APS March Meeting 2012
Boston, Massachusetts
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power. We discuss our results, which suggest these resonances are attributable to discrete two-level systems.

f resonance at 6.81 GHz, the loaded quality factor was 120,000. By moving a carefully machined Al pin towards the inductor of the resonator using a piezo stage, sapphire intended for coupling to hyperfine ground states of cold trapped 87Rb atoms, which are separated by about f_{Rb} = 6.83 GHz. At T=12 mK and on resonance at 6.81 GHz, the loaded quality factor was 120,000. By moving a carefully machined Al pin towards the inductor of the resonator using a piezo stage, we were able to tune the resonance frequency over a range of 35 MHz and within a few kHz of f_{Rb}. While measuring the power dependent response of the resonator at each tuned frequency, we observed anomalous decreases in the quality factor at several frequencies. These drops were more pronounced at lower power. We discuss our results, which suggest these resonances are attributable to discrete two-level systems.

1 Work supported by NSL through the Physics Frontier Center at the Joint Quantum Institute, Dept. of Physics, Univ. of Maryland.

2 S.K. acknowledges support by the Department of Defense (DoD) through the National Defense Science and Engineering Graduate Fellowship (NDSEG) Program.
9:00AM A4.00006 Coupling quantum microwave circuits to quantum optics via cavity electro-optic modulators1. MANKEI TSANG, National University of Singapore — Experimental circuit quantum electrodynamics has made great strides in recent years, but it remains an open question how the quantum information stored in the microwave circuits can be transferred for long distances. Just as in classical information, the most promising solution is to convert the microwave fields to optical frequencies, where ultra-low-loss photonic devices such as optical fibers can be used. Here I propose the use of cavity electro-optic modulators for coherent coupling between microwave and optical fields. The electro-optic effect is the change in optical refractive index in certain materials, such as lithium niobate, under an applied voltage. Leveraging the fact that cavity electro-optics has the same phase-matching properties as cavity quantum electrodynamics on the microwave side, we create an all-optical interface, including coherent frequency conversion, laser cooling of microwave resonance, hybrid entanglement, hybrid parametric amplification and oscillation, and optical quantum-non-demolition measurements of microwave quadrature and energy.

1This material is based on work supported by the Singapore National Research Foundation under NRF Grant No. NRF-NRF2011-07.

9:12AM A4.00007 Hybrid Quantum Systems with Circuit Quantum Electrodynamics1. DAVID SCHUSTER, University of Chicago — Quantum Information Processing presents daunting challenges, with competing requirements of fast manipulation, long storage, and strong coupling between quantum states. In aggregate, many of the challenges quantum computation have been met with nanosecond manipulations (quantum circuits), coherence times measured in seconds (atomic ions/nuclear spins), and entanglement transported over kilometers (linear optics). Yet this system has achieved all of the necessary components simultaneously. One promising direction is to leverage the best aspects of each system, much as is done in a conventional computer, where transistors provide fast processing, magnetic memory provides massive long term storage, and information is transmitted via microwaves or fiber optics. A review of the constituent quantum systems, and the types of couplings between them will be presented. The coupling of a superconducting cavity/qubit system to electrons floating on helium will be discussed as an example of how to construct a hybrid system. Recent results on trapping and detection of electrons on helium using a superconducting cavity will be presented.

1Andreas Fragner, Yang Ge, Bing Li, Rob Schoelkopf

9:48AM A4.00008 Nonlinear optics quantum computing with circuit QED2. PRABIN ADHIKARI, MOHAMMAD HAFEZI, Joint Quantum Institute at UMD, JACOB TAYLOR, Joint Quantum Institute at UMD and NIST — One approach to quantum information processing is to use photons as quantum bits and rely on linear optical elements for most operations. However, some optical non-linearity is necessary to enable universal quantum computing. We consider a circuit-QED approach to linear optics quantum computing in the microwave regime, including a deterministic two-photon phase gate. Our model is a hybrid quantum system comprising an LC resonator coupled to a flux or phase superconducting qubit, which will be used to implement a non-linear two photon phase shift operation. Using this model, we show how fast, low-noise two-qubit gates between photons are possible, and discuss limitations of these ideas based on current technology.

2This research supported by the Physics Frontier Center at the JQI.

10:00AM A4.00009 Towards Hybrid Quantum Information Processing with Electrons on Helium. ANDREAS FRAGNER, Department of Applied Physics, Yale University, DAVID SCHUSTER, Department of Physics, University of Chicago, MARK DYKMAN, Department of Physics, Michigan State University, STEPHEN LYON, Department of Electrical Engineering, Princeton University, LUIGI FRUNZIO, Department of Applied Physics, Yale University, ROBERT SCHOELKOPF, Department of Physics and Applied Physics, Yale University — Electrons above the surface of superfluid helium form a two-dimensional electron gas in which single-electron quantum dots can be defined using electrostatic gates submerged under the helium film. The quantized motion and spin state of such a trapped electron on helium can be coupled to a high finesse superconducting cavity in a hybrid circuit QED architecture [1]. The cavity is used for nondestructive readout and as a quantum bus mediating interactions between distant electrons or an electron and a superconducting qubit. Coupling between motional states and individual photons in the cavity is estimated at a Rabi frequency of \(g/2\pi \sim 20\) MHz with coherence times exceeding 20 \(\mu s\) for charge and 1 fs for spin [1, 2]. Here I will discuss recent experiments in which we successfully trap and detect a two-dimensional electron gas on helium in a dc-biased superconducting cavity. Experimental progress towards the single-electron regime will also be presented.


10:12AM A4.00010 An ab-initio microscopic theory of anomalous heating in planar ion traps. H.R. SADEGHPOUR, ITAMP, Harvard-Smithsonian Center for Astrophysics, A. SAFAVI-NAINI, ITAMP/Dept of Physics MIT, P. RABL, IQOQI, Innsbruck, P.F. WECK, Advanced Systems Analysis, Sandia — Anomalous heating of trapped ions limits the scalability of the planar trap architecture for quantum computation. Measurements of the electric field noise present in ion traps indicate that the noise-induced heating scales as the inverse fourth power of the distance from the trap electrodes to the ion and its spectral density scales with the inverse of frequency [1]. These measurements also suggest that some thermally activated random process is at work. In this work, we present an ab-initio theory of this noise due to oscillating dipoles on the trap electrode surface [2]. The dipoles are formed when atoms are adsorbed on the trap surface, whose interaction with the surface is described with density functional theory (DFT). We present calculations for the spectral noise density and its distance, frequency and temperature dependencies. We consider both independent and correlated dipoles.


1NSF

10:24AM A4.00011 Quantum logic for molecular quantum information processing. J. MUR-PETIT, J. PEREZ-RIOS, J. CAMPOS-MARTINEZ, M.I. HERNÁNDEZ, Instituto de Física Fundamental, IFF-CSIC, Spain, S. WILLITSCHE, Department of Chemistry, University of Basel, Switzerland, J.J. GARCÍA-RIPOL, Instituto de Física Fundamental, IFF-CSIC, Spain — Very recently, molecular ions have been trapped and cooled to the mK regime in well defined internal states [1] opening a new window for precision spectroscopy of molecular species and quantum information with cold molecular ions. A first requirement for both applications is the ability to control and measure the state of molecular ions. I will present our proposal [2] of a fast, non-destructive and temperature independent spectroscopy method suitable to study electronic, vibrational, rotational and Zeeman transitions in complex ions that implements quantum logic schemes [3] between an atomic ion and the molecular ion of interest, using optical forces on the atom, and optical forces or magnetic field gradients on the molecule. This method sets a starting point for a hybrid quantum computation scheme with molecular and atomic ions, covering the measurement and entangling steps. Finally I will discuss the remarkable decoherence properties of two Zeeman states of the \(^{16}\text{O}_2^+\) molecular ion that make it a promising system for QIPC purposes [4].

10:36AM A4.00012 Possibility of “magic” trapping of three-level system for Rydberg blockade implementation, MUIR J. MORRISON, ANDREI DEREVYANKO, University of Nevada, Reno — The Rydberg blockade mechanism has shown noteworthy promise for scalable quantum computation with neutral atoms. Both qubit states and gate-mediating Rydberg state belong to the same optically-trapped atom. The trapping fields, while being essential, induce detrimental decoherence. Here we theoretically demonstrate that this Stark-induced decoherence may be completely removed using powerful concepts of “magic” optical traps. We analyze “magic” trapping of a prototype three-level system: a Rydberg state along with two qubit states, which are hyperfine states attached to a \( J = 1/2 \) ground state. Our numerical results show that the group IIIB metals such as Al are suitable candidates. Such trapping may or may not be possible for the alkalics, as “magic” conditions depend sensitively on the the trap-Rydberg interaction. Calculations of these effects are ongoing, and the results will be presented.

1 This project was supported in part by the NSF and UNR Honors Undergraduate Research Award.

10:48AM A4.00013 Cooling in the single-photon regime of optomechanics, ANDREAS NUNNENKAMP, Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland, KJETIL BORKJE, STEVEN GIRVIN, Departments of Physics and Applied Physics, Yale University, New Haven, Connecticut 06520, USA — Optomechanics experiments are rapidly approaching the regime where the radiation pressure of a single photon displaces the mechanical oscillator by more than its zero-point uncertainty. We show that in this limit the power spectrum has multiple sidebands and that the cavity response has several resonances in the resolved-sideband limit [Phys. Rev. Lett. 107, 063602 (2011)]. We then discuss how red-sideband cooling is modified in this nonlinear regime. Using Fermi’s Golden rule we calculate the transition rates induced by the optical drive. In the resolved-sideband limit we find multiple cooling resonances for strong single-photon coupling. They lead to non-thermal steady states and are accompanied by multiple mechanical sidebands in the optical output spectrum. Our study provides tools to detect and take advantage of this novel regime of optomechanics.


11:15AM B1.00001 Low-temperature, high-density magneto-optical trapping of potassium using the open 4S → 5P transition at 405 nm, DYLAN JERVIS, DAVID MCKAY, DAN FINE, GRAHAM EDGE, University of Toronto, JOHN PORCO-SIMPSON, University of California Santa Barbara, JOSEPH THYWISSEN, University of Toronto — We report the laser cooling and trapping of neutral potassium on an open transition. Fermionic \(^{40}\text{K}\) is trapped using a magneto-optical trap (MOT) on the closed \( 4S_{1/2} \rightarrow 5P_{3/2} \) transition at 767 nm and then transferred, with unit efficiency, to a MOT on the open \( 4S_{1/2} \rightarrow 5P_{3/2} \) transition at 405 nm. Because the \( 5P_{3/2} \) state has a smaller line width than the \( 4P_{3/2} \) state, the Doppler limit is reduced. We observe temperatures as low as \( 63(6) \mu \text{K} \), the coldest potassium MOT reported to date. The density of trapped atoms also increases, due to reduced temperature and reduced expulsive force fields. We measure a two-body loss coefficient of \( \beta = 2 \times 10^{-10} \text{cm}^3 \text{s}^{-1} \), and estimate an upper bound of \( 8 \times 10^{-18} \text{cm}^2 \) for the ionization cross section of the \( 5P \) state at 405 nm. The combined temperature and density improvement in the 405 nm MOT is a twenty-fold increase in phase space density over our 767 nm MOT, showing enhanced pre-cooling for quantum gas experiments. A qualitatively similar enhancement is observed in a 405 nm MOT of bosonic \(^{41}\text{K}\).

11:27AM B1.00002 Four techniques to achieve deeper Fermi degeneracy in Fermi-Bose mixtures, ROBERTO ONOFRIO, Department of Physics and Astronomy, University of Padova and ITAMP, Harvard-Smithsonian Center for Astrophysics — The study of exotic superfluid phases of ultracold atoms requires the achievement of deeper Fermi degeneracy with respect to the one already available. I will describe four techniques for efficient sympathetic cooling of Fermi gases with a different species Bose gas: bichromatic optical dipole and light-assisted magnetic trapping [1], quasi one-dimensional Fermi-Bose mixtures [3], and fast adiabatic cooling [4].


11:39AM B1.00003 Optimized sympathetic cooling of atomic mixtures via fast adiabatic strategies, STEPHEN CHOI, Department of Physics, University of Massachusetts, Boston, MA 02125, ROBERTO ONOFRIO1, Dipartimento di Fisica Galilei2, Universit`a di Padova, Via Marzolo 8, Padova, Italy, BALA SUNDARAM, Department of Physics, University of Massachusetts, Boston, MA 02125 — The talk will explore the extent to which frictionless cooling techniques may be useful in sympathetic cooling of Fermi gases. It is argued that optimal cooling of an atomic species may be obtained by means of sympathetic cooling with another species whose trapping frequency is dynamically changed to maintain constancy of the Lewis-Riesenfeld adiabatic invariant, which in turn determines the temporal-profile of the changing frequency. An important motivating factor is that an usually undesired feature of these techniques, i.e., the fact that the atomic cloud does not increase its phase-space density and therefore its degeneracy, turns into a crucial asset when viewed from the perspective of maintaining the gas in the nondegenerate regime, thus making it an optimal coolant. Advantages and limitations of this cooling strategy are discussed, with particular regard to the possibility of cooling Fermi gases to a deeper degenerate regime. We also show that the links between the suggested method and quantum squeezing.

1) Department of Physics, University of Massachusetts, Boston, MA 02125; 2) ITAMP, Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138

11:51AM B1.00004 Quantum degenerate Bose-Fermi mixture of chemically different atomic species with widely tunable interactions, JEE WOO PARK, CHENG-HSUN WU, IBON SANTIAGO, Massachusetts Institute of Technology, TOBIAS TIECKE, Harvard University, PEYMAN AHMADI, MARTIN ZWIERLEIN, Massachusetts Institute of Technology — We have created a quantum degenerate Bose-Fermi mixture of \( ^{23}\text{Na} \) and \( ^{40}\text{K} \) with widely tunable interactions via broad inter-species Feshbach resonances. Twenty Feshbach resonances between \( ^{23}\text{Na} \) and \( ^{40}\text{K} \) were identified. The large and negative triplet background scattering length between \( ^{23}\text{Na} \) and \( ^{40}\text{K} \) causes a sharp enhancement of the fermion density in the presence of a Bose condensate. As explained via the asymptotic bound-state model (ABM), this strong background scattering leads to a series of wide Feshbach resonances observed at low magnetic fields. Our work opens up the prospect to create chemically stable, fermionic ground state molecules of \( ^{23}\text{Na}-40\text{K} \) where strong, long-range dipolar interactions will set the dominant energy scale.

3 Work was supported by the NSF, AFOSR-MURI and -PECASE, ARO-MURI, ONR YIP, DARPA YFA, a grant from the Army Research Office with funding from the DARPA OLE program and the David and Lucille Packard Foundation.
12:03PM B1.00005 Condensate Fraction in a BEC Dimer, DAVID CAMPBELL, Boston University, HOLGER HENNIG, Harvard University, DIRK WITTHAUT, Max Planck Institute for Dynamics and Self-Organization, Goettingen — Recent experiments studying a Bose Einstein Condensate (BEC) in a two-mode system, equivalent to a “dimer,” have shown that many qualitative dynamical features of the BEC can be understood from motions in the underlying classical (two-dimensional) phase space $(\phi, z)$. Using a Bose-Hubbard model for the dimer, we focus on quantum deviations from motions in the classical phase space. We introduce a “quantum” phase space (QPS), which we define as the minimum condensate fraction $c(tau; \phi, z)$ of initial coherent states $(\phi, z)$ in the time interval $[0,tau]$. We find that lines of equal condensate fraction in the QPS do mimic the classical trajectories of constant energy in many respects, such that the QPS clearly reflects Josephson oscillations and self-trapping. However, novel quantum features beyond the classical description appear at finite time tau. These include symmetry breaking and enhanced $c(tau; \phi, z)$ near the classical hyperbolic fixed point and along a ridge near the classical separatrix. These features of the QPS can be readily studied in current experiments.

12:15PM B1.00006 Resonant Hawking radiation in Bose-Einstein condensates, FERNANDO SOLS, IVAR ZAPATA, Universidad Complutense de Madrid (Spain), MATHIAS ALBERT, Universite de Geneve (Switzerland), RENAUD PARENTANI, Universite Paris-Sud, Orsay (France) — We study double-barrier interfaces separating regions of asymptotically subsonic and supersonic flow of Bose-condensed atoms [1]. These setups contain at least one black hole sonic horizon from which the analogue of Hawking radiation should be generated and emitted against the flow in the subsonic region. Multiple coherent scattering by the double-barrier structure strongly modulates the transmission probability of phonons, rendering it very sensitive to their frequency. As a result, resonant tunneling occurs with high probability within a few narrow frequency intervals. This gives rise to highly non-thermal spectra with sharp peaks. We find that these peaks are mostly associated with decaying resonances and only occasionally with dynamical instabilities. Even at achievable non-zero temperatures, the radiation peaks can be dominated by spontaneous emission, i.e. enhanced zero-point fluctuations, and not, as is often the case in analogue models, by stimulated emission.


12:27PM B1.00007 Momentum Resolved Optical Lattice Modulation Spectroscopy for Bosons in Optical Lattice, RAJDEEP SENSARMA, Condensed Matter Theory Center, University of Maryland, College Park, KRISHNENDU SENGUPTA, Indian Association for cultivation of Science, Kolkata, India, SANKAR DAS SARMA, Condensed Matter Theory Center, University of Maryland, College Park — We propose a new method of optical lattice modulation spectroscopy for studying the spectral function of ultracold bosons in an optical lattice. We show that different features of the single particle spectral function in different quantum phases can be obtained by measuring the change in momentum distribution after the modulation. In the Mott phase, this gives information about the momentum dependent gap to particle-hole excitations as well as their spectral weight. In the superfluid phase, one can obtain the spectrum of the gapless Bogoliubov quasiparticles as well as the gapped amplitude fluctuations. The distinct evolution of the response with modulation frequency in the two phases can be used to identify these phases and the quantum phase transition separating them.

12:39PM B1.00008 Population of atoms in the output of an atom Michelson interferometer, EBUBECHUKWU ILO-OKEKE, ALEXZOZULYA, Worcester Polytechnic Institute — A cloud of Bose-Einstein condensate (BEC) sitting at the center of a weakly confining trap in an atom Michelson interferometer is split into two clouds that travel along different paths. The two clouds evolve and accumulate relative phase between them due to field of interest, confining potential and interatomic interactions. At the end of the interferometric cycle, the two clouds are recombined and the population of atoms found in the cloud at rest and the moving clouds depends on the relative phase. We derive an expression for the probability of counting any number of atoms within each cloud after recombination, study the dependence of the probability on the relative phase and relate our findings with experiments.

12:51PM B1.00009 Prototyping method for Bragg-type atom interferometers, BRANDON BENTON, MICHAEL KRYGIER, JEFFREY HEWARD, Georgia Southern University, MARK EDWARDS, Georgia Southern University and NIST, CHARLES CLARK, Joint Quantum Institute and NIST — We present a method for rapid modeling of new Bragg ultracold atom-interferometer (AI) designs useful for assessing the performance of such interferometers. The method simulates the overall effect on the condensate wave function in a given AI design using two separate elements. These are (1) modeling the effect of a Bragg pulse on the wave function and (2) approximating its evolution during the intervals between the pulses. The actual sequence of these pulses and intervals is then followed to determine the approximate final wave function from which the interference pattern can be calculated. The exact evolution between pulses is assumed to be governed by the Gross-Pitaevskii equation (GPE). We have developed both 1D and 3D versions of this method and have determined their validity by comparing their predicted interference patterns with those obtained by numerical integration of the 1D GPE and with the results of an experiment performed at NIST. We find good agreement between the 1D interference patterns predicted by this method and those found by the GPE. We show that we can reproduce the results of the NIST experiment and that this method provides estimates of 1D interference patterns 10,000 times faster than direct integration of the GPE.

1This work supported by NSF grant number PHY-0758111

12:03PM B1.00010 Applications of chirped Raman adiabatic rapid passage to atom interferometry, KRISH KOTRU, DAVID L. BUTTS, C. S. Draper Laboratory, Inc., and MIT Dept. of Aeronautics and Astronautics, JOSEPH M. KINAST, DAVID M. JOHNSON, ANTONIJ M. RADOJEVIC, BRIAN P. TIMMONS, RICHARD E. STONER, C. S. Draper Laboratory, Inc. — We present robust atom optics, based on chirped Raman adiabatic rapid passage (ARP), in the context of atom interferometry. Such ARP light pulses drive coherent population transfer between two hyperfine ground states by sweeping the frequency difference of two fixed-intensity optical fields with large single photon detunings. Since adiabatic transfer is less sensitive to atom temperature and non-uniform Raman beam intensity than standard Raman pulses, this approach should improve the stability of atom interferometers operating in dynamic environments. In such applications, chirped Raman ARP may also provide advantages over the previously demonstrated stimulated Raman adiabatic passage (STIRAP) technique, which requires precise modulation of beam intensity and zeroing of the single photon detuning. We demonstrate a clock interferometer with chirped Raman ARP pulses, and compare its stability to that of a conventional Raman pulse interferometer. We also discuss potential improvements to inertially sensitive atom interferometers. Copyright © 2011 by The Charles Stark Draper Laboratory, Inc. All rights reserved.

1This work was supported by the Draper Laboratory IR&D program. KK and DB acknowledge support from Draper Laboratory Fellowships.
1:15PM B1.00011 Berry-gauge tuned Bose-Einstein condensate gyroscope
J.J. Hopfield, Proc. Nat. Acad. Sci., T-4, Los Alamos National Laboratory, Los Alamos, NM 87544 — If stable, the many-body ground state of a dilute gas of ultra-cold, bosonic atoms occupying a superposition of two internal (hyperfine) states is a Bose-Einstein condensate (BEC) of effective spin 1/2 bosons. The superfluid BEC dynamics admits long-lived quantized vortex states in which the complex phase of the superfluid order parameter, which we call the charge phase, undergoes an integer number of $2\pi$ windings along a multiply connected path — a closed trajectory that encloses a region in which the superfluid density vanishes. In response to an overall rotation of the ring, a quantization event can occur that can be used to sense rotation. Unfortunately, the sensitivity of the ring BEC gyroscope would be limited as the quantization event sets in at a rotation frequency that is not as low as the frequencies measured by other devices such as ring laser gyroscopes. We show that the recently realized synthetic magnetic fields, in which the controlled position dependence of the spin results in an effective gauge field, can tune the BEC ring gyroscope to trigger a quantization event at much smaller rotation frequency. In addition, the effective gauge field can undergo its own quantization events in which the spin vector undergoes an integer number of $2\pi$ or $4\pi$ windings.

1:27PM B1.00012 Frustration and glassiness in spin models with cavity-mediated interactions

1:39PM B1.00013 Manipulation of ultracold rubidium atoms using a single linearly chirped laser pulse

2:03PM B1.00015 Electron field noise sensing with a scanning ion

Monday, February 27, 2012 11:15AM - 2:15PM
Session B4 DAMOP: Hybrid Systems, Optomechanics and Macroscopic Systems at the Quantum Limit
11:15AM B4.00001 Observing quantum phenomena in cavity optomechanics1. NATHANIEL BRAHMS, DAN W. C. BROOKS, SYDNEY SCHREPPLE, THIERRY BOTTER, DAN M. STAMPER-KURN, Univ of California - Berkeley — Recent efforts have produced optomechanical systems whose mechanical elements are prepared at or near their quantum ground state. But what manifestly quantum effects can be measured with these new systems? Here we present results from our experiment, using the collective motion of an ultracold atom ensemble as a mechanical oscillator. The motion is driven by shot noise in the light’s radiation pressure, allowing us to observe the production of nonclassical states of light by optomechanics — here, quadrature-squeezed light. Notably, this nonlinear optical effect occurs with only 40 pW of pump power. We also measure the quantization of the oscillator, by observing a 3:1 asymmetry in the light it scatters to low- and high-energy optical sidebands. Analyzing the light emitted from the cavity moreover provides a spectroscopic record of the energy exchanged between light and motion, allowing us to directly quantify the necessary diffusive heating of a quantum backaction-limited position measurement.

11:27AM B4.00002 Cryogenic optomechanics with a 261kHz mechanical oscillator. DONGHUN LEE, ANDREW JAYICH, Yale University, JACK SANKEY, McGill University, CHEN YANG, LILY CHILDRESS, MITCHELL UNDERWOOD, KJETIL BORKJE, STEVE GIRVIN, JACK HARRIS, Yale University — Mechanical motion can interact with light via radiation pressure force. With recent experimental advances over the last few years, such optomechanical coupling has been used to reach quantum ground state of mechanical oscillators, which opens interesting new regime of observing quantum mechanics in macroscopic objects. The optomechanical devices used in this talk consist of a dielectric SiN membrane located inside a high finesse optical cavity. Combining cryogenic cooling in He3 refrigerator and resolved sideband laser cooling enables us to cool the membrane’s mechanical mode (whose mechanical frequency is 261kHz) to less than 60 phonons. We will describe some technical challenges in our experiments such as the role of classical phase noise of the cooling laser at the mechanical frequency and our efforts to significantly reduce it via a filter cavity.

11:39AM B4.00003 Ultraefficient Cooling of Resonators: Beating Sideband Cooling with Quantum Control. XIAOTING WANG, SAI VINJANAMPATHY, University of Massachusetts at Boston, FREDERICK STRAUCH, Williams College, KURT JACOBS, University of Massachusetts at Boston — There is presently a great deal of interest in cooling high-frequency micro- and nano-mechanical oscillators to their ground states. The present state of the art in cooling mechanical resonators is a version of sideband cooling, which was originally developed in the context of cooling trapped ions. Here we present a method based on quantum control that uses the same configuration as sideband cooling—cooling the resonator to be cooled to a second microwave (or optical) auxiliary resonator—but will cool significantly colder. This is achieved by applying optimal control and varying the strength of the coupling between the two resonators over a time on the order of the period of the mechanical resonator. As part of our analysis, we also obtain a method for fast, high-fidelity quantum information transfer between resonators.

11:51AM B4.00004 Postselected optomechanical superpositions1. BRIAN PEPPER, UC Santa Barbara, ROOHOL-LAH GHOBADI, University of Calgary / Sharif University of Technology, EVAN JEFFREY, University of Leiden, CHRISTOPH SIMON, University of Calgary, DIRK BOUWMEESTER, UC Santa Barbara / University of Leiden — We present a scheme for achieving macroscopic quantum superpositions in weakly coupled optomechanical systems by using single photon postselection. This method allows the creation of macroscopic superpositions with currently achievable device parameters, and allows observation of decoherence on a timescale unconstrained by the system’s optical decay time. This method relieves many of the challenges associated with previous optical schemes for measuring macroscopic superpositions, and only requires the devices to be in the weak coupling regime. Prospects for observing novel decoherence mechanisms are also discussed.

1 The authors gratefully acknowledge support from NSF PHY-0804177 and Marie Curie EXT-CT-2006-042580

12:03PM B4.00005 Coupling a single spin in diamond to the quantum motion of a mechanical cantilever. STEVEN BENNETT, SHIMON KOLKOWITZ, QUIRIN UNTERREITMEIER, Harvard University, PETER RABL, IQOQI-University of Innsbruck, ANIA BLESZYNSKI-JAYICH, University of California, Santa Barbara, JACK HARRIS, Yale University, MIKHAIL LUKIN, Harvard University — We present theoretical considerations for a magnetized mechanical cantilever coupled to a single electronic spin associated with a nitrogen-vacancy (NV) defect center in diamond. This coupled system has recently been implemented in an experiment where the NV spin was used to detect the thermal motion of a magnetic force microscope cantilever at room temperature, reading out the spin state optically using the spin-selective fluorescence of the NV. The possibility to extend this system to the quantum regime opens the door to applications such as readout and transfer of quantum information, as well as interesting theoretical questions. For instance, it would be possible to study the regime of strong coupling between the spin and the motion of the cantilever, in analogy to cavity quantum electrodynamics. We discuss the prospects for reaching the strong coupling regime and the conditions for measuring the onset of quantum effects, such as measuring the zero point motion of the cantilever using the spin as a detector.

12:15PM B4.00006 Thermally induced parametric instability in back-action evading measurement of micromechanical quadrature near the zero-point level. JUNHO SUH, MATT SHAW, AARON WEINSTEIN, KEITH SCHWAB, California Institute of Technology — Back-action evading (BAE) measurement of mechanical resonators allows, in principle, detection of a single quadrature of motion with sensitivity far below the standard quantum limit, limited in practice only by the non-idealities in the measurement. We report the results of experiments utilizing two-tone BAE in a tightly coupled cavity quantum electro-mechanical system (ωc=7.1GHz, ωm=10MHz, g=14MHz/nm). Due to excess dissipation in the microwave cavity, we observe a parametric instability induced by the thermal shift of mechanical resonance frequency. This bounds the minimum position imprecision on one quadrature and we measure the imprecision reaching twice the zero-point motion. We discuss the device requirements to avoid this thermal mechanism and perform measurements below the zero-point level.

12:27PM B4.00007 Mechanical squeezing via parametric amplification and feedback control1. ANDREW DOHERTY, Centre for Engineered Quantum Systems, University of Sydney, A. SZORKOVSKY, G. I. HARRIS, W. P. BOWEN, Centre for Engineered Quantum Systems, The University of Queensland — We discuss the mechanical squeezing that can result from position measurement and feedback applied to a parametrically driven mechanical oscillator. If the parametric drive is optimally detuned from resonance, correlations between the quadratures of motion allow unlimited steady-state squeezing. This contrasts to a parametric drive alone, which is limited to 3dB of squeezing. Compared to back-action evasion, we demonstrate that the measurement strength, temperature and efficiency requirements for quantum squeezing are significantly relaxed.

1 Supported by the Australian Research Council Centre of Excellence CE110001013 and Discovery Project DP0987146.
12:39PM B4.00008 Asymmetric absorption and emission of energy by a macroscopic mechanical oscillator in a microwave circuit optomechanical system, JENNIFER HARLOW, TAUNO PALOMAKI, JOSEPH KERCKHOFF, JILLA, University of Colorado and NIST, JOHN TEUFEL, RAYMOND SIMMONDS, NIST Boulder, KONRAD LEHNERT, JILLA, University of Colorado and NIST — We measure the asymmetry in rates for emission and absorption of mechanical energy in an electromechanical system composed of a macroscopic suspended membrane coupled to a high-Q, superconducting microwave resonant circuit. This asymmetry is inherently quantum mechanical because it arises from the inability to annihilate the mechanical ground state. As such, it is only appreciable when the average mechanical occupancy approaches one. This measurement is now possible due to the recent achievement of ground state cooling of macroscopic mechanical oscillators [1,2]. Crucially, we measure the thermal cavity photon occupancy and account for it in our analysis. Failure to correctly account for the interference of these thermal photons with the mechanical signal can lead to a misinterpretation of the data and an overestimate of the emission/absorption asymmetry.

