Workshop on

Ultracold Atoms and Gauge Theories

(Trieste, 13-17 May 2013)

POSTER SESSION

(14 May, 18:30)

Coherently coupled two-component Bose gases

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Coupled two-component Bose gases are the generalization of the well-known two-level system of quantum atom optics to a many-body interacting system. The interplay of the nonlinear interactions with the coherent coupling that allows transfer of atoms between the two components determines the properties of the gas, which differ in a fundamental way from the two component mixture (where no transfer of atoms is allowed). In the first case we address [1], the two Bose gases are condensed (spinor Bose-Einstein condensate) and uniform. We show that the ground state can go from an unpolarized to a polarized configuration through a (second-order) phase transition, which is seen as a bifurcation of the ground state solution. The spectrum of elementary excitations as well as the density and spin-density structure factors reflect this behaviour, which is fundamentally different from the demixing instability between the miscible and immiscible phases of mixtures. We show by solving the Gross-Pitaevskii equation that in a trapped system, due to the inhomogeneity of the density, these two ground states can coexist. The second problem we address [2] is the notion of superfluidity in a two component condensate, by means of numerically studying the stability of persistent currents in a toroidal trap. This topic has been very recently addressed experimentally [3]. Finally, by solving the two-component Bose-Hubbard model we investigate how the phase transition from Mott insulator to superfluid is modified by the presence of the Rabi coupling, when the two species are confined in a deep optical lattice [4].

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Aspects of gauge theory in systems with induced Dirac symmetry

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We investigate gauge field interactions in planner condensed matter systems with induced Dirac symmetry, both at zero and at finite temperature. Both perturbative and nonperturbative aspects have been analyzed, and possibility of obtaining 'bound states' of gauge particles is studied.

Derivation of nonlinear Schrodinger equations for ultracold gases by means of quantum hydrodynamic method.

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Various methods can be applied for studying of ultracold atoms, and gauge theories give powerful methods. However, our attention is focused on development of an alternative method, which allows to represent the many-particle Schrodinger equation as a chain of equations having hydrodynamic form [1]. Developing method of quantum hydrodynamic for neutral ultracold Bose atoms, in simplest case when chain can be cut off giving the continuity and Euler equations, gives the Gross-Pitaevskii equation [1], in the case of Fermi atoms it gives us corresponding nonlinear Schrodinger equation [1]. Considering evolution of neutral polar molecules in the BEC state we show that the quantum hydrodynamics allows to derive corresponding generalization of the Gross-Pitaevskii equation suggested in Ref.s [2], [3], [4], which appears for fully polarized dipoles [5]. This equation has been actively used in last decade [6]. We present non-integral form of the Gross-Pitaevskii equation for polarized molecules. We present estimation of evolution of electric dipole directions and consequences of the evolution on properties of wave dispersion in polarized BEC. We also point out differences in evolution of dipole directions for magnetic and electric dipoles, which reveals in differences in dispersion of collective excitation.

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Magnetization relaxation and geometric forces in a Bose ferromagnet

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We construct a hydrodynamic theory for spin-1/2 Bose gas at arbitrary temperature, that describes coupling between magnetization, normal fluid and superfluid. Phenomenological parameters of the hydrodynamic theory are calculated using Bogoliubov theory and Boltzmann equation in the relaxation time approximation. A Skyrmion is found to produce a topological Hall effect, which manifests itself in, for example, collective modes of the system. The dissipative coupling between magnetization and normal component is shown to give rise to magnetization relaxation that is fourth order in momentum.

Microscopical description and Insulating phases of dipolar fermions in 1D optical lattice

Luca Barbiero

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We prove that hidden long range order is always present in the gapped phases of interacting fermionic systems on one dimensional optical lattices. It is captured by correlation functions of appropriate nonlocal charge and/or spin operators, which remain asymptotically finite. The corresponding microscopic orders are classified. The results are confirmed by DMRG numerical simulation of the phase diagram of the extended Hubbard model, and of a Haldane insulator phase. These results can be of particular interest, both theoretically and experimentally, for particles interacting via dipolar interaction. More precisely we present an accuarte study of extended Hubbard model including the effect of long range dipolar effect 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 in both purely one dimensional and quasi-1D setups.

