8:00AM A41.00001 Theory of interaction-induced localization for mobile impurities1, JIAN LI, Texas Center for Superconductivity and Department of Physics, University of Houston, Houston, Texas 77204, USA, JIN AN, National Laboratory of Solid State Microstructures and Department of Physics, Nanjing University, Nanjing 210093, China, CHIN-SEN TING, Texas Center for Superconductivity and Department of Physics, University of Houston, Houston, Texas 77204, USA, TEXAS CENTER FOR SUPERCONDUCTIVITY TEAM — A phenomenological model is proposed for the interaction-induced localization of mobile impurities in the cold atomic systems. The fundamental properties of the transition between the extended and localized impurity state in one, two and three dimension are investigated with this model. We find that the transition is continuous in one and two dimension while discontinuous in three dimension. We show that the dynamics of single localized impurity is described by a soliton and predict the formation of bipolaron and Wigner lattices for many fermionic impurities. Our theory explains the essential features from specific models in a unified picture and can be used to realize several exotic phenomena with ultracold impurity atoms.

1This work was supported by the Texas Center for Superconductivity at the University of Houston and by the Robert A. Welch Foundation under Grant No. E-1146. Jin An was also supported by NSFC(China) Project No.1117416.

8:12AM A41.00002 Single parameter scaling for 1d systems with scale-free long-range correlated disordered potentials1, NANCY Sandler, GREG PETERSEN, Ohio University — Disordered optical lattices have renewed the interest in localization physics under power-law long-range correlated disorder potentials. For these systems, insight can be gained by combining numerical data and analytic expressions based on scaling laws. Thus, the absence of a transition in short-range correlated disordered systems can be proved by verifying the validity of the single parameter scaling (SPS) hypothesis for the distribution function of the dimensionless conductance. In this talk we discuss this hypothesis for a system with scale-free long-range correlated disorder potentials of the form $\sim 1/r^\alpha$ as a function of the correlation exponent $\alpha$. We present results for the 1$^{\text{st}}$ (the $\beta$-function) and 2$^{\text{nd}}$ (variance) cumulants of the distribution function, and show a violation of SPS at an energy scale $E_{\text{PS}}$, that scales with an $\alpha$-renormalized disorder strength. Calculations for the localization length reveals the existence of a crossover scale $E_{\text{cross}}$ between two regions as correlations increase. An increased number of more extended-like states appear near the band-center while states near the band edges experience reduced localization lengths. We confirm previously predicted scaling behavior near the band edge and center.

1Supported by NSF-MWN/CIAM and NSF-PIRE.

8:24AM A41.00003 Anderson localization of pairs in bichromatic optical lattices, GIULIANO ORSO, GABRIEL DUFOUR, Laboratoire Matériaux et Phénomènes Quantiques, Université Paris Diderot and CNRS, France — We investigate the formation of bound states made of two interacting atoms moving in a one dimensional quasi-periodic optical lattice. We derive the quantum phase diagram for Anderson localization of both attractively and repulsively bound pairs. We calculate the pair binding energy and show analytically that its behavior as a function of the interaction strength depends crucially on the nature -extended, multifractal, localized- of the single-particle atomic states. Experimental implications of our results are discussed. Reference: Phys. Rev. Lett. 109, 155306 (2012)

8:36AM A41.00004 Many-body localization transition in periodically driven system, LUCA D’ALESSIO, ANATOLI POLKOVNIKOV, Boston University — According to the second law of thermodynamics the total entropy and energy of a system is increased during almost any dynamical process. Notable exceptions are known in noninteracting systems of particles moving in periodic potentials. Here the phenomenon of dynamical localization can prevent heating beyond certain threshold. However, it was believed that driven ergodic systems will always heat without bound. Here, on the contrary, we report strong evidence of dynamical localization transition in periodically driven ergodic systems in the thermodynamic limit. This phenomenon is reminiscent of many-body localization in energy space. We report numerical evidence based on exact diagonalization of small spin chains and theoretical arguments based on the Magnus expansion. Our findings are valid for both classical and quantum systems.

8:48AM A41.00005 Many-Body Localization in a Quasiperiodic System, SHANKAR IYER, GIL REFAEL, California Institute of Technology, VADMID OGANESEYAN, College of Staten Island, City University of New York, DAVID HUSE, Princeton University — Recent theoretical and numerical evidence suggests that localization can survive the introduction of interactions in disordered many-body systems, giving rise to a so-called many-body localization transition. This dynamical phase transition is relevant to questions of thermalization in quantum systems. It separates a many-body localized phase, in which localization prevents thermalization, from an “ergodic” phase in which the usual assumptions of quantum statistical mechanics hold. Here, we present numerical evidence that many-body localization also occurs in models that omit true disorder in favor of a quasiperiodic potential. In one dimension, these systems already have a single-particle localization transition, and we show that this transition becomes a many-body localization transition upon the introduction of interactions. These issues are increasingly experimentally relevant, because quasiperiodic potentials have been used in place of true disorder in recent experiments with cold atoms and with photonic waveguides.

9:00AM A41.00006 Dynamic Localization of Interacting Particles in an Anharmonic Potential, MARK HERRERA, THOMAS ANTONSEN, EDWARD OTT, University of Maryland, SHMUEL FISHMAN, Technion-Israel Institute of Technology — We investigate the effect of anharmonicity and interactions on the dynamics of an initially Gaussian wavepacket in a weakly anharmonic potential. We note that depending on the strength and sign of interactions and anharmonicity, the quantum state can be either localized or delocalized in the potential. We formulate a classical model of this phenomenon and compare it to quantum simulations done for a self consistent potential given by the Gross-Pitaevskii Equation.

9:12AM A41.00007 Anderson Localization of a non-interacting Bose-Einstein condensate with effective spin-orbit interaction in a quasiperiodic optical lattice1, LU ZHOU, Department of Physics, East China Normal University, HAN PU, Department of Physics and Astronomy, Rice University, WEIPING ZHANG, Department of Physics, East China Normal University — We theoretically investigate the localization properties of a noninteracting atomic Bose-Einstein condensate moving in a one-dimensional quasiperiodic optical lattice potential in the tight-binding regime. The atoms are subject to effective spin-orbit coupling induced by external laser fields. We present the phase diagram in the parameter space of the disorder strength and those related to the effective spin-orbit coupling. The phase diagram are verified via multifractal analysis of the atomic wavefunctions. We found that spin-orbit coupling can lead to the spectra mixing (coexistence of extended and localized states) and the appearance of mobility edges.

1We acknowledge National Natural Science Foundation of China under Grant No 11004057, Shanghai Rising-Star Program under Grant No. 12QA1401000 and the "Chen Guang" project under Grant No 10CC24 for financial supports.
9:24AM A41.00008 Laser Controlled Rotational Cooling in Na\textsubscript{2} Based on Exceptional Points\textsuperscript{1}, ADAM WEARNE, VIATCHESLAV KOKOULINE, University of Central Florida, OSMAN ATABEK, ROLAND LEFEBVRE, Laboratoire de Photophysique Moléculaire du CNRS, Université Paris-Sud, Orsay, France, UCF-ISMO COLLABORATION — In this study, we describe a computational simulation of the interaction of diatomic molecule with an applied laser field. It is known that for certain laser wavelengths and intensities, the wave functions and eigenergies of two states become degenerate. Such locations in the laser parameter space are known as “exceptional points.” By applying a laser pulse which encircles one or more exceptional points in the parametric plane of wave length versus intensity, one can bring an ensemble of diatomic molecule into a pre-selected rovibrational state after the laser pulse is over. During this process, a fraction of the molecules dissociate, and those which remain, are brought to the chosen rovibrational state. Although this scheme can be applied more generally, here we use Na\textsubscript{2} as an illustrative example. We examine the locations in the parametric space of exceptional points, which lead to the exchange of rotational states, and how the shape of laser pulse in the parametric plane affects the “purification” of the chosen rovibrational state and the dissociation of other states.

\textsuperscript{1}This work is supported by the National Science Foundation, Grant No PHY-08-55622

9:36AM A41.00009 Dynamic dimer formation between superionic fluorines in CaF\textsubscript{2}, MASASHI SAITO, TOMOFUMI TASAQA, KAZUO TSUMURAYA, Meiji University, Kanagawa, Japan — Recently we have elucidated the formation of the dynamic dimers in the conductor α-Cu through the analyses of the correlation peaks of the partial pair-distribution functions and the partial angle distribution functions with the first principles molecular dynamics (MD) method. (J. Phys. Soc. Jpn. 81,055603(2012).) The present study investigate the formation of the dynamic dimers and the migration paths of the dimers in the conductor CaF\textsubscript{2} with the MD method. The fluorines form the dynamic 32f-8c dimers with the coordinate \((x,\dot{x},\ddot{x}) = 0.300\). These incommensurate dimers allow to decrease the migration barriers of the fluorines.

9:48AM A41.00010 Laser cooling of Iron atoms, THIERRY BASTIN, NICOLAS HUET, STEPHANIE KRINS, Univ de Liege — We report on the first laser cooling of Iron atoms. Our laser cooling setup makes use of 2 UV laser radiation sent collinearly in a 0.8 m Zeeman slower. One laser is meant for optical pumping of the Iron atoms from the ground state to the lowest energy metastable state. The second laser cools down the atoms using a quasi-perfect closed transition from the optical pumped metastable state. The velocity distribution at the exit of the Zeeman slower is obtained from a probe laser crossing the atom beam at an angle of 50 degrees. The fluorescence light is detected using a photomultiplier tube coupled with a boxcar analyzer. The Iron atom beam is produced with a commercial effusion cell working at around 1950 K. Our laser radiations are stabilized using standard saturated-absorption signals in both an Iron hollow cathode absorption cell and an Iodine cell. We will present our experimental setup, as well as the first evidences of cooled down Iron atoms at the exit of the Zeeman slower.

10:00AM A41.00011 Ytterbium in quantum gases and atomic clocks: van der Waals interactions and blackbody shifts, S. G. PORSEV, M. S. SAFRONOVA, University of Delaware, CHARLES W. CLARK, Joint Quantum Institute — We evaluated the \(C_{ij}\) coefficients of Yb-Yb and Yb-alkali/group II van der Waals interactions with 2\% uncertainty. The only existing results for such quantities are for the Yb-Yb dimer. Our value, \(C_{11} = 1929(39)\) a.u., is in excellent agreement with the recent experimental determination of 1932(35) a.u. [M. Kitagawa, et al., Phys. Rev. A 77, 012719 (2008)]. We have also developed a new approach for the calculation of the dynamic correction to the blackbody radiation shift. We have calculated this quantity for the Yb \(6s^2\ 1S_0 - 6s6p\ 3P_0\) clock transition with 3.5% uncertainty. This reduces the fractional uncertainty due to the blackbody radiation shift in the Yb optical clock at 300 K to the \(10^{-15}\) level. For further details, see http://arxiv.org/abs/1208.1456

10:12AM A41.00012 Blackbody radiation shift in the Sr optical atomic clock, M.S. SAFRONOVA, S.G. PORSEV, University of Delaware, U.I. SAFRONOVA, University of Nevada, Reno, M.G. KOZLOV, Petersburg Nuclear Physics Institute, CHARLES W. CLARK, Joint Quantum Institute — We estimated the static and dynamic polarizabilities of the \(5s^2\ 1S_0\) and \(5s5p\ 3P_0\) states of Sr using the high-precision relativistic configuration interaction + all-order method. Our calculation explains the discrepancy between the recent experimental \(5s^2\ 1S_0 - 5s5p\ 3P_0\) dc Stark shift measurement = 247.374(7) a.u. [T. Middelmann, S. Falke, C. Lisdat and U. Sterr, arXiv:1208.2848 (2012)] and the earlier theoretical result of 261(4) a.u. [S. G. Porsev and A. Derevianko, Phys. Rev. A 74, 020502(R) (2006)]. Our present value of 247.5 a.u. is in excellent agreement with the experimental result. We also evaluated the dynamic correction to the BBR shift with 1% uncertainty, \(-0.1492(16)\) Hz. The dynamic correction to the BBR shift is unusually large in the case of Sr (7\%) and it enters significantly into the uncertainty budget of the Sr optical lattice clock. We suggest future experiments that could further reduce the present uncertainties. For further information, see http://arxiv.org/abs/1210.7272


11:15AM B4.00001 Unconventional superfluidity in higher bands of an optical lattice, ANDREAS HEMMERIC, Institut für Laser-Physik, Hamburg University — Atoms trapped in optical lattices have been used successfully to study many-body phenomena. However, the shape that bosonic ground-state wavefunctions can take is limited, apparently compromising the usefulness of this approach. Such limitations, however, do not apply to excited states of bosons. The study of atomic superfluids realized in higher Bloch bands, where orbital degrees of freedom are essential, can bring the world of optical lattices closer to relevant condensed matter systems. I will discuss our observations of long coherence times, chiral superfluid order and topological features in higher bands in a square optical lattice.

11:51AM B4.00002 Beyond Standard Fermi Hubbard Models\textsuperscript{1}, MACIEJ LEWENSTEIN, ICFO - Institut of Photonic Sciences — In my talk I will focus on novel physics and novel quantum phases that are expected in a system of ultracold fermionic atoms with long range interactions, such dipolar ones. I will discuss various terms in the Hubbard model that, normally neglected, have to be included in the theory. These terms involve both lowest band physics, as well as higher bands. I will describe several exemplary effects that new terms may lead to: spontaneous breaking of symmetries, such as time-reversal, smectic-like metal phases, spontaneous formation of exotic lattices and 3D textures.

\textsuperscript{1}supported by ERC Grant QUAGATUA
12:27PM B4.00003 Higher orbital physics and artificial gauge fields with ultracold quantum gases
KLAUS SENGSTOCK, Universitaet Hamburg, ILP, Luruper Chaussee 149, 22761 Hamburg — Recently the physics of quantum gases in higher orbitals attracted a lot of attention, theoretically and experimentally. We report on studies of a new type of superfluid described by a complex order parameter, resulting from an interaction-induced hybridization of the two lowest orbitals for a binary spin-mixture. As a main result we observe a quantum phase transition between the normal superfluid and this unconventional superfluid phase, where the local phase angle of the complex order parameter is continuously twisted between neighboring lattice sites [1]. In addition we discuss new experimental work on the creation of artificial gauge potentials for neutral atoms in 1D and 2D lattices, which do not rely on the internal structure of the atoms. Via a time-dependent driving of the optical lattice we have full control over amplitude and phase of the complex valued hopping parameters. In a 2D triangular lattice, we demonstrate the realization of gauge invariant staggered fluxes [2]. Our system consists of an array of tubes filled with bosonic atoms having a well-defined local phase. The phase distribution obtained in presence of large amplitude staggered fluxes — where frustration plays a key role — obeys two fundamental symmetries, the discrete Ising symmetry (Z2) and a continuous global phase symmetry (U(1)). Via the full control of the staggered gauge fields [3], we are able to break the Ising symmetry on purpose which means lifting the degeneracy of the two possible Ising states, in analogy to a longitudinal homogenous magnetic field in the standard Ising-Spin model. The measurements reveal "textbook like" magnetization curves with the well known dependence on both, the external magnetic field and the temperature. We observe a thermally driven phase transition from an ordered Ising (ferromagnetic) to an unordered (paramagnetic) state. Future directions to combine orbital physics and gauge fields will be discussed.


1:03PM B4.00004 Orbital physics in one dimensional optical lattices
XIAOPENG LI, University of Pittsburgh — We explore orbital physics of fermions and bosons in one dimensional optical lattices. In a system of one dimensional p-orbital bosons, various phases, including anti-ferro-orbital Mott, anti-ferro-orbital superfluid and para-orbital superfluid, have been found. Signatures of phase transitions, in particular time-reversal symmetry breaking, in time-of-flight image are predicted. A fermionic ladder system composed of s and p orbitals is proposed, and we find a topological state featuring fractional defects. An equivalent of spin-orbit coupling naturally arises, not requiring artificial gauge field, in this quantum orbital ladder when the s and p orbital states are identified as a pseudo-spin 1/2. Extending this ladder system to two dimensions we find a flat-band protected by parity. The flat-band makes it plausible to study strongly correlated physics in this system. We also discuss the connection of this fermionic ladder to frustrated π flux models and spin-orbital coupled fermions.

Monday, March 18, 2013 11:15AM - 2:15PM –
Session B4I DAMOP: Non-equilibrium Physics with Cold Atoms II

11:15AM B4I.00001 Time dependent impurity in ultracold fermions: orthogonality catastrophe and beyond1
MICHAEL KNAP, Department of Physics, Harvard University, ADITYA SHASHI, Department of Physics and Astronomy, Rice University, YUSUKE NISHIDA, Theoretical Division, Los Alamos National Laboratory, ADILET IMAMBEKOV, Department of Physics and Astronomy, Rice University, DMITRY A. ABANIN, EUGENE DEMLER, Department of Physics, Harvard University — The physics of impurities in metals and mesoscopic structures provides a deeper understanding of electrical and thermal transport properties, guided the development of new mathematical techniques, and gave useful insights into the behavior of more complicated strongly correlated materials. In ultracold atoms, many new possibilities have opened up — first, the ability to control magnetic quantum states and the magnetic flux through an artificial gauge potential, and second, the control of many impurities close to each other. In a system of fermions in a one-dimensional optical lattice, we have prepared states with a time dependent density profile, similar to a time dependent impurity potential. We find that the quantum state of the system is strongly perturbed by the impurity and eventually becomes orthogonal to its unperturbed state. This behavior is independent of the nature of the impurity potential. The results of our experiments are in agreement with theoretical predictions. The study of such systems can lead to a better understanding of corresponding effects in condensed matter systems.

1Harvard-MIT CUA, NSF DMR-07-05472, DMR-10-49082, FWF J3361-N20

11:27AM B4I.00002 Topological charge pumping in a one-dimensional optical lattice
LEI WANG, MATTHIAS TROYER, Theoretische Physik, ETH Zurich, XI DAI, Beijing National Lab for Condensed Matter Physics and Institute of Physics, Chinese Academy of Sciences — A topological charge pump transfers charges in a quantized fashion. The quantization is stable against the detailed form of the pumping protocols and external noises. Such a quantum pump shares the same topological origin as the quantum Hall effect. We propose an experimental setup to realize the topological charge pumping of cold atoms in a one-dimensional optical lattice. The quantization of the pumped charge is confirmed by first-principle simulations of the dynamics of uniform and trapped systems. Quantum effects are shown to be crucial for the topological protection of the charge quantization. Finite-temperature and non-adiabatic effect on the experimental observables are discussed. Realization of such a topological charge pump servers as a firm step towards exploring topological nontrivial phases and non-equilibrium dynamics using cold atoms.

11:39AM B4I.00003 Heat and spin transport in a cold atomic fermi gas1
HYUNGWON KIM, DAVID HUSE, Princeton University — Motivated by recent experiments measuring the spin transport in ultracold unitary atomic Fermi gases [Sommer et al., Nature (London) 472, 201 (2011); Sommer et al., New J. Phys. 13, 055009 (2011)], we explore the theory of spin and heat transport in a three-dimensional spin-polarized atomic Fermi gas. We develop estimates of spin and thermal diffusivities and discuss magnetocaloric effects, namely the spin Seebeck and spin Peltier effects. We study these transport coefficients using a Boltzmann kinetic equation in the classical regime and present experimentally accessible signatures of the spin Seebeck effect. We study an exactly soluble model that illustrates the role of momentum-dependent scattering in the magnetocaloric effects.

1DARPA OLE Program
11:51 AM B41.00004 Non-equilibrium steady states in quenched s-wave superfluids, MAXIM DZERO, Kent State University, EMIL YUZBASHYAN, Rutgers University, VICTOR GURARIE, University of Colorado Boulder — Nature and microscopic structure of the non-equilibrium many-body states in strongly interacting quantum systems remains one of most active research areas in physics. In this work, we study the steady states, which appear in a s-wave superfluid at zero temperature following a quench of the pairing strength. We use the BCS Hamiltonian which we solve exactly in the thermodynamic limit using classical integrability. We obtain a generic phase diagram of the resulting steady states for quenches corresponding to an arbitrary change of the pairing strength. We calculate single particle distribution function for each of the steady states that we find. In addition, we determine the asymptotic behavior of the pairing amplitude at long times. The experimental signatures of the steady states will also be discussed.

12:03PM B41.00005 Mean-field description of non-equilibrium dynamics of a 1D Bose gas in a weak optical lattice potential, JUAN CARRASQUILLA, Georgetown University and The Pennsylvania State University, AARON REINHARDT, LAURA ZUNDEL, JEAN-FELIX RIOU, DAVID WEISS. The Pennsylvania State University, MARCOS RIGOL, Georgetown University and The Pennsylvania State University — We study the expansion of a large array of one-dimensional Bose gases subject to a weak optical lattice potential using Gutzwiller mean-field calculations aimed at describing a recent experiment with ultracold atoms. We calculate the evolution of the density profile, the quasimomentum distribution, and the density profile after a band-mapping protocol followed in experiments with ultracold atoms designed to measure the quasimomentum distribution. We find that the large fraction of bosons remains trapped at the center of the lattice. Furthermore, interactions during the expansion dynamically change the momentum distribution. Our simulations qualitatively capture most aspects of the experiment.

12:15PM B41.00006 Influence of the Amplitude in Lattice Modulation Spectroscopy, ANDREAS DIRKS, KARLIS MIKELSENS, JIM FREERRICKS, Georgetown University, H.R. KRISHNAMURTHY, Indian Institute of Science — Within the Mott-insulating phase of the Hubbard model, linear-response calculations for a periodically modulated optical lattice depth clearly predict a resonance when modulated at a frequency equal to the Hubbard repulsion U. In this work we examine the effect of the amplitude of the lattice depth modulation on the threshold for excitation. Based on a recently developed strong-coupling approach to the non-equilibrium Hubbard model, we report results on the nonlinear regime and discuss effects of the amplitude as compared to the frequency for driving excitations into the upper Hubbard band.

12:27PM B41.00007 Decoherence and heating of two species fermions in optical lattices, SADRAK SARKAR, JOHANNES SCHACHEMENGER, STEPHAN LANGER, ANDREW J. DALEY, Department of Physics and Astronomy, University of Pittsburgh — Experiments with ultracold fermionic atoms in optical lattices present a unique way to study strongly interacting many-body quantum systems, including the Fermi-Hubbard model, in a microscopically well-understood environment. A key challenge to explore many interesting quantum phases is to reach sufficiently low temperatures and therefore it is necessary to characterise and control competing heating processes in experiments. Incoherent scattering of light from the lasers that form the lattice can contribute significantly to the heating. We study the robustness of many-body states to this mechanism, deriving a many-body master equation for two-component fermions and investigating how the heating is influenced by choices in the atomic physics and how it depends on the parameters in the many-body Hamiltonian.

12:39PM B41.00008 Diffusive Spin Transport of Lattice Fermions in One Dimension, ANDREW SNYDER, THEJA DE SILVA, Binghamton University — We study the long-time spin transport of fermions moving diffusively in a one dimensional lattice due to a directly introduced population imbalance and harmonic trapping potential. We combine the thermodynamic Bethe ansatz technique with the local density approximation to calculate local quantities such as magnetization and polarization. Utilizing Fick’s Law, we are able to calculate the ratio of spin current to spin diffusion coefficient for both the weak and strong coupling cases that is driven by the population imbalance. We find spin current is characterized by magnetization moving from regions of low magnetization to high, with spin current being zero through insulating regions. Further, in the weak coupling limit, utilizing the linear response theory and calculating current-current correlation, we calculate local spin diffusion coefficient. The local spin diffusion coefficient shows maxima at all the insulating regions.

12:51PM B41.00009 Interaction-induced transport of ultra-cold atoms in 1D optical lattices, DANIEL GRUSS, Oregon State University, CHIH-CHUN CHIEN, Los Alamos National Laboratory, MASSIMILIANO DI VENTRA, University of California, San Diego, MICHAEL ZWOLAK, Oregon State University — The study of time-dependent, many-body transport phenomena is increasingly within reach of ultra-cold atom experiments. These systems not only allow experimental emulation of solid state systems, but allow us to probe the dynamics of transport at a previously unreachable level of detail. We will discuss computational results for the dynamics of electronic/atomic transport and, in particular, simulation of interacting fermionic atoms via a micro-canonical transport formalism using approximations that go beyond mean-field. We will discuss applications of this in terms of simulating particle currents under the influence of applied current and potentials, differing spin-spin interactions, and inhomogeneous lattice impurities. Finally, we will discuss these results in the context of present-day cold atom experiments.

1:03PM B41.00010 Effect of quantum fluctuations on classical motion near a separatrix in a weakly anharmonic lattice, RAFAEL HIPOLITO, Georgia Tech, VADIM OGANESYAN, CUNY College of Staten Island — We investigate the role of quantum fluctuations in the relaxation of a nonequilibrium interacting system for which the phase space curve of the corresponding classical dynamics lies near a separatrix. Such a system may be realized, for example, in a weakly interacting boson system if we initially excite a normal mode which lies in the low quasimomentum sector for which the the system is nearly dispersionless but of nondecay type $(\omega(q) < 0)$. As an example of such a system, we consider the case of a weakly anharmonic lattice in one dimension, where our results have some relevance to the famous Fermi-Pasta-Ulam problem. In the regime considered, we show that the classical dynamics is effectively dominated by just two normal modes which can be mapped into a single particle problem whose phase space curve lies near a separatrix. We show that for the quantum system the initial number of quanta plays the role of effective time. Quantum fluctuations have a dramatic effect on the classical trajectory, causing the system to relax into a steady state where both the time scales associated with the relaxation and the steady state itself are strongly dependent on effective time.

1:15PM B41.00011 Emergence of long distance pair coherence through incoherent local environmental coupling, JEAN-SEBASTIEN BERNIER, Department of Physics and Astronomy, University of British Columbia, PETER BARMETTLER, Departement de Physique Theorique, Universite de Geneve, DARIO POLETTI, Singapore University of Technology and Design, CORINNA KOLLATH, Departement de Physique Theorique, Universite de Geneve — We demonstrate that the interplay between a purely local incoherent environmental coupling, effectively heating up the system, and Hamiltonian dynamics generates quantum coherence. For a repulsively interacting fermionic lattice gas initially prepared in a Mott insulating state, coupling a noise field to the local spin density produces coherent fermionic pairs. We show that the formation of pair coherence is approximately diffusive with time, and is experimentally observed in the pair momentum distribution as the formation of a sharp feature at the zone boundary.
The spectrum of the oscillations reveals the discrete energy levels and relative importance of different Fock states in the initial superfluid and magnetic states. For example, in situ number oscillations reveal the spin-dependent interactions, and visibility oscillations reveal the ratio of on-site and spin-dependent interactions, and thus the various scattering lengths in different channels can be determined. To study the interplay of superfluidity and magnetism, we also examine the oscillations in various observables in the presence of an external magnetic field in the form of quadratic Zeeman energy. The frequency spectrum of the oscillations reveals the discrete energy levels and relative importance of different Fock states in the initial superfluid and magnetic states.

Starting with the ferromagnetic or antiferromagnetic superfluid ground state—a sudden raising of the lattice depth creates a non-equilibrium state. Analysis of the oscillations in atom numbers in different spin states and the collapse and revivals in visibility reveals details about the system parameters and the initial superfluid state. For example, in situ number oscillations reveal the spin-dependent interactions, and visibility oscillations reveal the ratio of on-site and spin-dependent interactions, and thus the various scattering lengths in different channels can be determined.

Joint Quantum Institute, University of Maryland and NIST — We study spin-mixing and collapse and revival dynamics of spin-1 atoms in an optical lattice. Starting with the ferromagnetic or antiferromagnetic superfluid ground state—a sudden raising of the lattice depth creates a non-equilibrium state. Analysis of the oscillations in atom numbers in different spin states and the collapse and revivals in visibility reveals details about the system parameters and the initial superfluid state. For example, in situ number oscillations reveal the spin-dependent interactions, and visibility oscillations reveal the ratio of on-site and spin-dependent interactions, and thus the various scattering lengths in different channels can be determined.

We consider moving bodies—a single rotating object or multiple objects in relative motion—and derive the frictional force by using techniques from non-equilibrium statistical physics as well as quantum optics. The radiation to the environment is obtained as a general expression in terms of the scattering matrix which is a powerful analytical tool. We apply our general formulas to several examples of systems out of equilibrium due to their motion.

Joint Quantum Institute, University of Pittsburgh, University of Innsbruck, and Institute for Quantum Optics and Quantum Information, Innsbruck, HANNES PICHLER, PETER ZOLLER, BEN LANYON, University of Innsbruck, and Institute for Quantum Optics and Quantum Information, Innsbruck, ANDREW J. DALEY, University of Pittsburgh — Systems of cold atoms in optical lattices or a string of ions in a linear trap offer the possibility to experimentally study non-equilibrium dynamics of 1D many-body quantum systems with interactions of varying range in a controlled environment. Entanglement is a basic feature of these systems, and the increase of the entanglement entropy between different blocks of a many-body state as a function of time determines whether the long-time evolution of the system can be efficiently simulated on a classical computer. Correspondingly, states with large-scale entanglement offer regimes where quantum simulators could be used to outperform classical simulation. Thus, there is a great interest to produce large-scale entanglement in these types of experiments. Here we present analytical and numerical results on the entanglement entropy growth behavior in 1D lattice systems after a sudden quench of a model parameter, and the dependence of this growth on the range of the interactions. Furthermore, we present how bipartite Rényi entropies can be measured solely by using tunnel couplings and local measurements, tools which are both available in recent experiments with bosons in optical lattices.

Joint Quantum Institute, University of Pittsburgh, University of Innsbruck, and Institute for Quantum Optics and Quantum Information, Innsbruck, HANNES PICHLER, PETER ZOLLER, BEN LANYON, University of Innsbruck, and Institute for Quantum Optics and Quantum Information, Innsbruck, ANDREW J. DALEY, University of Pittsburgh — Systems of cold atoms in optical lattices or a string of ions in a linear trap offer the possibility to experimentally study non-equilibrium dynamics of 1D many-body quantum systems with interactions of varying range in a controlled environment. Entanglement is a basic feature of these systems, and the increase of the entanglement entropy between different blocks of a many-body state as a function of time determines whether the long-time evolution of the system can be efficiently simulated on a classical computer. Correspondingly, states with large-scale entanglement offer regimes where quantum simulators could be used to outperform classical simulation. Thus, there is a great interest to produce large-scale entanglement in these types of experiments. Here we present analytical and numerical results on the entanglement entropy growth behavior in 1D lattice systems after a sudden quench of a model parameter, and the dependence of this growth on the range of the interactions. Furthermore, we present how bipartite Rényi entropies can be measured solely by using tunnel couplings and local measurements, tools which are both available in recent experiments with bosons in optical lattices.

2:03PM B41.00015 Non-equilibrium scaling, response and coarsening in the quantum large N vector model, ANUSHYA CHANDRAN, VEDIKA KHEMANI, ARUN NANDURI, S. S. GUBSER, S. L. SONDHI, Princeton University — The out-of-equilibrium dynamics of a quantum system that is suddenly or slowly driven in the vicinity of critical point is conjectured to be universal and can be described in a scaling framework. The long time tails of scaling functions for a quench from the disordered to the ordered phase are of particular experimental interest. We theoretically investigate this in the O(N) vector model as \( N \to \infty \) for different spatial dimensions. We demonstrate that the quartic operator that is irrelevant to the equilibrium physics above the upper critical dimension is dangerously irrelevant to the long time dynamics in the scaling limit. We also observe a quantum analogue of the classical process of coarsening in which a correlation length diverges at long times in the thermodynamic limit. Suitably defined linear response measurements offer the tantalizing possibility of directly observing the non-equilibrium scaling functions; we explore these in classical models and Chern insulators as well.

