Helmholtz Alliance
Extremes of Density and Temperature: Cosmic Matter in the Laboratory

ExtreMe Matter Institute EMMI

Finite-Temperature Non-Equilibrium Superfluid Systems

FINESS

Programme

18 - 21 September 2011

GSI HELMHOLTZ ASSOCIATION Center for Quantum Dynamics EMMI

Programme

Saturday, 17 September 2011

17:00	*Registration at the International Science Forum*	
17:30	*Welcome reception*	

Sunday, 18 September 2011

09:00	*Opening*	
09:10	W. Zurek (Los Alamos)	Winding up superfluid in a torus via Bose-Einstein condensation
10:00	M. Fleischhauer (Kaiserslautern)	Quench dynamics of strongly interacting 1D Bose gases
10:40	*Tea/Coffee*	
11:20	J. Ruostekoski (Southampton)	Continuous quantum measurement process in stochastic phase-methods of quantum dynamics: Classicality from quantum measurement
11:40	A. M. Rey (Boulder)	Simulating the Kondo Lattice Model with ultra cold atoms: From Kondo Insulators to Heavy Fermions
12:20	J. Schmiedmayer (Wien)	Relaxation Dynamics and Prethermalization in a Quantum System
13:00	*Lunch*	
14:30	A. Bulgac (Seattle)	Real-Time Dynamics of Superfluid Unitary Fermi Gases
15:10	T. Schaefer (Raleigh)	Conformal second order fluid dynamics for the dilute Fermi gas at unitarity
15:50	*Tea/Coffee*	
16:30	P. Deuar (Warszawa)	Bogoliubov quantum dynamics at $T > 0$ without a condensate
16:50	S. Gardiner (Durham)	Number conservation and self-consistency in BEC dynamics

Monday, 19 September 2011

09:00	C. Ewerz (EMMI)	The ExtreMe Matter Institute
09:10	G. Baym (Illinois)	The superfluid mass density
10:00	M. Davis (Queensland)	Non-equilibrium flows and superfluidity in finite temperature dilute gas Bose-Einstein condensates
10:40	*Tea/Coffee*	
11:20	A. Bradley (Otago)	Two-dimensional quantum turbulence: Signatures of an inverse energy cascade
11:40	G. Krstulovic (Nice)	Dispersive Bottleneck Delaying Thermalization of Turbulent Bose-Einstein Condensates
12:00	B. Nowak (Heidelberg)	Scaling laws of superfluid turbulence
12:20	N. Berloff (Cambridge)	Spontaneous pattern formation in exciton-polariton condensates.
13:00	*Lunch*	
14:30	C. Gardiner (Otago)	
14:45	E. Zaremba (Queen's University)	A Critical Look at ZNG Theory: A Tribute to Allan Griffin
15:50	*Tea/Coffee*	
16:30	L. Gilz (Kaiserslautern)	Quantum Kinetic Theory of Superfluid Internal Convection in the Collisionless Regime
16:50	U. Bissbort (Frankfurt/Main)	Detecting the Amplitude Mode of Strongly Interacting Lattice Bosons by Bragg Scattering
17:10	R. Scott (Trento)	The dynamics of dark solitons in a trapped superfluid Fermi gas
18:00	*Snacks and Posters*	

Tuesday, 20 September 2011

09:00	S. Demokritov (Münster)	BEC of magnons at room temperature and spatio-temporal properties of magnon condensate
09:50	D. Poletti (Genève)	Dynamics of driven ultra-cold bosons
10:30	*Tea/Coffee*	

11:20	A. Pelster (Bielefeld)	Nonequilibrium Dynamics of Bosons in Optical Lattices from Schwinger-Keldysh Calculation
11:40	R. Schuetzhold (Duisburg)	Quantum correlations in the Bose-Hubbard model
12:20	A. Daley (Pittsburgh)	Non-equilibrium dissipative dynamics of cold atoms in optical lattices
13:00	*Lunch*	
14:20	L. Santos (Hannover)	Ultra-cold polar gases in optical lattices
15:00	C. Henkel (Potsdam)	Cross-over to quasi-condensation - a non-gaussian challenge to mean-field theories
15:30	A. Filinov (Kiel)	Thermodynamics, quasiparticle and collective excitations of 2D dipolar gases
16:10	*Discussion Time*	
16:40	*Tea/Coffee/Sightseeing*	
19:00	*Conference Dinner Buffet*	

Wednesday, 21 September 2011

09:00	C. Gardiner (Otago)	C-Field Methods for Molecules and Atoms, with applications to Bragg Scattering
09:50	L. D'Alessio (Boston)	Universal energy fluctuations in thermally isolated driven systems
10:30	*Tea/Coffee*	
11:20	S. Mandt (Köln)	Ultracold fermionic atoms in optical lattices out of equilibrium: Hydrodynamics and beyond
11:40	M. Snoek (Amsterdam)	Rigorous mean-field dynamics of lattice bosons: Quenches from the Mott insulator
12:00	B. Fine (Heidelberg)	Emergence of non-thermal statistics in isolated many-particle quantum systems after multiple perturbations
12:30	*Closing and Lunch*	

Practical Information

The local participants will wear a green sticker on their name tag. They will answer any practical questions you may have.

The conference hall is in the Internationales Wissenschaftsforum Heidelberg (IWH), situated in the old town of Heidelberg at the foot of the castle hill. The address is the following:

Internationales Wissenschaftsforum Heidelberg
Hauptstrasse 242
D-69117 Heidelberg

The public transport station that is closest is "S-Bahnhof Altstadt". It can be reached with the S-Bahn (lines S1, S2 and S5/51) or the bus (lines 33 and 35). Then it's a 3 minutes walk in direction of the city centre to reach the IWH.

The nearest parking opportunities are "Parkhaus 13" at the "Karlsplatz" (16,30 € per day) and "Parkhaus 12" at the "Kornmarkt" (10,- € per day). It is a 3-minute walk from there to the IWH.

For more information, please look up the local public transportation and German railway Internet pages:

http://fahrplanauskunft.vrn.de/vrn/XSLT_TRIP_REQUEST2?language=en
http://www.bahn.com

Transportation to and from Frankfurt airport can be found at:

http://www.transcontinental-group.com/en/frankfurt-airport-shuttles/
https://www.tls-heidelberg.de/en/

There is also a map with many useful annotations at:

http://g.co/maps/yytgd

The web-page of the conference is:

http://www.thphys.uni-heidelberg.de/~nowak/FINESS2011/index.html

It contains additional information about the conference. We will try to assemble the material of the conference and make it available on the web-page as well.

Talks

Winding up superfluid in a torus via Bose Einstein condensation

Wojciech Zurek

LANL, Los Alamos, NM 87545, United States

We simulate Bose-Einstein condensation (BEC) in a ring employing stochastic Gross- Pitaevskii equation and show that cooling through the critical temperature can generate spontaneous quantized circulation around the ring of the newborn condensate, see [1].

[1] Arnab Das, Jacopo Sabbatini, Wojciech H. Zurek,
http://arxiv.org/abs/1102.5474

Quench dynamics of strongly interacting 1D bose gases

Michael Fleischhauer

Universität Kaiserslautern, Dept. of Physics, E. Schrödinger Str., 67663 Kaiserslautern, Germany

Continuous quantum measurement process in stochastic phase-methods of quantum dynamics: Classicality from quantum measurement

Janne Ruostekoski

University of Southampton, School of Mathematics, Southampton SO17 1BJ, United Kingdom

We derive a stochastic phase-space representation for a continuous quantum measurement process of a Bose-condensed atomic gas that approximately reproduces possible outcomes of measurement-induced back-action on an entire field operator. As a specific system we study a Bose-Einstein condensate in a double-well trap when the atom number in each potential well is monitored continuously via light scattering. We show how classical descrription of dynamics emerges from the full quantum dynamics as a result of the measurement-induced back-action.