Detecting Majorana fermions

Colin Benjamin

There is tremendous excitement in the wider physics community and the condensed matter community in particular over the existence of Majorana fermions. These elusive particles were thought for long to be just theoretical constructs until neutrinos changed this picture.
Detecting neutrinos is extremely difficult at costs a lot. However can these particles be detected in a small condensed matter setup which costs a fraction of what is being spent elsewhere. Well the answer seems to be yes although not unambiguously so far. The talk will suggest a novel way of detecting these particles using a set of Aharonov-Bohm type interferometric methods. The existence of these particles can be easily determined by the conductance oscillations as function of magnetic flux and/or electric voltage. The system in the presence and absence of Majorana bound states exhibits strikingly different behavior.
Importantly, we show that the presence of Majorana bound states can induce a persistent current in absence of any external magnetic field.

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Towards light induced spin-orbit coupling for ultra-cold neutral atoms

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Presentation of the experimental efforts we pursue towards engineering a 2D spin-orbit-coupling [1] of a neutral Rubidium Bose-Einstein condensate (BEC). Using multiple Raman transitions to couple cyclically three hyperfine Zeeman states of the atoms, an effective gauge field is predicted to be created which resembles the one occurring in spintronic systems [2]. Such an artificial interaction could be used to build advanced solid state simulators with non-Abelian character in a versatile cold-atom system. The first experimental steps realized to build a BEC machine featuring a hybrid source concept [3] are presented.

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Pseudomagnetic forces for a classical ultracold atomic gas

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There are essentially two avenues for realizing pseudo-magnetic fields for ultracold atomic gases: (i) by rotating the system at some angular frequency around a given axis [Cooper2008], and (ii) by using light-matter interactions [Dal2011]. The more perspective latter approach [Dal2011] is theoretically accounted for by introducing effective gauge potential(s) **A** in the Hamiltonian, which is equivalent as if a magnetic field **B=rot A** was present in a system of charged particles. However, there are only a few experiments demonstrating effective gauge potentials [Lin2009a, Lin2009, LeB2012] and pseudo-magnetic fields (often referred to as **synthetic magnetic fields**) by using light-matter interactions. These include demonstration of the Hall effect [LeB2012] and formation of vortices in a superfluid made of quantum-degenerate ultracold gases [Lin2009]. Here we theoretically and experimentally study novel schemes for introducing synthetic magnetic fields in normal (classical rather than quantum-degenerate) ultracold atomic gases. We will demonstrate a novel scheme for observing the Lorentz force in this system.
Our approach utilizes several laser fields operating at different frequencies, which are resonantly interacting with specific atomic levels. We have already performed calculations along the lines of our ideas by using realistic atomic levels and transition dipole moments in 87Rb, and the strength of the synthetic Lorentz force is compared to the Doppler cooling force in Figure 1.

This scheme is operational in a classical (normal) atomic gas, and the effect is predicted to be one order of magnitude stronger than in Ref. [LeB2012] operating on a quantum degenerate gas. The theoretical approach for calculating the synthetic Lorentz force on ultracold atoms [objective 1a)] is described in Ref. [Met1999]. The method utilizes density-matrix formalism, the standard form of light-matter interaction, and the Ehrenfest theorem [Met1999]. These methods were used to calculate the synthetic Lorentz force in a novel scheme with several laser beams impinging on a ultracold 87Rb atoms as displayed in Figure 1. In order to theoretically describe the effects of the synthetic magnetic force on the atomic cloud in experiments, we will describe the dynamics of the atomic gas by using the Fokker-Planck equation. At the workshop we will present our theoretical calculations and schemes in detail. However, experiments are underway and we may show experimental results with our MOT system as well.

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Anomalous Expansion of BEC and Vortex trap system with two Bose-Einstein condensates

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We spatial overlap two Bose-Einstein condensates to analyze the proprieties of an effective vortex trap configuration. Using appropriate unbalanced number of atoms between the species, we were able to found analytical solution for the coupled Gross-Pitaevskii equation, which allowed the study of thermodynamic proprieties of the system. Finally we mapped our Hamiltonian in a Bose-Hubbard kind considering an array of vortices in one specie, sifting its scattering length to induce a quantum phase transition in the other condensate cloud.

