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Lyon BEC 2012

Theory of Quantum Gases and Quantum Coherence

Ecole Thématique CNRS: *Physique mésoscopique avec des gaz quantiques*

Lyon, June 5-8, 2012

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Book of abstracts

Tuesday June 5th, 2012

DYNAMIC BEHAVIOR OF ULTRA COLD FERMI GASES

Sandro Stringari

University of Trento, Department of Physics, Via Sommarive, I-38126 Povo-Trento, Italy

A1

In my talk I will present an overview of recent advances in the study of the collective dynamics in harmonically trapped, ultra cold Fermi gases. I will discuss in particular the behavior of the collective oscillations of strongly interacting Fermi gases at both zero and finite temperature and the decay and collisonal properties of solitons along the BEC-BCS crossover.

ULTRACOLD ^{6}LI-^{40}K FERMI MIXTURES WITH RESONANT INTERACTIONS

Matteo Zaccanti

IQOQI, Technikerstrasse 21a, A-6020 Innsbruck, Austria

A2

The ^{6}Li-^{40}K mixture is a prime candidate for realizing resonantly interacting, mass imbalanced fermionic systems which represent an appealing new frontier of exploration in the realm of ultracold Fermi gases. First, I will report on our recent spectroscopic study of such a mixture in the regime of large population imbalance, which allowed for a complete characterization of the properties of attractive and repulsive K polarons in a Li Fermi sea as a function of the Li-K interaction [1]. Second, I will discuss our ongoing experiments on a population balanced Li-K mixture at the repulsive and at the attractive branch of an interspecies Feshbach resonance. On the one hand, we investigate the debated properties of repulsive Fermi gases; on the other hand, we look for the realization of a mass imbalanced fermionic superfluid with our system.

[1] Metastability and Coherence of Repulsive Polarons in a Strongly Interacting Fermi Mixture, C. Kohstall, M. Zaccanti, M. Jag, A. Trenkwalder, P. Massignan, G. M. Bruun, F. Schreck, R. Grimm, `arXiv:1112.0020`, Nature, in press (2012).

EQUATION OF STATE OF THE UNITARY GAS: TURNING THE SIGN PROBLEM INTO A SIGN BLESSING

Kris van Houcke

Ghent University, Proeftuinstraat 86, 9000 Gent, Belgium

A 3

Expansion in Feynman diagrams is a standard tool of quantum many-body theory. However, one is usually restricted to a few low-order diagrams. Bold diagrammatic Monte Carlo (BDMC) is a new technique to perform the summation of skeleton Feynman diagrams up to high order. We present a cross-validation between BDMC and precision experiments on ultra-cold atoms. Specifically, we focus on the normal-state equation of state of the unitary gas, a prototypical example of a strongly correlated fermionic system. The BDMC method works directly in the thermodynamic limit and with zero-range interactions. The diagrammatic series is found to be strongly oscillating but re-summable thanks to sign-alternation of the diagrammatic contributions. The obtained equation of state is in excellent agreement with recent high-precision measurements done at MIT. The contact and the critical temperature can also be extracted. The cross-validation demonstrates that a series of Feynman diagrams can be controllably resummed in a non-perturbative regime using BDMC. This opens the door to the solution of some of the most challenging problems across many areas of physics.

GROUND STATE OF AN IMPURITY IN A QUASI-2D FERMI GAS

Jesper Levinsen

University of Cambridge, 19 JJ Thomson Avenue, CB3 0HE Cambridge UK

A 4

We study the ground state of a highly imbalanced Fermi gas under quasi-two-dimensional confinement. We find that for typical experimental conditions, the location of the recently predicted polaron-molecule transition is shifted to lower values of the vacuum binding energy due to the interplay between transverse confinement and many-body physics. The energy of the attractive polaron is calculated in the 2D-3D crossover and displays a series of cusps before converging towards the 3D limit.
Reference: J. Levinsen and S. K. Baur, `arXiv:1202.6564`

TWO DIMENSIONAL ATTRACTIVE FERMI GAS: BALANCED AND HIGHLY POLARIZED REGIMES AT ZERO TEMPERATURE

Gianluca Bertaina

École polytechnique fédérale de Lausanne (EPFL), Station 3, CH-1015 Lausanne, Switzerland

We study a two dimensional two species Fermi gas with attractive short-range interactions at zero
temperature, both in the unpolarized regime, which shows a BCS-BEC crossover type of super
fluid ground state, and in the highly polarized regime, corresponding to an impurity immersed in
a Fermi sea, which exhibits a transition from a polaronic to a molecular ground state. We use A
Diffusion Monte Carlo with Fixed Node approximation in order to calculate the energy per particle 5
and extract the effective interactions among composite particles in the strongly interacting regime,
where beyond mean-field effects are crucial. In the impurity regime we calculate the evolution of
the quasiparticle weight in the attractive polaronic branch as a function of the coupling. We also
discuss the relevance of these results to ongoing experiments.

Wednesday, June 6th, 2012

ANDERSON LOCALIZATION OF ULTRA-COLD ATOMS IN A LASER SPECKLE DISORDERED POTENTIAL

Alain Aspect

Laboratoire Charles Fabry, Institut d'Optique, 2 Avenue Augustin Fresnel, F-91127 Palaiseau

We have observed 1D and 3D localization of non-interacting ultra-cold atoms in disordered potentials based on laser speckle[1, 2]. We will present these results and discuss them in the light of available theoretical treatment of Anderson localization[3, 4], and discuss the prospect of improving the present experiments and extending them to the 2D case[5], and to add controlled interactions.

References:

[1] J. Billy, V. Josse, Z. C. Zuo, A. Bernard, B. Hambrecht, P. Lugan, D. Clement, L. Sanchez-Palencia, P. Bouyer, and A. Aspect, Direct observation of anderson localization of matter waves in a controlled disorder, Nature **453** (2008) 891.

[2] Fred Jendrzejewski, Alain Bernard, Killian Mueller, Patrick Cheinet, Vincent Josse, Marie Piraud, Luca Pezze, Laurent Sanchez-Palencia, Alain Aspect, and Philippe Bouyer, Nature Physics (2012), `arXiv:1108.0137`

M 1

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EXPERIMENTAL PHASE DIAGRAM OF INTERACTING BOSONS IN A DISORDERED LATTICE

Eleonora Lucioni

LENS - Universitá di Firenze, via Nello Carrara 1, I-50019 Sesto Fiorentino, Italy

I will present our recent results which trace the first complete experimental phase diagram showing the different phases of interacting bosons in a disordered potential. The high degree of control over both the potential and the interatomic interactions in our system allows for an investigation of the effect of repulsive interactions from the regime of negligible interaction to the strongly correlated one. We study in detail the interplay between disorder, which tends to localize particles, and interaction, which can be a source of either localization or delocalization depending on its strength. We employ a tunable interacting Bose-Einstein Condensate of 39K in a one-dimensional quasiperiodic lattice. We characterize the different phases through the study of the correlation properties, the transport capability and the excitation spectrum of the system. In particular we report the observation of the so called Bose-glass phase in which the disordered system is globally insulating though it is locally superfluid and thus shows a gapless excitation spectrum.

M 2

BOGOLIUBOV THEORY OF DISORDERED BOSE-EINSTEIN CONDENSATES

Christopher Gaul

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M 3

In this contribution we tackle the interplay of interaction, disorder, and Bose statistics - a long standing problem known as the "dirty boson problem". Concretely, we present a Bogoliubov theory for disordered Bose-Einstein condensates: The bosonic field operator is split into the (mean field) condensate and (quantized) fluctuations. The mean-field part consists in solving the Gross-Pitaevskii equation to obtain the condensate wave function, which is deformed by the disorder potential. The deformed condensate, in turn, determines the Hamiltonian for the quantum fluctuations. Diagonalizing this Bogoliubov Hamiltonian is a difficult task. Anyway, it is not desirable to solve the problem for a particular realization of disorder. Thus, we resort to disorder perturbation theory in terms of Green functions to compute quantities like the disorder averaged sound velocity or the mean free path of Bogoliubov excitations. Beyond that, Bogoliubov theory can be used to count the number of particles that are excited out of the condensate, even at zero temperature. This depletion of the condensate is shown to remain small in presence of disorder, which validates a posteriory the Bogoliubov ansatz.

References:
C. Gaul & C.A. Müller, Phys. Rev. A **83**, 063629 (2011)
C.A. Müller& C. Gaul, `arXiv:1202.3489`

MIXTURES OF ULTRACOLD ATOMS IN ONE-DIMENSIONAL DISORDERED POTENTIALS

François Crépin

Universität Würzburg, Institute for Theoretical Physics and Astrophysics, Am Hubland, D-97074 Würzburg, Germany

M 4

The interplay between disorder and interactions in quantum systems is a long-standing topic of condensed matter physics. When confined to one dimension, non-interacting quantum liquids (be they fermions or bosons) are always localized by disorder and the effects of interactions can be readily studied. One (for fermions) or two (for bosons) insulator-superfluid quantum phase transitions are generically expected [1]. I will address in this theory talk the fate of a 2-component 1D mixture of cold atoms in the presence of a weak random potential [2]. We find that disorder-induced localization of one species can influence the localization of the other species through interactions. This is one of the main lessons of our analysis. We find typically three distinct phases: a delocalized phase described by a two-component Luttinger liquid, a hybrid phase where only one species is localized, and a fully localized phase where both components of the mixture are localized. The latter phase turns out to be the most interesting one since it is characterized by two nested localization length scales. We established the phase diagram by combining a renormalization group approach with the so-called Gaussian variational method, allowing us to capture the glassy phases, which appear as saddle point solutions with broken replica symmetry. Finally I will present possible signatures of these phases in various observables such as the structure factors (related to Bragg scattering experiments) and the momentum distributions observed in time-of-flight experiments.

[1] T. Giamarchi and H. J. Schulz, Phys. Rev. B **37**, 325 (1988)
[2] F. Crepin, G. Zarand and P. Simon, Phys. Rev. A **85**, 023625 (2012)

FERMIONIC AND BOSONIC EXCITATIONS IN DISORDERED SUPERCONDUCTORS

Karim Bouadim

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We obtain the finite temperature phase diagram arising from the competition between superconductivity and localization using Quantum Monte Carlo simulations. By further using Maximum Entropy methods we show that the single particle spectrum is gapped even in the presence of strong disorder, but coherence peaks are present only in the superconducting phase. Above the superconducting transition temperature, we find evidence for a pseudogap phase with suppressed density of states, finite pairing correlations but no long range phase coherence. At high disorder, there is a quantum phase transition at a critical disorder from a superconductor to a novel insulator with a finite gap for pair excitations that vanishes as the quantum critical point is approached from the insulating side.

M 5

INTERESTING LOW-DIMENSIONAL TOPICS

Thierry Jolicoeur

LPTMS UMR8626, bâtiment 100A, F-91405 Orsay Cedex, France

A 1

One-dimensional quantum systems exhibit various possible Luttinger type phases. In a first part, I review evidence for phases with trimers or multimers in cold atom systems, based to effective field theory approach (bosonization) as well as DMRG studies of lattice models. In a second part I will present results on fractional chern insulators possibly relevant to ultracold atoms involving Abelian correlated states akin to the fractional quantum Hall states at filling factors 1/2 for bosons and 1/3 for fermions.

MOMENTUM-RESOLVED SPECTROSCOPY OF ONE-DIMENSIONAL BOSE GASES

Nicole Fabbri

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A 2

The dynamical structure factor $S(q, \omega)$ provides an important depiction of the dynamic behavior of quantum many-body systems. For gaseous Bose-Einstein condensates, it allows a fully characterization of the excitation, providing information on both the collective excitations and the momentum distribution. In cold atoms experiments, $S(q, \omega)$ can be measured via inelastic light-scattering (Bragg spectroscopy), that couples two momentum states of the same internal ground-state by a stimulated two-photons transition. We are interested in characterizing one-dimensional chains of bosons, realized by loading a Bose-Einstein condensate of Rb-87 in a pair of orthogonal red-detuned optical lattices. In this talk, I will present the results of Bragg experiments on this system: We have studied its response to excitations with high momentum transfer q, which reflects the initial momentum distribution, dominated by phase fluctuations. Measuring the excitation spectra of the 1D gases for different lattice depths, we have observed an enlargement of the width of those spectra, revealing a reduction of the coherence length of the system. In addition, I will show that time-of-flight absorption imaging can be used as alternative simple probe to directly measure the coherence length of one-dimensional gases in the regime where phase fluctuations are strong [1]. This method is suitable for future studies such as investigating the effect of disorder on the phase coherence.

[1] N. Fabbri, D. Clément, L. Fallani, C. Fort, and M. Inguscio, Physical Review A **83**, 031604(R) (2011).

COHERENT DYNAMICS OF MANY-BODY SYSTEMS

Peter Barmettler

University of Geneva, 24, Quai Ernest-Ansermet, CH-1211 Geneva, Switzerland

In this talk dissipative and many-body dynamics of cold atomic gases are analyzed. One example of
the interplay of both effects is a Bose gas exposed to a local dissipative defect. We also show that the A
Mott regime of the 1D Bose-Hubbard model can be treated analytically by introducing appropriate 3
quasi-particles. This is used to explain the time-evolution of parity-correlations measured in a
recent quench experiment of a bosonic Mott insulator.

DYNAMIC KOSTERLITZ-THOULESS TRANSITION IN 2D BOSE MIXTURES OF ULTRA-COLD ATOMS

Ludwig Mathey

Center for Optical Quantum Technologies, University of Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany

We propose a realistic experiment to demonstrate a dynamic Kosterlitz-Thouless transition in
ultra-cold atomic gases in two dimensions. With a numerical implementation of the Truncated A
Wigner Approximation we simulate the time evolution of several correlation functions, which can 4
be measured via matter wave interference. We demonstrate that the relaxational dynamics is well-described by a real-time renormalization group approach, and argue that these experiments can guide the development of a theoretical framework for the understanding of critical dynamics.

STRING BREAKING MECHANISM AND THE COLD ATOM LATTICE GAUGE TOOLBOX

Marcello Dalmonte

Institute for Quantum Optics and Quantum Information, Technikerstraße 21a, 6020 Innsbruck, Austria

A 5

Lattice gauge theories constitute a valuable formalism which has lead to notable progresses on the way towards the understanding of fundamental interactions underlying particle physics. However, the computational complexity of dynamical processes and finite-density regimes is usually biased by the so called sign problem, which strongly reduces its applicability on classical machines. In this talk, we present a cold atomic toolbox to simulate basic lattice gauge theories in state-of-the-art experimental settings, showing how gauge invariance emerges in a series of different 1D and 2D setups. As a case study, we propose a possible Bose-Fermi mixture setup to observe the so called string breaking phenomenon, which represents one of the basic features of confinement mechanisms.

Thursday, June 7th, 2012

FIELD INDUCED BEC TRANSITIONS IN ANISOTROPIC MAGNETS

C. D. Batista

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M 1

Quantum magnets with uniaxial anisotropy can be described as gases of interacting bosons. An external field that acts like a chemical potential controls the particle concentration, while single-ion uniaxial anisotropy, $D(S^z)^2$, acts as an effective on-site repulsion or attraction between bosons, depending on the sign of D (easy-plane or easy-axis). We will see how these simple ingredients lead to unusual phases and magnetic field induced quantum phase transitions. The region near the field induced quantum phase transition can be universally described as a dilute gas of bosons whose effective interactions are determined from the magnetic exchange constants and single-ion anisotropy terms. Depending on the sign of these interactions and the topology of the underlying lattice, the applied field can induce simple Bose-Einstein condensates (BECs), BECs of pairs of bosons that are similar to the condensation of diatomic molecules, or even coexistence between BEC and crystalline states (the so-called spin supersolids). We will see that the field induced quantum phase transitions typically belong to the so-called BEC universality class, but they can also become first order transitions in presence of attractive boson-boson interactions.

