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Abstract Booklet

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Line-Centered Square Optical Lattices: Many Body Effects

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ABSTRACT

Recently a line-centered optical lattice has been proposed and analyzed for cold atoms [1]. The dispersion of such a lattice contains a Dirac cone intersecting with a completely flat band [1]. Here we analyze effects due to the atom-atom interaction of the Hubbard type for the line-centered lattice. The lattice is filled with fermionic atoms in two different internal states A and B. The Hubbard interaction takes place between the A and B state atoms populating the same lattice sites. We have identified localized eigen-states of the non-interacting Hamiltonian, which are immune to the atom-atom interaction and constitute a half of the flat band. Thus there is a cost in energy due to the atom-atom interaction to place an extra B atom in the flat band half-filled with the A atoms. However for smaller filling factors of the A atoms there is no energy cost to add a B atom. This leads to a jump in the chemical potential at the half-filled flat band.

The situation resembles to a certain degree the one appearing in the p-band honeycomb lattice in which two flat bands are formed. In such a lattice the Hubbard interaction takes place between two different atomic p-states [2]. On the other hand, in the present case we are dealing with the s-band of the line-centered lattice, and the interaction takes place between the atoms in different internal states A and B. In such a situation one can control the population ratio between these two states.

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Adiabatic preparation of a Heisenberg antiferromagnet using an optical superlattice

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Ultracold atoms trapped in optical lattices offer a unique possibility to experimentally explore strongly correlated states of quantum matter. The preparation of a Heisenberg antiferromagnet (AFM) currently represents one of the main challenges for the experiments in this field. Although a Mott insulator has already been observed in two dimensions [1], the realization of antiferromagnetic order requires a temperature and entropy significantly lower than presently achieved [2].

An alternative to the direct generation [3] which circumvents this entropy problem, is to use an adiabatic protocol [4]. Starting from a state with very low entropy, initially interactions are tuned such that this is the ground state, and then adiabatically changed towards the Heisenberg Hamiltonian. If the process is adiabatic, the final state will be the desired AFM. The questions that immediately arise are, what the conditions are to achieve adiabaticity and how the protocol will be affected by a finite temperature and the presence of a harmonic trap.

In our work, we propose a specific adiabatic scheme and analyze these issues numerically. We show that it is indeed possible to prepare a magnetically ordered state within feasible time scales. Starting from a band insulator (BI) with very low entropy, the ground state is transformed first to an array of decoupled singlets and finally to the AFM. This is achieved by adiabatically changing the depth of two superimposed optical lattices. A key advantage of the use of the BI is the possibility for a fast preparation using weakly or non-interacting atoms [5].

For the one dimensional case, we simulate the fermionic $t-J$ model with Matrix Product States (MPS) [6, 7] and identify the adiabatic conditions that allow the preparation of the antiferromagnetic state in an ideal case with no defects. We observe that, for slow enough variation of the Hamiltonian, the antiferromagnetic order is produced in the center of the chain, on a number of sites which depends on the speed. Therefore, the adiabaticity of a middle sublattice is determined by an effective gap related to this sublattice and not by the gap of the total lattice. Due to the finite temperature in real experiments, defects, or holes, are expected to occur in the starting state. The large initial energy of the holes can in principle destroy the antiferromagnetic order as they delocalize inside the sample. We find that, if the holes are initially located at the outer part of the sample, as expected in an experiment, a tradeoff can be reached between the degree of adiabaticity of the process and the distance the holes can travel inside the chain, so that the antiferromagnetic order is still produced in the center. Moreover, we show that a harmonic trap can avoid the problems due to the presence of holes by confining them to the outside of the sample, and thus preventing their destructive effect on the antiferromagnetic order.

Via Projected Entangled Pair States (PEPS) [7], we complement our analysis with a simulation of the two-dimensional $t-J$ model of hardcore bosons with antiferromagnetic interaction. This setting is easier to analyze numerically than the corresponding 2D fermionic system and provides evidence that the physics studied in the one dimensional case can be extrapolated to understand the conditions of an equivalent scheme in 2D.

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Interacting Harper's model for bosons and fermions

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Interacting Harper's model which describes quantum particles moving on a tight-binding lattice endowed with an addidtional potential that is incommensurate with the lattice period has been investigated. Both Fermi and Bose statistics of interacting particles have been considered. Numerical simulations in the mean-field approximations have been performed, and beyond-mean field quantum corrections to the correlations functions have been computed. Several regimes of the diffusion process have been identified. In particular, it has been found that the interactions between particles modify but do not destroy the localization properties of the standard (one-particle) Harper model.

Density-dependent processes of dipolar molecules in an optical lattice

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We study the extended Bose–Hubbard model describing an ultra-cold gas of dipolar molecules in an optical lattice, taking into account all on-site and nearest-neighbor interactions, including occupation-dependent tunneling and pair tunneling terms. We show that these terms lead to additional quantum phase transitions and can destroy insulating phases. These considerable changes of the phase diagram have to be taken into account in upcoming experiments with dipolar molecules.

Interferometric measurement of spin-fluctuations in cold Fermi gases

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The interplay of quantum-statistics and interactions leads in many physical systems to the emergence of interesting low-temperature properties, such as superfluidity or ferromagnetism. Ultracold fermionic gases are well suited to prepare such strongly correlated systems, due to the wide tunability of the atomic interactions [1]. Current theoretical and experimental efforts are directed towards the investigation of their magnetic properties [2], in the context of which the observation of spin-fluctuations has been proposed as a promising tool [3].

Here, we introduce a shot noise-limited interferometer with high spatial resolution and use it measure the probability distribution of the local spin-polarization in a trapped Fermi gas. Our interferometer is analogous to Young's double slit experiment. Two tightly focussed beams, the probe and the local oscillator, are focussed to separate points as shown in Fig. 1 and overlap in the far field. Position and visibility of the resulting interference pattern are determined by changes in phase and amplitude of the probe beam, and therefore reflect the local spin properties of the cloud. Repeating this measurement yields the probability distribution of the spin polarization.

We observe a temperature-dependent reduction of spin-fluctuations by up to 4.5(3) dB below shot-noise in weakly interacting Fermi gases and deduce the magnetic susceptibility. We find quantitative agreement with the expected behaviour of an ideal Fermi gas. For a strongly interacting gas of weakly bound molecules, we observe a reduction by 9.2(8) dB, which reveals the presence of entanglement in the cloud [4]. Our experiment constitutes a realization of [3], and brigdes the gap between experiments using quantum gases and quantum optics with atomic vapors.