The Bose gas in two dimensions

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Due to thermal fluctuations, two-dimensional (2D) systems cannot undergo a phase transition associated to the breaking of a continuous symmetry. Nevertheless they may exhibit a phase transition to a state with quasi-long range order via the Berezinskii Kosterlitz-Thouless (BKT) mechanism. The quasi-long range coherence and the microscopic nature of the BKT transition were recently explored with ultracold atomic gases. In our experimental setup producing 2D degenerate gas of Rubidium, we studied the thermodynamics of this system on both sides of the transition. In addition, a direct observation of superfluidity in terms of frictionless flow was still missing. Here we probed the superfluidity of a 2D trapped Bose gas with a moving obstable formed by a micron-sized laser beam. We find a dramatic variation of the response of the fluid, depending on its degree of degeneracy at the obstacle location.

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Condensation in the BEC-BCS crossover with spin-orbit interactions

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We investigate the pair condensation of a two-spin-component Fermi gas in the presence of both Rashba and Dresselhaus spin-orbit couplings. We calculate the condensate fraction in the BCS-BEC crossover both in two and in three dimensions by taking into account singlet and triplet pairings. These quantities are studied by varying the spin-orbit interaction from the case with the only Rashba to the equal-Rashba-Dresselhaus one. We find that, by mixing the two couplings, the singlet pairing decreases while the triplet pairing is suppressed in the BCS regime and increased in the BEC regime, both in two and three dimensions. At fixed spin-orbital strength, the greatest total condensate fraction is obtained when only one coupling (only Rashba or only Dresselhaus) is present.

Enhancing the FFLO state in a 3D Fermi gas using a 1D optical lattice

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In a spin-imbalanced Fermi gas, the number of spin up and spin down particles is made unequal, leading to a competition between Cooper-pairing with zero momentum and with finite momentum. The former is the well-known BCS superfluid, while the latter gives rise to the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state. Up till now this state has not been observed directly in experiments in more than 1 dimension. Here we propose a new way to enhance the presence of the FFLO state in a three-dimensional (3D) Fermi gas, by adding a one-dimensional (1D) periodic potential. To investigate the effect of this potential, we study the ground state properties of the system, starting from the partition sum of an imbalanced Fermi gas in the path-integral representation. To describe the FFLO state, a saddle point is chosen in which the pairs have a finite momentum. Minimizing the resulting free energy results in the phase diagram of the system as a function of the densities or chemical potentials. We find that the stability region of the FFLO state is greatly enhanced due to the presence of the periodic potential, compared to the ordinary 3D case. We further show that the FFLO state can exist at higher spin imbalance if the wavelength of the optical potential becomes smaller. We propose that this concept can be used experimentally to enhance the stability region of the FFLO state.

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An experiment for the investigation of artificial gauge fields in ultra-cold Ytterbium gases

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The well controllable systems of ultra-cold atoms in optical potentials offer fascinating opportunities to simulate quantum mechanical effects inaccessible in equivalent solid state systems. One example is the fractional quantum Hall effect in a 2D electron gas, which can be made accessible via strong artificial magnetic fields using fermionic atoms in optical lattices. Previous studies of artificial magnetic fields include rotating gases (simulating magnetic fields via the Lorentz force) [1], bulk ultracold atomic gases (using light-induced gauge fields) [2] and staggered fields in optical lattices [3]. This experiment focusses on the implementation using bosonic and fermionic Ytterbium atoms in optical lattices. I will present the experimental results on the route towards the achievement of artificial magnetic fields, including the production of a Bose-Einstein condensate of 174 Yb.

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Lifshitz tricritical point and its relation to the FFLO superconducting state

Arghya Dutta and Jayanta K. Bhattacharjee

We study the phase diagram of spatially inhomogeneous Fulde-Ferrell-Larkin-Ovchinnikov superconducting state using the Ginzburg-Landau free energy, derived from the microscopic Hamiltonian of the system, and notice that it has a very clear Lifshitz tricritical point. We find the specific heat jumps abruptly near the first-order line in the emergent phase diagram which is very similar to the recent experimental observation in layered organic superconductor. Comparison with experimental data allows us to obtain quantitative relations between the parameters of phenomenological free energy. The region of the phase diagram where the specific heat jumps can be probed by doing a dynamical analysis of the free energy.

Topological insulators in dynamically generated lattices

Omjyoti Dutta

Topological insulators are of fundamental and technological importance due to their exotic excitations that allow for robust transport of charges (matter) on the boundary and thus have potential applications in spintronics, quantum computing and spintomics. In this regard, due to the enormous control and possibility of quantum engineering, systems of ultracold gases trapped in optical lattices open promising avenues to follow. In this paper we show that starting from a trivial lattice, one can dynamically generate topologically non-trivial lattice which can host topologically insulating states in the form of Quantum Anomalous Hall states or Quantum Spin Hall states. We investigate the necessary experimental conditions to generate such states.