Simulating the Kondo Lattice Model with ultra cold atoms: From Kondo Insulators to Heavy Fermions

Ana Maria Rey

JILA, University of Colorado, University of Colorado/JILA Tower UCB 440, Boulder, CO 80309-0440, United States

The Kondo Lattice Model (KLM) is one of the canonical models used to study strongly correlated electron systems. In this talk I will describe our ideas on how to implement the KLM with ultra cold atoms. Two different implementations will be discussed. One specific for alkaline-earth atoms which uses two long-lived electronic levels and the other, more suitable for alkali atoms, which uses the control of multi-band superlattices. Using a mean field formulation I will discuss a possible fermionic KLM phase diagram which includes magnetic, heavy fermion and Kondo insulator phases as well the generalization of this phase diagram to bosonic systems. Keeping in mind the harmonic trapping potential present in cold atom experiments, I will discuss ways of probing and detecting the various phases via non-equilibrium dynamics.

Relaxation Dynamics and Pre-thermalization in a Quantum System

Jörg Schmiedmayer

TU Wien, Vienna Center for Quantum Science and Technology, Stadionallee 2, Wien, Austria

Understanding non-equilibrium dynamics of many-body quantum systems is crucial for understanding many fundamental and applied physics problems ranging from decoherence and equilibration to the development of future quantum technologies such as quantum computers which are inherently non-equilibrium quantum systems. One of the biggest challenges is that there is no general approach to characterize the resulting quantum states, such as the analogue of order parameters in equilibrium systems. As a new tool, the full distribution functions of a quantum observable enables us to study the relaxation dynamics in one-dimensional quantum systems and to characterize the underlying many body states.

Real-Time Dynamics of Superfluid Unitary Fermi Gases

Aurel Bulgac

University of Washington, Department of Physics, PO Box 351560, Seattle, WA 98195-1560, United States

I will discuss the extension of DFT to superfluid fermionic systems and real-time processes, its implementation and a range of phenomena: generation and dynamics of quantized vortices, vortex rings, crossing and reconnection of vortices and incipient phases of quantum turbulence, generation dark solitons and shock waves in collision of cold gases and possible further extensions of the theory to the stochastic regime.

Conformal second order fluid dynamics for the dilute Fermi gas at unitarity

Thomas Schaefer

North Carolina State University, Department of Physics, Box 8202, Raleigh, NC 27695, United States

We discuss hydrodynamics of the dilute Fermi gas at unitarity (mostly in the normal phase). We focus on i) efforts to extract transport coefficients from experiment, ii) constraints on the equations of fluid dynamics from conformal invariance, iii) studies of the spectral function of the shear tensor in kinetic theory.

Bogoliubov quantum dynamics at $T > 0$ without a condensate

Piotr Deuar

Polish Academy of Sciences, Institute of Physics, Al. Lotnikow 32/46, 02-668 Warszawa, Poland

Spontaneous scattering into empty modes occurs during supersonic processes both in BECs, quasicondensates and thermal clouds. The BEC case can be treated with Bogoliubov theory, and even huge systems of that sort have been simulated using stochastic time-adaptive Bogoliubov "STAB" methods. I will show how this same approach can be applied even when the condensate fraction is negligible, by combining it with a classical field representation of the initial clouds. As an example, a simulation of the collision of He* quasi-condensates from the Palaiseau experiment will be shown.

Number conservation and self-consistency in BEC dynamics

Simon Gardiner

University of Durham, Department of Physics, South Road, Durham, DH1 3LE, United Kingdom

Central to our understanding of weakly interacting atomic Bose-Einstein condensates (BECs) is the concept of each atom being in approximately the same motional state; this is manifest through the description of zero-temperature BEC dynamics with the Gross- Pitaevskii equation (GPE). Even at T=0 in a system of finite size there is always a finite noncondensate fraction, and one expects strong dynamics within the BEC to cause significant particle transfer from the condensate to the noncondensate fraction under quite general circumstances. Rapid such dynamical depletion has commonly been supposed to presage destruction of the BEC as a coherent entity, however previous studies have been hampered by the absence of a self-consistent treatment. One possibility is to use a number-conserving treatment (where one works within the canonical ensemble), to second order, which is the minimum order necessary to provide consistent coupled condensate and noncondensate number dynamics for a finite total number of particles. I will address the methodology and rationale for such a canonical (as opposed to grand-canonical) treatment, and describe the results considering a dynamical test- system based on the delta-kicked rotor.

The superfluid mass density

Gordon Baym

University of Illinois, 1110 W. Green St, Urbana, IL, United States

Non-equilibrium flows and superfluidity in finite temperature dilute gas Bose-Einstein condensates

Matthew Davis

University of Queensland, School of Mathematics and Physics, St Lucia Qld 4072, Australia

Superfluids exhibit a number of intriguing properties, such as frictionless flow and quantised rotation in the form of vortices. Initially discovered in superfluid helium, both these phenomena have now been observed in dilute gas Bose-Einstein condensates. However, the isolation of ultra-cold gas systems from the environment combined with their inhomogeneous density profiles make the observation of other phenomena, such as the thermo-mechanical effect, more challenging in the lab. The fundamental mechanism behind the superfluid thermo-mechanical effect is generating a sustained difference in the thermodynamic properties of the superfluid at spatially separated locations. This can be achieved in a single component dilute Bose gas by introducing a channel between two separated traps in which the initial state has different thermodynamic parameters. This will result in a non-equilibrium flow that can potentially achieve a steady state for sufficiently large reservoirs. Here we perform dynamical simulations of a finite temperature Bose-Einstein condensate coupled to spatially separated heat and particle reservoirs to investigate such non-equilibrium superfluid phenomena. We analyse the resulting steady-state non-equilibrium flows in the Bose gas, and observe a transition to sustained superfluid turbulence.

Two-dimensional quantum turbulence: signatures of an inverse energy cascade

Ashton Bradley

Jack Dodd Centre, Otago University, Dunedin, New Zealand

We report numerical simulations and analysis, and experimental observations of turbulent vortex dynamics during the formation of a persistent current in a Bose-Einstein condensate (BEC). In the experiment, a BEC is pierced with a blue-detuned laser beam that is moving relative to the BEC, creating a superfluid turbulent state containing many vortices. The system decays to a persistent current about the blue-detuned laser beam that can last for up to 50 seconds; winding numbers up to 8 have been observed. We perform first-principles stochastic c-field simulations of the experiment without any fitting parameters. Our approach gives a quantitative determination of the number of pinned quanta observed in the experiment. Spectral analysis of our numerical simulations reveals a double-cascade kinetic energy spectrum characteristic of two- dimensional turbulence, with forcing at a length-scale set by the stirring procedure. We also observe clustering of like-sign vortices into long-lived coherent structures. We interpret our results as evidence for an inverse energy cascade in two-dimensional quantum turbulence.

Dispersive Bottleneck Delaying Thermalization of Turbulent Bose-Einstein Condensates

Giorgio Krstulovic

Laboratoire Cassiopée. Observatoire de la Côte d'Azur, Département CASSIOPEE - CNRS/UMR 6202 Observatoire de la Côte d'Azur, 06304 NICE Cedex 4, France

A new mechanism of thermalization involving a direct energy cascade is obtained in the truncated Gross-Pitaevskii dynamics. A long transient with partial thermalization at small scales is observed before the system reaches equilibrium. Vortices are found to disappear as a prelude to final thermalization. A bottleneck that produces spontaneous effective self- truncation and delays thermalization is characterized when large dispersive effects are present at the truncation wave number. Order of magnitude estimates indicate that self- truncation takes place in turbulent Bose-Einstein condensates. This effect should also be present in classical hydrodynamics and models of turbulence.