1:15PM B4.00011 Measuring Quantum Optomechanical Self-induced Oscillations: Photon Correlation and Homodyne Tomography1, JIANG QIAN, School of Engineering, Case Western Reserve University, FLORIAN MARQUARDT, Department of Physics, FAU Erlangen-Nuremberg, AASHISH CLERK, Department of Physics, McGill University, KLEMENS HAMMERER, Institute for Theoretical Physics, University of Hannover — Motivated by recent experimental advances in fabricating systems with large optomechanical couplings, we study the self-induced mechanical oscillations in the strong quantum regime for a single cell optomechanical system. We show that, under strong optomechanical coupling \( g_M \geq \kappa \), the persistent state of the mechanical oscillator can have non-classical, strongly negative Wigner density, which can be measured by non-destructive homodyne tomography. We further propose to detect the onset of the quantum self-induced oscillation using the easier-to-measure photon two-point correlation functions \( g^{(2)}(t) \). We show that there are two distinct signatures in the long-term time-average and the line-shape of \( g^{(2)}(t) \) at the onset of self-induced oscillations. We show that \( g^{(2)}(t) \) exhibits long-term coherence extending much beyond the optical decay time \( 1/\kappa \), the decay of which in the red- and blue-detune regime we explain using models of optomechanical cooling and phase noise.

1:27PM B4.00012 Controllable Coherent Transfer between a Superconducting Resonator and a Mechanical Oscillator, TAUNO PALOMAKI, JENNIFER HARLOW, JOSEPH KERCKHOFF, REED ANDREWS, JILLA, NIST and the University of Colorado, Boulder — We report experimental results of controllable coupling between a 7.5 GHz superconducting resonator and a 10 MHz mechanical oscillator. Through time domain measurements, we demonstrate controlled energy transfer between these two systems. Furthermore, by utilizing a Josephson parametric amplifier we have been able to verify coherent transfer of small amplitude states. We compare these results to frequency domain measurements and discuss experimental limitations.

1:39PM B4.00013 Using interference for high fidelity quantum state transfer in optomechanics1, YING-DAN WANG, AASHISH A. CLERK, McGill University — We present a theoretical study of a two-cavity optomechanical system (e.g. a single mechanical resonator coupled to both a microwave and an optical cavity), investigating how interference can be used to perform mechanically-mediated quantum state transfer between the two cavities. We show that this optomechanical system possesses an effective “mechanically-dark” mode which is immune to mechanical dissipation; utilizing this feature allows highly efficient transfer of intra-cavity states, as well as of itinerant photon states. Simple analytic expressions for the fidelity of transferring both Gaussian and non-Gaussian states are provided. Our work has relevance to ongoing experimental efforts in quantum optomechanics (e.g., C. A. Regal and K. W. Lehnert, J. Phys.: Conf. Ser. 264, 012025 (2011); A. H. Safavi-Naeini and O. Painter, New J. Phys. 13, 013017 (2011)).

2:03PM B4.00014 Development of a dispersive read-out technique for quantum measurements of nanomechanical resonators1, FRANCISCO ROUXINOL, MATT LAHAYE, Syracuse University — The development of techniques to observe non-classical behavior of micro- and nano-scale mechanical structures has received considerable attention in recent years because of the potential to use these systems for fundamental studies of quantum mechanics as well as their potential role as new technologies for applications ranging from the sensing of weak forces to quantum communication. One important route for observing such behavior is the coupling of micro- and nanomechanical resonators with superconducting qubits. Under certain conditions, qubit-coupled mechanical devices are formally analogous to Jaynes-Cummings systems which have been used in fields such as cavity QED for explorations of matter-radiation interactions and the quantum nature of light. Correspondingly, experiments in the last couple of years have begun to develop superconducting qubits as tools to manipulate and measure quantum states of mechanics. In this talk, we will discuss our efforts to integrate charge-type superconducting qubits as elements for dispersive (non-resonant) read-out and control of nanomechanical resonators, including preliminary system design and the prospects of implementing this system for read-out of the number-state statistics of nanomechanical modes.

3This work is supported by NSF-DMR Career Award 1056423 and funding from the College of Arts and Sciences at Syracuse University.

3This work was supported by the DARPA ORCHID program under a grant from the AFOSR.
will provide chance to form Ryberg rings for quantum simulation. We include rotating single atoms in a ring optical lattice generated by a spatial light modulator, and trapping a single atom in a blue detuned optical bottle beam trap. Recently, we succeeded in trapping up to 6 atoms in a ring optical lattice with one atom in each site. Further laser cooling the array and manipulation of the inner states will provide chance to form Ryberg rings for quantum simulation.


Monday, February 27, 2012 11:15AM - 2:15PM —
Session B10 DCMP DAMOP: Invited Session: Equilibration and Relaxation in Cold Atoms 210A

11:15AM B10.00001 Timescales for equilibration and adiabaticity in optical lattices

STEFAN NATU, Cornell University — What are the timescales governing local and global dynamics in strongly correlated systems? How do we probe this dynamics in an isolated quantum system without coupling the system to leads? High in-situ resolved experiments on bosons in optical lattices are answering precisely these questions by imaging the gas following a sudden change of the lattice potential. The results are striking. Experiments have revealed a disparity as large as two orders of magnitude between fast equilibration of local number fluctuations and slow global mass redistribution. In this talk, I will provide a simple model which captures all the relevant physics. Additionally, I will show that the fast timescales for local dynamics challenge the accepted notions of adiabaticity times, invalidating routinely used techniques such as band-mapping as useful probes of quantum many body systems. References: S. S. Natu, K. R. A. Hazzard and E. J. Mueller, Phys. Rev. Lett. 106 125301 (2011).

1:03PM B4.00014 Adiabatic State Conversion and Photon Transmission in Optomechanical Systems

LIN TIAN, University of California, Merced — Light-matter interaction in optomechanical systems in the strong coupling regime can be explored as a tool to transfer cavity states and to transmit photon pulses. Here, we show that quantum state conversion between cavity modes with different wavelengths can be realized with high fidelity by adiabatically varying the effective optomechanical couplings. During this adiabatic process, the quantum state is preserved in the dark mode of the cavities, similar to the adiabatic transfer schemes in EIT systems. The fidelity for gaussian states is derived by solving the Langevin equation in the adiabatic limit and shows negligible dependence on the mechanical noise. We also show that an input pulse can be transmitted to an output channel with a different wavelength via the effective optomechanical couplings. The condition for optimal transmission is derived in the frequency domain. Input pulses with a narrow spectral width can be transmitted with high fidelity. For input pulses with a large spectral width, the shape of the output pulses can be manipulated by applying time-dependent effective couplings. (1) L. Tian, arXiv:1111.2119. (2) L. Tian and H. L. Wang, Phys. Rev. A 82, 053806 (2010).

This work is supported by DARPA-ORCHID, NSF-DMR-0956064, NSF-CCF-0916303, and NSF-COINS.

1:51PM B4.00015 Single atom array to form a Rydberg ring

MINGSHENG ZHAN, PENG XU, XIAODONG HE, MIN LIU, JIN WANG, Wuhan Institute of Physics and Mathematics, Chinese Academy of Sciences — Single atom arrays are ideal quantum systems for studying few-body quantum simulation and quantum computation [1]. Towards realizing a fully controllable array we did a lot of experimental efforts, which include rotating single atoms in a ring optical lattice generated by a spatial light modulator [2], high efficient loading of two atoms into a microscopic optical trap by dynamically reshaping the trap with a spatial light modulator [3], and trapping a single atom in a blue detuned optical bottle beam trap [4]. Recently, we succeeded in trapping up to 6 atoms in a ring optical lattice with one atom in each site. Further laser cooling the array and manipulation of the inner states will provide chance to form Rydberg rings for quantum simulation.


This work is supported by the National Basic Research Program of China under grant No.2012CB922101.
3:06PM D4.00004 Collective quantum jumps of Rydberg atoms. TONY LEE, California Institute of Technology.

Three-dimensional Rydberg blockade and the thermalization of Rydberg gases have been intensively studied in recent years. In this talk, we present a new method for observing collective quantum jumps in a group of Rydberg atoms. We demonstrate that these jumps can be controlled by varying the strength of the laser driving, and we show that the jumps are sensitive to the temperature of the Rydberg gas. This work has implications for the development of quantum technologies based on Rydberg atoms.
3:18PM D4.00005 Quantum crystals in a trapped Rydberg-dressed Bose-Einstein condensate, C.-H. HSUEH, Department of Physics, National Taiwan Normal University, T.-C. LIN, Department of Mathematics, National Taiwan University, T.-L. HORNG, Department of Applied Mathematics, Feng Chia University, W.C. WU, Department of Physics, National Taiwan Normal University — Spontaneously crystalline ground states, called quantum crystals, of a trapped Rydberg-dressed Bose-Einstein condensate are numerically investigated. As a result described by a mean-field order parameter, such states simultaneously possess crystalline and superfluid properties. A hexagonal droplet lattice is observed in a quasi-two-dimensional system when dressing interaction is sufficiently strong. Onset of these states is characterized by a drastic drop of the non-classical rotational inertia proposed by Leggett [Phys. Rev. Lett. 25, 1543 (1970)]. In addition, an AB stacking bilayer lattice can also be attained. Due to an anisotropic interaction possibly induced by an external electric field, transition from a hexagonal to a nearly square droplet lattice is also observed.

We acknowledge financial support from NSC, Taiwan.

3:30PM D4.00006 Quantum Magnetism with Polar Molecules: Tunable Generalized t-J Model, ALEXEY GORSHKOV, California Institute of Technology, SALVATORE MANNANA, University of Colorado, Boulder, KEVIN KUNS, California Institute of Technology, KADEN HAZZARD, GANG CHEN, JUN YE, University of Colorado, Boulder, EUGENE DEMLER, MIKHAIL LUKIN, Harvard University, ANA MARIA REY, University of Colorado, Boulder — We show that dipolar interactions between ultracold polar molecules in optical lattices can be used to realize a highly tunable generalization of the t-J model, which we refer to as the t-J-V-W model. The “spin” is encoded in the rotational degree of freedom of the molecules, while the interactions are controlled by applied static electric and continuous-wave microwave fields. We show that the tunability and the long-range nature of the interactions in the t-J-V-W model enable enhanced superfluidity in one dimension and controllable preparation of robust d-wave superfluids in two dimensions. The latter may provide fundamental insights into high-temperature superconductivity. [References: Phys. Rev. Lett. 107, 115301 (2011); Phys. Rev. A 84, 033619 (2011); arXiv:1110.5330]

4:06PM D4.00009 Interactions of polar molecules dressed by far-off-resonant light: Entangled dipoles up- or down-holding each other, MIKHAIL LEMESHKO, ITAMP, Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts 02138, USA, BREITSLAV FRIEDRICH, Fritz Haber Institute of the Max Planck Society, Faradayweg 4-6, D-14195 Berlin, Germany, FRIEDRICH TEAM — We show that the electric dipole-dipole interaction between a pair of polar molecules undergoes an all-out transformation when superimposed by a far-off-resonant optical field. The combined interaction potential becomes tunable by variation of wavelength, polarization and intensity of the optical field and its dependence on the intermolecular separation exhibits a crossover from an inverse-power to an oscillating behavior. The ability thereby offered to control molecular interactions opens up avenues toward the creation and manipulation of novel phases of ultracold polar gases among whose characteristics is a long-range entanglement of the dipolar molecules’ mutual rotation. We devised an adequate analytic model of such optical-field-dressed dipole-dipole interaction potentials, which enables a straightforward access to the optical-field parameters required for the design of intermolecular interactions in the laboratory.

4:18PM D4.00010 Clustering of cold polar molecules in arrays of one-dimensional tubes, MICHAEL KNAP, Graz University of Technology, EREZ BERG, EUGENE DEMLER, Harvard University — Cold polar molecules allow to study exciting new phenomena which arise from the long-range and anisotropic nature of their mutual interactions. Here, we demonstrate that a Wigner crystal of polar molecules confined in planar arrays of one-dimensional tubes can be made unstable with respect to the formation of clusters of particles. By controlling the orientation of the external electric field which aligns the dipole moments, increasingly complex structures with a varying number of particles per cluster and thus varying periodicity are formed. The spatial agglomeration of multiple polar molecules results from the interaction and can be described classically. However, we show that the effect survives when quantum fluctuations are present. For systems of a finite number of tubes, the result is a sequence of “clustered” Luttinger liquid states. Finally, we determine the ratio between the interaction and the kinetic energy which is necessary for the spatial agglomeration of polar molecules. We find that the requirements for clustering are reachable in current experiments with cold polar molecules.

4:30PM D4.00011 A dielectric superfluid of polar molecules, SETH RITTENHOUSE, ITAMP, Harvard-Smithsonian Center for Astrophysics, RYAN WILSON, JOHN BOHN, JILA and the Department of Physics, University of Colorado — We consider a Bose-Einstein condensate of heteronuclear molecules in an applied electric field. In the strong field regime, the molecules are fully polarized and produce fields that tend to be weak compared to the applied field. However, in weaker applied fields the internal fields due to the polarization of the molecules can become comparable to the applied field, and the system develops a dielectric character. We derive a set of self-consistent mean-field equations that couple the condensate density to its polarization field, leading to the emergence of polarization modes that are coupled to the quasiparticle spectrum of the condensate. While the roton instability is suppressed in this system, the coupling gives rise to a phonon-like instability that is characteristic of a dielectric material with a negative static dielectric function.

This work was supported by funding from the NSF and the DOE.
from BCS to BEC under artificial spin-orbit fields 


5:45PM D4.00013 Paired Phases of Dipoles in a Bilayer System 


5:06PM D4.00014 Bond Order Solid of Two-Dimensional Dipolar Fermions 


5:18PM D4.00015 Re-entrant first-order phase transitions and anomalous hysteresis of dipolar Bose gases in a triangular optical lattice 

5:30PM D4.00016 Topological phase transitions in ultra-cold Fermi superfluids: the evolution from BCS to BEC under artificial spin-orbit fields 

8:12AM H4.00002 BCS-BEC Crossover and Topological Phase Transition in 3D Spin-Orbit Coupled Degenerate Fermi Gases
8:24AM H4.00003 BCS-BEC crossover in 2D spin-orbit coupled degenerate Fermi gases\footnote{Supported by Marie Curie IRG FP7-PEOPLE-IRG-2010-268239; TUBITAK Career 3501-110T839, and TUBA-GEBIP grants.}. CHUANWEI ZHANG, GANG CHEN, MING GONG, Department of Physics and Astronomy, Washington State University, Pullman, WA 99164 — The recent experimental realization of spin-orbit coupling for ultra-cold atoms has generated much interest in the physics of spin-orbit coupled degenerate Fermi gases. Although recently the BCS-BEC crossover in 3D spin-orbit coupled Fermi gases has been intensively studied, the corresponding 2D crossover physics has remained unexplored. In this talk, we discuss the BCS-BEC crossover physics in 2D degenerate Fermi gases in the presence of spin-orbit coupling. We derive the zero temperature mean field gap and atom number equations suitable for the 2D spin-orbit coupled Fermi gases, from which the dependence of the ground state properties (pairing gap, chemical potential, etc.) on the system parameters (e.g., binding energy, spin-orbit coupling strength) is obtained, both numerically and analytically. We characterize the dependence of the BKT transition temperature as well as the vortex-antivortex lattice melting temperature on the spin-orbit coupling strength and the external Zeeman field.

8:36AM H4.00004 One-dimensional Ultracold Fermi Gases with Spin-orbit Coupling. YINGFEI GU, HUI ZHAI, Institute for Advanced Study, Tsinghua Univ., Beijing 100084 — We study one-dimensional ultracold Fermi gases with spin-orbit coupling. We use the Bogoliubov-de Gennes equations to determine pairing order parameter, and find out new phases in addition to fully polarized normal phase, fully paired BCS phase and the FFLO phase. We complete the phase diagram in terms of polarization, interaction parameter and strength of spin-orbit coupling.

8:48AM H4.00005 Who is the Lord of the Rings in the Zeeman-spin-orbit Saga: Majorana, Dirac or Lifshitz?\footnote{Supported by the Army Research Office (W911NF-09-1-0220) for support.}. CARLOS SA DE MELO, KANGJUN SEO, LI HAN, Georgia Institute of Technology — Zeeman, spin-orbit fields and interactions can be tuned in the context of ultra-cold atoms and allow for the visitation of several different phases. For systems with zero Zeeman field, the evolution from BCS to BEC superfluidity in the presence of spin-orbit effects is only a crossover\cite{1}. In contrast, for finite Zeeman fields, spin-orbit coupling induces a triplet component in the order parameter that produces nodes in the quasiparticle excitation spectrum leading to bulk topological phase transitions of the Lifshitz type\cite{2}. A fully gapped phase also exists, where a crossover from indirect to direct gap occurs. For spin-orbit couplings with equal Rashba and Dresselhaus components the nodal quasi-particles that live at and in the vicinity of rings of nodes. Transitions from and to nodal phases can occur via the emergence of zero-mode Majorana fermions at phase boundaries, where rings of nodes of Dirac fermions annihilate\cite{3}. Lastly, we characterize different phases via spectroscopic and thermodynamic properties and conclude that Lifshitz is the “Lord of the Rings.”


9:00AM H4.00006 Quantum phases of atomic Fermi gases with spin-orbit coupling. ISKIN, Koc University, LEVENT SUBASI, Istanbul Technical University — We consider a general anisotropic spin-orbit coupling and analyze the phase diagrams of both balanced and imbalanced Fermi gases for the entire BCS-BEC evolution. First we use the self-consistent mean-field theory at zero temperature, and show that the topological structure of the ground-state phase diagrams is quite robust against the effects of anisotropy. Then we go beyond the mean-field description, and investigate the effects of Gaussian fluctuations near the critical temperature. This allows us to derive the time-dependent Ginzburg-Landau theory, from which we extract the effective mass of the Cooper pairs and their critical condensation temperature in the molecular BEC limit.

9:12AM H4.00007 Low-density molecular gas of tightly-bound Rashba-Dresselhaus fermions. SO TAKEI, CHIEN-HUNG LIN, Condensed Matter Theory Center, The University of Maryland College Park, BRANDON ANDERSON, National Institute for Standards and Technology, VICTOR GALITSKI, Joint Quantum Institute and Physics Department, University of Maryland — We study interacting Rashba-Dresselhaus fermions in two spatial dimensions. First, we present a new exact pairing solution to the two-particle interacting problem of spin-orbit-coupled fermions for arbitrary Rashba and Dresselhaus spin-orbit interactions. An exact molecular wave function and the Green function are explicitly derived along with the binding energy and the spectrum of the molecular state. In the second part, we consider a thermal Boltzmann gas of fermionic molecules and compute the time-of-flight velocity and spin distributions for a single fermion in the gas. We show that the pairing signatures can be observed already in the first-moment expectation values, such as time-of-flight density and spin profiles.

9:24AM H4.00008 Order by Disorder in Spin-Orbit Coupled Bose-Einstein Condensates. RYAN BARNETT, STEPHEN POWELL, Joint Quantum Institute and Condensed Matter Theory Center, University of Maryland, TOBIAS GRASS, ICREA-Institucio Catalana de Recerca i Estudis Avancats, MÀCIEJ LEWENSTEIN, ICREA-Institucio Catalana de Recerca i Estudis Avancats and ICFQ, SANKAR DAS SARMA, Joint Quantum Institute and Condensed Matter Theory Center, University of Maryland — Motivated by recent experiments, we investigate the system of isotropically-interacting bosons with Rashba spin-orbit coupling. At the non-interacting level, there is a macroscopic ground-state degeneracy due to the many ways bosons can occupy the Rashba spectrum. Interactions treated at the mean-field level restrict the possible ground-state configurations, but there remains an accidental degeneracy not corresponding to any symmetry of the Hamiltonian, indicating the importance of fluctuations. By finding analytical expressions for the collective excitations in the long-wavelength limit and through numerical solution of the full Bogoliubov-de Gennes equations, we show that the system condenses into a single momentum state of the Rashba spectrum via the mechanism of order by disorder. We show that in 3D the quantum depletion for this system is small, while the thermal depletion has an infrared logarithmic divergence, which is removed for finite-size systems. In 2D, on the other hand, thermal fluctuations destabilize the system. This work is supported in part by JQI-PFC.

9:36AM H4.00009 Exotic 3D Spin-Orbit Couplings. BRANDON ANDERSON, JQI, NIST and the University of Maryland, GEDIMINAS JUZELIUNAS, Institute of Theoretical Physics and Astronomy and Vilnius University, IAN SPIELMAN, VICTOR GALITSKI, JQI, NIST and the University of Maryland — We describe a scheme for creating an isotropic three-dimensional spin-orbit coupling, dubbed Weyl spin-orbit coupling, in systems of ultracold atoms. This coupling is induced by Raman transitions that link four internal atomic states with a tetrahedral geometry. This spin-orbit coupling gives rise to a Dirac point that is robust against environmental perturbations. We then propose a general procedure for generating exotic three-dimensional spin-orbit couplings with degenerate ground states on more complex manifolds. The procedure is applied to produce a spin-orbit coupling with a toroidal ground state manifold. Finally, we discuss the many-body implications of the exotic spin-orbit couplings.
9:48AM H4.00010 Cold-atom systems with synthetic SU(3) spin-orbit coupling1, GREG BOYD, RYAN BARNETT, VICTOR GALITSKI, University of Maryland — Recently, the ability to create and control artificial gauge fields in cold gases has been experimentally demonstrated. Here, we propose a scheme to realize synthetic SU(3) spin-orbit interactions and derive an effective single-particle Hamiltonian, parameterized by the Gell-Mann matrices. We then investigate a many-body system of SU(3)-spin-orbit-coupled bosons and derive and analyze numerically the Gross-Pitaevskii equation to describe the effect of interaction on the possible ground states. The time-of-flight density profiles to probe various many-body states in the rich phase diagram of the system are calculated.

1This research is supported by ARO’s atomtrronics MURI (G.B. and V.G.) and JQI-PFC (R.B.)

10:00AM H4.00011 Superfluidity of Bosons in Optical lattices with Spin-Orbit coupling2, QINQIN LU, DANIEL SHEEHY, Louisiana State University — Recent experimental and theoretical work has explored artificial spin-orbit coupling induced among two species of boson. Here we examine superfluidity of a cold gas of bosons with spin-orbit coupling in a periodic optical lattice, in the presence of additional short-range interactions. We compute the density distribution after free expansion from the lattice as a probe of superfluidity, and phase transitions, of the trapped gas.

2This work has been supported by the Louisiana Board of Regents, under grant LEQSF (2008-11)-RD-A-10.

10:12AM H4.00012 Spinor Bose-Einstein Condensates Under Synthetic Gauge Field1, XIAO-QIANG XU, JUNG HOON HAN, Department of Physics and BK21 Physics Research Division, Sungkyunkwan University, Suwon 440-746, Korea — Due to the recent popularity of synthetic gauge field in ultracold atoms, I will talk about the combined effects of Rashba spin-orbit coupling (SOC) and rotation in spin -1/2 condensates [X.-Q. Xu et al, Phys. Rev. Lett. 107, 200401 (2011)]. Novel features appear in the ground state wave function, such as the existence of a half-quantum vortex or giant vortex, domains of stripe-like phase, suppressed Skyrmion order. Additionally, I will talk about the interesting mapping between pure Rashba BECs and chiral magnets with Dzyaloshinskii-Moriya (DM) interaction.

1We are supported by the Mid-career Researcher (No. 2010-0008529) and acknowledge helpful interactions with Hui Zhai.

10:24AM H4.00013 BCS-BEC crossover induced by a synthetic non-Abelian gauge field1, VIJAY B. SHENOY, JAYANTHA P. VYASANAKERE, Indian Institute of Science, S. ZHANG, Ohio State University — We investigate the ground state of interacting spin-half fermions(3D) at a finite density ($\rho \sim k_F^3$) in the presence of a uniform non-Abnonian gauge field (with magnitude $\lambda$) that generates a generalized Rashba spin-orbit interaction. For a weak attractive interaction in the singlet channel described by a small negative scattering length ($k_F|a_s| \ll 1$), the ground state in the absence of the gauge field ($\lambda = 0$) is a BCS superfluid with large overlapping pairs. With increasing $\lambda$, a non-Abelian gauge field engenders a crossover of this BCS ground state to a BEC ground state of bosons even with a weak attractive interaction. For large gauge couplings ($\lambda/k_F \gg 1$), the BEC attained is a condensate of bosons whose properties are solely determined by the gauge field (and not by the scattering length); we call these bosons “rashbons.” In the absence of interactions ($a_s = 0^{-}$), the shape of the Fermi surface of the system undergoes a topological transition at a critical gauge coupling $\lambda_T$. For high symmetry gauge field configurations we show that the crossover from the BCS superfluid to the rashbon BEC occurs in the regime of $\lambda$ near $\lambda_T$.

1Supported by DST and DAE, India

10:36AM H4.00014 Trapped fermions in a synthetic non-Abelian gauge field1, SUDEEP KUAMAR GHOSH, JAYANTHA P. VYASANAKERE, VIJAY B. SHENOY, Indian Institute of Science Bangalore — On increasing the coupling strength ($\lambda$) of a non-Abelian gauge field that induces a generalized Rashba spin-orbit coupling, the topology of the Fermi surface of a homogeneous gas of non-interacting fermions of density $\rho \sim k_F^3$, undergoes a change at a critical value, $\lambda_T \approx k_F$ [PRB 84, 014512 (2011)]. We analyze how this affects the size/shape of a cloud of fermions trapped in a harmonic potential. We develop an adiabatic formulation, with Pancharatnam-Berry phase terms, for the one particle states in a trap with the gauge field. Local density approximation reveals that the cloud shrinks in a characteristic fashion with increasing $\lambda$ and predicts a spherical cloud for all gauge field configurations. We show, via a calculation of the cloud shape using exact eigenstates, that for certain gauge fields there is systematic anisotropy in the cloud shape that increases with increasing gauge coupling $\lambda$. An important spin-off of our adiabatic formulation is that it reveals exciting possibilities for the cold-atom realization of interesting Hamiltonians (eg. quantum hall spherical geometry) by using a non-Abelian gauge field in conjunction with another potential.

1Supported by DST and DAE, India

10:48AM H4.00015 Effects of the interplay between spin-orbit coupling and interaction on bosons, QI ZHOU, The Chinese University of Hong Kong, XIAOLING CUI, Institute for Advanced Study, Tsinghua University — We show that spin-orbit coupling drastically changes the properties of bosons. The interplay between the spin-orbit coupling and interaction determines the fate of Bose-Einstein condensate, which may even not exist in the presence of isotropic spin-orbit coupling. For anisotropic spin-orbit coupling, condensates survive and are characterized by anisotropic energy spectrum, with a slower sound velocity along the direction of weaker spin-orbit coupling. The spectrum can also be used to distinguish the plane wave phase and the tripe phase.

Tuesday, February 28, 2012 8:00AM - 11:00AM –
Session H10 DAMOP: Invited Session: Strongly Interacting Photons 210A
Quantum dots (QDs) in photonic crystal nanocavities are interesting both as a testbed for fundamental cavity quantum electrodynamics (QED) experiments, as well as a platform for classical and quantum information processing. In addition to providing a scalable, on-chip, semiconductor platform, this system also enables very large dipole-field interaction strengths, as a result of the field localization inside of sub-cubic wavelength volumes (vacuum Rabi frequency is in the range of 10's of GHz). We have demonstrated controlled amplitude and phase modulation between two continuous wave (CW) optical beams at the single photon level (power less than a photon per cavity photon lifetime) interacting via a strongly coupled quantum dot - photonic crystal cavity system, and have subsequently extended this experiment to weak time-varying control field and a CW signal field. Recently, we have performed all-optical switching at the single photon level between two pulsed, resonant optical beams (with 40ps pulses and 80MHz repetition rate). In this experiment, we have measured transmission through the strongly coupled QD-cavity system as a function of delay between the two pulses, and have demonstrated a 22% increase in the transmission at zero delay. The increase in the transmission is a result of the saturation of the strongly coupled QD-cavity system. We have also studied the effects of the photon blockade and photon induced tunneling which result from the anharmonicity of the ladder of dressed states in a strongly coupled QD-nanocavity system. These effects lead to dramatic changes in the transmitted photon statistics, which can be varied from sub-Poissonian to super-Poissonian, and can be employed to generate nonclassical states of light (such as Fock or NOON states) with high efficiency. These concepts are an important capability that enables strong nonlinear optical effects, opening up the door for a new class of opto-electronic devices at ultra-low light levels. Photonic crystal based optical cavities have already been shown to serve as basic building blocks for future quantum information technology. By coupling these nanostructures to optical cavities the interaction strength between QDs and light can be significantly increased. Photonic crystals (materials with a periodic index of refraction) are particularly promising for enhancing these interactions due to their ability to guide and confine light on the size scale of an optical wavelength. Photonic crystal nanocavities (PCCs) have already shown to perform all optical switching with control pulse energies as small as 400 photons and switching times as fast as 140 ps. The approach can be improved through fast time scales, and therefore modify its interactions with the optical cavity through resonant detuning. Using this approach we demonstrate the ability to perform all optical switching with control pulse energies as small as 400 photons and switching times as fast as 140 ps. The approach can be improved through better cavity coupling methods to approach nonlinear optics near the single photon level.

This work has been supported by the ONR (PECASE Award), DARPA, and ARO.

