Workshop on

Ultracold Atoms and Gauge Theories

(Trieste, 13-17 May 2013)

TALKS

E. Babaev: *Paired phases in U(1)xU(1) gauge theories*

I will discuss a class multicomponent gauge theories where complex fields are coupled by either a vector potential or/and current-current interactions. Such theories can have a regime where (in contrast to single-component superconductors and superfluids) the energetically cheapest topological excitation is not the lowest-topological-charge vortex. Instead the energetically cheapest topological excitations are bound state of simplest vortices. When such composite topological defects proliferate the system undergoes a phase transition into a superfluid state of paired bosons, or, in case of superconductors, into charge-4e superconducting state. The talk will overview works in context of superconductivity and cold atoms (in particular Nucl.Phys. B686, 397 (2004) 397, Nature 431, 666 (2004), Phys. Rev. B 82, 134511 (2010), Phys. Rev. Lett. 101, 255301 (2008), Phys. Rev. B 78, 144510 (2008)) .

J. Berges: *Gauge fields far from equilibrium*

Gauge field dynamics out of equilibrium plays a crucial role for our understanding of high-energy physics, ranging from collision experiments of heavy nuclei to early-universe cosmology. Some important aspects of this dynamics may be simulated using ultracold atoms. As a first example I discuss universal properties far from equilibrium, which arise from the presence of a nonthermal fixed point in the space-time evolution of non-Abelian plasmas. A second example concerns fermion pair production in QED following a strong initial electric field pulse. In 1+1 dimensions striking phenomena such as 'string breaking' for the linear rising potential building up between produced fermion bunches may be studied in real time!

<u>M. Burrello:</u> *Two-dimensional arrays of Parafermionic zero modes*

It has recently been realized that zero modes with projective non-Abelian statistics, generalizing the notion of Majorana bound states, may exist at the interface between a superconductor and a ferromagnet along the edge of a fractional topological insulator (FTI). Here we study two dimensional architectures of these non-Abelian zero modes, whose interactions are generated by the charging and Josephson energies of the superconductors. We derive low-energy Hamiltonians for two different arrays of FTIs on the plane, revealing an interesting interplay between the real-space geometry of the system and its topological properties. On the one hand, in a geometry where the length of the FTI edges is independent on the system size, the array has a topologically ordered phase, giving rise to a qudit toric code Hamiltonian in perturbation theory. On the other hand, in a geometry where the length of the edges scales with system size, we find an exact duality to an Abelian lattice gauge theory and no topological order.

P. Calabrese: *Quantum quenches in one dimensional systems*

Non-equilibrium quantum systems represent one of the most promising possibilities for realizing novel states of matter. I will consider the non equilibrium situation known as quantum quench, in which a closed system evolves from an initial state that is not a Hamiltonian eigenstate such as those achieved by suddenly switching a control parameter. An important question is under what conditions the system reaches a stationary state and in which circumstances this state is characterized by an effective "thermal", i.e. equilibrium, distribution. I will discuss how to obtain the time evolution of observables and correlation functions with a variety of theoretical techniques including quantum field theory (in particular CFT) and integrability.

I. Carusotto: *Quantum fluids of light under synthetic gauge fields*

Following impressive recent experimental advances, quantum fluids of interacting photons in nonlinear optical media nowadays appear as promising candidates for studies of many-body physics in novel regimes, e.g. in the presence of synthetic gauge fields for photons. In this talk, after a short review of the general idea of quantum fluids of light, I will present the on-going theoretical activity of the Trento group on quantum Hall effects in optical systems.

L. Fallani: *Quantum simulation with two-electron Fermi gases in optical lattices*

We will report on recent experiments performed at LENS with ultracold degenerate ytterbium gases. Thanks to their electronic structure, two-electron atoms offer very interesting possibilities for advanced quantum simulations and for the implementation of synthetic gauge fields. In particular, 173Yb Fermi gases are characterized by a large nuclear spin and highly-symmetric atom-atom interactions, which result in the possibility of performing quantum simulation of systems with intrinsic SU(N) symmetry. We will report on the optical manipulation and detection of the atomic spin and on the first experimental results recently obtained with 173Yb atoms trapped in optical lattices.