1DMR10-06608

Monday, March 18, 2013 2:30PM - 5:30PM — Session C11 GQI DAMOP: Invited Session: Quantum Communication and Cryptography 310 - Mark Wilde, McGill University and Louisiana State University

2:30PM C11.00001 Limits on classical communication from quantum entropy power inequalities, GRAEME SMITH, IBM Research — Almost all modern communication systems rely on electromagnetic fields as a means of information transmission, and finding the capacities of these systems is a problem of significant practical importance. The Additive White Gaussian Noise (AWGN) channel is often a good approximate description of such systems, and its capacity is given by a simple formula. However, when quantum effects are important, estimating the capacity becomes difficult: a lower bound is known, but a similar upper bound is missing. Here we present strong new upper bounds for the classical capacity of quantum additive noise channels, including quantum analogues of the AWGN channel. Our main technical tool is a quantum entropy power inequality that controls the entropy production as two quantum signals combine at a beam splitter. Its proof involves a new connection between entropy production rates and a quantum Fisher information, and uses a quantum diffusion that smooths arbitrary states towards gaussians.

3:06PM C11.00002 Security of continuous-variable quantum key distribution against general attacks, ANTHONY LEVERRIER, INRIA Rocquencourt — We prove the security of Gaussian continuous-variable quantum key distribution with coherent states against arbitrary attacks in the finite-size regime. In contrast to previously known proofs of principle (based on the de Finetti theorem), our result is applicable in the practically relevant finite-size regime. This is achieved using a novel proof approach, which exploits phase-space symmetries of the protocols as well as the postselection technique introduced by Christandl, Koenig and Renner (Phys. Rev. Lett. 102, 020504 (2009)).

3DM10-06608

This work was supported by the SNF through the National Centre of Competence in Research “Quantum Science and Technology” and through Grant No. 200020-135048, the ERC (grant No. 258932), the Humboldt foundation and the F.R.S.-FNRS under project HIPERCOM.

3:42PM C11.00003 Fully device-independent quantum key distribution, THOMAS VIDICK, Massachusetts Institute of Technology (MIT) — The laws of quantum mechanics allow unconditionally secure key distribution protocols. Nevertheless, security proofs of traditional quantum key distribution (QKD) protocols rely on a crucial assumption, the trustworthiness of the quantum devices used in the protocol. In device-independent QKD, even this last assumption is relaxed: the devices used in the protocol may have been adversarially prepared, and there is no a priori guarantee that they perform according to specification. Proving security in this setting had been a central open problem in quantum cryptography. We give the first device-independent proof of security of a protocol for quantum key distribution that guarantees the extraction of a linear amount of key even when the devices are subject to a constant rate of noise. Our only assumptions are that the laboratories in which each party holds his or her own device are spatially isolated, and that both devices, as well as the eavesdropper, are bound by the laws of quantum mechanics. All previous proofs of security relied either on the use of many independent pairs of devices, or on the absence of noise.

4:18PM C11.00004 Quantum hacking, VADIM MAKAROV, University of Waterloo —
1Complete experimental toolbox for alignment-free quantum communication

**Monday, March 18, 2013 2:30PM - 5:30PM**

**Session C41 DAMOP: Quantum Simulation with Cold Atoms and Molecules**

**2:30PM C41.00001 ABSTRACT WITHDRAWN**

**2:42PM C41.00002 Towards Strongly Interacting Quantum Mixtures of Light Fermions and Heavy Bosons**

**2:54PM C41.00003 Making Dipolar Chain Liquid and Crystal**

**3:06PM C41.00004 Pomeranchuk Cooling in Frustrated Magnets – a Route to Spin Liquids in Cold Atoms**

**3:18PM C41.00005 Symmetry-protected topological phases of alkaline-earth cold fermionic atoms in one dimension**

**3:30PM C41.00006 Quantum Monte Carlo simulation of the power-law correlated SU(6) quantum magnets with \(^{133\text{Yb}}\) fermions**
3:42PM C41.00007 Thermodynamics for reaching SU(N) quantum magnetism in ultracold alkaline earth atoms, KADEN HAZZARD, JILA, NIST, CU-Boulder, LARS BONNES, Institute for Theoretical Physics, University of Innsbruck, SALVATORE MANMANA, Institute for Theoretical Physics, University of Göttingen, VICTOR GURARIE, MICHAEL HERMELE, Dept. of Physics, CU-Boulder, STEFAN WESSEL, Institute for Theoretical Solid State Physics, Aachen University, ANA MARIA REY, JILA, NIST, CU-Boulder — Motivated by the prediction that SU(N) Hubbard models in a large-N limit possess a chiral spin liquid ground state, we investigate how to exploit the large number of degrees of freedom to cool alkaline earth atoms in optical lattices, which are described by the SU(N) Hubbard model with N as large as 10. Combining analytic high temperature expansions and sophisticated quantum Monte Carlo calculations, we show that the entropy increases with N for $T > t^2/U$ independent of dimension and lattice geometry, and down to temperatures $T = 0.1t^2/U$ in one dimensional chains. As a consequence, when one loads these atoms into optical lattices, the final temperatures can be orders of magnitude colder for $N = 10$ than for the usual $N = 2$ case. The use of alkaline earths with large N is thus particularly exciting for cold atoms experiments, where achieving low entropy states displaying quantum magnetism remains an outstanding challenge. This finding explains the dramatic cooling seen in recent Yb ($N = 6$) experiments [Y. Tanaka et al., Nature Physics 8, 800 (2012)].

3:54PM C41.00008 Superfluid state of repulsively interacting three-component fermionic atoms in optical lattices, SEI-ICHIRO SUGA, University of Hyogo, KENSUKE INABA, NTT BRL, CREST — We investigate the superfluid state of repulsively interacting three-component (color) fermionic atoms in optical lattices using Feynman diagrammatic approaches and the dynamical mean field theory [1]. When the anisotropy of the three repulsive interactions is strong, atoms of two of the three colors form Cooper pairs and atoms of the third color remain a Fermi liquid. This superfluid emerges close to half filling at which the Mott insulating state characteristic of the three-component repulsive fermions appears [2]. An effective attractive interaction is induced by density fluctuations of the three-color atoms. The superfluid state is stable against the phase separation that occurs in the strongly repulsive region. We determine the phase diagrams in terms of temperature, filling, and the anisotropy of the repulsive interactions.


1This work was supported by Grant-in-Aid for Scientific Research (C) (No. 23540467) from the Japan Society for the Promotion of Science.

4:06PM C41.00009 Short-Range Correlations and Cooling of Ultracold Fermions in the Honeycomb Lattice, BAOMING TANG, Georgetown University, THEREZA PAIVA, Universidade Federal do Rio de Janeiro, EHSAN KHATAMI, MARCOS RIGOL, Georgetown University — We study experimentally relevant thermodynamic properties and spin correlations of the Hubbard model in the honeycomb lattice by using determinantal quantum Monte Carlo simulations and numerical linked-cluster expansions. We find that the honeycomb lattice exhibits a more pronounced anomalous region in the double occupancy that leads to stronger adiabatic cooling than in the square lattice. We also find that, at half filling and finite temperature, nearest-neighbor spin correlations can be stronger in the honeycomb lattice than in the square lattice, even in regimes where the ground state in the former is a semimetal or a spin liquid while it is an antiferromagnetic Mott insulator in the latter. The implications of these findings for optical experiments are also discussed.

4:18PM C41.00010 From Topological Insulator to Topological Superfluid, XIONG-JUN LIU, Institute of Advanced Study and Department of Physics, Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong, K.T. LAW, T.K. NG, Department of Physics, Hong Kong University of Science and Technology, Clear Water Bay, Hong Kong — Majorana zero bound state exists in the vortex core of a chiral spin liquid of polyacetylene, which models polyacetylene, we measure a difference of the Zak phase equal to $\pi$ for the two possible polyacetylene phases with different dimerization. This indicates that the two dimerized phases belong to different topological classes, such that for a filled band, domain walls have fractional quantum numbers. Our work establishes a new general approach for probing the topological structure of Bloch bands in optical lattices.

4:20PM C41.00011 Direct Measurement of the Zak phase in Topological Bloch Bands, MARCOS ATALA, MONIKA AIDELSBURGER, Ludwig-Maximilians Universitat, JULIO BARREIRO, Ludwig-Maximilians Universitat and Max-Planck Institute of Quantum Optics, DMITRY ABANIN, TAKUYA KITAGAWA, EUGENE DEMLER, Harvard University, IMMANUEL BLOCH, Ludwig-Maximilians Universitat and Max-Planck Institute of Quantum Optics — Geometric phases that characterize the topological properties of Bloch bands play a fundamental role in the modern band theory of solids. Here we report on the direct measurement of the geometric phase acquired by cold atoms moving in one-dimensional optical lattices. Using a combination of Bloch oscillations and Ramsey interferometry, we extract the Zak phase – the Berry phase acquired during an adiabatic motion of a particle across the Brillouin zone – which can be viewed as an invariant characterizing the topological properties of the band. For a dimerized optical lattice, which models polyacetylene, we measure a difference of the Zak phase equal to $\pi$ for the two possible polyacetylene phases with different dimerization. This indicates that the two dimerized phases belong to different topological classes, such that for a filled band, domain walls have fractional quantum numbers. Our work establishes a new general approach for probing the topological structure of Bloch bands in optical lattices.

4:42PM C41.00012 Ground-state properties of spin-imbalanced fermions on square lattices, SIMONE CHIESA, JIE XIU, SHIWEI ZHANG, College of William and Mary — Atoms in optical lattices offer the opportunity to probe exotic pairing states experimentally. We consider spin-imbalanced fermions on a square lattice. Using Bogoliubov-de Gennes theory and fully self-consistent numerical calculations reaching the thermodynamic limit, we make several predictions of the physics of the ground state and the Fulde-Ferrell-Larkin-Ovchinikov (FFLO) order. We show, in particular, that the experimentally accessible momentum distribution can be used to identify the hidden Fermi surface of the condensate and the presence of Fermi arcs. There exists a regime of density (away from half-filling) and interactions where the system can support a supersolid order. Finally, we address the crystallography of the inhomogeneous state by determining the leading wave vector as a function of U, density and polarization.

4:54PM C41.00013 ABSTRACT WITHDRAWN
5:06PM C41.00014 Enhancing the thermal stability of entanglement between Majorana fermions with dipoles in optical lattices. VITO SCAROLA, FEI LIN, Virginia Tech — Pairing between spinless fermions can generate Majorana fermion excitations. Such excitations may exhibit intriguing properties arising from non-local entanglement, including anyonic braid statistics and enough stability to encode quantum information. But simple models indicate that non-local entanglement between Majorana fermions becomes unstable at non-zero temperatures. We discuss this issue and show that anisotropic interactions between dipolar fermions in optical lattices can be used to form domains that significantly enhance thermal stability. We construct a model of oriented dipolar fermions in a square optical lattice. We explicitly compute the correlation functions defining entanglement. We find that domains established by strong interactions exhibit enhanced entanglement between Majorana fermions over large distances and long times even at finite temperatures.

5:18PM C41.00015 Structures forming out of quantum seeds in Bose condensates with time-dependent tunnel coupling. FLORIAN MARQUARDT, CLEMENS NEUENHAHN, University of Erlangen-Nuremberg, Germany, ANATOLI POLKOVNIKOV, Boston University — Quantum fluctuations can be amplified into macroscopic structures in the course of time. This can happen in quench scenarios, where some parameter is time-dependent, and it has wide-ranging implications, from condensed matter physics to cosmology. Here, we investigate the behaviour of a model system of two 1D clouds of bosonic atoms. Specifically, we track the time-evolution of the quantum field that describes the relative phase between the quasi-condensates as a function of position. When suddenly switching on the tunnel-coupling, the subsequent dynamics is first governed by parametric amplification of the initial quantum fluctuations. At a later stage, nonlinear dynamics takes over, and localized phase structures form. These structures, which we term quasi-breathers, then stochastically form and decay, and we characterize their features using numerical simulations of the underlying sine-Gordon equation based on the truncated Wigner approximation. We then turn to a scenario where the tunnel coupling is changed smoothly over time. It turns out this can be mapped to the evolution of the quantum sine-Gordon field in an expanding 1+1 dimensional toy universe, giving insight into nonlinear structure formation in cosmology.
superconducting loop in an external magnetic field, where the loop is interrupted by a weak link with a dynamically tunable current-phase relation. This system is directly analogous to a WRIGHT agreement with the NIST experimental results.

In the absence of circulation, the BEC expands and closes the central hole in a few milliseconds, eventually resulting in a density profile with a central peak by first solving the time–independent Gross–Pitaevskii equation (GPE) to obtain the initial condensate wavefunction, with the (quantized) circulation set by NOEL MURRAY, Georgia Southern University, KEVIN WRIGHT, GRETCHEN CAMPBELL, WILLIAM D. PHILLIPS, NIST and Joint Quantum Institute,


10:24AM F3.00005 Quantum information processing with trapped ions1. JOHN GAEBLER, National Institute for Standards and Technologies — Trapped ions are one promising architecture for scalable quantum information processing. Ion qubits are held in multizone traps created from segmented arrays of electrodes and transported between trap zones using time varying electric potentials applied to the electrodes. Quantum information is stored in the ions’ internal hyperfine states and quantum gates to manipulate the internal states and create entanglement are performed with laser beams and microwaves. Recently we have made progress in speeding up the ion transport and cooling processes that were the limiting tasks for the operation speed in previous experiments. We are also exploring improved two-qubit gates and new methods for creating ion entanglement.

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Tuesday, March 19, 2013 8:00AM - 10:00AM —
Session F41 DAMOP: Rotation, Effective Fields, and Hydrodynamics in Atomic Gases 350 - Phil Johnson, American University

8:00AM F41.00001 Hydrodynamics and universality in cold atomic gases, ALEXANDER ABANOV, Stony Brook University, MANUS KULKARNI, Princeton University — Recent flurry of experiments on out-of-equilibrium dynamics in cold gases (Bosonic and Fermionic) has raised great interest in understanding collective behaviour of interacting particles. Although the dynamics of interacting gases depends on many details of the system, a great insight can be obtained in a rather universal limit of weak non-linearity, dispersion and dissipation. In this limit, using a reductive perturbation method we map many hydrodynamic models relevant to cold atoms to well known chiral one-dimensional equations such as Korteweg-de Vries (KdV), Burgers, KdV-Burgers, and Benjamin-Ono equations. This mapping [1] of rather complicated hydrodynamic equations to known chiral one-dimensional equations is of great experimental and theoretical interest. For instance, this mapping gives a simple way to make estimates for original hydrodynamic equations and to study phenomena such as shock waves, solitons and the interplay between nonlinearity, dissipation and dispersion. All these phenomena have been observed in experiments and are the hallmarks of nonlinear hydrodynamics.


8:12AM F41.00002 Time-of-flight expansion dynamics of a circulating ring BEC1. MARK EDWARDS, NOEL MURRAY, Georgia Southern University, KEVIN WRIGHT, GRETCHEEN CAMPBELL, WILLIAM D. PHILLIPS, NIST and Joint Quantum Institute, CHARLES W. CLARK, Joint Quantum Institute — We have studied the effect of non–zero circulation on the time–of–flight expansion dynamics of a ring–shaped BEC, under conditions matching recent experiments at the Joint Quantum Institute/NIST in Maryland. We modeled the dynamics of the condensate by first solving the temperature–independent Gross–Pitaevskii equation (GPE) to obtain the initial condensate wavefunction, with the (quantized) circulation set by imprinting an azimuthal phase gradient. This state was then propagated using the time–dependent GPE in real time, with the trapping potential turned off. In the absence of circulation, the BEC expands and closes the central hole in a few milliseconds, eventually resulting in a density profile with a central peak surrounded by a pedestal modulated by weak concentric fringes. When the ring BEC is circulating, the central hole initially decreases in size but never closes due to the phase singularity. In the long–time limit, the size of the central hole scales nearly linearly with the winding number of the circulation state, in good agreement with the NIST experimental results.

[1] Support in part by NSF grant #1068761 and the NSF PFC at the JQI and the ARO Atomtronics MURI.

8:24AM F41.00003 Driving phase slips in a neutral-atom analog of an RF SQUID, KEVIN C. WRIGHT1, R.B. BLAKESTAD2, J.G. LEE, S.P. ECKEL, C.J. LOBB3, W.D. PHILLIPS, G.K. CAMPBELL, JQI/NIST/UMD — We can deterministically control the quantized circulation state of a toroidal atomic Bose-Einstein condensate by rotating a weak link around the ring above a critical velocity. We vary this critical velocity by controlling the strength of the repulsive optical dipole potential creating the weak link. This system is directly analogous to a superconducting loop in an external magnetic field, where the loop is interrupted by a weak link with a dynamically tunable current-phase relation.

[1] Current Affiliation: Dept. of Physics and Astronomy, Dartmouth College
8:36AM F41.00004 Observation of hysteresis in a superfluid Bose-Einstein condensate with a weak link.  S. ECKEL, J.G. LEE, K.C. WRIGHT, W.D. PHILLIPS, Joint Quantum Institute, NIST, University of Maryland, C.J. LOBB, University of Maryland, Department of Physics, G.K. CAMPBELL, Joint Quantum Institute, NIST, University of Maryland — Hysteresis is a common feature of superfluid and superconducting systems with Josephson junctions. We have observed hysteresis in the persistent current state of a toroidally-shaped, Bose-Einstein condensate, stirred with a rotating barrier potential. The barrier, which is modeled as a weak link, induces phase slips in the superfluid between well-defined persistent superconducting systems with Josephson junctions. We have observed hysteresis in the persistent current state of a toroidally-shaped, Bose-Einstein condensate, stirred with a rotating barrier potential. The barrier, which is modeled as a weak link, induces phase slips in the superfluid between well-defined persistent superconducting systems with Josephson junctions.

8:48AM F41.00005 Stirring a ring Bose-Einstein condensate: vortices and overall circulation1, NOEL MURRAY, MARK EDWARDS, Georgia Southern University, CHARLES W. CLARK, Joint Quantum Institute — We have studied the process whereby stirring a superfluid Bose-Einstein condensate confined in a ring-shaped potential leads to an overall circulation. We solved the time-dependent Gross–Pitaevskii equation under conditions chosen to match those of an experiment recently conducted at NIST. Briefly, 500,000 Na atoms where confined at the ring-shaped intersection of a red-detuned horizontal light sheet and a vertically propagating Laguerre–Gauss beam. Stirring was carried via a blue–detuned gaussian beam. We found that, at first, the stirring spawned a number of vortex–antivortex pairs and then stopped. These vortices displayed a complicated dynamical behavior which slowly reduced the number of vortices pairwise via annihilation and singly via diffusion into surface modes of the condensate. At the end of this dynamics, the set of vortices was replaced by an overall circulation of atoms around the ring. We present examples of this behavior, give a simple model of vortex motion and vortex-vortex interaction, and show how the production and annihilation of vortices gets turned into an overall circulation of the ring Bose–Einstein condensate.

1Support in part by NSF grant #1068761.

9:00AM F41.00006 Quantum Hall states in rapidly rotating two-component Bose gases, SHUNSUKE FURUKAWA, MASAHITOUEDA, Dept. of Physics, University of Tokyo — Ultracold atomic gases under rapid rotation offer interesting analogues of quantum Hall systems with variable statistics and spins of constituent particles. Here we study strongly correlated phases of two-component (or pseudo-spin-1/2) Bose gases under rapid rotation by means of exact diagonalization. As the ratio of the inter-component contact interaction $g_{11}$ to the intra-component one $g$ increases, the two components are expected to be entangled to form new ground states. For $g_{11} = g$, we find the formation of gapped spin-singlet states at the filling factors $\nu = k/3 + k/3$ (the $k/3$ filling for each component) with integer $k$. In particular, we present numerical evidences that the gapped state with $k = 2$ is well described as a non-Abelian spin-singlet (NASS) state, in which excitations feature non-Abelian statistics. Furthermore, we find the phase transition from the product of composite fermion states to the NASS state by changing the interaction ratio $g_{11}/g$. Reference: Phys. Rev. A 86, 031604(R) (2012).

9:12AM F41.00007 Vortex formation in a rotating reference frame1, MICHAEL RAY, THOMAS LANGIN, DAVID HALL, Amherst College — We create vortices in a trapped Bose-Einstein condensate by cooling the atomic sample through the phase transition in the presence of a rotating magnetic trapping potential. The thermal cloud remains in quasi-equilibrium during the cooling, ultimately producing condensates in the rotating ground state. We show that the trap rotation frequency at which a vortex first appears agrees closely with theoretical predictions. The number of vortices within the condensate is established by the rotation frequency at the phase transition; once the condensate has started to form, its vortex content is robust against frequency changes. Images of the condensate taken during evaporation suggest that the vortex spatial configuration is similarly determined early on in the growth of the condensate.

1Work supported by NSF through grant PHY-0855475

9:24AM F41.00008 Quantum Monte Carlo study of the drag coefficient for two-component BECs1, THOMAS GOLDSTEIN, CHRISTOPHER VARNEY, EGOR BABAEEV, NIKOLAY PROKOFIEV, BORIS SVISTUNOV, University of Massachusetts, Amherst — Groundbreaking advances in experimental techniques for ultracold gases have resulted in considerable interest in multi-component systems, which exhibit richer physics than single species systems. Recent theoretical work has established the strong possibility of “entrainment” coupling between components in a two-component BEC. In this talk, we present quantum Monte Carlo simulations of the drag coefficient in a two-component Bose-Hubbard model. Next, we utilize Langevin dynamics to determine manifestations of the intercomponent drag in the ground state structure of vortices in multi-component superfluids.

1NSF Awards No. DMR-0935902 and No. PHY-1005543

9:36AM F41.00009 Periodically kicked quantum Hall system of cold atoms, MAHMoud LABABIDI, INdUBALA SATIJA, ERHAI ZHAO, George Mason University — The integer quantum Hall state is characterized by chiral edge modes associated with the topological invariant, the Chern number. We numerically study a non-equilibrium, periodically driven quantum hall system of fermionic atoms in a square optical lattice. We show that periodically modulated tunneling gives rise to new edge states inside the quasi-energy band gaps. We present a phase diagram with a zoo of interesting phases as functions of driving parameters, along with the spectral evolution of the edge states through the topological quantum phase transitions.

9:48AM F41.00010 Experimental Validation of Interferometry Simulations on an Atom Chip, VIOLETA PRIETO, JASON ALEXANDER, CHRISTOPHER ROWLETT, WILLIAM GOLDING, PATRICIA LEE. Sensors and Electronic Devices Directorate, US Army Research Laboratory, Adelphi, MD — We report on recent experimental results on manipulating cold atoms trapped on a chip for the development of a compact atom interferometer using a double-well potential. The experiment uses $^{87}$Rb atoms magnetically confined in an atomic waveguide produced by wires on the surface of a lithographically patterned chip. The double-well potential is created by dynamically changing the current configuration on our atom chip. By dynamically powering traces on the atom chip while simultaneously varying external bias fields, we offer a means to coherently split the atomic cloud. We investigate real-time transformations, both adiabatic and non-adiabatic, between different double-well configurations and study their effects on the initially trapped atoms. We examine the coherence properties of the two atomic wavepackets and evaluate their potential use in an atom interferometer.

Tuesday, March 19, 2013 11:15AM - 2:27PM
Session G40 DAMOP: Spin-Orbit Coupling in Ultracold Atom Systems
349 - Carlos Sa De Melo, Georgia Institute of Technology
11:15AM G40.00001 Synthetic gauge fields for ultracold atoms, ROSS WILLIAMS, Joint Quantum Institute, NIST and University of Maryland — Ultracold atoms represent a unique system in which to investigate quantum many-body physics with unprecedented experimental control. The properties of these systems can be tailored to realize model many-particle Hamiltonians, familiar from condensed matter physics, in their most pure and essential form. Magnetic fields, and gauge fields in general, play an important role in collective phenomena in electronic systems, leading to iconic phenomena such as the fractional quantum Hall effect. More complex, matrix valued, gauge fields can be used to describe spin-orbit coupling: itself an essential ingredient in many topological insulators, and in spintronic devices. Given the charge neutrality of ultracold atoms it is not immediately obvious how such physics could be explored in a cold atom context. In this talk I will describe the experimental techniques we use to engineer artificial gauge fields for ultracold neutral atoms using Raman transitions. I will also describe the latest results from the NIST group.

11:51AM G40.00002 Search for Majorana fermions in Spin-Orbit Coupled Ultra-cold Fermi Gases\textsuperscript{1}, CHUANWEI ZHANG, Department of Physics, The University of Texas at Dallas, Richardson, Texas 75080, USA — Topological quantum matter has been an active research field in physics in the past three decades with numerous celebrated examples, including quantum Hall effect, chiral superconductor, topological insulator, etc. In topological materials, Majorana fermions, first envisioned by Majorana in 1935 to describe neutrinos, often emerge as topological quasiparticle excitations of the systems. Majorana fermions are intriguing because they can be construed as their own anti-particles and follow non-Abelian anyonic statistics under a pair-wise exchange of the many-particle wave function, unlike Dirac fermions where electrons and positrons (holes) are distinct. Although the emergence of Majorana fermions in any condensed matter or atomic system is by itself an extraordinary phenomenon, they have also come under a great deal of recent attention due to their potential use in fault tolerant quantum computation. Motivated by the recent experimental realization of spin-orbit coupling for cold atoms, in this talk, I will discuss the emergence of Majorana fermions in spin-orbit coupled Fermi cold atomic superfluids. I will talk about various experimental relevant issues for the observation of Majorana fermions in such cold atomic systems.

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\textsuperscript{1}This work is supported by ARO, DARPA, AFOSR, and NSF.

12:27PM G40.00003 Majorana fermions in one-dimensional spin-orbit coupled Fermi gases, RAN WEI, ERICH MUELLER, Cornell University — We theoretically study trapped one-dimensional Fermi gases in the presence of spin-orbit coupling induced by Raman lasers. The gas changes from a conventional (non-topological) superfluid to a topological superfluid as one increases the intensity of the Raman lasers above a critical chemical-potential dependent value. Solving the Bogoliubov-de Gennes equations self-consistently, we calculate the density of states in real and momentum space at finite temperatures. We study Majorana fermions (MFs) which appear at the boundaries between topologically trivial and topologically nontrivial regions. We linearize the trap near the location of a MF, finding an analytic expression for the localized MF wavefunction and the gap between the MF state and other edge states.

12:39PM G40.00004 Phase diagram of 1D spin-orbit coupled Fermi gases in optical lattices\textsuperscript{1}, CHUNLEI QU, MING GONG, CHUANWEI ZHANG, Department of Physics, The University of Texas at Dallas, Richardson, TX, 75080 — We consider a one dimensional spin-orbit coupled Fermi gas in optical lattices with open boundary condition. This system belongs to the BDI symmetry class because the Hamiltonian can be made real when the Zeeman field is assumed to be along the z direction, thus the topological superfluid is characterized by Z\textsubscript{2} instead of Z\textsubscript{2}. In the optical lattice system, each site admits at most two fermions. The system can host plenty of phases depending on the filling factor and the Zeeman field. At finite Zeeman field we observe a strong competition between the topological superfluid phase and the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) phase. The latter phase is more likely to be observed near the half filling. The spin-orbit coupling plays the role of enhancing the topological superfluid phase and suppressing the FFLO phase, which the Hartree shift plays an utterly opposite role. The possible observation of topological phase is also discussed in the presence of a harmonic trap.

\textsuperscript{1}This work is supported by ARO, AFOSR, and NSF.

12:51PM G40.00005 Topological Quantum Phase Transition of Fermi Gases and its Detections in a Synthetic Non-Abelian Gauge Potential\textsuperscript{1}, FADI SUN, XIAO-LU YU, JINWU YE, Department of Physics and Astronomy, Mississippi State University, P. O. Box 5167, Mississippi State, MS 39762, USA, HENG FAN, WU-MING LIU, Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China — We investigate the topological quantum phase transition of Fermi gases trapped in a honeycomb lattice in the presence of a synthetic non-Abelian gauge potential. We develop a systematic fermionic effective field theory to describe a topological quantum phase transition tuned by the non-Abelian gauge potential and explore its various important experimental consequences. We obtain the critical exponents at zero temperature, dynamic compressibility, uniform compressibility, specific heat and Wilson ratio at finite temperatures. We analyze the effects of atom-atom interactions and possible disorders in generating the non-Abelian gauge fields. We also perform direct numerical calculations on the lattice scale and compare with the results achieved from the fermionic effective field theory. When discussing various feasible experimental detections of the topological quantum phase transition, we stress the important roles of the gauge invariance to distinguish gauge invariant quantities from non-gauge invariant ones.

\textsuperscript{1}This work was mainly supported by NSF-DMR-1161497.

1:03PM G40.00006 Trapped Fermi gases with Rashba spin-orbit coupling\textsuperscript{1}, MENDERES ISKIN, Koc University — We use the Bogoliubov-de Gennes formalism to analyze harmonically trapped Fermi gases with Rashba-type spin-orbit coupling in two dimensions. We consider both population-balanced and -imbalanced Fermi gases throughout the BCS-BEC evolution, and study the effects of spin-orbit coupling on the spontaneously induced countercirculating mass currents and the associated intrinsic angular momentum. In particular, we find that even a small spin-orbit coupling destabilizes Fulde-Ferrell-Larkin-Ovchinnikov (FFLO)-type spatially modulated superfluid phases as well as the phase-separated states against the polarized superfluid phase. We also show that the continuum of quasiparticle and quasihole excitation spectrum can be connected by zero, one or two discrete branches of interface modes, depending on the number of interfaces between a topologically trivial phase (e.g. locally unpolarized/low-polarized superfluid or spin-polarized normal) and a topologically nontrivial one (e.g. locally high-polarized superfluid) that may be present in a trapped system.

\textsuperscript{1}This work is supported by the Marie Curie (FP7-PEOPLE-IRG-2010-268239), TUBITAK (3501-110T839) and TUBA-GEVIP.
and Technology show that such systems can be tuned to have very interesting normal states paving way for studying spin-orbit coupled Fermi liquids. When the fermions experience a contact attraction. In particular, a flow (finite center-of-mass momentum) produces a “stronger” superfluid. In addition, we produce systems with spin-orbit coupling, detuning and Zeeman fields. We show by theoretical considerations that such systems have many interesting features. We investigate the Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) phase in two dimensional spin-orbit coupled degenerate Fermi gas using mean-field theory at zero temperature. The FFLO phase has been greatly enhanced due to the deformation of the Fermi surface, which arise from the interplay between spin-orbit coupling and in-plane Zeeman field. The emergence of FFLO phase has been carefully examined from different angles, and the properties of the BCS superfluid, the FFLO phase and normal gas have also been studied. The in-plane Zeeman field break the rotation symmetry thus the eigenvalues no longer appear in pairs. The experimental signatures for the observation of FFLO phase is also discussed.

1:39PM G40.00009 FFLO and Topological Superfluid Phases in 2D Spin-Orbit Coupling Fermionic Optical Lattices1, YONG XU, CHUNLEI QU, MING GONG, CHUANWEI ZHANG, The University of Texas at Dallas — We investigate the phase diagram of 2D spin-orbit coupled ultra-cold Fermi atoms confined in a square lattice. By numerically solving the corresponding Bogoliubov-de Gennes equation self-consistently, we show that a finite Zeeman field can induce Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) and/or topological superfluid phases (which support Majorana fermions) in the presence of spin-orbit coupling. We find that the perpendicular Zeeman field favors the topological superfluid phase, while the in-plane Zeeman field favors the FFLO state. A simple physical explanation for the above results is also provided.

