Disordered Bose-Fermi mixtures: from fermi glasses to spin glasses and quantum percolation

V. Ahufinger, L. Sanchez-Palencia, A. Sanpera & M. Lewenstein

The physics of cold atoms approaches nowadays the frontiers of modern condensed matter physics. In particular many important challenges of this discipline can be addressed within the context of cold atoms [1]. In this talk, I shall present first a brief review of some of these challenges. I will focus then on those that could be addressed by using Bose-Fermi mixtures in the presence of disorder. Specifically I will discuss in this context the possibilities of realizing Fermi glasses, spin glasses and quantum percolation [2].


Dynamical correlation functions in 1D Bose gases

Jean-Sebastien Caux

The Lieb-Liniger interacting Bose gas is one of the paradigms of exactly solvable models having important experimental relevance to the field of atomic gases in optical lattices. This talk will show that new developments in the Bethe Ansatz allow to compute some important dynamical correlation functions (in particular density-density and one-body ones) either numerically for the repulsive gas, or even analytically for the attractive case, giving an extensive set of quantitative experimental predictions.

Geometric frustration and disorder

John Chalker

In this talk I will review the experimental consequences of disorder in geometrically frustrated antiferromagnets and our current theoretical understanding of them. One of the central features of classical models of geometrically frustrated antiferromagnets that makes them interesting is that, to a first approximation, they have macroscopically degenerate ground states. The experimental mirror of this degeneracy is the fact that highly frustrated magnetic materials remain in the paramagnetic phase to temperatures that are low on the scale set by the exchange interactions. At the lowest temperatures, however, something different may happen, and in many materials this is spin freezing. Although spin freezing takes place even in samples that appear to be stoichiometric and crystalline, it is natural to think that it arises because of residual disorder, albeit at a low level. I will compare spin freezing in geometrically frustrated magnets with that in canonical spin glasses, emphasising the new features.
Experiments on Fine-Grained Disorder in the 3D Bose-Hubbard Model

Brian DeMarco

I will describe recent experiments in which fine-grained disorder is applied to ultra-cold atoms confined in a three-dimensional optical lattice. We create disorder using a 532 nm optical speckle field focused through a high-numerical aperture lens; the 1/e\(^2\) radius of the transverse autocorrelation function for this speckle field is only 550 nm. Because of a unique geometry for the optical lattice beams, the resulting optical dipole potential generates disorder with highly suppressed site-to-site correlations along every direction of the lattice. I will discuss measurements of condensate fraction vs. speckle strength in this system and the implications for various theories of the disordered Bose-Hubbard model ground state phase diagram.

Phenomenology of the two-dimensional disordered fermionic Hubbard model

Peter Denteneer

The two-dimensional disordered fermionic Hubbard model has been studied using Determinant Quantum Monte Carlo calculations, motivated by the possible observation of a metal-insulator transition in semiconductor heterostructures. Results for transport properties of these studied are reviewed in the light of potential experimental confirmation of similar phenomena in cold fermionic atomic gases in optical lattices.

Anderson transition in the presence of electron-electron interactions

A.M. Finkelstein

We will demonstrate how the metal-insulator transition may occur in a disordered two dimensional electron gas with electron-electron interactions. Renormalization group equations beyond the lowest order in the disorder have been obtained using controlled large-N approximation scheme. As it follows from this analysis, there is a competition between the disorder and interaction that leads to an unstable fix point at the phase diagram controlling the metal to insulator transition. A survey of the current experimental situation will be also presented.

Disordered and quasi-periodic bosonic systems

Thierry Giamarchi
Excitations in Random Elastic Media

Victor Gurarie

Abstract: I will discuss the general properties of the bosonic excitations arising in disordered systems. Examples of such systems include phonons in a random solid, magnons in a random magnet, Bogoliubov excitations in a BEC in a random potential, and the excitations of pinned charge density waves. I will construct a classification scheme for these systems thus making it possible to identify the behavior of their excitations in terms of their symmetries.

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Bose Einstein condensates in disordered optical potentials

Massimo Inguscio

Laser light is used to engineer controlled disorder in the form of speckle fields or multi-chromatic lattices with incommensurate wavelengths. It will be shown how these are valuable tools for the study of disordered and quasi-disordered systems and for the investigation of quantum localization effects with Bose Einstein condensates.