F. Gerbier: *Artificial gauge fields for neutral atoms in optical lattices*

Ultracold gases of bosons and fermions are now considered as model systems where the physics of strongly interacting many-body systems, traditionally oriented towards condensed matter physics, can be investigated with good control over the microscopic model and over its parameters. In condensed matter, the orbital coupling of electrons to a magnetic field leads to many fascinating phases, in particular to the integer and fractional quantum Hall effects for quasi-two dimensional electronic systems in strong magnetic fields, or to the recently discovered topological insulators. From a quantum-mechanical point of view, such orbital coupling originates from the phase picked up by the particle when moving in space in presence of a magnetic field, or equivalently of a vector potential (the Aharonov-Bohm effect). Recently experiments have demonstrated that such a phase can be directly imprinted on a neutral atom by laser beams, leading to the same orbital physics even in absence of electrical charge. In other words one realizes an "artificial magnetic field" felt by the atoms. I will describe an experimental proposal generalizing these ideas to optical lattices where topological phases might appear. I will explain how ultra-narrow optical clock transitions (as found in alkaline-earth or in Ytterbium atoms) combined with spin-dependent optical lattices can be used to produce strong artificial magnetic fields and strong interactions at the same time and how this could lead to "quantum-Hall" atomic phases. I will finally discuss how these phases could be probed experimentally.

N. Goldman: *Imaging Topological States in Ultracold Atomic Gases*

The recent experimental realization of synthetic magnetic fields and spin-orbit couplings for ultracold (neutral) atoms [1–4] opens the attractive possibility to engineer a wide family of topological quantum phases. In such arrangements, one indeed expects to create quantum Hall liquids [5, 6] and topological insulating phases [7–9], in a highly controllable and clean environment. However, measuring unambiguous signatures of these quantum phases, such as non-trivial topological order or the presence of current-carrying edge states, remains a fundamental issue for the cold-atom community. In this talk, I will review the topological phases that could be realized in cold atomic gases. I will discuss the possibility to measure topological properties in these systems through available observables [10]. In particular, I will present efficient methods allowing for the detection of topological edge states in optical lattices [11, 12].

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D. Greif: *Exploring artificial quantum-many body systems with ultracold fermions in a tunable-geometry optical lattice*

Ultracold fermionic atoms in optical lattices have emerged as a versatile tool to study condensed matter model systems. Strong efforts have been directed to models for quantum magnetism, which has its origin in the exchange coupling between quantum mechanical spins and is believed to be closely connected to strongly correlated states, for example high-temperature superconductors. Yet, the low temperature scale required for entering the regime of quantum magnetism has so far hindered progress for optical lattice based systems with ultracold fermions. We report on the observation of nearest-neighbour magnetic spin correlations emerging in the many-body state of a thermalized Fermi gas in an optical lattice. The key to obtaining short-range magnetic order is a local redistribution of entropy, allowing for temperatures below the exchange energy for a subset of lattice bonds. When loading a repulsively interacting gas into either dimerized or anisotropic simple cubic configurations of a tunable-geometry lattice we observe an excess of singlets as compared to triplets consisting of two opposite spins. For the anisotropic lattice, the transverse spin correlator reveals antiferromagnetic correlations along one spatial axis. We furthermore report on experiments in of a non-interacting gas in a honeycomb optical lattice, in close resemblence to Graphene. The presence of Dirac points with adjustable properties is directly observed by identifying a minimum band gap inside the Brillouin zone from momentum-resolved interband transitions. We demonstrate full control over the Dirac point properties, such as the linear dispersion slope, the position in momentum space and the effective mass of the Dirac fermions.

Z. Hasan: *Topological Insulators and Superconductors*

Topological Insulators are a new phase of electronic matter which realizes a non-quantum-Hall-like topological state in the bulk matter and unlike the quantum Hall liquids can be turned into superconductors at the bulk and/or at the interface. I will first review the basic concepts defining topological matter and experimental probes that reveal topological order. I will present experimental results that demonstrate the fundamental properties of topological insulators such as spin-momentum locking, non-trivial Berry's phases, mirror Chern number, absence of backscattering, protection by time-reversal and other discrete symmetries and their persistence up to the room temperature (at the level of M.Z. Hasan and C.L. Kane, Rev. of Mod. Phys., 82, 3045 (2010)). I will then present recent results demonstrating broken symmetry phases such as superconductivity and magnetism in artificial hetero interfaces as well as outline the emerging experimental research frontiers of the field of topological insulators as a whole. Time permitting, I will also present experimental results on a new class of topological insulators beyond the Kane-Mele Z2 theory.