BOSE-EINSTEIN CONDENSATION IN MAGNETIC INSULATORS

Christian Rüegg

Laboratory for Neutron Scattering, Paul Scherrer Institute WHGA 149 Villigen CH-5232, Switzerland

M 2

Magnets offer a wealth of opportunities to study a broad range of novel physical phenomena. Examples include clean realizations of magnetic quantum phase transitions, investigations of quantum critical properties, and Bose-Einstein condensation of magnetic quasi-particles, for which there are increasing parallels to ultra-cold atoms in optical lattices [1]. In arrays of quantum spin dimers in some magnetic insulators the boson (quasi-particle) density can efficiently be controlled by application of a magnetic field to cause the formation of a Bose-Einstein condensate. We have investigated such states by inelastic neutron scattering in model magnets, which cover both the effects of dimensionality and the degree of quasi-particle mobility. Recent experimental results, which explore the exciting low-dimensional limit, will be compared to those obtained in higher dimensions and to elaborate predictions by theory. Hydrostatic pressure and chemical tuning open alternative routes to directly control the spin Hamiltonian in these materials with great potential for future studies. As a recent example, pressure-tuning of the spin fluctuations in a quantum critical antiferromagnet provides unprecedented information on the excitation spectrum at a quantum critical points, which can in principle also be realized in trapped, magnetically ordered ultra-cold quantum gases.

[1] T. Giamarchi, Ch. Rüegg, O. Tchernyshyov, Nature Physics **4**, 198 (2008).

POLARITON BOSE-EINSTEIN CONDENSATION: OVERVIEW AND PERSPECTIVES

Vincenzo Savona

Laboratory of Theoretical Physics of Nanosystems, Ecole Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland

The excited electronic states of most semiconductors with a direct gap are polaritons - hybrid states of light and matter. Thanks to their hybrid nature, these particles are characterized by a high degree of quantum coherence over long range - like photons - while having a finite mass and undergoing many-body interactions like atoms. This unique combination makes of polaritons an outstanding candidate for the study of the quantum degenerate Bose gas in condensed matter. The discovery of polariton BEC in 2006 and the impressive series of experiments that followed set polaritons at the forefront of fundamental research on quantum gases.

I will present an overview of the physics of polaritons, focusing on their quantum many-body M
properties. In particular, I will discuss polaritons as a two-component interacting Bose gas and will 3
illustrate the different theoretical approaches to polariton Bose-Einstein condensation. Polaritons are a driven-dissipative system, constantly out of thermal equilibrium. Specific theoretical tools have been developed to handle this special feature. I will discuss in particular the stochastic classical field approach - a stochastic method that accounts correctly for phase fluctuations of the system out of equilibrium.

Polaritons are an ideal system for addressing open problems in the physics of the quantum degenerate Bose gas, such as low dimensionality, and disorder. They also offer the unique possibility, by means of simple spectroscopic tools, to measure directly the amplitude and phase of the order parameter, thus allowing to visualize topological defects such as quantized, half-quantized vortices, and solitons. I will conclude by briefly reviewing highlights of the recent advances in this area.

POLARITON QUANTUM FLUIDS

Alberto Bramati

LKB-UPMC, 4 place Jussieu, F-75005 Paris, France

Polaritons are composite bosons which behave as a new type of quantum fluid: its specific properties will be presented in detail. Key-Words: Microcavity polaritons, quantum fluids Exciton-polaritons are mixed light-matter quasi-particles arising from the strong coupling between photons and excitons in a micrometer sized cavity with embedded quantum wells. They have been studied extensively since the discovery of strong light-matter coupling in these systems in 1992 [1]. Polaritons are bi-dimensional composite bosons that can exhibit macroscopic quantum coherence effects at high temperatures (5-300K) due to their very low mass ($\sim 10^{-4}$ times that of the electron, inherited from their photonic component). In particular, polaritons behave as a quantum fluid with specific properties coming from their out of equilibrium nature, determined by their short lifetime (few picoseconds). In this talk I will first discuss the observation of the superfluid propagation [2, 3] of a polariton fluid directly created by resonant laser excitation in a InGaAs semiconductor microcavity. The superfluidity manifests itself by the suppression of the Rayleigh scattering on the natural defects present in the microcavity when the speed of fluid is less than the speed of sound. In the opposite case, when the flow is supersonic, the Cerenkov regime is clearly observed.

These findings are in excellent quantitative agreement with a generalized Gross- Pitaevskii theory allowing the description of the polariton superfluidity in terms of the Landau criterion, originally developed to explain the results obtained with liquid helium and recently employed to demonstrate
M the superfluidity in atomic BECs. A remarkable situation is realised when the polariton superfluid
4 flows with high speed against an obstacle whose size is larger than the superfluid healing length:
the superfluidity is then broken and a rich variety of phenomena like as quantised vortex and soliton formation are expected. I will present our recent results demonstrating the transition from the superfluid regime to the turbulent vortex generation and dark soliton nucleation due to the interaction of a polariton fluid with a defect [4, 5]. All these results show that polaritons constitute an ideal system for the study of the quantum fluids properties.

In the last part of the talk I will present a recently developed flexible technique allowing generating optically controlled potential barriers and traps for polaritons fluids and I will discuss the perspectives opened for the observation of vortex lattices in these systems.

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[1] C. Weisbuch, M. Nishioka, A. Ishikawa, Y. Arakawa, Phys. Rev. Lett. **69**, 3314 (1992)

[2] A. Amo, D. Sanvitto, F. P. Laussy, D. Ballarini, et al., Nature **457**, 291 (2009)

[3] A. Amo, J. Lefrère, S. Pigeon, C. Adrados, C. Ciuti, I. Carusotto, R. Houdré, E. Giacobino, A. Bramati, Nature Physics **5**, 805 (2009)

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[5] D. Sanvitto, S. Pigeon, A. Amo, D. Ballarini, M. De Giorgi, I. Carusotto, R. Hivet, F. Pisanello, V. G. Sala, P. S. S. Guimaraes, R. Houdré, E. Giacobino, C. Ciuti, A. Bramati & G. Gigli, Nature Photonics, **5**, 610 (2011)

ULTRACOLD GASES AS A TOOL IN CONDENSED MATTER PHYSICS

Lev Pitaevskii

University of Trento, Via Sommarive 14, I-38123 Trento, Italy and Kapitza institute for physical problems, Kosygina 2, 119334 Moscow, Russia.

The lecture is devoted to a popular presentation of experiments with trapped ultra cold gases. These
experiments open new possibilities for the condensed matter physics, permitting to create new
substances, which cannot exist in usual conditions, demonstrate fundamental quantum phenomena E
in a visual way and to check sometimes exotic theoretical predictions. The possibility of tuning 1
atom-atom interactions, using the Feshbach resonance, is particularly fruitful. In some details
experiments with Bose-Einstein condensates, strongly interacting superfluid Fermi gases and atoms
in optical lattices are discussed.

Friday, June 8th, 2012

QUANTUM ATOM OPTICS

Markus Oberthaler

University of Heidelberg, Kirchhoff Institute of Physics, Im Neuenheimer Feld 227, D-69120 Heidelberg, Germany

Interferometry has proven to be one of the most sensitive measurement techniques and has found many applications in different fields of physics. In the context of atomic physics one of the paradigm applications of interferometry is Ramsey spectroscopy applied in every realization of the time standard. A principle limit of the precision of such a device is given by the finite number of atoms involved in the interrogation. This so-called standard quantum limit can be surpassed by realizing quantum mechanically entangled input states for the interferometer – spin squeezed states. How these states can be generated and characterized in the context of Bose Einstein condensates will be discussed in detail.

M 1

QUANTUM METROLOGY USING SPATIAL INTERFERENCE WITH BOSE-EINSTEIN CONDENSATES

Francesco Piazza

Technische Universität München, Physik Department T34, James-Franck-Strasse, 85747 Garching, Germany

The analysis of the spatial interference pattern created from expanding Bose-Einstein condensates is a widely applied tool for extracting a number of informations about the quantum state of the system. Here we study its potential for metrology, where the measurement of the interference pattern serves to infer the value of a physical parameter. The non-classical correlations arising in this many-body system can allow to surpass the performance of any equivalent classical device (shot-noise limit). We consider condensates trapped in two and multiple wells, and obtain predictions for the precision of parameter estimation with the inclusion of realistic particle detection errors.

M 2

PROBING NON-EQUILIBRIUM DYNAMICS USING MATTERWAVE INTERFEROMETRY

Tim Langen

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M 3

Understanding relaxation processes is an important unsolved problem in many areas of physics. A key challenge in studying such non-equilibrium dynamics is the scarcity of experimental tools to characterize complex transient states. We employ matterwave interference to experimentally study the relaxation dynamics of a coherently split one-dimensional Bose gas and obtain unprecedented information about the dynamical states of the system by mapping the corresponding quantum mechanical probability distributions. Following an initial rapid evolution, the distribution functions reveal the approach towards a thermal-like steady state characterized by an effective temperature significantly lower than the initial equilibrium temperature of the system before the splitting process. We conjecture that this state can be described through a generalized Gibbs ensemble and associate it with pre-thermalization.

ENTANGLEMENT GENERATED BY DISSIPATION AND STEADY STATE ENTANGLEMENT OF TWO MACROSCOPIC OBJECTS

Christine Muschik

ICFO - the institute of light sciences, Av. Carl Friedrich Gauss 13, E-08860 Castelldefelsi, Spain

M 4

Entanglement is a striking feature of quantum mechanics and an essential ingredient in most applications in quantum information. Typically, coupling of a system to an environment inhibits entanglement, particularly in macroscopic systems. Here we report on an experiment, where dissipation continuously generates entanglement between two macroscopic objects. This is achieved by engineering the dissipation using laser- and magnetic fields, and leads to robust event-ready entanglement maintained for 0.04s at room temperature. Our system consists of two ensembles containing about 10^{12} atoms and separated by 0.5m coupled to the environment composed of the vacuum modes of the electromagnetic field. By combining the dissipative mechanism with a continuous measurement, steady state entanglement is continuously generated and observed for up to an hour.

LARGE QUANTUM SUPERPOSITION OF NANOSPHERES

Oriol Romero-Isart

Max Planck Institute for Quantum Optics, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany

I will present a proposal to prepare and verify spatial quantum superpositions of a nanometer-sized
object separated by distances of the order of its size. This merges techniques and insights from M
cavity quantum optomechanics and matter-wave interferometry. I will discuss the limits put by 5
standard sources of decoherence as well as the unprecedented bounds that this experiment poses
to objective collapse models of the wave function.

COLD ATOMS IN OPTICAL LATTICES AND THE PHYSICS OF STRONG QUANTUM CORRELATIONS

Antoine Georges

Collège de France et Centre de Physique Théorique (CPHT) École Polytechnique 91128 Palaiseau Cedex France

A 1 “Artificial crystals” made of ultra-cold atoms trapped by laser beams can be engineered with a remarkable level of controllability, and allow for the study of quantum physics in previously unexplored regimes, hence opening up new frontiers between condensed matter physics and quantum optics. I will review various aspects of this field, ranging from the trapping, cooling and probing of fermionic atoms into the Mott and Nel states, to the competition between interactions and dissipation and its effects on decoherence.

ENGINEERING DIRAC POINTS WITH ULTRACOLD FERMIONS IN A TUNABLE HONEYCOMB OPTICAL LATTICE

Leticia Tarruell

LP2N , Université Bordeaux-I, 351 Cours de la Libération, F-33000 Talence, France

A 2 We report on the creation of Dirac points with adjustable properties in a tunable honeycomb optical lattice. Using momentum-resolved interband transitions, we observe a minimum band gap inside the Brillouin zone at the position of the Dirac points. We exploit the unique tunability of our lattice potential to adjust the effective mass of the Dirac fermions by breaking the inversion symmetry of the lattice. Moreover, changing the lattice anisotropy allows us to move the position of the Dirac points inside the Brillouin zone. When increasing the anisotropy beyond a critical limit, the two Dirac points merge and annihilate each other. We map out this topological transition in lattice parameter space and find excellent agreement with ab initio calculations [1]. Our results pave the way to model materials where the topology of the band structure plays a crucial role, and provide the possibility to explore many-body phases resulting from the interplay of complex lattice geometries with interactions.

[1] Leticia Tarruell, Daniel Greif, Thomas Uehlinger, Gregor Jotzu and Tilman Esslinger, Nature **483**, 302 (2012).

LIGHT-CONE-LIKE SPREADING OF CORRELATIONS IN A QUANTUM MANY-BODY SYSTEM

Marc Chéneau

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How fast can correlations spread in a quantum many-body system? Based on the seminal work by Lieb and Robinson, it has recently been shown that several interacting many-body systems exhibit an effective light cone that bounds the propagation speed of correlations. The existence of such a "speed of light" has profound implications for condensed matter physics and quantum information, but has never been observed experimentally. In this talk I will report on the time-resolved detection of propagating correlations in an interacting quantum many-body system. By quenching a one-dimensional quantum gas in an optical lattice, we have revealed how quasiparticle pairs transport correlations with a finite velocity across the system, resulting in an effective light cone for the quantum dynamics. These results open important perspectives for understanding relaxation of closed quantum systems far from equilibrium as well as for engineering efficient quantum channels necessary for fast quantum computations.

A
3

DETECTING TOPOLOGICAL EDGE STATES WITH NEUTRAL ATOMS

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The recent experimental realization of synthetic magnetic fields and spin-orbit couplings for ultracold atoms [1–6] opens the attractive possibility to engineer a wide family of topological phases [7–11]. In such arrangements, one indeed expects to reproduce the physics of the quantum Hall effects and topological insulators, in a highly controllable and clean environment. However, measuring unambiguous signatures of these fascinating quantum phases, such as non-trivial topological order or the presence of current-carrying edge states, remains a fundamental issue for the cold-atom community. In this talk, I will give a brief introduction to the field of synthetic gauge potentials for optical lattices. I will show how these setups can lead to non-trivial topological phases and discuss the possibility to measure them through realistic observables. In particular, I will present a realistic and efficient method allowing the detection of topological edge states in a two-dimensional optical lattice [12].

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TRAPPED ION QUANTUM SIMULATION - SYNTHETIC GAUGES AND SPIN-PHONON LIQUIDS.

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Coulomb Crystals of trapped ions are one or two dimentional regular structures, where the quantum state of atoms can be manipulated and measured at the single-particle level. In this talk I will show
that under suitable conditions, synthetic gauge fields may be induced in the vibrational modes of A
trapped ions, something that may allow us to create motional analogs of Quantum Hall systems. 5
Also, I will show that strong spin-phonon couplings give rise to strongly correlated states where magnetic effects merge with structural phase transitions.

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Thursday, June 7th

QUADRUPOLE OSCILLATION IN A DIPOLAR FERMI GAS: HYDRODYNAMIC VS COLLISIONLESS REGIME

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The radial quadrupole mode is a surface collective oscillation of a quantum gas, unsensitive to its equation of state but sensitive to its collisional regime. In contact-interacting Fermi gases it provides a good tool to distinguish between the collisionless and the hydrodynamic regimes, since the quadrupole mode frequency jumps from $\omega_Q = 2\omega_\perp$ in the first regime to $\omega_Q = \sqrt{2}\omega_\perp$ in the second [1]. With the experimental advancement towards the realization of a polarized dipolar Fermi gas of heteronuclear molecules [2], a tool to distinguish between the two collisional regimes is needed. In this work [3] we use a mean-field description of a dipolar Fermi gas [4] to calculate the radial quadrupole mode in both the hydrodynamic [5] and collisionless regimes. We show that dipolar interactions introduce a shift in frequency in these two regimes that depends strongly on the trap geometry, especially in the collisionless case. Our results suggest that the frequency of the surface quadrupole oscillation can provide a useful test for studying, at very low temperatures, the transition between the normal and the superfluid phase [6] and, in the normal phase at higher temperatures, the crossover between the collisional and collisionless regimes. The consequences of the anisotropy of the dipolar force on the virial theorem are also discussed.

P 1

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LOCALIZATION OF AN INHOMOGENEOUS BOSE-EINSTEIN CONDENSATE IN A MOVING RANDOM POTENTIAL

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We study the dynamics of a harmonically trapped quasi-one-dimensional Bose-Einstein condensate
P subjected to a moving disorder potential of finite extent. We show that, because of the inhomo-
2 geneity of the sample, only a percentage of the atoms is localized at supersonic velocities of the
random potential. This percentage can be sensitively increased by introducing suitable correlations such as the random dimer model in the disorder pattern.

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BREAKDOWN OF SUPERFLUIDITY AND EXTREME VALUE STATISTICS IN DISORDER

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Phase coherence is a key ingredient of many characteristic quantum effects in transport phenomena, some of the most striking ones being superfluidity, conductance quantization, or the quantum Hall effect. Recent advances in creating and manipulating guided cold atoms and atom lasers opens up
P the prospect to re-examine such transport phenomena in Bose-Einstein condensates.
Superfluidity is a quantum collective phenomenon characterized by the absence of excitations in
3 a fluid below a critical velocity. We consider here a guided Bose-Einstein matter wave flowing
through a disordered potential. We determine the critical velocity at which superfluidity is broken and compute its statistical properties. They are shown to be connected to extreme values of the random potential [1]. Experimental implementations of this physics are also discussed.