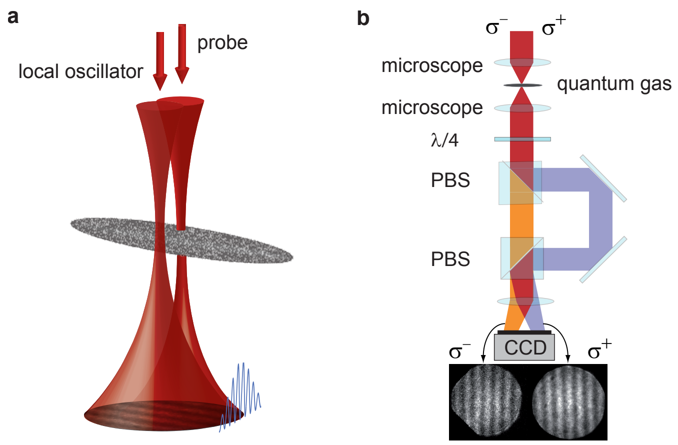

FIG. 1: (a) Interferometer beams in the vicinity of the atomic cloud: While the probe passes through the cloud shown in grey, the local oscillator passes by the side of it. The beams overlap to give an interference pattern as shown, which is averaged parallel to the fringes for processing. See methods for creation of the interferometer beams. (b) Optical setup to obtain two interference patterns, only one of which is affected by the atoms: Due to the birefringence of the atomic cloud in a magnetic field, only the σ^--polarized component of the light interacts with the atoms, while the σ^+- component passes undisturbed. Using a quarter-wave retardation plate ($\lambda/4$) and two polarizing beam splitters (PBS), the σ^-- and σ^+-components from both interferometer beams are separated, yielding two patterns on one image as shown in the lower part of the figure.

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Microscale phase separation in fermionic systems with exotic superfluidity

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The exotic coexistence of superconductivity and magnetism, first investigated by Fulde-Ferrell and Larkin-Ovchinnikov (FFLO), is predicted to show a spontaneous breaking of spatial symmetry. In fermionic spin-imbalanced systems, such inhomogeneous superfluidity would take place via a microscale phase separation, with alternating finite-momentum pairs and normal regions, the latter being composed by the majority spin. After almost fifty years since the FFLO-phase was predicted, despite the powerful theoretical methods available, the microscale phase separation has not been observed. Here we show that the ground-state of one-dimensional superfluids with spin-imbalanced populations is indeed microscale phase separated and evolves smoothly with the imbalance to a partially polarized normal phase. For strongly interacting systems, we find that the microscale structure can be read directly from the density profiles. We also deduce an expression for the critical polarization below which the FFLO-state emerges. Our phase diagram indicates the parameters for which exotic superfluidity can be theoretically and experimentally explored.

Time-reversal symmetry breaking in kinetically frustrated spinless fermions

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Abstract

We study a spin-polarised Fermi gas in a triangular lattice with frustrated hopping and long-range interactions. Inverting the sign of the hopping matrix elements leads to frustration, which manifests itself through the appearance of two non-equivalent minima in the dispersion relation. Therefore, at low enough fillings ($\nu < 1/4$), the system has two Fermi surfaces. We show that a repulsive long-range interaction introduces an instability towards a population imbalance between the two Fermi seas. Such a population imbalance is equivalent to the presence of staggered currents running around the elementary plaquettes of the lattice, which imply time-reversal symmetry breaking. We describe this effect within mean-field theory.

The type of Hamiltonian we are studying can be obtained in various ways. The frustrated hopping emerges as a hole property at high particle fillings, and is also found in elliptically shaken triangular lattices [1] and square lattices shaken along a diagonal [2], where low particle fillings are required to observe the effect. The long-range interactions can be realised by using polarised dipolar atoms, or as boson-mediated nearest-neighbour repulsions [3].

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Pairing in population imbalanced Fermi gas in one and two dimensions.

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Balanced populations of fermions, when interacting attractively, form bosonic pairs via the well understood BCS mechanism. When the populations are imbalanced, the pairing mechanism is not clear. Interest in this question has intensified recently due to realization of such polarized Fermion mixtures in trapped ultra-cold atom experiments both in three-dimensional and one-dimensional systems. There are two main pairing mechanisms thought to play a role. In the first, the "Fulde-Ferrell-Larkin-Ovchinnikov" (FFLO) mechanism, the pairs form with non-zero center of mass momentum (equal to the difference of the Fermi momenta) leading to an inhomogeneous phase with a spin gap. The second suggested mechanism is "breached pairing" (Sarma phase) where the BCS-type pairs are formed with zero center-of-mass momentum and the Fermi surfaces of each species are modified. The pairs in this phase are expected not to have a spin gap. Various theoretical calculations, mean field and variational, are often in disagreement as to which phase is favored. It is now however becoming widely accepted based on many numerical studies that in a one-dimensional system of imbalanced populations of fermions in the ground state the FFLO phase is realized over a wide range of parameters.

We use Quantum Monte Carlo (QMC) techniques to provide an approximation-free investigation of the phases of the one-dimensional and two-dimensional attractive Hubbard Hamiltonian in the presence of population imbalance. The temperature at which the FFLO phase is destroyed by thermal fluctuations is determined as a function of the polarization [1]. The phase is quite robust and persists to higher temperature for higher polarization. It is shown that the presence of a confining potential does not dramatically alter the FFLO regime. In the one-dimensional setup we find that recent experiments on trapped atomic gases likely lie just within the temperature range where the FFLO phase could be observed. Contrary to claims of fragility with increased dimensionality, in two-dimensions the phase is found to be stable for a wide range of values of polarization, temperature and interaction strength.

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Sub shot-noise sensitivity from single-particle measurements

Jan Chwedeńczuk

We show that a sub shot-noise sensitivity -- associated with the quantum correlations present in the state entering the interferometer -- can be achieved with particle-position measurements using a new phase estimator, which does not require *any* knowledge about these correlations, and is based on a single-body density. For the case of the estimation of the relative phase Θ between two interfering wave-packets we demonstrate that the sensitivity can scale as $\Delta^2\Theta \sim N^{-1.33}$ with the total number of particles N when phase-squeezed states are used. The necessary amount of squeezing could be created using a Bose-Einstein Condensate trapped in a double-well potential, and we argue that even with finite detection efficiency/resolution, sub shot-noise sensitivity can be preserved.

Quantum enhanced metrology with trapped atoms

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Ultra-precise measurements are of great importance for countless applications, such as atomic clocks, gravitational wave detectors, laser gyroscopes, ultra sensitive magnetometry or microscopy. Quantum enhanced precision measurements can drastically increase the accuracy of such applications compared to classical methods [1]. This is generally achieved by preparing a quantum probe-state which has a higher sensitivity with respect to the quantity to be estimated. Assuming that this probe consists of N non-interacting, identical subsystems (e.g. N particles), the estimation uncertainty in many applications including optical or atomic interferometry can then ideally be improved from the standard quantum limit, which scales like $1/\sqrt{N}$, to the Heisenberg limit, which scales like $1/N$ [1]. In atomic physics, the measurement of atomic transition frequencies with Ramsey interferometry has been established as an important tool, not only for general spectroscopic purposes but also to determine frequency standards on which atomic clocks are based on [2]. Improvements of Ramsey interferometry via quantum effects are therefore highly desirable. The biggest obstacle for the realization of such a quantum interferometer is the presence of unavoidable noise and imperfections. A practical quantum sensor must therefore use probe-states which are robust under realistic circumstances, as well as preparation and detection schemes which can be performed with high fidelity [3, 4].

