Dynamics of magneton excitations with trapped ions

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Quantum dynamics can be described by particle-like carriers of information that emerge in the collective behavior of the underlying system, the so-called quasiparticles. These elementary excitations are predicted to distribute quantum information in a fashion determined by the system's interactions. Here we report quasiparticle dynamics observed in a quantum many-body system of trapped atomic ions. First, we observe the entanglement distributed by quasiparticles as they trace out light-cone-like wavefronts. Second, using the ability to tune the interaction range in our system, we observe information propagation in an experimental regime where the effective-lightcone picture does not apply [1]. Moreover, a spectroscopic technique is presented to study artificial quantum matter and use it for characterizing quasiparticles in a many-body system of trapped atomic ions [2]. Our approach is to excite combinations of the system's fundamental quasiparticle eigenmodes, given by delocalized spin waves. By observing the dynamical response to superpositions of such eigenmodes, we extract the system dispersion relation, magnetic order, and even detect signatures of quasiparticle interactions.

[1] P. Jurcevic et al., Nature **511**, 202 (2014) [2] P. Jurcevic et al., arXiv: 1505.02066, to appear in PRL

Simulating quantum magnetism with 2D arrays of hundreds of trapped ions

Bollinger, John J.
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Quantum simulations using AMO systems promise a new way to experimentally study emergent quantum phenomena, but few systems have demonstrated the capability to control ensembles in which quantum effects cannot be directly computed. The 2D array of 100s of $^9Be^+$ ions in a Penning trap, crystallized in a triangular lattice when laser cooled, is a promising platform for intractable quantum simulations using the $^9Be^+$ valence electron spin as a qubit [1]. Spin-dependent forces are employed to modify the strong Coulomb interaction of the ions, mimicking a quantum magnetic interaction. The range of the magnetic interaction can be tuned from infinite to a dipole-dipole like coupling. Combining the application of the spin-dependent force with a transverse magnetic field should lead to the development of quantum correlations between the spins, which can be measured through optical readout of the spin state, both globally and with site-resolved imaging. I will discuss recent work from a new Penning trap set-up in which we are able to benckmark quantum effects.

[1]J. W. Britton, et al., Nature 484, 489492 (2012).

Quantum Quenches: From the Generalized Gibbs Ensemble to Prethermalization

Cazalilla, Miguel A.
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One important paradigm of condensed matter Physics is the notion of "adiabatic continuity", namely, the idea that the elementary excitations of a system can be put in one-to-one correspondence with the excitations of a certain non-interacting model. The correspondence can be achieved by the technical device of turning the (residual) interactions adiabatically. Good examples of the success of this idea are Landau's theory of Fermi liquids and Haldane's theory of Tomonaga-Luttinger liquids.

In this talk, I will consider the opposite limit, that is, a quantum quech in which the interactions are suddenly switched on. I will first discuss some (old) and new results [2,3] for a one dimensional Fermi gas (the so-called Luttinger model) and a Bose gas with long range hopping.

Next, I will turn on to the two dimensional Fermi gas, for which I present recent results for a a long-range interaction quench in a spinless Fermi gas [3]. For the latter, we have recently obtained the short to intermediate time dynamics using the method of bosonization of the Fermi surface. Thus, we find that the asymptotic state predicted by bosonization is consistent with the prethermalized state that has been previously observed in numerical simulations of other fermion models. From the bosonized representation, we are able to explicitly construct the Generalized Gibbs Ensamble that describes the prethermalized state. F

[1] MAC, Phys. Rev. Lett. 97, 156403 (2006); A. Iucci and MAC, Phys. Rev. A 80, 063619 (2009).
[2] Masaki Tezuka, Antonio M. García-García, and MAC, Phys. Rev. A 90, 053618 (2014).
[3] N. Nessi, A. Iucci, and MAC, Phys. Rev. Lett. 113, 210402 (2014).

Dynamics of ferromagnetic domains and roton excitations in a Bose superfluid

Chin, Cheng
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Dynamics of ferromagnetic domains and roton excitations in a Bose superfluid

We present a new experimental scheme to modify the band structure of an optical lattice. In an admixed band, a novel quantum phase transition is identified from the in situ observation of domains with ferromagnetic interactions. A careful study of the dynamics within one domain suggests the appearance of roton excitations, which greatly suppress superfluidity near the quantum critical point.