3Work supported by ARO, AFOSR, and NSF.

1:51PM G40.00010 Finite-Momentum Dimer Bound State in Spin-Orbit Coupled Fermi Gas1, LIN DONG, Rice University, LEI JIANG, Joint Quantum Institute, University of Maryland and National Institute of Standards and Technology, HUI HU, ARC Centre of Excellence for Quantum-Atom Optics, Centre for Atom Optics and Ultrafast Spectroscopy, Swinburne University of Technology, HAN PU, Rice University — We investigate the two-body properties of a spin-1/2 Fermi gas subject to a spin-orbit coupling induced by laser fields. When attractive s-wave interaction between unlike spins is present, the system may form a dimer bound state. Surprisingly, under proper conditions, the bound state obtains finite center-of-mass momentum, whereas under the same condition but in the absence of the two-body interaction, the system has zero total momentum. This unusual result can be regarded as a consequence of the broken Galilean invariance by the spin-orbit coupling. Such a finite-momentum bound state will have profound effects on the many-body properties of the system.

3HP is supported by the NSF, the Welch Foundation (Grant No. C-1669), and DARPA. HH is supported by the ARC Discovery Projects (Grant No. DP0984522) and the National Basic Research Program of China (NFRP-China, Grant No. 2011CB921502).

2:03PM G40.00011 Ultra-cold fermions in the flatland: evolution from BCS to Bose superfluidity in two-dimensions with spin-orbit and Zeeman fields1, LI HAN, CARLOS SA DE MELO, Georgia Institute of Technology — We discuss the evolution from BCS to Bose superfluidity for ultracold fermions in two-dimensions and in the presence of simultaneous spin-orbit and Zeeman fields. We analyze several thermodynamic properties to characterize different superfluid phases including pressure, compressibility, induced polarization, and spin susceptibility. Furthermore, we compute the momentum distribution and construct topological invariants for each of the superfluid phases.

3We thank ARO (Contract No. W911NF-09-1-0220) for support.

2:15PM G40.00012 Flow induced superfluidity and other novel effects in spin orbit coupled fermionic quantum gases1, VIJAY B. SHENOY, Indian Institute of Science — Recent experiments on fermions with synthetic gauge fields produce systems with spin-orbit coupling, detuning and Zeeman fields. We show by theoretical considerations that such systems have many interesting features when the fermions experience a contact attraction. In particular, a flow (finite center of mass momentum) produces a “stronger” superfluid. In addition, we show that such systems can be tuned to have very interesting normal states paving way for studying spin-orbit coupled Fermi liquids.

3Work supported by DST, DAE India.

Wednesday, March 20, 2013 11:15AM - 2:15PM —
Session G41 DAMOP: Attosecond Physics and Optics 350 - Stephen Eckel, National Institute of Standards and Technology
11:15AM G41.00001 Simulated Photoelectron-Based Imaging of Localized Surface Plasmons with Attosecond Resolution, JAMES PRELL, LAUREN BORJA, ANDREY GANDMAN, DESIRE WHITMORE, DANIEL NEUMARK, STEPHEN LEONE, University of California, Berkeley — Simulations of proposed photoelectron streaking experiments in the presence of an oscillating plasmon field are presented. The results indicate that localized surface plasmon dephasing can be imaged with attosecond resolution using electron time-of-flight (TOF) or velocity map imaging (VMI) techniques. In the simulation, localized surface plasmons are excited in metal nanoparticles by a few-cycle infrared or visible laser pulse. Using time-delayed single, isolated attosecond x-ray pulses, electrons are photoemitted from the metallic nanoparticles and streaked by both the plasmon and laser electric fields. The effects of these two fields in the streaking spectra and images can be separated so that the temporal evolution of the plasmon electric field can be directly extracted. The plasmon electric field induces a broadening of the photoelectron speed distribution with an envelope directly proportional to that of the plasmon dipole moment. Plasmon-induced oscillations of the angular distribution in VMI is predicted to report the spatial distribution of the plasmon electric field for nanoparticles with high aspect ratios. The simulations indicate that these techniques can be used to map plasmon dynamics with unprecedented temporal resolution.

11:27AM G41.00002 Metal nanofilm in strong ultrafast optical fields: subcycle Bloch oscillations, VADYM APALKOV, MARK STOCKMAN, Georgia State University — We predict theoretically that a metal nanofilm subjected to an ultrashort optical pulse of a high field amplitude ~ 3 V/Å shows semimetal behavior. At such high pulse intensity, the reflectivity of metal nanofilm is greatly reduced, while the transmissivity and the optical field inside the metal are greatly increased. The temporal profiles of the optical fields are predicted to exhibit pronounced subcycle oscillations which are attributed to the Bloch oscillations and formation of the Wannier-Stark ladder of electronic states. These effects are promising for applications as nanoplasmonic modulators and field-effect transistors with petahertz bandwidth.

11:39AM G41.00003 Attosecond Streaking Chronoscopy of Surfaces, JOACHIM BURGDOERFER, Institute for Theoretical Physics, Vienna University of Technology — With the advent of sub-femtosecond ultrashort XUV pulses and of phase-stabilized IR pulses with sub-cycle time resolution, novel pathways have been opened up for studying time-resolved electronic quantum dynamics on the attosecond scale. These experiments pose challenges for theory: How do short pulses interact with matter? Which novel information can be extracted from time-resolved spectroscopies that cannot be gained from precision experiments in the spectral domain? In this talk we discuss attosecond chronoscopy by streaking photoelectron emission from solid surfaces. Experimental photoemission data reveal a time delay between conduction electrons and core electrons on the ~50 attosecond scale. We show that the temporal information accessible for such a many-electron system in the condensed phase includes both the coherent wavepacket dynamics characterized by the Eisenbud-Wigner-Smith (EWS) time delay as well as decaying processes in transport and relaxation. Extensions to nanostructures will be discussed.

12:15PM G41.00004 Strong-Field Emission From High Aspect Ratio Si Emitter Arrays, PHILLIP KEATHLEY, MICHAEL SWANWICK, ALEXANDER SELL, WILLIAM PUTNAM, STEPHEN GUERRERA, LUIS VELÁSQUEZ-GARCÍA, FRANZ KÄRTNER, Massachusetts Institute of Technology — We discuss photoelectron emission from an arrays of high aspect ratio, sharp Si emitters both experimentally and theoretically. The structures are prepared from highly doped single-crystal silicon having a pencil-like shape with end radii of curvature of around 10 nm. The tips were illuminated at a grazing incidence of roughly 84°deg. with a laser pulse having a center wavelength of 800 nm, and a pulse duration of 35 fs from a regenerative amplifier system. Native oxide coated Si tips were characterized using a time of flight (TOF) electron energy spectrometer. An annealing process was observed, resulting in a red shift of the energy spectra along with an increased electron yield. Total current yield from samples having the oxide stripped were also studied. Apeak total emission of 0.68 pC/bunch, corresponding to around 1.5x10^3 electrons/tip/pulse was observed at a DC bias of 70 V. Both spectral and current characterization results are consistent with a strong-field photoemission process at the surface of the tip apex.

12:27PM G41.00005 Laser Beam Shaping For Lithography on Inclined and Curved Surfaces Using a liquid crystal Spatial Light Modulator, JAVAD R. GATABI, WILHELMUS GEERTS, Physics Department, Texas State University at San Marcos, DAN TAMIR, Department of Computer Science, Texas State University at San Marcos, KUMAR PANDEY, Department of Electrical Engineering, Texas State University at San Marcos — An exposure tool for lithography on non-flat substrates that includes a real-time photoresist thickness and surface topography monitor is under development at Texas State University. Exposure dose and focusing are correct on curved parts of the sample using novel laser beam shaping techniques: two approaches using a Holoeye liquid crystal spatial light modulator (LC-SLM) are being investigated: (1) the implementation of multiple lenses with different focal lengths to split the beam into several parts and keeping each part in focus depending on sample topography; (2) the implementation of a tilted lens function resulting in a tilt of the image plane. Image quality is limited by quantization aberration, caused by the phase modulation’s bit depth limitation, and pixelation aberration, caused by the modulator’s pixel size. A statistical analysis on lenses with different focal lengths provides a detailed description of the mentioned aberrations. The image quality, i.e. resolution and contrast of both techniques, are determined from developed photoresist patterns on curved samples and compared to the theory.

12:39PM G41.00006 Imaging the signals emitted by multiple sources originating from a turbid medium, GABRIEL CWILICH, Department of Physics, Yeshiva University, New York, USA, JUAN JOSE SAENZ, Departamento de Fisica de la Materia Condensada, Universidad Autonoma de Madrid, Spain, LUIS FROUFE PEREZ, Instituto de Estructura de la Materia, CSIC, Madrid, Spain — We studied the problem of spatially closely positioned sources which emit waves inside a turbid medium, through fluorescence or other mechanisms. While for many of the traditional imaging methods, including FRET, the disorder might impose an insurmountable obstacle for the detections of the sources, the interference of the waves in the case of multiple scattering, gives raise, due the coherent propagation of the signals at the mesoscopic scale, so important effects both in the correlations and the fluctuations of the intensity being detected at a point lying outside the medium. The information obtained that way can be used to monitor the displacement of the sources and their degree of coherence even at scales below the wavelength of the radiation being emitted.
12:51PM G41.00007 Attosecond view of the photoelectric effect and optical-field-induced current in dielectrics. RALPH ERNSTORFER, Fritz-Haber-Institut der Max-Planck-Gesellschaft — Fundamental electronic processes in condensed matter like electron transport on atomic length scales, the plasmonic response in metals, or the dielectric response in insulators occur on attosecond time scales. In the first part of my talk, I discuss how a streak camera operating at optical frequencies provides a time-resolved view of the photoelectric effect [1]. Photoelectrons emitted from metal surfaces by an attosecond extreme ultraviolet laser pulse are time-stamped by a few-cycle visible/near-infrared laser pulse. This technique allows for measuring the relative emission time of valence and core electrons with a precision of tens of attoseconds, thereby addressing the intrinsic dynamics of the photoemission. I present recent studies of a free-electron metal [2] as well as of oxygen-covered tungsten single crystals. The origin of the observed attosecond delays in the emission of photoelectrons from different initial states is discussed. In the second part of the talk, I report on electric current in dielectrics induced and controlled by ultrashort optical fields [3]. For very short periods of time, electric fields exceeding 10 V/nm, i.e. fields significantly beyond the threshold for dc dielectric breakdown, can be applied to insulators. In this regime, insulators exhibit a highly nonlinear dielectric response, resulting in an increase in conductivity by many orders of magnitude. Applying 1.5-cycle laser pulses to unbiased metal-dielectric-metal nanogaps, we demonstrate the generation of directly measurable photocurrents whose magnitude and directionality can be controlled with the carrier-envelope phase of the laser pulse, i.e. by the shape of the laser electric field. Such currents can be switched on and off on sub-femtosecond timescales as evidenced by employing two cross-polarized and time-delayed pulses. The ultrafast field-controlled current generation in a dielectric nanostructure may represent a first step towards the realization of optical-field-controlled electronics.

References:

1:27PM G41.00008 Nondiffracting accelerating wave packets beyond the paraxial limit. PENG ZHANG, University of California, Berkeley, YI HU, Institut National de la Recherche Scientifique, Canada, TONGCANG LI, University of California, Berkeley, DRAKE CANNAN, San Francisco State University, XIAOBO YIN, University of California, Berkeley, ROBERTO MORANDOTTI, Institut National de la Recherche Scientifique, Canada, ZHIGANG CHEN, San Francisco State University, XIANG ZHANG, University of California, Berkeley — Self-accelerating Airy wave packets have stimulated rapidly growing research interest in the past five years. However, optical Airy beams are inherently subject to the paraxial limit. Here, we prove both theoretically and experimentally linear and nonlinear self-accelerating beams propagating along circular trajectories beyond the paraxial approximation. Such nonparaxial accelerating beams are exact solutions of the Helmholtz equation. Furthermore, we introduce and demonstrate nonparaxial Mathieu and Weber accelerating beams, generalizing the concept of all previously found accelerating wave packets. We show that such beams bend into large angles along elliptical or parabolic trajectories but still retain nondiffracting and self-healing capabilities. The circular nonparaxial accelerating beams can be considered as a special case of the Mathieu accelerating beams, while an Airy beam is only a special case of the Weber beams at the paraxial limit. Not only do generalized nonparaxial accelerating wave packets open up many possibilities of beam engineering for applications, but the fundamental concept developed here can be applied to other linear wave systems in nature, ranging from electromagnetic and elastic waves to matter waves.

1:39PM G41.00009 Mapping of focused Laguerre-Gauss beams. JOSE R. RIOS LEITE, Departamento de Física, Universidade Federal de Pernambuco, 50670-901 Recife, PE, Brazil, VASILY KLIMOV, P.N. Lebedev Physical Institute, Russian Academy of Sciences, 53 Leninsky Prospekt, Moscow 119991, Russia, MARTIAL DUCLOY, DANIEL BLOCH, Laboratoire de Physique des Lasers, Universite Paris 13, Sorbonne Paris-Cite and CNRS, UMR 7538, 99 Ave. J.B. Clement, F-93430, BRAZIL- FRANCE CAPES546/04-COFECUBP740/12 COLLABORATION — (‘P.I.C.S.’ NO. 5813) BETWEEN C.N.R.S. AND THE RUSSIAN FOUNDATION FOR BASIC RESEARCH COLLABORATION — We study the detection of propagating optical fields bearing axial symmetry in the situation of an extreme focusing, when the paraxial approximation no longer holds. The results, obtained by general arguments based upon the vectorial nature of electromagnetic fields, show the rapid spatial variations of fields with “complicated” spatial structure [1]. Laguerre-Gauss beam, notably beams bearing a l = 2 orbital angular momentum for which a magnetic field and a gradient of the electric field are present on axis have been examined in their behavior upon an atomic size light detector sensitive to quadrupole electric transitions as well as to magnetic dipole transitions. nd apply it to the case of a Laguerre-Gauss beam. We detail how the mapping of such a beam depends on the nature and on the specific orientation of the detector. We also show that the interplay of mixing of polarization and topological charge, respectively associated to spin and orbital momentum when the paraxial polarization hold, modifies the apparent size of the beam in the focal plane.


1:51PM G41.00010 Photonic temperature sensor based on microring resonators. HAITAN XU, QJI, University of Maryland-College Park and NIST, ZEESHAN AHMED, NIST, MOHAMMAD HAFEZI, JIQI, University of Maryland-College Park and NIST, JINGYUN FAN, GREGORY STROUSE, ALAN MIGDALL, NIST, JACOB TAYLOR, QJI, University of Maryland-College Park and NIST — Temperature needs to be controlled accurately and precisely in various areas, yet it is one of the most inaccurately measured physical quantities. We consider a new measurement method for temperature using the thermal response of a microring resonator built using Silicon-on-Insulator. The temperature-dependence of the index refraction maps temperature to the resonance frequency of the resonator, which can be measured with higher precision. We study the resolution and accuracy of our device, as well as future challenges for this approach for temperature metrology.

2:03PM G41.00011 A new bound on excess frequency noise in second harmonic generation in PPKTP at the 10$^{-19}$ level. DAVID YEATON-MASSEY, RANA ADHIKARI, Caltech — Several experiments at the forefront of precision metrology and frequency standards use optical harmonic generation in their experiments. These include iodine stabilized Nd:YAG lasers, optical frequency combs, measurement of optical frequency ratios, and precision atomic spectroscopy. We present an experimental bound on the relative frequency fluctuations introduced in the nonlinear second harmonic generation process using PPKTP to double a 1064nm Nd:YAG laser. We report a measured frequency spectral density of frequency noise with total RMS frequency deviation of 3mHz and a minimum value of 20 µHz corresponding to an Allan deviation of 10$^{-19}$ at 20 seconds.

We gratefully acknowledge funding provided by NSF grant 0757058

Tuesday, March 19, 2013 2:30PM - 5:30PM – Session J27 DAMOP: Focus Session: Nano/Optomechanics I

329 - Mohammad Hafezi, University of Maryland
2:30PM J27.00001 Nanomechanics and superconducting qubits for quantum information1. ANDREW CLELAND, University of California - Santa Barbara — There has been tremendous progress in the capabilities of superconducting quantum circuits, both for fundamental quantum science as well as for applications in quantum information. Superconducting qubits are based on the Josephson junction, which provides the fundamental inductive nonlinearity that affords full quantum control of otherwise quite simple electrical circuits. I will outline how a superconducting qubit can be used to measure and control the quantum state of a nanomechanical system [1], completely control multi-photon states in superconducting resonators [2,3], factor the number 15 using a von Neumann-style computing architecture [4,5], and possibly allow the transfer of a GHz-frequency quantum state to an optical signal.


1Support from DARPA, IARPA and NSF.

3:06PM J27.00002 Observation of optical quantum measurement backaction on a mechanical resonator, THOMAS PURDY, ROBERT PETERSON, PEN-LI YU, CINDY REGAL, JILA-University of Colorado and NIST, and Department of Physics, University of Colorado, Boulder — Quantum mechanics provides an inextricable link between measurement and backaction on the subsequent dynamics of a system. Here we continuously monitor the position of a membrane microresonator in a cavity optomechanical system. We observe a fluctuating backaction force on the resonator which rises with measurement strength in accordance with the minimum allowed by the Heisenberg position-momentum uncertainty limit. For our optically-based position measurement backaction the measurement takes the form of a fluctuating radiation pressure due to optical shot noise. We demonstrate radiation pressure shot noise that is comparable to in magnitude to thermal fluctuations at frequencies near the mechanical resonance. Additionally, we observe temporal correlations between fluctuations in the radiation force and resonator position, which we interpret as a non-demolition measurement of the intracavity photon field fluctuations. We will also discuss possible methods to lower the technical noise floor in all measurement quadratures.

3:18PM J27.00003 Quantum optics experiments with micromechanical oscillators, SIMON GROEBBLACHER, AMIR SAFAVI-NAEINI, JEFF HILL, JASPER CHAN, OSKAR PAINTER, Caltech — Mechanical oscillators coupled to optical fields via the radiation pressure force have been of great interest lately as they allow for quantum experiments with macroscopic systems. Recent experiments have shown ground-state preparation and measurement of such resonators via sideband-resolved laser cooling. We will discuss our recent work that aims at achieving quantum control over nanoscale optomechanical crystal devices, both using strong coherent optical beams as well as single photons.

3:30PM J27.00004 Optomechanical Coupling Between Membrane Modes, ALEXEY B. SHKARIN, NATHAN E. FLOWERS-JACOBS, SCOTT W. HOCH, Dept of Physics, Yale University, CHRISTIAN DEUTSCH, JAKOB REICHEL, Laboratoire Kastler Brossel, ENS/UPMC, JACK G.E. HARRIS, Dept of Physics and Dept of Applied Physics, Yale University — In an optomechanical device, radiation pressure couples optical power to mechanical motion. While typical experiments couple a single optical cavity to a single mechanical resonance, there has been increasing theoretical and experimental interest in multi-mode systems where there is coupling between multiple mechanical resonances and/or multiple optical cavity modes. We report on a device consisting of a dielectric SiN membrane located inside a high finesse fiber-cavity, where two nearly-degenerate mechanical modes couple to a single cavity mode. We observe that the original mechanical modes can experience a large coupling that is mediated by intracavity field. This causes the mechanical eigenmodes of the system to depend strongly on the radiation pressure and change from the original mechanical modes to a symmetric and antisymmetric combination of the original modes. The symmetric/antisymmetric modes are also known as “dark” and “bright” modes, as they have very different coupling to the cavity. In the quantum regime, this effective interaction between mechanical modes would open up the possibility of state transfer between multiple mechanical modes.

3:42PM J27.00005 Gain-enhanced optical cooling in cavity optomechanics, LI GE, Department of Electrical Engineering, Princeton University, New Jersey 08544, USA, SANLI FAEZ, FLORIAN MARQUARDT, Max-Planck-Institute for the Science of Light, G"unther-Scharowsky-Strasse 1/Bau 24, DE-91058 Erlangen, Germany, HAKAN TURECI, Department of Electrical Engineering, Princeton University, Princeton, New Jersey 08544, USA — We study the optical cooling of the mechanical motion of the resonator mirror in a cavity-optomechanical system that contains an optical gain medium. We find that the optical damping caused by radiation pressure force is vanishingly small if the active medium is pumped incoherently above its lasing threshold. In addition, we find that the spontaneous emission of the active medium always tends to increase the final effective temperature of the mechanical motion. In the presence of an additional seeding signal, i.e. a coherent drive of fixed frequency within the width of the gain curve, however, we find that the cooling rate can be enhanced significantly with respect to that of a passive cavity. We attribute this effect to a reduced effective optical damping in the presence of incoherent pumping.

3:54PM J27.00006 Novel cooling mechanisms in optomechanical systems, JUAN RESTREPO, IVAN FAVERO, CRISTIANO CIUTI, Laboratoire MPQ, Université Paris Diderot and CNRS, France — We present here our theoretical work on unconventional cooling mechanisms in optomechanical systems. In particular our classical and quantum theory of photothermal cooling [1] and our more recent work on cooling of a mechanical oscillator in cavity QED systems [2].


4:06PM J27.00007 Optical measurement of the thermal motion of a micromechanical resonator and its modal interaction by sideband actuation scheme, SUNGWAN CHO, Korea Research Institute of Standards and Science, Seoul National University, MYUNG RAE CHO, SUNG UN CHO, Seoul National University, SANG GOON KIM, SEUNG BO SHIM, Korea Research Institute of Standards and Science; YUN DANIEL PARK, Seoul National University — We present our work on the measurement of the thermal motion of a micromechanical resonator and excitation of flexural mode by sideband actuation. Doubly-clamped micromechanical resonators are fabricated from high-stress silicon nitride on SiO2/Si substrate and patterned with standard e-beam lithographic techniques. Optical measurement of resonant response of micromechanical resonator reveals its fundamental flexural mode of thermal motion at approximately 3.4 MHz (f0) with quality factor up to 180,000 and higher modes at room temperature in moderate vacuum. With fundamental and higher flexural modes of thermal motion and sideband actuation scheme, we also observe amplitude increase in flexural mode of thermal motion with blue-detuned sideband pumping.
We discuss fabrication of monolithic optomechanical devices using dielectric mirrors and high-stress stoichiometric Si systems have been highly researched as a platform for testing macroscopic quantum effects and quantum decoherence. However, the required optical and BRIAN PEPPER, UC Santa Barbara, PETRO SONIN, University of Leiden, DIRK BOUWMEESTER, UC Santa Barbara / University of Leiden — Optomechanical and its transient response, approaching the regime of real-time detection of the carbon nanotube’s mechanical motion.

significantly by using a high-impedance, close-proximity HEMT amplifier. The increased bandwidth should allow us to observe the nanotube’s thermal motion with an intermediate frequency (IF) of 46 MHz and a timeconstant of 1 us, up to 5 orders of magnitude faster than before. Previous measurements suffered VIBHOR SINGH, BEN SCHNEIDER, RAYMOND SCHOUTEN, HERRE VAN DER ZANT, GARY STEELE, Delft University of Technology — We perform fast are found to correspond to an internal noise level of only 11

4:30PM J27.00009 Robust entanglement via optomechanical dark mode: adiabatic scheme1 . LIN TIAN, School of Natural Sciences, University of California, Merced, YING-DAN WANG, Department of Physics, McGill University, SUMEI HUANG, School of Natural Sciences, University of California, Merced, AASHISH CLERK, Department of Physics, McGill University — Entanglement is a powerful resource for studying quantum effects in macroscopic objects and for quantum information processing. Here, we show that robust entanglement between cavity modes with distinct frequencies can be generated via a mechanical dark mode in an optomechanical quantum interface. Due to quantum interference, the effect of the mechanical noise is cancelled in a way that is similar to the electromagnetically induced transparency. We derive the entanglement in the strong coupling regime by solving the quantum Langevin equation using a perturbation theory approach. The entanglement in the adiabatic scheme is then compared with the entanglement in the stationary state scheme. Given the robust entanglement schemes and our previous schemes on quantum wave length conversion, the optomechanical interface hence forms an effective building block for a quantum network.

1This work is supported by DARPA-ORCHID program, NSF-DMR-0956094, NSF-CCF-0916303, and NSF-COINS.

4:42PM J27.00010 Development of a dispersive read-out technique for quantum measurements of nanomechanical resonators1 , FRANCISCO ROUXINOL, MATTHEW LAHAYE, HUGO HAO, Syracuse University, SEUNG-BO SHIM, Korean Research Institute for Science and Standards — Over the last decade, there has been an active effort to prepare and measure mechanical structures in the quantum regime for the purpose of sensing weak forces and for studying fundamental topics in quantum mechanics such as quantum measurement, entanglement and decoherence in new macroscopic limits. One promising tool for such studies is the qubit-coupled mechanical resonator. In this work, we discuss some of our first results towards the development of a nanaolectromechanical system that integrates a charge-type superconducting qubit as a detector to probe the number-states of a nanomechanical mode. In our system the qubit-coupled nanoresonator is embedded in a superconducting microwave resonator (SMR); the SMR then serves to perform spectroscopic measurements of the qubit to infer the number-state statistics of the nanoresonator in a manner analogous to dispersive measurement techniques used in circuit and cavity QED to probe the number-states of electromagnetic cavities. We will discuss the design and measurement of our latest generation devices and the prospects for achieving single-phonon measurement resolution with this system.

1This work is supported by NSF-DMR Career Award 1056423 and funding from the College of Arts and Sciences at Syracuse University.

5:06PM J27.00012 Coherent optical wavelength conversion via cavity-optomechanics , JEFF HILL, AMIR SAFAVI-NAEINI, JASPER CHAN, OSKAR PAINTER, California Institute of Technology — In this talk we theoretically propose and experimentally demonstrate coherent wavelength conversion of optical photons using photon-phonon translation in a cavity-optomechanical system. Our system is an engineered silicon optomechanical crystal nanocavity supporting a 4 GHz localized phonon mode, optical signals in a 1.5 MHz bandwidth are coherently converted over a 11.2 THz frequency span between one cavity mode at wavelength 1460 nm and a second cavity mode at 1545 nm with a 93% internal (2% external) peak efficiency. The thermal and quantum limiting noise involved in the conversion process is also analyzed, and in terms of an equivalent photon number signal level are found to correspond to an internal noise level of only 6 and 4 x 10^{-3} quanta, respectively [1].


5:18PM J27.00013 Fast readout of carbon nanotube mechanical resonators , HAROLD MEERWALDT, VIBHOR SINGH, BEN SCHNEIDER, RAYMOND SCHOUTEN, HERRE VAN DER ZANT, GARY STEELE, Delft University of Technology — We perform fast readout measurements of carbon nanotube mechanical resonators. Using an electronic mixing scheme, we can detect the amplitude of the mechanical motion with an intermediate frequency (IF) of 46 MHz and a timeconstant of 1 us, up to 5 orders of magnitude faster than before. Previous measurements suffered from a low bandwidth due to the combination of the high resistance of the carbon nanotube and a large stray capacitance. We have increased the bandwidth significantly by using a high-impedance, close-proximity HEMT amplifier. The increased bandwidth should allow us to observe the nanotube’s thermal motion and its transient response, approaching the regime of real-time detection of the carbon nanotube’s mechanical motion.

Tuesday, March 19, 2013 2:30PM - 4:54PM — Session J40 DAMOP: Quantum Simulation II — 349 - Khan W. Mahmud, University of Maryland
1:30PM J40.00001 Simulation of a Non-Equilibrium Localization Transition of Photons in a Superconducting Circuit-QED Dimer, DARIUS SADRI, JAMES RAFTERY, ANDREW HOUCK, HAKAN TURECI, Princeton University, SEBASTIAN SCHMIDT, ETH Zurich, DEVIN UNDERWOOD, WILL SHANKS, SRIKANTH SRINIVASAN, MIKOLA BORDYUH, Princeton University — The exponential scaling of Hilbert space dimension with number of quantum degrees of freedom, while serving as a resource for quantum computation, makes simulation of large quantum systems on classical computers prohibitive, particularly when interactions with an environment are included. Quantum simulation promises to make the investigation of rich quantum behavior on a controlled quantum mechanical device (effectively a specialized quantum computer), deepening our understanding of fascinating physics such as quantum phase transitions, non-equilibrium quantum dynamics, and quantum chaos. Superconducting circuits and micro- and nanoscale Electron Tunneling Transistors (ETTs) offer a promising platform for such simulations. As a first step, we will present a novel, quantum simulator for a conjectured dissipation-driven localization transition of light in a dimer using cQED techniques. A proper understanding of the physics and signature of this transition has been made possible by our development of a new classical simulator based on the stochastic quantum jump method, taking advantage of a fractal structure in our Hamiltonian to enable a study of the very large Hilbert spaces demanded by this problem. We present recent results for these simulations, and discuss possible future directions.

2:30PM J40.00002 Quantum simulations of cooper pairing and driven nonlinear Schrödinger equation with stationary light, PRIYAM DAS, MINGXIA HUO, CHANGSUOK NOH, Center for Quantum Technologies, National University of Singapore, B. M. RODRIGUEZ-LARA, Instituto Nacional de Astrofisica, Optica y Electronica, Mexico, DIMITRIS G. ANGELAKIS, Center for Quantum Technologies, National University of Singapore and Singapore and Department, Technical University of Crete — Strongly correlated states of photonic matter, including all effects of the rotating frame. We show the character of the phonon modes and spectrum, which is crucial for engineering exotic spin interactions.

2:42PM J40.00003 Experimental investigation of a nonequilibrium delocalization-localization crossover of photons in circuit quantum electrodynamics, JAMES RAFTERY, DARIUS SADRI, MYKOLA BORDYUH, DEVIN UNDERWOOD, WILL SHANKS, SRIKANTH SRINIVASAN, Princeton University, SEBASTIAN SCHMIDT, ETH Zurich, HAKAN TURECI, ANDREW HOUCK, Princeton University — We report measurements of the time-dynamics of a Jaynes-Cummings dimer. The dimer is fabricated in the circuit quantum electrodynamics (cQED) architecture, with two coupled resonators each coupled to a single transmon qubit. Such a system is predicted to exhibit three distinct behavioral regimes: delocalized, in which photons can oscillate between the two cavities; localized, in which photons are locked into a single cavity; and exiguous, in which extremely low photon numbers lead to the disappearance of locking. Dissipation in the system drives crossovers between the regimes. The experimental measurements of the on and off-site correlation functions will be presented.

3:06PM J40.00004 On the phase transition of light in cavity QED lattices, MARCO SCHIRO, Princeton Center for Theoretical Science and Department of Physics, Joseph Henry Laboratories, Princeton University, Princeton, NJ 08544, USA, MYKOLA BORDYUH, BARIS OZTOP, HAKAN TURECI, Department of Electrical Engineering, Princeton University, Princeton, NJ 08544, USA — Systems of strongly interacting atoms and photons that can be realized with cold atom experiments and circuit QED systems into lattices, are perceived as a new platform for quantum simulation. By sharing important properties with other systems of interacting quantum particles here we argue that the nature of light-matter interaction gives rise to unique features with no analogs in condensed matter or atomic physics setups. By discussing the physics of a lattice model of delocalized photons coupled locally with two-level systems through the elementary light-matter interaction described by the Rabi model, we argue that the inclusion of counter rotating terms, so far neglected, is crucial to stabilize finite-density quantum phases of correlated photons out of the vacuum, with no need for an artificially engineered chemical potential. We show that the competition between photon delocalization and Rabi non-linearity drives the system across a novel $Z_2$ parity symmetry-breaking quantum criticality between two gapped phases which shares similarities with the Dicke transition of quantum optics and the Ising critical point of quantum magnetism. We discuss the phase diagram as well as the low-energy excitation spectrum and present analytic estimates for critical quantities.