In this talk I present methods for quantum enhanced estimation of atomic transition frequencies with Ramsey interferometry [Fig. 1(a)], and generalizations thereof [e.g. Fig. 1(b)], using trapped ions or neutral atoms [5]. Schemes for quantum enhanced Ramsey interferometry have been proposed before [6], but it has subsequently been shown that, in the presence of noise in form of *uncorrelated* dephasing, the scheme has only little or no advantage compared to its classical counterpart [7]. However, recent experimental breakthroughs with closely spaced particles, particularly ions stored in linear Paul traps (see, e.g., [8]), show that the major source of noise in these systems consists of *correlated* dephasing.

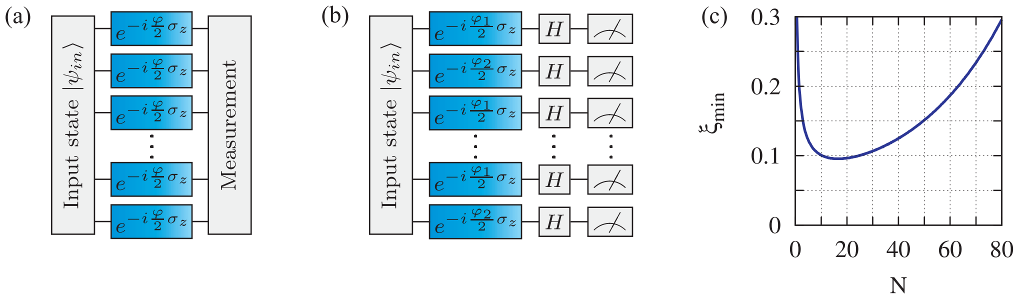

FIG. 1: (a) Schematic Ramsey interferometer. (b) Example of a generalized Ramsey setup where atoms acquire different phases. (c) Minimum state preparation fidelity ξ_{min} versus atom number N required to beat "classical" Ramsey interferometry.

Motivated by this insight we first analyze conventional Ramsey interferometry and show that in the presence of correlated dephasing hardly any quantum enhancement can be achieved. We therefore develop alternative methods, i.e. generalized Ramsey setups, which employ highly non-classical probe-states and decoherence free subspaces. These methods improve the measurement uncertainty to the Heisenberg limit in the presence of correlated dephasing and tolerate faulty detection and significantly imperfect state preparation [Fig. 1(c)]. They are therefore feasible with current experimental technology and can lead to improved spectroscopic methods with a variety of important applications in metrology.

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Control of quantum coherence in many-body quantum systems

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We discuss how quantum coherence can be enhanced through the application of suitably tailored driving fields. Considering a target of control that is maximized by a manyfold of quantum states, allows us to exert enough control on a quantum system's dynamics to reach close-to-ideal coherence properties, and, at the same time, to avoid restraining the dynamics unnecessarily. Potential targets that satisfy these conditions are for example entropies which are invariant under unitary transformations or entanglement measures which are invariant under single-particle (local) unitary transformations.

With these tools we investigate the creation of highly entangled many-body states, in the presence of dephasing and limited knowledge on the inter-particle interaction mechanisms. Here, we employ time-local control strategies [1], which allow us, in particular, to identify those states that have particularly robust entanglement properties [2]. Despite its simplicity our scheme is able to identify time-optimal solutions [3]. To create highly entangled state with limited knowledge on the system Hamiltonian, we make use oft the GRAPE algorithm [4], that helps to identify time-dependent pulse shapes which drive even broadly distributed ensembles of many-body systems towards highly entangled states.

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Limit of Spin Squeezing in Finite Temperature Bose-Einstein Condensates

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Atomic clocks based on cold alkali atoms in two hyperfine states a and b are widely used as frequency standards. When atoms in uncorrelated quantum states are used, the clock precision is limited by the so-called projection noise, resulting from the quantum nature of the collective spin $\mathbf{S}$, *i.e.* the sum of the effective spin 1/2 of each atom. This limit is actually already reached in most precise clocks [1]. Spin squeezing [2] amounts to creating quantum correlations among the atoms so as to increase the precision of the atomic clock beyond this standard quantum limit. The relative improvement on the variance of the measured frequency $\Delta\omega_{ab}^2$ defines the spin squeezing parameter ξ^2 [3]. The ultimate limits of the different paths to spin squeezing are still an open question. We determine here the influence of the non-condensed fraction for spin squeezing schemes using Bose-Einstein condensates [4–6]. A central issue is the *scaling of the squeezing* for large atom numbers. Most studies are based on a two-mode description [2]. In this case the squeezing parameter optimized over time $\xi^2_{\rm best}$ tends to zero (infinite metrology gain) for $N \to \infty$ as $\xi^2_{\rm best} \sim N^{-2/3}$. Here, using fully non-perturbative semi-classical field simulations and a powerful formulation of Bogoliubov theory in terms of the time dependent condensate phase operator [7], we find on the contrary a dramatic effect of the multimode nature of the field: For a spatially homogeneous system in the thermodynamic limit, the two-mode scaling $\xi^2_{\rm best} \sim N^{-2/3}$ turns out to be completely irrelevant, and the spin squeezing has a finite optimal value that we determine analytically [8].

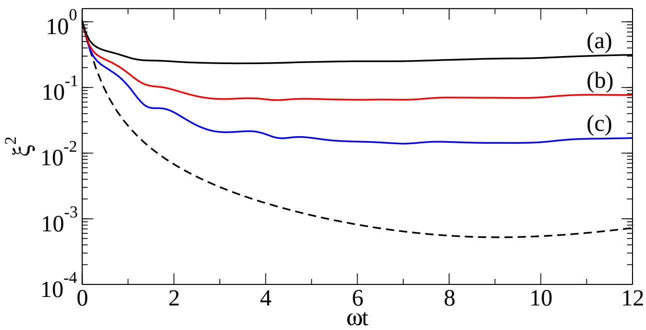

FIG. 1: (Color online) Spin squeezing parameter ξ^2 as a function of time after the pulse mixing the states a and b, for $N = 10^5$ Rb atoms (s-wave scattering length $a = 5.3$ nm), in a harmonic trap with oscillation frequency $\omega/2\pi = 50$Hz. The Thomas-Fermi chemical potential is $\mu = 15.36\hbar\omega$. Finite temperature semi-classical field simulations with initial non-condensed fractions: (a) $\langle N_{\rm nc}\rangle/N = 0.34$ (black solid line), (b) $\langle N_{\rm nc}\rangle/N = 0.20$ (red line), (c) $\langle N_{\rm nc}\rangle/N = 0.09$ (blue line), corresponding to $k_B T/\mu = 2.08, 1.53, 1.17$ respectively. Dashed line: Two-mode theory for comparison.