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This work has been supported by the ONR (PECASE Award), DARPA, and ARO.
8:00AM H16.00001 Weak to strong limits in confined superfluid helium\footnote{This work was supported by the NSF grants DMR-0605716 and DMR-1101189 and utilized The Cornell Nanoscale Science and Technology Facility.}, STEPHEN R.D. THOMSON, JUSTIN K. PERRON, FRANCIS M. GASPARINI, The State University of New York University at Buffalo — Experiments with $^4$He confined in (2 $\mu$m)$^3$ boxes connected via a thin film 33 nm thick have shown that the boxes act as isolated entities when spaced 4 $\mu$m edge-to-edge \cite{1}, whereas when spaced 2 $\mu$m edge-to-edge, they are strongly coupled to each other \cite{2}. To investigate the spatial dependence of this coupling we are currently measuring (2 $\mu$m)$^3$ boxes spaced 1 $\mu$m edge-to-edge. We report measurements of the specific heat and superfluid density of helium confined in this geometry. These new data will help us to map the transition between fully isolated to fully coupled boxes which, in this limit, should behave like a 2 $\mu$m thick film. Questions involving our understanding of the correlation length $\xi$ arise, since it is observed that coupling is manifest over much larger distances than $\xi$.

\begin{thebibliography}{9}
  \bibitem{1} Perron J K, Kimball M O, Mooney K P and Gasparini F M 2011 \textit{Nat. Phys.} 6 499–502
  \bibitem{2} Perron J K, and Gasparini F M 2011 \textit{submitted to PNAS}
\end{thebibliography}

8:12AM H16.00002 Critical point coupling in liquid helium and the significance of the correlation length\footnote{This work was supported by the NSF grants DMR-0605716 and DMR-1101189; The Cornell Nanoscale Science and Technology Facility; The Mark Diamond Research Fund of the GSA at the University at Buffalo, and internal funding from the University at Buffalo.}, JUSTIN K. PERRON, STEPHEN R.D. THOMSON, FRANCIS M. GASPARINI, The State University of New York, University at Buffalo — Recent measurements of liquid helium confined to (2 $\mu$m)$^3$ boxes connected through a 33 nm film have shown coupling effects between boxes spaced distances much larger than the critical length $\xi(t, L)$\cite{1,2} and proximity effects on the connecting film\cite{3}. An analysis of data suggests that $\xi(t, L)$ is the relevant parameter in these effects. This dependence on $\xi(t, L)$ is used to argue that the enhancement in the specific heat due to coupling is a reflection of the finite-size correlation length in the boxes and hence its scaling function. All this raises some profound questions about our physical understanding of $\xi(t, L)$.

\begin{thebibliography}{9}
  \bibitem{1} Perron J K, Kimball M O, Mooney K P and Gasparini F M 2010 \textit{Nat. Phys.} 6 499–502
  \bibitem{2} Perron J K, and Gasparini F M 2011 \textit{submitted to PNAS}
  \bibitem{3} Perron J K, and Gasparini F M 2011 to be published in JPCS
\end{thebibliography}

8:24AM H16.00003 Creating Only Isotropic Homogeneous Turbulence in Liquid Helium near Absolute Zero\footnote{Work supported in part by US NSF DMR#0602778 and #1007937.}, G.G. IHAS, K.J. THOMPSON, G. LABBE, Department of Physics, University of Florida, PO Box 118440, Gainesville, FL 32607, P.V.E. MCCINTOCK, Department of Physics, Lancaster University, Lancaster LA1 4YB, UK — Flow through a grid is a standard method to produce isotropic, homogeneous turbulence for laboratory study. This technique has been used to generate quantum turbulence (QT) above 1 K in superfluid helium\cite{2} where QT seems to mimic classical turbulence. Efforts have been made recently\cite{3} to make similar measurements near absolute zero, where there is an almost total absence of normal fluid and hence classical viscosity. This presents the difficulty that most motive force devices produce heat which overwhelms the phenomena being investigated. The process of designing and implementing a “dissipation-free” motor for pulling a grid through superfluid helium at millikelvin temperatures has resulted in the development of new techniques which have broad application in low temperature research. Some of these, such as Meissner-affect magnetic drives, capacitive and inductive position sensors, and magnetic centering devices will be described. Heating results for devices which can move in a controlled fashion from very low speed up to 10 cm/s will be presented. Acknowledgement: We thank W.F. Vinen for many useful discussions.

\begin{thebibliography}{9}
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8:36AM H16.00004 Superfluid Onset and 2D phase transitions of Helium-4 on Lithium and Sodium\footnote{This work was supported by the National Science Foundation DMR-1103625.}, ANGEL VELASCO, FAWN HUISMAN, University of California, Irvine, ELI VAN CLEVE, Lawrence Livermore National Laboratory, PETER TABOREK, University of California, Irvine — We have fabricated lithium and sodium films on quartz crystal microbalances (QCM) using in situ low temperature pulsed laser deposition. The frequency shift and dissipation of the QCM was measured as a function of helium pressure and chemical potential and used to construct the phase diagram of helium films on these substrates. Pressure measurement techniques based on an RGA mass spectrometer, which provides accurate measurement below 10$^{-4}$ Torr will be described. Lithium and sodium are predicted to be intermediate strength substrates which are strong enough to be wetted by He-4 but weak enough that solid-like layers do not form, so they are candidates for observing sub-monolayer superfluidity in direct contact with a metallic surface. Helium adsorption isotherms and quenches between 0.5K and 1.6K on both lithium and sodium indicated continuous, sub-monolayer helium film growth and superfluid onsets in sub-monolayer films. Features below 1K indicate a collision between a classical 2D liquid/vapor phase transition and the Kosterlitz-Thouless superfluid phase transition. We see no evidence for the pre-wetting step instability predicted for helium on sodium.

8:48AM H16.00005 ABSTRACT WITHDRAWN

9:00AM H16.00006 Discrepancies Between Theory and Experiment for Field-Dependence and $f$-wave Interactions in Superfluid $^3$He-$B$\footnote{This work was supported by the National Science Foundation DMR-1103625.}, C.A. COLLETT, J. POLLANEN, JIA LI, W.J. GANNON, W.P. HALPERIN, Department of Physics and Astronomy, Northwestern University — We have performed transverse acoustics experiments in superfluid $^3$He-$B$, exploring the magnetic field splitting of the imaginary squashing mode (ISQ), a collective mode of the order parameter labelled by its total angular momentum $J = 2$. We have compared theoretical calculation\cite{1} (of the Zeeman splitting, $g_\perp$, and its dependence on the strength of $f$-wave pairing interactions, $x_{\perp}$) with our recent experimental data, showing unexpected discrepancies. We suggest that the origin of these discrepancies can be traced to limits on the applicability of the theoretical calculations at high magnetic field and at frequencies some distance from the order parameter collective mode. We discuss the analysis done by Davis et al. in light of those limitations\cite{2}.

\begin{thebibliography}{9}
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9:12AM H16.00007 Role of the order parameter manifold on surface Majorana fermions and spin susceptibility of superfluid \(^3\)He-B. TAKESHI MIZUSHIMA, Dept. of Phys., Okayama University, MASATOSHI SATO, ISSP, The University of Tokyo, KAZUSHIGE MACHIDA, Dept. of Phys., Okayama University — Here, we theoretically investigate surface Andreev bound states (SABS) in superfluid \(^3\)He-B confined to a slab geometry. It is known that the Majorana property gives rise to the Ising anisotropy of spin susceptibility on the surface, which reflects the assumption that the order parameter manifold of the B-phase is restricted to the subspace. In this talk, we first demonstrate that the SO(3) manifold, which describes the relative rotation of spin and orbital, plays a critical role on the various properties associated with the SABS, such as the Majorana nature, gapless dispersion, topological invariant, and spin susceptibility. Then, based on the quasiclassical Eilenberger theory which takes account of the dipole interaction, we quantitatively discuss thermodynamics and the Majorana property of the SABS in superfluid \(^3\)He-B under a magnetic field, where the Majorana property and spin susceptibility is determined by the interplay of the magnetic field and dipole interaction.

9:24AM H16.00008 Macroscopic quantum tunneling of a single vortex in a rotating Bose-Einstein condensate\(^1\). KINJAL DASBISWAS, ALAN T. DORSEY, Department of Physics, University of Florida — A vortex can be created in a metastable state near the center of a harmonically trapped Bose condensate when it is rotated with suitable velocities. This state has a finite lifetime before which the vortex tunnels outwards to the edge of the trap. We estimate this tunneling rate semiclassically with the vortex treated as a point particle. This is followed by a more exact treatment incorporating the dynamics and mass of the vortex. The calculation is based on a Thomas-Fermi approximation, relevant to the typically large atomic densities used in experiments, but we also analyze the low density limit in a “weakly nonlinear” perturbative framework. We discuss the feasibility of detecting this effect with currently achievable experiments.

\(^1\)This work is supported by the NSF

9:36AM H16.00009 Expansion Dynamics of a Ring Bose–Einstein Condensate\(^1\). MARK EDWARDS, Georgia Southern University and NIST, HADAYAT SEDDIQI, MICHAEL KRYGIER, BRANDON BENTON, Georgia Southern University, CHARLES CLARK, Joint Quantum Institute and NIST — We studied the dynamics of BECs when released from a ring trap under conditions similar to those that obtained in a recent experiment done at NIST. In that experiment a ring-shaped BEC was formed in an all–optical trap created by intersecting a horizontal light sheet and a vertical Laguerre-Gaussian beam. Condensates were created in these traps and then “stirred” by applying Raman pulses having orbital angular momentum (OAM). We modeled the dynamics of condensates formed under these conditions by first solving the 2D time–dependent Gross–Pitaevskii equation (GPE) in imaginary time to obtain the initial condensate shape. We accounted for the OAM by applying a phase imprint to this wave function and then propagated it under the usual Hall-Vinen/Iordanskii equations are valid when \(\Omega \ll 1\) (the “classical regime”), but elsewhere, the equations are strongly memory dependent. We will discuss the experimental implications of this frequency dependence in Bose superfluids and cold atomic gases.

\(^1\)Work supported by NSF grant numbers PHY–0758111 and PHY–1068761

9:48AM H16.00010 Quantum Dynamics of a Bose Superfluid Vortex\(^1\). LARA THOMPSON, Massachusetts Institute of Technology, PHILIP STAMP, University of British Columbia, Pacific Institute of Theoretical Physics — Quantum vortex dynamics remain poorly understood despite decades of theoretical investigation. The vortex is a topological soliton, arising from the same medium as the quasiparticles with which it interacts. Hence the coupling between the vortex “zero mode” and the quasiparticles has no term linear in the quasiparticle variables — the lowest order coupling is quadratic. We present a fully quantum-mechanical derivation of the vortex equation of motion valid at low temperatures where the normal fluid density is small. The resulting equation of motion is naturally expressed as a function of the dimensionless frequency \(\tilde{\Omega} = \hbar \Omega / k_B T\). The usual Hall-Vinen/Iordanskii equations are valid when \(\tilde{\Omega} \ll 1\) (the “classical regime”), but elsewhere, the equations are strongly memory dependent. We will discuss the experimental implications of this frequency dependence in Bose superfluids and cold atomic gases.

\(^1\)This work was supported by NSERC, CIFAR, PITP, and by a Killam fellowship.

10:00AM H16.00011 Fragmented Many-Body states of definite angular momentum and stability of attractive 3D Condensates. MARIOS C. TSATSOS, ALEXEJ I. STRELTSOV, OFIR E. ALON, LORENZ S. CEDERBAUM, Heidelberg University — We consider a 3D Bose-Einstein Condensate (BEC), with attractive interparticle interactions, embedded in a harmonic, spherically symmetric trap. This system is metastable only if the total number of bosons \(N\) and the interaction strength \(\lambda\) do not exceed some critical values. Otherwise the system collapses. Gross-Pitaevskii (GP) theory predicts the maximum (critical) number of bosons \(N_{GP}\). However, we have a strong indication that in this case\(^1\), the mathematical mechanism enabling full spectrum transparency of a scattering object does not fall into any of the conventional paradigms.

\(^1\)Supported by NSF, ONR, and IFRAF

10:12AM H16.00012 Origins of bright soliton transparency to Bogoliubov quasi-particles\(^1\). ZAILjong HWANG, Maxim OLSHANII, University of Massachusetts Boston — Bogoliubov quasi-particles can pass through a one-dimensional bright soliton without reflection at all energies\(^2\). Reflectionless properties of this kind usually originate from a supersymmetric structure of the corresponding Hamiltonian\(^3\). However, we have a strong indication that in this case\(^4\), the mathematical mechanism enabling full spectrum transparency of a scattering object does not fall into any of the conventional paradigms.

10:24AM H16.00013 Supersymmetric Structure of two Families of Solitons

ANDREW KOLLER, MAXIM OLSHANII, University of Massachusetts Boston — Solitons have generated considerable interest in the cold atoms and condensed matter communities. We demonstrate that two families of $n$-soliton solutions (with $n$ an integer) — one for the attractive nonlinear Schrödinger (NLS) equation, and one for the sine-Gordon (sG) equation — originate from a quantum-mechanical supersymmetric (QM-SUSY) chain connecting a set of reflectionless operators $H_n$. The families consist of breather-type solitons for NLS and multi-(anti)kink solitons with specific velocities for sG. The operators $H_n$, which we refer to as Akulin’s Hamiltonians, form reflectionless direct-scattering initial conditions for the inverse scattering method. Such a QM-SUSY chain is analogous to the known connection between QM-SUSY chains of Pöschl-Teller potentials and solitons of the Korteweg-de Vries (KdV) equation. The existence of QM-SUSY chains connecting soliton solutions, now for three different integrable nonlinear equations, sheds light on the underlying mechanisms responsible for soliton generation.

1supported by NSF and ONR

10:36AM H16.00014 From Dark Solitons to Vortex Clusters in Bose-Einstein Condensates

PANAYOTIS KVRERIDIS, University of Massachusetts, Amherst — In this talk, we will start by considering the experimental, theoretical and numerical dynamical properties of dark solitons in quasi-one-dimensional trapped Bose-Einstein condensates. We will identify the oscillations and interactions of such coherent structures and we will then aim towards generalizing the corresponding notions to quasi-two-dimensional vortex states. In the latter setting, we will use two approaches: one from the linear limit of the underlying system that will permit us to identify the bifurcations of multi-vortex cluster states, while the second in the large density limit will enable our consideration of the vortices as precessing and interacting particles within the condensate. We will corroborate our analytical predictions within these limits and numerical results bridging the limits with experimental observations for the dynamics of few-vortex clusters.

10:48AM H16.00015 Multifractals in Soliton sea on Fibonacci Lattice

MASAHIRO TAKAHASHI, HOSHO KATSURA, Department of Physics, Gakushuin University, MAHITO KOHMOTO, The Institute for Solid State Physics, The University of Tokyo, TOHRU KOMA, Department of Physics, Gakushuin University — Systems exhibiting Bose-Einstein condensation are suitable for fabricating artificially designed structures, e.g., the bichromatic potentials have attracted much attention. More exotic structures also appear to be experimentally feasible in the optical imaging system with high resolution. We consider one of exotic structures, Fibonacci potential, which is quasiperiodic. On the Fibonacci potential without nonlinear interaction, it is known that the spectrum is singular continuous and all the eigenvectors are called a critical state, in which multifractal states are included. On the other hand, the physical properties of the Bose-Einstein condensates confined in an optical lattice can be described in terms of the Schrödinger equation with nonlinear term via particle-particle interactions. We numerically and mathematically investigated nonlinear Schrödinger equation on Fibonacci potential focusing on the competition between nonlinear fluctuation and criticality [M. Takahashi et al., arXiv:1110.6328]. The conclusion is that the critical states with the spectrum in the Cantor set retains their profile irrespective of the strength of the nonlinearity. The spectrum for the critical states is in a sea of “stationary solitons” which appear as a result of nonlinear effects.

1This work was supported by Grant-in-Aid for Research Activity Start-up (23840034) and Grant-in-Aid for Young Scientists (B) (23740298).

Tuesday, February 28, 2012 11:15AM - 2:15PM – Session J4 DAMOP: Non-Equilibrium Dynamics with Quantum Gases 205C

11:15AM J4.00001 Non Equilibrium Quantum Criticality: an intuitive approach

EMANUELE DALLA TORRE, EUGENE DEMLER, Department of Physics, Harvard University, THIERRY GIAMARCHI, DPMC-MaNEP, University of Geneva, Switzerland, EHUD ALTMAN, Department of Condensed Matter Physics, Weizmann Institute of Science, Israel — Since their discovery in 1976, equilibrium quantum critical points have attracted continuous interest, due to their universality (i.e. the independence from the microscopic details of the systems). In two recent papers [1,2] we have extended these concepts to non-equilibrium systems, by studying the universal properties of quantum systems driven by time-dependent noise. We were able to demonstrate that [1] they show a new class of non-equilibrium quantum criticality, and [2] small perturbations around the critical point lead to new physical phenomena, such as the spontaneous generation of an effective temperature and an effective dissipation. To this end, we developed a real-time renormalization group (RG) in the Keldysh path-integral formalism, which may however appear cryptic to the non-experts. In this talk, I will show how the main conclusions of the RG approach can be understood by simpler arguments based on circuit theory and fluctuation-dissipation relations.


11:27AM J4.00002 Dynamics of noise correlations of ultracold bosons in an optical lattice

KHAN W. MAHMUD, EITE TIESINGA, Joint Quantum Institute, NIST and University of Maryland, USA — We study second order correlations of ultracold bosons in an optical lattice for superfluid and Mott insulating phases. Starting with a superfluid ground state, a sudden increase in the lattice depth projects it into a non-equilibrium state. We examine the subsequent dynamics of the system—analyzing noise correlations of the atomic cloud after time-of-flight expansion. We also investigate the effects of three and higher-body interactions on noise correlations in deep lattices.

11:39AM J4.00003 Stability of Counterflow Superfluidity

NOAH BRAY-ALI, CARL WILLIAMS, Joint Quantum Institute, NIST and University of Maryland, 100 Bureau Drive, Stop 8423, Gaithersburg, MD 20899-8423, USA, EUGENE DEMLER, Department of Physics, Harvard University, Cambridge USA 02138 — We examine the stability of the counterflow superfluid state in two component mixtures of ultracold atoms in optical lattices. Using a Gutzwiller mean-field approach, we find a sharp boundary separating stable counterflow from a dynamically unstable regime. As the inter-component interaction strength increases, the critical counterflow rate drops, falling to zero when interactions are strong enough to induce phase separation of the two components. Going beyond mean-field theory, we compute the decay rate of counterflow within the stable regime due to phase slips. The results agree well with numerically exact simulations and are calculated in a regime of parameters relevant to current experiments on mixtures of ultracold alkali atoms.

1NBA acknowledges support from the National Research Council Postdoctoral Research Associateship
This talk will address the efficacy of using modified Gross-Pitaevskii (GP) equations to model the dynamics of Fermi systems. These GP-like equations are significantly easier to solve, yet still capture much of the relevant physics. We shall advocate an approach of using fermionic density functional theory (DFT) to adjust the form of the modified GP-like equations, and then use the latter to model more complicated phenomena beyond the capability of the fermionic DFT. The dynamics of vortices pinned on defects will serve as an example.

12:03PM J4.00005 Expansion of Bose-Hubbard Mott insulators in optical lattices1, MARK JREIS-SATY, Department of Mechanical Engineering, Columbia University, New York NY 10025, USA, JUAN CARRASQUILLA, Department of Physics, University of Washington, Washington DC 20057, USA, F. ALEXANDER WOLF, Theoretical Physics III, Center for Electronic Correlations and Magnetism, Institute of Physics, Augsburg University, D-86135 Augsburg, Germany, MARCOS RIGOL, Department of Physics, Georgetown University, Washington DC 20057, USA.

— We present a study of the expansion of bosonic Mott insulators in the presence of an optical lattice after switching off a confining potential. We use the Gutzwiller mean-field approximation and consider two different setups. In the first one, the expansion is restricted to one dimension. We show that this leads to the emergence of two condensates with well-defined momenta, and argue that such a construct can be used to create atom lasers in optical lattices. In the second setup, we study Mott insulators that are allowed to expand in all directions in the lattice. In this case, a simple condensate is seen to develop within the mean-field approximation. However, its constituent bosons are found to populate many nonzero momentum modes. An analytic understanding of both phenomena in terms of the exact dispersion relation in the hard-core limit is presented.

1This work was supported by the US Office of Naval Research.

12:15PM J4.00006 Protection of dissipative quantum state preparation by interlacing the control with dynamical decoupling pulses1, Z.R. GONG, WANG YAO, Department of Physics, and Center for Theoretical and Computational Physics, The University of Hong Kong — Various dissipative processes have recently been exploited for preparing quantum state with multipartite entanglement between many qubits. Most such schemes are applicable only to an ensemble of identical qubits, and inhomogeneous broadening will reduce the state preparation fidelity. Here we show that by interlacing the dynamical decoupling pulse sequence with the dissipative state preparation control, the errors resulting from the inhomogeneous broadening can be suppressed up to certain order of the pulse interval and the desired entangled states can be prepared with high fidelity. We give two examples where sequence of pi pulses interlaced with dissipative control realize high fidelity preparation of cluster states and many-body singlets of atomic qubits.

1The work was supported by the Research Grant Council of Hong Kong under Grant No. HKU 706711P.

12:27PM J4.00007 ABSTRACT_MOVED_TO_L4.00008 —

12:39PM J4.00008 Periodically and almost periodically driven quantum system, LUCA D’ALESSIO, ANATOLI POLKOVNIKOV, Boston University — When a quantum system is driven periodically in time it can display dynamical localization, i.e its energy grows extremely slowly and may saturate at a value smaller than the infinite temperature limit. We show that by making the period of the perturbation longer this phenomenon is destroyed and the energy of the system grows quickly and saturates at the infinite temperature limit. We argue that this process is related to the breaking down of a particular form of perturbation theory (in the duration in of driving) and can be interpreted as a transition from a local to a long-range effective Hamiltonian. We discuss how robust our findings are against small aperiodicity in the driving. We finally discuss how realize this interesting non-equilibrium physics in cold atom experiments.

12:51PM J4.00009 Cold bosons in noisy optical lattices, JOHANNES SCHACHENMAYER, Department of Physics and Astronomy, University of Pittsburgh, HANNES PICHLER, PETER Zoller, Institute for Theoretical Physics, University of Innsbruck, and Institute for Quantum Optics and Quantum Information, Innsbruck, ANDREW DALEY, Department of Physics and Astronomy, University of Pittsburgh — Cold atoms in optical lattices open the possibility to experimentally study strongly interacting many-body quantum systems with controllable parameters. A key challenge to prepare interesting quantum states in these systems is to achieve sufficiently low temperatures. At these temperatures a deep theoretical understanding of possible heating processes and how they affect the characteristics of the quantum state becomes essential. In every realistic experiment there exist many sources of noise that cause phase and amplitude fluctuations in the standing laser waves that form the optical lattice potential. This classical noise can lead to heating and a significant change of the quantum state. We study the stochastic many-body non-equilibrium dynamics of bosons in an optical lattice and determine how the state changes depending on the characteristics of the noise. We do this by solving time-dependent stochastic many-body Schrödinger equations, both analytically and numerically.

1:03PM J4.00010 Many-body Landau-Zener Transition in Cold Atom Double Well Optical Lattices, YINYIN QIAN, MING GONG, CHUANWEI ZHANG, Washington State University — Ultra-cold atoms in optical lattices provide an ideal platform for exploring many-body physics of a large system arising from the coupling among a series of small identical systems whose few-body dynamics are exactly solvable. Using Landau-Zener (LZ) transition of bosonic atoms in double well optical lattices as an experimentally realizable model, we investigate such few to many body route by exploring the relation and difference between the few-body (in one double well) and many-body (in double well lattice) non-equilibrium dynamics of cold atoms in optical lattices. We find the many-body coupling between double wells greatly enhances the LZ transition probability, while keeping the main features of the few-body dynamics. Various experimental signatures of the many-body LZ transition, including atom density, momentum distribution, and density-density correlation, are obtained.
applied to half of the lattice, we have found, using a Hartree-Fock approximation, a conducting-nonconducting transition in the fermionic case as the interaction in the thermodynamic limit [2]. The difference appears in uniform lattices as well as lattices with a harmonic trap. Further, when light-induced interactions are applied to half of the lattice, we have found, using a Hartree-Fock approximation, a conducting-nonconducting transition in the fermionic case as the interaction increases. Our studies are relevant to recent experiments on transport of ultra-cold atoms and address fundamental issues in nanoscale electronic transport.


1 Work supported in part by DOE.

1:30PM J4.00013 Universal energy fluctuations in thermally isolated driven systems, GUY BUNIN, Department of Physics, Technion, LUCA D’ALESSIO, Department of Physics, Boston University, YARIV KAFRI, Department of Physics, Technion, ANATOLI POLKOVNIKOV, Department of Physics, Boston University — When an isolated system is brought in contact with a heat bath, its final energy is random and follows the Gibbs distribution—this finding is a cornerstone of statistical physics. The system’s energy can also be changed by performing non-adiabatic work using a cyclic process. Almost nothing is known about the resulting energy distribution in this set-up, which is in particular relevant to recent experimental progress in cold atoms, ion traps, superconducting qubits and other systems. Here we show that when the non-adiabatic process consists of many repeated cyclic processes, the resulting energy distribution is universal and different from the Gibbs ensemble. We predict the existence of two qualitatively different regimes with a continuous second-order-like transition between them. We illustrate our approach by performing explicit calculations for both interacting and non-interacting systems.

1:51PM J4.00014 Lie-algebraic Approach to Dynamics of Closed Quantum Systems and Quantum-to-Classical Correspondence, VICTOR GALITSKI, Joint Quantum Institute and Physics Department, University of Maryland — I will briefly review our recent work on a Lie-algebraic approach to various non-equilibrium quantum-mechanical problems, which has been motivated by continuous experimental advances in the field of cold atoms. First, I will discuss non-equilibrium driven dynamics of a generic closed quantum system. It will be emphasized that mathematically a non-equilibrium Hamiltonian represents a trajectory in a Lie algebra, while the evolution operator is a trajectory in a Lie group generated by the underlying algebra via exponentiation. This turns out to be a constructive statement that establishes, in particular, the fact that classical and quantum unitary evolutions are two sides of the same coin determined uniquely by the same dynamic generators in the group. An equation for these generators - dubbed dual Schrödinger-Bloch equation - will be derived and analyzed for a few of specific examples. This non-linear equation allows one to construct new exact non-linear solutions to quantum-dynamical systems. An experimentally-relevant example of a family of exact solutions to the many-body Landau-Zener problem will be presented. One practical application of the latter result includes dynamical means to optimize molecular production rate following a quench across the Feshbach resonance.

3 This work was supported by NSF-CAREER award and US-ARO.

2:03PM J4.00015 Visibility of the Amplitude (Higgs) Mode in Condensed Matter and Cold Atomic Systems, DANIEL PODOLSKY, ASSA AUERBACH, Physics Department, Technion — Israel Institute of Technology, DANIEL P. AROVAS, Department of Physics, University of California at San Diego — The amplitude mode is a ubiquitous collective excitation in condensed matter systems with broken continuous symmetry. It is expected in antiferromagnets, short coherence length superconductors, charge density waves, and lattice Bose condensates. Its detection is a valuable test of the corresponding field theory, and its mass gap measures the proximity to a quantum critical point. However, since the amplitude mode can decay into low energy Goldstone modes, its experimental visibility has been questioned. Here we show that the visibility depends on the symmetry of the measured susceptibility. We discuss various experimental setups for measuring the scalar susceptibility. We show that the optical conductivity of the O(2) theory (relativistic superfluid) displays a threshold behavior at the Higgs mass.

Tuesday, February 28, 2012 11:15AM - 2:15PM –
Session J19 DCMP DAMOP: Invited Session: Strongly Interacting Cold Fermi Gases

11:15AM J19.00001 From ultracold Fermi Gases to Neutron Stars, CHRISTOPHE SALOMON, LKB, Ecole Normale superieure — Ultracold dilute atomic gases can be considered as model systems to address some pending problem in Many-Body physics that occur in condensed matter systems, nuclear physics, and astrophysics. We have developed a general method to probe with high precision the thermodynamics of locally homogeneous ultracold Bose and Fermi gases [1,2,3]. This method allows stringent tests of recent many-body theories. For attractive spin 1/2 fermions with tunable interaction (^{6}Li), we will show that the gas thermodynamic properties can continuously change from those of weakly interacting Cooper pairs described by Bardeen-Cooper-Schrieffer theory to those of strongly bound molecules undergoing Bose-Einstein condensation. First, we focus on the finite-temperature Equation of State (EoS) of the unpolarized unitary gas. Surprisingly, the low-temperature properties of the strongly interacting normal phase are well described by Fermi liquid theory [3] and we localize the superfluid phase transition. A detailed comparison with theories including recent Monte-Carlo calculations will be presented. Moving away from the unitary gas, the Lee-Huang-Yang and Lee-Yang beyond-mean-field corrections for low density bosonic and fermionic superfluids are quantitatively measured for the first time. Despite orders of magnitude difference in density and temperature, our equation of state can be used to describe low density neutron matter such as the outer shell of neutron stars.

11:51AM J19.00002 Spin-Imbalance in One and Three-Dimensional Fermi Gases¹, RANDALL HULET². Rice University — The FFLO modulated superconductor state was independently proposed by Fulde and Ferrell, and Larkin and Ovchinnikov, as a way of accommodating the excess spin in a spin-polarized superconductor. The pairs in the FFLO state have non-zero center-of-mass momentum, which can produce a periodic structure with a spatially-modulated order parameter. Although there is some evidence for FFLO pairing in certain heavy fermion compounds that are able to accommodate both magnetic and superconducting order, conclusive experimental proof remains elusive. Motivated by the search for exotic paired states, we have performed experiments with spin-imbalanced ultracold atomic Fermi gases in both 3D and 1D. We use two hyperfine levels of ⁶Li to emulate the spin-up and down states. The Ψ-wave pairing interactions are controlled via a magnetically-tuned collisional (Feshbach) resonance. In 3D, we find that the gas phase separates into an evenly paired BCS-like core, surrounded by the excess spin-up atoms [1]. For the 1D experiment, a two-dimensional optical lattice was used to create an array of 1D tubes that are each filled with ~200 atoms. The weak axial confinement again produces a phase separation, but in contrast to 3D we find a partially-polarized central core surrounded by either fully-paired or fully-polarized wings, depending on the degree of overall spin-polarization [2]. Theory predicts that the partially-polarized phase is an FFLO superfluid. We are currently trying to obtain direct evidence for FFLO pairing, which may be revealed in the pair momentum distribution found by releasing the atoms axially and allowing them to expand in time-of-flight. We are also exploring the 1D-3D dimensional crossover that occurs when the coupling between tubes is reduced.


12:27PM J19.00003 Many-body physics with ultracold alkali-earth fermions in optical lattices, JUN YE, University of Colorado at Boulder and NIST — No abstract available.

1:03PM J19.00004 Onset of a Pseudogap Regime in Ultracold Fermi Gases¹, AUREL BULGAC, University of Washington — We show, using an ab initio approach based on Quantum Monte Carlo technique, that the pseudogap regime emerges in ultracold Fermi gases close to the unitary point. We locate the onset of this regime at a value of the interaction strength slightly to the BCS side of the unitary point. We determine the evolution of the gap as a function of temperature and interaction strength in the Fermi gas around the unitary limit and show that our results exhibit a remarkable agreement with the recent wave-vector resolved radio frequency spectroscopy data. Our results indicate that a finite temperature structure of the Fermi gas around unitarity is complicated and involves the presence of preformed Cooper pairs, which however do not contribute to the long range order.