Quantum electrodynamics with ultracold matter

Dutta, Omjyoti
(Jagiellonian University, Marian Smoluchowski Institute of Physics, Atomic Optics Department, Krakow, Poland)

Fundamental forces of nature are described by field theories, also known as gauge theories, based on a local gauge invariance. The simplest of them is Quantum Electrodynamics which describes the dynamics of massless photons and their coupling to matter. It has been proposed that the long-wavelength fluctuations of certain low dimensional quantum spin systems can also be described as photons (gapless or gapped) coupled to matter fields. In this talk we will describe an ultracold atom based system in a two-dimensional geometry showing local gauge invariance. Moreover, we show that, due to the presence of additional symmetry, low energy excitations are described by free emergent gap-less photons-a characteristic of an exotic Bose liquid phase.

Spinor dynamics in an ultracold Fermi gas

Ebling, Ulrich
(The University of Tokyo, Department of Physics, Tokyo , Japan)

We present a study of the dynamics of harmonically trapped ultracold Fermi gases with large spin. Compared to the spin-1/2 case, large spin fermions must have one of two possible new properties. Either they obey an enlarged SU(N) symmetry, or they feature spin-changing collisions. The focus of this talk is on the latter case for the weakly interacting scenario, a gas of ultracold {}textsuperscript{40}K atoms. Because of a different order of magnitude of the scattering lengths for spin-changing and spin-conserving collisions in such a system, it can be in different collision regimes (collisionless, intermediate, hydrodynamic) at the same time. The spinor dynamics is described using a semi-classical Boltzmann equation with full spin coherence, an approach which treats the single-particle dynamics as an open system coupled to an environment given by all other particles. In combination with experimental work, we present the study of long-lived collective spin oscillations of an ultracold Fermi sea [1], as well as the relaxation behaviour of a gas of {}textsuperscript{40}K atoms prepared in a spin configuration far from equilibrium, for the 1d and 3d case [2,3].

[1] Krauser et al., Science 343, 157 (2014)
[2] Ebling et al., Phys. Rev. X 4, 021011 (2014)
[3] Ebling et al., in preparation

Exploring Dipolar Quantum Phenomena with Ultracold Erbium Atoms

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Exploring Dipolar Quantum Phenomena with Ultracold Erbium Atoms
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Given their strong magnetic moment and exotic electronic configuration, rare-earth atoms disclose a plethora of intriguing phenomena in ultracold quantum physics with dipole-dipole interaction. Here, we report our latest results on quantum many-body and few-body physics with the strongly dipolar ultracold erbium atoms. Particular emphasis will be given to the scattering properties of bosonic and fermionic Er, in which unconventional and fascinating phenomena appear as a result of both the magnetic and the orbital anisotropy of the underlying interactions.

Rosensweig instability of a dipolar BEC

Ferrier-Barbut, Igor
(University of Stuttgart, 5. Physikalisches Institut, Physics, Stuttgart, Germany)

A classical ferrofluid undergoes a Rosensweig - or normal field - instability resulting from a competition between gravity and surface tension, versus magnetic interactions. As a result, above a critical magnetization, the ferrofluid forms ordered structures. We will present the experimental observation of the equivalent of this instability with a “quantum ferrofluid”: a dipolar BEC of dysprosium atoms. The instability arises here from a competition between the trapping potential, the short-range isotropic repulsion characterized by the scattering length a, versus the dipole-dipole interaction, with a dipole moment of 10 μB for Dy. We drive this instability on a fully magnetized BEC by varying the scattering length on a Feshbach resonance. As a result of this instability, we observe the formation of ordered droplets ensembles. These structures show surprisingly long lifetimes of hundreds of ms, and offer prospects of observing the cohabitation of broken phase- and translation-invariance.