V. Hubeny: *Holographic Entanglement Entropy & Causal Holographic Information*

Entanglement entropy is an important quantity characterizing quantum systems, employed in diverse areas of research ranging from condensed matter physics to quantum computing. Using holography, an invaluable tool for elucidating certain strongly coupled quantum field theories by using their higher-dimensional classical gravitational dual, entanglement entropy is conjectured to be related to a simple geometrical construct: an area of an extremal surface in asymptotically AdS spacetime. In the first part of the talk, I will review this proposal and discuss some of the recent applications in time-dependent settings. Motivated by the power of holography, in the second part of the talk I will introduce another (more basic) geometrical construct, whose dual is hitherto unknown but provisionally called "causal holographic information". To understand its nature, I will contrast its predicted behaviour with that of the entanglement entropy and discuss its general properties.

<u>A. R. Kolovsky:</u> *Landau-Stark states for cold atoms in a parabolic lattice*

Landau-Stark states are eigenstates of a quantum particle in a 2D lattice in the Hall configuration, i.e., in the presence of normal to the lattice plane `magnetic' and in-plane `electric' fields. We report recent analytic results on the Landau-Stark states for a plane lattice. These results are then used to describe the spectrum, eigenstates, and dynamics of cold atoms in a parabolic optical lattice (lattice plus harmonic confinement) under the influence of an artificial magnetic field.

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quantum particle in a two-dimensional lattice II: Arbitrary electric field directions, Phys. Rev. E 86, 041146 (2012).

C. Kraus: *An AMO toolbox for Majorana Fermions in Optical Lattices*

A striking consequence of topological order is the existence of robust zero-energy modes localized at defects and edges of topological phases. One prominent example are zero-energy Majorana fermions that were originally introduced as pure real solutions of the Dirac equation. Nowadays, they are not only discussed in the context of high energy and condensed matter physics, but it is also believed that they serve, due to their anyonic statistics, as building blocks for topological quantum computing devices.

While most of the proposals for realizing and detecting Majorana fermions have been related to solid state systems, I will present possibilities to investigate Majorana physics with AMO tools. I will explain how Majorana fermions can be created, manipulated and detected in systems of cold atoms confined to an optical lattice. These tools do not only allow to study fundamental questions related to Majorana fermions, but they will also enable us to efficiently implement topologically protected quantum algorithms.

K. Le Hur: *Topological Insulators, Mott physics and Artificial Gauge Fields*

In this talk, we review the fate of topological insulators in the presence of interactions and show the stability towards moderate interactions. The transition to the Mott state in these systems is characterized by the disappearance of helical edge states. Above the Mott transition, the system can be in a Neel ordered phase or in a spin liquid phase dependently on the dimensionality of the system [1-4]. We discuss applications to materials and cold atomic systems where spin-orbit coupling and artificial gauge fields can be simulated. Finally, we study photon analogues and discuss the possibility to realize artificial gauge fields and topological phases [5-6].

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M: Lewenstein: *Quantum Simulators of Lattice Gauge Theories*

In the talk I will review efforts of atomic physics community to realize quantum simulators of atomic systems in intense external gauge fields, and ultimately of lattice gauge theory models. Particular attention will be paid to non-Abelian gauge fields and possibilities of experimental realization of various types of topological insulators, fractional Hall states, and confinement-deconfinement transitions.

Y. Li: *Superstripes and the excitation spectrum of a spin-orbit-coupled BEC*

Using Bogoliubov theory we calculate the excitation spectrum of a spinor BEC with equal Rashba and Dresselhaus spin-orbit coupling in the stripe phase. The emergence of a double gapless band is pointed out as a key signature of Bose-Einstein condensation and of the spontaneous breaking of translational invariance symmetry. In the long wavelength limit the lower and upper branches exhibit, respectively, a clear spin and density nature. For wave vectors close to the first Brillouin zone the lower branch acquires an important density character responsible for the divergent behavior of the structure factor and of the static response function. The sound velocities are obtained as functions of the Raman coupling.