Scaling laws of superfluid turbulence

Boris Nowak

Universität Heidelberg, Institut für Theoretische Physik, Philosophenweg 16,
69120 Heidelberg, Germany

Far-from-equilibrium dynamics of a dilute degenerate Bose gas is analysed in two and three spatial dimensions. The focus is set on the discussion of quasi- stationary infrared power-law momentum distributions. Universal scaling exponents are related to the statistics of point vortices, e.g. vortex pairing, and discussed in the context of a nonperturbative quantum-field theoretic approach.

Spontaneous Pattern formation in exciton-polariton condensates.

Natalia Berloff

University of Cambridge, Wilberforce Road, Cambridge, CB30WA, United Kingdom

Microcavity exciton-polaritons are quasi-particles that result from the hybridisation of excitons (bound electron hole pairs) and light confined inside semiconductor microcavities. At low enough densities, they behave as bosons according to Bose-Einstein statistics, and so one may investigate Bose-Einstein condensation (BEC) of these particles. Because of the imperfect confinement of the photon component, exciton-polaritons have a finite lifetime, and have to be continuously re-populated. Therefore, exciton-polariton condensates lie somewhere between equilibrium Bose-Einstein condensates and lasers. I review in particular the evidence for condensation, the coherence properties studied experimentally, and the wide variety of spatial structures either observed or predicted to exist in exciton-polariton condensates, including quantised vortices and other coherent structures.

A Critical Look at ZNG Theory: A Tribute to Allan Griffin

Eugene Zaremba

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Quantum Kinetic Theory of Superfluid Internal Convection in the Collisionless Regime

Lukas Gilz

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Superfluids can transport heat independently of mass via simultaneous opposite flows of their spatially interpenetrating superfluid and thermal components. This phenomenon of 'internal convection' is known from experiments on superfluid Helium and is usually described within Landau's phenomenological two fluid hydrodynamics. Applying quantum kinetic theory to a dilute Bose gas held between two thermal reservoirs at different temperatures, we identify the same phenomena in the collisionless Bogoliubov regime of a Bose-condensed gas. The emergence of internal convection as an environmentally induced coherent effect requires a long quasi-particle lifetime within the thermal reservoirs, and its analysis needs explicit treatment of non-resonant master equation terms. Our results for the energy and particle currents suggest that internal convection should be directly observable in currently feasible experiments on trapped ultracold vapors.

Detecting the Amplitude Mode of Strongly Interacting Lattice Bosons by Bragg Scattering

Ulf Bissbort

Universität Frankfurt, Institut für Theoretische Physik, Max-von-Laue Str. 1, 60438 Frankfurt, Germany

We report the first detection of the Higgs-type amplitude mode using Bragg spectroscopy in a strongly interacting condensate of ultracold atoms in an optical lattice. By the comparison of our experimental data with a spatially resolved, time-dependent dynamic Gutzwiller calculation, we obtain good quantitative agreement. This allows for a clear identification of the amplitude mode, showing that it can be detected with full momentum resolution by going beyond the linear response regime. A systematic shift of the sound and amplitude modes resonance frequencies due to the finite Bragg beam intensity is observed. An extended quantized quasi-particle theory, which is the systematic counterpart of Bogoliubov theory for strongly interacting bosons in a lattice and includes the amplitude as well as higher modes, is presented. This allows for an understanding of the dynamical processes during the spectroscopic measurement.

The dynamics of dark solitons in a trapped superfluid Fermi gas

Robin Scott

INO-CNR BEC Center, Universita di Trento, Trento, Via Sommarive 14, I-38123 Povo, Italy

I study soliton dynamics in a trapped superfluid Fermi gas across the Bose-Einstein condensate to Bardeen-Cooper-Schrieffer (BEC-BCS) crossover by solving the time-dependent Bogoliubov-de Gennes equations. I find that solitons can perform stable oscillations across the crossover, given that their speed does not approach the Landau critical speed for pair-breaking. Furthermore, the oscillation period dramatically increases as the soliton becomes shallower on the BCS side of the resonance. I propose an experimental protocol to test these predictions. Finally, I show that soliton collisions are only elastic in the BEC limit, and may destroy the solitons in the BCS regime.

BEC of magnons at room temperature and spatio-temporal properties of magnon condensate

Sergej Demokritov

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Magnons are the quanta of magnetic excitations in a magnetically ordered media. In thermal equilibrium, they can be considered as a gas of quasiparticles obeying the Bose-Einstein statistics with zero chemical potential and a temperature dependent density. We will discuss the room-temperature kinetics and thermodynamics of the magnons gas in yttrium iron garnet films driven by a microwave pumping and investigated by means of the Brillouin light scattering spectroscopy. We show that the thermalization of the driven gas results in a quasi-equilibrium state described the Bose-Einstein statistics with a non-zero chemical potential, the latter being dependent on the pumping power. For high enough pumping powers Bose-Einstein condensation (BEC) of magnons can be experimentally achieved at room temperature. Spatio-temporal kinetics of the BEC-condensate will be discussed in detail. Among others interference of two condensates, vortices, and propagating waves of the condensate density will be addressed.

Dynamics of driven ultra-cold bosons

Dario Poletti

University of Geneva, Department of Theoretical Physics, 24, quai E. Ansermet, 1211 Genève 4, Switzerland

Gases of atoms cooled to Nanokelvin temperatures and loaded into optical lattices are a powerful tool to study a broad range of quantum phenomena. In particular the remarkable degree of control of the system parameters achieved in these kind of experiments allows us to investigate the dynamics of strongly correlated quantum many body physics. Moreover, in recent years, there has been important advances in the use of fast periodic perturbations in order to engineer unconventional effective Hamiltonians. We study a slow variation of the system parameters in order to tackle issues relating to the adiabatic following of the ground-state of a Hamiltonian and heating. We discuss both the slow change of a system parameter and the slow variation of the effective parameters of a system due to a fast driving.

Nonequilibrium Dynamics of Bosons in Optical Lattices from Schwinger-Keldysh Calculation

Axel Pelster

Universität Bielefeld, Fakultät für Physik, Universitätsstraße 25, 33501 Bielefeld, Germany

Applying the Schwinger-Keldysh formalism to the Bose-Hubbard Model we derive a real-time Ginzburg-Landau theory at zero temperature [1,2]. Surprisingly, it reduces to the seminal Gross-Pitaevskii theory deep in the superfluid phase although it has been originally determined within a hopping expansion and should, therefore, be only applicable in the immediate vicinity of the quantum phase boundary. Furthermore, in an equilibrium application, we show that the particle-hole excitation spectra in the Mott phase merge continuously into corresponding excitation spectra of the amplitude and the phase of the order parameter in the superfluid phase, once the quantum phase boundary is crossed. Finally, we discuss as a non-equilibrium application that the damping observed within the collapse and revival experiments of Ref. [3] turns out to be due to the overall harmonic potential which confines the atoms inside a finite volume.