[1] Support is acknowledged from the DOE under grants DE-FG02-97ER41014 and DE-FC02-07ER41457, from the Polish Ministry of Science under contract N N202 128439. Calculations were performed on the UW Athena cluster and at the Interdisciplinary Centre for Mathe

1:39PM J19.00005 Strongly Repulsive Quantum Gases¹, TIN-LUN HO, Physics Department, The Ohio State University — Advances in cold atom experiments have shown that the properties of repulsive Fermi and Bose gases are far more intricate than generally expected, as these systems can produce molecules even in the weakly interacting regime. Recent experiments, however, reveal some general yet puzzling properties of these gases in the strongly repulsive regime. In this talk, we show that these properties are direct consequences of statistics, and are fundamental properties of quantum gases [1]. We shall also discuss the related issue of itinerant ferromagnetism, and discuss the physical settings in which ferromagnetism can be found.


2:30PM L4.00001 Finite temperature DMRG and the Drude weight of spin 1/2 Heisenberg chains, CHRISTOPH KARRASCH, JENS BARDARSON, JOEL MOORE, University of California at Berkeley — We propose an easy-to-implement approach to study time-dependent correlation functions of one dimensional systems at finite temperature T using the the density matrix renormalization group (DMRG). If the auxiliary degrees of freedom which purify the statistical operator are time-evolved with the physical Hamiltonian but reversed time, the entanglement blow-up inherent to any time-dependent DMRG calculation is dramatically reduced. The numerical effort of finite temperature DMRG becomes comparable to that at T = 0, and thus significantly longer timescales can be reached. We exploit this to investigate current correlation functions of the XXZ spin 1/2 Heisenberg chain. At intermediate to large T, we can explicitly extract the Drude weight D from the long-time asymptotics. For the isotropic chain, D is finite. At low temperatures, we establish an upper bound for the Drude weight.

2:42PM L4.00002 Universal non-equilibrium quantum dynamics in imaginary time, CLAUDIA DE GRANDI, Yale University, ANATOLI POLKOVNIKOV, ANDERS SANDVIK, Boston University — We propose a method to study the dynamical response of a quantum systems by evolving it with an imaginary-time dependent Hamiltonian. The leading non-adiabatic response of the system driven to a quantum-critical point is universal and characterized by the same exponents in real and imaginary time. For a linear quench protocol, the fidelity susceptibility and the geometric tensor naturally emerge in the response functions. Beyond linear response we extend the finite-size scaling theory of quantum phase transitions to non-equilibrium setups. Imaginary-time dynamics is also amenable to Quantum Monte Carlo simulations, which we apply here to quenches of the transverse-field Ising model to quantum critical points in one and two dimensions.

2:54PM L4.00003 The Approach To Typicality in Many-Body Quantum Systems, SAI VINJANAMPATHY, SHAWN DUBEY, LUCIANO SILVESTRI, KURT JACOBS, University of Massachusetts, Boston — The recent discovery that for large Hilbert spaces, almost all (that is, typical) Hamiltonians have eigenstates that place small subsystems in thermal equilibrium, has shed much light on the origins of irreversibility and thermalization. Here we present numerical evidence that many-body lattice systems generically approach typicality as the number of subsystems is increased, and thus provide further support for the eigenstate thermalization hypothesis. We will present our results that indicate that the deviation of many-body systems from typicality scales as an inverse power of the number of systems, and we compare this with the equivalent scaling for random Hamiltonians.
We acknowledge the support from DARPA OLE.

We acknowledge support from NSF DMR-0907275 (ED), ARO W911NF-08-1-0338 (NT) and the DARPA OLE program.

We acknowledge support from NSF DMR-0907275 (ED), ARO W911NF-08-1-0338 (NT) and the DARPA OLE program.

Supported by NSERC of Canada
4:18PM L4.00010 Feynman diagrams versus Feynman quantum emulator, KRIS VAN HOUCKE, Ghent University, FÉLIX VERNER, Laboratoire Kastler Brossel, Ecole Normale Supérieure, EVGENY KOZIK, ETH, Zürich, NIKOLAY PROKOF'EV, BORIS SVISTUNOV, University of Massachusetts, Amherst, MARK KU, ARIEL SOMMER, LAWRENCE CHEUK, Massachusetts Institute of Technology, ANDRÉ SCHIROTZEK, Advanced Light Source, Lawrence Berkeley National Laboratory, MARTIN ZWIERLEIN, Massachusetts Institute of Technology — Precise understanding of strongly interacting fermions, from electrons in modern materials to nuclear matter, presents a major goal in modern physics. However, the theoretical description of interacting Fermi systems is usually plagued by the intricate quantum statistics at play. Here we present a cross-validation between a new theoretical approach, Bold Diagrammatic Monte Carlo (BDMC), and precision experiments on ultra-cold atoms. Specifically, we compute and measure with unprecedented accuracy the normal-state equation of state of the unitary gas, a prototypical example of a strongly correlated fermionic system. Excellent agreement demonstrates that a series of Feynman diagrams can be controllably resummed in a non-perturbative regime using BDMC. This opens the door to the solution of some of the most challenging problems across many areas of physics.

4:30PM L4.00011 Non-equilibrium dynamics, heating, and thermalization of cold atoms in optical lattices, ANDREW DAILY, University of Pittsburgh — In recent years, out of equilibrium many-body dynamics have become accessible in a controlled way in experiments with ultracold quantum gases. Time-dependent processes in these systems are not only intrinsically interesting, but also extremely important for understanding many-body state preparation, heating, and thermalization as they arise in experiments. They also offer new connections to phenomena studied in solid-state systems. This interest has been complemented by the development of a range of numerical methods, including time-dependent density matrix renormalization group (t-DMRG) methods and matrix product state approaches, which have been applied to study dynamics in 1D lattice systems and spin chains. We have extended and applied these methods to study the non-equilibrium dynamics of cold atoms in optical lattices arising from different heating mechanisms, especially due to spontaneous emissions from incoherent scattering of the lattice light, or via classical noise on the optical potential. Understanding how these heating mechanisms affect the properties of different many-body states is crucial in addressing current experimental challenges in the preparation of interesting quantum phases at low temperatures. The resulting non-equilibrium dynamics typically depend strongly on the properties of the many-body state, with different states being more or less sensitive to different heating mechanisms. Moreover, there is often a separation of timescales between some excitations that thermalize rapidly, and some that do not properly thermalize in the duration of an experimental run, which can strongly modify, and even reduce the overall effects of the heating processes. Part of this work involves the treatment of open many-body quantum systems, where we derive many-body master equations to describe the dynamics and solve these numerically by combining t-DMRG methods with quantum trajectory techniques from quantum optics.

5:06PM L4.00012 Pattern formation in time-of-flight images of heavy-light mixtures of atoms undergoing Bloch oscillations, JAMES FREERICKS, Department of Physics, Georgetown University — Nonequilibrium dynamical mean-field theory is employed to solve for the response of a light-heavy Fermi-Fermi mixture of atoms to the presence of a uniform electric field (via “pulling” the lattice through the cloud of atoms). When we express the (momentum-dependent) light atom distribution functions as functions of the band energy and the projection of the velocity along the direction of the artificial electric field, the system develops characteristic spiral patterns that become more complex as the system evolves, but remain stable for a long period of time. These patterns typically show a contrast of about 10-20% fluctuations about the mean density, so they are challenging but possible to observe in a time-of-flight measurement. We also show a characteristic change of character of the system between small fields and large fields. The best candidate system for examining these patterns is a Lu$^2$-K$^{40}$ mixture on a two-dimensional optical lattice. We expect similar results should occur for light Fermi-heavy Bose mixtures as well, but it is likely this behavior will not be seen in Bose-Bose mixtures.

Wednesday, February 29, 2012 8:00AM - 11:00AM –
Session P4 DAMOP: Multi-Component BECs and Mixtures 205C

8:00AM P4.00001 Analytical solutions to the spin-1 Bose-Einstein condensates, SHI-JIE YANG, ZHI-HAI ZHANG, Department of Physics, Beijing Normal University — We present classes of exact stationary solutions for the one-dimensional coupled nonlinear Gross-Pitaevskii equations which describe the $F=1$ spinor Bose-Einstein condensates, both with and without the Zeeman splitting. The spin magnetization configurations and the spin currents are investigated. The soliton or the soliton train complexes are naturally produced.

8:12AM P4.00002 Geometry of Spinor Condensates with Large Spins, OMNARAYANI NAYAK, University of California, Berkeley, ARI TURNER, University of Amsterdam — Laser cooled atoms with spin can become magnetically ordered in a variety of ways, like electrons in a frustrated lattice, but the phases are more geometrical in this setting. For spin one, two and three atoms, states have been predicted with a nematic symmetry (the symmetry of a toothpick), a hexagon, and an octahedron, as well as other possibilities. As the spin becomes larger, the phase diagrams become more and more complicated. I will present a geometrical way of predicting regularities in the phases as the spin increases. For a certain form of interaction, we find a phase diagram for arbitrarily large spin. (In particular, a nematic phase does not occur beyond spin 2.) We have used a mapping to a classical problem of interacting particles arranging themselves on a sphere.

8:24AM P4.00003 Pomeranchuk cooling of SU(N) ultracold fermions in optical lattice, ZI CAI, HSIANG-HSUAN HUNG, Department of physics, UCSD, DONG ZHENG, Department of physics, Tsinghua University, CONGJUN WU, Department of physics, UCSD — We investigate thermodynamic properties of a half-filled SU(2N) Fermi-Hubbard model in two-dimensional square lattice using the determinant Quantum Monte Carlo simulation. We address the question how the large number of hyperfine-spin components makes thermodynamic properties of SU(N) ultracold fermions different from the conventional Hubbard model with $N=2$. Various thermodynamic quantities such as entropy, charge fluctuations, and spin correlations have been calculated. We devote special attention to the interaction-induced adiabatic cooling: an analogue of the Pomeranchuk effect in Helium-3.

8:36AM P4.00004 Deterministic Quantum Monte Carlo simulations on quantum magnetism of theSU(2N) ultra-cold fermions, DONG ZHENG, Department of Physics, Tsinghua University, HSIANG-HSUAN HUNG, Department of electrical and computer engineering, University of Illinois at Urbana-Champaign, ZI CAI, CONGJUN WU, Department of Physics, University of California, San Diego — We investigate the quantum magnetism of the repulsive SU(2N)-Hubbard model on a two-dimensional square lattice at half-filling. At 2N = 4, our numerical results suggest that there exists a long-range Neel ordering at large U. In this regime, both of the antiferromagnetic structure factor per site and the farthest two-point spin-spin correlation functions are saturated to finite values in the thermodynamic limit. The single-particle excitations are finite and the spin gaps vanish. All of above evidences support the presence of the Neel ordering in the SU(4)-Hubbard model. For 2N > 4, such features are not explicitly observed.

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1This work was supported by the NSF DMR-1105945 and the AFOSR-YIP program.

2NSF DMR-1105945
8:48AM P4.00005 Multi-component integrable models in cold atoms , YUZHU JIANG, Beijing Computational Science Research Center, Beijing 100084, China. JUNPENG CAO, YUPENG WANG, Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, PR China, HAIQING LIN, Beijing Computational Science Research Center, Beijing 100084, China — The quantum gases are intensively studied for the inspiring advances in ultra-cold atomic physics. Various kinds of lattice and gas systems are created in different dimensions. The multi-component cold atomic systems have rich phase diagrams. Our works focus on the one-dimensional integrable quantum systems. We find a series of integrable models of $Sp(2s+1)$ fermions and $SO(2s+1)$ bosons and solve them via Bethe ansatz techniques, where $s$ the hyperfine spin of the atoms. We find the paired bosons exist in both repulsive and attractive $SO(3)$ integrable bosonic gases with hyperfine spin-1. For the $Sp(2s+1)$ repulsive fermions, there are no bound states in the ground state, while 2-string bound solutions appear in the spin sector. We also calculate the spin-wave velocities and low temperature specific heat of the repulsive fermions. These systems have spin-charge separation property of Luttinger liquid. Different from the $SU(2s+1)$ repulsive models, the spin-wave velocities of the $Sp(2s+1)$ models are no longer the same. The holes of 1-strings (real rapidities) of different branches in the spin sector have a same spin-wave velocity $v_1$ and the ones of 2-strings share a same spin-wave velocity $v_2$. The two velocities are different.

9:00AM P4.00006 Haldane Phase of Ultra Cold Atom Gas Loaded on Pseudo-One-Dimensional Optical Lattice , KEITA KOBAYASHI, MASAHIKO OKUMURA, Center for Computational Science & e-System Japan Atomic Energy Agency, YUKIHIRO OTA, REKIN, SUSUMU YAMADA, MASAHIKO MACHIDA, Center for Computational Science & e-System Japan Atomic Energy Agency — Ultracold Fermi gas loaded on optical lattice (FGOL) has attracted considerable attention since its temperature, interaction, and filling factor are flexibly controllable and various quantum phases are accessible. In this study, we examine properties of pseudo-one-dimensional (P1D) FGOL obtained by including effects of the transverse excitation. At first, we prove that the P1D system at half-filling can be theoretically mapped on spin-1 Heisenberg chain. Secondly, we reveal by using DMRG scheme that Haldane phase emerges in the P1D FGOL. Finally, we clarify effects of trap potential and spin imbalance on not only the central Haldane phase but also various different magnetic structures around the Haldane phase.

9:12AM P4.00007 Half-quantum vortex state and its excitations in a spin-orbit coupled spinor Bose-Einstein condensate , B. RAMACHANDHRAN, Department of Physics and Astronomy, and Rice Quantum Institute, Rice University, Houston, TX 77005, USA, BOGDAN OPANCHUK, XIA-JI LIU, ACQAO and Centre for Atom Optics and Ultrafast Spectroscopy, Swinburne University of Technology, Melbourne 3122, Australia, HAN PU, Department of Physics and Astronomy, and Rice Quantum Institute, Rice University, Houston, TX 77005, USA, HUI HU, ACQAO and Centre for Atom Optics and Ultrafast Spectroscopy, Swinburne University of Technology, Melbourne 3122, Australia — We investigate theoretically the condensate state and collective excitations of a spin-orbit coupled spinor Bose gas in two-dimensional harmonic traps. In the weakly interacting regime, when the inter-species interaction is larger than the intra-species interaction ($g_{\uparrow\downarrow} > g$), we find that the condensate phase has a half-quantum-angular-momentum vortex configuration (half-vortex state) with spatial rotational symmetry and skyrmion-type spin texture. We investigate the stability of half-vortex state in the regime when $g_{\uparrow\downarrow}$ is greater than a threshold $g_{c}$, and in the regime when $g_{\uparrow\downarrow} < g_{c}$, by solving the Bogoliubov equations for collective density oscillations. In addition, we also investigate the dynamical properties of the half-vortex state. We present the phase diagram as a function of interatomic interaction and spin-orbit coupling.

1HP is supported by the NSF, the Welch Foundation (Grant No. C-1669) and the DARPA OLE program.

9:24AM P4.00008 Searching for Non-abelian Phases in Bose-Einstein Condensate of Dy , BIAO LIAN, HUI ZHAI, Institute for Advanced Study, Tsinghua University — Recently Bose-Einstein condensate of a spin 8 element, Dysprosium, has been realized. We compute the mean-field ground state and Bogoliubov excitation of Dy condensate for different scattering lengths and in presence of a magnetic field, and find various non-abelian phases in the parameter space. We suggest an experimental scheme for detecting the remaining discrete point group symmetry of these phases simply by looking at population of each spin components and the degeneracy of Goldstone modes. A BEC whose remaining symmetry is a non-abelian group can support exotic non-abelian vortices.

9:36AM P4.00009 Quasiparticles in a Bose-Fermi mixture in optical lattice , KAZUTO NODA, ROBERT PETERS, NORIO KAWAKAMI, Kyoto University, THOMAS PRUSCHKE, University of Goettingen — We investigate a mixture of interacting bosons and fermions using a generalized dynamical mean-field theory combined with the numerical renormalization group. We focus on many-body effects in the presence of the superfluidity. It is elucidated that fermionic particles are strongly renormalized by low-energy bosonic excitations via the boson-fermion interaction, giving rise to an anomalous peak structure in the density of states for fermions. We also address how the renormalization effects appear in the phases with long-range order such as a supersolid phase.

9:48AM P4.00010 Ultracold bosons in the presence of a second species in the Tonks-Girardeau regime: dynamics and quantum features , MIGUEL ANGEL GARCIA-MARCH, THOMAS FOGARTY, THOMAS BUSCH, Department of Physics, University College Cork — We develop a framework to study the interaction between two ultracold bosonic species in different regimes. One species is in the low correlation limit forming a Bose-Einstein condensate (BEC), while the other is in the strongly correlated Tonks-Girardeau regime. We use a Bose-Hubbard-like model where, due to the momentum distribution of the Tonks gas, many single particle states are considered and study the dynamics of the system by numerical simulation of the equations obtained. The atoms in the Tonks gas act as impurities submerged in the BEC, and the excitations created by their interactions with the BEC gas can be understood in terms of polaronics. We focus on the fundamental quantum properties of the system and investigate the effects the condensed environment has on the Tonks-Girardeau gas as a function of the interspecies scattering strength.

1This work is supported by SFI under grant number 10/IN.1/12979

10:00AM P4.00011 The Many-Body Correlation of Bose-Fermi Mixture in the Ring Trap , RYOSUKE SHIBATO, THOMAS Pruschke, University of Göttingen — The realization of Bose-Einstein Condensation in alkali atoms in 1995, studies on cold atomic gases have greatly advanced. The cold atoms are precisely controlled by electromagnetism and optics, and flexible to design quantum systems. In 2001, G. G"orlitz's group has realized the Bose-Einstein condensates in the quasi-one-dimensional system [1]. One have now obtained the ideal system to study the one-dimensional many-body physics experimentally. The purpose of our study is to clarify the effect of quantum many-body correlation beyond the mean-field approximation. To accomplish this purpose, we first prepare the bosons and fermions in the ring trap [2]. We prepare the initial state in the trap with the small distortion and study the collective density oscillations. In addition, we also investigate the dynamical properties of the half-vortex state. We present the phase diagram as a function of interatomic interaction and spin-orbit coupling.

10:12AM P4.00012 Cooling by corolling; a route to antiferromagnetism in optical lattices.  
YEN LEE LOH, University of North Dakota — Cold atoms in optical lattices have emerged as a promising tool for emulating condensed matter Hamiltonians. Current experiments have observed “Mott insulating” behavior in the Fermi-Hubbard model at an average entropy $S/N \approx 1k_B/\text{atom}$. Our quantum Monte Carlo simulations [1], in agreement with other methods, show that $S/N \approx 0.65k_B/\text{atom}$ is low enough to produce antiferromagnetism (AF) at the center of a harmonic trap. However, further progress in the field requires even lower entropies that are beyond the reach of traditional cooling techniques. I have proposed a way to attain very low temperatures and entropies ($S/N < 0.65k_B/\text{atom}$) by trapping fermions in a corral formed from another species of atoms [2]. This Fermi system can then be evolved into an antiferromagnet by morphing the lattice into a set of double wells, quasi-adiabatically. Quantum dynamics simulations have, so far, given promising results.


1DARPA #60025344 under OLE program

JIE XU, ERIC J. WALTER, SHIWEI ZHANG, College of William and Mary — We report unrestricted Hartree-Fock (UHF) results for the ground state of the single-band Hubbard model in three-dimensions (3D), with repulsive onsite interactions and nearest-neighbor hopping. Magnetic and charge properties are determined by full numerical solutions of the self-consistent UHF equation in large supercells, and quantified as a function of hole doping $h$. We focus on weak to intermediate interaction strengths, where UHF has been shown to capture the main characteristics of the magnetic correlations in two-dimensions (2D).[2] We find linear spin-density wave (SDW) states with AFM order and a long wavelength modulation whose wavelength is inversely proportional to $h$. We also study the dimensional crossover from 2D to 3D as the inter-plane distance is increased.

[1] Supported by NSF and ARO.


10:36AM P4.00014 Continuous measurement quantum state tomography of atomic spins.  
CARLOS RIOFRIO, IVAN DEUTSCH, Department of Physics and Astronomy, Center for Quantum Information and Control, University of New Mexico, AARON SMITH, BRIAN ANDERSON, HECTOR SOSA, POUL JESSEN, College of Optical Sciences, Center for Quantum Information and Control, University of Arizona — Quantum state tomography is a fundamental tool in quantum information science and technology. It requires estimates of the expectation values of an “informationally complete” set of observables. This is, in general, a very time-consuming process that requires a large number of measurements to gather sufficient statistics. There are, however, systems in which the data acquisition can be done more efficiently. An ensemble of quantum systems can be prepared and driven by external fields while being continuously and collectively probed, producing enough information in the time evolving measurement record to estimate the initial state. Such protocol has the advantage of being fast and robust. In this talk, I will present a study of a continuous-measurement quantum-state tomography protocol and its application to controlling large spin ensembles. We perform reconstruction of quantum states prepared in the 16 dimensional ground-electronic hyperfine manifolds of an ensemble of $^{133}$Cs atoms, controlled by microwaves and radio-frequency magnetic fields and probed via polarization spectroscopy. We present theoretical and experimental results of its implementation and discuss two estimation methods: constrained maximum likelihood and compressed sensing.

K.G.L. PEDERSEN, B.M. ANDERSEN, Niels Bohr Institute, University of Copenhagen, Denmark, G.M. BRUUN, Department of Physics and Astronomy, Aarhus University, Denmark, O.F. SYLJUÅSEN, Department of Physics, University of Oslo, Norway, A.S. SØRENSEN, Niels Bohr Institute, University of Copenhagen, Denmark — The study of ultracold atoms in optical lattices has produced several groundbreaking results. A major, but presently unrealized goal, is to study quantum magnetism using atoms in optical lattices. We suggest three different experimental methods for probing both short- and long-range spin correlations of atoms in optical lattices. The first method involves an adiabatic doubling of the periodicity of the underlying lattice to probe neighboring singlet (triplet) correlations for fermions (bosons) by the occupation of the resulting vibrational ground state. The second method utilizes a time-dependent superlattice potential to generate spin-dependent transport by any number of prescribed lattice sites, and probes correlations by the resulting number of doubly occupied sites. The third method relies on the difference in tunneling times for the vibrational ground state and the first excited state. Correct timing then allows for the spin correlations to be fingerprinted. For experimentally relevant parameters, we demonstrate how all three methods yield large signatures of antiferromagnetic correlations of strongly repulsive fermionic atoms in a single shot of the experiment.

Wednesday, February 29, 2012 8:00AM - 11:00AM – Session P10 DAMOP GQI: Invited Session: Quantum Simulations

8:00AM P10.00001 Quantum simulations and artificial gauge fields with ultracold atoms.  
IAN SPIELMAN, NIST — Here I present our experimental work synthesizing gauge fields for Bose-Einstein condensates (BECs). I will first summarize our earlier work creating a scalar (abelian) gauge field (akin to the electromagnetic vector potential) and then focus in detail our current work creating a matrix valued (although still abelian) gauge field. I will discuss this gauge field in the language of spin-orbit coupling where it consists of an equal sum of Rashba and Dresselhaus couplings. Specifically, we couple two internal states of rubidium $^{87}$Rb with a pair of “Raman” lasers and load our BEC into the resulting adiabatic eigenstates. In agreement with theory, we observe that below a critical coupling strength our BEC has well defined spin degrees of freedom and acts like a spin-orbit-coupled spin-1/2 Bose gas. As a function of the Raman laser strength, a new exchange-driven interaction between the two dressed spins develops, which drives a (quantum) phase transition from a state where the two dressed spin states spatially mix, to one where they phase separate. Our 3D mean field theory accurately locates the critical laser strength for this transition.

8:36AM P10.00002 Quantum simulations with trapped Ca+ ions.  
RAINER BLATT, Innsbruck University — No abstract available.
9:12AM P10.00003 Circuit QED Simulation of Interacting Bosons with Microwave Polaritons

STEVEN GIRVIN, Yale University — A polariton is a coherent superposition of a photon and an electronic excitation such as an exciton. Polaritons can have very low mass (associated with the photon component) and repulsive interactions (associated with the exciton component). Recent experimental progress has observed Bose-Einstein condensation and superfluidity in polaritons in semiconductor quantum wells. In this talk I will discuss the possibility that many-body physics and quantum phase transitions of interacting polaritons [1-3] can be observed in arrays of microwave resonators containing superconducting qubits [4-6]. If the qubits are not far-detuned from the cavities, the natural excitations are coherent superpositions of cavity and qubit excitations and they have interactions acquired from the anharmonicity of the qubits. These interactions can lead to quantum phase transitions in the limit of weak dissipation. It may even be possible to simulate the fractional quantum Hall effect for bosons by coupling the polaritons between sites using superconducting structures which act as ‘circuitors’ that break time-reversal and charge-conjugation symmetry. In light of recent progress in achieving very long-coherence times for superconducting qubits and strong qubit coupling to microwave photons, experimental prospects for observing quantum phase transitions in microwave resonator lattices will be described.


Work supported by the NSF, ARO, LPS and NSA. This work is a collaboration with Jens Koch, Karyn Le Hur, Andreas Nunnenkamp, Andrew Houck and Claudia DeGrandi.

9:48AM P10.00004 Quantum Hall physics with photons and its application

MOHAMMAD HAFEZI, Joint Quantum Institute — Phenomena associated with the topological properties of physical systems can be naturally robust against perturbations. This robustness is exemplified by quantized conductance and edge state transport in the quantum Hall and quantum spin Hall effects. Here we demonstrate how quantum spin Hall Hamiltonians can be simulated with linear optical elements using a network of coupled resonator optical waveguides (CROW) in two dimensions. Key features of quantum Hall systems, including the characteristic Hofstadter butterfly and robust edge state transport, can be obtained in such systems. As a specific application, we show that topological protection can be used to improve the performance of optical delay lines and to overcome some limitations related to disorder in photonic technologies. Furthermore, the addition of an optical non-linearity to our proposed system leads to the possibility of implementing a fractional quantum Hall state of photons, where phenomenon such as fractional statistics may be observable.

1 This work was partially supported by the US Army Research Office MURI award W911NF0910406

10:24AM P10.00005 Mixed Bose-Fermi Mott Phases and Phase Transitions

EHUD ALTMAN, Weizmann Institute of Science — A recent experiment with an ultra-cold mixture of \(^1\)T\(_4\)Yb and \(^1\)T\(_3\)Yb atoms in an optical lattice [S. Sugawa e. al. Nature Physics 7, 642 (2011)] found a remarkable quantum phase that can be described as a mixed Mott insulator. Such an incompressible state established at integer combined filling of the two species, must have residual low energy Fermionic degrees of freedom associated with relative motion of the two species. I will discuss the novel quantum states formed by the composite Fermions in the mixed Mott insulator as well as the unconventional phase transitions separating these states from the compressible Bose-Fermi mixture established at weak interactions. Finally I will propose to utilize the mixed Mott insulator as a quantum simulator for models of the doped Mott insulator relevant to high Tc superconductivity. The new approach, where the bosonic atoms play the role of doped holes offers significant advantages over direct simulation of the Hubbard model. In particular the mixed Mott plateau naturally provides a flat trap potential to the doped holes, while the hole doping is easily tuned by varying the relative fraction of the bosons.

1 Support from the Israel Science Foundation and from DIP is gratefully acknowledged

Wednesday, February 29, 2012 11:15AM - 2:15PM

Session Q4 DAMOP: Focus Session: Many-body Quantum Phases in Cold Atom Systems 205C

11:15AM Q4.00001 Orbital ice: an exact Coulomb phase on the diamond optical lattice

GIA-WEI CHERN, University of Wisconsin at Madison and Los Alamos National Lab, CONGJUN WU, University of California, San Diego — The rapid advances in loading and controlling alkali atoms on the excited bands of optical lattices have made it possible to investigate orbital-related many-body physics in new settings. Here we demonstrate the existence of orbital Coulomb phase as the exact ground state of \(p\)-orbital exchange Hamiltonian on the diamond lattice. The Coulomb phase is an emergent state characterized by algebraic dipolar correlations and a gauge structure resulting from local constraints (ice rules) of the underlying lattice models. For most ice models on the pyrochlore lattice, these local constraints are a direct consequence of minimizing the energy of each individual tetrahedron. On the contrary, the orbital ice rules are emergent phenomena resulting from the quantum orbital dynamics. We show that the orbital ice model exhibits an emergent geometrical frustration by mapping the degenerate quantum orbital ground states to the spin-ice states obeying the 2-in-2-out constraints on the pyrochlore lattice. We also discuss possible realization of the orbital ice model in optical lattices with p-band fermionic cold atoms. [1] Gia-Wei Chern and Congjun Wu, arXiv:1104.1614 (2011).

1 GWC thanks the supported of ICAM and NSF Grant DMR-0844115. CW acknowledges the support of NSF under DMR-1105945 and AFOSR-YIP program.

11:27AM Q4.00002 Time reversal symmetry breaking of \(p\)-orbital bosons in a one-dimensional optical lattice

XIAOPENG LI, ZIXU ZHANG, W. VINCENT LIU, University of Pittsburgh — We study bosons loaded in a one-dimensional optical lattice of two-fold \(p\)-orbital degeneracy at each site. Our numerical simulations find an anti-ferro-orbital \(p_x-i_p_y\), a homogeneous \(p_z\) Mott insulator phase and two kinds of superfluid phases distinguished by the orbital order (anti-ferro-orbital and para-orbital). The anti-ferro-orbital order breaks time reversal symmetry. Experimentally observable evidence is predicted for the phase transition between the two different superfluid phases. We also discover that the quantum noise measurement is able to provide a concrete evidence of time reversal symmetry breaking in the first Mott phase.

1 A. W. Mellon Fellowship
11:39 AM Q4.00003 Correlated phases of bosons in tilted, frustrated lattices\(^1\). SUBIR SACHDEV, Harvard University, SUSANNE PIELAWA, Wieland Institute of Science, TAKUAYA KITAGAWA, EREZ BERG, Harvard University — We study the “tilting” of Mott insulators of bosons into metastable states. These are described by Hamiltonians acting on resonant subspaces, and have rich possibilities for correlated phases with non-trivial entanglement of pseudospin degrees of freedom measuring the boson density. We extend a previous study (Phys. Rev. B 66, 075128 (2002)) of cubic lattices to a variety of lattices and tilt directions in 2 dimensions: square, triangular, decorated square, and Kagome, while noting the significance of three-body interactions. We find quantum phases with Ising density wave order, with superfluidity transverse to the tilt direction, a sliding Luttinger liquid phase, and quantum liquid states with no broken symmetry. Some cases map onto effective quantum dimer models.

\(^1\)Supported by DMR-1103860 and by a MURI grant from AFOSR.