3:18PM J40.00005 Phonon mediated quantum spin simulator made from a two-dimensional Wigner crystal in Penning traps, JOSEPH WANG, Theoretical Division, Los Alamos National Lab, ADAM KEITH, University of Cororado at Boulder, J. K. FREERRICKS, Georgetown University — Motivated by recent advances in quantum simulations in a Penning trap, we give a theoretical description for the use of two-dimensional cold ions in a rotating trap as a quantum emulator. The collective axial phonon modes and planar modes are studied in detail, including all effects of the rotating frame. We show the character of the phonon modes and spectrum, which is crucial for engineering exotic spin interactions.

In the presence of laser-ion coupling with these coherent phonon excitations, we show theoretically how the spin-spin Hamiltonian can be generated. Specifically, we notice certain parameter regimes in which the level of frustration between spins can be engineered by the coupling to the planar modes. This may be relevant for the use of two-dimensional cold ions in a rotating trap as a quantum emulator. The collective axial phonon modes and planar modes are studied in detail, including all effects of the rotating frame. We show the character of the phonon modes and spectrum, which is crucial for engineering exotic spin interactions.

"This work was supported under ARO grant number W911NF0710567 with funds from the DARPA OLE Program. J. K. F. also acknowledges the McDevitt bequest at Georgetown University. A. C. K. also acknowledges support of the National Science Foundation under grant 1307257."

3:30PM J40.00006 Goldstone and Higgs modes of photons inside an cavity and their detections, YU YIXIANG, Department of Physics and Astronomy, Mississippi State University, Mississippi State, 39762, YU CHEN, Department of Physics, Peking University, Beijing 100871, China, JINWU YE, Department of Physics and Astronomy, Mississippi State University, Mississippi State, 39762, WUMING LIU, Beijing National Laboratory for Condensed Matter Physics, Institute of Physics, Chinese Academy of Sciences, Beijing 100190, China — It was well known that a broken global continuous symmetry leads to two associated collective modes: a massless Goldstone mode and a massive Anderson-Higgs amplitude mode. The two modes have been detected in various condensed matter systems and recently also in cold atom systems. The Higgs mode in particle physics was finally detected in two recent LHC experiments. In this work, we show that the two modes can also be detected in optical systems inside a cavity with only a few (artificial) atoms. We demonstrate this connection by studying the $U(1)$ Dicke (Tavis-Cummings) model where $N$ qubits (atoms) coupled to a single photon mode. We perform both $1/N$ expansion and exact diagonalization (ED) study on the model. We determine the Goldstone and Higgs modes and their corresponding spectral weights from the system’s energy spectrum and also from various photon and atom correlation functions. We find nearly perfect agreement between the results achieved from the $1/N$ calculations with those from the ED studies in all these physical quantities even when $N$ gets down even to $N = 2$. The experimental detections of both modes are also discussed.

"Supported by NSF-DMR-1161497, NSF-C-11074173, 11174210."

"This work was supported under ARO grant number W911NF0710567 with funds from the DARPA OLE Program. J. K. F. also acknowledges the McDevitt bequest at Georgetown University. A. C. K. also acknowledges support of the National Science Foundation under grant 1307257."

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3:42PM J40.00007 Coherent radiation from a collection of molecules interacting with surface plasmons\textsuperscript{1}, MICHAEL STOPA, SEMION SAIKIN, ALAN ASPURU-GUZIK, Harvard University — A collection of molecules interacting coherently with a radiation field has dramatically different absorption and emission properties than the same collection of molecules interacting incoherently with the field. In the former case, the collective states of the molecules become important and these consist of states which radiate super-classically (Dicke superradiance) as well as states which are dark. Treated as two-level systems such a collection of molecules can be thought of as a set of spins. The product state of those spins can be transformed to a basis of states of good total “angular momentum” J, and good J\_z (z-component of total angular momentum). Here, we construct a numerical, invertible transformation between the direct product basis and the total J basis for N total molecules. For an arbitrary product state we calculate the rate of transition via radiation out of an arbitrary state in first order perturbation theory. For an ensemble of initial states we calculate the statistical distribution of the radiance (as a function of the J\_z quantum number and disorder in the couplings) of the initial state. We show that the average radiance is approximately equal to the classical value but that the distributions have an asymmetric tail toward superradiance.

\textsuperscript{1}Supported by DTRA.

3:54PM J40.00008 Exciton-Polaritons condensates with flat bands in a two-dimensional kagome lattice, NA YOUNG KIM, Stanford University, NAOKI MASUMOTO, National Institute of Informatics, YOSHIHISA YAMAMOTO, Stanford University, SVEN HOEFLING, ALFRED FORCHEL, University of Wuerzburg — Microcavity exciton-polariton condensates have provided immense opportunity to investigating hydrodynamic vortex properties, superfluidity, and low energy quantum state dynamics. Recently, exciton-condensates have been trapped in various artificial periodic potential geometries: one-dimensional, two-dimensional (2D) square, triangular, and hexagonal lattices. A 2D kagome lattice has been of interest for many decades, which exhibits spin frustration, giving rise to magnetic phase order in real materials. In particular, flat bands in the 2D kagome lattice are physically interesting in that localized states in the real space are formed. Here, we realize exciton-polariton condensates in a 2D kagome lattice potential and examine their photoluminescence properties. Above quantum degeneracy threshold values, we observe meta-stable condensation in high-energy bands; the third band exhibits a signature of weaker dispersive band structures, flat band. We perform single-particle band structure calculation to compare measured band structures.

4:06PM J40.00009 Spinor condensates of ortho- and para-positronium, YI-HSIEH WANG, Chemical Physics Program and Joint Quantum Institute, University of Maryland, CHARLES W. CLARK, Joint Quantum Institute — In 1994, Platzman and Mills \textsuperscript{1} considered the possibility of making a Bose-Einstein condensate (BEC) of positronium atoms (Ps). There are four low-lying states of Ps: a singlet, often called parapositronium (p-Ps); and three triplet states, often referred to as orthopositronium (o-Ps). The lifetime against electron-positron annihilation for o-Ps is a thousand times longer than that of p-Ps. By converting a long-lived triplet o-Ps BEC to a p-Ps condensate with a magnetic field, strong \(\gamma\)-ray emission can be generated as the outcome of the annihilation of coherent p-Ps atoms. However, inelastic scattering processes which convert p-Ps atoms to o-Ps may deplete the p-Ps population and further suppress the \(\gamma\)-ray emission. We investigate this possibility by treating the system as a spinor condensate, and use the coupled time dependent Gross-Pitaevskii (GP) equations to take into account possible population-exchanging scatterings and annihilation processes in the p-Ps/o-Ps BEC mixture. This GP simulation is used to predict the \(\gamma\)-ray yield in realistic experimental scenarios.

\textsuperscript{1}P. M. Platzman and A. P. Mills, Jr., Phys. Rev. B 49, 454 (1994)

4:18PM J40.00010 Quantum simulation of non-equilibrium dynamical maps with trapped ions, PHILIPP SCHINDLER, Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria, MARKUS MULLER, Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria, JULIO T. BARREIRO, LMU München, 80799 München, Germany, ESTEBAN A. MARTINEZ, INSTITUT FÜR EXPERIMENTALPHYSIK, 6020 Innsbruck, Austria, JULIO T. BARREIRO, LMU München, 80799 München, Germany, ESTEBAN A. MARTINEZ, MARKUS HENNICH, Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria, SEBASTIAN DIEHL, PETER ZOLLER, Institut für Theoretische Physik, Universität Innsbruck, und IQOQI, 6020 Innsbruck, Austria, RAINFOY BLATT, Institut für Experimentalphysik, Universität Innsbruck, und IQOQI, 6020 Innsbruck, Austria — Dynamical maps are central for the understanding of general state transformations of physical systems. Prime examples include classical nonlinear systems undergoing transitions to chaos, or single particle quantum mechanical counterparts showing intriguing phenomena such as dynamical localization. Here, we extend the concept of dynamical maps to an open-system, many-particle context and experimentally explore the stroboscopic dynamics of a complex many-body spin model in a universal quantum simulator using up to five ions. We generate quantum mechanical long range order by an iteration of purely dissipative maps, reveal the characteristic features of a combined coherent and dissipative non-equilibrium evolution, and develop and implement various error detection and reduction techniques that will facilitate the faithful quantum simulation of larger systems.

4:30PM J40.00011 Quantum simulations of neutrino oscillations and the Majorana equation\textsuperscript{1}, CHANGSUK NOH, Center for Quantum Technologies, NUS, BLAS RODRIGUEZ-LARA, Instituto Nacional de Astrofísica, Óptica y Electrónica, Coordinación de Óptica, DIMITRIS ANGELAKIS, Science Department, Technical University of Crete and Center for Quantum Technologies, NUS — Two recent works on quantum simulations of relativistic equations are presented. The first is on neutrino oscillations with trapped ions as a generalization of Dirac equation simulation in 1 spatial dimension. It is shown that with two or more ion qubits it is possible to mimic the flavour oscillations of neutrinos. The second part is on quantum simulations of the Majorana equation based on the earlier work by Casanova et al. (PRX 1, 021018). We show that by decoupling the equation, it is possible to simulate with a smaller number of qubits given that one can perform complete tomography, including the spatial degrees of freedom.

\textsuperscript{1}We acknowledge the financial support by the National Research Foundation and Ministry of Education, Singapore.

4:42PM J40.00012 Phase Diagram of a driven-dissipative Bose-Hubbard model, ALEXANDRE LE BOITÉ, GIULIANO ORSO, CRISTIANO CIUTI, Laboratoire MPQ, Université Paris Diderot-Paris 7 and CNRS — In recent years, quantum fluids of light in nonlinear optical systems have attracted a lot of interest [1]. In particular, a considerable activity is presently devoted to non-equilibrium many-body phenomena with light, such as superfluid propagation and generation of topological excitations. We present here recent theoretical results on strongly correlated photons in arrays of nonlinear cavities, described by a driven-dissipative Bose-Hubbard model. We have determined the mean-field phase diagram, studied the collective excitations and quantum correlations [2], finding interesting properties which are absent in the equilibrium case.


\[2\] A. Le Boitè, G. Orso, C. Ciuti, in preparation.

Tuesday, March 19, 2013 2:30PM - 5:30PM –
Session J41 DAMOP: Interacting Bosons in Optical Lattices

350 - Tigran Sedrakyan, University of Minnesota
2:30PM J41.00001 Characterizing boson density wave and valence bond orders in a lattice by its dual vortex degree of freedoms, YAN CHEN, Fudan University, China, JINWU YE, Mississippi State University — A duality transformation in quantum field theory is usually established first through partition functions. It is always important to explore the dual relations between various correlation functions in the transformation. Here, we explore such a dual relation to study quantum phases and phase transitions in an extended boson Hubbard model at $1/3$ ($2/3$) filling on a triangular lattice. We develop systematically a simple and effective way to use the vortex degree of freedoms on dual lattices to characterize both the density wave and valence bond symmetry breaking patterns of the boson insulating states in the direct lattices. In addition to a checkerboard charge density wave (X-CDW) and a stripe CDW, we find a novel CDW-VBS phase which has both local CDW and local valence bond solid (VBS) orders. Implications on QMC simulations are addressed. The possible experimental realizations of cold atoms loaded on optical lattices are discussed.

2:42PM J41.00002 Dynamics of interacting bosons in homogeneous lattices, STEPHAN LANGER, University of Pittsburgh, LMU Munich, JENS P. RONZHEIMER, MICHAEL SCHREIBER, SIMON BRAUN, SEAN HODGMAN, LMU and MPQ Munich, IAN P. MCCULLOCH, University of Queensland, FABIAN HEIDRICH-MEISNER, FAU Erlangen and LMU Munich, IMMANUEL BLOCH, ULRICH SCHNEIDER, LMU and MPQ Munich — Due to independent real-time control of Hamiltonian parameters in optical lattices, the non-equilibrium transport properties of interacting bosons and fermions can be studied in experiments with ultra-cold atomic gases (see [1] for a sudden expansion experiment with fermions). In this work, we experimentally and numerically investigate the expansion of initially localized bosons in homogeneous one- and two-dimensional optical lattices. Dimensionality has a crucial influence, since one-dimensional systems expand ballistically both in the non-interacting and the strongly interacting limit, separated by a pronounced minimum in the expansion velocity at intermediate interaction strengths. For two-dimensional and sufficiently strongly coupled one-dimensional systems, even weak interactions lead to a dramatic suppression of the expansion, indicative of diffusive dynamics. In the case of one dimension, we find an excellent agreement between the experimental results and time-dependent density-matrix renormalization group simulations. [1] Schneider et al. Nature Phys. 8, 213 (2012)

2:54PM J41.00003 Phase diagram of two-species hard-core bosons in a two-dimensional optical lattice, KALANI HETTIARACHCHILAGE, VALERY ROUSSEAU, KA-MING TAM, MARK JARRELL, JUANA MORENO, Louisiana State University, Baton Rouge, LA — We study the finite temperature phase diagram as a function of doping for strongly correlated two-species hard-core bosons in a two-dimensional optical lattice by using Quantum Monte Carlo simulations. This model contains a repulsive interspecies interaction and different hopping terms between nearest neighbors of the two species. The phase diagram shows several competing phases such as an anti-ferromagnetically ordered Mott insulator, a coexistent, a phase separated, a superfluid and a normal liquid phases. Among them, coexistence of anti-ferromagnetic and superfluid phases near half filling and a phase separated region inside superfluid region away from half filling are of main interests. Mott behaviors of heavy species and Mott and superfluid behaviors of light species at low temperatures create this novel phase separation region. At high temperatures only a normal liquid phase appears.

3:06PM J41.00004 Fractional charge separation in the hard-core Bose Hubbard Model on the Kagome Lattice, XUE FENG ZHANG, SEBASTIAN EGGERT, University of Kaiserslautern — We consider the hard core Bose Hubbard Model on a Kagome lattice with fixed (open) boundary conditions on two edges. We find that the fixed boundary conditions lift the degeneracy and freeze the system at $1/3$ and $2/3$ filling at small hopping. At larger hopping strengths, fractional charges spontaneously separate and are free to move to the edges of the system, which leads to a novel compressible phase with solid order. The compressibility is due to excitations on the edge which display a chiral symmetry breaking that is reminiscent of the quantum Hall effect. Large scale Monte Carlo simulations confirm the analytical calculations.

3:18PM J41.00005 Thermodynamics of the Two-Dimensional Hubbard Model, JAMES LEBLANC, Max-Planck Institute for the Physics of Complex Systems, EMMANUEL GULL, University of Michigan — The application of a numerically exact continuous time impurity solver with the DCA dynamical mean field theory has allowed us to study the thermodynamics of the two-dimensional Hubbard model for finite, but large cluster sizes. Variation in cluster size, upwards of 50-sites, allows for extrapolation to the thermodynamic limit. We present results relevant to cold gas systems, such as entropy, double occupancy and nearest-neighbour spin correlations as well as discuss the implications of these calculations on pseudogap physics of the High-Tc Cuprate superconductors away from half filling.

3:30PM J41.00006 Bosonic Mott Insulator with Pseudo-spin Meissner Currents, KARYN LE HUR, Center For Theoretical Physics (CPHT), Ecole Polytechnique and CNRS, 91128 Palaiseau France, ALEXANDRU PETRESCU, Yale University, Physics Department USA and CPHT Ecole Polytechnique France — We introduce a two-component bosonic Mott insulator that can support chiral Meissner edge currents as a result of time-reversal symmetry breaking due to the application of a uniform magnetic field. The key ingredient is the presence of two layers exhibiting both charge (total density) and pseudo-spin (relative density) degrees of freedom. This then allows for a Mott phase characterized by pseudospin edge currents of Meissner type [1]. A simple example can be built from a ladder system [2]. We determine the temperature scale for the existence of such a phase as a function of the interlayer Josephson coupling and interaction. We show that it is possible to probe this phase by introducing gauge fields parallel to the layers, and that in the weak-field limit the system exhibits a Meissner effect, in which interlayer currents are suppressed, and the overall current circulation in the layers opposes the applied field. For higher field values the currents organize themselves in vortices, as a result of a commensurate-incommensurate transition.


3:42PM J41.00007 Experimental predictions based on LOAF theory in dilute Bose atomic gases, BOGDAN MIHALIA, Los Alamos National Laboratory — We discuss possible new experimental signatures of correlations in dilute Bose gases with tunable interactions within the framework of LOAF theory. The leading-order auxiliary field (LOAF) theoretical framework is a non-perturbative approximation treating the contributions of the normal and anomalous densities on equal footing [Cooper et al. Phys. Rev. Lett. 105, 240402 (2012)]. LOAF is a conserving and gapless approximation, satisfies Goldstone’s theorem, yields a Bose-Einstein transition that is second order, and can be applied outside the regime of weakly-interacting particles.
Quadrature interferometry for nonequilibrium ultracold atoms in optical lattices

4:06PM J41.00009 Utilizing nonequilibrium effects to probe the Mott-insulator-superfluid transition of a trapped gas of interacting bosons

4:18PM J41.00010 Effects of Dissipation in a BEC Dimer

4:30PM J41.00011 Higgs boson in two dimensional superfluid and Mott insulator states

4:42PM J41.00012 How the scaling behavior changes near the quantum phase transition point?

4:54PM J41.00013 Real space renormalization of the Mott-insulator to Bose-glass transition in the disordered Bose-Hubbard model
5:06PM J41.00014 Anomalous hall phases in a bosonic Mott insulator, CLEMENT WONG, REMBERT DUINE, Utrecht University — Spin-orbit coupled systems that break time-reversal symmetry can exhibit the anomalous hall phase, which support a hall conductivity in the absence of a magnetic field. These topological phases are in a sense the building blocks of topological insulators and bears similarities to chiral topological superconductors. Recently, it has become possible to engineer spin-orbit couplings in cold atomic systems, making it possible to study these systems in the strongly interacting regime, for bosons and fermions. With these motivations, we study spin-orbit coupled bosons in an optical lattice in the Mott-insulating phase. We show that generically, strong interactions can induce an anomalous Hall phase even for a topologically trivial spin-orbit coupling. For the spin orbit coupling in experiment Lin et. al. [Nature (London) 471, 83 (2011)], we compute the quasiparticle dispersions, spectral weights, renormalized momentum space texture and the associated interaction-generated Berry curvature. Our results have implications for the Mott-insulating phases with textured magnetic order.

Wednesday, March 20, 2013 8:00AM - 11:00AM – Session M4 DAMOP: Invited Session: Quantum Simulation with Photons Ballroom IV - Ivan Deutsch, University of New Mexico

8:00AM M4.00001 High Orbital Exciton-Polariton Condensates in Two-Dimensional Lattices, NA YOUNG KIM, Stanford University — Microcavity exciton-polaritons are hybrid quantum quasi-particles as admixtures of cavity photons and quantum-well excitons. The inherent light-matter duality provides experimental advantages to undergo a phase change to condensation at high temperatures (e.g. 4-10 K in GaAs and room temperatures in GaN materials) due to the extremely light effective mass and stimulated scattering processes, and the dynamical nature in the open-dissipative condition allows us to control orbital symmetries of condensates. We have engineered two-dimensional polariton-lattice systems for the investigation of exotic quantum phase order arising from high orbital bands. Via photoluminescence signals in both real and momentum coordinates, we have observed d-orbital meta-stable condensation, vortex-antivortex phase order, linear Dirac dispersion, and flattened band structures in square, honeycomb, triangular and kagome lattices respectively. We envision that the polariton-lattice systems will be promising solid-state quantum emulators in the quest for understanding strongly correlated materials and in the development of novel optoelectronic devices.

8:36AM M4.00002 Quantum Hall physics with light, JACOB TAYLOR, Joint Quantum Institute/National Institute of Standards and Technology — Quantum Hall physics provides a variety of novel phenomena in both the integer and fractional domain, with applications in metrology, technology, and quantum computation. I will discuss implementing quantum Hall physics with optical systems by means of synthetic gauge fields and photon-photon interactions. First, in the integer quantum Hall regime, I consider our theoretical and experimental efforts using established photonics technology to see expected phenomena, such as edge states of light. I will then consider the nonlinear regime, where photon-photon interactions via optical or microwave nonlinearities enable the potential realization of fractional quantum Hall states, and indicate challenges and solutions for examining pumped, non-equilibrium systems that do not admit a mean-field description. Finally, potential applications of these ideas in passive and active photonics will be examined.

9:12AM M4.00003 Many body physics with light1, HAKAN E. TURECI, Princeton University — Systems of strongly interacting atoms and photons, which can be realized wiring up individual Cavity QED (CQED) systems into lattices, are perceived as a new platform for quantum simulation [1-3]. While sharing important properties with other systems of interacting quantum particles, the nature of light-matter interaction gives rise to unique features with no analogs in condensed matter or atomic physics setups. Such Lattice CQED systems operate on polaritonic quasi-particles that are hybrids of light and matter in a controllable proportion, combining long-range coherence of photons and strong interactions typically displayed by massive particles. In this talk, I will discuss our recent efforts on the possibility of observing quantum many body physics and quantum phase transitions in Lattice CQED systems. Unavoidable photon loss coupled with the ease of feeding in additional photons through continuous external driving renders such lattices open quantum systems [5]. Another key aspect of many body physics with light that I will focus on is the particle number non-conserving nature of the fundamental light-matter interaction [6] and the question of what, if not the chemical potential, can stabilize finite density quantum phases of correlated photons.

9:48AM M4.00004 Bose-Einstein condensation of photons, JAN KLAERS, Institut fur Angewandte Physik, Universitat Bonn, Wegelerstr. 8, 53111 Bonn, Germany — In recent work, we have observed Bose-Einstein condensation (BEC) of a two-dimensional photon gas in an optical microcavity [1]. Here, the transversal motional degrees of freedom of the photons are thermally coupled to the cavity environment by multiple absorption-fluorescence cycles in a dye medium, with the latter serving both as a heat bath and a particle reservoir. The photon energies in this system are found to follow a Bose-Einstein distribution at room temperature. Upon reaching a critical total photon number, a condensation into the transversal ground state of the resonator sets in, while the population of the transversally excited modes roughly saturates. The critical photon number is experimentally verified to agree well with theoretical predictions. Owing to particle exchange between the photon gas and the dye molecules, the grandcanonical experimental conditions can approximately be realized in this system. Under these conditions, two markedly different condensate regimes are theoretically expected [2]. On the one hand, this includes a condensate with Poissonian photon number statistics, being the analog to present atomic Bose condensates. Additionally, we predict a second regime with anomalously large condensate fluctuations accompanied by a Bose-Einstein-like photon number distribution that is not observed in present atomic BEC experiments. The crossover between these two regimes, corresponding to the emergence of second-order coherence, depends on the size of the molecular reservoir (e.g. the dye concentration) and is expected to occur at a temperature below the BEC phase transition. In my talk, I will give an update on our experimental work.

1Work supported by the NSF and the Swiss NSF. Work reported is a collaboration with M. Bordyuh, G. Blatter, M. Bordyuh, D. Gerace, A. Houck, J. Keeling, F. Nissen, B. Oztop, M. Schiro, S. Schmidt.


References:
10:24AM M41.00005 From Mott transitions to interacting relativistic theories with light: A brief history of photonic quantum simulators, DIMITRIS G. ANGELAKIS, Centre for Quantum Technologies Singapore/Technical University of Crete — I will start by reviewing our early works for observing photon-blockade induced Mott transitions in coupled cavity QED systems [1]. After briefly touching on the idea of simulating spin-models and the Fractional Hall effect [2], I will analyze more recent developments in realizing continuous 1D models in nonlinear optical fibers exhibiting electromagnetically induced transparency nonlinearity. Here the concept of the “photonic Luttinger liquid” will be introduced, along with a proposal to observe spin-charge separation with polarized photons in a nonlinear slow light set up [3]. I will continue by presenting our recent efforts in simulating 1D lattice models in the non-relativistic regime, such as the sine-Gordon and Bose-Hubbard [4], and the efforts for simulations of out of equilibrium phenomena using driven systems [5,6]. I will conclude with presenting ongoing work on interacting relativistic models (Thirring) [7]. Possible experimental implementations in quantum optical systems such as photonic crystals, optical fibers coupled to cold atoms, and Circuit QED will be discussed.


Wednesday, March 20, 2013 8:00AM - 10:36AM — Session M41 DAMOP: Theory of Quantum Gases in Low Dimensions 350 - Juraj Radic, University of Maryland

8:00AM M41.00001 Adiabatic evolution of the Fulde-Ferrell-Larkin-Ovchinnikov state of imbalanced fermionic-atom superfluids in an optical lattice of coupled tubes1, C.J. BOLECH, KUEI SUN, University of Cincinnati — We study two-species imbalanced fermionic superfluids in an array of one-dimensional tubes that are coupled via particle tunneling between nearest neighbors. Incorporating the interplay of Cooper pairing, spin imbalance (or magnetization), and single-particle tunneling, we obtain imbalance profiles accompanied with oscillatory pairing reminiscent of a Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state, and show that the magnetization of the system can undergo an incompressible-compressible transition by the tuning of the magnetic field as well as tunneling strength [Phys. Rev. A 85, 051607 (2012)]. The system’s phase diagram is well described by an effective extended Bose-Hubbard model. In addition, we discuss another viable process of pair tunneling that strongly affects the evolution of the FFLO profiles. With this new model, one can build a more detailed description of the signature characteristic of the incipience of the dimensional crossover and in partial agreement with preliminary experimental data.

1This work was supported by the ARO Award No. W911NF-07-1-0464

8:12AM M41.00002 Asymptotic Limit of Momentum Distribution Functions in the Sudden Expansion of a Spin-imbalanced Fermi Gas in One Dimension, FABIAN HEIDRICH-MEISNER, LMU Munich, Germany, CARLOS BOLECH, University of Cincinnati, USA, STEPHAN LANGER, University of Pittsburgh, USA, IAN MCCULLOCH, University of Brisbane, Australia, GIULIANO ORSO, University Paris Diderot, France, MARCOS RIGOL, Penn State University, USA — We study the sudden expansion of a spin-imbalanced Fermi gas in an optical lattice after quenching the trapping potential to zero [1], described by the attractive Hubbard model. Using time-dependent density matrix renormalization group simulations we demonstrate that the momentum distribution functions (MDFs) of majority and minority fermions become stationary after surprisingly short expansion times. We explain this via a quantum distillation mechanism [2] that results in a spatial separation of excess fermions and pairs, causing Fulde-Ferrell-Larkin-Ovchinnikov correlations to disappear rapidly. We further argue that the asymptotic form of the MDFs is determined by the integrals of motion of this integrable quantum system, namely the rapidities from the Bethe ansatz solution. We discuss the relevance of our results for the observation of Fulde-Ferrell-Larkin-Ovchinnikov correlations in 1D systems, related to recent experiments from Rice University [3].


8:24AM M41.00003 Superfluidity of Bosons in Kagome Lattices with Frustration, XIAO-QI SUN, ZHU CHEN, YI-ZHUANG YOU, HUI ZHAI, Institute for Advanced Study, Tsinghua University, Beijing, 100084, China — We consider spinless bosons in a Kagome lattice with nearest-neighbor hopping and on-site interaction, and the sign of hopping is inverted by inserting a π flux in each triangle of Kagome lattice so that the lowest single particle band is perfectly flat. We show that in the high density limit, despite of the infinite degeneracy of the single particle ground state, the ground state of the system is a non-interacting Fermi gas, and the Hartree-Fock approximation fails. By analyzing the band structure and the momentum distribution function of the system, we show that the superfluid phase exists in a broad temperature regime until the temperature is increased to the same order of hopping and then the system turns into normal phases. Finally we show that time of flight measurement of momentum distribution and its noise correlation can be used to distinguish these three phases.

8:36AM M41.00004 The Higgs amplitude mode in superfluids of Dirac fermions, SHUJU TSUCHIYA, Department of Physics, Faculty of Science, Tokyo University of Science, RAMACHANDRAN GANESHTH, Institute for Theoretical Solid State Physics, IFW Dresden, TETSURO NIKUNI, Department of Physics, Faculty of Science, Tokyo University of Science — Motivated by recent developments of cold atom experiments in optical lattices, we study collective modes of atomic Dirac fermions on the two-dimensional honeycomb lattice. The attractive fermion Hubbard model on the honeycomb lattice was found to exhibit the quantum phase transition at half-filling between a semimetal with massless Dirac fermion excitations and a simple s-wave superfluid phase[1]. We calculate collective modes in superfluid phase as well as in normal phase in the vicinity of the quantum critical point within the generalized random phase approximation. We find evidence for a undamped gapful Higgs amplitude mode below the two-particle continuum, together with a gapless Anderson-Bogoliubov (AB) mode in superfluid phase. As approaching the quantum critical point from the superfluid side, the energy gap of the Higgs mode decreases and eventually the Higgs mode and AB mode become degenerate at the quantum critical point. In the normal phase, we find that these collective modes split into Cooperon and exciton excitations that are particle-particle and particle-hole bound states, respectively. We discuss possibilities of observing these collective modes in optical lattice experiments.

Quantum phase-manipulation of a two-leg ladder in mixed dimensional Fermionic cold atoms. WEN-MIN HUANG, KYLE IRWIN, SHAN-WEN TSAI, Department of Physics and Astronomy, University of California, Riverside, CA 92521, USA — The recent realization of mixed dimensional cold atoms has attracted intense attentions from both experimentalists and theorists. Exotic phases arise due to correlation effects, and the systems can be engineered with quantum phase-tunable parameters. We investigate a two-species Fermi gas: one is confined in a two-leg ladder with on-site interactions, and the other is free in a two-dimensional square lattice. By integrating out the two-dimensional gas, a long-range mediated interaction in the ladder is generated due to the on-site interspecies interactions. Using the renormalization group method, we show that the mediated interactions enhance the instability of charge density waves, and can be controlled by the filling in the two-dimensional gas. Parameterizing the phase diagrams with different quantities, we discuss the possible quantum phase-manipulation of a two-leg ladder in mixed dimensional Fermionic cold atoms.


Tuning the Kosterlitz-Thouless transition to zero temperature in anisotropic boson systems. JIH-JIH YOU, HAO LEE, SHIANG FANG, Physics Division, National Center for Theoretical Sciences, Hsinchu, Taiwan, MIQUEL A. CAZALILLA, Graphene Research Centre National University of Singapore, 6 Science Drive 2, Singapore 117546, DAW-WEI WANG, Physics Division, National Center for Theoretical Sciences, Hsinchu, Taiwan — We study the two-dimensional Bose-Hubbard model with anisotropic hopping. Focusing on the effects of anisotropy on superfluid properties such as the helicity modulus and the normal-to-superfluid [Berezinskii-Kosterlitz-Thouless (BKT)] transition temperature, two different approaches are compared: large-scale quantum Monte Carlo simulations and the self-consistent harmonic approximation (SCHA). For the latter, two different formulations are considered, one applying near the isotropic limit and the other applying in the extremely anisotropic limit. Thus we find that the SCHA provides a reasonable description of superfluid properties of this system provided the appropriate type of formulation is employed. The accuracy of the SCHA in the extremely anisotropic limit, where the BKT transition temperature is tuned to zero (i.e., at a quantum critical point) and therefore quantum fluctuations play a dominant role, is particularly striking.

Abstract withdrawn.