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THERMALIZATION AND HIGH TEMPERATURE PHASE TRANSITIONS WITH COUPLED ATOM-LIGHT STATES

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The interaction of a hot (530K) two-level atomic ensemble with a quantized single-mode electromagnetic field in the presence of optical collisions is investigated. The main focus is on achieving thermal equilibrium for coupled atom-light states, i.e. dressed states and polaritons. First, we propose a model of atomic dressed-state thermalization that accounts for the evolution of the pseudo-spin Bloch vector components and characterize the essential role of the spontaneous emission rate in the thermalization process. Our model shows that the time of thermalization of the coupled atom-light states depends strictly on the ratio of the detuning to the resonant Rabi frequency. The predicted time of thermalization is in the nanosecond domain and about 10 times shorter than the natural lifetime for rubidium D-lines transition taken as an example. Second, the problem of photonic phase transition for the coupled atom-light system being under discussion is considered. We have shown that for large and negative atom-field detuning a photonic field exhibits high-temperature second-order phase transition to superradiant state under thermalization condition for coupled atom-light states. Such a transition can be connected with superfluid (coherent) properties of photon-like low branch polaritons. For positive detuning we have obtained population inversion in a two-level atomic ensemble. We have shown, that in this case for any finite Rabi frequency the variation of atom-field detuning or gas temperature drives a coupled atom-light system out of thermal equilibrium even if such an equilibrium (or quasi-equilibrium) has been initially achieved. In this sense population inversion in a two-level atomic ensemble enables to realize non-equilibrium (or quasi-equilibrium) transition to lasing as a result. We discuss the application of special biconical metallic waveguide cavities for polariton trapping and observing predicted effects.

P 4

INTERACTION EFFECTS IN ONE-DIMENSIONAL MANY-BODY BOSONIC TRANSPORT

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We calculate the transport properties of an ultracold gas of Bose-Einstein condensed atoms that is coupled from a magnetic trap into a one-dimensional waveguide [1,2]. A central aim of such guided atom lasers[1] is to study the role of atom-atom interaction in many-body transport processes across finite scattering regions within the waveguide resembling tunnel junctions and quantum dots. Our numerical approach to solve this many-body scattering problem is based on the Matrix Product State ansatz where we adapt absorbing boundary conditions and a external source of particles. We discuss the current, the density profiles and the transmission coefficient in the steady-state regime as functions of the interaction for varous scattering geometries.

P 5

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SPIN DRAG IN A PARTIALLY BOSE-EINSTEIN CONDENSED GAS

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P 6

Motivated by recent experiments on spin transport in a Bose gas close to Bose-Einstein condensation, we calculate the spin drag rate in a two-component Bose mixture for temperatures below the critical temperature. We find that in the case of a homogeneous gas, the spin drag rate vanishes as T^2 within the Hartree-Fock approximation and as T^5 within the Bogoliubov approximation. We also consider the trapped case and determine the damping rate of the spin-dipole mode which is related to the trap average of the spin drag relaxation time, offering predictions for future experiments.

DENSITY DISTRIBUTION IN 1D INTERACTING BOSE GAS

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P 7

Measurements of particle density fluctuations in 1D ultracold atomic gases have recently been discussed in literature (e.g [1], [2]). Quantities such as moments of density distribution function can often give access to key quantities that characterise the system, for example the third moment can tell us about the strength of three-body correlations. The experimental approach so far has been to divide the trapped 1D gas into pixels and measure how particle density fluctuates in each of them. Theoretical values can be obtained and compared by using the Fluctuation-Dissipation Theorem as applied to Yang-Yang thermodynamics. As a by-product of working with the Classical Field approximation (see [3]), we have obtained a full atomic density distribution on a given segment, for pixels of certain size scale. Relatively straightforward quantum mechanical calculations thus result in the full density distribution function, meaning that all the moments can be obtained at once.

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BOND ORDER WAVE IN 1D DIPOLAR FERMIONS

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The recent experimental realization of a quantum degenerate dipolar Fermi gas of Dysprosium, and the progress in trapping and cooling of dipolar molecules have opened the path towards ultracold quantum gases with dominant dipole interactions. In this study, we investigate the effect of dipolar interactions in commensurate one-dimensional systems in connection with the possibility of observing exotic many-body effects with trapped atomic and molecular dipolar gases. By combining analytical and numerical methods, we show how the competition between short- and long-range interactions, together with the anisotropic nature of the dipolar interaction, gives rise to frustrating effects which lead to the stabilization of spontaneously dimerized phases characterized by a bond-ordering (BOW) in both purely one dimensional and quasi-1D setups.

P 8

ELECTROMAGNETIC FIELD FLUCTUATIONS NEAR A DIELECTRIC HALF-SPACE AND APPEARANCE OF SURFACE DIVERGENCES IN THE IDEAL CONDUCTOR LIMIT

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The electromagnetic field fluctuations in the vacuum state are considered in the region external to a half-space filled with a homogeneous non-dissipative dielectric. We discuss the appropriate limits to a real and an ideal metal, focusing on the renormalized field fluctuations (equivalent to the energy densities) in the proximity of the dielectric-vacuum interface.

P 9

We show that, whereas in presence of a real conductor the renormalized field fluctuations are finite in any point of space, surface divergences at the interface arise in the ideal conductor limit. The main features of such divergences are discussed in detail. We point out that the bahavior of field fluctuations close to the interface can be investigated through the retarded Casimir-Polder interaction with an appropriate polarizable body.

NON-ABELIAN SPIN SINGLET STATES OF BOSE GASES IN ARTIFICIAL GAUGE FIELDS

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Using exact diagonalization we study strongly correlated phases of a two-component Bose gas in an artificial gauge field. The atoms are confined in two dimensions and interact via a two-body contact. For SU(2)-symmetric interactions and Abelian gauge fields, the spin singlet state is the ground state, and incompressible phases show up at fillings $\nu = 2k/3$, for which, in close analogy
P to the Read-Rezayi (RR) series in spin-polarized systems [1], a series of non-Abelian spin singlet
10 (NASS) states is known, being the exact zero-energy eigenstates of a $(k+1)$-body contact interaction
[2]. Explicit calculations reveal the relevance of these states also for our system with a realistic two-body interaction. Applying non-Abelian gauge fields, it becomes possible to switch between RR-like and NASS-like states by varying the non-Abelian gauge field strength.

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ULTRACOLD MOLECULES OF STRONTIUM: FROM Sr_2 TOWARDS RbSr

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Enhanced ability to produce ultracold molecular gases will impact many research areas, such as precision measurements of fundamental constants, study of dipolar physics, and quantum computation and simulation [1]. Here, I will report on the production of ultracold Sr_2 molecules. Since no magnetic Feshbach resonances exist in this system, we cannot use the magnetoassociation approach, which was so successful to form bi-alkali molecules. Instead, we optically associate molecules from atom pairs by stimulated Raman adiabatic passage (STIRAP). The molecule formation procedure starts with a Bose-Einstein condensate of ^{84}Sr [2]. In order to enhance the molecule creation efficiency, the condensate is loaded into an optical lattice, forming a Mott-insulator with doubly occupied sites. Then, atom pairs are associated by STIRAP using laser frequencies near the weak $^1S_0$-$^3P_1$ intercombination line. Currently, the apparatus is being extended to Rb-Sr-mixtures with the goal to produce RbSr ground-state molecules. In contrast to bi-alkalis, these molecules have not only a large electric dipole moment, but, due to three valence electrons, also a large magnetic moment. This property enables quantum simulation of spin-lattice models [3].

P 11

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THERMALIZATION MECHANISMS FOR ELEMENTARY QUANTUM SYSTEMS IN AN ENVIRONMENT OUT OF THERMAL EQUILIBRIUM

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We study the evolution and the thermalization mechanisms of an elementary quantum system embedded in a stationary radiation out of thermal equilibrium. The quantum system is placed close to a body of arbitrary geometry and dielectric permittivity, and whose temperature T_M is different from the environmental one T_E. This analysis is conducted in the case of a two and of a three level quantum system. Transition rates and steady-states become both qualitatively and quantitatively different from the case of radiation at thermal equilibrium.

P 12

Concerning the case of a two-level system [1], it thermalizes after a characteristic time to a thermal state with an effective temperature between T_M and T_E. Contrarily to the case of thermal equilibrium, the system steady state depends on the system-body distance, on the geometry of the body and on the interplay of all such parameters with the body optical resonances. Non-equilibrium steady populations result to be confined between their values at thermal equilibrium.

Concerning the case of a three-level system [2], differently from the case of a two-level system, now the steady state is not a thermal one in general and moreover steady populations can go outside their values at equilibrium. This peculiar behavior can be exploited, for example, to provide an efficient cooling mechanism for the quantum system.

We finally provide numerical studies and asymptotic expressions for the case where the body is a slab of finite thickness. Our predictions can be relevant for a wide class of experimental configurations involving different physical realizations of two or three-level systems.

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QUANTUM BROWNIAN MOTION OF IMPURITIES IN LUTTINGER LIQUIDS

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Motivated by recent experiments on impurity motion in one dimensional ultra cold quantum liquids we derive the generating functional for all non equilibrium correlation functions of a quantum Brownian particle coupled to a quantum bath of harmonic oscillators [1]. With our new method we investigate the evolution of an impurity in contact with a one dimensional bosonic quantum gas. The latter problem has been recently realized in experiments with cold atoms [2]. By using the Luttinger-Tomonaga theory we show that the quantum gas is equivalent to an exotic quantum bath of harmonic oscillators with intriguing features.

P 13

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BEHAVIOR OF THE ANOMALOUS DENSITY IN TWO-DIMENSIONAL BOSE GAS

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We investigate the behavior of the anomalous density in two dimensional homogenous Bose gas. We find that this quantity has a finite value in the limit of weak interactions at zero temperature. The effects of the anomalous density on some thermodynamic quantities are also considered. These effects can modify in particular the chemical potential, the depletion and the superluid fraction. We show also that the anomalous density presents a significant importance compared to the normal one at zero temperature. The single-particle anomalous correlation function is expressed in two dimensional homogenous Bose gases by using the density-phase fluctuation. We then confirm that the anomalous average accompanies in analogous manner the true condensate at zero temperature while it doesnt exist at finite temperature.

P 14

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HALDANE CHARGE CONJECTURE IN ULTRACOLD FERMIONS

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P 15

We investigate the nature of the Mott-insulating phases of half-filled $2N$-component fermionic cold atoms loaded into a one-dimensional optical lattice. By means of conformal field theory techniques and large-scale DMRG calculations, we show that the phase diagram strongly depends on the parity of N. This parity effect can be interpreted as the result of some frustration effect in the possible arrangement of BCS pairs on the lattice that arrises when N is odd. We single out charged, spin-singlet, degrees of freedom, that carry a pseudo-spin $J = N/2$ allowing to formulate a Haldane conjecture: for attractive interactions, we establish the emergence of Haldane insulating phases when N is even, whereas a BCS phase is found when N is odd. (The $N = 1, 2$ cases do not have the generic properties of each family.) The BCS phase for N odd and larger than 1 has a quasi-long range singlet pairing ordering. Moreover, the properties of the Haldane insulating phases with even N further depend on the parity of $N/2$. In this respect, within the low-energy approach, we argue that the Haldane phases with $N/2$ even are equivalent to a topologically trivial insulating phase and thus confirm the recent conjecture put forward by Pollmann *et al.* [3].

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DECAY OF SUPERCURRENT IN 1D METASTABLE SYSTEM

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P 16

A possible way in which a Luttinger liquid approaches equilibrium has recently been treated by Matveev and Andreev [1]. As source of dissipation, thermal fluctuations are considered. This leads to the backscattering of holes by means of scattering with bosonic excitations present in the system and the consequent thermal equilibration. The problem can be faced from the point of view of a metastable state on which excitations lie. The equilibration is obtained by introducing a dissipative term. At high enough temperatures, excitations can overcome the potential barrier of the metastable state by means of thermal fluctuations. As the temperature decreases, thermal fluctuations become small and the barrier is overcome through quantum tunnelling [2][3]. In this work, we present a review of such a scenario, emphasising a possible treatment of quantum fluctuations as the source of dissipation.

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STABILITY OF COUNTERFLOW SUPERFLUIDITY

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We examine the stability of the counterflow superfluid state in two component mixtures of ultracold atoms in optical lattices. Using a Gutzwiller mean-field approach, we find a sharp boundary separating stable counterflow from a dynamically unstable regime. As the inter-component interaction strength increases, the critical counterflow rate drops, falling to zero when interactions are strong enough to induce phase separation of the two components. Going beyond mean-field theory, we compute the decay rate of counterflow within the stable regime due to phase slips. The results agree well with numerically exact simulations and are calculated in a regime of parameters relevant to current experiments on mixtures of ultracold alkali atoms. P 17

TWO-PHOTON INTERFERENCES THROUGH DISORDERED MEDIUM

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Since the past decades, a lot of work have been done studying the propagation of light through disordered medium [1,2] and the properties of the speckle patterns obtained from classical states of light are well known [3]. Until recently little was known about how the quantum nature of light impacts this speckle pattern [4,5]. Theoretical study and experiments have shown that quantum fluctuations can be observed after a multiple scattering propagation [6,7] and that two-photon interferences survive after averaging [8]. In our theoretical work, we study the transmission of two-photon pairs through a diffusely scattering random medium. The main state of light we are dealing with is a frequency entangled two-photon state produced experimentally by parametrical down conversion [9]. We consider a slab of disorder media where light is scattered before reaching two output detectors. Using the scattering matrix theory with independent transmission coefficients [10], following a Gaussian distribution, we study the transmitted light. Its properties are characterized by the coincidence rate of photon detection in two transmitted modes. We perform the statistical analysis of this rate, which is a random quantity, and compare our results to those for a pair of independent photons (separable state) or coherent (classical) state. This allows us to clearly separate quantum and classical phenomena in our results. On the one hand,
P
we show that using entangled photons may be beneficial to probe stationary random media as
18
well as media evolving in time. On the other hand, two-photon speckle patterns contain information about the incident entangled state and can be used to measure its degree of entanglement.

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MOTT-INSULATING PHASES IN 1D FOUR-COMPONENTS FERMIONIC COLD ATOMS

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P 19

By using a combination of several non-perturbative techniques – a one-dimensional field theoretical approach together with numerical simulations using density matrix renormalization group – we present an extensive study of the phase diagram of the generalized Hund model at half-filling. This model encloses the physics of various strongly correlated one-dimensional systems, such as two-leg electronic ladders, ultracold degenerate fermionic gases carrying a large hyperfine spin $\frac{3}{2}$, other cold gases like Ytterbium 171 or alkaline-earth condensates. A particular emphasis is laid on the possibility to enumerate and exhaust the eight possible Mott insulating phases by means of a duality approach. We exhibit a one-to-one correspondence between these phases and those of the two-leg electronic ladders with interchain hopping. Our results obtained from a weak coupling analysis are in remarkable quantitative agreement with our numerical results carried out at moderate coupling.

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ULTRACOLD GASES AS A QUANTUM SIMULATOR FOR THE POLARON

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In recent years ultracold quantum gasses have revealed themselves as quantum simulators for many-body theories and in particular for those developed in the context of condensed matter physics. An example of such a system is an impurity in a Bose-Einstein condensate: this can be mapped onto the polaron which describes the quasiparticle consisting of an electron interacting with lattice vibrations. The polaron Hamiltonian has not been diagonalized analytically making it the subject of many approximation schemes of which the Jensen-Feyman variational path integral is the most general. In the weak polaronic coupling regime this approximation was experimentally confirmed to be very accurate. A comparison of the optical absorption in the strong polaronic coupling regime with diagrammatic Monte-Carlo calculations on the other hand leads to discrepancies. These have not been resolved experimentally since there is no known material that exhibits this regime.