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We investigate emergent electrodynamics in the 2dXY model at finite temperature. We find the model to be governed by laws entirely analogous to Maxwell's equations of real electrodynamics. We show how Maggs-Rossetto protocol is equivalent to 2dXY simulation and study the distribution of the longitudinal and transverse parts of the emergent field, linking our theory with the spin-wave analysis of José, Kadanoff, Kirkpatrick and Nelson's seminal paper.

Dynamics of quasihole excitations as a detection tool for quantum Hall phases

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Existing techniques for synthesizing gauge fields are able to bring a two-dimensional cloud of harmonically trapped bosonic atoms into a regime where the occupied single-particle states are restricted to the lowest Landau level (LLL). Repulsive short-range interactions drive various transitions from fully condensed into strongly correlated states which feature interesting topological properties [1]. In these different phases we study the response of the system to quasihole excitations which can be induced by a laser beam. We find that in the Laughlin state the quasihole performs a coherent constant rotation around the center. This is distinct to any other regime with higher density, where the quasihole is found to decay. At a characteristic time, the decay process is reversed, and revivals of the quasihole can be observed in the density. This collapse-and-revival mechanism provides a spectroscopic tool to identify the strongly correlated phases by measuring the period and position of the revivals [2].

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Effects of long range nonlinear interactions in multi-well potentials.

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We study the dynamics of N Rydberg dressed atoms using the mean field theory in multi-well potentials like double-well and triple-well potentials, in which the electric ground-state of each atom is weakly coupled to a highly excited Rydberg state by a far off-resonant laser. This dressing induces a switchable effective soft-core interaction between ground-state atoms which gives rise to on-site as well as long range interaction additional terms.
Our aim is to investigate the effects of these long-range interactions in the multi-well potentials by studying the differential equations of both the fractional population imbalances and the relative phases.

Mimicking and breaking U(3) monopoles into U(2) monopoles with tunable charge inultracold atomic systems

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Recently, a non-AbelianU(2) monopole was shown to emerge when atoms with degenerate internal states move in certain spatially-varying laser fields. Using an extended tripodscheme, we explain here how to generate a QCD-like U(3) monopole acting on the center ofmass motion of ultracold atoms. The scheme can also be applied to generate U(2) monopole with tunable charge.

Global phase diagram of superfluid phases with magnetic ordering in three-component fermion mixtures

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We investigate the global phase diagram of a three-component fermion mixture with weak attractive interactions, using a combination of equation of motion and Gaussian variational mean field approaches. Our methods allow for an unbiased treatment of superfluid and magnetic ordering, and capture the interplay between the two order parameters. This interplay significantly modifies the phase diagram, especialy the superfluid-normal phase boundaries. We find a rather rich phase diagram, with chemical potential-driven first- and second-order transitions and triple points as well as more exotic second-order multicritical points, and bicritical lines with O(2,2) symmetry.

A key two-component scenario for unconventional superconductivity in high- superconductors

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The discovery of high-Tc copper oxide (cuprate) superconductors has stimulated intensive development of condensed matter physics, material science and superconducting (SC) technology. The new high-Tc materials are rather complicated and differ markedly from the conventional superconductors. Various competing theories have been proposed for describing these systems. Most theoretical scenarios consider the non-phononic pairing of carriers and the Bose-Einstein condensation (BEC) of pre-formed Cooper pairs and ignore the important electron-phonon interactions. While, many experiments suggest that the electron-phonon interactions and charge carrier inhomogeneity play a key role in high-Tc cuprates. Some two-component scenarios based on the combined BCS and BEC models contain the electron-phonon interactions. To date most of the existing theories have not been convincing enough to be generally recognized as containing the essence of full understanding of superconductivity. Since the pairing of carriers is only necessary but not sufficient for the occurrence of superconductivity and the BEC state of the ideal Bose-gas of Cooper pairs is not at all SC state. In this work, starting from the new two-component scenario and two-stage Fermi-Bose-liquid model, we study the unconventional (or novel) superconductivity in the underdoped cuprates. Special emphasis is given to the self-trapping and precursor pairing of charge carriers in strong and intermediate electron-phonon coupling regimes and to the inhomogeneous spatial distribution of carriers leading to their segregation into the carrier-poor and carrier-rich domains. We argue that the precursor pairing of large polarons in the real-space and k-space results in formation of the noncoherent large bipolarons (in carrier-poor regions) and polaron Cooper pairs (in carrier-rich regions) above the SC transition temperature Tc and these composite bosons condense into a superfluid Bose-liquid state at Tc.