11:51 AM Q4.00004 Quantum simulations with ultracold atoms\(^1\). NIKOLAY PROKOPIEV, University of Massachusetts, Amherst — Precise understanding of strongly interacting systems, from electrons in materials and frustrated magnets to nuclear matter, is a major challenge for modern physics. Often, theoretical description of key models is severely plagued by the intricate quantum mechanics at play. This prompted a challenging effort of using ultra-cold atoms to realize Feynman’s emulators of fundamental microscopic models. I will discuss some of the current efforts in realizing quantum simulators for cold bosonic and fermionic systems and how the theory tries to catch up with the experiment in making reliable predictions for strongly interacting quantum matter.

\(^1\)NSF, grant PHY-1005543, ARO DARPA OLE

12:27PM Q4.00005 A Mott Glass to Superfluid Transition for Random Bosons in Two Dimensions. DAVID PEKKER, SHANKAR IYER, GIL REFAEL, Caltech — We study the zero temperature superfluid-insulator transition for a two-dimensional model of interacting, lattice bosons in the presence of quenched disorder and particle-hole symmetry. We follow the approach of a recent series of papers by Altman, Kafri, Polkovnikov, and Refael, in which the strong disorder renormalization group is used to study disordered bosons in one dimension. Adapting this method to two dimensions, we study several different species of disorder and uncover universal features of the superfluid-insulator transition. In particular, we locate an unstable finite disorder fixed point which governs the transition between the superfluid and a gapless, glassy insulator. We present numerical evidence that this glassy phase is the incompressible Mott glass and that the transition from this phase to the superfluid is driven by percolation-type process. Finally, we provide estimates of the critical exponents governing this transition.

12:39PM Q4.00006 Disordered Supersolids in the Extended Bose-Hubbard Model\(^1\). VITO SCAROLA, BHARGAV KEMBURI, Virginia Tech — Studies of the extended Bose-Hubbard model seek to capture the essential properties of a wide variety of physical systems including helium, Josephson junction arrays, certain narrow-band superconductors, and bosons in optical lattices. We theoretically study the stability of lattice supersolid states in the extended Bose-Hubbard model with bounded spatial disorder. We construct a disorder mean field theory and compare with Monte Carlo calculations. We find that the supersolid survives weak disorder on the simple cubic lattice. We also find that increasing disorder strength can transform a lattice solid into a supersolid as it tends to percolate through the disorder landscape.

\(^1\)This work is supported by AFOSR (FA9550-11-1-0313) and DARPA-YFA (N66001-1-1-4122).

12:51PM Q4.00007 Density instabilities in a two-dimensional dipolar Fermi gas. MEERA PARISH, University College London, FRANCESCA MARCHETTI, Universidad Autonoma de Madrid — We investigate the inhomogeneous phases of fermionic polar molecules confined in a single two-dimensional (2D) layer, where the molecule dipole moments are all aligned by an external electric field. We show that the Random Phase Approximation (RPA) for the density-density response function is never accurate for the 2D dipolar Fermi gas. To incorporate correlations beyond RPA, we use an improved version of the Singwi-Tosi-Land-Sjolander scheme, which has been successful for electron systems. In addition to density-wave instabilities, our formalism captures the collapse instability that is expected from Hartree-Fock calculations but is absent from RPA. Crucially, we find that when the dipoles are oriented perpendicular to the layer, the system spontaneously breaks rotational symmetry and forms a stripe phase, in defiance of conventional wisdom.

1:03PM Q4.00008 Scaling of noise correlations of hard-core bosons in incommensurate lattices. KAI HE, Georgetown University, INDUBALA I. SATJIA, George Mason University; Joint Quantum Institute, NIST, CHARLES W. CLARK, Joint Quantum Institute, NIST, ANA MARIA REY, JILA, NIST, MARCOS RIGOL, Georgetown University — We study the scaling of the momentum distribution function and the noise correlations in the Mott insulator, Bose glass, and superfluid quantum phases of hard-core bosons subjected to quasi-periodic disorder. The exponents of the correlation functions at the superfluid to Bose-glass transition are found to be approximately one half of the ones that characterize the superfluid phase. We also find a divergence in the derivative of the noise correlation peaks with respect to the strength of disorder at the superfluid to Bose-glass critical point. This behavior is found not to occur in the corresponding free fermion system, where an Anderson-like transition takes place at the same critical point.

1:15PM Q4.00009 Quantum Orders and Space-Time Vortices for Spin 2 Atomic Chains. ARI TURNER, University of Amsterdam, FRANK POLLMANN, Max-Planck-Institute for the Physics of Complex Systems, ASHVIN VISHWANATH, University of California, Berkeley — Laser cooled atoms with spin can become magnetically ordered, like electrons in solids, but a greater variety of orders is possible in this setting. Spin one atoms can form nematic states with the symmetry of an undirected line segment while spin two atoms can form states with the symmetry of a tetrahedron. Such atoms could be confined to a one-dimensional optical lattice. In one dimension, quantum fluctuations become much more significant, and lead to a few interesting phases. In particular, the nematic state spontaneously breaks translational symmetry. If a state has a Berry’s phase of a certain order under rotations, the fluctuations will often be modulated with a period of the same order. I will argue that this connection can be broken for a non-abelian symmetry group—both uniform and periodic phases can be stabilized. As an example, computer calculations (with DMRG) on a tetrahedral state find both a uniform and a period 3 phase.

1:27PM Q4.00010 Thermal versus quantum fluctuations of optical lattice fermions. CHRIS HOOLEY, SUPA, University of St Andrews, UK, VIVALDO CAMPO, Universidade Federal de Sao Carlos, Brazil, KLAUS CAPELLE, Universidade Federal do ABC, Brazil, JORGE QUINTANILLA, SEPnet, University of Kent and STFC Rutherford Appleton Laboratory, UK, VITO SCAROLA, Virginia Tech, USA — We show that, for fermionic atoms in a one-dimensional optical lattice, the fraction of atoms in doubly occupied sites is a highly non-monotonic function of temperature. We demonstrate that this property persists even in the presence of realistic harmonic confinement, and that it leads to a suppression of entropy at intermediate temperatures that offers a clear route to adiabatic cooling. Our interpretation of the suppression is that such intermediate temperatures are simultaneously too high for quantum coherence and too low for significant thermal excitation of double occupancy thus offering a clear indicator of the onset of quantum fluctuations.
1:51PM Q.4.00012 ABSTRACT WITHDRAWN

2:03PM Q.4.00013 The boson-Hubbard model on a kagome lattice with a sextic ring-exchange term1, VALERY ROUSSEAU, KA-MING TAM, JUANA MORENO, MARK JARRELL, Louisiana State University (LSU) — We present exact quantum Monte Carlo simulations of hard-core bosons in a two-dimensional Kagome lattice with a sextic ring-exchange term. We study how the superfluid density evolves as the ring-exchange interactions are increased. We show that the system becomes unstable in the limit of large interactions at all fillings and undergoes a phase separation, except at 3/4 and 2/3 fillings for which the superfluid density vanishes and a solid state forms.

1This work was supported by the National Science Foundation through OISE-0952300, the TeraGrid re-sources provided by NICS under grant number TG-DMR100007, the high performance computational re-sources provided by the Louisiana Optical Network.

Wednesday, February 29, 2012 2:30PM - 5:30PM — Session T1 DAMOP: Hybrid Systems, Optomechanics and Macroscopic Systems at the Quantum Limit II 203

2:30PM T.1.00001 Coupling propagating acoustic waves to quantum circuits1, MARTIN GUSTAFSSON, Chalmers University of Technology, PAULO SANTOS, Paul-Drude-Institut fur Festkorperelektronik, GöRAN JOHANSSON, PER DELSING, Chalmers University of Technology — We present a method for coupling propagating Surface Acoustic Waves (SAW) to charge sensitive quantum circuits, by direct piezoelectric charge induction. Using an RF-Single Electron Transistor as a high-performance electrometer, and employing an on-chip mixing technique we demonstrate ultra-high displacement sensitivity in the gigahertz frequency range, and an averaged detection sensitivity below the single-phonon level. Based on these experimental results, we discuss how the method can be enhanced and extended to superconducting qubits, and what roles Surface Acoustic Waves could potentially play in novel hybrid quantum devices.


2:42PM T.1.00002 Single Crystal Diamond Mechanical Resonators1, PREETI OVARC~HIYAPONG, BRYAN MYERS, PAUL LAURIA, ANIA BLESZYN~SKI JAYICH, University of California Santa Barbara — We report on the fabrication and measurement of single crystal diamond mechanical resonators. This is an important step towards realizing diamond photonics, optomechanics, and diamond-based scanning magnetometers. We present measurements of mechanical quality factors in excess of 10,000 as well as estimates of the coupling to embedded nitrogen-vacancy (NV) centers through strain. Strain tuning the NV’s zero-phonon line could facilitate coupling its spin state to a photonic network. We also discuss strain as a coupling mechanism between the spin and mechanical degree of freedom in a diamond based resonator.

1This work was supported by UCSB and the AFOSR, FA9550-11-1-0013

2:54PM T.1.00003 Resonant Optical Forces in Silicon Carbide Nanostructures, DONGFANG LI, RASHID ZIA, Brown University — Silicon carbide (SiC) materials are widely used for their exceptional electronic, mechanical, and thermal properties. For example, given its high stiffness to density ratio, SiC is an ideal material for mechanical resonators, and it has been explored for applications in nanoelectromechanical systems (NEMS). SiC also supports strong surface phonon-polariton resonances in the infrared region, which could enable its use for optomechanics. Similar to surface plasmon-polaritons supported by metal-dielectric interfaces, these surface waves at a SiC-vacuum interface can be used to guide and confine intense electromagnetic energy. Here, we investigate the resonant optical forces induced by phonon-polariton modes in different SiC nanostructures. Specifically, we calculate optical forces using the Maxwell Stress Tensor for three geometries: spherical particles, slab waveguides, and rectangular waveguides. We find that the high quality factor phonon-polariton modes in SiC can produce very large forces, more than two orders of magnitude larger than the plasmonic forces in similar metal nanostructures. These strong resonant forces, combined with its mechanical and thermal properties, make SiC a promising material for optomechanical applications.

3:06PM T.1.00004 Quantum Mechanical Scattering in Nanoscale Systems1, A.G. GIANFRANCESCO, A. ILYASHE~NKO, C.R. BOUCHER, I.R. RAM-MOHAN, Worcester Polytechnic Institute — We investigate quantum scattering using the finite element method. Unlike textbook treatments employing asymptotic boundary conditions (BCs), we use modified BCs, which permits computation close to the near-field region and reduces the Cauchy BCs to Dirichlet BCs, greatly simplifying the analysis. Scattering from any finite quantum mechanical potential can be modeled, including scattering in a finite waveguide geometry and in the open domain. Being numerical, our analysis goes beyond the Born Approximation, and the finite element approach allows us to transcend geometric constraints. Results of the formulation will be presented with several case studies, including spin dependent scattering, demonstrating the high accuracy and flexibility attained in this approach.

1This work was supported by AFRL/DARPA under contract #FA8650-10-1-7046, and by the National Science Foundation #ECS-0725427.
3:18PM T1.00005 Modeling time domain spectroscopy of electron-phonon coupled systems out of equilibrium. MICHAEL SENTEF, A.F. KEMPER, BRIAN MORITZ, T.P. DEVEREAUX, Stanford Institute for Materials and Energy Science, SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, CA 94025, USA — Recent advances in Terahertz large-electric field generation and pump-probe spectroscopies resloving pico- and even femtosecond time scales allow to study the behavor of photoexcited solids out of equilibrium. The relaxation after the pump pulse typically involves very fast processes related to purely electronic degrees of freedom, but for the slower return back to equilibrium it is essential to understand the interplay of electronic and lattice degrees of freedom. We present a theoretical investigation of electron-phonon coupled systems out of equilibrium, with results for various quantities (electronic distribution function, time-resolved angle-resolved photoemission, charge current). Our results show that the experimentally observed behavior can be related to the underlying microscopic properties of the system.

3:30PM T1.00006 Modeling lattice interaction in non-equilibrium pump-probe experiments. A.F. KEMPER, MICHAEL SENTEF, BRIAN MORITZ, T.P. DEVEREAUX, Stanford Institute for Materials and Energy Science — In past years, advances in experimental laser technology have allowed for the study of materials at even shorter timescales. In these pump-probe experiments, after excitation by the pulse, the systems evolve back to equilibrium through its inherent relaxation processes, which are typically temporally separated by their characteristic timescales. Among the slower processes are the electron-phonon interactions, which carry the majority of the energy transferred to the electrons away into the lattice. We present a direct calculation of the characteristic timescales for systems driven out of equilibrium via a short pulse and allowed to relax via electron-phonon interactions. We make a direct connection between the observable timescales and the microscopic specifities, both via decay rates and oscillations in various photon-spectroscopies.

3:42PM T1.00007 Fluctuation Induced Forces for Surface Relief Gratings. JEF WAGNER, ROYA ZANDI, University of California Riverside, THORSTEN EMIG, Laboratoire de Physique Théorique et Modeles Statistiques Université Paris Sud — In 1948 H. G. B. Casimir predicted that two flat parallel neutral perfectly conducting plates would attract each other due to the quantum fluctuations of the electromagnetic field. Since then progress has been made to allow one to calculate the interaction energy due to both quantum and thermal fluctuations between two objects of almost arbitrary shape and material properties. This work focuses on interaction with at least one object described by a surface relief grating. The Casimir energy is calculated using the scattering matrix approach, and the scattering matrix of the periodic surface is calculated using the C method from electromagnetic grating theory. The strengths and limitations of the method with regards to calculating the Casimir energy are discussed, and the results for simple 1-D and 2-D periodic structures are shown.

3:54PM T1.00008 Superfluid to Mott-Insulator Transition in Thermodynamic Limit of 1D Coupled Cavity Array. ADAM G. D’SOUZA, BARRY C. SANDERS, DAVID L. FEDER, IQIS, University of Calgary — In recent years, there has been great interest in simulating condensed matter models with quantum optical systems, which are usually characterized by a high degree of experimental control. One such model is the Jaynes-Cummings-Hubbard (JCH) model, an analog for the Bose-Hubbard (BH) model, in which mobile phonons interact with atoms localized within a regular lattice of weakly coupled cavities. Finite system Density Matrix Renormalization Group (DMRG) studies have predicted a superfluid (SF) to Mott insulator (MI) transition in the phase diagram of the JCH model, and finite-size scaling has been used to determine the phase boundary in the thermodynamic limit. In this work, we directly numerically investigate the JCH model in the thermodynamic limit using infinite-system DMRG. The preliminary results indicate that the properties of the expected SF state are not wholly consistent with those of a conventional superfluid.

4:06PM T1.00009 Dirac Exciton-Polariton Condensates in a Triangular Lattice. NA YOUNG KIM, Stanford University, KENICHIRO KUSUDO, National Institute of Informatics, SVEN HOEFLING, ALFRED FORCHEL, University of Wuerzburg, YOSHIIHISA YAMAMOTO, Stanford University — Microcavity exciton-polaritons are quantum boson particles arising from the strong light-matter coupling between cavity photons and quantum well excitons. Recently, we have investigated the behavior of condensates in artificial lattice geometries in two-dimension (2D). Coherent \( p \)- and \( d \)-orbital state in a 2D square lattice is recently observed. Here we investigate exciton-polariton condensates at Dirac points formed in a 2D triangular lattice and experimental mapping of Dirac dispersion and discuss the interaction effect. We anticipate that the preparation of high-orbital condensates can be further extended to probe dynamical quantum phase transition in a controlled manner as quantum simulation applications.

4:18PM T1.00010 Numerical Study of the Bose-Einstein Condensation of Exciton-Polaritons. ASLAN KASIMOV, JESUS SIERRA, King Abdullah University of Science and Technology, RADA-MARIA WEISHAUPL, Vienna University — Using the complex Gross-Pitaevskii equation (cGPE) with pumping and decay terms that models the Bose-Einstein condensate of exciton-polaritons, we numerically investigate the dynamics of instability of its radially symmetric steady solutions. We develop accurate algorithms for computing the steady state solution, the linear stability spectra, as well as the full nonlinear solutions of the cGPE. We accurately compute the thresholds of instability that depend, e.g. on the strength and size of the polariton pumping spot and observe the formation of vortices and such complex dynamics as the formation of vortex lattices and nucleation.

4:30PM T1.00011 Formation and decay of a Bose-Einstein condensate of trapped dipole excitons. GERMAN KOLMAKOV, OLEG BERMAN, ROMAN KEZERASHVILI, New York City College of Technology CUNY, YURIII LOZOVIK, Institute of Spectroscopy RAS — We study the nonlinear dynamics of formation and decay of a Bose-Einstein condensate of dipole excitons trapped in an external confining potential in coupled quantum wells. The problem is considered within an analytical approach and in numerical simulations. The trap restricts the spatial distribution of excitons and results in non-uniform density distribution in the exciton cloud. We demonstrate that under typical experimental conditions, regardless of a long-range nonlocal interaction of the dipole excitons, the system can be described by a generalized Gross-Pitaevskii equation with the local interaction between the excitons, and we find the effective interaction constant. In the numerical simulations, we account for the finite lifetime of dipole excitons and generation of the excitons due to continuous laser pumping. We also discuss formation and decay of vortex states in the condensate.

4:42PM T1.00012 Measurement of Casimir force with magnetic materials. Alexandr Banishev, Chia-Cheng Chang, Umar Mohideen Department of Physics and Astronomy, University of California, Riverside, USA , ALEXANDR BANISHEV, CHIA-CHENG CHANG, UMAR MOHIDEEN, Department of Physics and Astronomy, University of California, Riverside — The Casimir effect is important in various fields from atomic physics to nanotechnology. According to the Lifshitz theory of the Casimir force, the interaction between two objects depends both on their dielectric permittivity and magnetic permeability. Thus the role of magnetic properties on the Casimir force is interesting particularly due to the possibility of a reduction the Casimir force. In this report we will present the results of a Casimir force measurement between a magnetic material such as nickel coated on SiO\(_2\) plate and a Au-coated sphere.

4:54PM T1.00013 Geometry and fluctuation induced (Casimir) forces. SHOMEEK MUKHOPADHYAY, EHSAN NORUZIFAR, UMAR MOHIDEEN, University of California, Riverside — Since the original prediction of attraction between parallel, perfectly conducting plates by Casimir there has been significant amount of work done in extending the calculations to real materials, finite temperatures and micro or nanostructured geometries. Majority of the experimental work has been carried out in the sphere-plane geometry. In this talk we will present ongoing experimental work on sphere–cylinder and sphere–cone geometries using frequency modulated atomic force microscopy. We will discuss numerical results in the sphere cylinder geometry and the range of validity of the point force approximation (PFA).
5:06PM T1.00014 Temperature dependence of Casimir force. JUN XU, University of California, Riverside, RODRIGO CASTILLO-CARZA, University of Texas Austin, ROBERT SCHAFFER, SHOMEEK MUKHOPADHYAY, UMAR MOHIDEEEN, University of California, Riverside — Most of the experimental work till date on Casimir forces have been performed at or near room temperature. We report on our measurements of Casimir forces performed at liquid helium and liquid nitrogen temperatures using gold coated sphere and plate. These measurements were performed on a home built Atomic Force Microscope with a phase locked loop to track the frequency shift. We will discuss the results in the context of current theoretical understanding of temperature dependence in the sphere – plate geometry.

5:18PM T1.00015 Enhanced light-matter interactions of a single emitter coupled to a slot waveguide. MAIKEN H. MIKKELSEN, NITIPAT PHOLCHAI, PAVEL KOLCHIN, NSF Nanoscale Science and Engineering Center (NSEC), 3112 Etcheverry Hall, University of California, Berkeley, 94720, USA, JINYONG OH, M. SAIF ISLAM, Department of Electrical and Computer Engineering, 2064 Kemper Hall, University of California, Davis, CA95616, USA, XIANG ZHANG, NSF Nanoscale Science and Engineering Center (NSEC), 3112 Etcheverry Hall, University of California, Berkeley, 94720, USA — Traditionally, enhanced light-matter interactions are achieved using either plasmonic structures or photonic crystals. However, these structures suffer from inherent metal losses or narrow operating bandwidth. Instead, here we use an all-dielectric waveguide structure with ultra-small mode volume and low-loss and broadband capabilities. A slot-waveguide architecture is used for deep sub-wavelength light confinement in a low-index material surrounded by high-index barriers. Individual colloidal quantum dots are controllably coupled to this waveguide mode. A large Purcell enhancement is observed from lifetime measurements of the spontaneous emission rate of the quantum dot before and after coupling to the waveguide. Second order intensity correlation measurements verify that the observed fluorescence is indeed due to a single quantum dot. The demonstrated system is a promising broadband and low-loss platform for quantum information applications.

Wednesday, February 29, 2012 2:30PM - 5:30PM – Session T4 DAMOP: Vortices, Rotation, and Synthetic Gauge Fields 205C

2:30PM T4.00001 Rotating Ultracold Fermi Gases: Reduction in the Moment of Inertia Above the Superfluid Transition Temperature. K. LEVIN, VIVEK MISHRA, DAN WULIN, James Franck Institute, University of Chicago — There has been considerable interest in the viscosity of ultracold Fermi gases which is found to be anomalously suppressed even in the normal phase. This suppression, believed to derive from pseudogap effects, is also associated with a reduction in the moment of inertia, as measured by the Duke group. In this talk we address the relationship between viscosity and the reduced moment of inertia. We emphasize the very strong relation of the latter to the anomalous normal state diamagnetism of the high temperature superconductors. We present a simple physical picture for the origin of these related phenomena. Our picture gains strong support from establishing sum rule compatibility and leads to testable predictions.

2:42PM T4.00002 Vortices in spin-orbit-coupled Bose-Einstein condensates. JURAJ RADIC, TIGRAN A. SEDRAKYAN, Joint Quantum Institute, University of Maryland, College Park, IAN B. SPIELMAN, Joint Quantum Institute, University of Maryland, College Park and NIST, Gaithersburg, VICTOR GALITSKI, Joint Quantum Institute, University of Maryland, College Park — We discuss realistic methods to create vortices in spin-orbit-coupled Bose-Einstein condensates. We show that, contrary to common intuition, rotation of the trap containing a spin-orbit-coupled condensate does not lead to an equilibrium state with static vortex structures but gives rise instead to intrinsically time-dependent Hamiltonian. We propose alternative methods to create stable static vortex configurations: (1) to rotate both the lasers and the anisotropic trap; and (2) to impose a synthetic Abelian field on top of synthetic spin-orbit interactions. We derive the effective Hamiltonians for spin-orbit condensates under such perturbations for most currently known realistic laser schemes that induce synthetic spin-orbit couplings and we solve the Gross-Pitaevskii equation for several experimentally relevant regimes. The new interesting effects include spatial separation of left- and right-moving spin-orbit condensates and the appearance of unusual vortex arrangements.

2:54PM T4.00003 2D Vortex Dynamics and Quantum Tunneling in the Lowest Landau Level Limit. ROHIT HEGDE, Department of Physics, University of Texas at Austin, CHARLES B. HANNA, Department of Physics, Boise State University, ALLAN H. MACDONALD, Department of Physics, University of Texas at Austin — We examine the collective excitation spectrum of a rapidly rotating cold Bose gas in the lowest Landau level regime. The Gross-Pitaevskii action can be equivalently expressed in terms of the angular momentum state expansion of the boson field in the lowest Landau level. We consider the case of vortices and discuss their properties. We will also study the quantum tunneling of a single vortex, allowing for linear coupling to a bath of quadratic fluctuations of the lattice following the Caldeira-Leggett model, and comment on differences between the lowest Landau level limit and the case of vortices in a slowly rotating superfluid.

3:06PM T4.00004 Screening properties and phase transitions in unconventional plasmas for Ising-type quantum Hall states1. EIGIL V. HERLAND, Norwegian University of Science and Technology, EGOR BABAEEV, UMass Amherst and KTH Stockholm, PARSAG BONDENDER, Microsoft Research, Station Q, VICTOR GURARIE, University of Colorado, Boulder, CHETAN NAYAK, Microsoft Research, Station Q and University of California, Santa Barbara, ASLE SUDBO, Norwegian University of Science and Technology — Utilizing large-scale Monte-Carlo simulations, we investigate an unconventional two-component classical plasma in two dimensions that interacts with two different Coulomb interactions. This plasma controls the behavior of the norms and overlaps of the quantum-mechanical wavefunctions of Ising-type quantum Hall states. It also relates to a model for a rotating two-component Bose-Einstein condensate with an Andreev-Bashkin drag interaction. The plasma differs fundamentally from that which is associated with the two-dimensional XY model and Abelian fractional quantum Hall states. We find that this unconventional plasma undergoes a Berezinskii-Kosterlitz-Thouless phase transition from an insulator to a metal and that the parameter values corresponding to Ising-type quantum Hall states lie on the metallic side of this transition. This result verifies the required properties of the unconventional plasma used to demonstrate that Ising-type quantum Hall states possess quasiparticles with non-Abelian braiding statistics.

3:18PM T4.00005 Edge excitations of bosonic fractional quantum Hall phases in optical lattices. JONAS KJALL, JOEL MOORE, University of California, Berkeley — With the rapid development in ultracold gases, the realization of a fractional quantum Hall state on a lattice draws nearer. We investigate the impact of finite size effects in these kind of systems including different trapping potentials. A good understanding of finite size effects is essential for designing experiments and the edge excitations will likely be the best way to experimentally determine the topological order of the bulk. We find different fractional quantum Hall phases for bosons in a circular harmonic trap as the flux of the synthetic gauge field is varied, including phases like $\nu = 1/2$ and $\nu = 2/3$ with different edge spectra.

1Supported by the Knut and Alice Wallenberg Foundation, NSF grants No. DMR-0955902, No. PHY-0904017, DARPA QuEST program, NRC Grant No. 205591/V30 (FRINAT).
3:30PM T4.00006 Finite temperature phase structures of hard-core bosons in an optical lattice with a synthetic magnetic field\(^1\), KENICHI KASAMATSU, YUKI NAKANO, TETSUO MATSUI, Department of Physics, Kinki University — We study finite temperature phase structures of hard-core bosons in a two-dimensional optical lattice subject to a synthetic magnetic field by employing a gauged CP\(^1\) model. Based on the extensive Monte Carlo simulations, we study their phase structures at finite temperatures for several values of the magnetic flux per plaquette of the lattice and mean particle density. Despite the presence of the particle number fluctuation, the thermodynamic properties are qualitatively similar to those of the frustrated XY model with only the phase as a dynamical variable.

\(^1\)One of the authors (K.K.) is supported in part by Grant-in-Aid for Scientific Research (Grant No. 21740267) from MEXT, Japan.

3:42PM T4.00007 Modulated superfluid phases of lattice bosons in a non-abelian gauge field\(^1\), WILLIAM COLE, SHIZHONG ZHANG, NANDINI TRIVEDI, Department of Physics, The Ohio State University, Columbus OH 43210 — We consider the two-component Bose-Hubbard model subject to non-abelian gauge fields that give rise to spin-orbit coupling. We obtain the phase diagram based on an extended mean field theory and find many exotic superfluid phases (polarized, striped, checkerboard). We characterize the superfluid phases by finding their collective excitations within random phase approximation (RPA) and discuss the possibility of novel topological defects.

\(^1\)We acknowledge support from ARO W911NF-08-1-0338, DARPA OLE program (WC, SZ) and NSF DMR-0907275 (NT).

3:54PM T4.00008 ABSTRACT WITHDRAWN

4:06PM T4.00009 Bosons under an artificial staggered magnetic field in an optical ladder, MIN-CHUL CHA, IN-HO JEON, TAE-YANG AN, Department of Applied Physics, Hanyang University, Ansan, Gyeonggi-do, 426-791 Korea, CCMPL TEAM — We calculate the ground state properties of cold bosons in an frustrated optical ladder due to an artificial staggered magnetic field. By investigating the momentum distribution of bosons via a Lanczos diagonalization method, we find the signature of the transition from the Meissner to vortex states as a function of the staggering strength of the field. Various states with different frustrations are discussed.

4:18PM T4.00010 Chiral Mott insulator of kinetically frustrated bosons\(^1\), ARUN PARAMEKANTI, University of Toronto, ARYA DHAR, Indian Institute of Astrophysics, MAHESWAR MAJI, Indian Institute of Science, TAPAN MISHRA, Indian Institute of Astrophysics, SUBROTO MUKERJEE, Indian Institute of Science, RAMESH PAI, Goa University — We study the phase diagram of the fully frustrated Bose Hubbard (FFBH) model - the presence of a \(\pi\)-flux through each plaquette leads to kinetic frustration for the bosons making this a nontrivial model of quantum frustration. The FFBH model is equivalent to a model of frustrated quantum XY spins, or a fully frustrated Josephson junction array where one tunes the ratio of the charging energy to the Josephson coupling. Using Monte Carlo simulations and DMRG calculations on a ladder, we show that the ground state of this model is an intermediate correlations, a Chiral Mott insulator which supports staggered loop currents. We characterize this Mott phase as a vortex supersolid or an exciton condensate and discuss experimental observables and generalizations.

\(^1\)NSERC of Canada, CIAR, DST (Govt of India)

4:30PM T4.00011 Mean Field Dynamics of Spin-Orbit Coupled Bose-Einstein Condensates, YONGPING ZHANG, LI MAO, CHUANWEI ZHANG, Department of Physics and Astronomy, Washington State University, Pullman, WA — We derive the mean-field Gross-Pitaevskii equation for spin-orbit coupled Bose-Einstein condensates by taking account that the pseudospin states of atoms are superpositions of the hyperfine states with different scattering lengths. The ground state phases of the condensate in a harmonic trap are obtained numerically in various parameter regions. We find a new oscillation period in the center of mass motion of the condensate subject to a sudden shift of the harmonic trap. The oscillation period is dependent on the direction of the shift of the harmonic trap, linearly proportional to the spin-orbit coupling strength, and independent on the interaction strength.

4:42PM T4.00012 Rotation of supersolids in cold atomic condensates\(^1\), SANKALPA GHOSH, RASHI SACHDEVA, Indian Institute of Technology, Delhi — In the framework of Gross Pitaevskii equation, with non-local interaction, we study the formation of Supersolid phase and the effect of rotation on such a system. The effect of rotation is to induce vortex patterns in such Supersolid phase, whose structures are in principle, different from the ordinary vortex in Superfluids. At sufficiently high rotation, these vortices arrange in the form of a lattice and thus, one has to take into account the interplay of two lattice structures, the Supersolid crystal lattice and the vortex lattice induced by rotation. We aim to study the elastic properties of such a system and compare it with the corresponding superfluid phase.