P 20

We present a polaronic treatment based on the Jensen-Feynman variational path integral of an impurity in a condensate. This allows us to calculate the ground state properties and the response to Bragg scattering [1,2]. All typical polaronic features are retrieved and it is shown that an experimental realization is realistic. Furthermore the use of a Feshbach resonance allows a tuning of the polaronic coupling strength. This suggests it is possible to probe the polaronic strong coupling regime for the first time with this sytem. A comparison of our results with an experiment and with diagrammatic Monte Carlo calculations will shed light on important unresolved questions regarding the polaronic strong coupling regime.

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COLLECTIVE MODES IN COLD TRAPPED FERMI GASES

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P 21

We study the collective modes of cold trapped Fermi gases in the normal-fluid phase via the Boltzmann equation. Previous works showed that data are not described satisfactorily in this framework, not even including in-medium effects. We argue that the method used to solve Boltzmann equation was inappropriate. Thanks to a comparison of numerical and analytical approaches, we show that the commonly used 2nd-order moments method is insufficient. Extending the method to 4th order, we improve considerably the description of the frequency and damping of the modes.

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DYNAMICAL STRUCTURE FACTOR OF CONFINED INTERACTING ONE DIMENSIONAL QUANTUM GASES

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P 22

A confined strongly interacting one-dimensional gas at low-energy (bosonic or fermionic) is described by an inhomogeneous Tomonaga-Luttinger liquid (TLL). Due to the current experimental progress in the realization of such system by atom trapping techniques, we provide a simple analytic expression for the light-scattering cross section, requiring only the knowledge of the density dependence of the ground-state energy as it can be extracted, e.g., from exact or quantum Monte Carlo (QMC) techniques and a Thomas-Fermi description. We apply the result to the case of one-dimensional quantum bosonic gases with dipolar interaction in a harmonic trap, using an energy functional deduced from QMC computations. We find a universal scaling behavior peculiar to the TLL[1], a signature that can be probed eventually by Bragg spectroscopy in current experiments with polar molecules.

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PARAMETER ESTIMATION USING SPATIAL CORRELATION FUNCTIONS OF BOSE-EINSTEIN CONDENSATES

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P 23

We consider the measurement of spatial correlation functions as a means to infer the value of a physical parameter on which the quantum state of the system depends (e.g. the coupling to an external force, the temperature of the system, etc.). In this talk, we focus on the measure of the one-body density of a dilute interacting Bose-Einstein Condensate. We demonstrate that the precision of the estimation depends on the second order correlation function. For an ideal zero-temperature Bose gas the second order correlation trivially factorizes and does not modify the estimation precision. We provide some examples where second order correlations can instead either improve or spoil the estimation precision.

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FROM LOCALIZATION TO COHERENCE BY SINGLE PARTICLE OVERLAPS

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POLAR BOSONS IN ONE-DIMENSIONAL DISORDERED OPTICAL LATTICES

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We analyze the effects of disorder and quasi-disorder on the ground-state properties of ultra-cold polar bosons in optical lattices. We show that the interplay between disorder and inter-site interactions leads to rich phase diagrams. A uniform disorder leads to a Haldane-insulator phase with finite parity order, whereas the density-wave phase becomes a Bose-glass at very weak disorder. For quasi-disorder, the Haldane insulator connects with a gapped generalized incommesurate density wave without an intermediate critical region.
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SPONTANEOUS SOLITONS IN THE THERMAL EQUILIBRIUM OF A QUASI-ONE-DIMENSIONAL BOSE GAS

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Solitons in ultra-cold gases were first observed to be generated by phase-imprinting [1]. More recently, their spontaneous formation in 1D gases was predicted as a result of bringing the cloud out of equilibrium via the Kibble-Zurek mechanism [2] or quantum quenches [3]. We find that they actually occur generically in the thermal equilibrium state of a weakly-interacting elongated Bose gas, without the need for external forcing or perturbations [4]. This can be understood via thermal occupation of the famous and somewhat elusive Type II excitations in the Lieb-Liniger model of a uniform 1D gas.

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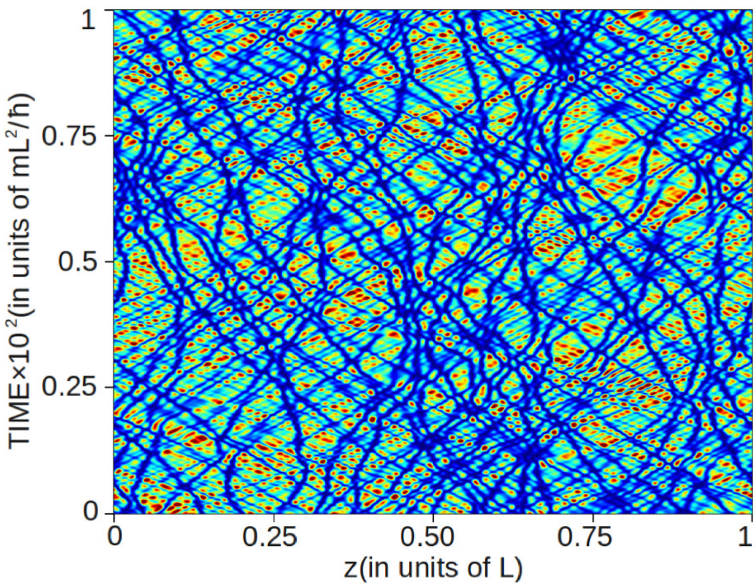

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FINITE-MOMENTUM BOSE-EINSTEIN CONDENSATES IN SHAKEN 2D SQUARE OPTICAL LATTICES

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P 27

We consider ultracold bosons in a two-dimensional square optical lattice described by the Bose-Hubbard model. In addition, an external time-dependent sinusoidal force is applied to the system, which shakes the lattice along one of the diagonals. The effect of the shaking is to renormalize the nearest-neighbor- hopping coefficients, which can be arbitrarily reduced, can vanish, or can even change sign, depending on the shaking parameter. Therefore, it is necessary to account for higher-order-hopping terms, which are renormalized differently by the shaking, and to introduce anisotropy into the problem. We show that the competition between these different hopping terms leads to finite-momentum condensates with a momentum that may be tuned via the strength of the shaking. We calculate the boundaries between the Mott insulator and the different superfluid phases and present the time-of-flight images expected to be observed experimentally. Our results open up possibilities for the realization of bosonic analogs of the LOFF phase describing inhomogeneous superconductivity.

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CRITICAL ROTATION OF AN ANNULAR SUPERFLUID BOSE GAS

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P 28

After the pioneering work on persistent flow in helium, recent experimental success at producing circulating superfluid flow of Bose gases in annular traps [1-3] has focused interest on the issue of dissipation of this macroscopic quantum state.
In this work [4], we analyze the excitation spectrum of a superfluid Bose-Einstein condensate rotating in a ring trap. We identify two important branches of the spectrum related to external and internal surface modes that lead to the instability of the superfluid. Depending on the initial circulation of the annular condensate, either the external or the internal modes become first unstable. This instability is crucially related to the superfluid nature of the rotating gas. In particular we point out the existence of a maximal circulation above which the superflow decays spontaneously, which cannot be explained by invoking the average speed of sound.

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GENERALIZED HUBBARD MODELS WITH OCCUPATION DEPENDENT PARAMETERS

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We study the ground-state properties of ultracold atoms and molecules in optical lattices in the regime of strong interactions. These systems are described by a non-standard Bose-Hubbard model with both occupation-dependent inter- and intra-band tunneling and on-site interactions. We investigate the effects of these additional terms on the phase diagram and report novel phases like pair-superfluidity, supersoldiity in polar fermions etc. P 29

ARTIFICIAL GAUGE FIELDS IN DRIVEN OPTICAL LATTICE

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The creation of artificial gauge fields is an important ingredient for engineering quantum lattice systems with ultracold neutral atoms. We show that time-periodic forcing offers a low-demanding method to generate artificial gauge fields in optical lattices. For that purpose the driving function is required to break certain temporal symmetries. We propose the realization of a topological or a quantum spin Hall insulator in a shaken spin-dependent hexagonal lattice. We describe how strong artificial magnetic fields can be achieved for example in a square lattice by employing superlattice modulation. Finally, exemplified on a shaken spin-dependent square lattice, we develop a method to create strong non-Abelian gauge fields. P 30

The poster is based on the references:

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BETHE ANSATZ AND ORDINARY DIFFERENTIAL EQUATION CORRESPONDENCE FOR DEGENERATE GAUDIN MODELS

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P 31

We generalize the numerical approach to Gaudin models developed earlier by us to degenerate systems showing that their treatment is surprisingly convenient from a numerical point of view. In fact, high degeneracies not only reduce the number of relevant states in the Hilbert space by a non negligible fraction, they also allow to write the relevant equations in the form of sparse matrix equations. Moreover, we introduce a new inversion method based on a basis of barycentric polynomials which leads to a more stable and efficient root extraction which most importantly avoids the necessity of working with arbitrary precision. As an example we show the results of our procedure applied to the Richardson model on a square lattice.

POLARON DYNAMICS AND TRANSPORT IN THE STRONGLY INTERACTING 2D FERMI GAS

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We study the strongly interacting 2D Fermi gas at large spin imbalance and compute the full spectral functions of molecules and impurity atoms ("Fermi polarons") [1]. Our predictions of a metastable repulsive polaron branch and its RF spectra have recently by confirmed experimentally [2]. For the transport properties of the balanced gas we find that scattering is strongly enhanced by the inclusion of medium effects [3]. This reduces the shear viscosity η and the spin diffusion coefficient D by a factor of three near T_c and brings the viscosity to entropy ratio close to the string theory bound $\eta/s = \hbar/(4\pi k_B)$. For the damping Γ_Q of the quadrupole mode in the trap we obtain good agreement with recent experiments [4]. As an outlook, we argue that the thermodynamic and transport properties of the unitary Fermi gas can be understood and computed rather accurately in the framework of quantum critical points and large-N expansion [5].

P
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DENSITY OF STATES IN AN OPTICAL SPECKLE POTENTIAL

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P 33

Speckles are high-contrast fine-scale granular patterns occurring whenever a radiation is scattered from a surface characterized by some roughness on the scale of the radiation wavelength. In recent years, optical speckles have been intensively employed in combination with cold atoms [1] and especially Bose-Einstein condensates (BECs) [2], in order to investigate the behavior of matter waves in the presence of disordered potentials [3]. In this work [4] we study the single particle density of states of a 1D speckle potential, which is correlated and non-Gaussian. We consider both the repulsive and attractive cases. We find that the system is controlled by a single dimensionless parameter determined by the mass of the particle, the correlation length and the average intensity of the field. Depending on the value of this parameter, the system exhibits different regimes, characterized by the localization properties of the eigenfunctions. We calculate the corresponding density of states using the statistical properties of the speckle potential. We find good agreement with the results of numerical simulations.

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GROSS-PITAEVSKII EQUATION FOR BOSE-EINSTEIN CONDENSATES IN A U-SHAPED PERMANENT MAGNETIC MICROTRAP

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In the presence of interactions, when the scattering length a is much less than the mean interparticle spacing, the nonlinear Gross-Pitaevskii equation (GPE), which employs mean-field theory, can describe the zero-temperature properties of a non-uniform Bose-Einstein condensate [1]. In some restricted situations, exact analytical solutions have already been found, but in general, solutions to the Gross-Pitaevskii equation need numerical methods [2]. Here, we numericaly solve the time-independent Gross-Pitaevskii equation for a U-shaped permanent magnetic microtrap [3], created by permanent magnetic slabs, and obtain the wave function as well as density for the rubidium atoms. We also compare these solutions with the Tomas-Fermi wave function and density. P 34

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QUANTUM KINETIC THEORY OF COLLISIONLESS SUPERFLUID INTERNAL CONVECTION

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Superfluids can transport heat via simultaneous opposite flows of their spatially interpenetrating condensate and noncondensate components. While this internal convection is usually described within Landaus phenomenological two-fluid hydrodynamics, we apply quantum kinetic theory to a dilute Bose gas held between thermal reservoirs at different temperatures and show that the phenomenon also appears in collisionless kinetic regimes and should be directly observable in currently feasible experiments on trapped ultracold vapors. P 35

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INTERACTION BETWEEN POLARONS AND ANALOGOUS EFFECTS IN POLARIZED FERMI GASES

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P 36

We have considered an imbalanced mixture of two different ultracold Fermi gases, which are strongly interacting. Calling spin-$\downarrow$ the minority component and spin-$\uparrow$ the majority component, the limit of small relative density $x = n_\downarrow/n_\uparrow$ is usually considered as a gas of noninteracting polarons. This has allowed us to calculate, in the expansion of the total energy of the system in powers of x, the terms proportional to x (corresponding to the binding energy of the polaron) and to $x^{5/3}$ (corresponding to the kinetic energy of the polaron Fermi sea). We have investigated terms physically due to an interaction between polarons and which are proportional to x^2 and $x^{7/3}$. We have found three such terms. The first one corresponds to the overlap between the clouds dressing two polarons. The two other ones are due to the modification of the single polaron binding energy caused by the nonzero density of polarons. The second term is due to the restriction of the polaron momentum by the Fermi sea formed by the other polarons. The last one results from the modification of the spin-$\downarrow$ Fermi sea brought by the other polarons. The calculation of all these terms has been made at the simplest level of a single particle-hole excitation. It has been performed for all the possible interaction strengths within the stability range of the polaron. At unitarity the last two terms give a fairly weak contribution while the first one is strong and leads to a marked disagreement with Monte Carlo results.

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ULTRA-COLD BOSONS IN ZIG-ZAG OPTICAL LATTICES

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Recent experimental advance in controlling motional degrees of freedom of ultracold bosonic atoms in optical lattices have opened the possibility of simulation of frustrated quantum antiferromagnetism. In this context we discuss properties of ultracold bosonic atoms in a quasi one dimensional zig-zag lattice, which present a rich physics due to the interplay between frustration, induced by lattice geometry, two-body interaction and a three-body constraint. Unconstrained bosons may develop chiral superfluidity and a Mott-insulator for integer fillings and a dimerized phase for half integer fillings even at vanishingly small interactions. For the case of incommensurate fillings the transitions between one- and two-component and chiral superfluid phases are studied. Bosons with an effective three-body constraint, which has been been shown to be induced by strong dissipative processes, allow for a Haldane-insulator phase - even in the absence of long range dipolar interactions - as well as pair-superfluidity and density wave phases for attractive interactions.

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RELAXATION RATES AND COLLISION INTEGRALS FOR BOSE-EINSTEIN CONDENSATES

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Mean field kinetic theory provides a method to derive kinetic equations of quantum systems at finite temperature. We apply this method to the gas of Bogoliubov excitations that is present in a dilute Bose-Einstein condensate, and obtain three distinct collision integrals. Each collision integral describes a certain type of collision between excitations that contributes towards the relaxation of the gas to equilibrium. We have linearized the collision integrals about equilibrium and computed the eigenvalues and eigenmodes of the resulting linear collision operator. These eigenvalues give the characteristic relaxation rates of each eigenmode and therefore constitute a description of the transport and dissipation properties of the gas.

P 38

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NON-ABELIAN GAUGE FIELDS AND TOPOLOGICAL INSULATORS IN SHAKEN OPTICAL LATTICES

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P 39

Time-periodic driving of an optical lattice offers a low-demanding method to generate artificial gauge fields [1]. We demonstrate that actually the power of this method is much larger. Applying it to the kagomé lattice, to a simple square lattice with superlattice modulation, and to spin-dependent hexagonal and square lattices, we show that various effects related to topological insulators [2] can be simulated. In particular, we show how it allows to control band structures with Dirac points, to create strong, slowly-varying magnetic fields in square lattices, to induce topological and quantum spin Hall physics [3], and to generate arbitrary non-Abelian SU(2) gauge fields leading to an anomalous integer quantum Hall effect [4].