[1] B. Bradlyn, F.E.A. dos Santos, and A. Pelster, Phys. Rev. A 79, 013615 (2009)
[2] T.D. Grass, F.E.A. dos Santos, and A. Pelster, Phys. Rev, A 84, 013613 (2011)
[3] M. Greiner, O. Mandel, T. W. Hänsch, and I. Bloch, Nature, 419, 51 (2002)

Quantum correlations in the Bose-Hubbard model

Ralf Schuetzhold

Universität Duisburg-Essen, Fakultät für Physik, Lotharstr. 1, 47048 Duisburg, Germany

Non-equilibrium dissipative dynamics of cold atoms in optical lattices

Andrew Daley

University of Pittsburgh, Department of Physics and Astronomy, 100 Allen Hall, 3941 O'Hara St., Pittsburgh, PA 15260, United States

One of the key challenges for current experiments with cold atoms in optical lattices is the production of many-body states with low temperature and entropy. In this context, it is important to be able to characterise and control the competing heating processes. We study the dissipative many-body dynamics of cold atoms in optical lattices induced by these heating processes, including spontaneous emissions and noise on the lattice potential. A key aspect of these intrinsically non-equilibrium dynamics is the interplay between the form of the dissipation and the many-body physics of the state present in the system, with different many-body states exhibiting different sensitivity to decoherence due to different mechanisms. We describe these processes by deriving microscopic master equations for the many-body system, and in some cases these are made tractable numerically by a combination of time-dependent density matrix renormalization group methods and quantum trajectory techniques. We discuss the numerical methods, and present results for bosonic systems related to (i) How different heating mechanisms will differently affect the characteristic correlation functions of different many-body states, and (ii) to what extent states in different parameter regimes are able to thermalise in the presence of dissipation.

Ultra-cold polar gases in optical lattices

Luis Santos

Leibniz Universität Hannover, Institute für Theoretische Physik, Appelstr. 2, 30167, Hannover, Germany

Ultra-cold polar gases in optical lattices present a rich novel physics characterized by significant inter-site interactions, contrary to the non-polar case. In this talk I will review some of our recent results in this field, including stability and non-linear physics of a Bose-Einstein condensate in an optical lattices, inter-layer superfluidity and state swapping for polar Fermi molecules in bilayer geometries, and quantum phases of strongly-correlated polar molecules in 1D lattices.

Thermodynamics, quasiparticle and collective excitations of 2D dipolar gases

Alexey Filinov

Universität Kiel, Institut für Theoretische Physik und Astrophysik, Leibnizstraße 15, 24098 Kiel, Germany

Dipolar bosonic systems are of increasing interest for recent experiments studying the onset of superfluidity in nonideal Bose systems and its connection with correlation and quantum degeneracy effects. Examples include dipolar atoms and molecules, indirect excitons in coupled quantum wells . For quantitative analysis we perform the path integral Monte Carlo simulations and study the superfluid-normal fluid phase transition of dipolar bosons in two dimensions. We investigate the equation of state, the temperature dependence of the superfluid density, the momentum distribution and the isothermal compressibility. The results for the excitation spectrum of the longitudinal density oscillations are evaluated and compared in several approximations: classical QLCA, the density response Lindhard function, the sum-rules formalism, the analytical continuation of the imaginary time density-density correlation function. The dispersion relations allow to analyze formation of the roton minima in the spectrum and its evolution with temperature. The coupling of the quasiparticle and density excitations in the superfluid phase is discussed.

C-Fields for Atoms, Molecules and Feshbach Resonances

Catarina E. Sahlberg and Crispin W. Gardiner

University of Otago, Jack Dodd Centre, Physics Dept, 730 Cumberland Street, Dunedin, New Zealand

We present a model of a coupled bosonic atom-molecule system, using the recently developed c-field methods as the basis in our formalism. We derive expressions for the s-wave scattering length and binding energy within this formalism, and by relating these to the corresponding experimental parameters, we can accurately determine the phenomenological parameters in our system. Using this model, we formulate the basic theoretical methods for Bose-Einstein condensation of atoms close to a Feshbach resonance, in which the tunable scattering length of the atoms is described using a system of coupled atom and molecule fields. These include the Thomas-Fermi description of the condensate profile, the c-field equations, and the Bogoliubov-de Gennes equations, and the Bogoliubov excitation spectrum for a homogenous condensed system. We apply this formalism to the special case of Bragg scattering from a uniform condensate, and find that for moderate and large scattering lengths, there is a dramatic difference in the shift of the peak of the Bragg spectra, compared to that based on a structureless atom model. The result is compatible with the experimental results of [1]. Finally we implement a full detailed simulation of the Bragg scattering from a condensate cloud including condensate inhomogeneity and three-body loss, and modelling correctly the essential experimental details. Results from these simulations are in very good quantitative agreement with the experimental results, confirming the importance of the resonance bound state in the dynamics of the condensate for fast experiments like Bragg scattering.

[1] S.B. Papp, J.M. Pino, R.J. Wild, S. Ronen, C.E. Wieman, D.S. Jin, and E.A. Cornell. Bragg spectroscopy of a strongly interacting $^{85}\mathrm{Rb}$ Bose-Einstein condensate. Phys. Rev. Lett. 101:135301, 2008.

Cross-over to quasi-condensation – a non-gaussian challenge to mean-field theories

Carsten Henkel

Universität Potsdam, Physik und Astronomie, Karl-Liebknecht-Str. 24/25, 14476 Potsdam, Germany

A. Negretti

Universität Ulm, Germany

S. Cockburn and N. Proukakis

Newcastle University, United Kingdom

We discuss in a low-dimensional Bose gas the cross-over from a dilute, degenerate system to a quasi-condensate where density fluctuations are suppressed. A few variants of mean-field theories are discussed who predict a critical point in a homogeneous system, as a condensate-related parameter is lowered: condensate, quasi-condensate, or anomalous density. We compare to numerical simulations within a stochastic Gross- Pitaevskii equation [1], to an interacting classical field theory [2] and to solutions of the Yang-Yang equations [3].

[1] S. P. Cockburn, A. Negretti, N. P. Proukakis, and C. Henkel, Phys. Rev. A 83 (2011) 043619
[2] L. W. Gruenberg and L. Gunther, Phys. Lett. A 38 (1972) 463; D. J. Scalapino, M. Sears, and R. A. Ferrell, Phys. Rev. B 6 (1972) 3409
[3] C. N. Yang and C. P. Yang, J. Math. Phys. 10 (1969) 1115

Ultracold fermionic atoms in optical lattices out of equilibrium: Hydrodynamics and beyond

Stephan Mandt

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We investigate theoretically the out-of-equilibrium dynamics of a finite cloud of fermionic atoms in an optical lattice in the presence of different external potentials. A finite atomic cloud in a gravitational potential doesn't simply 'drop down'. Instead, it diffuses symmetrically upwards and downwards. We demonstrated this effect both numerically and analytically, comparing Boltzmann-simulations with solutions of hydrodynamic equations for the Hubbard-model at high temperatures. During the expansion, the radius grows subdiffusively with $R \sim t^{1/3}$ for long times. The expansion is driven by an energy current that mediates between positive local temperatures at the top, and negative absolute temperatures at the bottom part of the cloud. We also showed how equilibrated negative absolute temperatures can be realized and detected in experiment. In a joint theoretical-experimental study with the Bloch-group, we analyzed the expansion-dynamics in the absence of external potentials. In this seemingly simpler case, we were able to recover the experimental observations by a Boltzmann-simulation. However, we found a fundamental breakdown of the hydrodynamic approach in two dimensions.

Rigorous mean-field dynamics of lattice bosons: quenches from the Mott insulator

Michiel Snoek

University of Amsterdam, Institute of Physics, Science Park 904, 1090 GL, Amsterdam, The Netherlands

will provide a rigorous derivation of Gutzwiller mean-field dynamics for lattice bosons, showing that it is exact on fully connected lattices. This formalism is applied to quenches in the interaction parameter from the Mott insulator to the superfluid state. Although within mean-field the Mott insulator is a steady state, I will show that a dynamical critical interaction U_d exists, such that for final interaction parameter $U_f > U_d$ the Mott insulator is exponentially unstable towards emerging long-range superfluid order, whereas for U_f

Universal energy fluctuations in thermally isolated driven systems

Luca D'Alessio

Boston University, 590 Commonwealth Avenue, 02215, Boston (MA), United States

When an isolated system is brought in contact with a heat bath its final energy is random and follows the Gibbs distribution; a cornerstone of statistical physics. The system's energy can also be changed by performing non-adiabatic work using a cyclic process. Almost nothing is known about the resulting energy distribution in this setup, which is especially relevant to recent experimental progress in cold atoms, ions traps, superconducting qubits and other systems. Here we show that when the non-adiabatic process comprises of many repeated cyclic processes the resulting energy distribution is universal and different from the Gibbs ensemble. We predict the existence of two qualitatively different regimes with a continuous second order like transition between them. We illustrate our approach performing explicit calculations for both interacting and non-interacting systems.