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Optical properties of the Heavy Fermion Metal LiV2O4

Petra Jönsson

Geometrical frustration suppresses magnetic order and generates new types of electronic behavior. For example, the d-electron metal LiV2O4 exhibits heavy fermion behavior below a characteristic temperature T* of 20K. The origin of the heavy fermion formation in this geometrically frustrated compound remains unclear. In this talk, I report the results of a recent optical study on single crystals of LiV2O4. The incoherent charge dynamics at temperatures above T* and the transfer of spectral weight over broad energy scales (~ 5 eV) reveal that LiV2O4, in contrast to conventional f-electron HF metals, is a correlated metal in proximity to a correlation driven insulating state. A scenario for the heavy quasiparticle formation in LiV2O4, possibly valid for other geometrically frustrated systems, will be presented.

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Dirac fermions in long-range correlated disorder

Dmitri Khveshchenko

We study the effects of long-range correlated disorder of both scalar (random potential) and vector (random magnetic field) type on the transport and localization properties of two-dimensional Dirac fermions describing the low-energy dynamics of a number of experimentally relevant nodal fermion systems.
Interplay of disorder and interactions in two dimensions

S. V. Kravchenko

The discovery of the metal-insulator transition (MIT) in two-dimensional electron systems challenged the veracity of one of the most influential conjectures in the physics of disordered electrons, which states that "in two dimensions, there are no true metals"; no matter how weak the disorder, electrons would be trapped and unable to conduct a current. However, that theory did not account for electron-electron interactions. Recently, we have investigated the interplay between interactions and disorder near the MIT using simultaneous measurements of electrical resistivity and magnetoconductance. It turns out that both the resistance and interaction amplitude exhibit a fan-like spread as the MIT is crossed.

From these data we have constructed a resistance-interaction flow diagram of the MIT that clearly reveals a quantum critical point that separates the metallic state, stabilized by interactions, from the insulating state, where disorder prevails. The metallic side of this diagram is quantitatively described by the recent renormalization group theory (Punnoose and Finkelstein, Science 310, 289 (2005)) without any fitting parameters.

Large effects by small disorder: from Anderson localization to random field induced order

Maciej Lewenstein

In my talk I will present a review of recent work on two subjects. First, I will discuss the quest for Anderson localization effects in ultracold weakly interacting gases. I will introduce the concept of Lifshitz glass, and discuss ground state and excitation properties of disordered BEC. Second, I will show how the continuous symmetry breaking disorder may induce order in ultracold gases. I will discuss examples of disordered XY model, randomly coupled two component BEC's, and Fermi superfluid with random photoassociation, or Feschbach coupling.

Probing locally disorder in geometrically frustrated antiferromagnets

Philippe Mendels

In correlated systems, non-magnetic defects induce a response in their vicinity which can be imaged through local probes such as resident nuclei (NMR). After describing shortly the case of High Temperature Superconductors, I'll show how NMR enables one to shed light in a unique manner on the effect of non-magnetic defects which differs substantially from the non-frustrated case. I'll also show how one might get insights into related dynamical effects.
Localization of cold atoms in 2D correlated disorder: the diagrammatic picture
Cord Müller

The dynamics of cold atoms in a 2D landscape of correlated speckle potentials can probe our current understanding of the Anderson localization transition. I will present a diagrammatic approach, taking into account the dephasing of weak localization corrections by inelastic light scattering. This permits to study the transition from the diffusive to the localized regime and back.

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Transport in strongly disordered classical spin chains
Vadim Oganesyan

We present a numerical study of diffusion of energy at high temperature through strongly disordered arrays of interacting classical spins with Hamiltonian dynamics. We find that quenched randomness strongly suppresses transport, with diffusion constant apparently becoming smaller than any power of spin-spin interaction rescaled by randomness. We have looked for but not found signs of a classical many-body localization transition at any finite strength of disorder.

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Superfluid-insulator transition in strongly disordered Boson chains: new results from real-space RG
Gil Refael

In this talk I will present recent progress in the study of strongly disordered one-dimensional Bosons. Using real-space renormalization group, we analyzed the superfluid-insulator transition of the U(1) rotor model with randomness in hopping, charging, and chemical potential. We find universal properties of the transition at large disorder, as well as detailed low energy description of the insulating phases. The phase diagram we find contains three different insulators - the incompressible Mott-glass, the compressible Bose glass, and the random-singlet glass, which has a divergent compressibility. The symmetry of the disorder in the chemical potential determines which of the three insulators obtains for a specific chain. Our method also allows a discussion of the nature and universality of the critical point, and the universal excitation spectrum of the insulating phases, with which I will conclude.