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QUANTUM PHASES OF BOSE-BOSE MIXTURES ON A TRIANGULAR LATTICE

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We investigate the zero temperature quantum phases of a Bose-Bose mixture on a triangular lattice using Bosonic Dynamical Mean Field Theory (BDMFT). We consider the case of total filling one where geometric frustration arises for asymmetric hopping. We map out a rich ground state phase diagram including xy-ferromagnetic, spin-density wave, superfluid, and supersolid phases. In particular, we identify a stripe spin-density wave phase for highly asymmetric hopping. On top of the spin-density wave, we find that the system generically shows weak charge (particle) density wave order. P 40

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SPIN 1/2 BOSONIC HUBBARD MODELS

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Cold atoms on optical lattices offers the possibility, besides the study of strongly correlated phases of spinless bosons, fermions, or mixtures of particles, to study new and interesting systems such as interacting spinfull bosons, leading to the exploration of a new interplay between superfluid, solid and magnetic behaviors. It is possible to select two degenerate internal degrees of freedom and then produce so-called "spin 1/2" bosons. We studied such bosonic spin 1/2 Hubbard models on square lattices at zero and finite temperature [1,2] in the case where spin interactions are ferro- or antiferromagnetic. We also discuss the relation to p-wave superfluidity [3]. P 41

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REALIZATIONS OF NOVEL JOSEPHSON DYNAMICS IN BOSE-EINSTEIN CONDENSATES

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In a recent work [1], we have introduced an effective few mode description for weakly driven Bose-Einstein condensates, which takes into account particle interactions in a full many-body context . The nature of the participating modes, and the mathematical equivalence of this effective description, leads us to describe it as the "Orbital Josephson Effect". Here, we present a collection of possible experimental setups to realize this novel Josephson dynamics. For one of these cases we explicitly test the effective description by comparing it directly to a many body study of the full system.

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LOSCHMIDT ECHO FOR THE MANY-ELECTRON DYNAMICS IN NON-PARABOLIC QUANTUM WELLS

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The Loschmidt echo (or quantum fidelity) is investigated in the context of the many-body electron dynamics in a nonparabolic quantum well, modeled by the self-consistent Wigner-Poisson system [1]. The quantum fidelity drops abruptly after a quiescent period, as was observed for other self-interacting systems [2,3]. A unifying interpretation of this phenomenon is given in terms of trajectory separation and the Eherenfest time. The effects of Planck's constant and environment-induced decoherence are also studied.

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QUANTUM ANOMALY, UNIVERSAL RELATIONS, AND BREATHING MODE OF A TWO-DIMENSIONAL FERMI GAS

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The properties of the unitary Fermi gas in three dimensions are constrained by a nonrelativistic conformal symmetry [1,2]. The symmetry holds for a two-dimensional Fermi gas on the classical level as well, and among other things implies the existence of undamped breathing modes. My poster presents the results of a recent work [3] in which I consider a harmonically trapped Fermi gas in two dimensions and show that there is a quantum anomaly, i.e., the classical symmetry is broken by quantum effects. The anomalous correction to the symmetry algebra is given by a two-particle operator that is well known as the contact. Taking into account this modification, I provide an alternative derivation of the virial theorem for the system and a universal relation for the pressure of a homogeneous gas. I also provide an estimate for the anomalous frequency shift of the first breathing mode oscillation at zero temperature.

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COHERENCE PROPERTIES AND INFLUENCE OF DISORDER IN 2D BOSE GASES

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We experimantally study the effect of disorder on trapped quasi 2D ^{87}Rb clouds in the vicinity of the BKT phase transition. The disorder correlation length is of the order of the Bose gas characteristic length scales (ζ, λ_T) and thus modifies the physics at a microscopic level. We analyse the coherence properties of the cloud through measurements of the momentum distributions, for two disorder strengths, as a function of its degenerancy. For modereate disorder, the emergence of coherence remains steep but is shifted to a lower entropy. In contrast, for strong disorder, the growth of coherence is hinderd.

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ABSENCE OF STATIC STRIPES IN THE TWO-DIMENSIONAL T–J MODEL BY AN ACCURATE AND SYSTEMATIC QUANTUM MONTE CARLO APPROACH

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We examine the two-dimensional t–J model by using variational approach combined with well established quantum Monte Carlo techniques [1] that are used to improve systematically the accuracy of the variational ansatz. Contrary to recent density-matrix renormalization group and projected entangled-pair state calculations [2], a uniform phase is found for $J/t = 0.4$, even when the calculation is biased with an ansatz that explicitly contains stripe order. Moreover, in the small hole doping regime, i.e., $\delta \lesssim 0.1$, our results support the coexistence of antiferromagnetism and superconductivity.

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STABILITY AND EXCITATIONS OF DIPOLAR QUANTUM GASES

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Due to the recent experimental advances in creating molecular quantum gases, dipolar systems have become a topic of great interest. We study the stability of these systems in different geometries. For our calculations we use the hypernetted–chain Euler Lagrange method for the ground state, and the correlated basis function method for the excited states. Both methods include two–body correlations, therefore they can be used to describe strongly interacting systems. Due to the attractive part of the dipole–dipole interaction, there are various, different instabilities in these systems. We show calculations for polarized, dipolar bosons in a pancake shaped trap, where we conclude that, under certain conditions, the system is unstable due to dimerization. Additionally we study a two–dimensional system of polarized dipoles, with varying orientation of the polarization direction with respect to the 2D-plane. The resulting anisotropy in this system leads to an anisotropic excitation spectrum, and we analyze the stability of the ground state upon changing the polarization angle.

QMC CALCULATION OF RÉNYI ENTANGLEMENT ENTROPIES AND LOCAL NUMBER FLUCTUATIONS

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We present a general scheme for the calculation of the Rényi entropy S_2 of a subsystem in quantum many-body models that can be efficiently simulated via quantum Monte Carlo [1]. When the simulation is performed at very low temperature, the above approach delivers the entanglement Rényi entropy of the subsystem, and it allows to explore the crossover to the thermal Rényi entropy as the temperature is increased. We show that relevant models in two dimensions with reduced symmetry (XX model or hardcore bosons, transverse-field Ising model at the quantum critical point) exhibit an area law for the scaling of the entanglement entropy. Furthermore we find that a peculiar cordlength dependence of a subleading bulk contribution to S_2, which was demonstrated numerically in reference [2] for several two-dimensional gapless systems, is also present in the XX model and in the critical transverse-field Ising model. P 48

Finally we try to relate the scaling of the entanglement entropy to the scaling of local number fluctuations, which in the case of hardcore bosons have recently become measurable in cold atoms experiments.

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ANISOTROPIC GINZBURG-LANDAU AND LAWRENCE-DONIACH MODELS FOR LAYERED ULTRACOLD FERMI GASES

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We study the anisotropic Ginzburg-Landau and Lawrence-Doniach models describing a layered superfluid ultracold Fermi gas in optical lattices. We derive the coefficients of the anisotropic Ginzburg-Landau and the mass tensor as a function of anisotropy, filling and interaction, showing that near the unitary limit the effective anisotropy of the masses is significantly reduced. The anisotropy parameter is shown to vary in realistic setups in a wide range of values. We also derive the Lawrence-Doniach model - often used to describe the 2D-3D dimensional crossover in layered superconductors - for a layered ultracold Fermi gas, obtaining a relation between the interlayer Josephson couplings and the Ginzburg-Landau masses. We find that using only couplings between adjacent planes is correct in the BEC side and that at the unitary limit one can use only nearest and next-nearest neighboring couplings, while in the BCS side contributions from longer range interlayer couplings appear. P 49

DYNAMICS OF PATTERN-LOADED BEC CHAINS, QUENCH DYNAMICS IN MANY-PARTICLE MODELS, AND TRANSPORT IN PERIODICALLY DRIVEN LATTICES

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We present several semiclassical studies related to BEC physics. Our approach is based on representing a quantum state as an ensemble of classical trajectories and propagating it in time (Truncated Wigner Approximation). Quantum observables are obtained by averaging over the classical ensemble; analytical results for such averaging are obtained using asymptotic methods of classical Hamiltonian dynamics. Firstly, we consider dynamics of small (three- and four-sites) pattern-loaded Bose-Hubbard chains [1,2]. Initially, in the four-site chain selectively every second site is loaded with Bose atoms, and in the three-site chain only one site (i.e., every third) is loaded. Subsequent far-from equilibrium dynamics of the systems is then investigated. Similar pattern-loaded systems has been investigated theoretically and experimentally recently [3,4], and serve to illustrate many fundamental issues in nonequilibrium many-body dynamics.

P Secondly, slow quench dynamics in few-site Bose-Hubbard models, and in Dicke models is studied
50 [2,5,6]. In these systems, as a parameter is slowly varied, classical trajectories of a semiclassical wavepacket undergo passage through a bifurcation, while the quantum system undergoes passage through a quantum phase transitions. Averaging over the classical ensemble enable to derive universal distributions in Hilbert space of corresponding quantum systems.

Thirdly, we consider transport phenomena in periodically driven quantum and classical lattices [2,7]. An asymptotic formula for average transport velocity is derived for the case of high-frequency driving [7].

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LIGHT SCATTERING FROM ULTRACOLD BOSONS IN BICHROMATIC OPTICAL LATTICE

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Anderson localization of particles in a quasi-periodic lattice was first investigated theoretically by Aubry and André [1]. It has been also realized in experiment with ultracold bosons in a bichromatic optical lattice [2]. In such a system, both the disorder strength and the interactions between the particles may be controlled separately, which allows to produce and study exotic quantum phases, such as the Bose glass.

In this work, we consider a gas of bosons in a bichromatic optical lattice at finite temperatures. As the amplitude of the secondary lattice grows, all the single-particle eigenstates become localized. We calculate the canonical partition function using exact methods for the noninteracting and strongly interacting limit and analyze the statistical properties of the superfluid phase, localized phase and the strongly interacting gas. We show that those phases may be distinguished in experiment using off-resonant light scattering. P 51

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LOCALIZATION OF ULTRACOLD ATOMS IN DISORDER: 3D LOCALIZATION AND COHERENT BACKSCATTERING.

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Phase coherence has dramatic effects on the transport properties of waves in random media. Indeed interferences between scattering events act against diffusion, and eventually lead to a complete halt of the wave, i.e. Anderson localization. Since its first prediction in 1958, this Anderson localization has been widely studied with various kinds of waves, from light to electronic waves. However open questions remain, especially about the precise nature of the celebrated Anderson transition between localized (insulating) states and diffusive (conducting) states that occurs in 3D.

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Here, I will first report the observation of the three-dimensional localization of ultracold atoms in a well-controlled laser speckle potential [1]. The observed localization cannot be interpreted as the classical trapping of particles with energy below the classical percolation threshold in the disorder, nor can it be understood as quantum trapping in local potential minima. Instead, our data are compatible with the self-consistent theory of AL tailored to our system. These results pave the way towards the precise investigation of the critical regime around the transition in 3D.

Last, I will report the direct observation of coherent backscattering of ultracold atoms. As proposed in [2,3], the CBS is revealed from the momentum space analysis. This observation does not only constitute a smoking gun of phase coherence in ultracold disordered gases but it also provides an alternative probe to study localization effects.

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BOSONIC FRACTIONAL QUANTUM HALL STATES IN GEOMETRIC GAUGE FIELDS

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We use the exact diagonalization method to analyze the possibility of generating strongly correlated states in two-dimensional clouds of ultracold bosonic atoms that are subjected to a geometric gauge field that was created by coupling two internal atomic states to a laser beam. On tuning the gauge field strength, the system undergoes stepwise transitions between different ground states (GSs), which we describe by using analytical trial wave functions, including the Pfaffian (Pf), the Laughlin and a Laughlin quasiparticle many-body state. Whereas for an infinitely strong laser field, the internal degree of freedom of the atoms can adiabatically follow their center-of-mass movement, a finite laser intensity gives rise to non-adiabatic transitions between the internal states, which are shown to break the cylindrical symmetry of the Hamiltonian. We study the influence of the asymmetry on the GS properties of the system. The main effect is to reduce the overlap of the numerical solutions with the analytical trial expressions by occupying states with higher angular momentum. Thus, we propose generalized wave functions arising from the Laughlin and Pf wave functions by including components where extra Jastrow factors appear while preserving important features of these states. We analyze quasihole excitations over the Laughlin and generalized Laughlin states and show that they possess effective fractional charge and obey anyonic statistics. Finally, we discuss the observability of the Laughlin state for increasing numbers of particles.

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MOBILE IMPURITIES IN ONE-DIMENSIONAL COLD GASES

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Advances in cold gases physics are beginning to enable experiments involving the direct manipulation and observation of single- or few-atom mobile impurities [1] within a many-body quantum system, a topic of longstanding interest for condensed matter theory, where it is related to studies of e.g. conductivity and the X-ray edge problem. Further progress in this direction is expected from the latest generation of experiments offering single-site addressability in optical lattices [2,3]. In light of these developments we study the dynamics of mobile impurities in 1D quantum liquids using a DMRG technique. We address the recently proposed subdiffusive regime of impurity motion
P [4], a class of excitations beyond those described by the standard Tomonaga-Luttinger theory.
54 We study the conditions for observing this regime and its' crossover to the ballistic regime. We furthermore examine the possibilities to observe the intermediate diffusive motion of impurities in these systems.

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SINGLE-ATOM-RESOLVED DETECTION AND MANIPULATION OF STRONGLY CORRELATED FERMIONS IN AN OPTICAL LATTICE

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Single-atom-resolved detection and manipulation of strongly correlated fermions in an optical lattice. We illustrate our progress and future plans in our attempts to realize single-atom-resolved, in-situ imaging and manipulation of strongly correlated fermions in an optical lattice. Whereas very recently strongly correlated bosonic systems have been imaged in an optical lattice at the single atom level, an experimental proof of single-site-resolved detection of fermions is still lacking.
P A dual-species two-stage Magneto-Optical Trap of 87Rb and 40K is loaded into a magnetic trap,
55 before transport and evaporative cooling in an optical trap delivers a quantum degenerate Bose-Fermi mixture to a 3-dimensional optical lattice. By selective removal of atoms from all lattice planes but the one at the focal plane of a NA 0.68 microscope objective, we will be able to resolve the distribution and evolution of atoms in the 2D lattice at the single-site level using fluorescence imaging. Furthermore, single-site manipulation will be possible by means of an addressing beam via the microscope. With the ability to detect and manipulate quantum states at the level of a single atom, our project will then exploit the potential of ultracold atoms as a quantum simulator for, e.g., the Fermi-Hubbard model, which is a key model in condensed matter physics.

SQUEEZING IN DRIVEN BIMODAL BOSE-EINSTEIN CONDENSATES: ERRATIC DRIVING VERSUS NOISE

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We study the interplay of squeezing and phase randomization near the hyperbolic instability in a two-site Bose-Hubbard model. Two different methods of randomization are contrasted – a quantum noise source and an erratic drive with the same fluctuations – and significant differences are found. These are related to the distribution of the squeezing factor, which has log-normal characteristics; P
hence its average is significantly different from its median due to the occurrence of rare events. 56
These events are missed by the sampling of the erratic drive; however, the ensemble statistics can be used to approximate correctly the long-time average, extending the previously found quantum Zeno expression.

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REAL-TIME DYNAMICS OF QUANTUM GASES WITH THE NONEQUILIBRIUM 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. P 57

HYDRODYNAMIC PHENOMENA IN A TWO-COMPONENT IMMISCIBLE BOSE-EINSTEIN CONDENSATE

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We develop analytical models for non-linear dynamics of analogue of capillary- gravitational waves on an interface between two Bose-Einstein condensates (BECs) at zero temperature [1],[2]. Two-component BECs can be realized experimentally [3] with the use of hyperfine states of ^{87}Rb which possess magnetic degree of freedom. This makes possible application of time-varying forces (oppositely) to both components. In the framework of coupled Gross-Pitaevskii equations (GP) we predict various dynamic structures due to quantum analogues to classical hydrodynamic instabilities, and describe in detail an exclusively quantum effect of dynamic interpenetration with subsequent onset of swapping of places of the components confined in an optical trap. We find good agreement of our predictions with our real-time numerical solution to the coupled GP.

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FUNCTIONAL RENORMALISATION GROUP: APPLICATION TO MANY-FERMION SYSTEMS

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We study the application of the exact renormalisation group to a many-fermion system with a short-range attractive force. We introduce a boson field to describe pairing effects, and take a simple ansatz for the effective action. We derive a set of approximate flow equations for the effective coupling including boson and fermionic fluctuations. At some critical value of the running scale, the numerical solutions show a phase transition to a gapped phase. Standard results are recovered if we omit the boson loops. We calculated the energy gap, ground state energy in both unitary and weak coupling regimes and study BCS-BEC crossover. We also analyze the systems with mass asymmetry.