Possibility to investigate pressure variations during formation of Turbulence in a BEC sample

Vanderlei Bagnato

University of Sao Paulo, Instituto de Fisica de Sao Carlos, Av. Trabalhador sao Carlense, 400, 13560-97-, Sao Carlos, Brazil

Using the concept of generalized pressure variable we have applied to a cloud presenting quantum turbulence and verify the ocurrence of a pressure drop when turbulence is developed.

Posters

Finite Temperature Vortex Dynamics via the ‘ZNG’ Method

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We study the precessional frequency of an off-centered vortex in a harmonically-trapped atomic condensate. In the absence of a thermal cloud, it is well understood the vortex rotates at a constant radius, as recently confirmed experimentally [1]. However, the thermal cloud induces a frictional force on the vortex, thereby leading it to a gradual decay. By an extension of earlier work [2], we perform a detailed quantitative study of the role of the dynamics of the thermal cloud of the motion of a vortex; we model the system by a dissipative Gross-Pitaevskii equation for the condensate, self-consistently coupled to a quantum Boltzmann equation for the thermal modes (Zaremba-Nikuni-Griffin formalism).
We acknowledge funding from the UK EPSRC.

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Possibility to investigate pressure variations during formation of Turbulence in a BEC sample

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Using the concept of generalized pressure variable we have applied to a cloud presenting quantum turbulence and verify the ocurrence of a pressure drop when turbulence is developed.

Finite temperature theory of cold gases in interesting potentials

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Bosons in optical lattices: We develop a practical finite temperature theory for the superfluid regime of a Bose gas in an optical lattice with additional harmonic confinement. We derive an extended Bose-Hubbard model that is valid for shallow lattices and when excited bands are occupied. Using the Hartree-Fock-Bogoliubov- Popov mean-field approach, and applying local density and coarse-grained envelope approximations, we arrive at a theory that can be numerically implemented accurately and efficiently. We also present theory for the critical temperature of a Bose gas in a combined harmonic lattice potential based on our theory. Bosons or fermions in toroidal traps: We analytically and numerically consider the heating involved in isentropic loading of a HFBP Bose or spin-polarized Fermi gas from a harmonic trap into the scale invariant toroidal regime. Bosons or fermions with dipolar interactions: We develop a mean field treatment of a trapped normal Fermi or fermi gas with dipolar interactions, based on self-consistent semiclassical Hartree-Fock theory that accounts for direct and exchange interactions.

Spin drag across the phase transition of a Spinor Bose gas

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Electronic transport is one of the main areas of interest in condensed matter physics. The transport properties of a material contain important physical information with respect to elementary excitations and their scattering mechanisms. Recently, there have been investigations into how bosonic transport can be studied using spin drag in normal spinor Bose gases [1,2], where bosons of one spin species drag along bosons of the other spin species. Experiments are currently being undertaken in this regime. Here, we develop the spinor Projected Gross-Pitaevskii equation (PGPE) formalism [3] to study spin drag in the critical regime of a Bose gas. The PGPE captures the full dynamics and interactions of the finite-temperature system, and has previously been successfully applied to the phase transitions of the spinor Bose gas [4]. Using this formalism to model an experimentally feasible system, we calculate the spin drag relaxation time over the phase transition and study the role of interactions between the condensed and normal fractions.

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BEC dynamics at finite temperature: A number-conserving approach

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Number-conserving approaches provide a perturbative, finite-temperature description of weakly interacting Bose gases with fixed particle number, such as atomic BECs. Such a description is particularly suited to driven BECs at low temperatures, where the interplay between driving, condensate mode, and low-lying quasiparticle modes is of critical importance to the dynamics; this interplay is captured neither by the GPE, nor by higher-temperature (thermal cloud) approaches. We have applied a second-order number-conserving approach to the dynamics of a driven BEC initially at zero temperature. Compared to a first-order approach — which predicts unbounded growth of the noncondensate —

the higher-order effects in our description lead to a "switch off" of noncondensate growth, followed by oscillations in the (non)condensate population and overall coherence of the system. We outline our ongoing work to adapt the method to other experimental systems and finite initial temperatures.

Finite temperature stability of a trapped dipolar Bose gas

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We calculate the stability diagram for a trapped normal Bose gas with dipole-dipole interactions. Our study characterizes the roles of trap geometry, temperature, and short-range interactions on the stability. We predict a robust double instability feature in oblate trapping geometries arising from the interplay of thermal gas saturation and the anisotropy of the interaction.

Topological Defects in Spinor Condensates with Polar-Ferromagnetic Interface

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In a spin-1 Bose-Einstein condensate where there exists a boundary between polar and ferromagnetic regions, it is possible to have topological defects that end on the boundary or connect to a defect on the other side of the boundary. We present a number of example cases and study their energetic stability using imaginary-time evolution of the spinor Gross-Pitaevskii equation. We demonstrate that it is possible to achieve stable vortex configurations under rotation.

Emergence of exotic condensates from a melting bosonic Mott insulator in 2D optical lattices

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We investigate expansion dynamics of a bosonic quantum gas prepared in the Mott insulating ground state of an optical lattice. Once released from harmonic confinement the interacting many-body system is observed to develop coherence while simultaneously populating finite quasi-momenta states. We demonstrate that in the strong and intermediate interacting regimes the emerging condensate fraction depends on the number of particles in the MI phase rather than on the particular interaction or tunneling strength. During expansion, the condensate was observed to develop spiked structure breaking the initial spherical symmetry. Thereby, the expanding spikes exhibit the maximal lattice velocity independent of system parameters. The dynamical properties of this system are obtained by means of the Gutzwiller mean-field theory and confirmed analytically.

1D Bose gases on an atom chip : density fluctuations and momentum distribution

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We present several recent results of elongated Bose gases obtained from our atom-chip setup. Using in-situ density fluctuation measurements, we investigated in detail the quasi-condensation transition for weakly interacting gases, and the 1D-3D dimensional crossover has been clarified. We also reached the so-called quantum quasi-condensate regime where the atom number fluctuations are sub-poissonian. Finally, thanks to the use of an original AC atom guide that eliminates the roughness of the trapping potential, we were able to approach the fermionised (or strongly interacting) regime. The gas then no longer show

super-poissonian fluctuations : the fluctuations, poissonian at low density become sub-poissonian at high density, as that of a Fermi gas. Recently we are investigating momentum distribution of 1D gases, measured using the focusing technics. We will present preliminary results.

Creating exotic condensates via quantum phase revival dynamics in engineered lattice potentials

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In the field of ultracold atoms in optical lattices a plethora of phenomena governed by the hopping energy J and the interaction energy U have been studied in recent years. However, the trapping potential typically present in these systems sets another energy scale and the effects of the corresponding time scale on the quantum dynamics have rarely been considered. Here we study the quantum collapse and revival of a lattice Bose-Einstein condensate (BEC) in an arbitrary spatial potential, focusing on the special case of harmonic confinement. Analyzing the time evolution of the single particle density matrix, we show that the physics arising at the (temporally) recurrent quantum phase revivals is essentially captured by an effective single particle theory. This opens the possibility to prepare exotic non-equilibrium condensate states with a large degree of freedom by engineering the underlying spatial lattice potential.