Variational Matrix Product Ansatz for Interacting 1D Gases1. SANGWOO CHUNG, KUEI SUN, C.J. BOLECH, University of Cincinnati — Shortly after the advent of the density matrix renormalization group (DMRG) method, Oystun and Rommer [PRL 75, 3537-3540 (1995)] have demonstrated that ground states of one-dimensional lattice systems obtained with the DMRG procedure can be written in terms of products of matrices and, remarkably, that those ground states can be obtained from variational methods without making any reference to DMRG. Since then, a lot of activity ensued and recently there was some additional success in going beyond lattice models and obtaining the ground state properties of interacting bosons in the continuum. We extend those findings and discuss systems of both interacting Bosons and Fermions in one-dimension.1

Revealing the breakdown of spin-charge separation in spin-imbalanced fermions in one dimension using quench dynamics1. PAATA KAKASHVILI, Department of Physics and Astronomy, Rutgers University, MICHAEL SEKANIA, Center for Electronic Correlations and Magnetism, Institute of Physics, University of Augsburg — Recently, spin-imbalanced fermions in one dimension have attracted considerable attention both theoretically and experimentally. This system was successfully simulated using ultracold atoms in optical lattices. The phase diagram was measured and found to be in agreement with exact analytical calculations. It was also established theoretically that the spin-charge separation, an important property of Luttinger liquids, is absent. Low-energy bosonic excitations do not carry spin and charge separately due to the interaction between spin and charge degrees of freedom. Based on our numerical (time-dependent density matrix renormalization group method (t-DMRG)) and analytical calculations (Bethe Ansatz, Bosonization) on the Hubbard model, we propose quench experiments which not only reveal the breakdown of spin-charge separation but also make it possible to study the so called “string” bound states in this system.1

Exploration of the Exact Bose-Fermi Mixture Phase Diagram via Quantum Monte Carlo. KYUNG DUK YOON, Salisbury School, Salisbury, CT — Following unprecedented success studying Bose and Fermi gases in optical lattices, atomic physicists are becoming increasingly interested in Bose-Fermi mixtures. It has been suggested that mixtures possess a complex phase diagram, containing a number of intriguing phases, including two-particle superfluids, supersolids, and density waves. Nevertheless, much of this phase diagram remains unknown because of algorithmic limitations. In this work, we explore the exact phase diagram of Bose-Fermi mixtures at finite temperatures in the hopes of uncovering Bose-Fermi density waves using a novel Auxiliary Field Quantum Monte Carlo (AFQMC) technique. Our AFQMC method expresses the Bose-Fermi partition function as a determinant that can be sampled to obtain accurate results throughout the phase diagram. Based upon this determinant, we calculate several correlation functions to look for signatures of mixture density waves. For certain system sizes and in certain parameter regimes, we compare and contrast with Exact Diagonalization and Mean Field Theory. Here, we begin this study by focusing on one-dimensional systems; future work will be extended to multidimensional systems where AFQMC is expected to be the only method capable of studying them.
10:24AM M41.00013 Finite-size scaling of the chemical potential of bosonic quantum fluids
C.M. HERDMAN, ADRIAN DEL MAESTRO, University of Vermont — We study the finite-size scaling of the chemical potential of interacting bosonic quantum fluids using large-scale quantum Monte Carlo calculations. We consider realistic interactions for helium as well as short range repulsive interactions for bosons in one, two and three dimensions at finite temperatures. In one dimension, we compare our results to the scaling predicted by Luttinger liquid theory allowing for the identification of a parametric regime of validity for quantum linear hydrodynamics. In higher dimensions, grand canonical simulations of helium allow for the accurate computation of experimentally relevant quantities such as the chemical potential along the liquid-solid transition line at low temperatures.

Wednesday, March 20, 2013 11:15AM - 2:15PM
Session N40 DAMOP: Dipolar Gases and Rydberg Atoms

11:15AM N40.00001 Time-reversal-breaking and d-wave superfluidity of ultracold dipolar fermions in optical lattices1, CARLOS SÁ DE MELO, LI HAN, Georgia Institute of Technology — We describe possible superfluid phases of ultracold dipolar fermions in optical lattices for two-dimensional systems. Considering the many-body screening of dipolar interactions at larger filling factors, we show that several superfluid phases with distinct pairing symmetries naturally emerge in the singlet channel: local s-wave (sl), extended s-wave (se), d-wave (d) or time-reversal-symmetry breaking (sl ± se ± id)-wave. The temperature versus filling factor phase diagram indicates that d-wave is favored near half-filling, that (sl + se)-wave is favored near zero or full filling, and that time-reversal-breaking (sl ± se ± id)-wave is favored in between. When a harmonic trap is included a sequence of phases can exist in the cloud depending on the filling factor at the center of the trap. Most notably in the region where the (sl + se ± id)-wave superfluid exists, spontaneous currents are generated, and may be detected using velocity sensitive Bragg spectroscopy.

21:27AM N40.00002 Dipolar Fermions in Quasi-Two-Dimensional Square Lattice, CHEN-YEN LAI, SHAN-WEN TSAI, University of California Riverside — Motivated by recent experimental realization of quantum degenerate dipolar Fermi gas, we study a system of ultracold single- and two-species polar fermions in a double layer two-dimensional square lattice. The long-range anisotropic nature of dipole-dipole interaction has shown a rich phase diagram on a two dimensional square lattice. We investigate how the interlayer coupling affects the monolayer system. Our study focuses on the regime where the fermions are closed to half-filling, which is when lattice effects play an important role. We find several correlated phases by using a functional renormalization group technique, which also provides estimates for the critical temperature of each phase. [*] S. G. Bhongale et. al. arXiv:1209.2671 and Phys. Rev. Lett. 108 145301 (2012).

11:39AM N40.00003 Orbital coupled dipolar fermions in an asymmetric optical ladder1, XIAOPENG LI, W. VINCENT LIU, University of Pittsburgh — We study a quantum ladder of dipolar atoms/molecules with coupled s and p orbitals. The interaction of such a system can be controlled with dipole moments being aligned by an external field. The two orbital components have distinct hoppings. The tunneling between them is equivalent to a partial Rashba spin-orbital coupling when the orbital space (s, p) is identified as spanned by pseudo-spin 1/2 states. A rich phase diagram is established. In particular a superconducting phase is found for repulsive fermions and a plaquette phase is found for bosons at 1/4 filling.

11:51AM N40.00004 Emergence of unconventional spin density waves in dipolar Fermi gases, S. G. BHONGALE, George Mason University, LUDWIG MATHEY, University of Hamburg, SHAN-WEN TSAI, University of California, Riverside, CHARLES W. CLARK, NIST, JILA, and University of Maryland, ERHAI ZHAO, George Mason University — Motivated by experiments on Fermi gases of dipolar molecules and dysprosium, we study the competing quantum phases of two-component (pseudo-spin 1/2) dipolar fermions on a two-dimensional optical lattice. The anisotropic, long-range dipole-dipole interaction leads to the occurrence of numerous exotic many-body states, e.g. supersolid, nematic, and topological superfluid. Here, using unbiased functional renormalization group approach, we discover that another quantum phase of matter, spin density wave (SDW) with p-wave orbital symmetry, emerges in this system when the dipoles are tilted at intermediate angles with respect to the lattice plane. This phase can be viewed as the particle-hole analogue of p-wave superconductors. We present the phase diagram of the system and show that the order parameter of the unconventional SDW is a vector quantity in spin space, and, moreover, is defined on lattice bonds rather than on lattice sites.

12:03PM N40.00005 Topological phases in polaronic and quantum magnetic materials, ALEXEY GORSHKOV, California Institute of Technology, SALVATORE MANMANA, Georg-August-University Goettingen, E.M. STOUDENMIRE, University of California, Irvine, KADEN HAZZARD, ANA MARIA REY, University of Colorado, Boulder, NORMAN YAO, CHRIS LAUMANN, STEVEN BENNETT, Harvard University, ANDREAS LAUCHLI, PETER ZOLLER, University of Innsbruck, JUN YE, University of Colorado, Boulder, EUGENE DEMLER, MIKHAIL LUKIN, Harvard University — We show that ultracold polar molecules pinned in an optical lattice and interacting via dipolar interactions can be used to implement a huge variety of exotic quantum magnets. These can be realized to model the spin-1 Hamiltonian, and the Kitaev honeycomb model. [References for some of the results: arXiv:1207.4479, arXiv:1210.5518]

12:15PM N40.00006 Symmetry Protected Topological Phases in Polar Molecule Spin Ladder Systems, S.R. MANMANA, Institute f. Theoretical Physics, University of Göttingen, D-37077 Göttingen, Germany, E.M. STOUDENMIRE, Department of Physics and Astronomy, UC Irvine, CA 92697, USA, K.R.A. HAZZARD, A.M. REY, JILA, NIST and Department of Physics, CU Boulder, CO 80309, USA, A.V. GORSHKOV, IQI, Caltech, Pasadena, CA 91125, USA — We show how to use polar molecules in an optical lattice to engineer quantum spin models with arbitrary spin S ≥ 1/2 and with interactions featuring a direction-dependent spin anisotropy. This is achieved by encoding the effective spin degrees of freedom in microwave-dressed rotational states of the molecules and by coupling the spins through dipolar interactions. We demonstrate how one of the experimentally most accessible anisotropies stabilizes symmetry protected topological phases in spin ladders. Using the numerically exact density matrix renormalization group method, we find that these phases — previously studied only in the nearest-neighbor case — survive in the presence of long-range dipolar interactions. We also show how to use our approach to realize the bilinear-biquadratic spin-1 Hamiltonian, and the Kitaev honeycomb models. Experimental detection schemes and imperfections are discussed.

12:27PM N40.00007 Realizing Fractional Chern Insulators with Dipolar Spins, NORMAN YAO, CHRIS LAUMANN, Harvard University, ANDREAS LAUCHLI, University of Innsbruck, EUGENE DEMLER, Harvard University, JUN YE, JILA, CU Boulder, PETER ZOLLER, University of Innsbruck, MIKHAIL LUKIN, Harvard University, ALEXEY GORSHKOV, IQI, California Institute of Technology — Strongly correlated quantum systems can exhibit exotic behavior that is determined and controlled by topology. Such topological systems are of interest because they constitute fundamentally new states of matter exhibiting fractionalized excitations and robust chiral edge modes. We theoretically predict that the nu = 1/2 fractional Chern insulator, a recently proposed topological state of lattice bosons, arises naturally in a two-dimensional array of driven, dipolar-interacting spins.
12:39PM N40.00008 Preparation and detection of dipolar fractional Chern insulators, CHRIS LAUMANN, NORMAN YAO, Harvard University, ALEXEY GORSHKOV, IQI, MIKHAIL LUKN, Harvard University — We describe schemes for preparation and detection of fractional Chern insulators as arise in driven dipolar spin systems. Such topological phases generically compete with superfluid and crystalline orders. We discuss the nature of the phase transitions and describe a dynamical preparation procedure. Prospects for measuring the properties of these topological phases using cold atomic techniques are considered.

12:51PM N40.00009 Parafermion excitations in superfluid of quasi-molecular chains formed by dipolar molecules or indirect excitons1, ANATOLY KUKLOV, CSI, CUNY, ALEXEI TSVELIK, BNL — We study a quantum phase transition in a system of dipoles confined in a stack of N identical 1D lattices (tubes) polarized perpendicularly to the lattices. The dipoles may represent polar molecules or indirect excitons. The transition separates two phases; in one of them superfluidity takes place in each individual lattice, in the other (chain superfluid) the order parameter is the product of bosonic operators from all lattices. We argue that in the presence of finite inter-lattice tunneling the transition belongs to the universality class of the \( g = N \) two-dimensional classical Potts model. For \( N = 2,3,4 \) the corresponding low energy field theory is the model of \( Z_2 \) parafermions perturbed by the thermal operator. Results of Monte Carlo simulations are consistent with these predictions. The detection schemes for the chain superfluid of dipolar molecules and indirect excitons are outlined.

1ABK was supported by the NSF under Grant No.PHY1005527; AMT acknowledges a support from US DOE under contract DE-AC02-98 CH10883

1:03PM N40.00010 Collective excitations of quasi-two-dimensional trapped dipolar fermions, MEHTHAST BABADI, EUGENE DEMLER, Harvard University — We study the collective excitations of quasi-two-dimensional fermions with dipole-dipole interactions in an isotropic harmonic trap by solving the collisional Boltzmann-Vlasov equation. Except for the scaling monopole mode which exhibits a negligible damping, the other collective modes undergo a transition from the collisionless regime to a highly dissipative crossover regime and finally to the hydrodynamic regime upon increasing the dipolar interaction strength. In the 2D limit, we predict the existence of a temperature window within which the characteristics of the collective modes become temperature independent.

1:15PM N40.00011 Unconventional triplet pairing state in a polarized dipolar Fermi gas1, YUKI ENDO, DAISUKE INOTANI, YOJI OHASHI, Keio University — We theoretically discuss the possibility of a triplet superfluid state in a polarized dipolar Fermi gas. In this system, it is usually believed that a high-energy cutoff is necessary in solving the superfluid BCS gap equation, reflecting the non-convergent behavior of a dipole-dipole interaction in the high-momentum limit. Because of this, the superfluid theory for a dipolar Fermi gas is believed to need a regularization for the angular-dependent dipole-dipole interaction as in the case of the s-wave interaction. In this talk, we show that such a renormalization is actually unnecessary, when one carefully includes the detailed structure of a dipolar molecule. We present a superfluid theory for a dipolar Fermi gas where the dipole-dipole interaction is only described by the two physical parameters, dipole size and dipole-dipole coupling constant. Using this, we discuss the possibility of a triplet pairing state, as well as superfluid properties, of this system. Since our theory only involves observable physical parameters, it would be useful in quantitatively evaluating superfluid properties of a dipolar Fermi gas, such as the superfluid phase transition temperature.

1This work is supported by a Grant-in-Aid for JSPS Fellows.

1:27PM N40.00012 P-wave superfluid in a quasi-two-dimensional dipolar Bose-Fermi quantum gas mixture1, BEN KAIN, College of the Holy Cross. HONG LING, Rowan University — The p-wave (\( j_x + i j_y \)) superfluid has attracted significant attention in recent years mainly because its vortex core supports a Majorana fermion which, due to its non-Abelian statistics, can be explored for implementing topological quantum computation (TQC). Mixing in bosons may lead to p-wave pairing in a Fermi gas. In a dipolar condensate, the dipole-dipole interaction represents a control knob inaccessible to nondipolar Bosons. Thus, mixing dipolar bosons with fermions opens up new possibilities. We consider a mixture of a spin-polarized Fermi gas and a dipolar Bose-Einstein condensate in a quasi-two-dimensional trap setting. We take the Hartree-Fock-Bogoliubov mean-field approach and develop a theory for studying the stability of the mixture and estimating the critical temperature of the p-wave superfluid. We use this theory to identify the experimentally accessible parameter space in which the mixture is stable against phase separation and the p-wave superfluid pairing can be resonantly enhanced. An enhanced p-wave superfluid order parameter can make the fault tolerant TQC less susceptible to thermal fluctuations. This work aims to stimulate experimental activity in creating dipolar Bose-Fermi mixtures.

1This work is supported by the US National Science Foundation and the US Army Research Office.

1:39PM N40.00013 Superfluidity of atomic Fermi gases with dipolar interactions1, YANMING CHE, QIJIN CHEN, Zhejiang University — While quantum degenerate dipolar Fermi gases have been made available in experiment, the superfluidity in such Fermi gases has been of very high interest. In this talk, we study the superfluidity and associated BCS-BEC crossover behavior of a two-component atomic Fermi gases in three dimensions in the presence of dipole-dipole interactions, such as polar molecules \( ^{87} \text{K}^{39} \text{Rb} \) and magnetic atoms \( ^{161} \text{Dy} \), using a pairing fluctuation theory. The relative interaction strength can be tuned via the atomic number. Various geometric configurations will be explored. We show that in certain configurations, the superfluidity may disappear altogether for a narrow range of interaction strength, and the Tc curve throughout the BCS-BEC crossover exhibits a reentrant behavior. We argue that such disappearance of the superfluidity is associated with the long range nature of the dipole-dipole interaction. A pseudogap develops naturally as the relative interaction becomes strong.

1Supported by NSF, MOE and MOST of China.

1:51PM N40.00014 Superfluid Pairing and Majorana Zero Mode in an Ultracold Rydberg Fermi Gas, BO XIONG, H.H. JEN, JHIIH-SHIH YOU, DAW-WEI WANG, Physics Department National Tsing-Hua University, Hsinchu, Taiwan — We systematically calculate the p-wave superfluid phase of spin polarized Fermi gases in a Rydberg state. The mutual interaction between atoms are dressed by loading into optical lattice, we also show the proximity effect of Tc near half filling. Finally, when considering the harmonic confinement potential, we obtain the gapless Majorana Fermions confined to the boundary via self-consistently solving the DBG equation. We will discuss how to experimentally prepare and measure these Majorana states in Rydberg atoms.
captures and cools atoms to load on the nanofiber to work at cryogenic temperatures. We will present our technique, key results, and progress towards trapping good evanescent fields; as well as more than 85% transmission when using higher order modes. A single-beam, magneto-optical trap that uses optical gratings that allow matching of the optical field in the tapered and untapered sections. We have achieved more than 99.95% transmission of the fundamental mode and that operates at 10 mK. A key component in this experiment is a long section (10 cm) of optical fiber with a uniform diameter of about 500 nm, sufficiently to trap neutral atoms in the evanescent optical field from an optical nanofiber and move them to within a few microns above a SQUID in a dilution refrigerator.


Wednesday, March 20, 2013 11:15AM - 2:15PM – Session GSNP DAMOP: Hybrid Systems for Quantum Simulation 350 -

11:15AM N41.00001 Counting statistics of phase slips in superconducting interferometers
PHILLIP WEINBERG, Michigan State University, ANDREW MURPHY, University of Illinois Urbana-Champaign, ALEX LEVCHENKO, Michigan State University, VICTOR VAKARYUK, The Johns Hopkins University, ALEXEY BEZRYADIN, University of Illinois Urbana-Champaign — In the superconducting proximity circuits, stochastic switching from the super-current carrying state to dissipative normal state is triggered by the topological fluctuations of the order parameter - phase slips. We study theoretically switching current statistics in a double-nanowire quantum interferometer as a function of the applied magnetic field perpendicular to the plane of the device. This system is a prototype of the double-slit experiment in optics which allows to probe macroscopic coherence of superconducting condensates. Magnetic field induces Meissner currents in the leads that lock superconducting phases across the wires. As a result phase slips that occur in the wires are not independent. We calculate dispersion of the switching current distribution as well as higher moment and find that they oscillate as the function of the field.

11:27AM N41.00002 Inverse Landau-Zener-Stueckelberg interferometry for the measurement of a resonator’s state using a qubit, SERGEY SHEVCHENKO, B. Verkin Institute for Low Temperature Physics and Engineering, Kharkov, Ukraine, SAHEL ASHHAB, FRANCO NORI, RIKEN Advanced Science Institute, Wako-shi, Saitama, Japan; Department of Physics, The University of Michigan, Ann Arbor, Michigan, USA — We consider theoretically a superconducting qubit - nanomechanical resonator system, which was realized recently by LaHaye et al. [Nature 459, 960 (2009)]. We formulate and solve the inverse Landau-Zener-Stueckelberg problem, where we assume the driven qubit’s state to be known (i.e. measured by some other device) and aim to find the parameters of the qubit’s Hamiltonian. In particular, for our system the qubit’s bias is defined by the nanomechanical resonator’s displacement. This may provide a tool for monitoring the nanomechanical resonator’s position. [S. N. Shevchenko, S. Ashhab, and F. Nori, Phys. Rev. B 85, 094502 (2012)].

11:39AM N41.00003 Towards a spin-ensemble quantum memory for superconducting qubits, PATRICE BERTET, YUIMARU KUBO, CECILE GREZÈS, DENIS VION, DANIEL ESTEVE, CEA Saclay, IGOR DINIZ, ALEXIA AUFEVES, Institut Neel, JUNICHI ISOYA, Tsukuba University, ANAIS DREAU, JEAN-FRANÇOIS ROCCH, VINCENT JACQUES, ENS Cachan, BRIAN JULGARDA, KLAUS MOELMER, Aarhus University — A multi-mode quantum memory able to store coherently large numbers of qubit states is a desirable resource for quantum information. We report progress toward this direction, using an ensemble of electronic spins (NV centers in diamond) coupled to a superconducting transmon qubit via a tunable resonator. We demonstrate the reversible coherent storage and retrieval of a single microwave photon from the qubit into the spin ensemble. In this experiment the storage time was however limited by inhomogeneous broadening of the ensemble of spins. We propose a realistic protocol that should extend the ensemble storage time by several orders of magnitude, based on spin-echo like pulse sequences; first experimental results will be presented.


11:51AM N41.00004 Superconducting Microstrip Resonator for Spin-Based Quantum Processes, HAMID REZA MOHEBBI, Institute for Quantum Computing, University of Waterloo, OLAF BENNINGHOF, TROY BORNEMAN, IVAR TAMINIAU, Institute for Quantum Computing, University of Waterloo, DAVID G. CORY, Institute for Quantum Computing, University of Waterloo — We report the design and results of a novel superconducting microstrip line resonator for pulsed ESR experiments of thin films. The resonator generates a homogeneous in-plane microwave magnetic field. This resonator consists of an array of superconducting half-wave microstrip transmission lines to achieve high-Q resonance. They are driven via an in-phase splitter and so maintain a resonance at one single frequency. In addition the resonator has a relatively small mode. The performance, sensitivity and small mode volume are demonstrated through our observation of strong coupling and ESR spectroscopy.

12:03PM N41.00005 Systematic studies of optically-trapped dielectric nanospheres, LEVI NEUKIRCH, Department of Physics and Astronomy, University of Rochester, Rochester, New York 14627, USA, JAN GIESELER, ROMAIN QUIJANT, ICFO-Institut de Ciencies Fotoniques, Mediterranean Technology Park, 08860 Castelldefels (Barcelona), Spain, LUKAS NOVOTNY, Institute of Optics, University of Rochester, Rochester, New York 14627, USA; Photonics Laboratory, ETH Zürich, 8093 Zürich, Switzerland, NICK VAMIVAKAS, Institute of Optics, University of Rochester, Rochester, NICK VAMIVAKAS, Institute of Optics, University of Rochester, Rochester, New York 14627, USA — Mesoscopic resonators have garnered significant interest recently in a number of experiments designed to blur the line between classical and quantum systems. In particular, optically trapped mesoscopic particles offer a distinct advantage over many other systems, as they can be mechanically isolated from the environment. We present results from dynamical studies of micro- and nano-scale dielectric particles suspended in a free-space optical dipole trap. Particle position is monitored via the interference of scattered and unscattered laser light. Of interest are the effects of the trap laser and ambient pressure on the external motion and internal temperature of the particles.

12:15PM N41.00006 Atomic manipulation for a hybrid system: tapered optical fibers with high transmission and a pyramid MOT, J.E. HOFFMAN, J.A. GROVER, JQI/UMD, M. HAFEZI, JQI/NIST, J.B. HERTZBERG, P. KORDELL, J. LEE, JQI/UMD, S. RAVETS, Institute d’Optique, Palaiseau, U. CHUKWU, K.D. VOIGT, J.R. ANDERSON, G. BEADIE, F.K. FATEMI, C.J. LOBB, L.A. OROZCO, JQI/UMD, J.M. TAYLOR, JQI/NIST, S.L. ROLSTON, F.C. WELLSSTOOD, JQI/UMD — To create a hybrid quantum system, we plan to trap neutral atoms in the evanescent optical field from an optical nanofiber and move them to within a few microns above a SQUID in a dilution refrigerator. A key component in this experiment is a long section (10 cm) of optical fiber with a uniform diameter of about 500 nm, sufficiently small that the light propagates on the surface of the fiber as an evanescent wave. We have produced suitably long nanofibers with carefully tapered sections that allow matching of the optical field in the tapered and untapered sections. We have achieved more than 99.95% transmission of the fundamental mode and good evanescent fields, as well as more than 85% transmission when using higher order modes. A single-beam, magneto-optical trap that uses optical gratings captures and cools atoms to load on the nanofiber to work at cryogenic temperatures. We will present our technique, key results, and progress towards trapping atoms on the fibers.

1Work supported by ONR, ARO Atomtronics MURI, DARPA, the Fulbright Foundation, and NSF through the PFC at JQI.

Financial support from the NSC of Taiwan is acknowledged.
12:27PM N41.00007 Development of a hybrid quantum system employing a tunable high-Q superconducting microwave resonator and trapped laser-cooled atoms\textsuperscript{1}. JARED HERTZBERG, K. VOIGT, Z. KIM, J. HOFFMAN, J. GROVER, J. LEE, S. RAVENTS, QJI/UMD, M. HAFEZI, J. TAYLOR, QJI/NIST/UMD, A. CHOUDHARY, UMD, J. ANDERSON, QJI/UMD, C. LOBB, QJI/NIST/UMD, L. OROZCO, S. ROLSTON, F. WELLSTOOD, QJI/UMD — We present progress toward a hybrid quantum system in which microwave quanta stored in a superconducting flux qubit are coupled through a magnetic dipole interaction to laser- trapped atoms. In initial experiments, our goal will be to couple to a microfabricated superconducting LC resonator to the 6.835 GHz hyperfine splitting in an ensemble of $^{87}\text{Rb}$ atoms. By trapping the atoms in the evanescent field of a 500-nm-wide optical fiber, we will seek to place them within 10 micrometers of the chip surface, where they will interact with the near-field of the microwave mode. In previous work we have demonstrated a frequency-tunable superconducting resonator having Q > 100,000. \textsuperscript{[1]} Here we will describe improvements in the resonator’s design to reduce its sensitivity to absorbed photons, as well as the design of components to position the resonator relative to the optical fiber within a dilution refrigerator.

\textsuperscript{1} Work supported by NSF through the Physics Frontier Center at the Joint Quantum Institute, Dept. of Physics, Univ. of Maryland.

12:39PM N41.00008 Quantum hybrid platform using electrons and superconducting electronics\textsuperscript{1}, N. DANILIDIS, D. GORMAN, Department of Physics, University of California Berkeley, L. TIAN, School of Natural Sciences, University of California, Merced, H. HAEFFNER, Department of Physics, University of California Berkeley; Materials Sciences Division, Lawrence Berkeley National Laboratory — We describe a quantum information processing (QIP) architecture based on single trapped electrons and superconducting electronics. The electron spins function as quantum memory elements, and the electron motion is used to couple the electrons to microwave circuits. To achieve this, we propose a parametric coupling mechanism which utilizes the non-linearity of the electrostatic potential of a sharp electrode placed 10 μm from a single trapped electron. This mechanism allows parametric coupling rates higher than 350 kHz for electrons with trap frequency of 300 MHz, coupled to a 7 GHz resonant circuit. We discuss state transfer and entangling operations between distant electrons, as well as between electrons and superconducting quibits, e.g. transmon qubits. The coupling to high frequency superconducting electronics enables initialization as well as state read-out of the electron motion. In addition, the electron’s ($|0\rangle$, $|1\rangle$) motional manifold can be mapped onto its spin using a non-linear oscillating magnetic field, completing all requirements for quantum computing with the electron spin. We estimate that all involved operations can be carried out with fidelities on the order of 0.999 enabling fault-tolerant quantum computing.

\textsuperscript{1} This work is supported by IARPA, Agilent, DARPA, AFOSR, and NSF.

12:51PM N41.00009 Discrete Two-Level Systems Coupled to a Tunable High Q Superconducting Microwave Resonator\textsuperscript{1}, KRISTEN VOIGT, J. HERTZBERG, Z. KIM, J. HOFFMAN, J. GROVER, J. LEE, S. RAVENTS, QJI/UMD, M. HAFEZI, J. TAYLOR, QJI/NIST/UMD, A. CHOUDHARY, UMD, J. ANDERSON, QJI/UMD, C. LOBB, QJI/NIST/UMD, L. OROZCO, S. ROLSTON, F. WELLSTOOD, QJI/UMD — We have developed a tunable “jumped-element” thin-film superconducting Al microwave resonator \textsuperscript{[1]} and used it for measuring two level systems. The device is intended for coupling to the hyperfine splitting of trapped $^{87}\text{Rb}$ atoms at 6.83 GHz. By moving a superconducting Al pin towards the inductor of the resonator using a piezo stage, we can tune the resonance over a range of 130 MHz. We measure the system by weakly coupling to an on-chip transmission line. At 12 mK the quality factor is typically 100,000. While holding the tuning pin at a fixed position, we can also apply a dc voltage to the transmission line. We observe small reproducible shifts of the resonance frequency as the voltage is changed. These shifts are more pronounced at lower power, which suggests the effect is attributable to discrete charged two-level systems in the substrate or surface Al oxide. We discuss our results and the characteristics of the underlying two-level systems.

\textsuperscript{1} Work supported by NSF through the Physics Frontier Center at the Joint Quantum Institute, Dept. of Physics, Univ. of Maryland.

1:03PM N41.00010 High cooperativity in coupled microwave resonator - ferromagnetic insulator hybrids, HANS HUEBL, CHRISTOPH ZOLLITSC, JOHANNES LOTZE, FREDRIK HOCKE, MORITZ GREIFENSTEIN, ACHIM MARX, RUDOLF GRÖSS, SEBASTIAN T.B. GRÖSS, Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — Solid-state based quantum systems (e.g. single spin systems like NV centers in diamond or phosphor donors in silicon, superconducting qubits, nanomagnets) are building blocks for devices exploiting quantum physics phenomena. While different quantum systems available, schemes allowing to couple them move into focus. In particular, a coupling will enable the exchange of information between dressed states. Here, we report the observation of strong coupling between the exchange-coupled spins in gallium-doped yttrium iron garnet, and a superconducting coplanar microwave resonator made from Nb \textsuperscript{[1]}. The measured coupling rate of 450 MHz is proportional to the square-root of the number of exchange-coupled spins and well exceeds the loss rate of 50 MHz of the spin system. This demonstrates that exchange-coupled systems are suitable for cavity quantum electrodynamics experiments, while allowing high integration densities due to their extraordinary high spin densities. Our results furthermore show that experiments with multiple exchange-coupled spin systems interacting via a single resonator are within reach. \textsuperscript{[1]} H. Huebl, C. Zollitsch, J. Lotze, F. Hocke, M. Greifenstein, A. Marx, R. Gross, S.T.B. Goennenwein, arXiv: 1207.6039 (2012).

1:15PM N41.00011 Interfacing Rydberg atoms with superconducting circuits, S. FILIPP, T. THIELE, M. STAMMEIER, A. WALLRAFF, ETH Zurich, S.D. HOGAN, University College London, J.A. AGNER, F. MERKT, ETH Zurich — Hybrid quantum system are promising candidates for future quantum computing architectures because they provide the potential to combine the best properties of different physical systems. Here, we bring together Rydberg atoms and microwave photons emanating from a co-planar waveguide with the ultimate goal to interface long-lived Rydberg atoms with well-controllable superconducting qubits. In our cryogenic experiment, helium atoms pass over microwave electrodes hosted on a printed circuit board. By applying resonant microwave pulses, we induce transitions between Rydberg states with principal quantum number n=31-35 and observe a coupling will enable the exchange of information between dressed states. In our experiment, we demonstrate a strong interaction between the dressed states. Here, we report the observation of strong coupling between the exchange-coupled spins in gallium-doped yttrium iron garnet, and a superconducting coplanar microwave resonator made from Nb \textsuperscript{[1]}. The measured coupling rate of 450 MHz is proportional to the square-root of the number of exchange-coupled spins and well exceeds the loss rate of 50 MHz of the spin system. This demonstrates that exchange-coupled systems are suitable for cavity quantum electrodynamics experiments, while allowing high integration densities due to their extraordinary high spin densities. Our results furthermore show that experiments with multiple exchange-coupled spin systems interacting via a single resonator are within reach. \textsuperscript{[1]} H. Huebl, C. Zollitsch, J. Lotze, F. Hocke, M. Greifenstein, A. Marx, R. Gross, S.T.B. Goennenwein, arXiv: 1207.6039 (2012).