We develop the consistent theory of the superfluid condensation of large bipolarons and Cooper pairs, going beyond the scope of the standard BCS and BEC theories and show that the specific predictions of this theory of superconductivity are confirmed by the accurate experimental data (e.g.,lambda-like SC transition and two-bell (or SC dome)-shaped doping dependence of Tc with the local minimum or plateau between two SC domes).

Production of Yb Quantum Gases for Optical Lattice Experiments

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We report on the first experimental setup based on a 2D-/3D-MOT scheme to create both Bose-Einstein condensates and degenerate Fermi gases of several Ytterbium isotopes. Our setup does not require a Zeeman slower and offers the flexibility to simultaneously produce ultracold samples of other atomic species. Furthermore, the extraordinary optical access further favors future experiments in optical lattices. With such a system at hand, artificial gauge fields can be imposed by modulating the lattice beams or effects predicted by the Kondo Model can be observed by using state dependent optical lattices.

Simulation of frustrated classical XY models with ultracold atoms in three-dimensional triangular optical lattices

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Miscellaneous magnetic systems are currently being intensively investigated because of their potential applications in modern technologies. Nonetheless, a many-body dynamical description of complex magnetic systems may be cumbersome, especially when the system exhibits a geometrical frustration. This paper deals with simulations of the classical XY model on a three-dimensional triangular lattice with anisotropic couplings, including an analysis of the phase diagram and a Bogoliubov description of the dynamical stability of mean-field stationary solutions. We also discuss the possibilities of the realization of Bose-Hubbard models with complex tunneling amplitudes in shaken optical lattices without breaking the generalized time-reversal symmetry and the opposite, i.e., real tunneling amplitudes in systems with the time-reversal symmetry broken.

On the viscosity to entropy density ratio for unitary Bose and Fermi Gases

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We calculate the ratio of the viscosity to the entropy density for both Bose and Fermi gases in the unitary limit using a new approach to the quantum statistical mechanics of gases based on the S-matrix. In the unitary limit the scattering length diverges and the S-matrix equals −1. For the fermion case we obtain η/s > 4.7 times the proposed lower bound of hbar/4π kB which came from the AdS/CFT correspondence for gauge theories, consistent with the most recent experiments. For the bosonic case we present evidence that the gas undergoes a phase transition to a strongly interacting Bose-Einstein condensate, and is a more perfect fluid, with η/s > 1.3 times the bound.

Color-Flavour Locked Phases and Fractional Vortices with Non-Abelian Modes in Ultracold Fermionic Mixtures

Luca Lepori

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We describe a setup of ultracold fermionic mixture in optical lattices where it is possible to synthesize superfluid phases with symmetry obtained via the locking of independent invariance groups of the normal state. Due to their peculiar symmetry, these phases can also host exotic soliton structures, as vortices with semi-integer flux and gapless non-Abelian Goldstone modes localized on them. The origin of the non-Abelianity, the braiding properties, the mechanism and the consequences of fractionality for such vortices are discussed. The scenario proposed displays remarkable similarities to what arises in ultra-dense QCD matter, as in the core of some neutron stars. A discussion about the experimental detection of locked phases and fractional vortices is as well provided.

Study of the Interacting Fermi-Hubbard Model with Synthetic Gauge Coupling

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We study the interacting Fermi-Hubbard model in two spatial dimensions with synthetic gauge coupling of the spin orbit Rashba type, at half-filling. Using real space mean field theory, we numerically determine phase diagrams of the theory for different values of the gauge field parameters. For a fixed value of the gauge field, we observe that when the strength of the repulsive interaction is increased, the system enters into an antiferromagnetic phase, then undergoes a first order phase transition to an itinerant magnetic phase. Depending on the gauge field parameter, this phase further evolves to the one predicted from the effective Heisenberg model obtained in the limit of large interaction strength. We explain the presence of the antiferromagnetic phase at small interaction from the computation of the spin-spin susceptibility which displays a divergence at low temperatures for the antiferromagnetic ordering, which is related to the nature of the underlying Fermi surface. Finally, the fact that the first order phase transitions for different gauge field parameters occur at unrelated critical interaction strengths arises from a Hofstadter-like situation, i.e. for different itinerant magnetic phases, the mean-field Hamiltonians have different translational symmetries.