Nonequilibrium dynamics in one-dimensional Bose gases

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I will present results of our group related to exact solutions for nonequilibrium dynamics of 1D Bose gases within the Lieb-Liniger and Tonks-Girardeau models. I will present dynamics of the so called Loschmidt echo in these systems. Moreover, I intend to give an outline and compare dynamics in these systems with dynamics of partially coherent classical light in nonlinear optical systems, and show results related to Anderson localization.

Universal energy fluctuations in thermally isolated driven systems

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When an isolated system is brought in contact with a heat bath its final energy is random and follows the Gibbs distribution; a cornerstone of statistical physics. The system's energy can also be changed by performing non-adiabatic work using a cyclic process. Almost nothing is known about the resulting energy distribution in this setup, which is especially relevant to recent experimental progress in cold atoms, ions traps, superconducting qubits and other systems. Here we show that when the non-adiabatic process comprises of many repeated cyclic processes the resulting energy distribution is universal and different from the Gibbs ensemble. We predict the existence of two qualitatively different regimes with a continuous second order like transition between them. We illustrate our approach performing explicit calculations for both interacting and non-interacting systems.

Phase Space Theory of BEC and Time Dependent Modes

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A phase space theory has been developed for describing dynamical processes in BEC close to zero temperature, such as for interferometry experiments based on interacting bosons in time-dependent double-well traps. Time dependent modes obtained from coupled generalised Gross-Pitaevskii equations are a good first approximation to the behaviour near zero temperature for the condensate mode bosons, and are suitable for describing system states. The present phase space theory involves separate field operators for condensate and non-condensate modes [1], the treatment involving a hybrid Wigner and positive P distribution functional for the highly occupied condensate and mainly unoccupied non-condensate modes respectively [2-4]. Mode annihilation, creation operators are represented via time dependent phase space variables in accordance with the mode function time dependence, instead of time independent phase space variable treatment as in [4]. The functional Fokker-Planck equations have additional diffusion terms involving coupling between condensate and non-condensate fields related to the mode time dependence. Additional drift terms involving such coupling occur in the relationship between the Ito stochastic field equations and the functional Fokker-Planck equation, as well as the noise field terms now being related to the new diffusion term.

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Non-equilibrium flows and superfluidity in finite temperature dilute gas Bose-Einstein condensates

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Superfluids exhibit a number of intriguing properties, such as frictionless flow and quantised rotation in the form of vortices. Initially discovered in superfluid helium, both these phenomena have now been observed in dilute gas Bose-Einstein condensates. However, the isolation of ultra-cold gas systems from the environment combined with their inhomogeneous density profiles make the observation of other phenomena, such as the thermo-mechanical effect, more challenging in the lab. The fundamental mechanism behind the superfluid thermo-mechanical effect is generating a sustained difference in the thermodynamic properties of the superfluid at spatially separated locations. This can be achieved in a single component dilute Bose gas by introducing a channel between two separated traps in which the initial state has different thermodynamic parameters. This will result in a non-equilibrium flow that can potentially achieve a steady state for sufficiently large reservoirs. Here we perform dynamical simulations of a finite temperature Bose-Einstein condensate coupled to spatially separated heat and particle reservoirs to investigate such non-equilibrium superfluid phenomena. We analyse the resulting steady-state non-equilibrium flows in the Bose gas, and observe a transition to sustained superfluid turbulence.

Emergence of non-thermal statistics in isolated many-particle quantum systems after multiple perturbations

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We investigate the emergence of a non-thermal statistics in the isolated quantum spin clusters. By performing computer simulations, we show that, if a finite isolated cluster of interacting spins $1/2$ is subjected to a series of small non-adiabatic perturbations by the external magnetic field, then the resulting occupation distributions are no longer of the conventional Boltzmann-Gibbs statistics, even though the staring distributions are of the thermal type. The emerging non-thermal occupations are significantly higher than the thermal ones on both the low and the high ends of the energy spectra. This behavior semi-quantitatively agrees with the statistics predicted for the "quantum micro-canonical" (QMC) ensemble [1,2]. The QMC ensemble admits all possible superpositions of energy eigenstates with a specified energy expectation value. The fact that all energy eigenstates can participate in the QMC ensemble distinguishes it from the conventional microcanonical ensemble, where participation of energy eigenstatates is only limited to a narrow energy window around the energy expectation value. Our results also indicate that the eigenstates of the perturbation operators are generally localized in the energy basis of the unperturbed Hamiltonian if the perturbations are periodically applied.

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Quench dynamics of strongly interacting 1D bose gases

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Mott-Insulator to Liquid Transition and Population Trapping in Ultracold Fermi Gases by Non-Equilibrium Modulation of the Optical Lattice

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An ultracold gas of interacting fermionic atoms in a three dimensional optical lattice is considered, where the lattice potential strength is periodically modulated. This non-equilibrium system is nonperturbativley described by means of a Keldysh-Floquet-Green's function approach employing a generalized dynamical mean field theory (DMFT). Strong repulsive interactions between different atoms lead to a Mott-Insulator state for the equilibrium system, but the additional external driving yields a non-equilibrium density of Floquet-states and a transition to a liquid or conducting state.

Stochastic modelling of quasi-condensate experiments

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The stochastic Gross-Pitaevskii equation (SGPE) is an excellent model for investigating the dynamics and equilibrium properties of weakly interacting Bose gases at finite temperatures. In this work the SGPE is shown [1] to accurately reproduce the density profiles [2,3] and density fluctuations [4] of recent experiments. We additionally investigate phase fluctuations in the quasi-one-dimensional regime, where currently disagreement to theory exists; in particular, using a suitable reinterpretation of the experimental measurements reported in [5,6] we resolve this discrepancy and demonstrate excellent agreement between theory and experiments. We acknowledge funding by EPSRC.

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Quantum Kinetic Theory of Superfluid Internal Convection in the Collisionless Regime

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Superfluids can transport heat independently of mass via simultaneous opposite flows of their spatially interpenetrating superfluid and thermal components. This phenomon of 'internal convection' is known from experiments on superfluid Helium and is usually described within Landau's phenomenological two fluid hydrodynamics. Applying quantum kinetic theory to a dilute Bose gas held between two thermal reservoirs at different temperatures, we identify the same phenomena in the collisionless Bogoliubov regime of a Bose-condensed gas. The emergence of internal convection as an environmentally induced coherent effect requires a long quasi-particle lifetime within the thermal reservoirs, and its analysis needs explicit treatment of non-resonant master equation terms. Our results for the energy and particle currents suggest that internal convection should be directly observable in currently feasible experiments on trapped ultracold vapors.

Mach-Zehnder interferometry with interacting trapped Bose-Einstein condensates

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According to the common belief, atom interferometers using trapped Bose-Einstein condensates suffer from atom-atom interactions. In Mach-Zehnder interferometers, even very small interactions during the interferometer performance destroy coherent spin squeezing and drastically reduce the phase sensitivity. In our studies of a Mach-Zehnder interferometer with trapped interacting condensates we find that the sensitivity is not substantially limited by interactions, but

the signal can be uncovered using a Bayesian phase estimation strategy. The phase sensitivity for a Twin-Fock input state always shows up Heisenberg scaling even for large interactions and durations of the nonlinear beam splitters. Finally we show that the results of this work are applicable under realistic conditions. We therefore simulate a Mach-Zehnder interferometer sequence in real space using the Multi-configurational time-dependent Hartree for Bosons method. During the beam splitters, rapid condensate oscillations are induced. In order to guarantee stationary condensates during phase accumulation and at the final time, we employ optimal control theory. A phase sensitivity close to the Heisenberg limit can be achieved also within the realistic model. We further demonstrate that the interferometer is robust against a realistic atom detection error, which only induces a gradual loss of sensitivity.