1:27PM N41.00012 Quantum-classical transition of synchronization of two coupled cavities, TONY LEE, ITAMP / Harvard, MICHAEL CROSS, Caltech — Synchronization is a phenomenon that appears throughout physics, biology, and chemistry. There has been much work on how synchronization arises in the classical regime. Motivated by current interest in quantum dissipative systems, we investigate whether synchronization can exist in the quantum regime. We consider a pair of cavities with second harmonic generation. In the classical limit, each cavity has a limit cycle solution, in which the photon number oscillates periodically in time. Coupling between the cavities leads to synchronization of the limit cycles. We follow what happens to the synchronization as the system becomes more quantum, by decreasing the photon number. We find that temporal correlations between the cavities survive deep in the quantum limit when there is much less than one photon in each cavity, because classical correlations are replaced by quantum correlations. Our results can be extended to optomechanics and Jaynes-Cummings cavities.
1:39PM N41.00013 Linear Coupling between Transverse Modes of a Nanomechanical Resonator, PATRICK TRUITT, Montclair State University, JARED HERTZBERG, University of Maryland, KEITH SCHWAB, California Institute of Technology — Recently, several groups have identified a linear coupling between different vibrational modes of nanomechanical resonators. We report observations of such a coupling between the two transverse modes of a doubly-clamped Si_N resonator with transverse resonance frequencies of 8.4 and 8.7 MHz. The resonator is voltage biased with respect to a nearby gate electrode for capacitive readout. Increasing the gate bias introduces an electrostatic contribution to the spring constant of each mode, reducing the frequency gap between the two modes. At degeneracy, we observe an avoided crossing of 100 kHz. Measurements of the displacement amplitudes and quality factors through degeneracy is consistent with a linear superposition of the two modes. Magnetomotive measurements, which are sensitive to the projection of each mode’s displacement onto an applied field, show that the coupled modes remain linearly polarized, with the direction of polarization rotating with increasing gate bias. In an effort to identify the source of the coupling, we constructed a finite element model of the resonator-gate capacitance and find that the observed coupling is an order of magnitude larger than what is expected from electrostatic gradients alone.

1:51PM N41.00014 Dynamic Simulation of Trapping and Controlled Rotation of a Microscale Rod Driven by Line Optical Tweezers1, MAHDI HAGHSHEH-JARYANI, ALAN BOWLING, University of Texas at Arlington, Department of Mechanical and Aerospace Engineering, SAMARENDRA MOHANTY, University of Texas at Arlington, Department of Physics — Since the invention of optical tweezers, several biological and engineering applications, especially in micro-nanofluid, have been developed. For example, development of optically driven micromotors, which has an important role in microfluidic applications, has vastly been considered. Despite extensive experimental studies in this field, there is a lack of theoretical work that can verify and analyze these observations. This work develops a dynamic model to simulate trapping and controlled rotation of a microscale rod under influence of the optical trapping forces. The laser beam, used in line optical tweezers with a varying trap’s length, was modeled based on a ray-optics approach. Herein, the effects of viscosity of the surrounding fluid (water), gravity, and buoyancy were included in the proposed model. The predicted results are in overall agreement with the experimental observation, which make the theoretical model a viable tool for investigating the dynamic behavior of small size objects manipulated by optical tweezers in fluid environments.

2:03PM N41.00015 Ion photon networks for quantum computing and quantum repeaters, SUSAN CLARK, DAVID HAYES, DAVID HUCUL, VOLKAN INLEK, CHRISTOPHER MONROE, University of Maryland and Joint Quantum Institute — Quantum information based on ion-trap technology is well regarded for its stability, high detection fidelity, and ease of manipulation. Here we demonstrate a proof of principle experiment for scaling this technology to large numbers of ions in separate traps by linking the ions via photons. We give results for entanglement between distant ions via probabilistic photonic gates that is then swapped between ions in the same trap via deterministic Coulombic gates. We report fidelities above 65% and show encouraging preliminary results for the next stage of experimental improvement. Such a system could be used for quantum computing requiring large numbers of qubits or for quantum repeaters requiring the qubits to be separated by large distances.

Wednesday, March 20, 2013 2:30PM - 5:30PM — Session R41 DAMOP: Casimir Forces 350 -

2:30PM R41.00001 Measurement of the Casimir force between ferromagnetic surfaces, UMAR MOHIDEEN, ALEXANDR BANISHEV, Department of Physics and Astronomy, University of California, Riverside, USA, GALINA KLIMCHITSKAYA, VLADIMIR MOSTEPANENKO, Central Astronomical Observatory at Pulkovo of the Russian Academy of Science, St. Petersburg, Russia — We have measured the Casimir interaction between two ferromagnetic boundary surfaces using the dynamic atomic force microscope in the frequency shift technique. The experimental data are found to be in excellent agreement with the predictions of the Lifshitz theory for magnetic boundary surfaces combined with the plasma model approach for the free electrons in the metal. In an important difference from non-magnetic metals, the Drude description of the free electrons leads to a Casimir force that is less than that from the plasma model approach. Thus the role of hypothetical patch potentials will be opposite to that required for reconciliation of the data with the Drude model.

2:42PM R41.00002 Validity of effective medium theories in Casimir force calculations1, RAUL ESQUIVEL-SIRVENT, Instituto de Fisica, Universidad Nacional Autonoma de Mexico — Effective medium theories have been used extensively to describe the dielectric response of inhomogeneous media. This is media that is composed of a mixture of materials with different dielectric functions. The possibility of using inhomogeneous media to control or tune Casimir forces has been discussed in the literature. In this paper we present results for the Casimir force between two inhomogeneous plates described by different effective medium models. In particular we show how the force depends on the model used. This has implications on the comparison between theoretical and experimental results. Furthermore, we calculate the force between an inhomogeneous sphere like multi layered nano shells and a plane to study the effects of effective models when using the proximity force approximations. The conditions under which effective medium models can be used in the context of the Casimir force are discussed in detail.

1Supported by DGAPA-UNAM

2:54PM R41.00003 Experiments on Sphere Cylinder Geometry Dependence in the Electromagnetic Casimir Effect, SHOMEK MUKHOPADHYAY, EHSAN NORUZIFAR, JEFFREY WAGNER, ROYA ZANDI, UMAR MOHIDEEN, University of California, Riverside — We report on ongoing experimental investigations on the geometry dependence of the electromagnetic Casimir force in the sphere-cylinder configuration. A gold coated hollow glass sphere which forms one surface is attached to a Silicon AFM cantilever. The cylinder, which is constructed from tapered optical fiber is also gold coated. The resonance frequency shift of the cantilever is measured as a function of the sphere-cylinder surface separation. The sphere-cylinder electrostatic force is used for alignment of the sphere and the cylinder and also for calibrating the system. The results are compared to numerical simulations in the framework of the Proximity Force Approximation (PFA).

3:06PM R41.00004 Sum-over-modes approach to the Casimir effect in dissipative systems, FRANCESCO INTRAVAIA, RYAN BEHUNIN, Theoretical Division, MS B213, Los Alamos National Laboratory, Los Alamos, NM 87545, USA — We show that, within the open-system framework, the sum-over-modes approach to the Casimir leads to the Lifshitz formula for the Casimir free energy. A general result applicable to arbitrary geometries is obtained through the use of Ford, Lewis, & O’Connell’s remarkable formula. Additionally, we address the possibility for obtaining the Casimir energy as a sum over complex “modes.” We show in this case that the standard sum-over-modes formula must be suitably generalized to avert unphysical complex energies.
3:18PM R41.00005 Influence of Casimir-Lifshitz forces on actuation dynamics of MEMS. WJINAND BROER, GEORGE PALASANTZAS, JASPER KNOESTER, University of Groningen, VITALY SVETOV. University of Twente — Electromagnetic fluctuations generate forces between neutral bodies known as Casimir-Lifshitz forces, of which van der Waals forces are special cases, and which can become important in micromechanical systems (MEMS). For surface areas big enough but gaps small enough, the Casimir force can possibly draw and lock MEMS components together, an effect called stiction, causing device malfunction. Alternatively, stiction can also be exploited to add new functionalities to MEMS architecture. Here, using as inputs the measured frequency dependent dielectric response and surface roughness statistics from Atomic Force Microscopy (AFM) images, we perform the first realistic calculation of MEMS actuation. For our analysis the Casimir force is combined with the electrostatic force between rough surfaces to counterbalance the elastic restoring force. It is found that, even though surface roughness has an adverse effect on the availability of (stable) equilibria, it ensures that those stable equilibria can be reached more easily than in the case of flat surfaces. Hence our results can have significant implications on how to design MEMS surfaces. The author would like this abstract to appear in a Casimir related session.

3:30PM R41.00006 Scattering Theory Calculations of Casimir Energies at High Curvature1. NOAH GRAHAM, MIDDLEBURY COLLEGE, THORSTEN EMIG, Universite Paris Sud, ADEN FORROW, MIDDLEBURY COLLEGE, ROBERT JAFFE, MEHRAN KARDAR, MOHAMMAD MAGHRIBI, MAssachusetts Institute of Technology, JAMAL RAHI, Rockefeller University, ALEX SHPUNT, PrimeSense Inc. — Scattering theory provides a powerful tool for capturing the response of an object to electromagnetic charge and field fluctuations. Techniques based on scattering theory have made possible a wide range of new calculations of Casimir energies. In this approach, the Casimir interaction energy for a collection of objects can be expressed in terms of the scattering T-matrices for each object individually, combined with universal translation matrices describing the objects’ relative positions and orientations. These translation matrices are derived from an expansion of the free Green’s function in an appropriate coordinate system, independent of the details of the objects themselves. This method proves particularly valuable for geometries involving high curvature, such as edges and tips. We will describe this approach in general terms and then give results from several problems to which it has been applied successfully. We will also discuss new developments in scattering theory that have been motivated by these problems.

1Supported by the National Science Foundation, the US Department of Energy, the Defense Advanced Research Projects Agency, and the Deutsche Forschungsgemeinschaft

3:42PM R41.00007 ABSTRACT WITHDRAWN —

3:54PM R41.00008 Investigation of electrostatic “patches” on Au samples: Effects on the Casimir measurements. RICARDO DECCA, GUILLAUME VOISIN, Department of Physics, Indiana University-Purdue University Indianapolis — It has been argued by Behunin and co-workers that the measurements done of the Casimir force on Au coated surfaces could suffer from substantial systematic errors arising from the presence of so called electrostatic “patches” (i.e. an electrostatic potential distribution on the surface of the Au layer). While these effects can be minimized, in principle they cannot be nullified by the application of uniform potential differences between the investigated surfaces. We present Kelvin probe microscopy studies of Au samples on Si. Au samples (about 200 nm thick) were deposited by thermal evaporation and sputtering. A thin (about 10 nm thick) layer of Cr is used as an adhesion layer. We will discuss the methodology used. We will show that, although the application of a simple deposition method, there are two characteristic scales for the potential distribution: One, with a typical size of about 100 nm, associated with grain sizes and the other one, typical dimension 1 µm, most likely associated with unavoidable sample contamination. The effect of this potential is found to be too small to affect the conclusions found in previous measurements of the Casimir effect.

4:06PM R41.00009 Casimir effect between Topological Insulators: a proposal for quantum levitation. PABLO RODRIGUEZ-LOPEZ, Universidad Carlos III de Madrid, ADOLFO GRUSHIN, ALBERTO CORTIJO, CSIC — In this talk we will study the Casimir interaction between Topological Insulators (TIs). We will start with a brief description of the TIs, to explain what a TI is, and why they are interesting from a Casimir effect point of view. In particular, a three dimensional Topological Insulator is characterized by its topological magnetoelectric coupling θ ≠0. We will discuss the electromagnetic response of the TIs, how a magnetoelectric coupling between TE and TM modes appears in this material and its consequences. We will show how, by tuning the parameter θ of the TI, we will be able to change the behavior of the Casimir energy between TIs from attraction to repulsion for all distances, and even the appearance of an equilibrium distance in the system. Then TIs can be potentially used to obtain “quantum levitation” and to avoid the sticking phenomena in NEMS.

4:18PM R41.00010 Three-body Casimir effects and repulsion1. KIMBALL MILTON, University of Oklahoma — The Casimir effect arises from quantum fluctuations in the electromagnetic field and results in forces between atoms (van der Waals and Casimir-Polder forces), between atoms and surfaces (Casimir-Polder forces), and between conducting and dielectric surfaces (Casimir-Lifshitz forces). In the past few years, there has been a revival of interest in problems related to Casimir forces between different materials. Pseudo-summation of interaction forces in general is very inadequate to describe the physics. In particular three-body effects can be large. Two-body forces, for example, between a dielectric sphere and a dielectric plane, can be calculated by a combination of analytic and numerical techniques; non-monotonic effects can occur when three-body interactions are considered. Anisotropic objects with ordinary electrical properties can give rise to repulsive quantum vacuum forces, which might have application in nanotechnology. This talk will focus on the overlap of the three-body force regime and Casimir repulsion, for example, the interaction between an anisotropically polarizable atom and a pair of conducting wedges, or two conducting half-planes constituting an aperture.

1Supported by NSF, DOE, and Julian Schwinger Foundation

4:30PM R41.00011 Electromagnetic fluctuation-induced interactions with metallic gratings. DIEGO DALVIT, Los Alamos National Laboratory — In this talk I will discuss electromagnetic equilibrium and non-equilibrium fluctuation-induced interactions involving metallic gratings. In particular, I will describe a modal approach [1] to compute Casimir forces between metallic gratings and discuss the description of a recent Casimir force experiment with nanostructures that shows a strong force reduction. I will also discuss the related non-equilibrium problem of nanoscale heat transfer in metallic gratings from a modal approach point of view [2].


4:42PM R41.00012 Fundamental limitations on force sensing due to patch potentials. RYAN BEHUNIN, Los Alamos National Laboratory, LOS ALAMOS NATIONAL LABORATORY COLLABORATION, UNIVERSITY OF BIRMINGHAM COLLABORATION, INDIANA UNIVERSITY-PURDUE UNIVERSITY INDIANAPOLIS COLLABORATION, UNIVERSITY OF BIRMINGHAM COLLABORATION — In this talk I will discuss some of the current methods used for measuring non-Newtonian corrections to gravity at short separation. When polycrystalline metallic test masses are used in these experiments patch potentials may provide a large source of noise. I will present a simple model to quantify patch effects from which insights may be gained for minimizing deleterious effects on force signal to noise in these experiments.
4:54PM R41.00013 Measurement of the Casimir force between gold surfaces using a Frequency-Modulation technique. JOE GARRETT, JEREMY MUNDAY, University of Maryland — The Casimir force arises from the interactions between fluctuating dipoles in two media separated by a gap. We measure the derivative of the Casimir force with respect to sample separation between a gold-coated sphere and a gold-coated planar substrate using a non-contact Frequency-Modulation (FM) method of Atomic Force Microscopy (AFM) in a thermally controlled environment. The resonant frequency of the cantilever is tracked as the sphere is brought close to the surface. At each distance from the surface, the bias voltage of the sphere is swept, both to measure the distance between the sphere and the plate and to mitigate the effect of any contact potential difference. We will present recently obtained experimental data and discuss the various artifacts associated with Casimir force measurements.

5:06PM R41.00014 Shape and material effects in Casimir forces. THORSTEN EMIG, LPTMS, CNRS and Universite Paris-Sud, UMR6626, 91405 Orsay, France, GIUSEPPE BIMONTE, Dipartimento di Scienze Fisiche, Università di Napoli Federico II, Via Cintia, 80126 Napoli, Italy, MOHAMMAD MAGHREBI, Physics Department, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, NOAH GRAHAM, Department of Physics, Middlebury College Middlebury, VT 05753, ROBERT JAFFE, Center for Theoretical Physics, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139, MEHRAN KARDAR, Physics Department, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139 — Casimir forces depend non-trivially on shape and material properties. We have derived a number of novel analytical and numerical results for Casimir interactions. We shall give a brief overview of the general approach and present explicit results for some generic examples, including short- and long-distance expansions, interaction of perfect conductors with sharp edges and tips, and exact solutions in two and three dimensions. The predictions are compared to recent experiments.

Thursday, March 21, 2013 8:00AM - 11:00AM —
Session T9 DAMOP: Invited Session: Thermalization and Non-Equilibrium Dynamics in Isolated Quantum Systems

8:00AM T9.00001 Non-Equilibrium Thermodynamic Relations in Driven Systems. ANATOLI POLKOVNIKOV, Boston University — In this talk I will review some recent results on non-equilibrium thermodynamic relations, which follow from combining unitary dynamics with the Eigenstate thermalization hypothesis. In particular, I will mention fluctuation theorems, general properties of energy and entropy production in driven systems (both open and thermally isolated), and fundamental limitations on efficiency of non-equilibrium heat engines.

8:36AM T9.00002 Quantum dynamics of a single, mobile spin impurity. STEFAN KUHR, University of Strathclyde, Glasgow — Quantum magnetism describes the properties of many materials such as transition metal oxides and cuprate superconductors. One of its elementary processes is the propagation of spin excitations. Here we study the quantum dynamics of a deterministically created spin-impurity atom, as it propagates in a one-dimensional lattice system. We probe the full spatial probability distribution of the impurity at different times using single-site-resolved imaging of bosonic atoms in an optical lattice. In the Mott-insulating regime, a post-selection of the data allows to reduce the effect of temperature, giving access to a space- and time-resolved measurement of the quantum-coherent propagation of a magnetic excitation in the Heisenberg model. Extending the study to the bath’s superfluid regime, we determine quantitatively how the bath strongly affects the motion of the impurity. The experimental data shows a remarkable agreement with theoretical predictions allowing us to determine the effect of temperature on the coherence and velocity of impurity motion. Our results pave the way for a new approach to study quantum magnetism, mobile impurities in quantum fluids, and polarons in lattice systems.

9:12AM T9.00003 Dynamics and description after relaxation of disordered quantum systems after a sudden quench. EHSAN KHATAMI, University of California, Santa Cruz / Georgetown University — After a sudden quench, the dynamics and thermalization of isolated quantum systems are topics that have generated increasing attention in recent years. This is in part motivated by the desire of gaining a deeper understanding of how statistical behavior emerges out of the unitary evolution in isolated quantum systems and in part by novel experiments with ultracold gases. Several studies have found that while unitary dynamics in generic systems lead to thermal behavior of observables after relaxation, the same is not true for integrable systems. The latter need to be described using generalized ensembles, which take into account the existence of relevant sets of conserved quantities. In this talk, we discuss how delocalization-to-localization transitions in integrable and non-integrable disordered quantum systems change the picture above. We find that the relaxation dynamics, whenever relaxation takes place, is close to power law in those systems. In addition, statistical mechanics descriptions break down in the localized regimes. We discuss how this relates to the failure of eigenstate thermalization in the presence of localization.

9:48AM T9.00004 Conduction properties of strongly interacting Fermions. JEAN-PHILIPPE BRANTUT, ETH Zürich — We experimentally study the transport process of ultracold fermionic atoms through a mesoscopic, quasi two-dimensional channel connecting macroscopic reservoirs. By observing the current response to a bias applied between the reservoirs, we directly access the resistance of the channel in a manner analogous to a solid state conduction measurement. The resistance is further controlled by a gate potential reducing the atomic density in the channel, like in a field effect transistor. In this setup, we study the flow of a strongly interacting Fermi gas, and observe a striking drop of resistance with increasing density in the channel, as expected at the onset of superfluidity. We relate the transport properties to the in-situ evolution of the thermodynamic potential, providing a model-independent thermodynamic scale. By resistance is compared to that of an ideal Fermi gas in the same geometry, which shows an order of magnitude larger resistance, originating from the contact resistance between the channel and the reservoirs. The extension of this study to a channel containing a tunable disorder is briefly outlined.
10:24AM T40.00005 Analytical methods for studying quantum quenches in integrable models. FABIAN ESSLER, Oxford University — I consider the non-equilibrium time evolution in integrable models after a quantum quench. For the case of a magnetic field quench in the transverse field Ising chain I present detailed results for the time evolution of local observables, which are shown to relax to a generalised Gibbs ensemble (GGE) [2] at late times. More generally, the reduced density matrix of a subsystem is shown to relax to a GGE in a power-law fashion in time. Dynamical response functions are studied as a function of the time after the quench and are shown to approach values given by the GGE as well. Finally generalizations to the sine-Gordon model [3] are discussed.


Thursday, March 21, 2013 8:00AM - 10:48AM — Session T40 DAMOP: Strongly Interacting Quantum Gases 349 - Qi Zhou

8:00AM T40.00001 Symmetry methods for harmonically trapped, interacting particles. NATHAN HARSHMAN, Department of Physics, American University — We present a new method for exploiting the symmetries of interacting few-body systems trapped in harmonic potentials to achieve efficient numerical calculations of energy eigenstates. Precision experiments with ultracold atoms trapped in deep optical wells, as well as connections to recombination loss rates in trapped BCS-BEC, have driven experimental interest in this topic. Our method has two key elements. First, transformations from the particle observables into the center-of-mass/Jacobi observables can be implemented using the U(N) symmetries of N harmonic oscillators in d dimensions. Second, particle exchange symmetries are realized geometrically as orthogonal transformations in Jacobi relative hypercoordinates.

8:12AM T40.00002 Unitary thermodynamics calculated from thermodynamic geometry. GEORGE RUPPEINER, New College of Florida — Degenerate atomic Fermi gases of atoms near a Feshbach resonance show universal thermodynamic properties, which are here calculated with the geometry of thermodynamics. The thermodynamic curvature R. Unitary thermodynamics is expressed as the solution to a pair of ordinary differential equations, a "superfluid" one valid for small entropy per particle and a "normal" one valid for large z. These two solutions are joined at a second-order phase transition at z = ze. Define the internal energy per particle in units of the Fermi energy as \( Y = Y(z) \). For small z, \( Y(z) \sim y_0 + y_1 z + y_2 z^2 + \cdots \), where the coefficients \( y_0 \) and \( y_1 \) are scaling factors, and the series coefficients \( y_i, i \geq 2 \) are determined uniquely in terms of the parameters \( y_0, y_1, y_2 \).

8:24AM T40.00003 Density and particle-hole fluctuation effects on the position of Feshbach resonances in atomic Fermi gases. QIJIN CHEN, Zhejiang University — Feshbach resonances have been the key to achieve tunable effective pairing interaction strength in atomic Fermi gases. Most important experiments, as well as their theoretical explanations, rely on precise determination of the locations of these resonances. For the extensively studied ^4\text{Li} and ^\text{13}^\text{K} Fermi gases, the positions of the widely used \( s \)-wave Feshbach resonances have been regarded as being measured with high precision. In this talk, we show that due to inevitable particle-hole fluctuations, there is a significant density dependence on the resonance locations. For a ^4\text{Li} gas with a realistic \( T_F \), the shift in position in terms of magnetic field can be as high as 8G at low temperature \( T \), and this effect does not necessarily go away at high \( T \). This will cause important consequences as to whether and how the scattering length taken from the literature need to be re-calibrated for the concrete parameters specific to a given experiment. Reference: Q.J. Chen, arXiv:1109.2307.

8:36AM T40.00004 Scale Invariance in 2D BCS-BEC Crossover. RAJDEEP SENSARMA, Tata Institute of Fundamental Research, EDWARD TAYLOR, McMaster University, MOHIT RANDERIA, The Ohio State University — In 2D BCS-BEC crossover, the frequency of the breathing mode in a harmonic trap, as well as the lower edge of the radio frequency spectroscopy response, show remarkable scale-invariance throughout the crossover regime, i.e., they are independent of the coupling constant. Using functional integral methods, we study the behaviour of these quantities in the 2D BCS-BEC crossover and comment on the possible reasons for this scale independence.

8:48AM T40.00005 Apparent Low-Energy Scale Invariance in Two-Dimensional Fermi Gases. EDWARD TAYLOR, McMaster University, MOHIT RANDERIA, The Ohio State University — Recent experiments on a 2D Fermi gas find an undamped breathing mode oscillating at twice the trap frequency over a wide range of parameters [1]. To understand this seemingly scale-invariant behavior in a system with an energy scale, the dimer binding energy, we derive two exact results valid across the entire BCS-BEC crossover at all temperatures [2]. We relate both the shift of mode frequency from its scale-invariant value as well as a sum rule characterizing the low-energy spectral weight in the bulk viscosity to a single parameter. This parameter characterizes the deviation from scale invariance at low energies and remarkably, vanishes exactly at zero temperature within mean-field BCS theory. Only thermal and quantum fluctuations contribute a nonzero value for this parameter and hence, break the low-energy, effective scale invariance. We discuss reasons why, in 2D time, the interaction effects as well as the local Fermi energy, or Fermi momentum, depend on the density. We report on experiments that use optical pumping with shaped light beams to spatially select the center part of a trapped gas for probing. This technique is compatible with momentum resolved measurements. For a weakly interacting Fermi gas of ^\text{40}^\text{K} atoms, we present measurements of the momentum distribution that reveal for the first time a sharp Fermi surface. We then apply this technique to a strongly interacting Fermi gas at the Feshbach resonance, where we measured the temperature dependence of the Tan's contact locally in the trapped gas.
9:12AM T40.00007 Magnetic properties and pseudogap phenomenon in an ultracold Fermi gas with population imbalance. TAKASHI KASHIMURA, RYOTA WATANABE, YOJI OHASHI, Department of Physics, Keio University — We discuss the magnetic properties of an ultracold Fermi gas with population imbalance. In the unpolarized case, the spin wave spectrum shows a gap-like (pseudogap) structure in the normal state above the superfluid phase transition temperature, such an anomalous structure has not been detected in the highly-polarized regime. In this talk, we discuss how the pseudogap phenomenon is affected by the polarization of the system. Within the framework of an extended T-matrix theory, we calculate the polarization dependence of DOS to show that the pseudogap gradually disappears with increasing the polarization rate. In a highly-polarized regime, the system is simply described as a gas of long-lived quasiparticles. We also show that the calculated polarization as a function of an effective “magnetic” field \( h = (\mu_1 - \mu_2)/2 \) agrees well with the experimental data [where \( \mu \) is the chemical potential of atoms with pseudospin \( \sigma = \uparrow, \downarrow \)].

9:24AM T40.00008 Spin Diffusion in a Cold Fermi Gas Close to Unitarity. HUA LI, KEVIN BEDELL, Boston College. JASON JACKIEWICZ, New Mexico State University — We study the transport properties of a normal two component Fermi gas with strong attractive interactions close to the unitary limit. In particular, we compute its spin diffusion coefficient in the extreme low temperature limit. To calculate the spin diffusion coefficient we need the scattering amplitudes. The scattering amplitudes are calculated from the Landau parameters. These parameters are obtained from the local version of the induced interaction model for computing Landau parameters. The leading order finite temperature corrections to the spin diffusion coefficient are also calculated. At temperatures close to the BCS transition temperature, pairing fluctuations are considered in calculating the scattering amplitudes. A minimum is found on the calculated temperature dependent spin diffusion coefficient curve. The position and magnitude of this minimum is sensitive to the Landau parameter \( F_0 \). Upon choosing a proper value of \( F_0 \), we are able to present a good match between the theoretical result and the experimental measurement which has a minimum with a value of order \( h/m \) being observed at some finite temperature below the Fermi temperature.

9:36AM T40.00009 Fulde-Ferrell-Larkin-Ovchinnikov states in Fermi-Fermi mixtures¹. JIBIAO WANG, QIJIN CHEN, Zhejiang University — Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) states have been of great interest in the study of population imbalanced atomic Fermi gases. It has been known that the phase space of FFLO states for an equal-mass Fermi gas in three dimension (3D) is rather small and thus has not been observed experimentally. In this talk, we will explore possible effects of mass imbalance as in a Fermi-Fermi mixture on the FFLO phases for a 3D homogeneous case. In particular, we will use a pairing fluctuation theory to show that the pairing fluctuations constitute a key ingredient of the theory and thus lead naturally to the appearance of a pseudogap when the pairing interaction becomes strong. We will present various phase diagrams related to the FFLO phases and phase transitions in this system using variational Monte Carlo. Within a single-channel model appropriate near broad Feshbach resonances, we show that as the boson-fermion coupling increases, the Bose-Einstein condensate disappears and the atomic Fermi surface is destroyed while the Fermi surface vanishes at a critical coupling.

9:48AM T40.00010 Observation of Feshbach resonances between ultracold Na and Rb atoms. FUDONG WANG, DEZHI XIONG, XIAOKE LI, DAJUN WANG, Department of Physics, The Chinese University of Hong Kong — Absolute ground-state \(^{23}\)Na\(^{87}\)Rb molecule has a large electric dipole moment of 3.3 Debye and its two body exchange chemical reaction is energetically forbidden at ultracold temperatures. It is thus a nice candidate for studying quantum gases with dipolar interactions. We have built an experiment setup to investigate ultracold collisions between Na and Rb atoms as a first step toward the production of ground state molecular samples. Ultracold mixtures are first obtained by evaporative cooling of Rb and sympathetic cooling of Na. They are then transferred to a crossed dipole trap and prepared in different spin combinations for Feshbach resonance study. Several resonances below 1000 G are observed with both atoms prepared in either \( |F = 1, m_F = 1 \rangle \) or \( |F = 1, m_F = -1 \rangle \) hyperfine states. Most of them are within 30 G of predicted values based on potentials obtained by high quality molecular spectroscopy studies. This work is supported by RGC Hong Kong.

§ E. Tiemann, private communications

10:00AM T40.00011 Quantum Phase Transitions in a Bose-Fermi Mixture¹, ERIC DUCHON, The Ohio State University, SHIZHONG ZHANG, The University of Hong Kong, SOON-YONG CHANG, MOHIT RANDERIA, NANDINI TRIVEDI, The Ohio State University — Motivated by the recent experimental realization of stable Bose-Fermi mixtures with broad Feshbach resonances, we investigate possible quantum phases and phase transitions in this system using variational Monte Carlo. Within a single-channel model appropriate near broad Feshbach resonances, we show that as the boson-fermion coupling increases, the Bose-Einstein condensate disappears and the atomic Fermi surface is destroyed while the Fermi surface of the composite molecules emerges. We calculate the momentum distribution of atomic and molecular fermions and demonstrate that the atomic fermion’s quasi-particle weight \( Z \) vanishes at a critical coupling.

3We would like to acknowledge support from NSF DMR-0907275 (E.D., N.T.) and NSF DMR-1006532 (M.R.).

10:12AM T40.00012 From the Cooper problem to canted supersolids in Bose-Fermi mixtures. LODE POLLET, Department of Physics, LMU Munich, Germany, PETER ANDERS, Theoretische Physik, ETH Zurich, Switzerland, PHILIPP WERNER, Department of Physics, University of Fribourg, Switzerland, MATTHIAS TROYER, MANFRED SIGRIST, Theoretische Physik, ETH Zurich, Switzerland — We calculate the phase diagram of the Bose-Fermi Hubbard model on the 3d cubic lattice at fermionic half filling and bosonic unit filling by means of single-site dynamical mean-field theory (DMFT). For fast bosons, this is equivalent to the Cooper problem in which the bosons can induce \( s \)-wave pairing between the fermions. We also find miscible superfluid and canted supersolids phases depending on the interspecies coupling strength. In contrast, slow bosons favor fermionic charge density wave structures for attractive fermionic interactions. These competing instabilities lead to a rich phase diagram within reach of cold gas experiments.