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Solitons as the Early Stage of Quasicondensate Formation during Evaporative Cooling

E. Witkowska, P. Deuar, M. Gajda, and K. Rzążewski

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

Microscopic scattering theory for a BEC in disordered potentials

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Abstract

In recent years Bose-Einstein condensates have been used experimentally to prove a variety of quantum mechanical phenomena in a clean and well-controllable surrounding. It is due to this high controllability that more and more sophisticated experiments can be conducted where by turning just a "knob" additional effects like random disorder and/or stronger interparticle interactions can be taken into account with high precision. On the theoretical side, with increasing amounts of disorder and interaction, the stationary solution of the widely applied mean field description [1] – and eventually also the mean field description itself – breaks down. Therefore, a more complex mathematical treatment is required which goes beyond the celebrated Gross-Pitaevskii equation. Physically, by scattering with the random disorder potential and with each other the bosons acquire random phases and wavevectors and hence, the condensate is depleted. As this is intuitively expected, the precise effects due to the interplay of disorder and growing nonlinearity are mostly unknown.
To shed light on this question, we treat the full bosonic N-body problem microscopically in a nonlinear scattering setup. By employing a diagrammatic technique relying on the assumption of a weakly scattering disorder potential [2], one is in principle able to sum up all different orders of the nonlinear scattering series, where an average over the random disorder potential ensures that only certain diagrammatic paths – ladder and crossed – contribute to the final result. Here, we compare our findings to the results obtained by the Gross-Pitaevskii equation. We present furthermore results of the non-condensate fraction as a function of disorder and interaction strength and estimate how the coherent transport of the cloud – in particular coherent backscattering – is affected by the strength of the nonlinearity.

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Disordered bosons: condensate and excitations

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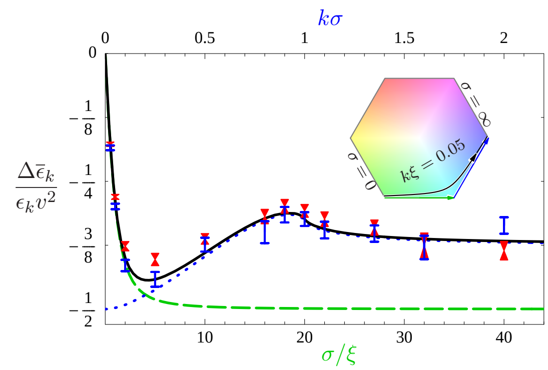
We report substantial progress on the analytical description of disordered Bose-Einstein condensates and their excitations. We start from the many-body Hamiltonian $\int \mathrm{d}^d r\, \hat\Psi^\dagger \left[\frac{-\hbar^2}{2m}\nabla^2 - \mu + \frac{g}{2}\hat\Psi^\dagger\hat\Psi + V(\boldsymbol{r})\right]\hat\Psi$ where $V(\boldsymbol{r})$ is a spatially correlated disorder potential. We are interested in the low-temperature regime and study both condensate and excitations in the presence of weak disorder. We expand the many-body Hamiltonian to second order in the fluctuations around the deformed ground state $\Phi(\boldsymbol{r})$. After a combined Fourier-Bogoliubov transformation, we arrive [1] at the fundamental Hamiltonian of Bogoliubov excitations in the form $\hat H = \hat H^{(0)} + \hat H^{(V)}$:

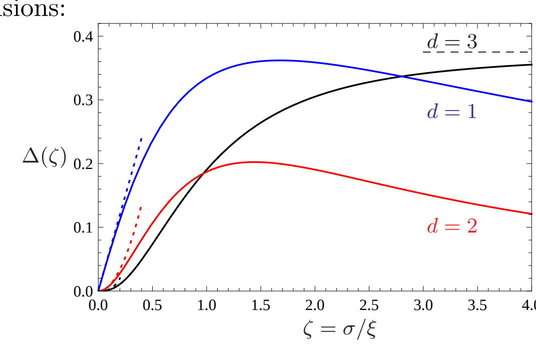
$$\hat H = \sum_{\boldsymbol{k}} \epsilon_k \hat\gamma^\dagger_{\boldsymbol{k}}\hat\gamma_{\boldsymbol{k}} + \frac{1}{2}\sum_{\boldsymbol{k},\boldsymbol{k}'} \left(\hat\gamma^\dagger_{\boldsymbol{k}}, \hat\gamma_{-\boldsymbol{k}}\right) \begin{pmatrix} W_{\boldsymbol{k}\boldsymbol{k}'} & Y_{\boldsymbol{k}\boldsymbol{k}'} \\ Y_{\boldsymbol{k}\boldsymbol{k}'} & W_{\boldsymbol{k}\boldsymbol{k}'} \end{pmatrix} \begin{pmatrix} \hat\gamma_{\boldsymbol{k}'} \\ \hat\gamma^\dagger_{-\boldsymbol{k}'} \end{pmatrix}$$

The clean Hamiltonian has the usual Bogoliubov dispersion ϵ_k. The correction $\hat H^{(V)}$ still exact in disorder, via the groundstate $\Phi[V(\boldsymbol{r})]$. Crucially, the fluctuations are expressed in a basis of deformed plane waves that are orthogonal to the Bogoliubov vacuum $\Phi(\boldsymbol{r})$ [2]. From here, standard perturbation theory permits to compute any disorder-averaged physical quantity.

First, we determine the disorder-renormalized excitation dispersion relation $\bar\epsilon_k$ via the self-energy of the single-quasiparticle Green's function, as function of the disorder correlation length σ and the condensate healing length ξ [2]. The analytical prediction agrees excellently with a direct numerical simulation using time-dependent Gross-Pitaevskii theory [3]; the inset shows the plot's path in the parameter space [2]. Notably, we find that spatial disorder correlations give a negative sound-velocity shift, opposite to the known result of delta-correlated disorder ($\sigma \ll \xi$) in $d = 3$.



Second, we can calculate, for the first time, the disorder-induced condensate depletion properly speaking, namely $\delta n := L^{-d}\int \mathrm{d}^d r \left\langle \delta\hat\Psi(\boldsymbol{r})^\dagger \delta\hat\Psi(\boldsymbol{r})\right\rangle$, which is the density of particles that are not part of the deformed condensate. Using Matsubara-Nambu-Green perturbation theory, we find the condensate depletion in all dimensions:



The average depletion induced by the disorder, $\overline{\delta n^{(2)}}/n = (\delta n^{(0)}/n) v^2 \Delta(\zeta)$, is a factor $\delta n^{(0)}/n \ll 1$ smaller than the mean-field condensate deformation, which is of order $v^2 = V^2/(gn)^2$. This is a plausible result: the primary effect of the external disorder potential is to deform the condensate. The depletion of the condensate is a secondary effect, mediated by the weak boson repulsion. The smallness of the condensate depletion guarantees that our Bogoliubov theory should fare very well in describing the finite-temperature properties of disordered condensates.