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Density matrix renormalization for impurity and disordered systems
Ulrich Schollwoeck

In this talk, I will present new concepts and some results on how techniques of the density matrix renormalization group algorithm can be generalized such as to allow for new methods of calculating ensemble averages of disordered systems based on time-evolution algorithms and to calculate the
spectral properties of systems with a quantum impurity, potentially improving on current numerical renormalization group techniques.

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**Transport, Localization and Nonlinearity in Disordered Photonic Lattices**

*Tal Schwartz,* Guy Bartal, Shmuel Fishman, and Mordechai Segev

We present the first observation of Anderson Localization in disordered photonic lattices. We study the combined effects of nonlinearity and disorder, under normal and anomalous dispersion.

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**Physics of quantum gas mixtures in optical lattices**

*Klaus Sengstock*

The talk will give an overview on the physics of quantum gas mixtures in optical lattices. Mixtures of bosonic and/or fermionic quantum gases in lattices offer a wide range of innovative systems which also allow a comparison to condensed matter systems. I will especially focus on Fermi-Bose mixtures and the possibilities to study disorder, transport and fully new quantum phases. Also a link to the creation of molecules and the possibility of disordered molecular systems will be given.

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**Imbalanced Fermi Gases: The Rice Story**

*Henk Stoof*

In this contribution we present in detail our theoretical analysis of the recent Rice experiments with resonantly-interacting imbalanced Fermi gases.

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**Metal-insulator transitions of correlated lattice fermions with disorder**

*Dieter Vollhardt*

The simultaneous presence of interactions and disorder in quantum many-particle systems is known to lead to fascinating and often quite surprising phenomena. In my talk I will discuss some of the consequences of the interplay between local correlations and disorder in three-dimensional lattice fermion systems with emphasis on metal-insulator transitions (MIT). In particular, I will review results obtained with the dynamical mean-field theory for Hubbard-type models with and without local random potentials, e.g., on the competition between the Mott-Hubbard MIT and Anderson localization, the possibility of a Mott-Hubbard MIT at fractional fillings, and the effect of disorder on magnetic phases.
Trionic phase of ultracold fermions in an optical lattice: a variational study

Gergely Zarand

To investigate ultracold fermionic atoms of three internal states (colors) in an optical lattice, subject to strong attractive interaction, we study the attractive three-color Hubbard model in infinite dimensions using a variational approach. We find a quantum phase transition between a weak coupling superconducting phase and a strong coupling trionic phase where groups of three atoms are bound to a composite fermion. We show how the Gutzwiller variational theory can be reformulated in terms of an effective field theory with three-body interactions, and how this effective field theory can be solved exactly in infinite dimensions using the methods of dynamical mean field theory.

POSTERS

Spinor Condensates: Magnetization Waves, Triangular Lattices and Solitons

C.Becker, S. Soltan-Panahi, S. Stellmer, S. Dörscher, J. Kronjäger, K. Bongs and K. Sengstock

We present new results concerning F=2 Spinor BEC in a quasi one dimensional optical dipole trap showing distinguishing wave-like features of the magnetization. A transition from local density dependent spin dynamics to highly anti-correlated spin states as a function of time and magnetic field strength could be demonstrated. Furthermore results of F=1 Spinor BEC loaded into a triangular optical lattice are shown illustrating that the onset of the Mott-insulator transition occurs at much lower lattice depth compared to a cubic lattice. Preliminary results regarding spin dynamics at the MI-transition point will be given as well. As a third field of interest we introduce first experiments aiming at the generation and investigation of two component solitons and their dynamics employing state-of-the-art spatial light modulator techniques.
Competition of Mott metal-insulator transition, antiferromagnetism, and Anderson localization in correlated electron systems with disorder

K. Byczuk, W. Hofstetter, & D. Vollhardt

The phase diagram of correlated, disordered lattice fermions is determined within dynamical mean-field theory supplemented by the geometrically averaged ("typical") local density of states. Antiferromagnetic insulator, Mott insulator and Anderson insulator phases are found to be separated by continuous phase transitions. Predictions for cold fermionic atoms on optical lattices and solid state systems are presented.