Quantum Hall physics of bosons in synthetic gauge fields

Furukawa, Shunsuke
(University of Tokyo, Department of Physics, Bunkyo-ku, Japan)

Recent years have witnessed a rapid development in experimental techniques for creating synthetic gauge fields in ultracold atomic gases. A sufficiently strong synthetic magnetic field for ultracold atoms is expected to offer intriguing analogues of quantum Hall systems with a rich diversity of statistics and spins of constituent particles. Here we study two-component (or pseudo-spin-1/2) Bose gases in a strong synthetic magnetic field by means of exact diagonalization in the lowest Landau level basis. We show [1] that the ground state at the total filling factor $nu=4/3$ is well described by an $SU(3)_2$ spin-singlet state, whose quasiparticles feature non-Abelian statistics. Furthermore, we show [2] that a bosonic analogue of an integer quantum Hall state appears at $nu=2$. The entanglement spectrum of this state reveals the emergence of counter-propagating edge modes protected by a U(1) symmetry. These results demonstrate rich topological features of the present system exhibiting both non-Abelian and symmetry-protected topological phases.

[1] S. F. and M. Ueda, Phys. Rev. A 86, 031604(R) (2012).
[2] S. F. and M. Ueda, Phys. Rev. Lett. 111, 090401 (2013).

Correlations in a system of few trapped fermions

Gajda, Mariusz
(Polish Academy of Sciences, Institute of Physics, Warszawa, Poland)

A system of a few spin-1/2 fermions confined in a harmonic trap will be discussed. In a case of strong attractive interactions and 1D geometry I analyze the ground and the thermal state of the system in terms of one– and two–particle reduced density matrices as obtained by an exact diagonalization method. I show how the correlated pairs emerge in the system. Temperature dependence of a fraction of the correlated pairs has universal properties analogous to the gap function known from the theory of superconductivity.
In the second part of my talk I will discuss the geometrical correlations in 2D and 3D Fermi systems.

Chains with loops - synthetic magnetic fluxes in 1D

Grass, Tobias
(ICFO - Institut de Ciencies Fotoniques, Castelldefels, Spain)

In the presence of long-range interactions loops with non-zero magnetic flux can appear even in one-dimensional systems. We propose the realization of such scenario in spin chains of atoms coupled to photonic waveguides, or trapped ions. Magnetic fluxes can be induced via periodic driving. For such system, we calculate Chern numbers and edge spectra, demonstrating the occurrence of topological phases. Varying the magnetic flux, the system exhibits a fractal energy spectrum similar to the Hofstadter butterfly.

Observation of an entanglement wave in a Bose-Hubbard chain.

Groß, Christian
(Max-Planck-Institut für Quantenoptik, Garching, Germany)

The local detection of spin-entanglement in many-body systems was so far limited to trapped ion systems. Here we report on the observation of an entanglement wave in a Bose-Hubbard chain realized with ultracold atoms. We developed a protocol to measure the concurrence between any two sites in the chain and use this technique to track the evolution of an initially localized spin excitation. In our system not only the spin, but also the onsite particle number is a relevant degree of freedom. We demonstrate experimentally, that holes in the atomic chain rapidly lead to a loss of coherence in the spin sector and, hence, to a decrease of the detectable concurrence.

Unconventional disorder physics in long-range interacting spin systems

Gurarie, Victor
(University of Colorado, Physics, Boulder, USA)

Spin chains with long-range interactions can be created with trapped ions. Such systems, when random on-site potential is added, may exhibit new types of disorder-driven behavior, distinct from conventional

Anderson localization phenomena. Similar physics can also be observed with spin-orbit coupled systems with Dirac-like spectra in dimensions higher than 2. I will describe in what ways this physics differs from conventional Anderson localization, and how it can be observed in these systems.

Unconventional optical lattices: orbital degrees of freedom and long-range interaction

Hemmerich, Andreas
(Universität Hamburg, Institut für LAser-Physik, Physics, Hamburg, Germany)

I discuss our recent results on optical lattices of bosons prepared in metastable bands and on optical lattices formed inside a high finesse cavity.