\(^1\)Physics Department, Indian Institute of Technology, Delhi

4:54PM T4.00013 Rashbons: Emergent bosonic fermion-pairs in synthetic non-Abelian gauge fields\(^1\), JAYANTHA P. VYASANAKERE, VIJAY B. SHENOY, Indian Institute of Science Bangalore — In presence of a synthetic non-Abelian gauge field that produces a Rashba like spin-orbit interaction, a collection of weakly interacting fermions undergoes a crossover from a BCS ground state to a BEC ground state when the strength of the gauge field is increased [PRB 84, 014512 (2011)]. The BEC that is obtained at large gauge coupling strengths is a condensate of tightly bound bosonic fermion-pairs called rashbons. This study reveals a new qualitative aspect that the rashbon state ceases to exist when the center of mass momentum of the fermions exceeds a critical value of the order of the gauge coupling strength. The study allows us to estimate the transition temperature of the rashbon BEC and suggests a route to enhance the exponentially small transition temperature of the system with a fixed weak attraction to the order of the Fermi temperature by tuning the strength of the non-Abelian gauge field. The absence of the rashbon states at large momenta, suggests a regime in parameter space where the normal state of the system will be a dynamical mixture of uncondensed rashbons and unpaired helical fermions. Such a state should show many novel features including pseudogap physics.

\(^1\)Supported by DST and DAE, India

5:06PM T4.00014 Evolution of the structure of vortex core across the BCS-BEC crossover induced by a synthetic non-Abelian gauge field\(^1\), NABYENDU Das, JAYANTHA P. VYASANAKERE, VIJAY B. SHENOY, Indian Institute of Science Bangalore — We study the evolution of the structure of vortex core of fermionic superfluids with increasing strength of a non-Abelian gauge field which induces a spin-orbit interaction. Using the Bogoliubov de-Gennes formulation, we study the spectrum of core states both in the BCS limit (small gauge coupling) and in the rashbon BEC limit where the superfluid is a condensate of rashbons. We show that the novel features of rashbon dispersion, the vanishing of the bound state at finite centre of mass momentum, result in a larger core region for vortices in the rashbon BEC.

\(^1\)Supported by DST and DAE, India
8:00AM V4.00001 Doubled production rate by optical lattice modulation for strongly correlated Fermionic atoms, AKIYUKI TOKUNO, DPMC-MaNEP, University of Geneva, EUGENE DEMLER, Harvard University, THIERRY GIAMARCHI, DPMC-MaNEP, University of Geneva — Currently lattice modulation spectroscopy technique is applied to experiments. [1] In this spectroscopy, the number of doubly occupying atom (doubloon) produced by amplitude modulation of an optical lattice potential is probed. Theoretically, it allows us to access a kinetic energy correlation function. [2] We discuss doubled excitations of strongly correlated fermionic atoms in a high-temperature regime relevant to current experiments of fermionic atoms in an optical lattice. [3] We employ a slave particle representation, and the self-energy is estimated by using non-crossing approximation based on a spin-incoherent assumption. Furthermore, this formalism is applied to calculation of the doubloon production rate as a function of the lattice modulation frequency, chemical potential and temperature. Using parameters given in the experiment [1], a fit to the experimental data is implemented, and quantitatively good agreement is obtained.


8:12AM V4.00002 Superfluid to normal phase transition in strongly correlated bosons in two and three dimensions, JUAN CARRASQUILLA, MARCOS RIGOL, Georgetown University — Using quantum Monte Carlo simulations, we investigate the finite temperature phase diagrams of hardcore bosons in two- and three-dimensional lattices. To determine the phase boundaries, we perform a finite-size-scaling analysis of the condensate fraction and/or the superfluid stiffness. We then discuss how these phase diagrams can be measured in experiments with trapped ultracold gases, where the systems are inhomogeneous. For that, we introduce a method based on the measurement of the zero-momentum occupation, which is adequate for experiments dealing with both homogeneous and trapped systems, and compare it with previously proposed approaches.

8:24AM V4.00003 Double occupancy as a universal probe for antiferromagnetic correlations and entropy in cold fermions on optical lattices, NILS BLUEMER, ELENA GORELIK, DANIEL ROST, Institute of Physics, Johannes Gutenberg University, Mainz, Germany, THEREZA PAIVA, Instituto de Física, Universidade Federal do Rio de Janeiro, Brazil, RICHARD SCALETTRAR, Department of Physics, UC Davis, USA, ANDREAS KLUEMPER, University of Wuppertal, Wuppertal, Germany — We study antiferromagnetic (AF) order and correlations in the half-filled Hubbard model used in dynamical mean-field theory, determinental quantum Monte Carlo (in dimensions $d = 2, 3$), and Bethe Ansatz (in $d = 1$). We establish a low-temperature enhancement of the double occupancy $D$ at strong coupling as a local probe of strong AF correlations accessible in cold-atoms experiments [1]. As a function of entropy $s = S/(Nk_B)$, $D$ is nearly universal with respect to dimensionality, with a minimum in $D(s)$ at $s \approx \log(2)$ [2]. The quantum AF Heisenberg regime at $s \lesssim \log(2)$, driven by an abrupt gain in kinetic energy and with clear signatures also in the next-nearest neighbor correlation function, should be in immediate experimental reach. Long-range order appears hardly relevant for the current search of AF signatures in cold fermions. Thus, experimentalists need not achieve $s < \log(2)/2$ (on a cubic lattice) and should consider lower dimensions, for which the AF effects are larger, or even use dimensionality as a tunable parameter.


8:36AM V4.00004 Tunable Phases of Fermionic Cold Atoms Systems in Mixed Dimensions, KYLE IRWIN, SHAN-WEN TSAI, University of California, Riverside — We investigate a system with two species of fermions. One species, f-fermions, moves on a two-dimensional square lattice. Another species, c-fermions, is constrained to move on a one-dimensional lattice embedded in the square lattice of f-fermions. The phases of the effective one-dimensional system whose interactions are mediated by the two-dimensional system can be tuned by manipulating the two-dimensional density. We explore effective theories, quantum phases, correlations, and relevant energy scales for various fillings of the mixed dimensional system using a functional renormalization group approach.

8:48AM V4.00005 Pairing and Density-Wave Phases of Population Imbalanced Fermi-Fermi Mixture on Optical Lattice, CHEN-YEN LAI, CHUNTAI SHI, SHAN-WEN TSAI, University of California Riverside — We study a two species fermion mixture with different populations on a square lattice, which can be modeled by a Hubbard Hamiltonian with on-site inter-species interaction. Such a model can be realized in a cold atom system with fermionic atoms in two different hyperfine states loaded on an optical lattice, and with interaction strength that can be tuned by an external magnetic field. When one of the fermion species is close to half-filling, the system is highly affected by lattice effects. We find several correlated phases for this system, including spin density wave state, d-wave charge density wave state, and p-wave superfluid state for the minority species. We study this system using a functional renormalization group method, determining its phase diagram and providing an estimate for the critical temperature of each phase. These phases emerge from a combination of interaction, population imbalance, and lattice effects. Lattice effects in particular lead to a much richer phase diagram than that of a imbalanced mixture of fermionic gas.

9:00AM V4.00006 ABSTRACT WITHDRAWN —

9:12AM V4.00007 Finite-temperature Properties of the Fermi-Hubbard Model on the Honeycomb Lattice, BAOMING TANG, EHSAN KHATAMI, Georgetown University, THEREZA PAIVA, Universidade Federal do Rio de Janeiro, MARCOS RIGOL, Georgetown University — We study thermodynamic properties of the Fermi-Hubbard model on the honeycomb lattice utilizing the numerical linked-cluster expansion, which is exact in the thermodynamic limit, and quantum Monte Carlo simulations. We obtain the equation of state, double occupancy, entropy and spin correlations for a wide range of temperatures, chemical potentials, and interaction strengths. Employing a local density approximation, we study properties of the system in the presence of a harmonic trapping potential and compare the efficiency of various adiabatic cooling schemes to those obtained for such model on the square lattice.
9:24AM V4.00008 Realizing a fermionic superfluid state from a band insulator in an optical lattice. YOGESHWAR P. SARASWAT, AMAL MEDHI, VUJAY B. SHENOY, Indian Institute of Science Bangalore — We propose a route to realizing a fermionic superfluid state in an optical lattice starting from a band insulator. We show that by increasing the strength of attractive interaction between the fermions in the single channel, a band insulator can be driven to a superfluid state in an optical lattice. The band structure is suitably designed to avoid other competing states. We estimate the Kosterlitz-Thouless transition temperature of such a superfluid. The proposal could help the realization of a superfluid state of fermions in an optical lattice circumventing the cooling problem.

1Supported by CSIR, DST and DAE, India

9:36AM V4.00009 A Boson Core Compressibility Measure for Optical Lattices. YASAMIN KHORRAMZADEH, FEI LIN, V.W. SCAROLA, Virginia Tech — Trapping in experiments on cold atomic gases in optical lattices leads to inhomogeneity and different phases within the trap. We model a global measure, the boson core compressibility, that can be used to access local properties of a single phase at the center of the trap using observations of double occupancy. We test this measure on the trapped Bose-Hubbard model using mean field theory and quantum Monte Carlo. We find that the boson core compressibility focuses on the core region of the system and eliminates edge effects. We use the core compressibility to identify the transition from Mott insulator to superfluid and show that it is essentially the same as local compressibility in the core region when the system has doubly occupied sites. We generalize the definition of core compressibility to study systems with large densities at the trap center.

This work is supported by AFOSR (FA9550-11-1-0313) and DARPA-YFA (N66001-1-1-4122).

9:48AM V4.00010 Numerical studies of exotic paired states in optical lattices. SIMONE CHIESA, College William & Mary, SHIWEI ZHANG, College of William & Mary, GEORGE BATROUNI, Instituté Non-Linaire de Nice — Ultracold atoms are a unique tool that allows the exploration of phases of matter not easily accessible in condensed matter systems. Two interesting possibilities are spin-imbalanced systems and spin dependent optical lattices with Fermi surfaces that differ for the two hyperfine species. We use mean-field theory and quantum Monte Carlo simulations of Hubbard-like models with an attractive contact interaction to study the FFLO state and, by rotating the two Fermi surfaces by 90 degrees with respect to each other, a recently proposed exotic paired state [Feiguin and Fisher, 2009].

1Supported by ARO and NSF.

10:00AM V4.00011 Competing instabilities in a two band Hubbard model on a square lattice. CHUNTALI SHI, SHAN-WEN TSAI, Department of Physics and Astronomy, University of California Riverside — We study a two band Hubbard model on a two dimensional square lattice. In particular, we focus on the cases wherein one band is doped to have a small electron pocket while the other band is doped to have a hole pocket and the Fermi lines of these two pockets are nearly nested. Similar models have been studied extensively in the context related to the Iron-based material where the interactions between electrons are always repulsive. Here we investigate the generalized cases that the interactions between the fermions within the same band $U_1$ and $U_2$ and the interactions between electrons in different bands $U_{12}$ can be tuned independently. Such models can potentially be realized in a cold atom system where the manipulation of the interaction is possible by taking advantage of the Feshbach resonance. The freedom of tuning the strength and the sign (repulsive or attractive) of the interactions, combined with the nearly nested Fermi lines, allows both the density wave phases and the pairing phases to be potential candidates for the ground state. We employ the functional renormalization group approach so that we can investigate the competition between these possible instabilities on an equal footing.

10:12AM V4.00012 Condensate Properties for Strongly Repulsive Bosons in a Double Well. JOEL CORBO, UC Berkeley, JONATHAN DOBUIS, LLNL, BIRGITTA WHALEY, UC Berkeley — We present path integral ground state (PIGS) quantum Monte Carlo calculations for the ground state $(T = 0)$ properties of repulsively interacting bosons in a three-dimensional external double well potential over a range of interaction strengths and potential parameters. We focus on calculation of ground state number statistics in order to understand the level of squeezing that the system may exhibit as a function of interaction strength. For weak interactions (i.e. where the standard two-mode model of a BEC in a double well is applicable) we produce results consistent with the two-mode model. However, for stronger interactions, we find a novel and somewhat surprising relationship between squeezing and interaction strength. We find that these new features are qualitatively consistent with squeezing calculations carried out using an improved, recently-proposed eight-mode model, although this model is insufficient to quantititively predict the results of the full quantum Monte Carlo simulation.

10:24AM V4.00013 A Quantum Plasmonic Circuit for Cold Atoms. MICHAEL GULLANS, Harvard University, DARRICK CHANG, California Institute of Technology, JOHANNES FEIST, TOBIAS TIECKE, JEFF THOMPSON, Harvard University, IGNACIO CIRAC, Max-Planck-Institut fur Quantenoptik, PETER ZOLLER, Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, MIKHAIL LUKIN, Harvard University — We propose a new architecture for quantum simulation with atoms using a two dimensional lattice of plasmonic nanoparticles to both trap the atoms and mediate interactions between them. This proposal combines existing technologies from ultracold atoms and plasmonics to exploit the unique coherence properties of atoms and the strong light-matter interaction and subwavelength confinement provided by plasmonic systems. We first show that this system allows to increase the energy scales of Hubbard models by two orders of magnitude compared to optical lattices. We then show how this system can realize a dissipative quantum simulator to prepare a wide range of many-body entangled states.

Thursday, March 1, 2012 8:00AM - 11:00AM — Session V10 GQI DAMOP: Invited Session: Quantum Entanglement in Many-Body Systems 210A

8:00AM V10.00001 Entanglement, teleportation and memory in atomic spin ensembles. EUGENE POLZIK, Niels Bohr Institute, Copenhagen University — Recent experimental progress with entanglement generation and processing in macroscopic atomic spin ensembles will be reviewed. It includes atomic entanglement maintained for an unlimited time via engineered collective dissipation mediated by light and teleportation of collective atomic spin states. A proposal for quantum memory assisted detection of strongly coupled systems will be presented.

8:36AM V10.00002 Entanglement and real-space renormalization group methods for quantum field theories. FRANK VERSTRAETE, University of Vienna — We will demonstrate how the reformulation of the density matrix renormalization group as a variational method within the class of matrix product states has lead to a wide class of novel applications and insights into strongly correlated quantum systems in 1 dimension. The discussion will detail the crucial role of entanglement and area laws, and then focus on the generalization of matrix product state methods to quantum field theories and the prospects of simulating experiments with cold gasses. Joint work with I. Cirac, J. Haegeman, T. Osborne.
9:12AM V10.00003 Entangled States of Trapped Ions\(^1\). DIETRICH LEIBFRIED, National Institute of Standards and Technology — Entangled states of the internal degrees of freedom are an important resource in Quantum Information Processing (QIP) and Quantum Simulation (QS) with trapped ions. Most basic requirements for QIP and QS have been demonstrated for trapped ions, with two big challenges remaining: Improving operation fidelity and scaling up to larger numbers of qubits. In the last few years, steady progress has been achieved with laser-based entanglement schemes with demonstrated fidelities of deterministically produced Bell states of 99.3% and up to 14 ion-qubits entangled in generalized GHZ-states. Scalable architectures have been proposed; one scheme, where ion-qubits are moved through a multi-zone trap array, is studied in several laboratories. Sympathetic cooling with a second ion species, which initializes the motional states for multi-qubit operations, has been demonstrated in an experiment where arbitrary operations on two qubits were implemented. Micro-fabrication approaches to ion-trap-arrays have yielded structures that should be capable of holding and manipulating large numbers of ions. Recently, with the use of microwaves, single-qubit rotations with fidelities of 99.998% per gate operation were demonstrated and two ion-qubit gates have been implemented. Microwave control could potentially be easier to scale by directly integrating microwave-lines on micro-fabricated trap devices. It also eliminates several sources of decoherence that are present in laser-based schemes by exclusively coupling to long lived hyperfine ground states.

\(^1\)NIST work has been supported by IARPA, DARPA, NSA, ONR and the NIST Quantum Information Program.

9:48AM V10.00004 Topological order and long range quantum entanglements. XIAO-GANG WEN, Dept. of Physics, MIT — What is the origin of fractional charges and fractional statistics in FQH states? What is the origin of light? It turns out that long range entanglement is the reason why fractional charges and fractional statistics can appear FQH state. Long range entanglement also lead to a deeper understanding of gapped quantum phases. It allows us to obtain a classification of interacting topological insulators/superconductors, as well as the much more general symmetry protected topological phases, and intrinsic topological phases.

10:24AM V10.00005 Entangled states as resources in quantum complexity theory. SCOTT AARONSON, MIT Dept. of Electrical Engineering and Computer Science — No abstract available.

Thursday, March 1, 2012 11:15AM - 1:51PM – Session W1 DAMOP: Photonic Systems and Entanglement Generation 203

11:15AM W1.00001 Efficient quantum computing using coherent photon conversion. NATHAN K. LANGFORD, University of Vienna, Austrian Academy of Sciences, University of Oxford, SVEN RAMELOW, University of Vienna, Austrian Academy of Sciences, ROBERT PREVEDEL, University of Vienna, University of Waterloo, WILLIAM J. MUNRO, NII and NTT Basic Research Laboratories, GERARD J. MILBURN, University of Queensland, University of Vienna, ANTON ZEILINGER, University of Vienna, Austrian Academy of Sciences — Single photons make very good quantum information carriers, but current schemes for photonic quantum information processing (QIP) are inefficient. We describe a new scheme, coherent photon conversion (CPC), using classically pumped nonlinearities to generate and process complex multiqubit states. One example based on four-wave mixing provides a full suite of CPC tools for scalable quantum computing from a single, versatile process, including: deterministic multiqubit entanglement gates based on a novel photon-photon interaction, high-quality heralded multiphoton states without higher-order imperfections, and robust, high-efficiency detection. Using photonic crystal fibres, we present observations of quantum correlations from a four-colour nonlinear process suitable for CPC and study the feasibility of reaching the deterministic regime with current technology. The scheme could also be implemented in optomechanical, electromechanical and superconducting systems.

\(^1\)Published in Nature 478, 360 (2011)

11:27AM W1.00002 Dephasing of multiparticle Rydberg excitations for fast entanglement generation\(^1\). F. BARIANI, Y.O. DUDIN, T.A.B KENNEDY, A. KUZMICH, School of Physics, Georgia Institute of Technology, Atlanta, GA, 30332-0430, USA — We propose an approach to fast entanglement generation based on Rydberg dephasing of collective excitations (spin waves) in large, optically thick atomic ensembles. Rather than trying to prevent multiple excitations via the Rydberg blockade mechanism, our idea is to allow multiple Rydberg level excitations to self-interact and dephase. The strong interaction required to dephase multiple excitations is induced by mixing adjacent, opposite-parity Rydberg levels with a microwave field. These levels experience resonant $1/r^3$ dipole-dipole interactions $(n s+n p \rightarrow n p+n s)$ that extend over the whole ensemble in contrast to the weaker, short range $1/r^6$ Van der Waals coupling due to non-resonant processes $(n s+n s \rightarrow n p+(n-1)p)$. The interaction-induced phase shifts suppress the contribution of multiply excited states in phase matched optical retrieval. The dephasing mechanism therefore permits isolation and manipulation of individual spin wave excitations. High quality single photons can be created with $1/e$ maximum efficiency in few microseconds. The dephasing mechanism is shown to have favorable, approximately exponential, scaling. Required long coherence times are achieved via four-photon excitation and read-out of long wavelength spin waves.

\(^1\)We acknowledge financial support from NSF and AFOSR.

11:39AM W1.00003 Unconventional ultra-efficient photon blockade and single-photon emitters from weakly nonlinear systems based on coupled cavities. MOTOAKI BAMBA, CRISTIANO CIUTI, Laboratory MPQ, University Paris Diderot - Paris 7 and CNRS — Single photons are usually generated by non-resonant excitation of single (artificial) atoms or by resonant excitation of Kerr systems with a giant nonlinear interaction much larger than the losses of the system (standard photon blockade). Here, we present a general class of destructive quantum interference effects [1,2], which provide a robust protocol to achieve strong photon antibunching and single-photon emission in a double cavity system, where one resonantly driven cavity is coupled to an auxiliary nonlinear cavity. An original scheme [2] shows the single-photon emission can be also produced by the auxiliary cavity with orthogonal polarization with respect to the pump beam, hence providing a direct way to get spatial and polarization selection.


11:51AM W1.00004 Anomalous Stokes scattering by an atomic ensemble: detection of entanglement and vector metrology of field gradient\(^1\). WANG YAO, HONGYI YU, Department of Physics and Center for Theoretical and Computational Physics, The University of Hong Kong — We investigate the collective Stokes scattering by a typical atomic cloud, i.e. with size much larger than the light wavelength and with density much lower than that required for Dicke superradiance. We show that the diffraction pattern of the Stokes photon can be used to detect entanglement in the atomic ensemble. When the atomic cloud is placed in a static magnetic field or electric field, the change of diffraction pattern by the evolution in the field can also provide sensitive vector metrology of the spatial gradient of the field.

\(^1\)The work was supported by the Research Grant Council of Hong Kong under Grant No. HKU 706711P.

12:03PM W1.00005 Unique Properties and Prospects: Quantum Theory of the Orbital Angular Momentum of Ince-Gauss Beams\(^1\), WILLIAM PLICK, MARIO KRENN, ROBERT FICKLER, SVEN RAMELOW, ANTON ZEILINGER, Institute for Quantum Optics and Quantum Information — The Ince-Gauss modes represent a new addition to the standard solutions to the paraxial wave equation. Parametrized by the ellipticity of the beam, they span the solution space between the Hermite-Gauss and the Laguerre-Gauss modes. These beams may be decomposed in either basis, and single photons in the Ince-Gauss modes exist naturally as superpositions of either Laguerre-Gauss or Hermite-Gauss modes. We present the fully quantum theory of the orbital angular momentum of these beams. Interesting features that arise are: stable beams with fractional orbital angular momentum, non-monotonic behavior of the OAM with respect to ellipticity, and the possibility of orthogonal modes possessing the same OAM. We believe that these modes may open up a fully new parameter space for quantum informatics and communication, and thus are worthy of thorough study.

\(^1\)Austrian Academy of Sciences

12:15PM W1.00006 Entanglement of Ince-Gauss Modes of Photons\(^1\), MARIO KRENN, ROBERT FICKLER, WILLIAM PLICK, RADEK LAPKIEWICZ, SVEN RAMELOW, ANTON ZEILINGER, University of Vienna, Faculty of Physics, IQOQI Vienna, Austrian Academy of Sciences, Austria — Ince-Gauss modes are solutions of the paraxial wave equation in elliptical coordinates [1]. They are natural generalizations both of Laguerre-Gauss and of Hermite-Gauss modes, which have been used extensively in quantum optics and quantum information processing over the last decade [2]. Ince-Gauss modes are described by one additional real parameter – ellipticity. For each value of ellipticity, a discrete infinite-dimensional Hilbert space exists. This conceptually new degree of freedom could open up exciting possibilities for higher-dimensional quantum optical experiments. We present the first entanglement of non-trivial Ince-Gauss Modes. In our setup, we take advantage of a spontaneous parametric down-conversion process in a non-linear crystal to create entangled photon pairs. Spatial light modulators (SLMs) are used as analyzers. [1] Miguel A. Bandres and Julio C. Gutiérrez-Vega “Ince-Gaussian beams”, Optics Letters, Vol. 29, Issue 2, 144-146 (2004) [2] Adetunmise C. Dada, Jonathan Leach, Gerald S. Buller, Miles J. Padgett, and Erika Andersson, “Experimental high-dimensional two-photon entanglement and violations of generalized Bell inequalities”, Nature Physics 7, 677-680 (2011)

\(^1\)Supported by ERC (Advanced Grant QIT4QAD) and the Austrian Science Fund (SFB F4007, CoQuS).

12:27PM W1.00007 Entangling two spatially separated qubits via interaction with nonclassical radiation\(^1\). EYOB SETE, Department of Physics and Astronomy, Texas A&M University, SUMANTA DAS, Max-Planck-Institute fur Kernphysik — We propose a scheme for entangling two spatially separated noninteracting qubits using two-mode squeezed light in a cavity. Unlike other methods that typically require dipolar coupling for creating entanglement, our proposal relies solely on the interaction of the qubits with the squeezed cavity field. The squeezed field induces exchange of correlated photons which leads to transfer of entanglement from the field to discrete entanglement between qubits. Our scheme exhibits substantial steady-state entanglement which is robust against decoherence under the strong squeezing condition. In addition, we find that the entanglement generated between two asymmetric qubits is stronger than that generated by identical ones and crucially depends on the degree of squeezing.

\(^1\)E. A. S. is supported by the Herman F. Heep and Minnie Belle Heep Texas A&M University Endowed Fund held and administered by the Texas A&M Foundation.

12:39PM W1.00008 Generating coherent states of entangled spins\(^1\), HONGYI YU, YU LUO, WANG YAO, Department of Physics and Center of Theoretical and Computational Physics, The University of Hong Kong, Hong Kong, China — A coherent state of many spins contains quantum entanglement, which increases with the decrease of the collective spin value. We present a scheme to engineer this class of pure state based on incoherent spin pumping with several collective raising and lowering operators. In a pumping scenario aimed for maximum entanglement, the N-qubit steady state realizes the ideal resource for the \(1\rightarrow N/2\) quantum telecloning. We show how the scheme can be implemented in the cold atomic system in an optical lattice. Error analysis shows that high-fidelity state engineering is possible for \(N\sim O(100)\) spins in the presence of decoherence. The scheme can also prepare the large-scale Affleck-Kennedy-Lieb-Tasaki state.

\(^1\)The work was supported by the Research Grant Council of Hong Kong under Grant No. HKU 706711P.

12:51PM W1.00009 Non-destructively probing matter-photon correlations described by the Dicke-Hubbard Lattice model\(^1\). SARA RAJARAM, NANDINI TRIVEDI, The Ohio State University — The Dicke-Hubbard Lattice (DHL) Hamiltonian is a prototypical system to study photon matter entanglement across a symmetry breaking quantum phase transition in the matter subsystem. The model describes a cavity containing a periodic lattice, with a single mode photon field delocalized across the cavity. Like the Bose-Hubbard model, the Hamiltonian includes on-site repulsion between atoms and nearest neighbor hopping of an atom from one site to another. In addition, matter-light coupling in the DHL model can excite an atom to a high excited state that is a superposition of a photon and a three-body resonance. We feature the DHL model in a region of parameter space in which light is “superradiant” and matter is either a Mott-insulator or superfluid of both bands. Through mean field, exact diagonalization, and quantum Monte Carlo calculations we examine photon statistics across the matter quantum phase transition in order to elucidate how the photon statistics reflect the matter correlations. Doing so provides a novel technique to non-destructively probe the Mott-insulator to superfluid phase transition.

\(^1\)We acknowledge support from ARO W911NF-08-1-0338 (SR) and NSF DMR-0907275 (NT).

1:03PM W1.00010 The Impact of Geometry on the TM PBGs of Photonic Crystals and Quasicrystals\(^1\), LIN JIA, MIT, ION BITA, Qualcomm MEMS Technologies, EDWIN THOMAS, Rice University — Here we demonstrate a novel quantitative procedure to pursue statistical studies on the geometric properties of photonic crystals and photonic quasicrystals (PQCs) which consist of separate dielectric particles. The geometric properties are quantified and correlated to the size of the photonic band gap (PBG) for wide permittivity range using three characteristic parameters: shape anisotropy, size distribution, and feature-feature distribution. Our concept brings statistical analysis to the photonic crystal research and offers the possibility to predict the PBG from a morphological analysis.
1:15PM W1.00011 A low-dimensional population-competition model for analyzing transverse optical patterns 1, Y.C. TSE, M.H. LUK, Physics Department, Chinese University of Hong Kong, N.H. KWONG, College of Optical Sciences, University of Arizona, P.T. LEUNG, Physics Department, Chinese University of Hong Kong, S. SCHUMACHER, Physics Department and Center for Optoelectronics and Photonics Paderborn, University of Paderborn, R. BINDER, College of Optical Sciences and Department of Physics, University of Arizona — Under favorable conditions, laser beams passing through a nonlinear medium (e.g. atomic vapors) can undergo directional instabilities, generating transverse optical patterns in the far field. In particular, a low intensity all-optical switching scheme using these transverse patterns in semiconductor quantum well microcavities was numerically demonstrated. Trying to understand the switching mechanism through the simulation results has turned out to be a complicated task. In this contribution, we present a low-dimensional “population-competition” model that (i) exhibits nearly all the pattern selection and switching behaviors and (ii) is simple enough to allow a comprehensive analysis of its solution structure in the relevant region of parameter space. We will explain the relation between this simple model and the realistic theory. Using elementary methods in Catastrophe Theory, we analyze the “phase diagrams” of our model’s steady state solutions in parameter space, with the help of which we construct an organized picture of the behaviors of the realistic simulation results.

1S. S. acknowledges financial support from the Deutsche Forschungsgemeinschaft.

1:27PM W1.00012 Phonon effects on analog quantum simulation with ultracold ions in a linear Paul trap, C.-C. JOSEPH WANG, JAMES FREERICKS, Georgetown University — Linear Paul traps have been used to simulate the transverse field Ising model with long-range spin couplings. Here, we study the effects of phonon creation on the spin state probability and spin entanglement. The effective spin models are created by applying a spin-dependent force with a laser that couples the spin state to the phonons of the ion crystal. Adiabatically removing the phonons creates an action described by a static spin Hamiltonian plus additional quantum time-dependent phases. In appropriate limits, the system is described predominantly by the static spin Hamiltonian. Here, we solve for the evolution of the coupled spin-phonon system exactly using exact diagonalization and examine the effect of phonon creation during the simulation on the probabilities of different spin states and on their entanglement. In particular, we examine phonon effects on the possibility for seeing the kink transition when the laser is detuned between the two phonon modes that lie below the COM mode.

1:39PM W1.00013 Entanglement Effects in Highly Dense Systems, SAMINA MASOOD, University of Houston-Clear Lake — We study the effect of entanglement in Jaynes-Cummings model using Neumann Entropy in the highly dense systems. We study a highly dense system such as neutron star as a good application of our results.

Thursday, March 1, 2012 11:15AM - 1:51PM – Session W4 DAMOP: Strongly Interacting Fermi Gases 205C

11:15AM W4.00001 Revealing the Superfluid Lambda Transition in the Universal Thermodynamics of a Unitary Fermi Gas 1, MARK KU, ARIEL SOMMER, LAWRENCE CHEUK, MARTIN ZWIERLEIN, Department of Physics, MIT-Harvard Center for Ultracold Atoms, and Research Laboratory of Electronics, MIT, Cambridge, Massachusetts 02139, USA — We have observed the superfluid phase transition in a strongly interacting Fermi gas via high-precision measurements of the local compressibility, density and pressure down to near-zero entropy. We perform the measurements by in-situ imaging of ultracold 6Li at a Feshbach resonance. Our data completely determine the universal thermodynamics of strongly interacting fermions without any fit or external thermometer. The onset of superfluidity is observed in the compressibility, the chemical potential, the entropy, and the heat capacity. In particular, the heat capacity displays a characteristic lambda-like feature at the critical temperature of $T_s/T_F = 0.167(13)$. This is the first clear thermodynamic signature of the superfluid transition in a spin-balanced atomic Fermi gas. We provide a new value of the Bertsch parameter $\xi_c$. The experimental results are compared to recent Monte-Carlo calculations. Our measurements provide a benchmark for many-body theories on strongly interacting fermions, relevant for problems ranging from high-temperature superconductivity to the equation of state of neutron stars.