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Disordered spin-1 Bose-Hubbard model

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ABSTRACT

Spinor Bose-Hubbard (BH) models describe strongly correlated lattice systems where bosons have internal angular momentum -spin- whose orientation in space is not externally constrained. In atomic gases, the spin degree of freedom corresponds to the manifold of Zeeman energy states associated to a given hyperfine level. As in the spinless BH case [1], the competition between the different energy scales present in spinor BH models determines the ordering properties of the ground state. Modifying the energy ratio between the hoping and interactions allows to cross a quantum phase transition between now a spinor superfluid condensate and a Mott insulator (MI) state [2,3].

Here we study the zero temperature phase diagram of the spin 1 BH model in a 2D square lattice in the presence of disorder using a mean field Gutzwiller ansatz and a stochastic mean field approximation [4]. We focus on the antiferromagnetic case and we study three different types of disorder: in the chemical potential, in the spinor interaction and in the spinless interaction coupling. Our main results can be summarized as follows. In the presence of disorder in the chemical potential, we obtain that MI lobes with odd occupation disappear and the emergence of the Bose glass (BG) phase between MI lobes with even occupancy occurs. For large enough spinor coupling, when the disappearance of the lobes with odd occupancy occurs already in the absence of disorder, a BG of singlets is predicted. Adding disorder in the spinor coupling, we observe that the BG phase appears only between lobes corresponding to n and $n+1$ occupations with n-odd. We explain such a behavior using perturbation theory in the vanishing tunneling limit. Disorder on the spinless interaction coupling reproduces qualitatively the results found for scalar gases [5], i.e., lobes with occupation larger than a critical value, fixed by the magnitude of the disorder, disappear and BG appears between the remaining ones.

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Coherent transport of waves in nonlinear disordered media

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Abstract

As it is well known, waves are fundamentally distinct from (classical) particles in their ability to display interference. However, in presence of disorder, interferences tend to be washed out. In this case, wave propagation reduces to a simple diffusion process - like a random walk of a classical particle. But under appropriate circumstances, some interferences may also survive the disorder average and induce interesting effects, for example turn a metal into an insulator (Anderson localization) or increase the brightness of saturn's rings (coherent backscattering).

After a general introduction into the physics of multiple scattering, the second part of the talk deals with propagation of waves in nonlinear random media. Generally, a nonlinearity arises whenever the wave interacts with itself or with the scattering medium in such a way that properties like refractive index, mean free path, etc., are not constant, but depend on the wave intensity. The question is now: how do these nonlinearities affect the multiple scattering interferences? To tackle this problem, we develop a diagrammatic theory for performing disorder averages with nonlinear wave equations. As main result, we show how the coherent backscattering interference is either diminished or amplified, depending on the type of nonlinearity. Whereas this result applies to classical or single-particle quantum waves, we will finally also address multi-photon scattering from strongly driven two-level atoms, where coherent transport is additionally affected by quantum mechanical decoherence.

On the Robustness of Quantum Simulators

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(Dated: June 3, 2011)

Many poorly understood phenomena with high practical importance are of quantum mechanical origin (a prime example being high-temperature superconductivity). To understand them, one would traditionally develop simplified models identifying the responsible key mechanisms, and extract from them predictions to compare with experiment. However, the lack of analytical tools and the exponential complexity of classical simulation of quantum mechanical problems hinder solving such models. As a solution, Feynman proposed in 1982 to have the model be simulated by a *quantum simulator*. These are quantum mechanical systems with a high degree of control and cleanness which can be understood as dedicated, non-universal quantum computers. In comparison to a full-fledged quantum computer, it is widely assumed that quantum simulators are less affected by decoherence, thus making them much easier to accomplish. Until now, almost all research has focused on improving control over quantum simulators and broadening the class of models amenable to quantum simulation. The tremendous progress in this respect let the journal Science consider five experimental quantum simulations as 'breakthrough of the year 2010'. This effort, however, has relied on two implicit assumptions: i) the robustness of quantum simulators is superior to universal quantum computers, and ii) a quantum simulator can outperform any classical simulation. The latter becomes questionable in the light of recent ideas allowing to approximately simulate quantum mechanics on a classical computer with polynomial (rather than exponential) resources. In this talk, we want to question these two conventional assumptions. As a first step, we theoretically compare both static and dynamic properties of a supposed ideal quantum simulator with a noisy one. We find that generically global properties are not robust to noise, while local ones are. Fortunately, many-body quantum simulations normally pose questions about such local properties (contrary to quantum computations). However, in special cases, noise-affected non-local quantities are important, like in quantum criticality, where they can characterize the universality class. On the up-side, the levels of noise for a relevant change to occur seem generally to be large. We will discuss these aspects in detail in this talk. We hope that our work will stimulate more, badly-needed research into the validity of quantum simulators.

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An Optical-Lattice-Based Quantum Simulator For Relativistic Field Theories and Topological Insulators

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We present a proposal for a versatile cold-atom-based quantum simulator of relativistic fermionic theories and topological insulators in arbitrary dimensions. The setup consists of a spin-independent optical lattice that traps a collection of hyperfine states of the same alkaline atom, to which the different degrees of freedom of the field theory to be simulated are then mapped. We show that the combination of bi-chromatic optical lattices with Raman transitions can allow the engineering of a spin-dependent tunneling of the atoms between neighboring lattice sites. These assisted-hopping processes can be employed for the quantum simulation of various interesting models, ranging from non-interacting relativistic fermionic theories to topological insulators. We present a toolbox for the realization of different types of relativistic lattice fermions, which can then be exploited to synthesize the majority of phases in the periodic table of topological insulators.

References: PRL **105** 190404 (2010) and arXiv:1105:0932

Entanglement resonances in periodically driven quantum systems

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As demonstrated recently [1,2], periodic driving of a composite quantum system can induce entanglement that significantly exceeds the threshold of the static case.
Alike general resonance phenomena this enhancement of entanglement occurs for very specific amplitudes and frequencies of the driving fields.

We aim to develop a general understanding of the underlying mechanisms. To this end, we consider a multi-partite quantum system, consisting of several weakly coupled qubits, and study the interplay of periodic driving and multi-partite entanglement within the Floquet picture; i.e., we identify the dressed states of this driven, closed quantum system and quantify their entanglement by means of a multi-partite entanglement measure. Indeed, at well-defined values of the driving frequency and amplitude, we find a resonant behavior of entanglement [3]. The occurrence of these resonances can be understood in terms of the single particle Floquet spectra only, what permits to predict resonances without solving the underlying many-body problem.

In a second step, we investigate entanglement of the corresponding open system. I.e., we consider weakly interacting qubits that are not only periodically driven, but also coupled to a heat bath at finite temperature. By employing a Markovian master equation based on the Floquet picture, we analyze the entanglement of the stationary dynamics. Similar to the results of the corresponding closed system, we find entanglement resonances at certain driving parameters. We show that this phenomenon is largely independent of the details of the model system, and discuss when and why the resonances occur.