M. Mannarelli: *Ultracold color superconductors*

We discuss the properties of various color superconductors which may be realized in the interior of compact stars. The low energy properties of some of these phases are characterized by the presence of Nambu-Goldstone bosons; we derive the low energy effective action for these modes in the color flavor locked phase and in the crystalline color superconducting phase of QCD. Their relevance for the evolution of compact stars is briefly outlined.

M. A. Martin-Delgado: *Topological Insulators under Quantum Dissipative Dynamics*

In this talk I will present recent results regarding the stability of fermionic topological orders in the presence of dissipation. Particularly, we address the behavior of topological insulators in the presence of thermal baths. These systems present non-vanishing topological conductivity at zero temperature, as their conduction and valence bands are connected by the so-called (topologically protected) edge states. I shall explain that, in general, these edge states are no longer protected when the system is in contact with a thermal bath. However, for some kind of environments, it is possible to obtain and characterize topologically ordered phases even in the presence of thermal dissipation. We will illustrate both results with examples for models with gauge symmetries: the Creutz Ladder in 1D and the Haldane model in 2D.

P. Ohberg: *Simulating an interacting gauge theory with ultracold Bose gases*

We show how density dependent gauge potentials can

be induced in dilute gases of ultracold atoms using light-matter interactions. We study the effect of the resulting interacting gauge theory and show how it gives rise to novel topological states in the ultracold gas. We find in particular that the onset of persistent currents in a ring geometry is governed by a critical number of particles. The density-dependent gauge potential is also found to support chiral solitons in a quasi-one-dimensional ultracold Bose gas.

A. Paramekanti: *Accessing strongly correlated atomic states and probing atom currents in synthetic gauge fields*

We show that new phases, such as chiral Mott insulators or superfluids with novel spin textures, arise for bosons in an optical lattices in the combined presence of strong correlations and synthetic magnetic fields or spin orbit coupling. Such phases are uncovered using a variety of tools such as inhomogeneous mean field theory, DMR calculations, slave boson approaches, and classical Monte Carlo simulations. We also show how anisotropic quenches of the lattice potential can detect equiibrium bulk or topological edge currents associated with such states for both bosons or fermions.

<u>L. P. Pitaevskii:</u> *First and second sound in Fermi gas at unitarity*

Recent achievements of experimental technique permitted create fluids with odd properties – ultracold Fermi gases near the Feshbach resonance in magnetic field. These gases are dilute and interaction between their atoms is defined by a single parameter – the scattering length. At some values of the magnetic field this length becomes infinite. One obtains a universal fluid – a unitary Fermy gas, a system with strong interaction, which properties does not depend on any parameters.

Experiments with ultracold gases are typically performed in elongated traps. If the viscosity and thermal conductivity are large enough, one can reformulate the Landau two-fluid hydrodynamics as a system of 1D equations. The equations have been applied to description of the first and second sound oscillations at unitary Fermi gas.

Two types of experiments with the unitary Fermi gas were performed in Prof. Grimm group at Innsbruck. Discrete modes of first sound were observed and frequencies coincide with the theoretical predictions with good accuracy. (Data on the equation of state from MIT group were used.) Propagation of the second sound pulse was also observed and temperature dependency of the superfluid density was defined.

M. Rangamani: *The holographic master field*

I will review the holographic gauge/gravity correspondence and its applications in understanding the quantum dynamics of strongly coupled field theories. I will focus specifically on demonstrating how one computes correlation functions of operators thus ascertain interesting transport properties of the field theories. The class of field theories I describe will include critical systems with both relativistic and non-relativistic scaling symmetries as well as gapped models.

B. Reznik: *Simulation of dynamic abelian and non-abelian gauge theories with ultracold atoms*

Dynamical gauge fields play the key role of force mediators between matter fields in HEP models such as QED and QCD. The smallness of the fine-structure constant, leads to perturbatively well behaved results for QED, however for QCD, gauge fields give rise to the effect of Quark confinement, which determines the basic structure of Hadronic matter, as well as to other effects (e.g. Color Superconductivity), which are non-perturbative and hard computationally.

Recently it has been suggested that the above systems can be simulated using ultra cold atoms. I shall discuss these recent developments.

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E. Rico Ortega: *Atomic Quantum Simulation of U(N) and SU(N) Non-Abelian Lattice Gauge Theories*

Using ultracold alkaline-earth atoms in optical lattices, we construct a quantum simulator for U(N) and SU(N) lattice gauge theories with fermionic matter based on quantum link models. These systems share qualitative features with QCD, including chiral symmetry breaking and restoration at non-zero temperature or baryon density. Unlike classical simulations, a quantum simulator does not suffer from sign problems and can address the corresponding chiral dynamics in real time.