Dipolar chromium atoms: Spin dynamics in optical lattices and thermodynamics

Laburthe Tolra, Bruno
(Centre National de la Recherche Scientifique (CNRS), Laboratoire de Physique des Lasers, Université Paris 13, Villetaneuse, France)

Dipole-dipole interactions profoundly modify the magnetic properties of Bose-Einstein condensates made of strongly magnetic atoms such as Chromium. First, the anisotropy of the interaction introduces the possibility of magnetization-changing collisions, which creates an intrinsic coupling between the spin degrees of freedom and the orbital degrees of freedom. Second, dipole-dipole interactions are long-ranged, which leads to non-local spin-spin interactions, for example in an optical lattice. For these reasons, dipolar gases in optical lattices are a fascinating new platform to study quantum magnetism and quantum many-body physics.

In this seminar, I will first describe an experiment where magnetic atoms in different sites of a 3D optical lattice undergo spin-exchange processes due to dipole-dipole interactions. A Bose-Einstein condensate of Chromium atoms is loaded into deep 3D optical lattices. After the atoms are transferred into a spin-excited state, we observe a non-equilibrium spinor dynamics resulting from inter-site Heisenberg-like spin-spin interactions provided by non-local dipole-dipole interactions. This spin dynamics is inherently many-body, as each atom is coupled to its many neighbors. Our experiment thus reveals the interest of chromium lattice gases for the study of quantum magnetism of high-spin systems.

We have also studied the thermodynamics of chromium atoms at low magnetic field. Due to the anisotropy of dipolar interactions, magnetization is free and adapts to temperature. We observe that the BEC always forms in the lowest energy Zeeman state. By applying a magnetic field gradient, we introduce a selective loss of atoms in spin-excited states, which provides a specific loss channel for thermal atoms. This new cooling mechanism based on spin filtering results in purification of the BEC and an increased phase-space density.

Orbital physics as a route to simulating quantum magnetism with optical lattices

Larson, Jonas
(Stockholm University, Department of Physics, Stockholm, Sweden)

In this talk I will present an alternative method to realize effective spin models with cold atoms confined in optical lattices. Most schemes utilize internal atomic electronic states or occupied/unoccupied sites in order to map the system onto effective spin degrees of freedom, but we propose instead to make use of external 'vibrational' (orbital) states of the onsite atomic states. Degenerate orbital states appear on excited bands, and even for bosons these may be very long-lived necessary for experimental verifications. I will focus on a couple of different lattice geometries that lead to interesting spin models; Heisenberg $XY!Z$ and $SU(3)$. If time permits I also mention the influence of disorder on prospects to explore glass phases or localization effects.

Generating synthetic gauge fields in the presence of complex scattering properties

Lev, Benjamin L.
(Stanford University, Departments of Applied Physics and Physics, Stanford, USA)

Over the last few years our group and others have succeeded in creating quantum gases of highly magnetic atoms. For example, we have created BECs of 160Dy, 164Dy, and 162Dy, the latter with a population of 10^5 atoms; our degenerate Fermi gases of 161Dy exceed 40,000 atoms at 0.2 T/T_F. The anisotropic van der Waals and dipolar interaction in this high-spin, highly magnetic open-shell lanthanide---mu = 10 mu_B; L = 6; J = 8 (boson); F = 21/2 (fermion)---affects scattering properties in an atypical manner. To shed light on the collisional physics of Dy, we have performed experiments measuring loss spectra of spin-polarized and spin-mixed gases; rethermalization rates of gases driven out of equilibrium; cloud collisions; and anisotropic expansion. These experiments, revealing universal dipolar elastic and inelastic scattering, among other effects, will be discussed before reporting on how these properties affect the prospects for generating synthetic gauge fields in Dy.

Topological physics with a BEC: geometric pumping and edge states

Hsin-I Lu
(University of Maryland, Department of Physics, College Park, USA)

Ultracold atoms in optical lattices provide a unique setting for experimentally studying concepts that lie at the heart of theoretical condensed matter physics, but are
out of reach of current condensed matter experiments.
Here we focus on using a Bose-Einstein condensate (BEC) to realize a geometric pump in a new bipartite magnetic lattice [1] and visualize the edge states of a synthetic lattice in the quantum Hall regime [2].