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From molecular rotation to entanglement of atoms

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In 1935 Einstein, Podolsky and Rosen (EPR) published an article [1], in which they concluded that probabilistic quantum mechanical description of the physical reality is incomplete (EPR paradox). In 1950 Bohm introduced [2] a version of the EPR paradox for two spin-1/2 particles created in a decay of a singlet-state system described as a combination of two antiparallel spins forming so-called ***entangled state***. In a ground-breaking article of Bell [3], published in 1964, the author suggested so-called *local hidden variables* theory and introduced a criterion, called Bell's inequality, which permitted a verification of any local theory (including quantum mechanics) with *local hidden variables*. Statistical predictions of any local theory that complete quantum mechanics in the EPR sense had to satisfy Bell's inequality whereas statistical predictions of quantum mechanics should violate the inequality. Consequently, an experimental verification of quantum mechanical predictions was possible for the first time.

Here, a Fry-Walther-Li's proposal [4] for studies of *quantum entanglement* in pair of atoms created in a process of controlled dissociation of homonuclear diatoms will be presented. Our experimental approach [5], which differs from the original one formulated for $^{199}Hg_2$, employes a technique of supersonic molecular beam and stimulated Raman transition in $^{111}Cd_2$. It will result in a creation of *quantum entanglement* between two ^{111}Cd atoms possessing antiparallel components of an atomic nuclear angular momentum in a single act of selective molecular dissociation. Analysis of the *quantum entanglement* will rely on a detection of coincidences of two ^{111}Cd atoms with antiparallel components of the atomic nuclear angular momentum appearing in two distant detectors localized in so-called planes of detection using a process of spin state selective two-photon excitation-ionization.

Total atomic angular momentum F of ^{111}Cd depends only on its nuclear angular momentum I=1/2 (S=0, L=0, J=0), so the ^{111}Cd atom is spin-1/2 particle (fermion) possessing two antiparallel projections of m_I=±1/2 on a quantization axis (note that pairs of ^{111}Cd atoms are created from the $^{111}Cd_2$ in its molecular nuclear singlet state I=0). The main reason of employing $^{111}Cd_2$ rather than $^{199}Hg_2$ is that in the former the first-step of the stimulated Raman transition is executed using a singlet-singlet $A^1 0_u^+ \leftarrow X^1 0_g^+$, Ω=0←Ω=0 electronic transition. The singlet-singlet transition possess only two P- and R-branches in its rotational structure. In the Fry-Walther-Li's proposal [4], the first-step $D^3 1_u \leftarrow X^1 0_g^+$, Ω=1←Ω=0 transition in $^{199}Hg_2$ characterizes itself with "denser" rotational structure constituting of three P-, Q- and R-branches. Consequently, less complex rotational structure of $^{111}Cd_2$ enables easier selection of well separated J'←J" rotational transition consisting the first-step of the stimulated Raman transition.

Realization of the proposed experiment will account for first experimental realization of *quantum entanglement* between atoms "born" from a single molecule *via* its selective dissociation. This constitutes a huge step forward in understanding of *quantum entanglement* between particles - other than photons - having a large rest mass.

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Collectibility - a new entanglement test based on uncertainty relations

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Paweł Horodecki and Karol Życzkowski

Abstract

For a given pure state $|\Psi\rangle$ of a composite quantum system we propose a new entanglement test based on uncertainty relations analogous to the best known Deutsch entropic uncertainty relation. The main result is a family of sensitive entanglement witnesses, we shall call collectibility, which generalize the geometric measure of entanglement. However, properties of the collectibility are substantially different because of a presence of the nontrivial upper bound mentioned above. Our approach is fruitful in the case of a *K-partite Hilbert space* $\mathcal{H} = \mathcal{H}^1 \otimes \ldots \otimes \mathcal{H}^K$, where the dimensions $\dim\left(\mathcal{H}^i\right)$ can be arbitrarily chosen.

For bipartite systems we shall describe a state in the Schmidt form

$$|\Psi_2\rangle = (U_1 \otimes U_2)\left[\cos\left(\frac{\psi}{2}\right)|11\rangle + \sin\left(\frac{\psi}{2}\right)|22\rangle\right], \tag{1}$$

where $U_1 \otimes U_2$ is a local unitary. In this case the derived upper bound is saturated for maximally entangled states ($\psi = \pi/2$). Moreover we may show that if $\pi/6 \leq \psi \leq 5\pi/6$ then our test will always confirm the entanglement. In our work we present how the collectibility can be experimentally accessible, thus our result contributes to the task of experimental quantification of quantum entanglement. In a tripartite case we show how the collectibility is connected with the 3-tangle measure. More elaborate investigations prove that there is a way to generalize the collectibility approach to the case of the mixed states.

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Phase Space Theory of Bose-Einstein Condensates and Time Dependent Modes

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A phase space theory has been developed for describing dynamical processes in BEC close to zero temperature, such as for interferometry experiments based on time-dependent traps. Phase space methods first involve a consideration of what single particle states or modes are suitable for describing states of the bosonic system. For interacting bosons in time dependent double well traps the time dependent modes obtained from coupled generalised Gross-Pitaevskii equations give a good first approximation to the behaviour near zero temperature for the bosons in condensate modes, and incorporating such condensate modes into phase space theories along with orthogonal non-condensate modes to allow for non mean field effects such as Bogoliubov excitations ought to provide a good basis for understanding BEC dynamics. It is also possible that choosing such physically based time-dependent modes could facilitate numerical calculations.

The present phase space theory involves separate field operators for condensate and non-condensate modes [1], the treatment involving a hybrid Wigner and positive P distribution functional for the highly occupied condensate and mainly unoccupied non-condensate modes respectively [2-4]. For situations well below the transition temperature often only one or two condensate modes are involved. The Liouville-von Neumann or master equation for the density operator is replaced by a functional Fokker-Planck equation for the distribution functional. Finally, the Fokker-Planck equations are replaced by equivalent Ito stochastic equations for condensate and non-condensate fields, and the phase space functional integrals for the quantum correlation functions given by stochastic averages.

However, a theory based on time dependent modes leads to time dependent annihilation, creation operators for the modes. Since in phase space theories mode annihilation, creation operators are represented via the phase space variables, the question arises as to whether these should be chosen to be time dependent in accordance with the related time dependence of the mode functions. This approach is applied here, rather than the time independent phase space variable treatment previously used [4]. The functional Fokker-Planck equations now have additional diffusion terms involving coupling between condensate and non-condensate fields which depend on the time dependence of the modes. Also, additional drift terms involving such coupling need to be included in the relationship between the Ito stochastic field equations and the functional Fokker-Planck equation, as well as the noise field terms now being related to the new diffusion term. Bogoliubov excitations are treated.

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Patterns and excitations in antiferromagnetic condensates

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We analyze the spontaneous formation of periodic patterns in spin-1 and spin-2 antiferromagnetic Bose-Einstein condensates under the influence of the quadratic Zeeman effect [1, 2]. Two regimes, the interaction dominated and the Zeeman dominated, can be distinguished by two different kinds of spin patterns that emerge in the experiment [1]. We explain this behaviour by the leading contribution of unstable spin wave modes and quadrupole modes, respectively in the two regimes. We develop two approximate analytical methods, based on Bogoliubov-de Gennes approach and the energy conservation together with the golden Fermi rule, to determine the pattern period and growth rate. We compare the analytical results with numerical and experimental data.