1This work was supported by the NSF, AFOSR-MURI, ARO-MURI, ONR, DARPA YFA, a grant from the Army Research Office with funding from the DARPA OLE program, an AFOSR PECASE, the David and Lucile Packard Foundation, and the Alfred P. Sloan Foundation.

11:27AM W4.00002 Probing upper branch physics in strongly interacting Fermi gases 1, SHIZHONG ZHANG, The Ohio State University, EDWARD TAYLOR, McMaster University, WILLIAM SCHNEIDER, MOHIT RANDERIA, The Ohio State University — Motivated by a recent experiment at MIT, we consider the collision of two clouds of spin-polarized atomic Fermi gases close to a Feshbach resonance. We explain why two dilute gas clouds, with attractive interactions between its constituents, bounce off each other as if they were billiard balls. Our hydrodynamic analysis, in excellent agreement with experiment, gives strong evidence for a novel metastable many-body state, the so-called upper branch, with repulsive interaction imbalances at finite temperature. In this talk, we will address the finite temperature phase diagrams of two component atomic Fermi gases with both mass and population imbalances, as well as species dependent trapping potential. Indeed, the mixture of 6Li and 40K gases has been of great interest, with and without population imbalance. In this talk, we will address the finite temperature phase diagrams of two component atomic Fermi gases with both mass and population imbalances in a trap, using a pairing fluctuation theory. We show that in certain parameter ranges, there exist intermediate temperature superfluids as well as phase separation with exotic sandwich-like shell structure with superfluid or pseudogapped normal state in the middle. We consider pairing strength over the entire range of BCS-BEC crossover. Our result is relevant to future experiment on mixtures of 6Li and 40K and possibly other Fermi atoms. References: H. Guo, C.-C. Chien, Q.J. Chen, Y. He, and K. Levin, Phys. Rev. A 80, 011601(R) (2009); C.-C. Chien, Q.J. Chen, Y. He, and K. Levin, Phys. Rev. Lett. 98, 110404 (2007); C.-C. Chien, Q.J. Chen, Y. He, and K. Levin, Phys. Rev. Lett. 97, 090402 (2006); Q.J. Chen, I. Kosztin, B. Janko, and K. Levin, Phys. Rev. Lett. 81, 4708 (1998).

1Supported by NSF-DMR 0706203, NSF-DMR 0907666, and ARO W911NF-08-1-0338, and NSEC.

11:39AM W4.00003 Strongly interacting atomic Fermi gases in a trap with mass and population imbalances at finite temperature 1, JIBIAO WANG, Zhejiang University, HAO GUO, Hong Kong University, QUIN CHEN, Zhejiang University — A great advantage of studying atomic Fermi gases is the easy tunability of multiple physical parameters, including interaction strength, mass and population imbalances, as well as species dependent trapping potential. Indeed, the mixture of 6Li and 40K gases has been of great interest, with and without population imbalance. In this talk, we will address the finite temperature phase diagrams of two component atomic Fermi gases with both mass and population imbalances in a trap, using a pairing fluctuation theory. We show that in certain parameter ranges, there exist intermediate temperature superfluids as well as phase separation with exotic sandwich-like shell structure with superfluid or pseudogapped normal state in the middle. We consider pairing strength over the entire range of BCS-BEC crossover. Our result is relevant to future experiment on mixtures of 6Li and 40K and possibly other Fermi atoms. References: H. Guo, C.-C. Chien, Q.J. Chen, Y. He, and K. Levin, Phys. Rev. A 80, 011601(R) (2009); C.-C. Chien, Q.J. Chen, Y. He, and K. Levin, Phys. Rev. Lett. 98, 110404 (2007); C.-C. Chien, Q.J. Chen, Y. He, and K. Levin, Phys. Rev. Lett. 97, 090402 (2006); Q.J. Chen, I. Kosztin, B. Janko, and K. Levin, Phys. Rev. Lett. 81, 4708 (1998).

1Supported by NSF, MOE and MOST of China.
Two-particle current from Superfluid Fermi Gases in the BCS-BEC Crossover

11:51AM W4.00004 Two-particle current from Superfluid Fermi Gases in the BCS-BEC Crossover, EMIKO ARAHATA, Department of Basic Science, The University of Tokyo, TETSURO NIKUNI, Department of Physics, Faculty of Science, Tokyo University of Science — In recent years, the crossover from the BCS-type superfluid to the Bose-Einstein condensation (BEC) of tightly-bound molecules has been realized in ultracold atomic Fermi gases using a tunable pairing interaction associated with a Feshbach resonance. In the BCS-BEC crossover it will be important to reveal the nature of fermion pairs. In this paper, we propose that two-particle (double photoemission) current (DPE current) is a powerful technics to provide direct insight into the pair-correlations. The DPE from superconductors has been studied both theoretically and experimentally, where a pair of electrons is emitted from the system upon the absorption of one photon. In this study, we consider an analogous situation in ultracold atomic gases, and derive a general expression for DPE current in the BCS-BEC crossover. We show DPE current as a function of energy and momentum to provide direct insight into the pair-correlations. The DPE from superconductors has been studied both theoretically and experimentally, where a pair of electrons is emitted from the system upon the absorption of one photon. In this study, we consider an analogous situation in ultracold atomic gases, and derive a general expression for DPE current in the BCS-BEC crossover. We show DPE current as a function of energy and momentum to provide direct insight into the pair-correlations.

ZHAOCHUAN SHEN, LEO RADZIHOVSKY, VICTOR GURARIE, Department of Physics, University of Colorado — In this talk we study Feshbach resonances of fermionic atoms placed in a periodic potential. We investigate the criteria when such a system can be described by a Hubbard model with variable interaction strength in case of broad resonance, or by a tight binding model of atoms and molecules with can convert into each other on sites of the lattice in case of narrow resonances. Assuming the applicability of these models, we first study the BCS-BEC crossover for broad resonance. We find that while below half filling the system undergoes the convectional crossover from a BCS superconductor to a Bose condensate of molecules, above half filling the nature of the BEC phase changes to that of a condensate of molecules made of holes. Switching our attention to the case of narrow resonance, we find that the crossover takes the system from a BCS to hole-BEC regime, than back to BCS, and finally to a conventional BEC of atomic molecules. In the latter crossover, we find that the size of Cooper pairs/molecules changes non-monotonously, being larger in the BCS and smaller in the BEC regimes. Finally, at a unity filling we find a quantum phase transition from a band insulator to a BCS-BEC superfluid replacing the crossover.

12:03PM W4.00005 Feshbach resonances and BCS-BEC crossover in optical lattices, ZHAOCHUAN SHEN, LEO RADZIHOVSKY, VICTOR GURARIE, Department of Physics, University of Colorado — In this talk we study Feshbach resonances of fermionic atoms placed in a periodic potential. We investigate the criteria when such a system can be described by a Hubbard model with variable interaction strength in case of broad resonance, or by a tight binding model of atoms and molecules with can convert into each other on sites of the lattice in case of narrow resonances. Assuming the applicability of these models, we first study the BCS-BEC crossover for broad resonance. We find that while below half filling the system undergoes the convectional crossover from a BCS superconductor to a Bose condensate of molecules, above half filling the nature of the BEC phase changes to that of a condensate of molecules made of holes. Switching our attention to the case of narrow resonance, we find that the crossover takes the system from a BCS to hole-BEC regime, than back to BCS, and finally to a conventional BEC of atomic molecules. In the latter crossover, we find that the size of Cooper pairs/molecules changes non-monotonously, being larger in the BCS and smaller in the BEC regimes. Finally, at a unity filling we find a quantum phase transition from a band insulator to a BCS-BEC superfluid replacing the crossover.

12:15PM W4.00006 Resonant enhancement of the FFLO state in 3D by an optical potential, JEROEN DEVREESE, SERGHEI KLIMIN, MICHEL WOUTERS, JACQUES TEMPERE, Universiteit Antwerpen, TQC (THEORIE VAN KWANTUMSYSTEEMEN EN COMPLEXE SYSTEMEN) TEAM — In a two component Fermi gas, spin-imbalance leads to a competition between Cooper-pairing with zero momentum and with nonzero momentum. The latter gives rise to the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state. Hitherto this state has not been observed in a 3D Fermi gas. We propose a new way to enhance the presence of the FFLO state, by adding a 1D periodic potential. To investigate the effect of this potential, we study the ground state properties of the system, starting from the partition sum of an imbalanced Fermi gas in path-integral representation. To describe the FFLO state, a saddle point is chosen in which the pairs can have nonzero momentum. Minimizing the resulting free energy leads to the phase diagram of the system. The stability region of the FFLO state is found to be greatly enlarged due to the presence of the periodic potential, compared to the ordinary 3D case. We find that the FFLO state can exist at higher spin imbalance if the wavelength of the optical potential becomes smaller. We propose that this concept can be used experimentally to enhance the FFLO state.

12:27PM W4.00007 Single magnetic impurity in a spin-imbalanced superfluid Fermi gas, JIAN LI, CHIN-SEN TING, Texas Center for Superconductivity and Department of Physics, University of Houston, TEXAS CENTER FOR SUPERCONDUCTIVITY AND DEPARTMENT OF PHYSICS, UNIVERSITY TEAM — A spin-imbalanced superfluid Fermi gas harmonically trapped in a two-dimensional optical lattice with a single classical magnetic impurity is investigated by Bogoliubov-de Gennes equations. In spin-balanced and weak spin-imbalanced case, we show that a strong magnetic impurity can change sign of the pairing order parameter. The amplitude of the sign-changed order parameter caused by impurity is affected by the strength of impurity potential, temperature and particle density. Compared to spin-balanced case, we find that an additional in-gap bound state can be indicated for a strong magnetic impurity in weak spin-imbalanced case. In strong spin-imbalanced case where the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state is established as the ground state, the impurity induces wide spatial oscillations of pairing order parameters and can enhance the order parameters by suppressing the local spin-imbalance. Our results can be used to create and manipulate the FFLO state with magnetic impurities in spin-imbalanced Fermi gases.

12:39PM W4.00008 Proposal for interferometric detection of the topological character of modulated superfluidity in ultracold Fermi gases, MASON SWANSON, The Ohio State University, YEN LEE LOH, The University of North Dakota, NANDINI TRIVEDI, The Ohio State University — A system with unequal populations of up and down fermions may exhibit a Larkin-Ovchinnikov (LO) phase characterized by periodic domain walls across which the order parameter changes sign and the excess polarization is localized. Despite fifty years of theoretical and experimental work, there has so far been no unambiguous observation of an LO phase. We propose an experiment in which two fermion clouds, prepared with unequal population imbalances, are allowed to expand and interfere. We show that a pattern of staggered fringes in the interference is unequivocal evidence of LO physics. The resilience of these interference signatures against thermal and quantum fluctuations is also discussed, and our results are supported with time-of-flight simulations of the experiment. Y.-L. Loh and N. Trivedi, Phys. Rev. Lett. 104, 165302 (2010). M. Swanson et al., arXiv:1106.3908

12:51PM W4.00009 A single impurity atom in a two-dimensional Fermi gas, JESPER LEVINSEN, University of Cambridge, MEERA PARISH, University College London — We consider a single impurity atom immersed in a Fermi gas in two dimensions and interacting with an attractive short-range potential. Using variational wave functions for polarons, molecules, trimers, and quadrupoles, we arrive at the ground state phase diagram as a function of mass ratio and interaction strength. We show that the phase diagram includes a Fulde-Ferrell-Larkin-Ovchinnikov phase for experimentally relevant mass ratios.

1:03PM W4.00010 Realization of a Resonant Fermi Gas with a Large Effective Range, ERIC HAZLETT, YI ZHANG, RON STITES, KEN O'HARA, The Pennsylvania State University — We have measured the interaction energy and three-body recombination rate for a two-component Fermi gas near a narrow Feshbach resonance and found both to be strongly energy dependent. Even for deBroglie wavelengths greatly exceeding the van der Waals length scale, the behavior of the interaction energy as a function of temperature cannot be described by atoms interacting via a contact potential. Rather, energy-dependent corrections beyond the scattering length approximation are required, indicating a resonance with an anomalously large effective range. For fields where the molecular state is above threshold, the rate of three-body recombination is enhanced by a sharp, two-body resonance arising from the closed-channel molecular state which can be magnetically tuned through the continuum. This narrow resonance can be used to study strongly correlated Fermi gases that simultaneously have a sizeable effective range and a large scattering length.
Magnons, Rydberg Atoms, and Polar Molecules

Sergej Demokritov, Institute for Applied Physics, University of Münster, Germany

1:03PM W10.00004 An ultracold high-density sample of rovibronic ground-state molecules in an optical lattice, HANS-CHRISTOPH NAEGELI, University of Innsbruck — No abstract available.

1:39PM W4.00011 Anomalous Dimers in Quantum Mixtures near Broad Resonances: Pauli Blocking, Fermi Surface Dynamics and Implications

JUNLIANG SONG, Institute of Quantum Optics and Quantum Information of Austrian Academy of Sciences, FEI ZHOU, University of British Columbia — We study the energetics and dispersion of anomalous dimers that are induced by the Pauli blocking effect in a quantum Fermi gas of majority atoms near interspecies resonances. Unlike in vacuum, we find that both the sign and magnitude of the dimer masses are tunable via Feshbach resonances. We also investigate the effects of particle-hole fluctuations on the dispersion of dimers and demonstrate that the particle-hole fluctuations near a Fermi surface (with Fermi momentum \( h k_F \)) generally reduce the effective two-body interactions and the binding energy of dimers. Furthermore, in the limit of light minority atoms the particle-hole fluctuations disfavor the formation of dimers with a total momentum \( h k_F \), because near \( h k_F \) the modes where the dominating particle-hole fluctuations appear are the softest. Our calculation suggests that near broad interspecies resonances when the minority-majority mass ratio \( m_B/m_P \) is smaller than a critical value (estimated to be 0.136), dimers in a finite-momentum channel are energetically favored over dimers in the zero-momentum channel. We apply our theory to quantum gases of \( ^6\text{Li}^{40}\text{K}, ^6\text{Li}^{87}\text{Rb}, ^{40}\text{K}^{87}\text{Rb} \) and \( ^6\text{Li}^{23}\text{Na} \) near broad interspecies resonances, and discuss the implications.

3 Austrian Science Fund FWF FOCUS

1:27PM W4.00012 Unpolarized Fermi gas in squeezed anisotropic harmonic trap by Quantum Monte Carlo methods

XIN LI, LUBOS MITAS, Physics Department, North Carolina State University — Using diffusion Monte Carlo (DMC) method, we calculate the ground state properties of unpolarized Fermi gas at unitarity regime in both isotropic and anisotropic harmonic potentials. We study the effects of anisotropy by increasing the frequency in z direction \( \omega_z \) of the harmonic potential while keeping the frequency in x and y direction unchanged. The true unitarity regime is obtained by extrapolating the interaction range to zero and the calculations are done using the fixed-node diffusion Monte Carlo method. The trial function is of the BCS form with the pairing function expanded in appropriate linear combinations of the anisotropic oscillator eigenstates. We evaluate the binding energies for various particle numbers and we estimate its behavior in the limit of large number of atoms. We estimate dependence of projected density profile and momentum distribution on the X-Y plane with respect to \( \omega_z \). Our results can be readily used as a benchmark for the cold atom experiment with similar experimental set-up. Supported by ARO and NSF.

1:39PM W4.00013 A Theory for Normal Fermi Gases at Unitarity

ERIK WEILER, THEJA DE SILVA, Binghamton University — In this study, we will develop a simple, yet accurate, mean-field-like theory for the normal phase of a unitarity Fermi gas. First, we derive a self-consistent equation for the self-energy using a momentum-dependent coupling constant. Using zero temperature Monte Carlo results as a starting point, we then derive an analytical expression for the momentum-dependent self-energy within one-step iteration. Lastly, we determine the validity of our analytical self-energy by comparing it to fully numerical calculations. Our theory shows excellent agreement with pressure measurements made by Nascimbene, et al. in a recent experiment performed by the ENS group.


11:15AM W10.00001 Bose-Einstein condensation of photons

MARTIN WEITZ, University of Bonn — Bose-Einstein condensation, the macroscopic ground state accumulation of particles with integer spin (bosons) at low temperature and high density, has been observed in several physical systems, including cold atomic gases and solid state physics quasiparticles. However, the most omnipresent Bose gas, blackbody radiation (radiation in thermal equilibrium with the cavity walls) does not show this phase transition. The photon number is not conserved when the temperature of the photon gas is varied (vanishing chemical potential), and at low temperatures photons disappear in the cavity walls instead of occupying the cavity ground state. Here I will describe an experiment observing a Bose-Einstein condensation of photons in a dye-filled optical microcavity [1]. The cavity mirrors provide both a confining potential and a non-vanishing effective photon mass, making the system formally equivalent to a two-dimensional gas of trapped, massive bosons. By multiple scattering of the dye molecules, the photons thermalize to the temperature of the dye solution. In my talk, I will begin with a general introduction and give an account of current work and future plans of the Bonn photon gas experiment.


11:51AM W10.00002 Superfluid Phase Transition of Long-Lifetime Polaritons

DAVID SNOKE, University of Pittsburgh — Exciton-polaritons are quanta of electronic excitation which can have their properties tailored in semiconductor structures to have extremely light mass, about four orders of magnitude less than a free electron. One can think of them as photons dressed with an effective mass and an atom-like interaction. Because of their very light mass, exciton-polaritons show Bose quantum effects even at moderate densities and temperatures from tens of Kelvin up to room temperature. In the past five years, multiple experiments have shown effects of polaritons analogous to Bose condensation of cold atoms, such as a bimodal momentum distribution, quantized vortices, a Bogoliubov excitation spectrum, spatial condensation in a trap, and Josephson junction oscillations. In these experiments, though, the lifetime of the polaritons has been just a little longer than their thermalization time, which means that nonequilibrium effects are induced by the Pauli blocking effect in a quantum Fermi gas of majority atoms near interspecies resonances. Unlike in vacuum, we find that both the sign and magnitude of the dimer masses are tunable via Feshbach resonances. We also investigate the effects of particle-hole fluctuations on the dispersion of dimers and demonstrate that the particle-hole fluctuations near a Fermi surface (with Fermi momentum \( h k_F \)) generally reduce the effective two-body interactions and the binding energy of dimers. Furthermore, in the limit of light minority atoms the particle-hole fluctuations disfavor the formation of dimers with a total momentum \( h k_F \), because near \( h k_F \) the modes where the dominating particle-hole fluctuations appear are the softest. Our calculation suggests that near broad interspecies resonances when the minority-majority mass ratio \( m_B/m_P \) is smaller than a critical value (estimated to be 0.136), dimers in a finite-momentum channel are energetically favored over dimers in the zero-momentum channel. We apply our theory to quantum gases of \( ^6\text{Li}^{40}\text{K}, ^6\text{Li}^{87}\text{Rb}, ^{40}\text{K}^{87}\text{Rb} \) and \( ^6\text{Li}^{23}\text{Na} \) near broad interspecies resonances, and discuss the implications.

3 This material is based upon work supported by the National Science Foundation under Grant No. 0706331.

12:27PM W10.00003 BEC of magnons at room temperature and spatio-temporal properties of magnon condensate

SERGEJ DEMOKRITOV, Institute for Applied Physics, University of Münster, Germany — No abstract available.

1:03PM W10.00004 An ultracold high-density sample of rovibronic ground-state molecules in an optical lattice, HANS-CHRISTOPH NAEGELI, University of Innsbruck — No abstract available.

1:39PM W10.00005 BEC of Rydberg atoms

MATTHIAS WEIDEMUELLER, Univ. Heidelberg — No abstract available.

Thursday, March 1, 2012 2:30PM - 5:30PM - Session X4 DAMOP: Focus Session: Quantum Quench Dynamics in Cold Atom Systems 205C
In the strict 1D case, we identify conditions for which the expansion is ballistic, characterized by an increase of the cloud's radius that is linear in time. This notion is valid in optical lattices. In recent experiments, this situation was addressed in 2D and 3D optical lattices [1]. We focus on the 1D case in which an exact numerical solution of the Schrödinger equation can be obtained by letting a two-component Fermi gas that is originally confined by the presence of a trapping potential expand into an empty optical lattice. In this case, the quench dynamics can be described analytically, demonstrating the universal statistical relaxation of the systems irrespectively of whether they are chaotic or not.

The sensitivity of the result to the nature of the nonequilibrium steady state is explored by also employing the random phase approximation. As a result of the quench, the distribution function of the fermions is greatly broadened. This gives rise to an important consequence on the athermal steady state as it generates a temperature as well as a dissipation and hence a finite life-time for the bosonic modes.

This work was supported by ONR, NSF, and IFRAF.
4:18PM X.00008 Quenching across a quantum critical point: dependence of scaling laws on spatial periodicity. SMITHA VISHVESHWARA, University of Illinois at Urbana-Champaign, MANISHA THAKURATHI, Indian Institute of Science, Bangalore, India — We study the quenching dynamics of a quantum many-body system in one dimension described by a Hamiltonian having spatial periodicity. Specifically, we consider a spin-1/2 XX chain subject to a periodically varying magnetic field in the z direction or, equivalently, a tight-binding model of spinless fermions having a periodic local chemical potential. If the strength of the magnetic field (or chemical potential) is varied slowly in time at a rate 1/τ so as to take the system across a quantum critical point, we find that the density of excitations thereby produced scales as a power of 1/τ. Remarkably, the power depends on the spatial periodicity of the field and deviates from the 1/√τ scaling that is ubiquitous to a range of systems. This behavior is analyzed by mapping the slow quenching problem to a collection of fermionic two-level systems, labeled by the lattice momentum k, for which the effective Hamiltonians vary as a power of the time close to the quantum critical point. For a magnetic field described by multiple periodicities, the power depends on the smallest period for very large values of τ. Finally, we find that if there are interactions between the fermions, the power varies continuously with the interaction strength.

4:30PM X.00009 Kibble-Zurek Scaling: Universality and scaling. ANUSHYA CHANDRAN, Princeton University, AMIR EREZ1, Ben-Gurion University, SHIVAJI L. SONDI, STEVEN S. GUBSER, Princeton University — Near a critical point, the equilibrium relaxation time of a system diverges and any change of control/thermodynamic parameters leads to non-equilibrium behavior. The Kibble-Zurek (KZ) problem is to determine the dynamical evolution of the system parametrically close to its critical point when the change is parametrically slow. We formulate the KZ problem as a scaling limit and compute its universal content analytically (critical exponents+scaling functions) in a few classical and quantum models. We also use gauge-gravity duality to compute KZ response functions in more exotic critical theories.

4:42PM X.00010 Universal Quantum Dynamics of the Transverse-Field Ising Model. MICHAEL KOLODRUBETZ, BRYAN CLARK, DAVID HUSE, Princeton University — The one-dimensional transverse field Ising model is a prototypical example of a quantum phase transition. While its equilibrium quantum scaling has been known for more than half a century, we discuss the non-equilibrium quantum dynamics as the system is swept slowly through the critical point (a Kibble-Zurek ramp). Scaling is well understood for Kibble-Zurek ramps that end at the quantum critical point or deep in the ferromagnetic regime. We solve for the full finite-size scaling forms of excess heat and spin-spin correlation function for an arbitrary point along the ramp. We also confirm the postulated universality of the dynamic scaling forms by numerically simulating Mott insulating bosons in a tilted potential, an experimentally realizable model in the same universality class [Simon et. al., Nature 472, 372 (2011)]. Our numerics indicate that the time-scales necessary to see non-equilibrium scaling should already be within the reach of experiment.

4:54PM X.00011 Self-consistent theory of instabilities in the spin-1 Bose gas. AUSTEN LAMACRAFT, University of Virginia, RYAN BARNETT, University of Maryland — We discuss instabilities of a spin-1 Bose condensate using a Hartree-Fock-Bogoliubov approximation to account for the interactions between the unstable modes. There is a close analogy to the “S-theory” that describes parametric excitation of magnons in solid state systems. We particularly emphasize the pair-breaking effect of phase fluctuations in the parent condensate and their role in inhibiting the instability.

5:06PM X.00012 Decay of classical quasiperiodic state and emergence of prethermalization in quenched Fermi-Pasta-Ulam system. RAFAEL HIPOLITO, City University of New York, College of Staten Island, IPPEI DANSHITA, Computational Condensed Matter Physics Laboratory, RIKEN, VADIM OGANESYAN, City University of New York, College of Staten Island, ANATOLI POLKOVNIKOV, Boston University — We will discuss the relaxation of the Fermi Pasta Ulam system in the presence of quantum fluctuations. In order to make comparisons with the classical relaxation, we strongly excite a single normal mode, while the rest of the modes are initially in the quantum ground state. We confine ourselves to the quasiperiodic regime where the classical system never thermalizes. We show that the short time dynamics of the quantum problem are very different from classical evolution, with the quantum zero point energy playing a key role. The short time dynamics can be viewed as an enhancement of zero point energy, parametrically driven by the classical degrees of freedom. This introduces nontrivial off-diagonal correlations in the low momentum sector and dampens the classical oscillations eventually leading to both dephasing and decay, and we identify the time scales associated with these processes. Eventually the system reaches a nontrivial very long lived quasistationary regime where off-diagonal correlations disappear and the energy remains mostly localized in the low q sector while the high q sector relaxes to a uniform effective temperature. In this regime, correlations are very well described by a generalized Gibbs ensemble.

5:18PM X.00013 Fisher zeroes and non-analytic real time evolution for quenches in the transverse field Ising model. STEFAN KEHREIN, University of Goettingen, MARKUS HEYL, University of Munich, ANATOLI POLKOVNIKOV, Boston University — We study quenches of the magnetic field in the transverse field Ising model. For quenches across the quantum critical point, the boundary partition function in the complex temperature-time-plane shows lines of Fisher zeroes that intersect the time axis, indicating non-analytic real time evolution in the thermodynamic limit (analogous to well-known thermodynamic phase transitions). We obtain exact analytical results for these dynamic transitions and show that the dynamic behavior cannot be obtained from a naive analytic continuation of the thermal equilibrium partition function. Real time evolution across this quantum critical point generates a new non-equilibrium energy scale. We argue that this behavior is expected to be generic for interaction quenches across quantum critical points in other models as well.

Friday, March 2, 2012 8:00AM - 10:48AM
Session Y4 DAMOP: Cold Quantum Gases in Reduced Dimensions 205C

8:00AM Y.00001 Tunneling-driven transitions in magnetization compressibility and density redistributions in a fermionic superfluid of cold atoms trapped in an array of one-dimensional tubes. KUEI SUN, C.J. BOLECH, University of Cincinnati — We study two-species fermion gases with attractive interactions in optical lattices that are made as an array of one-dimensional tube confinements. With the decrease in lattice depth, we find that the increase in tunneling between tubes leads to an incompressible-compressible transition in magnetization. The role of pair tunneling is considered, as well as the experimental implications.
8:12AM Y4.00002 Fermion Pairing in a One-Dimensional Optical Lattice\(^1\), ARIEL SOMMER, LAWRENCE CHEUK, MARK KU, WASEEM BAKR, MARTIN ZWIERLEIN, Department of Physics, MIT-Harvard Center for Ultracold Atoms, and Research Laboratory of Electronics, MIT, Cambridge, Massachusetts 02139, USA — Strongly correlated fermions in an array of two-dimensional planes coupled via tunneling serve as an important model system for studies of high-temperature superconductors and layered organic conductors. We realize this model using ultracold fermionic \(^6\)Li atoms in a one-dimensional optical lattice near a Feshbach resonance. The depth of the lattice controls the interlayer coupling, and tunes the system between two and three dimensions. Pairing between fermions is studied using radio-frequency spectroscopy. The binding energy of fermion pairs is determined along the dimensional crossover and for different interaction strengths through the BEC-BCS crossover. Probes of superfluidity in the coupled layer system are also discussed.

\(^1\)This work was supported by the NSF, AFOSR-MURI, ARO-MURI, ONR, DARPA YFA, a grant from the Army Research Office with funding from the DARPA OLE program, the David and Lucile Packard Foundation and the Alfred P. Sloan Foundation.

8:24AM Y4.00003 ABSTRACT WITHDRAWN

8:36AM Y4.00004 Entanglement-based perturbation theory for highly anisotropic Bose-Einstein condensates, ALEXANDRE TACLA, CARLTON CAVES, University of New Mexico — We investigate the emergence of three-dimensional behavior in a reduced-dimension Bose-Einstein condensate trapped by a highly anisotropic potential. We handle the problem analytically by performing a perturbative Schmidt decomposition of the condensate wave function between the tightly confined direction(s) and the loosely confined direction(s). The perturbation theory is valid when the nonlinear scattering energy is small compared to the transverse energy scales. Our approach provides a straightforward way, first, to derive corrections to the transverse and longitudinal wave functions of the reduced-dimension approximation and, second, to calculate the amount of entanglement, which arises between the transverse and longitudinal spatial directions. Numerical integration of the three-dimensional Gross-Pitaevskii equation for different cigar-shaped potentials and experimentally accessible parameters reveals good agreement with our analytical model even for relatively high nonlinearities. In particular, we show that even for such strong nonlinearities the entanglement remains remarkably small, which allows the condensate to be well described by a product wave function that corresponds to a single Schmidt term.

8:48AM Y4.00005 Phase Diagram of the Bose Hubbard Model with Weak Links, KALANI HET-TIARACHCHILAGE, VALY ROUSSEAU, KA-MING TAM, JUANA MORENO, MARK JARRELL, DANIEL SHEEHY, Department of Physics and Astronomy, Louisiana State University, Baton Rouge, Louisiana 70803, USA — We study the ground state phase diagram of strongly interacting ultracold Bose gas in a one-dimensional optical lattice with a tunable weak link, by means of Quantum Monte Carlo simulation. This model contains an on-site repulsive interaction (U) and two different near-neighbor hopping terms, J and \( t \), for the weak link and the remainder of the chain, respectively. We show that by reducing the strength of \( J \), a novel intermediate phase develops which is compressible and non-superfluid. This novel phase is identified as a Normal Bose Liquid (NBL) which does not appear in the phase diagram of the homogeneous bosonic Hubbard model. Further, we find a linear variation of the phase boundary of Normal Bose Liquid (NBL) to SuperFluid (SF) as a function of the strength of the weak link. These results may provide a new path to design advanced atomtronic devices in the future.