Correlated bosons on a lattice: Dynamical mean-field theory for Bose-Einstein condensed and normal phases

K. Byczuk & D. Vollhardt

We formulate the first comprehensive, thermodynamically consistent theory of correlated lattice boson systems. It cooresponds to a bosonic dynamical mean-field theory (B-DMFT) which is applicable for arbitrary values of the coupling parameters and temperature. B-DMFT includes all local, dynamical correlations of the many-boson system and becomes exact in the limit of infinite space dimensions in analogy with its fermionic counterpart.

Yang-Yang thermodynamics on an atom chip

A.H. van Amerongen, J.J.P. van Es, P. Wicke, K.V. Kheruntsyan & N.J. van Druten

We investigate the behavior of a weakly interacting nearly one-dimensional trapped Bose gas at finite temperature. We perform in situ measurements of spatial density profiles and show that they are very well described by a model based on exact solutions obtained using the Yang-Yang thermodynamic formalism, in a regime where other, approximate theoretical approaches fail. We demonstrate Bose gas focusing as a means to gain experimental access to the axial momentum distribution of the gas, and find good agreement with the in situ results. (arXiv:0709:1899)

Localization of Bosonic Atoms by Fermionic Impurities in a Three-Dimensional Optical Lattice

S. Ospelkaus, C. Ospelkaus, P. Ernst, S. Götze, K. Sengstock, and K. Bongs

We observe a localized phase of ultracold bosonic quantum gases in a 3-dimensional optical lattice enhanced by a small contribution of fermionic atoms in a Fermi-Bose quantum gas mixture. In particular, we study the dependence of the fermionic $^{40}$K impurity concentration on the superfluid-Mott-insulator transition by a comparison to the corresponding transition in a pure bosonic $^{87}$Rb.
gas. We find a significant shift in the onset of the transition in terms of the lattice depth. Possible mechanisms including disorder and entropy-based adiabatic temperature change scenarios are discussed.

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Static Screening and Delocalization Effects in the 
Hubbard-Anderson Model

Peter Henseler, Johann Kroha & Boris Shapiro

We study the suppression of electron localization due to the screening of disorder in a Hubbard-Anderson model. We focus on the change of the electron localization length at the Fermi level within a static picture, where interactions are absorbed into the redefinition of the random on-site energies. Two different approximations are presented, either one yielding a non-monotonic dependence of the localization length on the interaction strength, with a pronounced maximum at an intermediate interaction strength. In spite of its simplicity, our approach is in good agreement with recent numerical results.

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Density Matrix Renormalization group study of bosonic Fractional 
Quantum Hall States

D.L. Kovrizhin

We will report on the application of the Density Matrix Renormalization Group technique to the calculations of Fractional Quantum Hall states in the systems of fast rotating bosons

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Ultracold bosons in optical lattices in the presence of random “heavy” impurities

K.V. Krutitsky

We present our recent results on ultracold bosons in optical lattices in the presence of disorder created by the interaction with impurity atoms having large effective mass. The system is described by the Bose-Hubbard Hamiltonian with the random on-site terms which have a discrete probability distribution. First, we consider a single-particle problem and study the Anderson localization. Second, we consider a system of bosons with repulsive interactions and calculate the phase diagram at zero temperature using several methods like exact numerical diagonalization, strong-coupling expansion, Bose-Fermi mapping, as well as different versions of the mean-field theory.

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3D strong localization of matter waves by scattering from atoms in a lattice with a confinement-induced resonance

Pietro Massignan and Yvan Castin

The possibility of using ultracold atoms to observe strong localization of matter waves is now a subject of great interest, as undesirable decoherence and interactions can be made negligible in these systems. It was proposed that a static-disordered potential can be realized by trapping atoms of a given species in randomly chosen sites of a deep three-dimensional (3D) optical lattice with no multiple occupation. We analyze in detail the prospects of this scheme for observing localized states in 3D for a matter wave of a different atomic species that interacts with the trapped particles and that is sufficiently far detuned from the optical lattice to be insensitive to it. We demonstrate that at low energy a large number of 3D strongly localized states can be produced for the matter wave, if the effective scattering length describing the interaction of the matter wave with a trapped atom is of the order of the mean distance between the trapped particles. Such high values of the effective scattering length can be obtained by using a Feshbach resonance to adjust the free-space interspecies scattering length and by taking advantage of confinement-induced resonances induced by the trapping of the scatterers in the lattice.