10:24AM T40.00013 Closed Channel Amplitude in a Many Body Feshbach System. NICOLAS LOPEZ, University of California Riverside, EDDY TIMMERMANS, Los Alamos National Lab, SHAN-WEI TSAI, University of California Riverside — Near a narrow Feshbach resonance (with magnetic field width 10 mG or smaller) the ultra-cold atom interactions acquire an effective range that can be comparable to the average inter-particle distance. Although requiring a more accurate magnetic field control than their broad counterparts, the narrow Feshbach resonances can free cold atom physics from its straightjacket of the contact interaction paradigm. The finite-range effects can give rise to roton features in the phonon dispersion of dilute Bose-Einstein condensates (BECs) and BEC’s can support a ground state with modulated density patterns that breaks translational symmetry. We show that the finite range interaction is the consequence of the time-delay in atom-atom collisions. The narrow regime is also the parameter region in which the interacting atoms can spend a significant fraction of their time in the spin-rearranged (also called “closed”) channel. To study the interaction physics we describe two atoms in a harmonic trap, interacting near a narrow resonance. We find the fraction of time that the atoms spend in the closed channel at fixed magnetic field and we extend this result to estimate the fraction of time that a distinguishable atom moving through a BEC spends in the closed channel state, quasibound to BEC-atoms.

10:36AM T40.00014 ABSTRACT WITHDRAWN —
Thursday, March 21, 2013 8:00AM - 11:00AM –
Session T41 GQI DAMOP: Focus Session: Nano/Optomechanics III

8:00AM T41.00001 Surprises in three-mode quantum optomechanics: adiabatic quantum state transfer and entanglement by dissipation

8:36AM T41.00002 Optomechanical transducer for microwave-to-optical photon conversion

8:48AM T41.00003 State Transfer between a Mechanical Oscillator and Itinerant Microwave Fields

9:00AM T41.00004 Electro-optical transduction via a mechanical membrane

9:12AM T41.00005 Dispersive optomechanical coupling between a SiN nanomechanical oscillator and evanescent fields of a silica optical resonator

9:24AM T41.00006 Cavity optomechanics with silicon nitride sub-wavelength grating membranes

9:36AM T41.00007 Exploiting the nonlinear dynamics of a single-electron shuttle for highly regular current transport
9:48AM T41.00008 Branched comb fingers improve capacitative readout sensitivity to vertical motion in a MEMS sound sensor1, RICHARD DOWNEY, GAMANI KARUNASIRI, Naval Postgraduate School. A microelectromechanical (MEMS) device that relies on capacitive readout of vertical, out-of-plane displacements can be made more sensitive by replacing the traditional straight comb fingers with a branched design. A branched structure allows for larger capacitors using shorter fingers. When fabrication design rules limit finger length, a branched design can have greater surface area, greater capacitance, and therefore greater sensitivity to vertical displacements. Applying this concept to a MEMS acoustic direction-finding (DF) sensor, we predict and then demonstrate an approximate doubling of signal output.

1NCMR/NSF

10:00AM T41.00009 Optomechanics and integrated photonics and in aluminum nitride1, A. VAINSENCHER, J. BOCHMANN, D.D. AWSCHALOM, A.N. CLELAND, Department of Physics and California Nanosystems Institute, University of California, Santa Barbara — Integrated photonics devices based on silicon have proven enormously successful, with low loss and high confinement optical and optomechanical devices. We show that aluminum nitride is also an excellent material for photonic integrated circuits, with an extremely wide bandgap and very significantly strong piezoelectric and electro-optic effects. Optical-grade AlN can be deposited on substrates with a CMOS-compatible process. We demonstrate integrated photonic circuits and optomechanical devices based on this novel material. Operating in the optical telecommunications band, we demonstrate ring resonators with ultrahigh optical Q factors as well as one-dimensional optomechanical crystals operating in the resolved sideband regime with localized 4 GHz mechanical modes. This talk will present recent results with the eventual goal of integrating these devices with superconducting quantum bits.

1This work is funded through DARPA/DSO.

10:12AM T41.00010 Control and measurement of an electro-mechanical system with a phase qubit, FLORENT LECOCQ, JOHN TFEUFL, MICHAEL ALLMAN, KATARINA CICAK, FABIO DA SILVA, ADAM SIROIS, JED WHITTKER, JOE AUMENTADO, RAY SIMMONDS, NIST Boulder. We discuss a hybrid device that merges an electro-mechanical system with a metastable phase qubit. The phase qubit can act as a single photon source and detector, allowing the preparation and readout of a lumped element electrical resonator, whose capacitance is formed by a mechanically compliant vacuum-gap capacitor. Via radiation pressure induced parametric coupling, we can map the quantum state of the 10 GHz electrical resonator on the long-lived, ~10 MHz fundamental mode of the mechanical oscillator. This work opens the way toward the preparation of complex phonon states of mechanical motion. We will discuss current progress with this device.

10:24AM T41.00011 Design and Construction of Cryogenic Optomechanical System, DONGHUN LEE, MITCHELL UNDERWOOD, DAVID MASON, Department of Physics, Yale University, ANDREW JAYICH, Department of Physics, UCLA, ANYA KASHKANOVA, Department of Physics, Yale University, JACK HARRIS, Department of Physics and Applied Physics, Yale University — One key challenge to observing quantum phenomena in a macroscopic mechanical oscillator is reaching its ground state. To achieve the low temperatures required for this, we utilize resolved sideband laser cooling of a few hundred kHz mechanical oscillator with high mechanical Q (a Si3N4 membrane) inside a high finesse optical cavity, in addition to cryogenically reducing the bath temperature. Realizing high Q and high finesse cavity optomechanical devices in a cryogenic environment requires overcoming a number of challenges. In this talk, we describe the design and construction of such a device working at a bath temperature of 300 mK (in a 3He refrigerator) and suited for operation at lower temperatures (in a dilution refrigerator). The design incorporates in-situ commercial piezo actuators (manufactured by Janssen Precision Engineering) to couple externally prepared laser light into the cold optical cavity. The design also incorporates filtering cavities to suppress classical laser noise, and acoustic and seismic isolation of the experiment.

10:36AM T41.00012 Two-tone experiments and time domain control in circuit nano-electromechanics, F. HOCHE, H. HUEBL, Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany, X. ZHOU, A. SCHLIESSENER, T. J. KIPPENBERG, École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, Switzerland; Max-Planck-Institut für Quantenoptik, Garching, Germany, R. GROSS, Walther-Meissner-Institut, Bayerische Akademie der Wissenschaften and Physik-Department TU München, Garching, Germany — In the field of optomechanics, a light field trapped in an optical resonator dynamically interacts with a mechanical degree of freedom, enabling cooling and amplification of mechanical motion. This concept of light matter interaction can be transferred to the microwave (MW) regime combining superconducting MW circuits with nanometer-sized mechanical beams, establishing the class of circuit nano-electromechanics. Here, two-tone spectroscopy is a tool to access a wider class of phenomena, employing interference of a pump and a probe tone inside the MW cavity. We discuss electromechanically induced transparency and electromechanically induced absorption employing continuous and pulsed excitation. With the latter technique, we access the dynamics of the hybrid system revealing that the switching dynamics of the transmitted light are not limited by the time constant imposed by the mechanical beam, the slowing of light pulses, and the phonon repopulation of a precooled mechanical mode due to thermal decoherence [1,2]. Our experiments provide a key tool towards full quantum control of electromagnetic systems, including squeezing, state transfer and entanglement between mechanical and optical degree of freedom. [1] X. Zhou et al. arXiv:1206.6052 [2] F. Hocque et al. arXiv:1209.4470

10:48AM T41.00013 Reading, writing and squeezing the entangled states of two nanomechanical resonators coupled to a SQUID, GUY COHEN, MASSIMILIANO DI VENTRA, University of California, San Diego — We study a system of two nanomechanical resonators embedded in a dc SQUID. We show that the inductively-coupled resonators can be treated as two entangled qubits with states that can be read from, or written on by employing the SQUID as a displacement detector or switching additional external magnetic fields, respectively. We present a scheme to squeeze the even mode of the state of the resonators and consequently reduce the noise in the measurement of the magnetic flux threading the SQUID. We finally analyze the effect of dissipation on the squeezing using the quantum master equation, and show the qualitatively different behavior for the weak and strong damping regimes. Our predictions can be tested using current experimental capabilities.


11:15AM U40.00001 Emergence of an effective thermal correlation length in the course of prethermalization, REMI GEIGER, MAXIMILIAN KUHNERT, TIM LANGEN, MICHAEL GRING, BERNHARD RAUER, Atomistitut, TU Wien (Vienna University of Technology), TAKUYA KITAGAWA, EUGENE DEMLER, Harvard University, DAVID ADU-SMITH, JOERG SCHMIEDMAYER, Atomistitut, TU Wien (Vienna University of Technology) — Understanding non-equilibrium processes in many-body quantum systems is an important unsolved problem in many areas of physics. Here, we study the relaxation dynamics of a coherently split one-dimensional Bose gas by measuring the full probability distribution functions of matter-wave interference. After splitting, the system rapidly relaxes to a thermal-like quasi-steady state retaining partial information about the initial conditions. We observe this state to be independent on the initial temperature before splitting and associate the relaxation dynamics with prethermalization. Observing the system on different length scales allows us to probe the dynamics of excitations on different energy scales, revealing two distinct length-scale dependent regimes of relaxation. We measure the crossover length-scale separating these two regimes and identify it with the prethermalized phase-correlation length of the system. Our work provides a direct visualization of prethermalization and multimode dynamics in a one-dimensional many-body quantum system.
11:27AM U40.00002 Quasi-universal transient behavior of a nonequilibrium Mott insulator driven by an electric field, KARLIS MIKELSONS, JIM FREERICKS, Georgetown University, H.R. KRISHNAMURTHY, Indian Institute of Science, Bangalore — We use a self-consistent strong-coupling expansion for the self-energy (perturbation theory in the hopping) to describe the nonequilibrium dynamics of strongly correlated lattice fermions. We study the three-dimensional homogeneous Fermi-Hubbard model driven by an external electric field showing that the damping of the ensuing Bloch oscillations depends on the direction of the field, and that for a broad range of field strengths, a long-lived transient prethermalized state emerges. This long-lived transient regime implies that thermal equilibrium may be out of reach of the time scales accessible in present cold atom experiments, but shows that an interesting new quasi-universal transient state exists in nonequilibrium governed by a thermalized kinetic energy, but not a thermalized potential energy. In addition, when the field strength is equal in magnitude to the interaction between atoms, the system undergoes a rapid thermalization, characterized by a different quasi-universal behavior of the current and spectral function for different values of the hopping.

11:39AM U40.00003 Quench Dynamics in the Presence of a Bath, ADAM RANCON, James Franck Institute, ANDREAS GLATZ, IGOR ARANSON, Argonne National Laboratory, KATHY LEVIN, James Franck Institute — Feshbach resonance are now widely used to tune the interaction strength in cold atoms. This allows one to experimentally study the out-of-equilibrium dynamics of a quench associated with instantaneously changing the strength of the interactions between fermionic and bosonic atoms. Previous theoretical studies based on standard time dependent Bogoliubov or BCS theory (for bosons and fermions) have not included the presence of a thermal bath. This bath is essential for ultimate equilibration. In this talk we show how to include the bath following a Leggett-Caldeira type approach. We point out some of the important differences in the quench dynamics between bosonic and fermionic fluids.

11:51AM U40.00004 Many-body analysis of a quasi-disordered integrable lattice system after a quench, LEA SANTOS, Yeshiva University, MARCOS RIGOL, Penn State University — It has been recently argued that the transition between a delocalized and a localized regime in a quasi-disordered integrable lattice system affects the dynamics and description of one-body observables after relaxation following a quench [1]. Specifically, the generalized Gibbs ensemble description was found to be applicable in the delocalized phase, but to break down in the localized phase. Here we present a many-body analysis of those quenches. We discuss how the expectation values of one-body observables in the many-body eigenstates behave in both regimes, and provide a microscopic understanding of the results in Ref. [1].


12:03PM U40.00005 When Is a Bath a Bath? Relaxation Dynamics and Thermalization in a Fermionic Chain, NICHOLAS SEDLMAYR, JIE REN, TU Kaiserslautern, FLORIAN GEBHARD, Marburg University, JESKO SIRKER, TU Kaiserslautern — We study thermalization in a one-dimensional quantum system consisting of a non-interacting fermionic chain with each site of the chain coupled to an additional bath site. Using a time-dependent density matrix renormalization group algorithm we investigate the time evolution of observables in the chain after a quantum quench. For a weakly interacting bath and low densities we show that the dynamics can be quantitatively described by a system of coupled equations of motion. For higher densities our numerical results show equilibration for local observables and a thermalization to the canonical ensemble independent of the initial state. In particular, we find a Fermi momentum distribution in the chain in equilibrium in spite of the seemingly oversimplified bath in our model.

12:15PM U40.00006 Quench dynamics in the one-dimensional sine-Gordon model: Quantum kinetic equation approach, MARCO TAVORA, ADITI MITRA, New York University — We study dynamics after a quantum quench in the one-dimensional sine-Gordon model in its gapless phase. We construct the Dyson equation to leading (quadratic) order in the cosine potential and show that the resulting quantum kinetic equation is atypical in that it involves multi-particle scattering processes. We also show that using an effective action, which generates the Dyson equation by a variational principle, the conserved stress-momentum tensor can be constructed. We solve the dynamics numerically by making a quasi-classical approximation that makes the quantum kinetic equation local in time while retaining the multi-particle nature of the scattering processes. We find that the boson distribution function reaches a steady-state characterized by an effective temperature in the long-wavelength limit. We present an analytic argument for the value of the effective temperature and the time-scales to reach this steady-state. 

1Supported by NSF-DMR 1004589.

12:27PM U40.00007 Thermalization in isolated quantum many-body systems and dependence on initial states, EDUARDO TORRES-HERRERA, LEA SANTOS, Yeshiva University — We study the viability of thermalization in isolated quantum many-body systems described by one-dimensional Heisenberg spin-1/2 models. We show that the onset of thermal equilibrium depends on the interplay between initial states, observables and regimes. Our numerical studies are based on the spectrum analysis of the system and on its long-time evolution after a quench.

12:39PM U40.00008 Initial-state dependence of the quench dynamics in integrable quantum systems at finite temperature, KAI HE, Georgetown University, MARCOS RIGOL, Georgetown University, Penn State University — We study properties of isolated integrable quantum systems after a sudden quench starting from thermal states. We show that, even if the system is initially in equilibrium at finite temperature, the diagonal entropy after a quench remains a fraction of the entropy in the generalized ensembles introduced to describe integrable systems after relaxation. The latter is also, in general, different from the entropy in thermal equilibrium. Furthermore, we examine the difference between the distribution of conserved quantities in the thermal and generalized ensembles after a quench and show that they are also, in general, different from each other. This explains why these systems fail to thermalize in the usual sense. A finite size scaling analysis is presented for each quantity, which allows us making predictions for thermodynamically large lattice sizes.

12:51PM U40.00009 Non-Equilibrium Behavior and Thermalization in 1D Bose Gases, ROBERT KONIK, Brookhaven National Lab, JEAN-SEBASTIEN CAUX, University of Amsterdam — Using a new numerical renormalization group based on exploiting an underlying exactly solvable nonrelativistic theory, we study the equilibrium properties and out-of-equilibrium dynamics of interacting many-body quantum systems. Focusing on the example of the Lieb-Liniger model we study quantum quenches with a focus on protocols in which the gas is released from a parabolic trap. Our method allows one not only to accurately describe the equilibrium state of the gas in the trap, but also to track the post-quench dynamics all the way to infinite time. Exploiting integrability, we are also able to exhibit a general protocol for the explicit construction of the generalized Gibbs ensemble, which is a candidate to govern the equilibration of the trapped gas after its release. This construction does not rely on the underlying Hamiltonian being quadratic and works for arbitrary initial conditions. By comparing the predictions of equilibration from this ensemble against the long time dynamics observed in our method, we find that it is considerably more accurate than the effective grand canonical ensemble. See J.S. Caux and R. M. Konik, PRL 109, 175301 (2012).
1:03PM U40.00010 How Long Does it Take for a Non-Equilibrium System to Reach a Quasi-Thermal State?  
HERBERT F. FOTSO, KARLS MIKELSONS, JAMES K. FREERICKS, Department of Physics, Georgetown University — We study the relaxation of an interacting system driven out of equilibrium by a constant electric field using Non-Equilibrium Dynamical Mean Field Theory. We use on the one hand a DMFT method which solves the steady state problem directly in frequency space, and on the other hand, a DMFT method that follows the transient time evolution of the system on the Keldysh contour. The system is described by the Falicov Kimball model which we follow across the metal-insulator transition. We find that the retarded Green’s function quickly approaches that of the steady state while the lesser Green’s function and, as a result the distribution function, slowly approach that of a steady state with an increased temperature due to the additional energy transferred to the system by the electric field. Analyses of this type can help understand the results of some experiments involving ultracold atomic gases.

1:15PM U40.00011 Probing thermalization and dephasing using the Kibble-Zurek mechanism, M. KULKARNI, K. TIWARI, D. SEGAL, University of Toronto — The Kibble-Zurek mechanism was introduced to describe defect creation after ramping through critical points. Recent work has extended this concept to a full non-equilibrium scaling theory, described by the same low-energy critical exponents as in equilibrium. In this talk, I will discuss applying Kibble-Zurek analysis and its extensions to probe open questions in non-equilibrium dynamics, specifically working to understand thermalization or — in the case of integrable systems — dephasing to a generalized Gibbs ensemble. The major advantage of investigating these questions within the Kibble-Zurek scaling regime is that the results are universal in the renormalization group sense, i.e., insensitive to microscopic details that often confound analyses of thermalization. I will describe both analytical and numerical (TEBD) approaches to address the problem, with an emphasis on understanding the long-time behavior after a slow ramps and small quenches.

1:27PM U40.00012 Dynamics of Large Quantum Systems: Equilibration, Thermalization and Interactions, MANAS KULKARNI, Princeton University, KUNAL TIWARI, McGill University — The question of how/whether large quantum systems equilibrate and/or thermalize when prepared in an out-of-equilibrium state has been of enormous interest given recent experimental progress. We address this question in fermionic [1,2] and bosonic [3] systems, by following the dynamics of the full density matrix. We particularly study the case of two large-twin systems connected by a weak link (a quantum impurity), and we show that the total system equilibrates and thermalizes when the weak link is susceptible to incoherent and inelastic processes. We thus provide an experimentally feasible prescription for equilibrating and thermalizing large finite quantum systems. Our calculations are based on extending methods originally developed to treat subsystem dynamics (such as impurity), namely, the quantum Langevin equation method, the well known fermionic trace formula, and an iterative path integral approach. We also explore the role of interactions. While the fermionic system [1,2] shares many common features with the bosonic analog [3], we will describe certain crucial differences that arise as a result of different statistics.

1:39PM U40.00013 Quench Dynamics of the Interacting Bose Gas in one Dimension, NATAN ANDREI, DEEPAK IYER, Department of Physics, Rutgers University — We obtain an exact expression for the time evolution of the interacting Bose gas following a quench from a generic initial state using the Yudson representation for integrable systems. We study the evolution of the density and noise correlation for a small number of bosons and their asymptotic for any number. We show that for any value of the coupling, as long as it is repulsive, the system asymptotes towards a strongly repulsive gas, while for any value of an attractive coupling long time behavior is dominated by the maximal bound state. This occurs independently of the initial state and can be viewed as an emerging “dynamic universality”.

This work was supported by NSF grant DMR 1006684.

1:51PM U40.00014 Quantum Quenches of Ultracold Atoms in the Presence of Synthetic Gauge Fields, MATTHEW KILLI, STEFAN TROTZYK, ARUN PARAMEKANTI, University of Toronto — Motivated by the experimental realization of synthetic gauge fields for ultracold atoms in optical lattices, we consider quantum quenches in such gauge field backgrounds. We show that the density dynamics following sudden anisotropic quenches can be used as a probe of equilibrium mass currents of atoms. We show, using diverse examples of Bose superfluids and normal Fermi fluids, that bulk equilibrium currents produced by the background gauge fields can be uncovered using this method. Such quenches are also shown to provide an effective route to probing the edge currents in topological states such as quantum Hall or quantum spin Hall insulators.

This work was supported by NSERC.

2:03PM U40.00015 Thermalization Processes in Quantum Mechanics, VAN NGO, STEPHAN HAAS, University of Southern California — In quantum mechanics, the emergence of thermalization processes from unitary evolution has remained one of the greatest challenges. The two outstanding theories of this issue by Srednicki and Tasaki cannot address the concepts of temperature, heat, and work. Here, we present a theory using multiple quenches to examine the thermalization processes to advance thermodynamics concepts. To perform multiple quenches, one can vary one single control parameter ($\lambda$) in a series of time evolutions, which create a set of density operators. The average of these density operators results into a diagonal operator with probability distribution function that can describe the emerging ensembles. Measuring probability distribution functions of key physical observables, temperature, equal to the derivative of energy with respect to entropy, can be easily measured. Therefore, simulations via multiple quenches can mimic dynamics in open quantum systems with much cheaper computational cost. They allow (1) tuning of temperature and entropy via $\lambda$, (2) measuring work distribution functions from distributions of a reaction coordinate, and (3) computing free-energy changes via Jarzynski’s Equality. We hope that this approach can provide a new foundation and open up new directions for studying control of quantum systems.

Thursday, March 21, 2013 11:15AM - 2:15PM
Session U41 GQI DAMOP: Quantum Simulation in Hybrid Systems (and Nano/Optomechanics IV) 350 - Aashish Clerk, McGill University

11:15AM U41.00001 Quantum Dynamics of Photon Condensates, PETER KIRTON, JONATHAN KEELING, University of St Andrews — Recent experiments have, for the first time, been able to observe the Bose condensation of a gas of weakly interacting photons. We develop a full out-of-equilibrium quantum mechanical treatment of the dynamics of this system. Our model consists of a series of photon modes coupled to the background dye molecules which we simply treat as two-level systems in which each level is separated into a ladder of rovibrational states. We find that the behavior of the photon field is very much like that of a two-level laser in which there is an asymmetry between the effective pump and decay rates induced by the rovibrational states of the dye. This motivates us to use techniques based on those for the inversionless two-level laser. We are able to calculate the coherence properties of the photons as well as giving insights into the thermalization processes which equilibrate the populations of the various photon modes.
Excitations of a driven condensate in a cavity: dynamics of the roton-like mode.

Recent experiments have demonstrated the superfluid-supersolid quantum phase transition (PT) of an optically driven Bose-Einstein condensate (BEC), via the observation of a roton-like softening of a mode in the Bogoliubov excitation spectrum [1,2]. This phenomenon is usually studied within two-mode approximation for the BEC which results in Dicke-like effective model. In this system, the long-range interactions between the atoms are mediated by cavity photons and the strength of the interactions is controlled by pump power. In this work, we investigate the effect of including the full spectrum of atomic modes. We find a finite lifetime for the roton-like mode below the threshold that is strongly pump-dependent. The corresponding decay rate and critical exponents for the PT are calculated.

Quantum optomechanics in the strong-driving, strong-coupling regime.

We previously proposed a nano-mechanical system where phonons trapped in an acoustic cavity can strongly hybridize with impurity qubit states in silicon (forming a so-called cavity-phoniton). Here, we extend the idea to the quantum many-body limit by investigating the physics of phonon-tunnel-coupled arrays of such components. The silicon qubit cavity phoniton system potentially offers advantages in this regime over purely optomechanical systems where the optomechanical coupling is still quite small. First, single phonons in a crystal can have large effective de Broglie wavelengths (microns). Second, as we have previously shown, qubit-phonon coupling can be quite large, easily allowing the system to enter the strong coupling regime and enabling phonon-blockade. Such arrays can be fabricated in semiconductor heterostructures or on-chip, optomechanical crystals. We calculate the parameter regime where the Mott-Superfluid quantum phase transition occurs in realizable devices. We also demonstrate the emergence of super-splitting, phonon anti-bunching, and phonon blockade through the non-equilibrium density matrix master equation approach in few cavity systems.

Quantum Dynamics of Optomechanical Arrays.

In this talk, we will introduce an array of optomechanical cells, and discuss our theoretical results on the nonlinear dynamics of such a setup. In particular, we have discovered a phase transition between incoherent mechanical oscillations and a collective phase-coherent mechanical state. We describe how quantum fluctuations drive this transition at low temperatures. We will also discuss the prospects of observing these non-equilibrium dynamics in an experimental implementation based on currently available setups.

Signatures of nonlinear optomechanics and engineering of nonclassical mechanical steady states.

Motivated by recent improvements in coupling strength between light and mechanical motion, we study the strong coupling regime of cavity optomechanics theoretically. We focus on the regime where the optomechanical coupling rate is still small compared to the mechanical resonance frequency, but where the mechanically induced Kerr nonlinearity is significant. The response of the system to an optical drive is characterized. The average photon number in the cavity as a function of drive detuning can feature several peaks due to multi-phonon transitions. Furthermore, we show that by optically driving the system at multiple frequencies, multi-phonon transitions can facilitate the engineering of nonclassical steady states of the mechanical oscillator.

Nonlinear Quantum Relaxation and Generation of Non-classical States in Duffing Oscillators.

The dissipative quantum dynamics of an anharmonic oscillator is theoretically investigated in the context of carbon-based nano-oscillator systems. In the short-time limit, it is known that macroscopic superposition states appear for such oscillators [1]. Linear and non-linear dissipation leads to decoherence of such non-classical states in the long-time limit. However, as a result of two-vibron losses at zero temperature, the quantum oscillator eventually evolves into a non-classical stationary state—a qubit-like state. The relaxation of the qubit due to thermal excitations and one-vibron losses is numerically and analytically studied. The possibility of verifying the occurrence of the qubit is discussed and signatures of the non-classically arising in a ring-down setup are presented. Additionally, the generation of entanglement between two coupled oscillators in presence of strong two-vibron losses is discussed.

Parametric feedback squeezing of an opto-electromechanical device below 3dB.

Parametric squeezing can reduce the uncertainty in one quadrature of the position of a mechanical resonator, even below the standard quantum limit, and it can improve measurement sensitivity. Here we demonstrate squeezing of the thermal motion of a 570 kHz opto-electromechanical resonator made out of high-stress SiN by modulating its spring constant at twice the resonance frequency. Parametric and direct actuation are achieved by applying a.c. voltages between strongly coupled electrodes on the resonator and a fixed one. It is well known that using this method the motion of one quadrature cannot be decreased more than 3 dB below the undriven case before instabilities kick in. However, by measuring the phase-space trajectory of the resonator and adjusting the phase of the parametric drive in real-time we achieve a stationary reduction in both quadratures that is far beyond this limit. Finally, due to the strong coupling between the drive electrodes, the nonlinearity of the resonator can be tuned all the way from a stiffening spring to a softening one.


1. The author acknowledges financial support from The Danish Council for Independent Research under the Sapere Aude program.


12:51PM U41.00009 Non-classical correlations of scattered photons in a one-dimensional waveguide with multiple atoms¹. DIBYENDU ROY, Theoretical Division and Center for Nonlinear Studies, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA — We study the scaling of photon-photon correlations mediated by resonant interactions of photons with atoms in a one-dimensional photonic waveguide. Recently a new theoretical approach based on the Bethe-ansatz technique has been developed to study transport in an open quantum impurity. Here we generalize the approach to study multiple atoms. We derive the exact solution of single and two-photon scattering states, and the corresponding photon transmission through the atomic ensemble. We show how various two-photon nonlinear effects, such as spatial attraction and repulsion between photons as well as background fluorescence can be tuned by changing the number of atoms and the coupling between atoms (controlled by the separation). Finally we propose a simple scheme for non-reciprocal transmission in the waveguide by placing different atoms. Our fully quantum-mechanical approach provides a better understanding of cascaded optical nonlinearity at the microscopic level.

¹The support of the U.S. Department of Energy through LANL/LDRD Program for this work is gratefully acknowledged.

1:03PM U41.00010 Recent theoretical advances on superradiant phase transitions. ALEXANDRE BAKSIC, PIERRE NATAF, CRISTIANO CIUTI, Laboratoire MPQ, Université Paris Diderot-Paris 7 and CNRS — The Dicke model describing a single-mode boson field coupled to two-level systems is an important paradigm in quantum optics. In particular, the physics of “superradiant phase transitions” in the ultrastrong coupling regime is the subject of a vigorous research activity in both cavity and circuit QED. Recently, we explored the rich physics of two interesting generalizations of the Dicke model: (i) A model describing the coupling of a boson mode to two independent chains A and B of two-level systems [1], where chain A is coupled to one quadrature of the boson field and chain B to the orthogonal quadrature. This original model leads to a quantum phase transition with a double symmetry breaking and a fourfold ground state degeneracy. (ii) A generalized Dicke model with three-level systems [2,3] including the diamagnetic term. In contrast to the case of two-level atoms for which no-go theorems exist, in the case of three-level system we prove that the Thomas-Reich-Kuhn sum rule does not always prevent a superradiant phase transition.


1:15PM U41.00011 Light-induced phase transition in a quantum spin chain: Breakdown of the Haldane phase by circularly polarized laser. SHINTARO TAKAYOSHI, Department of Applied Physics, University of Tokyo, HIDEO AOKI, Department of Physics, University of Tokyo, TAKASHI OKA, Department of Applied Physics, University of Tokyo — We theoretically propose a new category of non-equilibrium phase transitions in quantum spin systems that can be induced by the magnetic component of strong lasers. As an example, we consider a Haldane chain with single ion anisotropy radiated by circularly polarized light. We study the dynamics by combining the numerical infinite time-evolving block decimation method and an analytical calculation via the Floquet theory, and demonstrate that the laser can magnetize even an antiferromagnet quantum mechanically. It is also shown that the string order is broken by the magnetization, which indicates that a photo-induced breakdown of the Haldane phase has occurred. This phenomenon can be realized using strong THz lasers.

1:27PM U41.00012 Testing Kibble-Zurek mechanism in ion traps. RAMIL NIGMATULLIN, Imperial College London, ADOLFO DEL CAMPO, T4 and Center for Nonlinear Studies, Los Alamos National Laboratory, GABRIELE DE CHIARA, Centre for Theoretical Atomic Physics, Monash University, BANGOR ROBERT, School of Physics, The Queen’s University of Belfast, GIOVANNA MORICI, Theoretical Physics, University of Saarland, MARTIN PILNIO, Institute of Theoretical Physics, Ulm University, ALEX RETZKER, The Racah Institute of Physics, Hebrew University of Jerusalem — A quench through a critical point of a second order phase transition results in the formation of topological defects in the system. Kibble-Zurek (KZ) theory predicts the scaling of a number of defects as a function of quench rate. This scaling depends on the critical exponents of the phase transition, and hence the study of the defect density reveals something about the nature of phase transition itself. There are several proposals to test KZ theory experimentally. In this talk, we discuss the possibility of studying defect formation in ion traps. A linear ion chain confined in a Paul trap undergoes a continuous phase transition to a zigzag chain when the confining potential is lowered. If the chain is in a ring trap then the zigzag chain can be in a helical configuration with a nonzero winding number. Using molecular dynamics simulations we show that the scaling of the average winding number of the resulting helical chain is consistent with KZ theory.

1:39PM U41.00013 Space-Time Crystals of Trapped Ions. TONGCANG LI, University of California, Berkeley, ZHE-XUAN GONG, University of Michigan, Ann Arbor, ZHANG-QI YIN, Tsinghua University, H. T. QUAN, University of Maryland, College Park, XIAOBO YIN, PENG ZHANG, University of California, Berkeley, -M. DUAN, University of Michigan, Ann Arbor, XUAN ZHANG, University of California, Berkeley — Spontaneous symmetry breaking can lead to the formation of time crystals, as well as spatial crystals. Here we propose a space-time crystal of trapped ions and a method to directly observe it by concatenating a spatially modulated trapping potential with a spatially periodic magnetic field. The ions spontaneously form a spatial ring crystal due to Coulomb repulsion. This ion crystal can rotate persistently at the lowest quantum energy state in magnetic fields with fractional fluxes. The persistent rotation of trapped ions produces the temporal order, leading to the formation of a space-time crystal. We show that these spacetime crystals are robust for direct experimental observation. We also study the effects of finite temperatures on the persistent rotation. The proposed space-time crystals of trapped ions provide a new dimension for exploring many-body physics and emerging properties of matter.