The Role of Non Unitary Gauge Fields as Emulators of Curved Spacetimes

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We consider cold fermionic atoms on the lattice. We discuss possible physical interpretation of Hamiltonians with non-unitary synthetic gauge fields in terms of fermionic fields in curved spacetime. This interpretation holds for fermions described by both Dirac and Pauli Hamiltonians, where the latter is a non-relativistic limit of the former.

Dark soliton in a disorder potential

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We consider a dark soliton in a Bose-Einstein condensate in the presence of a weak disorder potential. Deformation of the soliton shape is analyzed within the Bogoliubov approach and by employing an expansion in eigenstates of the Poschl-Teller Hamiltonian. Comparison of the results with the numerical simulations indicates that the linear response analysis reveals a good agreement even if the strength of disorder is of the order of the chemical potential of the system. In the second part of the paper we concentrate on the quantum nature of the dark soliton and demonstrate that the soliton may reveal Anderson localization in the presence of disorder. The Anderson localized soliton may decay due to quasi-particle excitations induced by the disorder. However, we show that the corresponding lifetime is much longer than the condensate lifetime in a typical experiment.

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Measuring the Berry Curvature of Optical Lattices

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New schemes propose how artificial gauge fields may be imprinted on ultracold atomic gases in optical lattices, allowing experiments to access strongly correlated phenomena. In particular, fractional quantum Hall physics may be explored in systems where the lowest energy band resembles a Landau level, as in the proposed "optical flux lattices". These energy bands have a nonzero Chern number and are topologically nontrivial. The physical properties of such a band are encoded not only in its energy spectrum over the Brillouin zone (the "bandstructure" in the usual sense) but also importantly, in its Berry curvature. When the Berry curvature is nonzero, it can have many important physical consequences; for example it can modify the semiclassical dynamics of a wave packet undergoing Bloch oscillations or it can change the collective mode frequencies of a gas. We will explain how experimentalists may turn such physical consequences into new tools to determine the topological properties of a band. We will discuss how Berry curvature effects may be observed in ultracold gases and give examples in systems relevant to future experiments.

Ultracold atoms in optical lattices: beyond the Hubbard model

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Ultracold atomic gases trapped in optical lattices offer the possibility to study - in a clean and tunable experimental setup - the intriguing properties of strongly correlated quantum many-body systems. Most theoretical studies of these systems are based on simplified (single-band) models defined on a discrete lattice.
In this work, we address the regime of shallow optical lattices where the single-band models are not reliable, and investigate the effects of the interplay between strong inter-particle interactions and external periodic potentials.
Using methods based on Kohn-Sham Density Functional Theory (DFT), which is the most powerful computational tool routinely used in material science to simulate the electronic structures of solids, we study the ferromagnetic and the antiferromagnetic phases of repulsive Fermi gases in optical lattices. We compare the DFT results against fixed-node Quantum Monte Carlo data, and analyze the breakdown of the local-spin density approximation used in the DFT simulations. As an outlook, we discuss how the development of DFT for ultracold Fermi gases can form a strong link between materials science and atomic physics.

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 bandpass 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.

Nonlocal Long Range Orders in 1D Systems

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It is shown on a prototype Hamiltonian that hidden long range order is always present in the gapped phases of interacting fermionic systems on one dimensional lattices. Such order is captured by correlation functions of appropriate nonlocal charge and/or spin operators, which remain asymptotically finite. The corresponding microscopic orders are classified.
The results are confirmed by DMRG numerical simulation of the phase diagram of the extended Hubbard model, and of a Haldane insulator phase.

Artificial gauge fields for bosons in shaken optical lattices: a numerical study

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Neutral atoms in a periodically shaken optical lattice experience artificial gauge fields and kinetic frustration, with the potential of realizing fundamental models of frustrated magnetism. I will present our recent numerical studies for models of frustrated bosons relevant to current and future experiments, including bosons in a triangular and Kagomé lattice with negative hoppings, and bosons in a triangular lattice under a staggered magnetic flux. In the regime of large, integer filling, sign-problem-free quantum Monte Carlo simulations can be performed, fully capturing the effect of quantum fluctuations (namely of interparticle repulsion) on the strongly frustrated classical states. In particular I will demonstrate numerically the potential use of frustration via lattice shaking to achieve extreme adiabatic cooling of the atoms, and to achieve absolute thermometry of the lattice gas via fluctuation-dissipation relations.