In the geometric pump experiment, the magnetic lattice is characterized by non-trivial topological invariants for its bands: the Zak phases.
For each band, the Zak phase is determined by that band's integrated Berry curvature, a geometric quantity defined at each crystal momentum.
We probed this Berry curvature by periodically and adiabatically driving the system (a ``charge" pump experiment).
Unlike topological charge pumps in filled bands that yield quantized pumping, our BEC occupied just a single crystal momentum state allowing us to access its band's local geometry.
Like topological charge pumps, for each pump cycle we observed an overall displacement (here, not quantized) and a temporal modulation of the atomic wavepacket's position in each unit cell, i.e., the polarization. Our magnetic lattice enabled us to observe this modulation by measuring the BEC's magnetization.
While our periodic drive shifted the lattice potential by one unit cell per cycle, the displacement of the BEC, solely determined by the underlying Berry curvature, was always less than the lattice's displacement.

In the second experiment, we engineered an effective magnetic field in a two-dimensional lattice with an elongated strip geometry, consisting of the sites of an optical lattice in the long direction and three internal atomic spin states in the short direction. We imaged the localized static states of BECs in this strip; by exciting dynamics, we further observed the skipping orbits of excited atoms traveling down the system’s edges, analogous to edge magnetoplasmons in two-dimensional electron systems."

[1] Lu et al., arXiv:1508.04480 (2015).
[2] Stuhl et al., arXiv:1502.02496 (2015).

The SU(N) Heisenberg model of quantum permutations

Mila, Frederic
(Ecole Polytechnique Federale de Lausanne, Institute of Theoretical Physics, BSP UNIL, Lausanne, Switzerland)

The interest in the SU(N) Heisenberg model has dramatically raised recently due to the possibility to realize it experimentally in the context of ultra-cold, multi-color fermionic atoms in optical lattices. For the fundamental irreducible representation, this model simply describes quantum permutations between N-flavor objects on a lattice, the same way as the spin-1/2 Heisenberg model describes permutations between up and down spins. In this talk, after a brief review of its basic properties and of some exact results in 1D, I will discuss the phases that have been identified so far in 2D and for intermediate values of N (typically N=3 and 4), which range from long-range or algebraic color order to the spontaneous formation of singlet plaquettes. Then, I will discuss the more difficult case of larger values of N, for which exact diagonalizations could only be performed very recently thanks to the implementation of advanced properties of the permutation group. Finally, I will briefly discuss the case of higher irreducible representations, for which more exotic ground states such as chiral liquids have been proposed.

Quantum Magnetism with Trapped Ions

Monroe, Christopher
(University of Maryland, JQI, Physics, College Park, USA)

Abstract -- Trapped atomic ions represent a very clean platform for the quantum simulation of interacting spin models. When spin-dependent optical dipole forces are applied to a collection of trapped ions, an effective long-range quantum magnetic interaction arises, with reconfigurable and tunable graphs that are determined by the spectrum of the laser forces. Recent experiments have implemented transverse Ising or XY models with up to 20 trapped ions, and this seminar will cover recent experimental results, from studies of equilibrium ground states [1,2] and dynamics [3,4] to the implementation of certain interacting spin-1 models [5] that may show certain topologically-ordered ground states. Soon these experiments will be extended to >20 spins, where no classical computer can predict its behavior, particularly the many-body dynamics. Such results are expected to shed light on the behavior of spin-liquids and other interesting forms of magnetism that feature frustration and massive entanglement.

[1] R. Islam, et al., Science 340, 583 (2013).
[2] P. Richerme, et al., Phys. Rev. Lett. 111, 100506 (2013).
[3] P. Richerme, et al., Nature 511, 198 (2014).
[4] C. Senko, et al., Science 345, 430 (2014).
[5] C. Senko, et al., Phys. Rev. X 5, 021026 (2015).