1:51PM U41.00014 Electromagnetic induced transparency and slow light in strongly correlated atomic gases. HSIAH-HUA JEN, BO XIONG, ITE A. YU, DAW-WEI WANG, National Tsing Hua University, PHYSICS DEPARTMENT, NATIONAL TSING HUA UNIVERSITY TEAM, PHYSICS DIVISION, NATIONAL CENTER FOR THEORETICAL SCIENCES TEAM. — We develop the quantum theory for the electromagnetic induced transparency (EIT) and slow light property in ultracold Bose and Fermi gases. It shows a very different property from the classical theory which assumes frozen atomic motion. For example, the speed of light inside the atomic gases can be changed dramatically near the Bose-Einstein condensation temperature, while the presence of the Fermi sea can destroy the EIT effect even at zero temperature. This quantum EIT property is mostly manifested in the counter-propagating excitation schemes in either the low-lying Rydberg transition or in D2 transition with a very weak coupling field. Using linear response theory, we further derive an exact and universal form for the EIT spectrum, which applies even in strongly correlated systems of ultracold atoms. We find that the spectrum is closely related to the single particle Green’s function, which is not easily observable in most experimental technique. As an example, we show results of 1D Luttinger liquid, Mott-insulator state, and BCS pairing phase, and compare to the results of standard classical theory. Our theory therefore paves the way to measure strongly correlated physics of ultracold atoms via the state-of-art manipulation of light propagation inside the quantum gases.

2:03PM U41.00015 Orbital Angular Momentum as Manifestation of Photonic Zitterbewegung. BASIL DAVIS, Tulane University — The phenomenon of photonic orbital angular momentum has received considerable attention since its theoretical prediction by Allen et al in 1992. It has been established theoretically and experimentally that laser beams with a Laguerre Gaussian profile possess angular momentum in addition to their intrinsic spin angular momentum. A parallel development has been the renewed interest in photonic zitterbewegung, first predicted for relativistic electrons by Schrodinger. It is now known that zitterbewegung is a property of all particles, regardless of spin, charge or rest mass, since it is basically a quantum mechanical phenomenon. Recently there has arisen an interest in photonic zitterbewegung. This paper shows that photonic orbital angular momentum is one experimentally observable manifestation of photonic zitterbewegung.
2:30PM W10.00001 Magnetic correlations and density ordering in quantum gases, TILMAN ESSLINGER, ETH Zurich — Quantum gases provide a unique avenue to study fundamental concepts in quantum many-body physics. In our research we go beyond the class of atomic many-body systems that are governed by the interplay between kinetic energy and contact interactions. Using a tunable geometry optical lattice, we create hexagonal, dimerized or anisotropic lattice structures [1]. This allows us to control the exchange energy in a repulsive two-component Fermi gas and study the formation of magnetic correlations. In a different approach, we place a Bose-Einstein condensate into a dynamic lattice potential created by the interaction of the atoms with the vacuum field of an optical cavity. This gives rise to long-range interactions, which result in a transition to a supersolid phase with a broken discrete symmetry, preceded by a mode softening [2]. In the talk I will introduce our experiments and discuss recent results.


3:06PM W10.00002 Dissipative quantum glasses in optical cavities, PHILIPP STRACK, Harvard University — Strong light-matter interactions offer the prospects of quantum realizations of soft matter phases. We discuss how glassy phases of matter may appear with atomic ensembles in multi-mode optical cavities. Our computations show that some of these quantum optical glasses have no direct analogue in condensed matter realizations due to the photon-mediated long-range interactions and the nature of the driving and dissipation that occurs in the many-body cavity QED systems.

3:42PM W10.00003 Non-Equilibrium Dynamics of Ultra Cold Atoms and Effective Spin Models in Optical Cavities, JOE BHASEEN, King’s College London — There has been spectacular progress in exploring the properties of ultra cold atoms using light. Recent experiments [1] on Bose–Einstein condensates in optical cavities have reported a novel self-organization transition of the atom-light system. This coincides with the superradiance transition in an effective non-equilibrium Dicke model, describing two-level “spins” coupled to light. The light leaking out of the cavity provides valuable information on this hybrid matter-light system, and the time-dependent nature of the experiments demands considerations of the associated dynamics. We present a rich dynamical phase diagram [2,3], accessible by quench experiments, with distinct regimes of collective dynamics separated by non-equilibrium phase transitions. These findings open new directions to study the emergent dynamics and non-equilibrium phase transitions of quantum many body systems and effective spin models.

In collaboration with J. Keeling (University of St Andrews), J. Mayoh (University of Cambridge) and B. D. Simons (University of Cambridge).


4:18PM W10.00004 Heavy Solitons in a Fermionic Superfluid, MARTIN W. ZWIERLEIN, Massachusetts Institute of Technology — Topological excitations are found throughout nature, in proteins and DNA, as dislocations in crystals, as vortices and solitons in superfluids and superconductors, and generally in the wake of symmetry-breaking phase transitions. In fermionic systems, topological defects may provide bound states for fermions that often play a crucial role for the system’s transport properties. Famous examples are Andreev bound states inside vortex cores, fractionally charged solitons in relativistic quantum field theory, and the spinless charged solitons responsible for the high conductivity of polymers. However, the free motion of topological defects in electronic systems is hindered by pinning at impurities. We have created long-lived solitons in a strongly interacting fermionic superfluid by imprinting a phase step into the superfluid wavefunction, and directly observed their oscillatory motion in the trapped superfluid. As the interactions are tuned from the regime of Bose-Einstein condensation (BEC) of tightly bound molecules towards the Bardeen-Cooper-Schrieffer (BCS) limit of long-range Cooper pairs, the effective mass of the solitons increases dramatically to more than 200 times their bare mass. This signals their filling with Andreev states and strong quantum fluctuations. For the unitary Fermi gas, the mass enhancement is more than fifty times larger than expectations from mean-field Bogoliubov-de Gennes theory. Our work paves the way towards the experimental study and control of Andreev bound states in ultracold atomic gases. In the presence of spin imbalance, the solitons created in our experiment represent one of the long sought-after Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) state of mobile Cooper pairs.


4:54PM W10.00005 Collective Dipole Oscillations of a Spin-Orbit Coupled Bose-Einstein Condensate, SHUAI CHEN, Hefei National Lab for Physical Sciences at Microscale and Department of Modern Physics, University of Science and Technology of China, Hefei, 230026 — We present an experimental study of the collective dipole oscillation of a spin-orbit coupled Bose-Einstein condensate in a harmonic trap. The dynamics of the center-of-mass dipole oscillation is studied in a broad parameter region as a function of spin-orbit coupling parameters as well as the oscillation amplitude. The anharmonic properties beyond the effective-mass approximation are revealed, such as the amplitude-dependent frequency and finite oscillation frequency at a place with a divergent effective mass. These anharmonic behaviors agree quantitatively with variational wave-function calculations. Moreover, we experimentally demonstrate a unique feature of the spin-orbit coupled system predicted by a sum-rule approach, stating that spin polarization susceptibility—a static physical quantity—can be measured via the dynamics of dipole oscillation. The divergence of polarization susceptibility is observed at the quantum phase transition that separates the magnetic nonzero-momentum condensate from the nonmagnetic zero-momentum phase. The good agreement between the experimental and theoretical results provides a benchmark for recently developed theoretical approaches.

2:42PM W40.00002 Two Electromagnetically Induced Transparency Windows and Cross-Phase Modulation with Four-Level Superconducting Artificial Atoms

HESSA ALOTAIBI, BARRY SANDERS, University of Calgary — Superconducting circuit quantum electrodynamics (SCQED) employs microwave transmission lines coupled to artificial atoms, which are typical two-level and recently three-level for electromagnetically induced transparency (EIT). We propose SCQED with a four-level tripod-configuration artificial atom to enable cross-phase modulation between two traveling-wave microwave fields. Our master-equation analysis for three driving fields (“signal,” “probe” and “coupling”) demonstrates the existence of two distinct EIT transparency windows in the spectral-response profile as a function of coupling and weak fields strength. We provide the first theoretical analysis of this unexpected second window and show its advantages over the known first EIT window. Specifically we show that this second EIT window provides both the signal and probe fields with identical response functions provided that their Rabi frequencies and detunings are the same. Exploiting the second window with judiciously chosen external flux and energy detuning result in low absorption, excellent group velocity matching, and high nonlinearity, thereby enabling strong cross-phase modulation for SCQED.

1This work is supported by CIFAR, NSERC, and AITF

2:54PM W40.00003 Nonlocal Interferometry Using Macroscopic Coherent States and Weak Nonlinearities

BRIAN KIRBY, JAMES FRANSON, University of Maryland, Baltimore County — Bell’s inequality has been violated numerous times in microscopic systems with the use of nonlocal interferometry. Described here will be an extension of the Franson interferometer to the macroscopic case of coherent states entangled in phase. The entanglement is generated using weak nonlinearities, and the entanglement is probed using single photons and homodyne detection. Without loss the predicted nonlocal interference visibility of the interferometer is unity, and the inclusion of atomic absorption allows for a large number of photons to be absorbed with only a small reduction in the visibility. This interferometer can be extended in a straightforward manner to a quantum key distribution scheme using the Ekert protocol to secure a key. A method for the extension of the entanglement distance using entanglement swapping is described. This nonlocal interferometer may therefore be of practical use in quantum communications in addition to being of fundamental interest.

3:06PM W40.00004 Efficacy of weak measurement reversal for stochastic amplitude damping

DAVID STARLING, Penn State Hazleton, NATHAN WILLIAMS, Willamette University — A recent experiment demonstrated the restoration of entanglement in a photonic system using weak measurement reversal [S. Kim et al., Nature Physics 8, 117 (2012)]. Here, we analyze the statistical properties of entanglement for pairs and triples of entangled qubits subject to stochastic amplitude damping followed by restoration. After the random disturbance, the state is restored by applying a static weak measurement reversal. We then show that the fidelity of the restored state, and therefore its entanglement, can be restored with high success, despite the statistical fluctuations of the disturbance. In particular, we show that the variance of the entanglement of the restored states is substantially reduced, independent of the strength of the disturbance. We conclude with a proposed experimental implementation.

3:18PM W40.00005 Nonlinear waveguide arrays and disorder

AMIT RAI, DIMITRIS ANGELAKIS, Centre for Quantum Technologies, National University of Singapore — Waveguide arrays with quadratic nonlinearity has been studied recently. We investigated the waveguide arrays with quadratic nonlinearity and explored the possibility of generating broadband continuous-variable entanglement in such structures. We propose an integrated approach toward continuous-variable entanglement based on integrated waveguide quantum circuits, which are compact and relatively more stable. We further continued our work on waveguide arrays by studying a hybrid system which contains a combination of linear and nonlinear waveguides. We assume that all the waveguides except the central one are assumed to be linear. The central waveguide is assumed to have a quantum key distribution scheme using the Ekert protocol to secure a key. A method for the extension of the entanglement distance using entanglement swapping is described. This nonlocal interferometer may therefore be of practical use in quantum communications in addition to being of fundamental interest.

3:30PM W40.00006 Squeezing of Spin Waves in a Three-Dimensional Atomic Ensemble

LEIGH NORRIS, BEN BARAGIOLA, CQIC University of New Mexico, ENRIQUE MONTANO, PASCAL MICHELSON, POUL JESSEN, CQIC University of Arizona, IVAN DEUTSCH, CQIC University of New Mexico — Spin squeezed states (SSS) have generated considerable interest for their potential applications in quantum metrology and quantum information processing. Many protocols for generating SSS in atomic gases rely on the Faraday interaction that creates entanglement between atoms through the coupling of the collective spin of the ensemble to polarization modes of an optical field. Most descriptions of this process rely on an idealized one-dimensional plane wave model of light-matter interactions that is not appropriate for describing a real system consisting of a cigar-shaped cold atomic cloud in dipole trap interacting with a probe laser beam. We provide a first principles three-dimensional model of squeezing via a quantum nondemolition measurement of the collective magnetization for an ensemble of atoms with hyperfine spin f. The model includes spin waves, diffraction, paraxial modes, and optical pumping, derived by a full master equation description. Including dissipative dynamics, we find the optimal ensemble geometry and input Gaussian beam parameters for generating spin squeezing. We also study the effect of enhancing the atom-light interface using internal hyperfine control of atoms with large spin f.

1Supported by NSF

3:42PM W40.00007 Selection of semiconductor quantum dots for multi-qubit encoding using an optical microcavity

ANGELA GAMOURAS, MATHEW BRITTON, Dalhousie University, DAN DALACU, PHILIP POOLE, DANIEL POITRAS, ROBIN L. WILLIAMS, National Research Council of Canada, KIMBERLEY C. HALL, Dalhousie University — Controlling the quantum states of excitons or spin-polarized carriers in semiconductor quantum dots (QDs) has been the focus of a considerable research effort in recent years due to the promise of using this approach to develop a solid state quantum computing architecture. In such experiments, the need to isolate the optical response of a single QD represents a formidable challenge, one that is greatest for QDs with emission wavelengths compatible with existing telecommunications infrastructure due to the lower quantum efficiency of the associated detectors. Encoding qubits in ensembles of QDs would greatly facilitate quantum state readout due to the larger optical signals involved, however the spread of optical transition energies limits the fidelity of the control process. Here we report time-resolved differential transmission experiments on QDs in a dielectric Bragg stack optical microcavity. Our results indicate that the angle dependent transmission resonance of the cavity allows for the separate excitation and detection of distinct subsets of QDs in the ensemble differentiated by their optical transition energies. These findings demonstrate the feasibility of developing a scalable computing architecture based on multi-qubit encoding using semiconductor QDs.
3:54PM W40.00008 Quantum plasmonics of a metal nanoparticle array for on-chip nanophotonic network. CHANGYOLP LEE, CHANGSUK NOH, DIMITRIS ANGELAKIS, Centre for Quantum Technologies, National University of Singapore, Singapore, MARK TAME, QOLS, The Blackett Laboratory, Imperial College London, United Kingdom, JAMES LIM, JINHYOUNG LEE, Department of Physics, Hanyang University, Korea — With the advancement of nanofabrication techniques, metallic nanoparticles have been attracting significant attention due to their novel capabilities offering the prospects of miniaturization, scalability, and strong coherent coupling to single-emitters that conventional photonics cannot achieve. In this work, we investigate an array of metal nanoparticles for on-chip quantum networking, quantum computation and communication on scales far below the diffraction limit. For this purpose, we first consider the transfer of quantum states, including single qubits as plasmonic wave packets, and explore the interference of single plasmons associated with the quantum properties of the plasmon excitation. In addition, we study dipole induced reflection effects in the plasmonic setting. The results seem promising for quantum control applications such as single-photon switching and slow light in the nanoscale. We also propose a scheme of entanglement generation between distant emitters embedded in the array of metal nanoparticles. The techniques introduced in this work may assist in the further theoretical and experimental studies of plasmonic nanostructures for quantum control applications and probing nanoscale optical phenomena.

1Science Department, Technical University of Crete, Crete, Greece

4:06PM W40.00009 Dynamic Hole Trapping Effect in an InAs/AlGaAs quantum dot molecule. WEIWEN LIU, University of Delaware. ALLAN BRACKER, DANIEL GAMMON, Naval Research Laboratory. MATTHEW DOTY, University of Delaware — It is well established that the charge and spin configurations of single electrons or holes are promising candidates for next generation computational and logic devices. Quantum Dots Molecules (QDMs) are attractive components for confining and manipulating single charges because the discrete energy levels, charge interactions and spin properties can be tailored with size and composition. The strong confinement QDMs causes overlap of wavefunctions and results in different Coulomb interactions and unique energy levels for different numbers of charges and even for distinct spatial distributions of the same total charge. Quantitative measurements of the Coulomb interactions are important in order to understand charge and spin interactions and design structures for device applications. We present a new phenomenon discovered during optical spectroscopy of a QDM with an AlGaAs barrier between two QDs. AlGaAs barrier allows an extra hole to be trapped in a metastable state of the higher energy QD due to the higher barrier potential. This dynamic trapped hole? occurs only under certain electric field conditions and perturbs the Coulomb interactions of the other charges present in the QDM. We propose a model of the kinetic pathways that leads to this dynamic hole trapping effect. We compare the energy of states with and without the extra hole in order to understand many body Coulomb interactions that perturb states energies. We then discuss the challenges and opportunities this effect provides for future devices.

4:18PM W40.00010 Ideal Multipole Ion Traps from Planar Ring Electrodes. ROBERT CLARK, The Citadel, Charleston, SC, 29409 — We present designs for multipole ion traps based on a set of planar, annular, concentric electrodes which require only rf potentials to confine ions. We illustrate the desirable properties of the traps by considering a few simple cases of confined ions. We predict that mm-scale surface traps may have trap depths as high as tens of electron volts, or micromotion amplitudes in a 2-D ion crystal as low as tens of nanometers, given realistic experimental parameters. We also discuss applications to quantum information science, frequency metrology, and cold ion-atom collisions.

4:30PM W40.00011 Resolved sideband spectra of calcium ions in a Penning trap. JOE GOODWIN, GRAHAM STUTTER, DANIEL SEGAL, RICHARD THOMPSON, Imperial College London — I report on recent work at Imperial College London, with laser cooled calcium-40 ion Coulomb crystals in Penning traps. Penning traps provide a number of advantages over the more common radiofrequency (RF) trap; namely the ability to trap 3-dimensional, micromotion-free ion Coulomb crystals, and the ability to produce deep traps while maintaining a large ion-electrode surface distance. While these factors should permit lower heating rates than in typical RF traps, very little research has been conducted into the behavior and control of small Coulomb crystals in Penning traps due to the experimental challenges involved. We have spent several years developing techniques to overcome these obstacles, and are now making rapid progress towards the sub-Doppler cooling and coherent control of small ion crystals. We have already observed high resolution optical spectra showing sidebands due to radial and axial motions, giving estimated temperatures close to the Doppler limit.

4:42PM W40.00012 Rapid ion cooling by controlled collision. HOI KWAN LAU, University of Toronto — I propose a method to cool trapped ions by controlled collisions. Motional excitation of a hot ion is transferred to a coolant ion due to Coulomb interaction when they are brought to proximity. The whole process can be conducted diabatically, involving only a few oscillation periods of the harmonic trap. Our proposal is useful for rapid recooling of ion qubits during quantum computation and fast cooling of an ion whose mass is significantly different from the coolant ion.

Thursday, March 21, 2013 2:30PM - 5:30PM –
Session W41 DAMOP: Bose Gauge Fields 350 - Mark Edwards

2:30PM W41.00001 3D quaternionic condensation and spin textures with Hopf invariants from synthetic spin-orbit coupling1. CONGJUN WU, YI LI, Department of Physics, University of California, San Diego, XIANGFA ZHOU, Key Laboratory of Quantum Information, University of Science and Technology of China, CAS, Hefei, Anhui 230026, China — We study unconventional condensations of two-component bosons in a harmonic trap subject to the 3D \(\tau\)-\(j\)-type spin-orbit (SO) coupling. The topology of condensate wavefunctions manifests in the quaternionic representation. The spatial distributions of the \(S^2\) quaternionic phase exhibit 3D skyrmion configurations, while those of the \(S^2\) spin orientation possess non-zero Hopf invariants. As increasing SO coupling strength, spin textures evolve from concentric distributions to lattice structures at weak interactions. Strong interactions change condensates into spin-polarized plane-wave states, or, superpositions of two plane-waves exhibiting helical spin spirals.

1This project is supported by AFOSR FA9550-11-1-0067(YIP) and NSF-DMR-1105945.

2:42PM W41.00002 Rashba Spin-Orbit Coupled Bose-Einstein Condensates with Magnetic Dipole-Dipole Interactions. RYAN WILSON, BRANDON ANDERSON, CHARLES CLARK, Joint Quantum Institute, National Institute of Standards and Technology and University of Maryland, Gaithersburg, MD 20899, USA — In this talk we consider the effect of Rashba spin-orbit coupling on a quasi-two dimensional Bose-Einstein Condensate with dipolar interactions. The interplay of the spin-orbit coupling, which favors textured and vortex-antivortex lattice ground states, and the dipole-dipole interaction, which introduces non-local spin-exchange processes and a strongly geometry-dependent interaction character, leads to a variety of novel ground states including combinations of spin and purely motional vortices. With the assistance of a numerical Bogoliubov-de Gennes analysis, we map the relevant phase boundaries, thereby characterizing the rich ground-state phase diagram of this system.
2:54PM W41.00003 Exotic Quantum States of Rashba Bosons
Tigran Sedrakyan, Alex Kamenet.
Fine Theoretical Physics Institute, University of Minnesota; Leonid Glazman, Department of Physics, Yale University. — The recently discovered spin-orbit coupled boson systems are remarkable for their capacity to explore physics that may not be revealed in any other way. The spin-orbit couplings, which can be artificially engineered in cold-atom experiments, in many instances lead to single-particle dispersion relations exhibiting multiple minima or even degenerate manifold of minimal energy states. It is entirely the effect of collisions (i.e. boson-boson interactions) which lifts this degeneracy and leads to an amazing variety of completely new quantum many-body states. This talk describes a theoretical discovery of a novel phase of matter governed by Rashba spin-orbit coupled bosons, where, at low densities, bosons essentially redress themselves and behave as fermions. This state is a composite fermion state with a Chern-Simons gauge field and filling factor one.

3:06PM W41.00004 Exotic Quantum Spin Models in Spin-Orbit-Coupled Mott Insulators
Juraj Radic, University of Maryland, College Park; Andrea Di CioLo, University of Maryland, College Park and Georgetown University; Kai Sun, University of Maryland, College Park and University of Michigan, Ann Arbor; Victor Galitski, University of Maryland, College Park. — We study cold atoms in an optical lattice with synthetic spin-orbit coupling in the Mott-insulator regime. We calculate the parameters of the corresponding tight-binding model using Peierls substitution and “localized Wannier states method” and derive the low-energy spin Hamiltonian for bosons and fermions. The spin Hamiltonian is a combination of Heisenberg model, quantum compass model and Dzyaloshinskii-Moriya interactions and it has a rich classical phase diagram with collinear, spiral and vortex phases. We discuss the state of the art of experiments to realize and detect magnetic orderings in strongly correlated optical lattices.

3:18PM W41.00005 The Fate of Bose-Einstein Condensate in the Presence of Spin-orbit Coupling
Qi Zhou, Department of Physics, The Chinese University of Hong Kong; Xiaoleng Cui, Institute for Advanced Study, Tsinghua University, Beijing. — We show that spin-orbit coupling can destroy a Bose-Einstein condensate. For non-interacting bosons, some types of spin-orbit coupling destroy a condensate at any finite temperature or even at the ground state, due to the drastic change of single-particle Density of States at low energies. Whereas interaction stabilizes the condensate at zero temperature, condensate depletion is significantly enhanced by spin-orbit coupling. Particularly, thermal depletion becomes divergent when both interaction and spin-orbit coupling become isotropic, leading to the disappearance of a three-dimensional condensate at any finite temperature.

3:30PM W41.00006 Emergence of Topological and Strongly Correlated Ground States in Rashba Spin-Orbit Coupled Bose Gases
B. Ramachandhran, Rice University, Houston, TX 77005, USA; Hui Hu, Swinburne University of Technology, Melbourne 3122, Australia; Han Pu, Rice University, Houston, TX 77005, USA. — We theoretically study an interacting few-body system of two-component Bose gases with isotropic Rashba spin-orbit coupling in a 2D isotropic harmonic trap. We show that the Hamiltonian is gauge-equivalent to particles subject to a pure non-abelian vector potential preserving time-reversal symmetry. We use Exact Diagonalization scheme to obtain the low-energy states of the system with large Rashba spin-orbit coupling strength for a range of interatomic interaction strengths. At small particle numbers, we observe that the bosons condense to an array of topological ground states that have $n + 1/2$ quantum angular momentum vortex configuration, with $n = 0, 1, 2, 5$. At relatively large particle numbers, we observe two distinct regimes: (a) at weak interaction strengths (mean-field regime), we observe ground states with topological and symmetry properties that are also obtained via mean-field theory computations. (b) at intermediate to strong interaction strengths (beyond mean-field regime), we report the emergence of strongly correlated ground states. We analyze ground state properties using various techniques: energy spectrum, density distribution, pair-correlation function, conditional wavefunction, entanglement spectrum, and entanglement entropy.

3:42PM W41.00007 Many-body ground states for bosons with Rashba spin-orbit coupling
William Cole, Department of Physics, the Ohio State University; Shizhong Zhang, Department of Physics and Center of Theoretical and Computational Physics, the University of Hong Kong; Zhenhua Yu, Institute for Advanced Study, Tsinghua University; Nandini Trivedi, Department of Physics, the Ohio State University. — The ground state of $N$ non-interacting bosons with a Rashba dispersion is macroscopically degenerate. It is of fundamental interest—and also relevant to current experiments in cold atomic gases with synthetic spin-orbit coupling—to determine whether a unique ground state is stabilized by interactions and what the properties of such a state might be. Motivated by exact solutions for the two-body problem, we construct many-body bosonic wave functions that saturate the kinetic energy and minimize the interaction energy, and compare with other recently proposed trial ground states.

3:54PM W41.00008 Flat-band engineering of interactions in spin-orbit coupled optical lattices
Fei Lin, Vito Scarola, Virginia Tech. — The recent experimental realization of spin-orbit coupled ultra cold atomic gases established a new platform to investigate many-body states of matter. In this talk we show that for such a system in optical lattices we can tune the spin-orbit coupling to achieve a flat energy band. We then model this system with a tight-binding Hamiltonian and further project the Hamiltonian to the Hilbert subspace of the lowest flat band. We will also discuss the important effect of interactions in such a projected flat-band system.

4:06PM W41.00009 Bosons on the Kagome lattice with artificial gauge fields
Alexandru Petrescu, Yale University and Center For Theoretical Physics (CPHT), Ecole Polytechnique, S.M. Girvin, Yale University, Karyn Le Hur, Center For Theoretical Physics (CPHT), Ecole Polytechnique and CNRS, 91128 Palaiseau France. — We investigate bosons on the Kagome lattice subject to artificial gauge fields such that no net flux is applied on a unit cell. This allows for example the existence of quantized and non-quantized anomalous Hall effects on the Kagome lattice [1]. If two layers or two-component bosons are introduced, the topological phase is robust to inter-species interactions of moderate strength. We study the conditions under which the total density degree of freedom undergoes a Mott transition, while the pseudo-spin, or charge difference between layers, is in a superfluid phase with topological properties. Similar results can be obtained for two-component bosons on the honeycomb lattice. Such systems could work as a template for the realization of interacting topological phases in cold atom or cavity QED systems.

4:18PM W41.00010 A spin Hall effect in a quantum gas
Matthew Beeler, Ross Williams, Karina Jimenez-Garcia, Lindsay LeBlanc, Abigail Perry, Ian Spielman, Joint Quantum Institute, National Institute of Standards and Technology and University of Maryland. — The spin Hall effect is a phenomenon that couples spin current to particle current via spin-orbit coupling. The effect may be used to develop useful devices for spintronics, which may have advantages over corresponding conventional electronic devices. In addition, the spin-Hall effect is intimately related to certain types of topological insulators. Spin-orbit coupling in an ultracold bosonic sample of $^{87}$Rb has been demonstrated. We now use this spin-orbit coupling to produce a spin Hall effect in a bosonic sample, the first demonstration of the effect in an ultracold atom system.

probed using the spin structure factor. Different types of superfluids may also possess different excitation spectra.

between different superfluids are found to be the first-order. We investigate the rich periodic structure of the phases of the superfluids, which may be directly

the interplay between spin independent and spin-dependent tunnelings may give rise to a few different types of phase-modulated superfluids. The transitions

YINYIN QIAN, MING GONG, The University of Texas at Dallas, VITO SCAROLA, Virginia Tech, CHUANWEI ZHANG, The University of Texas at Dallas

grant DMR-1151717

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Bogoliubov sound velocity in the mixed phase, and propose that it can be used as a probe of the spatially-varying density (i.e. stripe order) of the mixed phase

two interpenetrating dressed-state condensates), and phase separation (between regions of single dressed-state condensate). We present our results on the

as a function of the interaction parameters, strength of SOC, and the densities of the two species of bosons, possesses regimes of mixed superfluid (featuring

Einstein Condensates

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in developing novel devices in the thriving field of atomtronics.

under the same setup. We also find that an approximate form of the QSSC survives when perturbative effects from interactions, weak harmonic background

entanglement entropy does not increase when the QSSC lasts. Due to different spin statistics, condensed non-interacting bosons do not support a finite QSSC

non-interacting fermions. The direction and magnitude of the current can be controlled by the overall phase difference but not the details of the ramp. The

the phase of the complex tunneling coefficient in a spatially uniform fashion, a finite quasi steady-state current (QSSC) ensues from the exact dynamics of

as a lattice with a complex tunneling coefficient – may be used to induce quantum transport of ultra-cold atoms. In particular, we show that by ramping up

the topological properties of a band. We will discuss how Berry curvature effects may be observed in ultracold gases and give examples in systems relevant to

dynamics of a wave packet undergoing Bloch oscillations. We will explain how experimentalists may turn such physical consequences into new tools to determine

properties of such a band are encoded not only in its energy spectrum over the Brillouin zone (the "bandstructure" in the usual sense) but also importantly,
in its Berry curvature. When the Berry curvature is nonzero, it can have many important physical consequences; for example it can modify the semiclassical
dynamics of a wave packet undergoing Bloch oscillations. We will explain how experimentalists may turn such physical consequences into new tools to determine

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5:06PM W41.00014 Phase Transitions and Collective Modes in Spin-Orbit Coupled Bose-Einstein Condensates1, QIN-QIN LU, DANIEL E. SHEEHY, Louisiana State University — Recent experiments on trapped bosonic atomic gases interacting with Raman lasers have realized an artificial spin-orbit coupling (SOC) among two dressed spin states of bosons. The phase diagram of this system, as a function of the interaction parameters, strength of SOC, and the densities of the two species of bosons, possesses regimes of mixed superfluid (featuring two interpenetrating dressed-state condensates), and phase separation (between regions of single dressed-state condensate). We present our results on the Bogoliubov sound velocity in the mixed phase, and propose that it can be used as a probe of the spatially-varying density (i.e. stripe order) of the mixed phase as well as of the phase transition to the phase separation regime. The effects of the trapping potential are also discussed.

1This work was supported by the Louisiana Board of Regents, under grant LEQSF (2008-11)-RD-A-10 and by the National Science Foundation, under grant DMR-1151717

5:18PM W41.00015 Phase-modulated superfluids of bosons in spin-orbit coupled optical lattice , YINYIN QIAN, MING GONG, The University of Texas at Dallas, VITO SCAROLA, Virginia Tech, CHUANWEI ZHANG, The University of Texas at Dallas — We study the phase diagram of spin-orbit coupled ultra-cold bosons in a square lattice using the Gutzwiller method. In the superfluid regime, we show that the interplay between spin independent and spin-dependent tunnelings may give rise to a few different types of phase-modulated superfluids. The transitions between different superfluids are found to be the first-order. We investigate the rich periodic structure of the phases of the superfluids, which may be directly probed using the spin structure factor. Different types of superfluids may also possess different excitation spectra.