SPREADING OF A BOSE GAS IN A BICHROMATIC LATTICE

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We study the spreading of a Bose gas in a one dimensional bichromatic lattice focusing on the interplay between interaction and disorder induced localization. The dynamics of interacting bosons is modelled using the discrete nonlinear Schrdinger equation. We show that the interaction between atoms introduces two main effects: it destroys localization, resulting in a subdiffusive spreading of P the atomic cloud $w(t) \sim t^{\gamma}$ with spreading exponent $\gamma < 0.5$ and, if it is large enough, it also leads to 60 self-trapping. We compare the spreading exponents obtained from the numerical simulations with those measured experimentally. Finally we theoretically interpret this delocalization on the basis of mode-mode resonances and show that one can predict different spreading regimes by comparing the strength of the nonlinearity with the energy scales of the underlying linear system.

QUANTUM FLUCTUATIONS AND HAWKING RADIATION AROUND BLACK HOLE HORIZONS IN BOSE–EINSTEIN CONDENSATES

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Simple sonic analogues of black holes can be realized by the flow of a liquid through a pipe. If the flow is supersonic in some region of space, a sound wave issued from this region is dragged away and cannot flow upstream. One speaks of a dumb hole.

Dumb holes have been considered as potential tools for studying black hole radiation which is a P quantum effect predicted by S. Hawking in the 70's. This domain has recently gained interest in 61 the BEC community because of the extraordinary experimental control over BEC systems and also thanks to an idea of two Italian groups who proposed to study density correlations as probes of the Hawking radiation.

I will present several realistic experimental configurations allowing to measure black hole radiation and will discuss some analytical and numerical predictions.

ANDERSON LOCALIZATION AND MOBILITY EDGES IN A SYSTEM OF STRONGLY-INTERACTING BOSONS IN A ONE-DIMENSIONAL LATTICE

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We study a system of strongly interacting bosons in a one-dimensional lattice in the presence of incommensurate modulating potentials. Such a system is known to display Anderson localization. Focussing on situations where there is a mobility edge in the spectrum, we study both ground state and dynamical properties using exact and approximate numerical techniques.

SUPERFLUID-INSULATOR TRANSITION IN DISORDERED BOSE GASES AT FINITE TEMPERATURE

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We investigate the superfluid to insulator transition of a weakly-interacting Bose gas at finite temperature in the presence of disorder. We show that the superfluid properties are governed by two competiting effects: on the one hand, the disorder modulates the meanfield background, which tends to deplete the superfluid fraction. On the other hand, the disorder makes the excitations of the gas more robust to an imposed superfluid flow, which reduces the thermal depletion of the superfluid fraction. As a result, the superfluidity shows a non trivial behavior versus temperature and disorder. For instance, we find that in some regimes, the superfluidity is enhanced by the disorder.

POMERANCHUK EFFECT AND SPIN-GRADIENT COOLING OF BOSE-BOSE MIXTURES IN AN OPTICAL LATTICE

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We theoretically investigate finite-temperature thermodynamics and demagnetization cooling of two-component Bose-Bose mixtures in a cubic optical lattice, by using bosonic dynamical mean field theory (BDMFT) [1]. We calculate the finite-temperature phase diagram, and remarkably find that the system can be *heated* from the superfluid into the Mott insulator at low temperature, analogous to the Pomeranchuk effect in ^{3}He. This provides a promising many-body cooling technique. We examine the entropy distribution in the trapped system and discuss its dependence on temperature and an applied magnetic field gradient. Our numerical simulations quantitatively validate the spin-gradient demagnetization cooling scheme proposed in recent experiments [2].

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BLOCH-ZENER OSCILLATIONS ACROSS A MERGING TRANSITION OF DIRAC POINTS

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Bloch oscillations are a powerful tool to investigate spectra with Dirac points. By varying band parameters, Dirac points can be manipulated and merged at a topological transition towards a gapped phase. Under a constant force, a Fermi sea initially in the lower band performs Bloch oscillations and may Zener tunnel to the upper band mostly at the location of the Dirac points. The tunneling probability is computed from the low energy universal Hamiltonian describing the vicinity of the merging [1]. The agreement with a recent experiment on cold atoms in an optical lattice is very good [2].

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ENERGETICALLY STABLE SINGULAR VORTEX CORES IN SPIN-1 BOSE-EINSTEIN CONDENSATES

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We analyze the structure and stability of singular singly quantized vortices in a rotating spin-1 Bose-Einstein condensate. We show that the singular vortex can be energetically stable in both the ferromagnetic and polar phases despite the existence of a lower-energy nonsingular coreless vortex in the ferromagnetic phase. The spin-1 system exhibits an energetic hierarchy of length scales resulting from different interaction strengths and we find that the vortex cores deform to a larger size determined by the characteristic length scale of the spin-dependent interaction. We show that in the ferromagnetic phase the resulting stable core structure, despite apparent complexity, can be identified as a single polar core with an axially symmetric density profile which is nonvanishing everywhere. In the polar phase, the energetically favored core deformation leads to a splitting of a singly quantized vortex into a pair of half-quantum vortices that preserves the topology of the vortex outside the extended core region, but breaks the axial symmetry of the core. The resulting half-quantum vortices exhibit nonvanishing ferromagnetic cores.

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TWO-DIMENSIONAL DIPOLAR FERMI SYSTEM: FERMI LIQUID VERSUS CRYSTAL

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The ground state properties of a homogeneous 2D dipolar Fermi system was studied by the fixed-node diffusion Monte-Carlo method at zero temperature. At the weak interaction regime the system can be described in terms of Fermi liquid theory. When the interaction increases the quantum phase transition to crystalline phase occurs. We have found the phase transition point by comparing the liquid and crystal ground state energies. Also we have calculated the pair-distribution function, momentum distribution and effective mass of a quasiparticle for Fermi liquid phase. From discontinuity of momentum distribution the renormalization factor has been established.

FINITE TEMPERATURE EFFECTS IN TWO-MODE BOSONIC JOSEPHSON JUNCTIONS

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We analyze the effects of the temperature on a bosonic Josephson junction realized with ultracold and dilute atoms in a double-well potential. Starting from the eigenstates of the two-site Bose-Hubbard Hamiltonian, we calculate the coherence visibility and the fluctuation of the on-site occupation number and study them as functions of the temperature. We show that, contrary to naive expectations, when the boson-boson interaction is suitably chosen thermal effects can increase the coherence visibility and reduce the on-site number fluctuation. P 68

ENTANGLEMENT OF IMPURITIES IN A BOSE-EINSTEIN CONDENSATE NON-MARKOVIAN RESEVOIR

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P 69

In quantum physics, we often study systems in isolation to avoid disturbances due to environmental effects. However, in recent years the area of open quantum systems has sought to consider a system of interest together with an environment, such as a light field. This area has two key advantages. The experimental challenge of fully isolating systems from outside influences makes an approach that allows us to include an additional environment appealing. Further, with a careful choice of environment, it is possible to have beneficial effects on the subsystem, such as increased stability or sudden death and sudden rebirth of entanglement.

In this research we consider an experimentally realisable system consisting of an optical lattice with two atom impurities superimposed on a dilute Bose-Einstein condensate dephasing environment. The atoms are trapped in a deep double well geometry such that tunnelling between adjacent wells is suppressed. There is, however, interaction between the trapped atoms and the Bose-Einstein condensate environment mediated by the Bogoliubov excitations of the condensate.

Using a master equation approach, we calculate the decoherence exponents for the time evolution of the density matrix for the system. We consider two body quantum effects such as quantum correlations and entanglement. Using experimentally accessible parameters of the reservoir and the optical lattice, we create a phase diagram showing the occurrence of quantum effects such as sudden death and rebirth of entanglement for different parameter regimes.

CURRENT AND ENTANGLEMENT IN A BOSE-HUBBARD LATTICE

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We study the generation of entanglement for interacting cold atoms in an optical lattice. The entanglement is generated by managing the interaction between two distinct atomic species. It is found that the current of one of the species can be used as a good indicator of entanglement generation. The thermalization process between the species is also shown to be closely related to the evolution of the current. P 70

QUANTUM KINETIC ELECTRON-HOLE TRANSPORT IN MULTIBAND STRUCTURES

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An increasing activity has been devoted to design new electronic devices able to exploit the unusual transport properties showed by some new materials. In particular various experimentalist groups showed the possibility to produce high quality graphene sheet which can be easily connected with silicon-based heterostructures. the intriguing possibility to study the implication of relativistic-like electron behaviour in the low energy solid state framework [1]. Different approaches have been proposed to achieve a quantum description of electron transport in quantum devices. Among them, the phase-space formulation of quantum mechanics offers a framework in which quantum phenomena can be described in a classical language and the question of the quantum-classical correspondence can be directly investigated. In particular, the visual representation of the motion by quantum-corrected phases-plane trajectories, is a valuable aid to a conceptual unders tanding of the complex quantum dynamics. In our contribution, a full quantum dynamical model based on the phase-space framework has been applied to study the motion of particles in graphene including scattering processes and the interband tunneling. The quantum coherence between the particles in the upper and the lower band is taken into account by the definition of a suitable multi-component Wigner function. Our procedure allow us to describe the motion of a particle in graphene in a full quantum contest where the relevant intraband and interband interference effects can be included. P 71

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WAVE-PACKET DYNAMICS IN NONLINEAR SCHRÖDINGER EQUATIONS

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Coherent states play an important role in quantum mechanics because of their unique properties under time evolution. Here we explore this concept for one-dimensional repulsive nonlinear Schrdinger equations, which describe weakly interacting Bose-Einstein condensates or light propagation in a nonlinear medium. It is shown that the dynamics of phase-space translations of the ground state of a harmonic potential is quite simple: The center follows a classical trajectory whereas its shape does not vary in time. The parabolic potential is the only one that satisfies this property. We study the time evolution of these nonlinear coherent states under perturbations of their shape or of the confining potential. A rich variety of effects emerges. In particular, in the presence of anharmonicities, we observe that the packet splits into two distinct components. A fraction of the wavepacket is transferred toward incoherent high-energy modes, while the amplitude of oscillation of the remaining coherent component is damped toward the bottom of the well.

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INTERFERENCE OF ULTRACOLD MATTER WAVES AT THE ANDERSON LOCALIZATION THRESHOLD

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We investigate the dynamics of coherent matter waves launched in a two-dimensional random potential. Phase-coherent transport leads to a pronounced coherent backscattering (CBS) peak in the momentum distribution [1,2]. At the onset of Anderson localization, we discover a novel interference peak in the forward direction. An explanation in terms of chained CBS events predicts that a coherent forward scattering (CFS) peak emerges on the scale of the localization-volume Heisenberg time $\tau_H = 2\pi\nu\xi^2$ (ν is the density of states per unit surface, and ξ the localization length). Monitoring the momentum-space dynamics thus gives access to all relevant time scales, and the twin peaks of CBS and CFS together are an unambiguous signal for Anderson localization. P 73

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NONEQUILIBRIUM PROPERTIES OF AN ATOMIC QUANTUM DOT COUPLED TO A BOSE-EISTEIN CONDENSATE

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We consider an atomic quantum dot (AQD) realized by a focused laser beam superimposed to a trapped atomic Bose Einstein condensate (BEC) in which a single atom is coupled to a superfluid reservoir via laser transitions[1]. In this contribution we study nonequilibrium quantum transport [2] in such a system within Keldysh-Green's function formalism when the AQD level is varied harmonically in time. The energy absorption and the atom current through the dot are calculated in the Coulomb blockade limit. We find that nonequilibrium features develop in the AQD energy absorption spectrum as an effect of photon absorption and emission. Finally we show that atoms can be efficiently transferred from the BEC into the AQD for the parameter regime of current experiments with cold atoms. P 74

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DYNAMICS OF BISOLITONIC MATTER WAVES IN A BOSE-EINSTEIN CONDENSATE SUBJECTED TO AN ATOMIC BEAM SPLITTER AND GRAVITY

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We consider a theoretical scheme for an experimental implementation involving bisolitonic matter waves from an attractive Bose-Einstein condensate within the framework of a non-perturbative approach to the associate Gross-Pitaevskii equation. The model consists of a single condensate subjected to an expulsive harmonic potential, resulting in a double-condensate structure, and a gravitational potential that induces atomic exchanges between the two overlapping post condensates.

Using a non-isospectral scattering transform method, exact expressions for the bright-matter wave bisolitons are obtained in terms of double-lump envelopes with the co-propagating pulses displaying more or less pronounced differences in their widths and tails depending on the mass of atoms composing the condensate.

EXOTIC QUANTUM CRITICALITY IN 1D COUPLED DIPOLAR BOSONS TUBES

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A lot of efforts were made in the past few years to realize quantum gases with dipole-dipole interactions. Their long-range anisotropic character could give access to exotic phenomena, that differ from those occuring in quantum gases with contact interactions, in particular in the strongly correlated regime. Here, we investigate the competition between intertube hopping processes and density-density interactions in one-dimensional quantum dipolar bosons systems of N coupled tubes at zero temperature. Using a phenomenological bosonization approach, we show that the resulting competition leads to an exotic quantum phase transition described by a $\mathrm{U}(1) \times \mathbb{Z}_N$ conformal field theory with a fractional central charge. The emerging $\mathbb{Z}_N$ parafermionic critical degrees of freedom are highly nontrivial in terms of the original atoms or polar molecules of the model. This opens the possibility to study the exotic properties of the $\mathbb{Z}_N$ parafermions in the context of ultracold quantum Bose gases.

ANDERSON LOCALIZATION OF MOLECULES IN QUASI-PERIODIC OPTICAL LATTICES

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We investigate the formation of molecules made of two interacting atoms moving in a bicromatic optical lattice with incommensurate periodicities. We show how the fractal behavior of the single particle spectrum at the metal -insulator transition manifests itself in the energy of weakly bound molecules. We then discuss the localization properties of molecules and give the complete phase diagram which holds for both attractively and repulsively bound pairs. Experimental signatures of such transition are also discussed. P 77

TRAP ANHARMONICITY AND SLOSHING MODE OF A FERMI GAS

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For a gas trapped in a harmonic potential, the sloshing (or Kohn) mode is undamped and its frequency coincides with the trap one, whatever the statistics, interaction and temperature of the gas are. However, experimental traps are gaussians and anharmonicity effects appear as the filling of the trap is increased. In this work, we study the sloshing mode of a trapped degenerate Fermi gas via the phase-space moments method for the Boltzmann equation, that has proven quite successful in the description of other collective modes. We include in-medium effects in both the transport and collision terms and apply the method at first (lowest) and third (next) order. We find that the sloshing mode in an experimental trap and with in-medium effects shows a deviation of its pulsation (of about 10 % for a temperature around the Fermi temperature) and exhibits a non-negligible damping which is increasing with the gas temperature. P 78

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CONTROLLING INTEGRABILITY IN A QUASI-1D ATOM-DIMER MIXTURE

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We analytically study the atom-dimer scattering problem in the near-integrable limit when the oscillator length l_0 of the transverse confinement is smaller than the dimer size, $\sim l_0^2/|a|$, where $a < 0$ is the interatomic scattering length. The leading contributions to the atom-diatom reflection and break-up probabilities are proportional to a^6 in the bosonic case and to a^8 for the $\uparrow$-$\uparrow\downarrow$ scattering in a two-component fermionic mixture. We show that by tuning a and l_0 one can control the "degree of integrability" in a quasi-1D atom-dimer mixture in an extremely wide range leaving thermodynamic quantities unchanged. We find that the relaxation to deeply bound states in the fermionic (bosonic) case is slower (faster) than transitions between different Bethe ansatz states. We propose a realistic experiment for detailed studies of the crossover from integrable to nonintegrable dynamics.

ELASTIC CONSTANTS OF HCP ^{4}HE THROUGH OF PATH INTEGRAL MONTE CARLO.

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Through of Path Integral Monte Carlo method **(PIMC)** we determine the elastic constants of solid ^{4}He in its hcp phase. These elastic properties are very important in view of their apparent involvement in the phenomenon of supersolidity in solid ^{4}He . The stiffness coefficients are obtained by imposing different distortions to a periodic cell containing 180 atoms, followed by measurement of the elements of the corresponding stress tensor. For this purpose an appropriate path-integral expression for the stress tensor observable is derived and implemented into the pimc$_{++}$ package. A comparison of the results to available experimental data shows an overall good agreement of the density dependence of the elastic constants, with the single exception of C_{13}.