Quantum square ice and its emergent lattice gauge theory

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Using a combination of numerical and analytical results, we investigate the phase diagram of quantum ice on the square lattice (corresponding to the transverse-field Ising model - TFIM - on the checkerboard lattice and in a transverse magnetic field). Classical ice is known to be described by an emergent compact U(1) gauge field satisfying Gauss's law, with deconfined monopole excitations; quantum fluctuations are instead expected to lead to confinement in D=2 due to the Polyakov mechanism. We show that the TFIM on the checkerboard lattice actually exhibits two distinct confined phases, corresponding to a valence-bond solid (VBS) and a Néel phase, separated by a quantum phase transition; in particular the VBS phase occurs at an exceedingly low temperature, above which the system is in a thermally deconfined phase. The two phases in question correspond to those recently identified in the phase diagram of a U(1) quantum link model - U(1) lattice gauge theory with S=1/2 degrees of freedom. Making use of degenerate perturbation theory, we reconstruct the emergent U(1) gauge theory associated with the quantum square ice, which shows striking similarities to the quantum link model. Trapped ions, serving as an ideal template to realize the physics of the TFIM, are ideal candidates to implement this emergent lattice gauge theory.

Effect of artificial gauge field on Supersolid phase in ultracold atomic condensates

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We discuss the signatures for detection of Supersolid phase in ultracold atomic condensates subjected to an artificial gauge field. We study the effect of such gauge fields on the continuum system of cold atoms with long range non local interaction and construct a hydrodynamic theory for rotating supersolids. The hydrodynamic description gives the dispersion modes for rotating supersolids which carry distinguishing features compared to rotating superfluids.

Imaging and characterization of cloud dynamics in a magneto-optical trap induced by external forces

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Previous methods of observing cloud dynamics in a magneto-optical trap [Xu2002] have used a probe laser beam perpendicular to the axes along witch external forces have been imposed. Change in cloud density, and hence cloud motion, can be deduced from the resulting change in absorption of the probe laser beam. Other methods, limited to detection of dynamics in only one dimension, have also been used [Kohn1993]. In addition, these methods are only applicable for small displacements which is a limiting factor. These methods are ill suited for systems in which external forces are applied and resulting dynamics occur in two dimensions. For instance, in a MOT in which synthetic magnetic fields have been introduced, the characterization of induced forces would necessitate two dimensional detection of cloud dynamics. We outline a novel scheme for introducing a synthetic magnetic field in a MOT. To challenge requirements, mentioned above, of detecting these forces we use a standard CMOS camera for stroboscopic imaging of cloud dynamics. To demonstrate temporal and spatial resolution of our technique we performed experiments in which we imaged Rb87 cloud center-of-mass damped oscillations in two dimensions in a standard MOT. An example of the results is shown in Figure 1.
The approach in the used theoretical model is similar to the Doppler cooling theory, described in [Met1999]. The strength of the force on the atoms is strongly dependent on the saturation intensity for a given transition. We measured the saturation intensity for a D1 Rb87 transition of atoms confined in our MOT. Good agreement with theoretical predictions based on the Bloch equations is shown.

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Position dependent phases in BEC based quantum metrology

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We consider quantum limited measurements using Bose Einstein condensates (BECs) using a two mode BEC. The relative phase between the two internal levels is tied via a suitable coupling to the parameter to be measured so that an estimate of the this phase after a short measurement time can reveal the value of the parameter. The rate at which the relative phase builds up is enhanced by a factor equal to the number of atoms, N , in the BEC because of the nonlinear interaction term in the coupled Gross-Pitaevskii (GP) equations governing the time evolution of the system. This enhanced rate for the phase evolution leads to measurement uncertainties that scale better than 1/N as a function of the resources used (number of atoms in the BEC). In order to model a realistic experimental scenario, we present an approach for going beyond the GP equation constructed keeping the BEC based metrology protocol in mind. This approach leads to a collection of GP like equations for the amplitudes and a system of associated equations for the phases for the wave functions of the different occupation number components of the many body system. This lets us compute the position dependence of the relative phase between the two modes that arise due to the differences in their scattering lengths.