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Spin domain formation in an expanding anti-ferromagnetic quantum gas.

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The spontaneous spin-symmetry breaking and spin domain formation have attracted great interest in recent years due to their relation to the theory of quantum phase transitions [1] as well as possible applications in precise measurements [2]. We present an experimental observation of the spontaneous spin-symmetry breaking and generation of spin domains in an anti-ferromagnetic ^{87}Rb F=2 Bose-Einstein condensate. The condensate is formed by up to 10^6 ^{87}Rb atoms in the $|F = 2, m_F = 2>$ hfs component of their ground state contained in a magnetic trap. Contrary to all previously published experiments, the spin evolution and spin domain formation occurs during the free-fall expansion in the field of gravity in a presence of a homogeneous magnetic field. In the successive realizations of the identically performed experiment the positions of spin domains vary (Fig). Although after averaging over many realizations the spin domains vanish, they are still present in the averaged power spectra. Additionally collisions between spin domains have been studied experimentally.

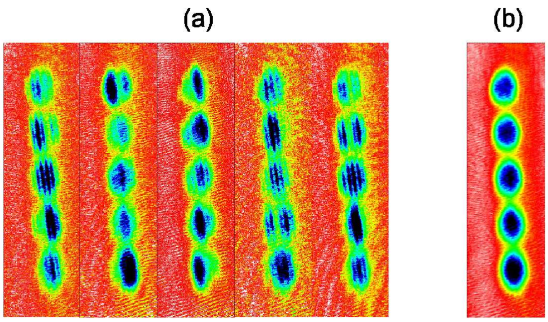

Fig. Successive realizations of the spin domains starting from the same initial experimental conditions (a). The averaged image of 72 realizations (b).

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Beyond standard two mode dynamics in bosonic josephson junctions

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We examine the dynamics of a Bose-Einstein condensate in a symmetric double-well potential for a broad range of non-linear couplings. We demonstrate the existence of a region, beyond those of Josephson oscillations and self-trapping, which involves the dynamical excitation of the third mode of the double-well potential. We develop a simple semiclassical model for the coupling between the second and third modes that describes very satisfactorily the full time-dependent dynamics. Experimental conditions are proposed to probe this phenomenon.

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Decoherence in Bose-Einstein condensate

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All experiments with ultracold atoms are performed in the presence of many sources of decoherenece. Here I will focus on an influence of particle losses and comment on an external noise[1]. The system under study is BEC in a double well potential in the case of supressed tunneling. The problem is studied with the help of a master equation. It turns out that the equation has an exact solution in a single well, which can be easily generalized to a double well potential. The consequences for the coherence properties of the system will be presented.

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Macroscopic States of Light Generated by Quantum Cloners
Magdalena Stobińska

Quantum mechanical laws apply to all the living and inanimate matter. Surprisingly, although the macroscopic quantum systems decohere very fast making the experimental verification of their quantum features extremely challenging, the macroscopically populated states of light produced by the optimal phase covariant quantum cloning are particulary well suited for closing the detection loophole in Bell test, even in presence of losses. Here we present a loophole-free Bell inequality test with preselected macroscopic states of light by a filter, a threshold measurement which is believed not to be useful for this purpose. The test is based on linear optical elements and is feasible within the current technology. Threshold detectors examine each single superposition component of a quantum state separately under a condition. Implementation of those is challenging. We propose a measurement scheme of a filter applicable for any two mode polarization state with super-Poissonian statistics. This filter is important for engineering of macroscopic quantum states of light: it preserves their quantum macroscopic character and improves distinguishability with classical detection. It is based on single measurement outcomes, not mean values.

Dirac Equation For Cold Atoms In Artificial Curved Spacetimes

Alessio Celi

We argue that the Fermi-Hubbard Hamiltonian describing the physics of ultracold atoms on optical lattices in the presence of artificial non-Abelian gauge fields, is exactly equivalent to the gauge theory Hamiltonian describing Dirac fermions in the lattice. We show that it is possible to couple the Dirac fermions to an "artificial" gravitational field, i.e. to consider the Dirac physics in a curved spacetime. We identify the special class of spacetime metrics that admit a simple realization in terms of a Fermi-Hubbard model subjected to an artificial SU(2) field, corresponding to position dependent hopping matrices. As an example, we discuss in more detail the physics of the 2+1D Rindler metric, its possible experimental realization and detection.

Synthetic magnetic fluxes on the honeycomb lattice

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We devise experimental schemes able to mimic uniform and staggered magnetic fluxes acting on ultracold two-electron atoms, such as ytterbium atoms, propagating in a honeycomb lattice. The atoms are first trapped into two independent state-selective triangular lattices and are further exposed to a suitable configuration of resonant Raman laser beams. These beams induce hops between the two triangular lattices and make atoms move in a honeycomb lattice. Atoms traveling around each unit cell of this honeycomb lattice pick up a nonzero phase. In the uniform case, the artificial magnetic flux sustained by each cell can reach about two flux quanta, thereby realizing a cold atom analogue of the Harper model with its notorious Hofstadter's butterfly structure. Different condensed-matter phenomena such as the relativistic integer and fractional quantum Hall effects, as observed in graphene samples, could be targeted with this scheme.

***Title*: Gauge Fields for Cold Atoms: New Environments for Quantum Hall Effects**

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Abstract

Thirty years after its discovery in GaAs-AlGaAs heterojunctions the fractional quantum Hall effect still remains to be the topic of current research, as nowadays this former solid-state phenomenon is re-discovered within the scope of quantum gases in two dimensions. Different proposals to achieve the crucial ingredient, a perpendicular magnetic field, in such systems of neutral particles are at hand. In this talk we discuss a simple scheme, where an artificial *U(1)* gauge field is generated by a laser beam that couples two internal atomic states. The gauge field is related to Berry's geometrical phase that emerges when an atom follows adiabatically one of the two eigenstates of the atom-laser coupling. While transitions between the eigenstates are suppressed for a strong atom-laser coupling, and, given some repulsive interaction, the system can be perfectly described by the Laughlin wave function, a weaker atom-laser coupling requires to go beyond this adiabatic approximation. Therefore we have applied exact diagonalization to a small system of cold bosonic atoms with contact interaction and analyzed the emergence of strongly correlated states. It turns out that even beyond the adiabatic approximation the system can be described by a generalized version of the Laughlin wave function.

In the second part of the talk, we follow the adiabatic approximation and consider a system of fermionic dipoles. We analyze the robustness of the fractional quantum Hall state which is measured as the energy gap separating the Laughlin ground-state from excitations. Using thermodynamic approximations for the correlation functions of the Laughlin state and an excited quasihole state, only a small gap is found in a system of dipolar atoms exposed to an Abelian gauge field. Therefore we also discuss a generalized scheme which, by coupling four internal states of the atoms, allows for creating an artificial *SU(2)* gauge field. This non-Abelian field may result in a squeezing of the Landau levels which is shown to significantly increase the gap.

