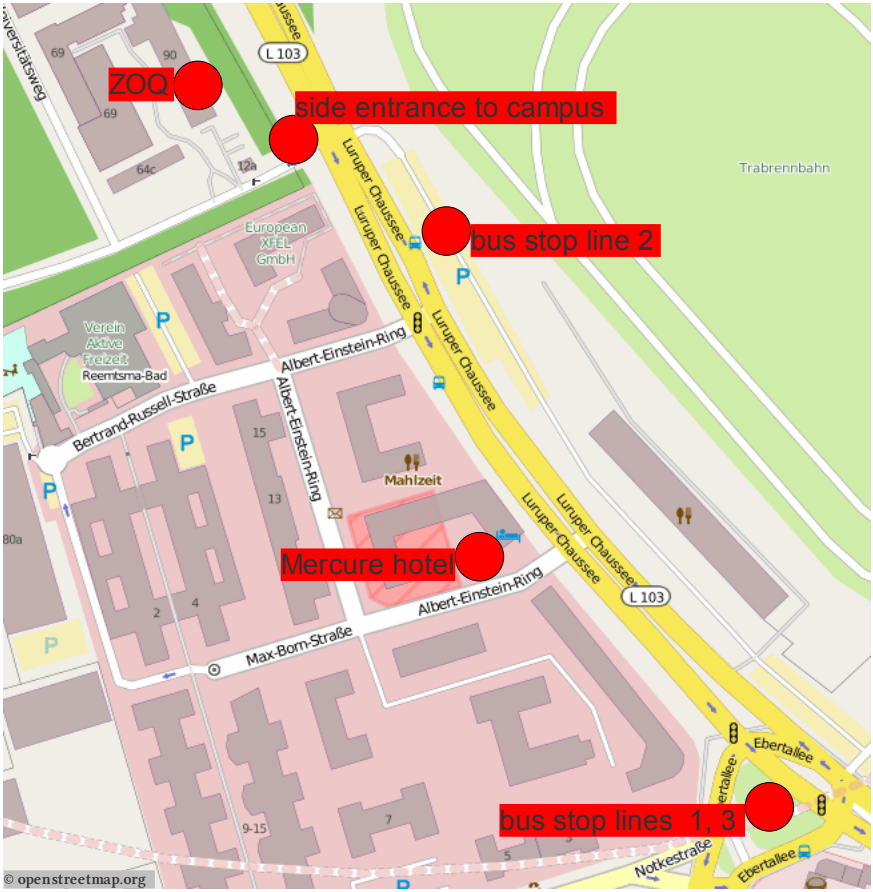
Directions

Center for Optical Quantum Technologies (ZOQ)
Luruper Chaussee 149, 22761 Hamburg

building 90 on the DESY/university campus, directly on your right when entering the campus through the side entrance facing Luruper Chaussee (see map below)

coming from the airport:
– public transport: Take the train S1 to *Othmarschen* (45 minutes), then bus 1 to *Trabrennbahn Bahrenfeld* (5 minutes). From here it is a short walk down Luruper Chaussee to the hotel and the side entrance of the campus.
– taxi: Going by taxi will take around 35 minutes.

coming from Hamburg Altona train station:
– Take bus 2 to *Luruper Chaussee/DESY* (15 minutes). The hotel and side entrance of the campus are on the opposite side of the street.



For more information on directions and the Hamburg public transport, please contact us or check www.hvv.de.

Accommodation

Mercure Hotel Hamburg am Volkspark
Albert-Einstein-Ring 2, 22761 Hamburg

H1659@accor.com, phone: (+49)40899520

DESY guest house
Notkestraße 85, 22607 Hamburg

hostel@desy.de, phone: (+49)4089982740
buildings 32/33 on the DESY campus, close to the main entrance facing Notkestraße
bus stop: *Zum Hünengrab* (bus 1)

Conference dinner

Hotel Hafen Hamburg, Restaurant Port
Seewartenstraße 9, 20459 Hamburg

Contact the organizers

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This workshop is organized by the Center for Optical Quantum Technologies (ZOQ, University of Hamburg) and financed by the Körber foundation.

Schedule

Wednesday 14/5

9:55 am *Welcome and introduction to the workshop*

10:00 am S. M. Reimann
Quantum gases in a low-dimensional confinement – from few-body properties to the thermodynamic limit

11:30 am G. Pupillo
Dynamics of blockaded Rydberg gases in low dimensions

2:30 pm K. Sengstock
Quantum gases in lower dimensions: solitons and 2D lattice structures

3:30 pm D. Guéry-Odelin
Guided atom optics

5:00 pm *Lab tours*

Thursday 15/5

9:00 am A. Rauschenbeutel
Nanofiber-Based Trapping of Cold Neutral Atoms

10:30 am J. Stockhofe
Ultracold atoms in curved quantum waveguides

11:30 am A. V. Zampetaki
Charged particles confined on 1D helical manifolds: Classical few body dynamics and equilibrium properties

2:30 pm N. T. Zinner
Classical and quantum particles in helical geometries

3:30 pm M. G. Boshier
Experiments with BECs in a Painted Potential

5:00 pm D. J. Frantzeskakis
Ring dark solitons: From optics to superfluids

6:15 pm *Departure for conference dinner*

Schedule

Friday 16/5

9:00 am	F. Jendrzejewski *Experiments with superfluid atom circuits*
10:30 am	A. Minguzzi *Optimal persistent currents for interacting bosons stirred on a ring*
11:30 am	P. G. Kevrekidis *Dynamics of Vortices in Bose-Einstein Condensates: some recent developments*
2:30 pm	*A. Szameit* *Photonic Graphene: Ultrastrong magnetic fields and Floquet topological insulators*
3:30 pm	B. A. Malomed *Bright solitons in self-defocusing nonlinear waveguides*