L. Salasnich: *BCS-BEC crossover with Rashba and Dresselhaus couplings*

We study theoretically the effects of spin-orbit coupling on a two-spin-component ultracold atomic Fermi gas along the BCS-BEC crossover of a Feshbach resonance. We find that the condensate fraction of Cooper pairs characterizes the crossover better than other quantities, like the chemical potential or the pairing gap. We also find that, due to the spin-orbit coupling, in addition to singlet pairing, there is a finite triplet pairing. We predict that a large enough spin-orbit interaction enhances the singlet condensate fraction with respect to the triplet one in the BCS side while suppressing it on the BEC side.

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V. Savona: *Quantum correlations in driven-dissipative arrays of weakly nonlinear optical cavities*

Recent progress in nanotechnology has made it possible to fabricate various kinds of optical nanocavities – embedding a nonlinear optical medium – in which a sizeable nonlinearity arises already at the level of single photon occupation. Arrays of these nanocavities bear a close analogy with strongly correlated systems in condensed matter and atomic physics, but with the added possibility of selective coherent optical control of each individual cavity mode. This unique combination of features makes the system ideal for the generation and control of quantum correlated states of many photons, and ultimately for the investigation of a large variety of many-body phenomena in a quantum simulator fashion. Due to the dissipative nature of the optical cavities however, in order for quantum correlations to build up from interactions, a stringent requirement is that the two-body interaction energy be much larger than the dissipation rate. Parameters of current state-of-the-art systems lie still significantly behind this minimal requirement.

Quantum correlations however are not necessarily produced by interactions alone. We demonstrate that quantum correlations can arise in an array of weakly nonlinear cavities from the interplay of small nonlinear energy shifts (due to weak interaction) and quantum interference between different excitation pathways. By solving the quantum equations for the density operator of the driven-dissipative system, we show how this mechanism allows for the generation of photons with sub-poissonian statistics, and of multipartite entangled states of few photons, required by the *one-way quantum computation paradigm*. The simulations show that these phenomena are expected for realistic values of the nonlinearity, dissipation and decoherence rates, which are easily available in several state-of-the-art quantum optical systems.

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K. Schoutens: *Symmetries of spin-orbit coupled particles*

We explain the finite as well as infinite degeneracies in a particular system of spin-1/2 fermions with spin-orbit coupling in D=3 spatial dimensions. We explicitly construct the complete set of symmetry operators, which span a non-compact SO(3,2) algebra. The physical spectrum only involves a particular, infinite, representation known as the singleton. In the flat branches (`3D Landau levels') the full singleton representation appears. The other branches display a finite degeneracy due to a truncation of the singleton representation.

G. S. Singh: *Effect of synthetic spin-orbit coupling on statistical interactions in atomic quantum gases*

Exact analytical expression for the grand potential of noninteracting atomic quantum gases having Weyl spin-orbit (SO) coupling, the three-dimensional analogue of the Rashba coupling, has been developed. The final expression is in terms of polylogarithmic functions, and further a unified form has been achieved by introducing in the distribution function a parameter which takes the values -1, 0, and +1 for Fermi, Boltzmann and Bose gases, respectively. The expression for the grand potential so obtained has been utilized to study complete thermodynamics and we have presented the results for chemical potential, internal energy, free energy, entropy, specific heat, isothermal compressibility, P – v isotherms (v = V/N) and P - T isochores for various SO coupling strengths.

It is found that the pressure decreases with increase in the coupling strength at any fixed temperature for fermions whereas there is reverse trend for bosons implying thereby that coupling weakens the “statistical interactions" for fermionic as well as bosonic systems as compared to the corresponding ideal gas without coupling. This result is corroborated by plots of isothermal compressibility and also analytically by the virial expansion. Our studies suggest that many intriguing features of SO-coupled systems studied by various researchers could straightforwardly be understood as many-body phenomena arising as a consequence of modifications in statistical potentials whereas some of these properties have been explained in the literature plausibly in terms of enhancement in single-particle density of states. The temperature-dependence of chemical potential, specific heat and isothermal compressibility for a Bose gas is found for very weak coupling to have signature of the incipient Bose-Einstein condensation although the system does not really go in the Bose-condensed phase due to presence of coupling-weighted one-dimensional character in the density of states. Also, anomalous behavior of some thermodynamic quantities, typically akin to that in dimensions less than two, appears for fermions as soon as the Fermi level goes down the Dirac point on increasing the coupling strength.