Literature:

- B. Julía-Díaz, D. Dagnino, K. J. Guenter, T. Grass, N. Barberán, M. Lewenstein, J. Dalibard, *arXiv:1105.5021*

- T. Grass, M. A. Baranov, M. Lewenstein, *arXiv:1105.0299*

Storing and releasing of multi-component slow light in atomic media

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ABSTRACT

Over the last decade there has been a great deal of interest in slowing down and storing the probe pulse of light in a resonant atomic medium illuminated by a control laser beam of higher intensity [1–6]. Usually the probe and control beams act on atoms in the Lambda configuration of the atom-light coupling. By switching off the control laser one can store the probe light, whereas by switching it on again the probe beam is regenerated [1–4].

Here we consider another possibility of storing and release of the probe beam without switching off and on the control beams. For this we suggest to use a more complex scheme involving two pairs of counter-propagating control laser beams acting on the atoms in a double tripod scheme of the atom-light coupling [7]. As a result a two-component slow light is formed. The propagation of the probe beam can then be controlled by changing the relative phase of the control beams or introducing a two-photon detuning. Using these means the probe beams can be frozen in the medium forming a stationary light and subsequently released. We analyze an efficiency of such a storing and release scheme.

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An achromatic polarization retarder realized with the analogy of rapid adiabatic technique from quantum optics

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Using the phenomena of linear and circular birefringence we propose a device that can alter general elliptical polarization of a beam by a predetermined amount, thereby allowing conversion between linearly-polarized light and circularly polarized light or changes to the handedness of the polarization. Based on an analogy with two-state adiabatic following of quantum optics, the proposed device is insensitive to the frequency of the light – it serves as an achromatic polarization retarder. [1];

[1] A. A. Rangelov "An achromatic polarization retarder realized with slowly varying linear and circular birefringence" arXiv:1105.0316v1

Coherent Backscattering of Ultracold Matter Waves: Momentum Space Signatures

Tomasz Karpiuk

Using analytical and numerical methods, it is shown that the momentum distribution of a matter wave packet launched in a random potential exhibits a pronounced coherent backscattering (CBS) peak. By analysing the momentum distribution, key transport times can be directly measured. The CBS peak can be used to prove that transport occurs in the phase-coherent regime, and measuring its time dependence permits monitoring the transition from classical diffusion to Anderson localization.

I. SIMULATING MANY BODY DYNAMICS OF HARMONICALLY CONFINED ATOMS IN REDUCED DIMENSION

Modelling the behaviour of many body systems is, in general, quite a difficult and computation intensive task. Mean field descriptions provide a powerful tool to describe weakly interacting systems of Bosons. However, the mean field approximation is found to break down in the case of strong interactions (e.g. the Tonks Girardeau regime) and in some dynamic cases [e.g. Streltsov, et al PRL. 100, 130401], it is also important for some QIP applications to understand the excitation spectrum more quantitatively. This talk relates to the modeling of a Bose gas in a one dimensional harmonic trap via matrix diagonalisation in a truncated Hilbert space, particularly focusing on the case of attractive interactions with relevance to solitons and soliton trains produced experimentally. These objects are of interest as they have possible uses for interferometry [e.g. N. Veretenov et al EPJ D 2007] and studying quantum reflection, there are also unanswered questions as to whether this system retains macroscopic quantum coherence. These calculations are aided by exact theoretical results for the untrapped system and the separation of the center of mass eigenstates that occurs in a harmonic potential in any number of dimensions, allowing for a projection to a much smaller set of basis states.

Tomasz Wasak

"Scattering of atoms in collision of quasi-Bose-Einstein Condensates"

The dynamics of Bose-Einstein Condensate is described very accurately within mean field theory by Gross-Pitaevskii equation. There are processes, however, which lie beyond the simple description of mean field, an example of which is the collision of two Bose-Einstein Condensates, when the halo of scattered atoms is produced.

If the condensate is very elongated in one spatial dimension, the axial phase fluctuations may be meaningful, which would lead to condensate with fluctuating phase (quasi-condensate). The process of the collision of two quasi-Bose-Einstein Condensates is interesting since the properties of the halo are already measured in experiment.

We developed a model of a collision of two quasi-Bose-Einstein Condensates and showed how the halo of scattered atoms is produced. Within perturbation theory and under certain approximations, we calculated the correlation functions, which describe the properties of the atoms out of quasi-condensates.

In this talk, I will present the model and some results concerning the description of quasi-Bose-Einstein Condensates collision.

Bose-Einstein Condensates on slightly asymmetric double-well potentials

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An analytical insight into the symmetry breaking mechanisms underlying the transition from Josephson to self-trapping regimes in Bose-Einstein condensates is presented. We obtain expressions for the ground state properties of the system of a gas of attractive bosons modelized by a two site Bose-Hubbard hamiltonian with an external bias. Simple formulas are found relating the appearance of fragmentation in the condensate with the large quantum fluctuations of the population imbalance occurring in the transition from the Josephson to the self-trapped regime. The effects of temperature on the properties of the system are also examined.

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Resonant Einstein-de Hass effect on the plaquette

Tomasz Świsłocki

We study a square plaquette of four optical traps containing ultra cold 87Rb atoms in F=1 hyperfine state. In a single axially symmetric harmonic trap the dipolar interactions in a presence of an external resonant magnetic field couple initial mF=1 component to other Zeeman sublevels. This effect, known as Einsteinde Haas effect in condensed atomic gas, results in effective transfer of atoms to other Zeeman states and leads to a various final states depending on the trap geometry and the value of magnetic fields. We study competition between the local axial symmetry of individual trap and the discrete symmetry of the plaquette. The impact of the global plaquette symmetry on the dynamics can be controlled via the height of the potential barrier separating neighboring traps. In deep axially symmetric micro traps, when tunneling between different traps is suppressed, the local symmetry determines a topology of the final atomic state. Due to the conservation of the "z" axis projection of the total angular momentum of interacting atoms a vortex superfluid can be created with vortices localized at individual traps. On the contrary, for shallow traps and larger tunneling the symmetry of the whole plaquette has a dominant influence on the behavior of the system and a discreet single vortex is created.

Manipulating atoms near surfaces

Tomasz Kawalec

The interaction of an atom with a dielectric or metallic surface has been interesting for physicists for many years. However it has recently attracted much attention and became a popular subject of investigation both in technological and fundamental research, thanks to merging two rapidly developing areas of physics and engineering: cold atoms manipulation and structured surface preparation.

The new scientific tools are surface mirrors, traps and guides for cold and ultracold atoms. Employing a structured surface allows one to obtain sophisticated magnetic or optical potentials, ensuring precise manipulation of both atomic movement and internal degrees of freedom, what is in turn the key issue for studying fundamental quantum phenomena.

The talk will review recent developments and prospects in atomic-surface physics, including atom-chips, micro optical potentials, surface plasmon polaritons and hybrid opto-magnetic traps.