Spin-Asymmetric Josephson Effect, and Speed of Sound in the FFLO State

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We propose that with ultracold Fermi gases one can realize a spin-asymmetric Josephson effect in which the two spin components of a Cooper pair are driven asymmetrically, corresponding to driving a Josephson junction of two superconductors with different voltages for spin up and down electrons. We predict that the spin up and down components oscillate at the same frequency but with different amplitudes. We explain this seemingly paradoxical breakdown of the Cooper pair tunneling picture by describing the Josephson effect as interfering Rabi processes in which the contribution of intermediate tunneling states with broken Cooper pairs accounts for the spin-asymmetric result. [1] The Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state describes fermionic superfluids with imbalanced spin populations. We consider the density response of a spin-imbalanced ultracold Fermi gas in the FFLO state in an optical lattice. We calculate the collective mode spectrum of the gas in the generalised random phase approximation and show that the anisotropic pairing mechanism of the FFLO state can be observed as an anisotropy in the speed of sound. We also consider the damping

of the collective modes. [2]

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Cross-over to quasi-condensation – a non-gaussian challenge to mean-field theories

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We discuss in a low-dimensional Bose gas the cross-over from a dilute, degenerate system to a quasi-condensate where density fluctuations are suppressed. A few variants of mean-field theories are discussed who predict a critical point in a homogeneous system, as a condensate-related parameter is lowered: condensate, quasi-condensate, or anomalous density. We compare to numerical simulations within a stochastic Gross- Pitaevskii equation [1], to an interacting classical field theory [2] and to solutions of the Yang-Yang equations [3].

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A Functional renormalization group approach for many-body systems out of equilibrium

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Functional renormalization group methods are used in order to describe a system of non-interacting bosons coupled to a bath of phonons.

Hartree shift in unitary Fermi gases

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The Hartree energy shift is calculated for a unitary Fermi gas. By including the momentum dependence of the scattering amplitude explicitly, the Hartree energy shift remains finite even at unitarity. Extending the theory also for spin-imbalanced systems allows calculation of polaron properties. The results are in good agreement with more involved theories and experiments.

Nonequilibrium time evolution of bosons from the functional renormalization group

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We develop a functional renormalization group approach to obtain the time evolution of the momentum distribution function of interacting bosons out of equilibrium. Using an external out-scattering rate as flow parameter, we derive formally exact renormalization group flow equations for the nonequilibrium self-energies in the Keldysh basis. A simple perturbative truncation of these flow equations leads to an approximate solution of the quantum Boltzmann equation, which does not suffer from secular terms and gives accurate results even for long times. We demonstrate this explicitly within a simple exactly solvable toy model describing a quartic oscillator with off-diagonal pairing terms.

Tunneling Dynamics of Open Ultracold Bosonic Systems

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The dynamics of the tunneling process of open, repulsively interacting, initially coherent, few-boson systems is investigated by solving the time-dependent Schrödinger equation numerically exactly using the multi-configurational time-dependent Hartree for bosons method. We demonstrate that the system fragments during the tunneling dynamics. This fragmentation causes mean field methods, such as the time-dependent Gross-Pitaevskii equation to fail in the description of such systems. Starting from a two-boson system with weak interactions we find two tendencies when increasing a) the particle number and b) the interaction strength: a) the incoherence is counterintuitively growing with the particle number and b) the incoherence is growing with the increase of interparticle repulsion. This leads to the general conclusion that the tunneling dynamics in

open ultracold bosonic systems is not coherent and therefore it exhibits a wealth of interaction-dependent phenomena.

Stability of Bose-Einstein condensates of dipolar gases

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We develop techniques to calculate the Bogoliubov-de Gennes excitations of dipolar Bose- Einstein condensates (BEC) trapped in three dimensions. The behaviour of the excitation energies indicates regimes of instability of the BEC to collapse.

Disordered bosons: condensate and excitations

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Deep in the superfluid phase of condensed interacting bosons, the most economic theory is Bogoliubov's approach. We present a Bogoliubov theory that is custom-tailored for interacting bosons in spatially correlated disorder potentials. From the fundamental quadratic excitation Hamiltonian, we can determine the full quantum depletion, both at zero and finite temperature, as well as numerous other, physically relevant quantities.

Effects of thermal and quantum fluctuations on the phase diagram of a spin-1 ^{87}Rb Bose-Einstein condensate

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We investigate the effects of thermal and quantum fluctuations on the phase diagram of a spin-1 ^{87}Rb Bose-Einstein condensate (BEC) under a quadratic Zeeman effect. Due to the large ratio of the spin-independent to spin-dependent interactions of ^{87}Rb atoms, the effect of a small fraction of non-condensed atoms on the condensate is much more significant than that of scalar BECs. We find that the condensate and spontaneous magnetization appear at different temperatures when the ground state is in the broken-axisymmetry phase. In this phase, the magnetized condensate induces a spin coherence among the non-condensed atoms in different magnetic sublevels, resulting in a temperature-dependent magnetization of the non-condensed component. We also examine the effect of quantum fluctuations on the order parameter at absolute zero, and find that the ground-state phase diagram is significantly modified by the quantum depletion.

Dynamics of driven ultra-cold bosons

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Gases of atoms cooled to Nanokelvin temperatures and loaded into optical lattices are a powerful tool to study a broad range of quantum phenomena. In particular the remarkable degree of control of the system parameters achieved in these kind of experiments allows us to investigate the dynamics of strongly correlated quantum many body physics. Moreover, in recent years, there has been important advances in the use of fast periodic perturbations in order to engineer unconventional effective Hamiltonians. We study a slow variation of the system

parameters in order to tackle issues relating to the adiabatic following of the ground-state of a Hamiltonian and heating. We discuss both the slow change of a system parameter and the slow variation of the effective parameters of a system due to a fast driving.

Phenomenological descriprition of new Josephson junction architectures

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We describe the Josephson junction devices made by putting non-superconducting element on the top of superconductor strip. The non-superconducting material under numerical investigation is metal, ferromagnet and ferrielectric. Josephson effect is being induced in the given structure by means of Cooper pair diffusion from the superconductor into non-superconductor and by means of electric and magnetic fields occurring at the superconductor-nonsuperconductor interface. We use Time Dependent Ginzburg Landau (TDGL) formalism to describe the properties of the system, particularly in certain types of temperature gradients across the junction. The superconducting and non-superconducting order parameter distribution is being investigated for different geometries of the system. The use of non-equilibrium Green functions in the studied system is being discussed.

Finite temperature dynamics of persistent current formation

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We quantitatively model a recent persistent current formation experiment performed at the University of Arizona, using the stochastic projected Gross-Pitaevskii Equation (SPGPE). Experimentally, a persistent current is formed by stirring of a Bose-Einstein condensate at a finite temperature of $T \sim 0.9T_c$. A blue-detuned laser is used to stir the condensate, which nucleates many vortices. The subsequent thermal damping of vortices in a toroidal condensate leads to the formation of a persistent current, where a number of vortices become stabilized in this geometry by pinning to the blue-detuned laser. We are able to quantitatively model the full dynamics of the Arizona experiment using the SPGPE, finding our calculations accurately predict the size of the persistent current as well as the decay time of the vortices. We also observe the crucial role that thermal fluctuations have on enabling these quantitatively accurate calculations, showing our comprehensive SPGPE treatment is necessary. We thus find quantitative agreement of the Arizona persistent current formation experiment with the SPGPE theory of dissipation, using no fitting parameters.

Optimal time-dependent lattice models for nonequilibrium dynamics

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Lattice models are central to the physics of ultracold atoms and condensed matter. Generally, lattice models contain time-independent hopping and interaction parameters that are derived from the Wannier functions of the noninteracting problem. Here, we present a new concept based on time-dependent Wannier

functions and the variational principle that leads to optimal time-dependent lattice models. As an application, we use the Bose-Hubbard model with time-dependent Wannier functions to study an interaction quench scenario involving higher bands. We find a separation of time-scales in the dynamics. The results are compared with numerically exact results of the time-dependent many-body Schrödinger equation. We thereby show that, under some circumstances, the multi-band nonequilibrium dynamics of a quantum system can be obtained essentially at the cost of a single-band model.