B. K. Stuhl: *Making Gauge Fields Real*

Over the past several years, synthetic gauge field effects have been conclusively demonstrated in ultracold atomic systems, both by our group and others. I will describe some of our recent results, including phase transitions in spin-orbit coupled (SOC) Bose gases, an observation of the Spin-Hall effect, and the measurement of Zitterbewegung of an SOC Bose-Einstein condensate.

J. M. Taylor: *Quantum Hall physics with light*

Quantum Hall physics provides a variety of novel phenomena in both the integer and fractional domain, with applications in metrology, technology, and quantum computation. I will discuss implementing quantum Hall physics with optical systems by means of synthetic gauge fields and photon-photon interactions. First, in the integer quantum Hall regime, I consider our theoretical and experimental efforts using established photonics technology to see expected phenomena, such as edge states of light. I will then consider the nonlinear regime, where photon-photon interactions via optical or microwave nonlinearities enable the potential realization of fractional quantum Hall states, and indicate challenges and solutions for examining pumped, non-equilibrium systems that do not admit a mean-field description. Finally, potential applications of these ideas in passive and active photonics will be examined.

T. Yefsah: *Spin-Orbit Coupling and Heavy Solitons in Fermi Gases*

The coupling of the spin of electrons to their motional state lies at the heart of topological phases of matter. We have created and detected spin-orbit coupling in an atomic Fermi gas via spin-injection spectroscopy, which characterizes the energy-momentum dispersion and spin composition of the quantum states. In the presence of s-wave interactions, spin-orbit coupled fermion systems should display induced p-wave pairing and consequently topological superfluidity, where the key ingredient is the existence of topologically protected edge states. A system that similarly supports bound edges states is a fermionic superfluid in a solitonic state. In such system, the gas supports a planar defect – a soliton – at a location where the order parameter changes sign, giving rise to localized bound states. We have created and directly observed long-lived solitons in a fermionic superfluid by imprinting a phase step into the superfluid wavefunction. In order to reveal the filling of these solitons we have studied their oscillatory motion in the trapped superfluid through the BEC-BCS crossover. We have found their oscillation period to be much larger than the trap period and to increase toward the BCS side, signaling an enhanced effective mass which we attribute to a strong filling of the soliton. At the Feshbach resonance, we measure a period which is an order of magnitude larger than available predictions. Our work opens the study of fermionic edge states in ultracold gases.

H. Zhai: *Exotic Superfluid in Ultracold Atomic Gases from Synthetic Gauge Fields*

Superfluidity of bosons is usually characterized by the off-diagonal long-range order of single boson operator, while we are interested in finding unconventional superfluids in which single boson operator does not exhibit long-range order, but boson pairs or even triple bosons exhibit long-range order. We propose two of such examples in ultracold atomic systems. The first is bosons with Rashba spin-orbit coupling. The ground state is a superfluid with stripe order, while the large single particle ground state degeneracy leads to significant fluctuations, which melt stripe order and give rise to boson-paired superfluid. The second example is bosons in Kagome lattice with frustration, where the lowest band is completely flat. At the lowest temperature bosons all condense in the K-point, while at finite temperature thermal fluctuations melt the Z3 order and lead to a trion superfluid phase. These two examples indicate a universal route toward a class of exotic superfluid phase.

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J. Zhang: *Experimental realization of spin-orbit coupled degenerate Fermi gas*

We report the first experimental realization of SO coupled degenerate Fermi gas. Evidences of spin-orbit coupling have been obtained from the Raman Rabi oscillation and the spin-dependent momentum distribution asymmetry. We also find that the momentum distribution in helical bases is consistent with topological changes of Fermi surfaces. Recently, we bring the system close to a Feshbach resonance where the s-wave interaction becomes strongly attractive. This progress enables us to study stronger pairing and higher Tc enhanced by SO coupling in resonant interacting Fermi gases and topological insulator and topological superfluid in a more flexible setup in near future.

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