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INVESTIGATION OF THE DRAG FORCE ON A FINITE WIDTH IMPURITY IN A BOSE-EINSTEIN CONDENSATE

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The remarkable appearance of a nonzero drag force on impurities in a superfluid *below* the critical velocity has been reported recently[1]. That work considered a zero-width moving impurity in a Bose-Einstein condensate. Here we report progress on the analysis of this effect for more realistic impurities. We consider a model composed of a two-component gas in which a bright soliton in one component interacts with a uniformly flowing condensate in the other component. P 81

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STATE-CHANGING COLLISIONS IN ULTRA-COLD POLAR MOLECULES IN A BILAYER

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Ultra-cold polar molecules in a bilayer geometry interact by dipole–dipole forces. We show that these interactions may lead to interesting effects even if the molecules are not polarized, i.e. in weak electric fields. If the molecules in each layer are initially prepared in a different rotational state, we show that the inter-layer dipole–dipole interaction leads a swap of the rotational state of molecules in different layers in two-body collisions. The rate of these state-changing collisions shows a non-trivial behavior as a function of density, temperature, and layer spacing. Remarkably, for optically trapped highly reactive molecules like KRb, such state swaps lead to losses by chemical reactions, and hence the sigantures of state-changing collisions can be easily observed by monitoring the molecule number. [Phys. Rev. A 84, 061605(R) (2011)] P 82

ULTRACOLD ATOMS IN OPTICAL LATTICES: BEYOND THE HUBBARD MODEL

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We investigate the properties of strongly interacting atomic gases in optical lattices, addressing the regime of weak and intermediate optical potentials where the conventional description in terms of the single band Hubbard model is not reliable. In the case of bosonic atoms, we introduce a novel hybrid Monte Carlo technique which allows to simulate the superfluid to insulator transition in continuous space, thus going beyond the single-band approximation [1]. We compare the Monte Carlo results with experimental data [2], finding excellent agreement. For fermions, we apply Kohn-Sham Density Functional Theory (DFT), which is the most powerful computational tool routinely used in material science to simulate the electronic structure of solids. In this work, we use a new energy-density functional for repulsive Fermi gases with short-range interactions, as opposed to the Coulomb interaction in electronic systems. The first results based on a local spin-density approximation show evidence of a ferromagnetic phase due to repulsive interactions, and of anti-ferromagnetic order at half filling. As an outlook, we will discuss how the development of DFT for ultracold atomic gases can form a strong link between materials science and atomic physics.

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MATTER WAVE TRANSPORT AND ANDERSON LOCALIZATION IN ANISOTROPIC DISORDER

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We study theoretically quantum transport of matter waves in anisotropic three-dimensional disorder. We will first show that structured correlations can induce strong and unexpected effects, such as reversed anisotropies of scattering and diffusion, anisotropic suppression of the white-noise limit, and inversion of the transport anisotropy. We will also show that the localization threshold (mobility edge) is strongly affected by a disorder-induced shift of the energy states, which we calculate. P 84

Our work is directly relevant to recent experiments of ultracold-matter waves in optical disorder [1,2] and implications on those experiments will be discussed. It also offers scope for further studies of anisotropy effects in other systems with controlled disorder, where counterparts of the discussed effects can be expected.

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MATTER WAVES ANALOG OF AN OPTICAL RANDOM LASER

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The accumulation of atoms in the lowest energy level of a trap and the subsequent out-coupling of these atoms is a realization of a matter-wave analog of a conventional optical laser. Optical random lasers require materials that provide optical gain but, contrary to conventional lasers, the modes are determined by multiple scattering and not a cavity. We show that a Bose-Einstein condensate can be loaded in a spatially correlated disorder potential prepared in such a way that the Anderson localization phenomenon operates as a band-pass filter. A multiple scattering process selects atoms with certain momenta and determines laser modes which represents a matter-wave analog of an optical random laser. P 85

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UNIVERSAL THERMODYNAMICS OF A BOSE GAS NEAR THE MOTT TRANSITION

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We study the thermodynamics of a Bose gas near the density-driven Mott transition in the framework of the Bose-Hubbard model. Renormalization-group arguments predict that once the effective mass m^* and scattering length a^* of the elementary excitations at the quantum critical point between the superfluid phase and Mott insulator are known, thermodynamic quantities such as pressure, superfluid transition temperature, condensate density, etc., are fully determined by universal scaling functions characteristic of the three-dimensional dilute Bose gas universality class. We use a nonperturbative renormalization-group approach to compute m^* and a^* as a function of the ratio t/U between hopping amplitude and on-site repulsion, and obtain various thermodynamic quantities. In the vicinity of the density-driven Mott transtion, our results show that thermodynamic quantities are very well described by the universal scaling functions of the dilute Bose gas universality class.

MASCROSCOPIC QUANTUM SELF-TRAPPING OF COLD BOSONIC OSCILLATORS AND BREATHERS

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P 87

In the regime of large occupation numbers and low temperatures, Bose-Einstein condensates in optical lattices show an interesting dynamical effect called Macroscopic Quantum Self-trapping (MQST): If the inter-particle interaction exceeds a critical value, an initially macroscopically occupied potential site remains macroscopically occupied due to spontaneous symmetry breaking (see e.g. [1,2,3]).
Here, we consider MQST of oscillating and breathing modes that occur in lattices with two greatly differing tunneling rates, as were recently introduced for modeling heat transfer in mesoscopic quantum systems [4]. We describe the self-trapping transition by means of an approximate mapping to systems with fewer degrees of freedom which in some cases allow for closed form analytical approximations [5].

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LIOUVILLE COHERENT STATES

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For a certain class of open quantum systems there exists a dynamical symmetry which connects different time-evolved density matrices. We show how to use this symmetry for dynamics in the Liouville space with time-dependent parameters. This allows us to introduce a concept of generalized coherent states in the Liouville space (i.e. for density matrices). Dynamics of this class of density matrices is characterized by robustness with respect to any time-dependent perturbations of the couplings. We study their dynamical context while focusing on common physical situations corresponding to compact and non-compact symmetries. P 88

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BOSE-EINSTEIN CONDENSATION IN QUANTUM CRYSTALS: THE QUEST OF SUPERSOLIDITY

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P 89

The experimental observation of superfluidity effects in solid ^{4}He at low temperature [1] suggests the existence of a *supersolid* state of matter, i.e. a crystalline phase performing Bose-Einstein condensation (BEC). Although the first conjectures on supersolidity appeared some decades ago [2-3], a reliable microscopic model of this phenomenon is still lacking, since it is hard to describe the competing effects of localization, due to the crystalline order, and delocalization, due to the zero-point motion, which characterize the atoms in quantum solids.

In this work, we present a microscopic approach to the solid phase of ^{4}He, based on Path Integral Monte Carlo simulations. In particular, we compute the one-body density matrix $\rho_1(r)$ of ^{4}He crystals at different temperatures, in order to study the BEC properties of these systems: we find that perfect crystals do not support BEC at any temperature [4] and that crystals presenting vacancies below a certain temperature become supersolid [5].

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CRITICAL ROTATIONAL SPEEDS IN THE GROSS-PITAEVSKII THEORY OF BOSE-EINSTEIN CONDENSATES

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A rotating trapped Bose-Einstein condensate is usually described using the Gross-Pitaevskii (GP) theory. Of particular interest are the quantized vortices of the condensate, unveiling its superfluid nature, and it is a major issue to understand these within the framework of GP theory.

When increasing the rotation speed, three critical values can be identified at which the distribution of the vortices in the ground state of the condensate changes drastically. When crossing the first critical speed, the condensate evolves from a vortex free state to a vortex lattice state with singly-quantized vortices densely packed in the fluid. At a second threshold, the centrifugal force dips a P
hole in the condensate, the annulus where the bulk of the mass sits being still filled with vortices 90
(vortex lattice plus hole state). Finally, the third critical speed is characterized by the transition to a giant vortex state where all the vorticity resides in a central multi-quantized vortex at the center of the trap, surrounded by a thin vortex free condensate.

These three critical speeds may be estimated in a mathematically rigorous manner by means of an asymptotic analysis in the so-called Thomas Fermi regime of strong inter-particle interactions. We review results in this direction and explain how the physics of the three phase transitions may be mathematically characterized.

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INELASTIC CONFINEMENT-INDUCED RESONANCES IN LOW-DIMENSIONAL QUANTUM SYSTEMS

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P 91

Ultracold atomic systems of reduced dimensionality show intriguing phenomena like fermionization of bosons in the Tonks-Girardeau gas or confinement-induced resonances (CIRs) which allow for a manipulation of the interaction strength by varying the trap geometry. Here, a theoretical model is presented describing inelastic confinement-induced resonances which appear in addition to the regular (elastic) ones and were observed in the recent loss experiment of Haller et al. in terms of particle losses [1]. These resonances originate from possible molecule formation due to the coupling of center-of-mass and relative motion. The model is verified by ab initio calculations and predicts the resonance positions in 1D as well as in 2D confinement in agreement with the experiment. This resolves the contradiction of the experimental observations to previous theoretical predictions.

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SUPERFLUIDITY AND MACROSCOPIC SUPERPOSITIONS OF TONKS-GIRARDEAU BOSONS STIRRED ON A 1D RING TRAP

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Recent experimental activities of boson trapping on a ring geometry open the way to explore a novel topology. We focus on a tight ring trap with strong transverse confinement leading to an effectively one-dimensional motion along its circumference. We consider a strongly interacting bose gas on the ring subjected to a localized barrier potential which is suddenly set into motion. Using the time-dependent Bose-Fermi mapping [1] an exact solution for the dynamical evolution in the impenetrable-boson (Tonks-Girardeau) limit is obtained. The exact solution allows to obtain the particle current, the particle current fluctuations and the drag force acting on the barrier [2]. In the weak barrier limit the stirring drives the system into a state with net zero current and vanishingly small current fluctuations for velocities smaller than $v_c = \pi\hbar/mL$, with m the atomic mass and L the ring circumference. The existence of a velocity threshold for current generation indicates superfluid-like behavior of the mesoscopic Tonks-Girardeau gas, different from the non-superfluid behavior predicted for the TG gas in an infinite tube. At velocities approaching integer multiples of v_c, angular momentum can be transferred to the fluid and a nonzero drag force arises. At these velocities we predict the formation of a macroscopic superposition of a rotating and a nonrotating Fermi sphere of the mapped Fermi gas [3]. We calculate the momentum distribution, time of flight images and the Wigner function of the Bose gas, the latter allowing to identify quantum interferences in the superposition. We find that the barrier velocity should be larger than the sound velocity for a better discrimination of the two components of the superposition.

P 92

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WEAK LOCALIZATION WITH INTERACTING BOSE-EINSTEIN CONDENSATES

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P 93

We study the quasi-stationary propagation of Bose-Einstein condensates through two-dimensional mesoscopic scattering geometries that correspond to disorder potentials [1] or to ballistic billiard confinements with chaotic classical dynamics [2]. Our theoretical approach is based on the two-dimensional Gross-Pitaevskii equation, which is numerically integrated in order to determine reflection and transmission probabilities associated with self-consistent stationary scattering states, and which represents the starting point for an analytical description of the scattering process in terms of a nonlinear diagrammatic theory. Both numerically and analytically, we find that the presence of the atom-atom interaction within the condensate gives rise to signatures of weak antilocalization, i.e. to an inversion of the coherent backscattering peak in disordered systems [1] and to a reduction, instead of an enhancement, of the retro-reflection probability in chaotic billiard geometries [2]. Short-path contributions associated, in particular, with self-retraced trajectories are conjectured to be at the origin of this antilocalization phenomenon.

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SUPPRESSION OF PAIRING AT OVERFLOW SITUATIONS. QUANTAL AND SEMICLASSICAL STUDIES

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P 94

We investigate what happens to a system of superfluid fermions contained in a trapping potential where a narrow container suddenly widens strongly giving rise to an overflow situation when the chemical potential reaches the edge of the narrow potential. Such situations may be studied with cold fermionic atoms where traps of this configuration already have been fabricated but, so far, only for bosons. On the other hand in the crust of superfluid neutron stars similar situations can occur. Since the solution of BCS equations with strongly varying geometries and large number of particles is difficult, we propose a novel Thomas-Fermi solution of the BCS equations. Various systems with overflow configurations will be studied and the quenching of pairing correlations will be demonstrated for these cases.

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LIMIT TO SPIN SQUEEZING IN FINITE TEMPERATURE BOSE-EINSTEIN CONDENSATES

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Quantum correlations could be used in atomic clocks and interferometers to increase their sensitivity with respect of using uncorrelated atoms. A simple class of states useful for metrology are *spin squeezed states*. Recently such states could be obtained using interactions in condensates with two internal states [1,2]. A crucial question is the scaling of the spin squeezing (or metrology gain) with the atom number. We show that, at finite temperature, the maximum spin squeezing achievable using interactions in Bose-Einstein condensates has a finite limit when the atom number $N \to \infty$ at fixed density and interaction strength. We calculate the limit of the squeezing parameter for a spatially homogeneous system and show that it is bounded from above by the initial non-condensed fraction [3,4]. We are presently investigating the trapped case. P 95

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RANDOM GREEN MATRICES FOR WAVES IN DISORDERED MEDIA

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We propose a novel approach to the the study of wave propagation in disordered systems. The disordered medium is modeled by an ensemble of N point-like scattering centers and the physics of the problem is encoded in the statistical properties of the $N \times N$ random Green matrix $\hat{G}$ with elements G_{ij} equal to the Green's function of the wave equation that describe wave propagation in free space between the points $\mathbf{r}_i$ and $\mathbf{r}_j$ where the scatterers are located.

We study the statistical properties of the eigenvalues and eigenvectors of the matrix $\hat{G}$ by using both analytic and numerical methods [1,2]. These properties carry signatures of a number of physical phenomena that can be observed in disordered systems: collective spontaneous emission in large ensembles of atoms, random lasing [3], diffusion and Anderson localization of waves, wave transport through extended ("necklace") modes in the localized regime, etc. P 96

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QUANTUM MAGNETISM OF MASS-IMBALANCED FERMIONIC MIXTURES

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P 97

We study magnetic phases of two-component mixtures of repulsive fermions in optical lattices in the presence of mass imbalance. The analysis is based on dynamical mean-field theory (DMFT) and its real-space generalization at finite temperature. The dependencies of the transition temperature to the ordered state on the interaction strength and the imbalance parameter are studied both in two and three spatial dimensions. For a harmonic trap, we compare our results obtained by real-space DMFT to results from a local-density approximation.
Our approach allows us to calculate the entropy at different parameters of the system and discuss the cases in which mass-imbalanced mixtures can have additional advantages for reaching quantum magnetism. We point out that at half-filling with a finite value of hopping imbalance the system has additional signatures (e.g., charge-density wave) of Neel (magnetic) ordering. We also consider additional population imbalance and study characteristics of different magnetic phases in this case.
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EDGES OF THE FRACTIONAL QUANTUM HALL EFFECT ON THE CYLINDER GEOMETRY

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P 98

We study fractional quantum Hall states in the cylinder geometry with open boundaries. By truncating the Coulomb interactions between electrons we show that it is possible to keep the fractional quantum Hall physic and to construct infinitely many exact eigenstates including the ground state, quasiholes, quasielectrons and the magnetoroton branch of excited states.

EMERGENCE OF QUINTET SUPERFLUIDITY IN THE CHAIN OF PARTIALLY POLARIZED SPIN-3/2 ULTRACOLD ATOMS

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The system of ultracold atoms with hyperfine spin $F = 3/2$ might be unstable against the formation of quintet pairs if the interaction is attractive in the quintet channel. It was shown earlier that in unpolarized system different quartetting phases are energetically more favorable than quintet pairs [1]. Nevertheless, it is expected that finite population imbalance of the different spin components can destroy the phase of singlet quartets permitting of other superfluid like instability with additional magnetic order. Thus motivated we studied the possible formation of local quintet pairs and their stability in a one-dimensional chain of fermionic atoms with hyperfine spin $F = 3/2$ [2]. We have found that in fact spin-population imbalance induced for instance by external magnetic field can stabilize different quintet pair states. For sufficiently large population imbalance —when two
spin components are frozen out and the remaining two components with $F_z = 3/2$ and $F_z = 1/2$ P
form an effective spin-1/2 system— we have found an FFLO-like state of $m = 2$ quintet pairs. Sim- 99
ilar FFLO phase recently has been realized experimentally and studied by the group of Hulet and Mueller [2]. Contrary, for intermediate values of the magnetization even more exotic superfluidity of coexisting quintet pairs with different magnetic moments becomes dominant. The inner structure of these quintet superfluid phases depends on the scattering length in the singlet and quintet channels. This type of behavior characterizes the system for moderated population imbalance in a broad range of the parameter space including also the high SU(4) symmetric case that is the most relevant situation with respect to alkaline earth atom experiments. Since our model contains only s-wave interaction, this result might also open new direction for experimental realization and studies of nonsinglet pairing with ultracold atomic systems.