Approximating Steady States in Equilibrium and Nonequilibrium Condensates

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We obtain approximations for the time-independent Gross-Pitaevskii (GP) equation in two and three spatial dimensions using the divergence-free WKB method. The results include an explicit expression of a uniformly valid approximation for the condensate density of an ultracold Bose gas confined in a harmonic trap that extends into the classically forbidden region. This provides an accurate approximation of the condensate density that includes healing effects at leading order that are missing in the widely adopted Thomas-Fermi approximation. The results presented herein allow us to formulate useful approximations to a range of experimental systems including the equilibrium properties of a finite temperature Bose gas and the steady-state properties of a 2D nonequilibrium condensate. Comparisons between our asymptotic and numerical results for the conservative and forced-dissipative forms of the GP equations as applied to these systems show excellent agreement between the two sets of solutions thereby illustrating the accuracy of these approximations.

Entropy and superfluidity effects on the size of a trapped fermionic cloud in an optical lattice

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We theoretically investigate the thermodynamic properties of an inhomogeneous Fermi gas in an optical lattice. We study the interplay between the strong correlation effects and entropy of the trapped gas. Upon increasing the attractive interaction, this interplay leads to an anomalous expansion in the size of the atomic cloud. We model the system by an inhomogeneous Fermi-Hubbard model and we apply a Dynamical Mean-Field Theory (DMFT) combined with a Local Density Approximation to compute the atomic density, superfluid order parameter, entropy and the atomic cloud size. Whenever applicable, we also compare DMFT findings with a high-temperature expansion. Comparison with the experiment in which the anomalous expansion of a trapped Fermi gas was observed reveals deviations, which are due to non-equilibrium effects. We analyze these effects with DMFT and a simple non-adiabatic model.

Critical dynamics of ultracold bosons in one dimension

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Critical dynamics in an ultracold Bose gas, in one spatial dimension, is analysed with respect to topological excitations and compared to quantum turbulence in two and three dimensions. A special focus is set on the time-evolution of characteristic quantities such as the energy and velocity distributions, soliton densities and the spectral function. The results give insight into the structure of stationary states of an ultracold Bose gas away from equilibrium.

Turbulent dynamics of ultracold bosons

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Turbulent dynamics in ultracold Bose gases in two dimensions are analyzed by means of statistical simulations using the classical field equation. A special focus is set on the time-evolution of vortical density, energy and velocity distributions, and vortex correlations.

Real-time effective-action approach to the Anderson quantum dot

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The non-equilibrium time evolution of an Anderson quantum dot is investigated. The quantum dot is coupled between two leads forming a chemical-potential gradient. We use Kadanoff-Baym dynamic equations within a non-perturbative resummation of the s-channel bubble chains. The effect of the resummation leads to the introduction of a frequency-dependent 4-point vertex. The tunneling to the leads is taken into account exactly. The method allows the determination of the transient as well as stationary transport through the quantum dot, and results are compared with different schemes discussed in the literature (fRG, ISPI, tDMRG and QMC).

Parity-Violation in Hydrogen: Precision Enhancement through Many-Particle Squeezing

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We discuss the propagation of hydrogen atoms in static electric and magnetic fields in a longitudinal atomic beam spin echo (lABSE) Interferometer. The atoms acquire geometric (Berry) phases that exhibit a manifestation of parity-(P-)violation effects arising from electroweak Z-boson exchange between electron and nucleus. We provide analytical as well as numerical calculations of the behaviour of the metastable n=2 states of hydrogen. Possible measurements of P-violating geometric phases in lABSE experiments require a high precision for detecting atoms in specific states. We investigate possibilities to enhance the precision of lABSE experiments beyond the standard quantum limit using squeezed many-particle hydrogen states.

Angular momentum stabilizes a 3D attractive BEC.

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We consider a 3D Bose-Einstein Condensate (BEC), with attractive interparticle interactions, embedded in a harmonic, spherically symmetric trap. This system is metastable only if the total number of bosons N and the interaction strength λ_0 do not exceed some critical values. Otherwise the system collapses. Gross-Pitaevskii (GP) theory predicts the maximum (critical) number of bosons N_{cr}^{GP} that, for a given λ_0, can be loaded to the system, without its collapse. But, what happens to the excited states? To investigate the structure and stability of these states we must go beyond GP theory; these states have definite values of angular momentum L, are highly fragmented and can support number of bosons much greater than N_{cr}^{GP}.

Properties of turbulent Bose-Einstein Condensates

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We highlight a few key properties of quantum turbulence, a dynamically reconnecting system of quantum vortices. Although fundamentally different mechanisms dictate the dynamics of quantum and classical turbulence, turbulence in quantum fluids exhibit some remarkable similarities to classical turbulence, such as the same Kolmogorov energy spectrum in continuously excited turbulence. 1) Firstly we look at a fundamental difference between quantum and classical turbulence, the non-Gaussian statistics of the velocity components, which we argue arise as a result of the singular nature of quantized vorticity [1]. By monitoring tracer particles in turbulent superfluid He, Paoletti et. al. [2] observed that the velocity components follow non-Gaussian statistics which we have shown to also feature in turbulent atomic Bose-Einstein condensates (BECs). This contrasts to the Gaussian statistics observed in classical turbulence. 2) Secondly, we look at the dissipation of energy in turbulent quantum fluids at scales smaller than the average inter-vortex spacing, thought to be dominated by the Kelvin wave cascade. We study the Kelvin wave cascade process in a homogeneous BEC by phase imprinting Kelvin waves on a few vortices and tracking the resultant vortex amplitude. 3) Turbulence is also comprised of chaotic events and in classical fluids, few vortex systems are known to be chaotic. Finally we investigate few-vortex systems in BECs, to see if the trajectories of quantum vortices also exhibit chaotic behaviour.

[1] White et. al., PRL 2010
[2] Paoletti et. al., PRL 2008

Solitons as the Early Stage of Quasicondensate Formation

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I will show the evaporative cooling dynamics of trapped one-dimensional Bose-Einstein condensates for parameters leading to a range of condensates and quasicondensates in the final equilibrium state. Solitons are created during the evaporation process by the Kibble-Zurek mechanism, but subsequently dissipate during thermalization. However,their signature remains in the phase coherence length, which is approximately conserved during dissipation in this system.

Superfluidity and Anomalous Correlations in a Two-Dimensional Bose Gas

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The relationship between superfluidity, Bose condensation, and the Berezinskii-Kosterlitz-Thouless (BKT) phase transition in finite-size quasi-two-dimensional Bose gases has been the source of some confusion in experimental and theoretical investigations in recent years. Here we use a classical-field method to demonstrate that the transition to a superfluid quasicondensate in a finite-sized 2D homogeneous Bose gas is associated with the emergence of an underlying Bose condensate, as evidenced by the appearance of anomalous ("symmetry-broken") correlations in the gas. We consider dynamical aspects of the 2D Bose field, and calculate dynamic density and phase structure factors of the system. These correlations further elucidate the character of the superfluid transition, and the nature of the pre-superfluid phase immediately above the BKT transition. We apply our findings to the non-equilibrium dynamics of a metastable superflow in a quasi-two-dimensional toroid in the presence of a non-rotating thermal cloud.

We exploit the locking of the superfluid velocity field to the underlying condensate to properly determine the local superfluid density in metastable equilibrium. We find that the superfluid density is larger than the condensate density due to the erosion of long-range correlations by purely thermal (classical) fluctuations.

Dissipative Dynamics of a Harmonically Confined Bose-Einstein Condensate

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