9:00AM Y4.00006 The effective mass of ultracold atoms in one-dimensional optical lattices, FEDERICO DUQUE GOMEZ, J.E. SIPE, Department of Physics, University of Tokyo — According to the effective mass theorem, in the presence of an external force the wavepacket associated with a crystal electron in one band accelerates as a particle with an effective mass. However, when the force is turned on suddenly, the expectation value of the acceleration initially behaves according to the electron’s bare mass, and afterwards oscillates around the value given by the usual effective mass. These oscillations are difficult to measure in typical solid state systems because they decay after a time of the order of femtoseconds. We consider this oscillatory behaviour with ultracold atoms in a one-dimensional optical lattice where the time scale of the oscillations and the coherence times are much longer. Our theoretical analysis is based on a perturbation scheme that decouples the bands to any order in the external force. We check the validity of this perturbative approach, comparing its results with those obtained from a full numerical calculation. Experimental investigations are underway.

9:12AM Y4.00007 Supercurrent decay via quantum nucleation of phase slips in one-dimensional lattice bosons, IPPEI DANSHITA, RIKEN, Wako, Saitama 351-0198, Japan, ANATOLI POLKOVNIKOV, Department of Physics, Boston University, Boston, MA 02215 — We study transport properties of one-dimensional (1D) Bose gases in a periodic potential. In 1D, superflow at zero temperature can decay via quantum nucleation of phase slips even when the flow velocity is much smaller than the critical velocity predicted by mean-field theories. We use instanton techniques to find that the decay rate \( G \) is algebraically increases with the flow momentum \( p \) as \( G \propto L^2 p^{2K-2} \), where \( L \) is the system size, \( K \) the Luttinger parameter. We also discuss the relation between the nucleation rate and the quantum superfluid-INSulator transition in order to present a physical interpretation of the scaling formula.

\(^1\)D. Pfrisch and E. Spenke, Z. Physik 137, 309 (1954).


\(^4\)A. Steinberg, private communication.

9:24AM Y4.00008 Compressibility and Entropy of One Dimensional Fermions in a combined Harmonic and Periodic Potential, ANDREW SNYDER, THEJA DE SILVA, Binghamton University — We solve the homogeneous Hubbard model for repulsively interacting fermions using thermodynamic Bethe ansatz method. Treating the harmonic potential in local density approximation, we calculate particle density, various compressibilities, double occupancy, and entropy as a function of temperature and interaction. These quantities show characteristic features that can be used to detect temperature, metal-insulator transition, and coexistence of metallic and insulating phases.

9:36AM Y4.00009 From GPE to KPZ: Finite temperature dynamical structure factor of the 1D Bose gas, MANAS KULKARNI, University of Toronto, AUSTEN LAMACRAFT, University of Virginia — Recent experiments on 1D Bose gases have raised interest in the investigation of dynamical properties at finite temperature such as the structure factor. For weak enough interaction and high enough temperature, we expect a classical description in terms of the Gross–Pitaevskii equation with thermally populated modes to be valid. Here, we present numerical results for the finite temperature dynamical structure factor and its universal anomalous scaling behavior, arising from resonant interactions between phonons. Our results are also relevant to sound damping in 1D classical fluids. Somewhat more surprisingly, there is a deep connection to systems in the Kardar–Parisi–Zhang universality class, describing growing fluctuating interfaces.
9:48AM Y4.00010 Photoinduced phase transition in one dimensional extended Hubbard model, HANTAO LU, SHIGETOSHI SOTA, Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto, 606-8502, Japan, HIROAKI MATSUEDA, Sendai National College of Technology, Sendai, 989-3128, Japan, TAKAMI TOHYAMA, Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto, 606-8502, Japan — We illustrate one interesting example of the photoinduced phase transitions due to a nonequilibrium process. The impact of laser pump on one dimensional half-filled extended Hubbard model in the spin-density-wave (SDW) phase is investigated by using time-dependent density-matrix renormalization group. With proper laser frequencies and strengths, we find that charge-density wave (CDW) can be observed during the pulse. Further, in some situations, for instance, near the boundary between SDW and CDW in the ground state, the CDW signature can be sustained even after the pulse turned off. The underlying physics and possible experimental realization are discussed.

10:00AM Y4.00011 Separation induced resonances in quasi-one-dimensional ultracold atomic gases, WENBO FU, Institute for Advanced Study, Tsinghua University, Beijing, 100084, ZHENHUA YU, Department of Physics, Ohio State University, Columbus, OH 43210, XIAOLING CUI, Institute for Advanced Study, Tsinghua University, Beijing, 100084 — We study the effective one-dimensional (1D) scattering of two distinguishable atoms confined individually by separated transverse harmonic traps. With equal trapping frequency for two s-wave interacting atoms, we find that by tuning the trap separations, the system can undergo double 1D scattering resonance, named as the separation induced resonance (SIR), when the ratio between the confinement length and s-wave scattering length is within (0.79, 1.46). Near SIR, the scattering property shows unique dependence on the resonance position. Right at SIR, the universal property of a many-body system is manifested by studying the interaction effect of a localized impurity immersed in a Fermi sea of light atoms. The proposed SIR can be realized in cold atom experiment.

10:12AM Y4.00012 Boson pairing and unusual criticality in a generalized XY model, YIFEI SHI, University of Virginia — Motivated by the physics of condensates of boson pairs, we study the generalized XY model in two dimension, which has a term proportional to $\cos(2\theta)$ in addition to the normal XY Hamiltonian. This corresponds to having half vortices connected by solitons, as well as integer vortices. From both renormalization group analysis and Monte Carlo simulation using the worm algorithm, we find that the phase diagram includes Kosterlitz-Thouless transitions of half and integer vortices, together with an Ising transition. Remarkably, part of the Ising line is a direct transition from the quasi-long-ranged ordered state to the disordered state.

10:24AM Y4.00013 Pairing and pseudogap for ultracold fermions in two dimensions1, J. TEMPERE2, S.N. KLININ, J.T. DEVREESE, Theorie van Quantum en Complexe Systemen (TQC), Universiteit Antwerpen, Belgium — The T-matrix approach, straightforwardly applied to cold fermions in two dimensions, leads to a divergent fermion density for any finite temperature. We have shown that the Gaussian pair fluctuation theory, which is an improvement of the Nozières – Schmitt-Rink approach, provides a convergent density in the paired fermion state. In our work, special attention is paid to the pseudogap state above the BKT transition temperature. In the pseudogap state, the modulus of the order parameter is finite, while phase coherence is absent. The pairing crossover temperature in 2D has been determined. Owing to the fluctuations, this pairing temperature is considerably lower than the mean-field critical temperature. With increasing coupling strength, the pairing temperature behaves non-monotonically reaching a maximum before decreasing to a finite value. For an imbalanced Fermi gas, the fluctuations lower the critical value of the imbalance at which the superfluid or non-coherent paired state is formed. This effect exists even at zero temperature, where only the quantum fluctuations survive. The obtained pairing temperatures and spectral functions are in fair agreement with recent experimental results on pairing of fermionic atoms in strongly anisotropic optical lattices.

1This work was supported by FWO-V projects G.0356.06, G.0370.09N, G.0180.09N, G.0365.08, the WOG WO.035.04N (Belgium).
2Also at Lyman Laboratory of Physics, Harvard University, USA

10:36AM Y4.00014 Excitation spectrum of two-dimensional cold fermionic gases in the dilute limit, C. BERTHOD, C. KOLLATH, T. GIAMARCHI, University of Geneva, Switzerland, M. FELD, B. FRÖHLICH, M. KOSCHORRECK, E. VOGL, M. KOHL, University of Cambridge, United Kingdom — Two-dimensional gases of fermionic atoms have been recently realized, and cooled down to temperatures a few tenths of the Fermi temperature. Such ultracold atom systems are ideal tools to investigate the fundamental properties of Fermi ensembles subject to short-range interactions. One of the key questions is whether the interaction changes the ground state and excitation spectrum in a non-perturbative way, or whether the weak-coupling perturbation theory and Fermi-liquid idea remain valid in two dimensions. In contrast to condensed-matter systems, in atomic gases the perturbation theory must be carried out at finite temperature and far from the Fermi surface for a meaningful comparison with experiment. We have calculated the electronic self-energy of dilute two-dimensional Fermi gases at arbitrary temperature and momentum, using the ladder approximation. This scheme is expected to become exact (in a perturbative sense) in the low-density limit. For short-range attractive interaction, we study the evolution of the excitation spectrum as a function of temperature and interaction strength, and we compare our results with recent experiments.

Friday, March 2, 2012 11:15AM - 1:51PM — Session Z1 DAMOP: General Atomic, Molecular and Optical Physics 203

11:15AM Z1.00001 The Timing of Sonoluminescence1, THOMAS BRENNAN, West Virginia Wesleyan College, GUSTAVE FRALICK, NASA Glenn Research Center — We measured the timing of the sonoluminescence flash by scattering laser light from the bubble. We performed this measurement on 17.8 kHz, 13.28 kHz and 7920 Hz systems and found that the flash typically occurs 100 nanoseconds before the minimum radius, contrary to previous claims that the flash always occurs within a nanosecond of the minimum radius. These results are important because they imply that previous hot models of sonoluminescence are wrong. We propose a new model: that the flash results from the discharge of an excited cold condensate, formed during the adiabatic expansion of the bubble.

1We thank the Instrumentation Division at the NASA Glenn research center in Cleveland, Ohio for supporting this research.

11:27AM Z1.00002 Coherence Enhanced Transient Lasing, PANKAJ IHA, ANATOLY SVIDZINSKY, Texas A&M University, MARLAN SCULLY, Texas A&M University and Princeton University — We study the effect of a coherent drive on transient lasing with inversion in three-level $\Lambda$ and $\Xi$ configurations ($c \leftrightarrow a \leftrightarrow b$). We show that the presence of a resonant coherent drive on the $a \leftrightarrow c$ optical transition can yield substantial enhancement of the output laser energy on a $a \rightarrow b$ XUV or X-ray transition. We demonstrate the crucial role of coherence $\rho_{ab}$ for this laser power enhancement. Contrary to the forward direction, where forward gain can be enhanced for some choice of $\Omega_c$, coherent drive on the $ac$ transition always suppresses the backward gain. Thus, the use of a coherent drive at optical frequency could be a useful tool for increasing power of lasers in XUV and X-ray regions.
that by selecting molecules with suitable shape for buffer-gas cooling, one could cool molecules with a very large number of degrees of freedom. In buffer-gas cooling experiments by increasing the density of helium. In addition, we find that the shape of molecules is important for the collision dynamics and stable clusters under the experimental conditions. Our results suggest that it may be possible to improve the efficiency of the production of cold molecules using this method, we investigate the formation of molecule-helium complexes in buffer-gas cooling experiments at the temperature of 6.5 K for molecules. Using this method, we introduce a method for classical trajectory calculations to simulate collisions between atoms and large rigid asymmetric-top molecules. The dynamical mean-field method is found to capture about 50% of the total correlation energy, and to produce very good results for the d-level correlated orbitals and correlations to treat dynamically is discussed. The dynamical mean field solutions are compared to state of the art quantum chemical calculations. The dynamical mean-field approximation in quantum chemistry is investigated in the context of transition metal dioxide molecules including TiO2 and CrO2. The choice of the inversion and the other equation determining the inversion given the field intensities. In both cases we find excellent agreement between theory and experiment is carefully analyzed. The discrepancy between theory and experiment is carefully analyzed.

11:39 AM Z1.00003 Variable Atomic Radius of Hydrogen Due to Vibrating Nucleus. STEWART BREKKE, Northeastern Illinois University (former grad student) — The H-atomic radius is variable because the H-nucleus is vibrating and the electric field upon the electron is repeatedly changing due to the changing distance from the positive nucleus to the negatively charged electron. If the distance from the nucleus to the electron is \( d = r + A \cos(2\pi f t) \) where \( r = 5.29 \times 10^{-11} \text{m} \), the calculated Bohr radius, and \( d = 2.5 \times 10^{-11} \text{m} \), the measured atomic radius of the H-atom, then the equation for the variable atomic radius of the H-atom is \( 5.29 \times 10^{-11} \text{m} + A \cos(2\pi f t) = 2.5 \times 10^{-11} \text{m} \). If the RMS value for the average cosine is 0.707, solving for \( A \), the average amplitude of nuclear vibration, \( A = 3.95 \times 10^{-11} \text{m} \). Therefore, the oscillating orbit of the electron in an H-atom has an average amplitude of \( A = 3.95 \times 10^{-11} \text{m} \).

11:51 AM Z1.00004 Strong Field Control of Atomic and Molecular Dynamics: An Attosecond Resolved Study. NIRANJAN SHIVARAM, HENRY TIMMERS, University of Arizona, XIAO-MIN TONG, University of Tsukuba, ARVINDE SANDHU, University of Arizona — Strong laser fields are routinely used in attosecond pump-probe studies of atomic and molecular phenomena. However, even a moderately strong field (\( \sim 10^{12} \text{W/cm}^2 \)) can significantly alter the electronic structure. By understanding and quantifying the effect of strong fields, one can obtain a high degree of control over the photo-absorption and photo-fragmentation processes. Here, we study the atomic and molecular response to the simultaneous presence of XUV attosecond pulse trains and strong IR fields. We describe an IR laser-dressed atom using Floquet picture. We observe quantum interference between XUV excitation paths to the Fourier components of a given Floquet state, which leads to oscillations in the ion-yield. By measuring the phase of the ion-yield oscillations, we extract the quantum phase difference between the Fourier components of that Floquet state. We obtain a quantitative understanding of how Floquet ionization channels change with intensity and what is the phase associated with each channel. We also extend our studies to molecular fragmentation processes. Our work represents real-time measurement and control of dynamics using strong-field modification of the atomic and molecular structure. This work was support by NSF grant PHY-0955274.
symmetry and that the ground state of certain four-level atom-cavity systems will undergo parity change at large coupling.

2. Reviewed in the exciton-phonon/atom-field interpretations and related to a new integrability criterion [2]. The model predicts that a single-mode two-site system reduces to the single-mode spin-boson model, also known as the Rabi Hamiltonian. Two higher dimensional generalizations are extensions contain arbitrary numbers of parameters and often ignore the symmetries of their respective systems. This work presents a simple model for the N-site systems have parity symmetry and that the ground state of certain four-level atom-cavity systems will undergo parity change at large coupling.

1. We gratefully acknowledge support by the National Science Foundation under DMR-084377.

2. Y. Zhang and D.P. Clougherty, arXiv:1012.4405

1:03PM Z1.00010 Thermal Effects on Quantum Sticking1. YANTING ZHANG, DENNIS CLougherty, University of Vermont — Many-body effects on the threshold law of quantum sticking of a particle coupled to an ohmic bosonic bath are examined for finite temperature surfaces. Generalizing a variational mean-field method previously applied to zero temperature surfaces, we obtain an explicit expression for the sticking probability of a particle with incident energy E. We find that there is a critical particle energy below which the probability of its sticking to the surface discontinuously drops to zero. We show that this singularity, whose origin is rooted by analogy to the localization transition in the spin-boson model, is experimentally accessible for ultracold particles. We provide detailed numerical results for this effect.

1:15PM Z1.00011 Theory of Non-Markovian dynamics in resonance fluorescence spectra. ABHISHEK KUMAR, SIGURDJAR I. ERLINGSSON, School of Science and Engineering, Reykjavik University, Iceland, BILL COISH, Department of Physics, McGill University, Canada — Robust quantum coherence is an important prerequisite for any system that may be used to perform quantum information processing tasks. For systems that can be probed optically, the resonance fluorescence spectrum may provide indirect evidence of coherence times when supplemented with an appropriate model of the decay process. A common approach is to assume a Markovian system, resulting in exponential decay of correlation functions and Lorentzian features in the associated spectrum. For physical systems with strongly history-dependent (non-Markovian) dynamics, there is currently no satisfying systematic theoretical approach to establish the associated spectrum. We present a detailed theoretical method to obtain the resonance fluorescence spectrum for a general system undergoing non-Markovian dynamics. This procedure can be used to systematically account for features in resonance-fluorescence spectra due to genuine non-Markovian dynamics. Our approach is based on a Nakajima-Zwanzig generalised master equation for the dynamics of the reduced density matrix. We apply this theory to study the resonance fluorescence in the non-Markovian dynamics of a three-level lambda system, relevant to recent experiments on heavy-hole spin dynamics in a quantum dot.

1:27PM Z1.00012 Quantum Revivals of the Morse Oscillator in Position Space and Momentum Space. ALVASON ZHENHUA LI, Microelectronics and Photonics Program, University of Arkansas at Fayetteville, AR 72701, WILLIAM HARTER, Department of Physics, University of Arkansas at Fayetteville, AR 72701 — Analytical solutions for the Morse oscillator are applied to investigate the quantum revivals both in position and momentum spaces. The properties of this anharmonic oscillator came across interesting space-time phenomena. These findings include simple Farey arithmetic revival structures. Such dynamic systems may have applications for quantum information technology and quantum computing.

1:39PM Z1.00013 Trapping of particles in the ray optics regime using DNG materials. JOSEPH SHAHBAZIAN, Tufts University — Optical tweezers use to confine and manipulate microscopic objects including living cells and bacteria, with high accuracy. The objective is calibrating the force on targets using DPS-DNG layered structure. Using this layered structure which acts as a tunable optical band-pass filter would assist calibration of the force on the target(s). Here shown that the proposed DNG-DPS structure would help to have highly focused calibrated tweezers without worrying about the polarization of optical wave. Calculation can describe well the experimental results.

Friday, March 2, 2012 11:15AM - 2:03PM – Session Z4 DAMOP: Disorder and Pairing in Ultracold Systems 206C

11:15AM Z4.00001 Many Body Localization in Incommensurate Potentials. SHANKAR IYER, California Institute of Technology, DAVID HUSE, Princeton University, GIL REFAEL, California Institute of Technology — A long-standing problem concerns the survival of Anderson localization in a many body system with interparticle interactions. In recent years, this problem has resurfaced due to work by Basko, Aleiner, and Altschuler, who have argued that highly excited states of an interacting, many body system can be localized in Fock space. Consequently, a dynamical quantum phase transition may separate such a many body localized phase from a delocalized, ergodic phase, and there is now numerical evidence for the existence of such a transition in disordered 1D systems. Meanwhile, 1D lattice models that lack genuine disorder, but which instead contain a periodic potential that is incommensurate with the lattice spacing, are known to have a localization transition even in the absence of interactions. Here, we numerically investigate whether this transition survives the introduction of interactions and, if so, how it is modified. These questions are increasingly experimentally relevant, because ultracold atom experiments sometimes use incommensurate potentials in place of true disorder to probe localization physics.

11:27AM Z4.00002 Mobile impurities in one-dimensional cold gases: subdiffusive, diffusive and ballistic regimes. ADRIAN KANTIAN, THIERRY GIAMARCHI, University of Geneva — Advances in cold gases physics are beginning to enable experiments involving the direct manipulation and observation of single- or few-atom mobile impurities [1] within a many-body quantum system, a topic of longstanding interest for condensed matter theory, where it is related to studies of e.g. conductivity and the X-ray edge problem. Further progress in this direction is expected from the latest generation of experiments offering single-site addressability in optical lattices [2,3]. In light of these developments we study the dynamics of mobile impurities in 1D quantum liquids using a DMRG technique. We address the recently proposed subdiffusive regime of impurity motion [4], a class of excitations beyond those described by the standard Tomonaga-Luttinger theory. We study the conditions for observing this regime and its' crossover to the ballistic regime. We furthermore examine the possibilities to observe the intermediate diffusive motion of impurities in these systems.

11:39AM Z4.00003 Collective mode of an impurity and a Tonks-Girardeau gas\textsuperscript{1}. CHARLES MATHY, Institute for Theoretical Atomic, Molecular and Optical Physics, MIKHAIL ZVONAREV, EUGENE DEMLER, Physics Department, Harvard University — We investigate the quantum dynamics of an impurity immersed in a one-dimensional gas of strongly repulsive bosons, or equivalently fully-polarized fermions, interacting via a contact interaction. Using Bethe Ansatz we obtain essentially exact results at all timescales and for all couplings to the impurity. We find that the impurity starts off with a momentum of the order of the Fermi momentum or higher if a new type of collective mode is excited, corresponding to long lived oscillations of the impurity with respect to the background gas. We characterize this mode and discuss how it can be observed experimentally.

\textsuperscript{1}C.M. acknowledges support from the NSF through ITAMP at Harvard University and the Smithsonian Astrophysical Observatory.

11:51AM Z4.00004 Dynamics of mobile impurities in one-dimensional quantum liquids\textsuperscript{1}. MICHAEL SCHECHER, University of Minnesota, School of Physics and Astronomy, ALEX KAMENEV, University of Minnesota, School of Physics and Astronomy and Fine Institute for Theoretical Physics, DIMITRI GANGARDT, University of Birmingham, United Kingdom, AUSTEN LAMACRAFT, University of Virginia — We consider the dynamics of mobile impurities immersed in one-dimensional (1d) quantum liquids. Such systems have been realized experimentally in the context of ultracold atomic gases in optical lattices. We show that, on very general grounds, the dispersion relation of the impurity dressed by the liquid is a periodic function of momentum with period $2\pi \hbar n$, $n$ being the 1d density. An impurity subject to a small external force thus exhibits the phenomenon of Bloch oscillations about a fixed point in real space, in the absence of a periodic potential. To compare with experiments, we set out to address the consequences of both finite temperature and finite force on the Bloch oscillation sequence. Our main results are as follows: (i) There exists a finite window of parameters where Bloch oscillations exist $F_{\text{min}}(T) < F < F_{\text{max}}$ (ii) The lower bound is fixed by thermal friction depending on temperature $T$, and interaction parameters. In particular, we show that $F_{\text{min}} = 0$ for integrable impurity models. (iii) The upper bound $F_{\text{max}}$ is set by friction associated with dipole radiation of phonons due to the accelerating impurity. The ensuing energy loss results in the uniform drift of the oscillation center.

\textsuperscript{1}This work was supported by DOE contract DE-FG02-08ER46482

12:03PM Z4.00005 Gapless superfluid phase with spin-dependent disorder. MI JIANG, RAVINDRA NANGUNERI, Physics Department, UC Davis, NANDINI TRIVEDI, Department of Physics, Ohio State University, GEORGE BATROUNI, INLN, Université de Nice-Sophia Antipolis, CNRS, RICHARD SCALETAR, Physics Department, UC Davis — Motivated by the recent experimental development on spin-dependent optical lattices and disordered systems, we observe the presence of a spin-dependent random potential on a superconductor or a superfluid atomic gas leading to distinct transitions at which the energy gap and average order parameter vanish, generating an intermediate gapless superfluid phase. This behavior is in marked contrast to the case of spin-symmetric randomness. The calculations are performed for a two-dimensional attractive Hubbard model within Bogoliubov-de Gennes mean field theory. We characterize the different phases by correlating the local order parameter and the density of states.

12:15PM Z4.00006 Superdiffusive nonequilibrium transport of an impurity in a Fermi sea. HYUNWON KIM, DAVID HUSE, Princeton University — We discuss a nonequilibrium transport of a single impurity atom immersed in a low-temperature Fermi sea with a short range double well. We find that the impurity does a superdiffusive geometric random walk in which the characteristic momentum decay rate shows a quartic decrease in its momentum in three dimension. Then, we construct a master equation and its scaled form that governs the time evolution of the impurity. Next, we discuss two dimensional case in which the momentum decay rate decreases with the third power of its momentum.

12:27PM Z4.00007 Repulsive polarons in two-dimensional Fermi gases. VUDTWAT NGAMPRUETIKORN, JESPER LEVINSEN, University of Cambridge, MEERA PARISH, London Centre for Nanotechnology — We consider a single spin-down impurity interacting via an attractive short-range potential with a spin-up Fermi sea in two dimensions (2D). Similarly to 3D, we show that the impurity can form a metastable state (the “repulsive polaron”) with energy greater than that of the non-interacting impurity. Moreover, we find that the repulsive polaron can acquire a finite momentum for sufficiently weak attractive interactions. Even though the energy of the repulsive polaron can become sizeable, we argue that saturated ferromagnetism is unfavorable in 2D because of the polaron’s finite lifetime and small quasiparticle weight.

12:39PM Z4.00008 Universal bound states of two atoms near a Feshbach resonance\textsuperscript{1}. SHINA TAN, Georgia Institute of Technology — The Efimov effect was traditionally thought to exist for three or more particles only. It will be shown how to make universal shallow bound states of TWO atoms only, which will exhibit a universal energy spectrum reminiscent of the Efimov effect, by using potentials to constrain the spatial motion of atoms. Several related theories of such two-body states will be described. These diatomic “artificial molecules”, if isolated from each other, will be free from three-body recombination, and can have long lifetimes in principle.

\textsuperscript{1}Alfred P. Sloan Foundation; National Science Foundation

12:51PM Z4.00009 Feshbach Correlations and Closed Channel Amplitudes. NICOLAS LOPEZ, SHAN-WEN TSAI, UC Riverside, EDDY TIMMERMANS, Los Alamos National Lab — The magnetically controlled Feshbach resonance is a prominent member of the cold atom toolbox. The ability to tune binary particle interactions in a quantum many body system has given access to collapsing BEC-physics in bosonovas, to BEC-BCS crossover physics, to the unitarity regime, and to quantum phase transitions. The resonance is accessed by tuning the energy of a quasi-bound spin-rearranged molecular state near the vacuum of the interacting particles. Does the amplitude of the spin-rearranged or “closed channel” state play a significant role in the many body physics? We present a microscopic derivation of the Feshbach resonance interactions and obtain the parameters of the two-channel model in an optical lattice. We study two atoms interacting in a harmonic oscillator potential near a Feshbach resonance to derive the closed channel probability and to uncover the validity-range of the two channel lattice model.

1:03PM Z4.00010 Superfluid pairing in a mixture of a spin-polarized Fermi gas and a dipolar condensate\textsuperscript{1}. BEN KAIN, Department of Physics, College of the Holy Cross, Worcester, MA 01610, HONG LING, Department of Physics, Rowan University, Glassboro, NJ 08028 — We consider a mixture of a spin-polarized Fermi gas and a dipolar Bose-Einstein condensate in which $s$-wave scattering between fermions and the quasiparticles of the dipolar condensate can result in an effective attractive Fermi-Fermi interaction anisotropic in nature and tunable by the dipolar interaction. We show that such an interaction can significantly increase the prospect of realizing a superfluid with a gap parameter characterized with a coherent superposition of all odd partial waves. We formulate, in the spirit of the Hartree-Fock-Bogoliubov mean-field approach, a theory which allows us to estimate the critical temperature when the anisotropic Fock potential is taken into consideration and study how to prepare the mixture in order to optimize the critical temperature at which such a superfluid emerges before the system starts to phase separate.

\textsuperscript{1}This work is supported by the US National Science Foundation and the US Army Research Office
1:15PM Z4.00011 Superfluid transition temperature and its zero density limit extrapolation in a unitary atomic Fermi gas on a lattice¹. QUIN CHEN, Zhejiang University — The superfluid transition temperature \( T_c \) of a unitary Fermi gas has been of great interest. One way to study \( T_c \) in a 3D continuum is to study fermions on a lattice at finite densities and then extrapolate to the zero density limit, as has been done in quantum Monte Carlo (QMC) simulation studies. For this extrapolation to work, it is essential to probe the densities in the asymptotic regime. In this talk, we study fermions on a three-dimensional isotropic lattice with an attractive on-site interaction as a function of density \( n \), from half filling down to \( 5 \times 10^{-7} \) per unit cell, using a pairing fluctuation theory. As \( n \) decreases towards \( n = 0 \), \( T_c/E_F \) increases to the leading order linearly in \( n^{1/3} \), and reaches the zero density limit \( T_c/E_F = 0.256 \), consistent with that calculated directly in the continuum for a contact potential. Inclusion of the particle-hole channel reduces \( T_c/E_F \) to 0.217, in agreement with experiment. However, except for very low \( n \), \( T_c/E_F \) exhibits significant higher order nonlinear dependence on \( n^{1/3} \). The densities accessed by QMC studies are still not low enough to be in the asymptotic regime. References: Q.J. Chen, arXiv:1109.5327; arXiv:1109.2307; Q.J. Chen et al, PRL 81, 4708(1998); PRB 59, 7083(1999).

¹Supported by NSF, MOE and MOST of China

1:27PM Z4.00012 Pair Condensation in a Finite Trapped Fermi Gas¹. CHRISTOPHER GILBRETH, YORAM ALHASSID, Center for Theoretical Physics, Yale University — Cold atomic fermi gases are widely studied examples of strongly interacting quantum systems. Examples include \(^{40}\text{K}\), \(^{6}\text{Li}\) and neutron matter. In the unitary regime, where the scattering length is very large compared to the mean inter-particle distance, they are nonperturbative and exhibit universal behavior. Moreover, they can be created in the lab, providing an excellent testing ground for theory. In this talk I will describe quantum Monte Carlo calculations we have been performing to study the signatures of pairing and the superfluid phase transition in finite-size systems. Using the Auxiliary Field Monte Carlo (AFMC) method, we study the pairing gap, condensate fraction, pair wavefunction and density profile as a function of temperature. Defining the onset of condensation \( T_{\text{cond}} \) as the temperature when the condensate fraction crosses its (finite) noninteracting limit, we consider the question of whether pairing occurs prior to condensation in the unitary regime.

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1:39PM Z4.00013 Cooling across the superfluid-normal interface of a unitary Fermi gas - an analogue of a dilution fridge². ARIJEET PAL, DAVID HUSE, Princeton University — Phase separation between paired superfluid and partially polarized normal phases has been observed by various experimental groups around the world using resonantly-interacting spin-imbalanced, hyperfine states of fermionic atoms. In this work we phenomenologically study the effect of the evaporation of atoms and explore the possibility of realizing a non-equilibrium steady state with chemical potential and temperature gradients in some of these experiments.

1:51PM Z4.00014 Upper Branch Bosons at High Temperatures, WEIRAN LI, TIN-LUN HO, the Ohio State University — We use a generalized Nozieres-Schmitt-Rink (NSR) approach, which excludes the molecule poles in the T-matrix, to study the “upper branch” Bose gases at high temperatures. We show that when we tune the scattering length from positive side across the resonance, the Bose system can remain stable even with attractive interactions at relatively high temperatures. The energy of this upper branch Bose gas has a maximum at negative scattering length, which indicates pair formations are enhanced by Bose statistics in a many body system, in contrast to the Fermionic case where the maximum occurs at positive scattering length.

²V.B.Shenoy and Tin-Lun Ho, arXiv:1106.0960, to appear in PRL.