Many-body spin systems with ultracold polar molecules

Moses, Steven
(JILA, University of Colorado-Boulder, Physics, Boulder, CO, USA)

Ultracold polar molecules, with their long-range electric dipolar interactions, are a promising platform for studying correlated many-body phenomena such as quantum magnetism. Recently, we observed spin exchange interactions between KRb molecules in a deep 3D optical lattice [1,2], which is one of the first steps towards studying lattice spin models with polar molecules. Thanks to the long-range dipolar interactions, these observations were possible even though the lattice fillings were quite dilute (less than 0.1). Future experiments to probe more sophisticated dynamics or realize novel quantum phases will benefit greatly from higher lattice fillings. By utilizing the quantum statistics and interspecies interactions of the initial quantum gases, we simultaneously load a Mott insulator of Rb and a band insulator of K into a 3D optical lattice. Combined with efficient magnetoassociation and optical state transfer, we realize ground-state molecule filling fractions $sim 0.25$, 3 times better than previous

results. At these fillings, the system is well suited for novel studies of transport and entanglement propagation in a many-body system with long-range dipolar interactions. We will soon install a new apparatus which features many technical improvements that will greatly improve our control over, and detection of, the molecular gas.

[1] B. Yan textit{et al.}, Nature textbf{501}, 521-525 (2013).

[2] K. R. A. Hazzard textit{et al.}, PRL textbf{113}, 195302 (2014).

Topological Charge Pumping in a One-Dimensional Optical Superlattice

Nakajima, Shuta
(Kyoto University, Graduate School of Science, Division of Physics and Astronomy, Kyoto, Japan)

When a one-dimensional periodic potential is slowly and periodically modulated in time, a gas of electrons in this potential can be transported, i.e., the dc current is induced even in the absence of dc bias potential through cyclic change of system parameters. This phenomenon, so called charge pumping, was first invoked by Thouless [1] and he showed that the charge transferred by this device in each pumping cycle is exactly quantized. This quantization of one-dimensional charge pumping shares the same topological origin as the two-dimensional quantum Hall effect; the amount of pumped charge per cycle is given by the Chern number over the (1+1) dimensional Brillouin zone.
In this talk, I will discuss about our experiments on such topological charge pumping using ultracold fermionic Yb atoms in a dynamically-controlled optical superlattice. In our experiments, we constructed a time-dependent superlattice structure by using 266-nm-spacing and 532-nm-spacing optical lattices and modulated the phase and amplitude of these optical lattices to realize a continuous Rice-Mele model [2]. We observed onset of the pumping as the shift of the atomic cloud and evaluated the amount of pumped atoms per cycle or the Chern number of the pumping system. We also studied nonadiabatic (finite pump speed) and finite-temperature effects on the quantization of pumped charge. We constructed two topologically-distinct pumping procedures and compared the amount of pumped atoms of these pumping. We will discuss the relation between the observed pumped atoms and the topology of the trajectories of these pumping procedures in parameter space.

[1] D. J. Thouless, Phys. Rev. B 27, 6083 (1983)
[2] L. Wang, M. Troyer, and X. Dai, Phys. Rev. Lett. 111, 026802 (2013)

Dynamics of ultracold bosons under strong confinement

Nägerl, Hanns-Christoph
(University of Innsbruck, Institut für Experimentalphysik, Innsbruck, Austria)

I plan to give an overview over the experiments in my group on the dynamics of ultracold bosons in lattice potentials and under strong confinement. In 1D geometry we have studied (higher-order) tunneling dynamics in tilted lattices [1,2]. In particular, we have observed the effect of density-induced tunneling [3]. We have observed collapse and revival for Bloch oscillations in 1D and the transition to the quantum chaotic regime in the Bose-Hubbard model [4]. Also in 1D we have we measured the excitation spectrum of the strongly correlated Lieb-Liniger system for a wide range of the interaction parameter [5]. Presently, we are studying the dynamics of a strongly interacting spin impurity in 1D and the effect of rapidly modulating the interaction strength in the context of the Bose-Hubbard model.

[1] Many-body quantum quench in an atomic one-dimensional Ising chain,
F. Meinert et al., Phys. Rev. Lett. 111, 053003 (2013)

[2] Observation of many-body long-range tunneling after a quantum quench,
F. Meinert et al., Science 344, 1259 (2014)

[3] Observation of density-induced tunneling,
O. Jürgensen, et al., Phys. Rev. Lett. 113, 193003 (2014)

[4] Interaction-induced quantum phase revivals and evidence for the transition to the quantum chaotic regime in 1D atomic Bloch oscillations,
F. Meinert et al., Phys. Rev. Lett. 112, 193003 (2014)