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The quenched disorder in hole-doped manganites

Roland Mathieu

A macroscopic phase separation, in which ferromagnetic clusters are observed in an insulating matrix, is sometimes observed, and believed to be essential to the colossal magnetoresistive (CMR) properties of manganese oxides with ABO$_3$ perovskite structure. The application of a magnetic field may indeed trigger large magnetoresistance effects due to the percolation between clusters allowing the movement of the charge carriers. However, this macroscopic phase separation is mainly related to extrinsic defects or impurities, which hinder the long-ranged charge-orbital order of the system. In the poster, I show that rather than the macroscopic phase separation, an homogeneous short-ranged charge-orbital order accompanied by a spin glass state occurs, as an intrinsic result of the uniformity of the random potential perturbation induced by the solid solution of the cations on the A-sites of the structure of these materials. Hence the phase separation does occur, but in a more subtle and interesting nanoscopic form. Remarkably, this ”nanoscale phase separation” alone is able to bring forth the colossal magnetoresistance in the perovskite manganites, and is potentially relevant to a wide variety of other magnetic and/or electrical properties of manganites, as well as many other transition metal oxides, as we exemplify in the poster.

The data, analyzes and conclusions presented in the poster were obtained within the ERATO Spin Superstructure Project of the Japan Science and Technology Agency (JST), in collaboration with J. P. He, X. Z. Yu, Y. Kaneko, M. Uchida, Y. S. Lee, T. Arima, A. Asamitsu, Y. Matsui and Y. Tokura, as well as D. Akahoshi, Y. Tomioka, and R. Kumai from the Correlated Electron Research Center (CERC, AIST Tsukuba, Japan), and T. Kimura and N. Hanasaki at the time from the Department of Applied Physics, University of Tokyo, Japan.

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The Bose-Fermi Hubbard model in the light and heavy fermion limits

Alexander Mering, Dominik Muth, Michael Fleischhauer

We discuss mixtures of bosons and spin-polarized fermions in optical lattices in the limits of heavy and light fermions. The first case is mapped to a Bose-Hubbard system with binary disorder or a super-lattice potential. Boundaries between Mott-insulating and compressible phases are determined analytically within an extended strong-coupling expansion. DMRG calculations reveal furthermore a novel phase with Bose-glass character. In the opposite limit of ultra-light fermions an effective boson Hamiltonian is derived with an oscillatory long-range interactions leading to additional phases such as compressible density-waves. Numerical simulations suggest that CDW and Luttinger-liquid phase are separated by a Bose-glass phase.

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Exotic transport properties of 2D Bogoliubov excitations

Cord Müller

The interplay of interaction and disorder is studied with 2D Bogoliubov excitations in correlated potentials. The scattering of a Bogoliubov wave on a single obstacle displays an intriguing interference effect. As a consequence, there are regimes where the diffusion transport length shows a nonmonotonic behaviour or becomes smaller than the elastic scattering length.

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Strongly repulsive Luttinger liquid state in one-dimensional dipolar bosons

M.-L. Chiofalo, R. Citro, S. De Palo, E. Orignac

Using a combination of bosonization techniques and Reptation Quantum Monte Carlo simulation, we have studied the Luttinger liquid state of a one-dimensional gas of dipolar bosons. At low density, the behavior of the density correlations is similar to that of a free one-dimensional Fermi gas. As density is increased, a strongly repulsive regime is obtained.

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Trionic phase of ultracold fermions in an optical lattice: a variational study

Akos Rapp, Walter Hofstetter, Gergely Zarand

To investigate ultracold fermionic atoms of three internal states (colors) in an optical lattice, subject to strong attractive interaction, we study the attractive three-color Hubbard model in infinite dimensions using a variational approach. We find a quantum phase transition between a weak coupling superconducting phase and a strong coupling trionic phase where groups of three atoms are bound to a composite fermion. We show how the Gutzwiller variational theory can be reformulated in terms of an effective field theory with three-body interactions, and how this effective
field theory can be solved exactly in infinite dimensions using the methods of dynamical mean field theory.