Engineering XY-Ising spins in a triangular optical lattice via tunable artificial gauge fields

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The emulation of synthetic gauge fields for ultracold atomic systems is crucial in order to access the rich physics arising when condensed matter is placed into magnetic fields. Indeed standard electromagnetic fields do not couple to the motional degrees of freedom of the chargeless atomic species investigated in optical lattices. However an effective Aharonov-Bohm phase can be engineered if the atomic wave function acquires a nontrivial phase tunneling from one lattice site to another. In this perspective, shaken optical lattices constitute a versatile tool, which allows to control both phase and amplitude of the tunneling parameters and thus generate artificial gauge potentials [1]. Here, we report on the experimental realization of tunable staggered gauge fluxes on a periodically driven triangular lattice.

For symmetric staggered magnetic fluxes, two degenerate ground states with opposite chiralities exist [2]. At low temperatures, the system spontaneously breaks both an Ising, Z2 symmetry, and a continuous, U(1) symmetry. The presence and interplay of different symmetries naturally raises the question of a coupling between order parameters, and whether this changes the universality class of the phase transition.

The Ising-like magnetization of the system shows a thermally driven phase transition from an ordered, antiferromagnetic to an unordered, paramagnetic state. The analysis of the coherence properties of the three-dimensional ultracold gas demonstrates the strong influence of the discrete symmetry onto the BEC phase, revealed here as a drastic reduction of the coherence length.

In addition the tunability of the artificial gauge field allows to bias the Z2 order parameter in analogy to a longitudinal magnetic field in the Ising-spin model. The occupation of metastable states having a polarization opposite to the bias fied is a non-equilibrium signature of the investigated phase transition. This constitutes a fundamental, defining property of phase transitions, obtained with a novel method in the field of ultra-cold atoms.

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Spin liquid phases of alkaline earth atoms at finite temperatures

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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 calculate the free energy at finite temperature and determine the phase diagram relevant for experiments.

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Ultracold Lithium 6 and Potassium 40 mixture

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In Paris, we are currently finishing a new experimental setup designed for the study of quantum degenerate mixtures of fermions of different atomic species. Using species selective potential, these novel systems offer new possibilities for the study of quantum many-body physics using cold atoms, such as mixed dimensional geometries where the two species are free to move in a different number of dimensions.
Major improvements have recently been obtained by implementing a D1 molasses cooling scheme for each species and have already lead to the quantum degeneracy of potassium. In this poster, we will show those results and our perspectives towards a degenerated mixture.

Modulational Instability of Bose-Einstein condensates with quantum fluctuations

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We use a Gross-Pitaevskii equation comprising cubic, quartic, and residual nonlinearities to investigate the modulational instability (MI) of Bose-Einstein condensates with repulsive interaction in the presence of quantum fluctuations, by means of analytical and numerical methods. We obtain explicit time-dependent criteria for the MI and the instability domains of the condensates. Solitons are generated by suitably exciting the MI. We find that quantum fluctuations can completely change the instability of condensates by reversing the nature of the effective two-body interactions.

BEC-BCS crossover in QCD and gauge theories

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The BEC-BCS crossover phenomena appear not only in cold atom physics but in high-energy physics. In this talk, we argue the importance of the BEC-BCS crossover phenomena in QCD and other gauge theories at finite density. In particular, we discuss the continuity between the hadron phase and color superconducting phase in QCD at finite baryon density [1, 2] and its possible implications to the quark confinement [3]. We also show that the phase diaragms of QCD and a class of gauge theories are universal in the limit where the sizes of the gauge groups are large [4], based on the notion originating from the string theory —the orbifold equivalence.

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Collective modes of interacting bosons in artificial gauge fields

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Rapid experimental progress in the realization of artificial magnetic fields for cold neutral atoms heads toward the creation and direct observation of exotic quantum states under highly controllable experimental conditions. By combining mean-field and beyond mean-field approaches, we explore the Mott insulator and the superfluid phase of interacting lattice bosons in an artificial magnetic field.

We calculate ground states and excitation spectra of these phases. To demonstrate how the physical quantities of our system can be detected in experiments, we perform numerical calculations of the systems non-equilibrium behaviour under realistic perturbations.

Vortex of an anomalous mode in Fermi gas near the unitarity limit

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We investigate the dynamics of a quantized vortex in a trapped superfluid Fermi gas near the unitarity limit. By taking a trial wave function for the order-parameter of a condensate in a rotated axisymmetric trap confinement and using a time-dependent variational analysis we obtain the equations of motion and their solutions for anomalous mode. The results show that the critical rotating frequency of the trap increases when the system is ranging from the BCS side to the BEC side of the unitarity limit, while the period of the vortex decreases in this regime.