[5] Probing the Excitations of a Lieb-Liniger Gas from Weak to Strong Coupling
F. Meinert et al., Phys. Rev. Letter in print, preprint at: arXiv:1505.08152

Synthetic gauge fields and many-body physics in an optical lattice clock

Rey, Ana Maria
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We propose the implementation of a synthetic gauge field in a one dimensional optical lattice clock and explore the resulting single-particle and many-body physics. The system can realize effective n-leg ladders by using the two electronic clock states and internal nuclear levels as a synthetic dimension, together with the tunneling-coupled 1D lattice sites. A large flux per plaquette is naturally generated because the clock laser imprints a phase that varies significantly across lattice sites. We propose to use standard spectroscopic tools -- Ramsey and Rabi spectroscopy -- to probe the band structure and reveal signatures of the spin-orbit coupling, including chiral edge states and the modification of single-particle physics due to s-wave and p-wave interactions. These effects can be probed in spite of the relatively high temperatures (~ microKelvin) and weak interactions, thanks to the exquisite precision and sensitivity of the JILA Sr optical lattice clock. We also discuss the possibility of using the nuclear spin degrees of freedom to realize adiabatic quantized particle transport in a direction that depends on the internal state, and for sensitive force measurements using spectroscopic preparation and readout.

Entanglement properties in spin triangular lattices

Sanpera Trigueros, Anna
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The different quantum phases appearing in strongly correlated systems as well as their transitions are closely related to the entanglement shared between their constituents. In 1D systems, it is well established that the entanglement spectrum is linked to the symmetries that protect the different quantum phases. This relation extends even further at the phase transitions where a direct link associates the entanglement spectrum to the conformal field theory describing the former. For 2D systems much less is known. The lattice geometry becomes a crucial aspect to consider when studying entanglement and phase transitions. Here, we analyze the entanglement properties of triangular spin lattice models by considering also concepts borrowed from quantum information theory such as geometric entanglement.

Floquet engineering in periodically driven optical lattices and beyond

Simonet, Juliette
(Universität Hamburg, Institut für Laserphysik, Universität Hamburg, Hamburg, Germany)

Floquet engineering in periodically driven optical lattices and beyond

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The realization of artificial gauge potentials for neutral atoms constitutes a major achievement for the emulation of condensed matter models with quantum gases. Diverse static gauge potentials that

effectively emerge in the atomic dynamics can now be experimentally engineered: Abelian gauge potentials, giving rise to synthetic electric and magnetic fields as well as non-Abelian gauge potentials. A well-known example of the later is the spin–orbit coupling, which links a particle's velocity to its quantum-mechanical spin.

Periodic driving of quantum systems allows for the targeted engineering of such gauge potentials. In a 1D optical lattice, time-periodic forcing can lead to complex valued tunnel matrix elements if the driving force breaks specific symmetries, resulting in a gauge-dependent shift of the dispersion relation [1]. A 1D spin-orbit coupling can be realized by forcing two magnetic spin states trapped in a spin-dependent lattice in a spin dependent manner with a time-varying magnetic field gradient [2]. The effective dispersion relations of the two spin states are thus shifted in opposite direction due to the inverted drive for both states. An additional radio-frequency coupling between the spin states leads to a mixing of the spin dispersion relations and a spin-orbit gap in the band structure. In contrast to previous experimental realizations in ultracold gases, this scheme does not involve near-resonant laser fields, avoiding the heating processes induced by the spontaneous emission of photons.

The underlying principle of all driving schemes implemented so far is that the properties of the periodically driven system are determined by a time-independent effective Hamiltonian. This so-called Floquet engineering typically assumes that excited Bloch bands can be neglected. However, periodic inertial forcing of the atomic ensemble, similar to an oscillating light field, results in interband excitations due to the absorption of low-energy driving photons. Thus, a deeper understanding of such excitations processes is essential for tailoring appropriate driving schemes. We report here on the first systematic study of multiphoton excitations of ultracold bosonic quantum gases in driven optical lattices, which reveals close analogies with laser-irradiated solid state materials where nonlinear processes play crucial role at large field strengths [3].