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SPIN LIQUID PHASES OF ALKALINE EARTH ATOMS AT FINITE TEMPERATURES

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P 100

Mott insulator phases of lattice systems composed of fermions with internal states are characterized by frozen charge dynamics. However, the spin degrees of freedom remain dynamical, and actually they are governed by a Heisenberg like Hamiltonian with antiferromagnetic coupling. It was pointed out that such multicomponent systems in 1 and 2 dimensions and at zero temperature realize states without breaking the spin rotation symmetry when the number of components is large enough [1-3]. The low energy fluctuations on top of these so called spin liquid states are described by various gauge theories whose character depend on the symmetries of the mean-field solution [4]. Therefore high spin, ultracold, fermionic alkaline earth metal atoms loaded into optical lattices can serve as simulators of quantum gauge theories. Since in experiments with ultracold atoms it is a hard task to go to sufficiently low temperatures it becomes important to study the effects of finite temperature. We carry out the stability analysis of the mean-field solution and calculate the free energy at finite temperature to determine the phase diagram relevant for experiments.

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ESTIMATING QUASI-LONG-RANGE ORDER VIA RÉNYI ENTROPIES

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We show how entanglement entropies allow for the estimation of quasi-long-range order in one dimensional systems whose low-energy physics is well captured by the Tomonaga-Luttinger liquid universality class. First, we check our procedure in the exactly solvable XXZ spin-1/2 chain in its entire critical region, finding very good agreement with Bethe ansatz results. Then, we show how phase transitions between different dominant orders may be efficiently estimated by considering the superfluid-charge density wave transition in a system of dipolar bosons; moreover, we discuss the application of this method to multispecies systems such as the one dimensional Hubbard model. Finally, we study the case of the critical non-integrable XXZ spin-3/2 chain.

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COHERENT CONTROL OF QUANTUM TRANSPORT IN DRIVEN OPTICAL LATTICES FOR PRECISE FORCE MEASUREMENTS

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Coherent control of atomic motion inside an optical lattice allows precise measurement of forces by means of amplitude-modulation (AM) driven resonant tunneling and delocalization-enhanced Bloch oscillations (DEBO). We report about the recently-performed high precision measurements of gravitational acceleration using ultracold strontium atoms trapped in an AM driven vertical optical lattice. We reached an uncertainty $\Delta g/g \approx 10^{-7}$ by AM resonant tunneling at the 5^{th} harmonic of the Bloch oscillation frequency. We compared the two measurement techniques, i.e. AM resonant tunneling vs. DEBO, and we analyzed the systematic effects induced by the trapping optical lattice, such as the intensity gradient and the lattice frequency-induced shift. Short-distance measurements of gravity near dielectric surfaces and decoherence-induced effects are discussed. These results prospect a new way to new tests of gravity and quantum coherence.

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LATTICE MODULATION SPECTROSCOPY WITH SPIN-1/2 FERMIONS IN SPIN-INCOHERENT REGIME

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Recently, in order to probe excitation spectra of strongly correlated systems, a spectroscopy method by using modulation of optical lattice potentials has been developed and implemented in experiments. [1] In this spectroscopy, the number of doubly occupied sites (doublons) created by modulation of amplitude of an optical lattice potential is measured. In the theoretical viewpoint, the production rate allows us to access to a correlation function of the kinetic term in the Hamiltonian. We discuss doublon excitations of a magnetically disordered Mott insulator which is relevant to current experiments of fermionic atoms in optical lattice potentials. [2] To describe such excitations, we employ a slave particle representation and diagrammatic approach based on non-crossing approximation under the assumption of a spin-incoherent state, and the single particle spectrum function is estimated. Applying this formalism to the calculation of the production rate of doublons by lattice modulation, we implement a fit to the experiment [1]. As a result, the quantitatively good agreement is obtained.

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DYNAMICS OF THE ROTATED DICKE MODEL

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P 104

We study the quantum dynamics of a rotationally driven Dicke model, i.e., of the Dicke model where the collective spin is rotated around the z axis, without using the rotating wave approximation. We observe that depending on the choice of the initial quantum state the static quantum criticality of the Dicke model (the critical atom-field coupling strength at which the undriven Dicke model undergoes a quantum phase transition) can be shifted by the amount of the applied rotation velocity. This allows one to probe the quantum criticality of the Dicke model from a distance. Which means without actually crossing the quantum criticality but just by encircling it.

A UNIFYING CORE APPROACH TO COMPETING ORDERS IN FRUSTRATED MAGNETS

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Recently a variety of unconventional quantum phases (*e.g.* multipolar and chiral phases) have been found in frustrated magnets. Though extensive numerical simulations have established detailed phase diagrams for specific models, a unifying picture for the global phase structure is still lacking. In this poster, we propose an approach based on effective Bose-Hubbard-like models. Specifically, we consider the $S = 1/2$ Heisenberg model modified by the four-spin ring exchange interaction [1,2] in 1D (two-leg ladder) and 2D (square lattice). In order to single out relevant low-energy degrees of freedom, we systematically classify all possible states on each cluster and, by looking at P
the form of the order parameters, identify what kind of long-range orders occurs when these states 105
condense. Then we use contractor renormalization (CORE) method [3] to rewrite the original Hamiltonian in terms of the effective bosonic particles corresponding to the important low-energy states on the clusters. By changing parameters, some of the bosonic particles condense to form (conventional/exotic) long-range orders.

In 1D (two-leg spin ladder), we arrived at the description in terms of spin-1 Bosons and could (semi-quantitatively) reproduce what is known from numerical- and analytic (bosonization [4]) approaches.

In 2D (square lattice), we found different (bosonic) particles such as $S = 1$ bosons and $S = 2$ bosons come into play and obtained richer phase diagrams. Extension to other systems will be discussed.

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IMPURITY IN A FERMI SEA ON A NARROW FESHBACH RESONANCE: A VARIATIONAL STUDY OF THE POLARONIC AND DIMERONIC BRANCHES

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P 106

We study the problem of a single impurity of mass M immersed in a Fermi sea of particles of mass m. The impurity and the fermions interact through an s-wave narrow Feshbach resonance, so that the Feshbach length R_* naturally appears in the system. We use simple variational ansätze, limited to at most one pair of particle-hole excitations of the Fermi sea, and we determine for the polaronic and dimeronic branches the phase diagram between absolute ground state, local minimum, thermodynamically unstable regions (with negative effective mass), and regions of complex energies (with negative imaginary part). We also determine the closed-channel population which is experimentally accessible. Finally, we identify a nontrivial weakly attractive limit where analytical results can be obtained, in particular for the crossing point between the polaronic and dimeronic energy branches.

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SPONTANEOUS GENERATION OF SPIN-ORBIT COUPLING IN MAGNETIC DIPOLAR FERMI GASES

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The stability of an unpolarized two-component dipolar Fermi gas is studied within mean-field and RPA theory. Besides the known instability towards spontaneous magnetization with Fermi sphere deformation, another instability toward spontaneous formation of a spin-orbit coupled phase with a Rashba-like spin texture is found. A phase diagram is presented and consequences are briefly discussed.

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VORTEX TRANSFER IN CHARGED-SUPERFLUID MIXTURES

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We study a mixture of a charged and a neutral superfluid under a magnetic field and whether vortices can be created in neutral component due to superfluid drag. We first examine the two particle problem on a ring which is solved exactly to demonstrate the angular momentum transfer from the charged particle to the neutral particle due to interactions. This solution is valid even in the presence of resonant interactions and gives a good estimate for the interaction strength P 108 needed for vortex transfer between the components. Next, we consider the many body problem on a ring and show that the Bogoliubov modes of the system become unstable for sufficiently strong interactions signaling vortex transfer between the components. The critical interaction strength for vortex transfer is always close to the interaction strength for phase separation, and approaches it as the system size tends to infinity. However, recent experiments in toroidal traps should be able to access the vortex transfer region before phase separation sets in.

EFFECTS OF INTERACTIONS ON THE QUASIPERIODIC KICKED ROTOR METAL-INSULATOR TRANSITION

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In a disordered potential, the diffusive transport of non-interacting particles can be inhibited by quantum interference effects, a phenomenon known as Anderson localization [1]. In 3 dimensions, there exists a quantum phase-transition between localized (insulator) and diffusive (metal) dynamics. A long-standing question is the effect of interactions on such dynamics. We investigated this problem numerically using a "quantum simulator" of the 3D Anderson model, the quasiperiodic P 109 kicked rotor, recently used for precise experimental measurements of the critical exponent [2]. Interactions are included using a mean-field approximation, and we identified two regimes according to the properties of the initial state. The former implies only few changes in the characterization of the critical state whereas the latter is far more promising. For strong enough interactions, multifractality is transitorily suppressed.

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MAGNETIC PROPERTIES OF COMMENSURATE BOSE-BOSE MIXTURES IN ONE-DIMENSIONAL OPTICAL LATTICES

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In recent years, Bose-Einstein condensation has been achieved both in weakly and strongly interacting cold gases. The latter may be realized by confining atoms in optical lattices and, from a theoretical point of view, are described by the Bose-Hubbard model. The aim of this work is to analyze the magnetic phases of the Bose-Hubbard model for an optical lattice loaded with atoms of two bosonic species in different values of the parameter space. First, we analyze the half-filling case (one boson per site). The effective hamiltonian acting in the low energy Hilbert space is that of the XXZ spin 1/2 model and a transition from a planar ferromagnet to an antiferromagnet is expected by varying the inter-species interaction energy. This transition is studied by a DMRG analysis showing the evolution of the spin gap opening, in the thermodynamic limit, when the transition occurs. Then, we turn to the integer filling case (two bosons per site). For general hopping terms and interaction energies, the effective hamiltonian is that of a spin 1 Heisenberg model. Then, we show that the hamiltonian reduces to the spin 1 $\lambda - D$ model if the inter-species interaction energy U belongs to certain intervals. This allows us to predict that, by varying U, the system can be lead to the different phases of the model. In particular, the system can be brought in the celebrated Haldane phase if the depth of the optical potential is not larger than the recoil energy of the atoms in the lattice (their ratio have not to exceed the value of 10).

References:

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LA RÉCEPTION PAR LES PHILOSOPHES DE LA MÉCANIQUE QUANTIQUE.

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I propose in this course the following two general objectives: the first one is to know why philosophers have dedicated many pages to the relativity theory but they haven‘t done the same thing with the quantum theory; the second one is to understand why relations between quantum and phylosophy are so difficult. And also two specific objetives: the first one is to limit the authority of the philosophy for the science finds its place, it become specific and generic as the quantum: because a generic science could understand the immanence of thought; and the second one is to get that the phylosophy make the same abstration effort than quantum y became rigorous science. I will deal the reasons for the slow reactivity of philosophy with respect to quantum science and if this reactivity is associated with a transformation of rules and concepts. Some physicists (Bernard D' Espagnat) make dualisms objections and opposing systems in Western philosophies. From analyzing the path walked by the philosophy and the path walked by the quantum I will try to give the conditions of possibility of a philosophy inspired by quantum science. To do this I put forward my problem: How to transfer and move the concepts, issues and principles of quantum mechanics
to philosophy? Quantum works with operators, virtual fields, with $| \Psi |^2$ and principles such as P
superposition and interaction of entities, the principle of non-separability, indistinguishability and 111
quantum entanglement, using matrix algebra, no-ncommutative $\mathbf{C}^*$ algebra (von Neumann) and non-locality. To move a concept you have to invent new philosophical ways and change the language of philosophy to give birth to a rational wisdom: the 'contemporary sophia'. This problem leads us to:

1. identify the traces of these ideas in some contemporary philosophies.
2. examine and compare the differences between the classical physical theories and quantum theory.
3. search why quantum mechanics had need for philosophical interpretations about itself and the reason for its popularization.
4. to relate the philosophy of the philosophers with the philosophy of science.

Quantum mechanics, like another rationality, becomes a generic paradigm for thought and encourages philosophers to reform the thought leaving the classical categories.

INTERACTING BOSONS IN A RANDOM POTENTIAL

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We study the effects of random scatterers on the ground state of the one-dimensional Lieb-Liniger model of interacting bosons in the Gross-Pitaevskii regime. Our main findings are as follows:

1. Bose-Einstein condensation (BEC) in the ground state of the interacting gas in the Gross-Pitaevskii regime can survive even in a strong random potential. As far as BEC is concerned, the
P interacting gas in this regime thus behaves in a similar way as an ideal gas at zero temperature. The character of the wave function of the condensate, however, is strongly affected by the
112 interaction.

2. A random potential may lead to localization of the wave function of the condensate, even though the density of obstacles is much less than the particle density. The interparticle interaction counteracts this effect and can lead to complete delocalization if the interaction is strong enough.

3. In terms of the interaction strength, γ, and density of scatterers, ν, the transition between localization and delocalization of occurs in the model considered when $\gamma \sim \nu^2$. For $\gamma \lesssim \nu/(\ln \nu)$ the condensate is localized in a small number of intervals with fluctuating particle numbers.

In the course of the proof of Bose-Einstein condensation in the model we generalize a result of Kirsch and Simon on spectral gaps in one-dimensional Schrödinger operators.

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	THEORY OF QUANTUM GASES AND QUANTUM COHERENCE	**ENS Lyon, 5-8 June, 2012**			
	TUESDAY, June 5th		**WEDNESDAY, June 6th**	**THURSDAY, June 7th**	**FRIDAY, June 8th**
			Disordered cold gases	**Bose-Einstein condensation in condensed matter systems**	**Atom interferometry & quantum metrology**
		9:00 AM	**Alain Aspect (Palaiseau) (50'+10')**	**9:00 Christian Rüegg (Villigen) (40'+5')**	**Markus Oberthaler (Heidelberg) (50'+10')**
		10:00 AM	Eleonora Lucioni (Sesto Fiorentino) (25'+5')	**9:45 Cristian Batista (Los Alamos) (40'+5')**	Francesco Piazza (Munich) (25'+5')
		10:30 AM	*Coffee break*	*Coffee break*	*Coffee break*
		11:00 AM	Christopher Gaul (Madrid) (25'+5')	**11:00 Alberto Bramati (Paris) (40'+5')**	Tim Langen (Vienna) (25'+5')
		11:30 AM	François Crépin (Würzburg) (25'+5')	**11:45 Vincenzo Savona (Lausanne) (40'+5')**	Christine Muschik (Castelldefels) (25'+5')
		12:00 PM	Karim Bouadim (Stuttgart) (25'+5')		Oriol Romero-Isart (Garching) (25'+5')
		12:45-3:00 PM	*Lunch break*	*Lunch break*	*Lunch break*
3:50 PM	**Opening remarks**		**Cold gases in low dimensions**	**Poster session**	**Quantum simulators with cold gases**
	Fermions	**3:00 PM**	**Thierry Jolicoeur (Orsay) (50'+10')**	Session 1	**Antoine Georges (Palaiseau) (50'+10')**
4:00 PM	**Sandro Stringari (Trento) (50'+10')**	**4:00 PM**	Nicole Fabbri (Sesto Fiorentino) (25'+5')		Leticia Tarruell (Zurich) (25'+5')
5:00 PM	Matteo Zaccanti (Innsbruck) (25'+5')				
		4:30 PM	*Coffee break*	*Coffee break*	*Coffee break*
5:30 PM	*Coffee break*				
		5:00 PM	Peter Barmettler (Geneva) (25'+5')	Session 2	Marc Chéneau (Munich) (25'+5')
6:00 PM	Kris van Houcke (Ghent) (25'+5')	**5:30 PM**	Ludwig Mathey (Hamburg) (25'+5')		Nathan Goldman (Brussels) (25'+5')
6:30 PM	Jesper Levinsen (Cambridge) (25'+5')	**6:00 PM**	Marcello Dalmonte (Innsbruck) (25'+5')	**Colloquium** Lev Pitaevskii (Trento)	Diego Porras (Madrid) (25'+5')
7:00 PM	Gianluca Bertaina (Lausanne) (25'+5')				
	7:30 PM: Welcome reception (Amphi Mérieux)			*8:45 PM: Social Dinner (Brasserie Georges)*	