References:
[1] J. Struck et al., Phys. Rev. Lett. 108, 225304 (2012)
[2] J. Struck et al., Phys. Rev. A 90, 031301(R) (2014)
[3] M. Weinberg et al., arXiv:1505.02657 (2015)

Magnon excitations in spinor Bose gases: optics, thermometry and condensation

Stamper-Kurn, Dan
(University of California, Berkeley, USA)

The quantum degenerate spinor Bose gas is a new material characterized by both magnetic and superfluid order. Like other ordered magnetic materials, the gas supports magnon excitations. We have developed techniques to create and image magnon excitations in ferromagnetic rubidium spinor condensates. At short times after their creation, magnons are observed to propagate coherently, allowing us to measure their energy dispersion with high precision through interferometry. Using high-resolution spin-sensitive imaging, we measure the magnon spectrum to be gapped due to magnetic dipole interactions (as it often is in magnetic solids). At longer times, the magnons thermalize. We show that this thermalization allows one to measure the temperature of highly degenerate gases, and to reduce this temperature further by a new form of evaporative cooling. Upon recooling the gas, the thermalized magnons condense. I will present recent measurements that explore such magnon condensation.

Short-range quantum magnetism of ultracold fermions in an optical lattice

Tarruell, Leticia
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We report on the observation of nearest-neighbor magnetic spin correlations emerging in a two-component repulsively interacting Fermi gas [1]. The experiments are performed in a tunable-geometry optical lattice, which allows for the realization of lattice structures favoring the emergence of the correlations and also enables their detection. We study both a dimerized and an anisotropic simple cubic lattice. In both cases the correlations manifest as an excess number of singlets as compared to triplets consisting of two atoms with opposite spins. For the anisotropic lattice, we determine the transverse spin correlator from the singlet-triplet imbalance and observe antiferromagnetic correlations along one spatial axis. Our results are in good agreement with state-of-the-art numerical simulations of the anisotropic Fermi-Hubbard model, and confirm that we can achieve temperatures in the lattice below the exchange energy [2,3].

[1] D. Greif, T. Uehlinger, G. Jotzu, L. Tarruell, and T. Esslinger, Science 340, 1307-1310 (2013).
[2] J. Imriška, M. Iazzi, L. Wang, E. Gull, D. Greif, T. Uehlinger, G. Jotzu, L. Tarruell, T. Esslinger, and M. Troyer, Phys. Rev. Lett. 112, 115301 (2014).
[3] B. Sciolla, A. Tokuno, S. Uchino, P. Barmettler, T. Giamarchi, and C. Kollath, Phys. Rev. A 88, 063629 (2013).

Simulation of Hubbard Models in the Era of Synthetic Gauge Field

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Interacting fermions dressed by artificial gauge fields exhibit intriguing ground state phases due to the interplay of strong correlation, band topology and conventional long range orders. Using sign-problem free quantum Monte Carlo simulations we address several related topics: topological phase transition from a quantum-spin-Hall to a superfluid state, novel quantum critical points of multi-flavor and asymmetric Dirac fermions.
Those results are relevant to the current efforts in creating synthetic gauge fields in optical lattices.

Quantum Magnetism and Quantum Spin Dimers from Driven-Dissipative Dynamics in Quantum Optical Systems

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Quantum magnetism, and the emergence of quantum phases involving quantum spin dimers is traditionally discussed in a Hamiltonian context for spin systems in thermodynamics equilibrium. Instead we study the formation of quantum spin dimers as steady state in driven-dissipative non-equilibrium (open system) dynamics. The system of interest is a quantum optical network of two-level atoms (spin-½ systems) coupled to a chiral 1D bosonic waveguide. By chiral coupling we mean an asymmetric coupling of the atomic decay to the left and right propagating guided modes. We formulate a quantum optical master equation treatment for this non-equilibrium dynamics Remarkably, our master equation predicts steady states in form of pure states consisting of quantum dimers (a dissipative 1D valence bond solid), or entangled spin-clusters. Our model has a natural realization with atoms coupled to nanofibers or nanostructures, or with spin chains coupled by dipolar interactions (trapped ions or polar molecules). We conclude with a theory outlook on how modern many-body quantum techniques (DMRG) can be applied to efficiently compute non-Markovian dynamics in a quantum optics context.