8:00AM A2.00001 Out-of-equilibrium phenomena and Transport in Cold Atoms

THIERRY GIAMARCHI, DQMMP, University of Geneva — Transport of particle or charge current between two reservoirs is one of the most studied phenomenon in the context of condensed matter. Despite its apparent simplicity this phenomenon is in fact a case of an out of equilibrium situation requiring in principle new theoretical tools and concepts for its solution. One way to sweep the difficulty under the rug has been usually to tackle this problem in the linear response, where one can come back to the comfortable case of equilibrium. There are however many cases when the linear response is not enough and when a full solution of the non-equilibrium problem is needed. This is in particular the case for quantum point contacts or junctions where the full current-voltage characteristics gives direct information on the physics of the problem. In the recent years, in complement to condensed matter experimental realizations, due to the full control on the parameters of the problem and the fact that they realize isolated quantum systems cold atoms have proven a fantastic laboratory to produce out of equilibrium situations. This ranges from the case of quenches, to more recently via experiments of the ETHZ group to the case of real transport between reservoirs. This experimental activity has in turn thus stimulated strongly theoretical developments in this field. I will discuss in this talk some of the recent advances and realizations both at the experimental and of course the theoretical level. I will in particular focus on a recent study [1] which was able to realize a tunable, ballistic quantum point contact between two fermi reservoirs with a tunable interaction allowing to reach unitarity and to provide a theoretical description of the out-of-equilibrium corresponding problem. In such a system the current has been shown to originate from multiple Andreev reflections which leads to a very non-linear current-chemical potential characteristics. The geometry of the contact can be changed showing a competition between superfluidity and thermally activated transport which leads to a conductance minimum and poses several theoretical questions for its theoretical description. [1] “Connecting strongly correlated superfluids by a quantum point contact”, D. Husmann, S. Uchino, S. Krinner, M. Lebrat, T. Giamarchi, T. Esslinger and J.-F. Brantut, arXiv:1508.00578 (2015).

1Work supported in part by Swiss NSF under division II and the ARO-MURI Non-equilibrium Many-body Dynamics grant (W911NF-14-1-0003)

8:36AM A2.00002 'Consistent bosonization-debosonization': A resolution of the non-equilibrium transport puzzle blazes a new path forward

NAYANA SHAH, University of Cincinnati — In this talk, we will critically reexamine the bosonization-debosonization procedure for systems including certain types of localized features (although more general scenarios are possible). By focusing on the case of a tunneling junction out of equilibrium, I will show that the conventional approach gives results that are not consistent with the exact solution of the problem even at the qualitative level and highlight the inconsistencies that can adversely affect the results of all types of calculations. I will subsequently report on a 'Consistent bosonization-debosonization' procedure that we have developed to resolve the aforementioned non-equilibrium transport puzzle and argue that this framework should be widely applicable [1]. I will touch upon its application for the two-lead Kondo problem [2] that besides being a key theoretical prototype of a strongly correlated system is also of immediate experimental relevance in many ways (see also related talk by Bolech). [1] Nayana Shah, C. J. Bolech, arXiv:1508.03078, [2] C. J. Bolech, Nayana Shah, arXiv:1508.03079

9:12AM A2.00003 Non-equilibrium Aspects of Quantum Integrable Systems

NATAN ANDREI, Rutgers University — The study of non-equilibrium dynamics of interacting many body systems is currently one of the main challenges of modern condensed matter physics, driven by the spectacular progress in the ability to create experimental systems - trapped cold atomic gases are a prime example - that can be isolated from their environment and be highly controlled. Many old and new questions can be addressed: thermalization of isolated systems, nonequilibrium steady states, the interplay between non equilibrium currents and strong correlations, quantum phase transitions in time, universality among others. In this talk I will describe nonequilibrium quench dynamics in integrable quantum systems. I’ll discuss the time evolution of the Lieb-Liniger system, a gas of interacting bosons moving on the continuous infinite line and interacting via a short range potential. Considering a finite number of bosons on the line we find that for any value of repulsive coupling the system asymptotes towards a strongly repulsive gas for any initial state, while for an attractive coupling, the system forms a maximal bound state that dominates at longer times. In the thermodynamic limit -with the number of bosons and the system size sent to infinity at a constant density and the long time limit taken subsequently- I’ll show that the density and density-density correlation functions for strong but finite positive coupling are described by GGE for translationally invariant initial states with short range correlations. As examples I’ll discuss quenches from a Mott insulator initial state or a Newton’s Cradle. Then I will show that if the initial state is strongly non translational invariant, e.g. a domain wall configuration, the system does not equilibrate but evolves into a nonequilibrium steady state (NESS). A related NESS arises when the quench consists of coupling a quantum dot to two leads held at different chemical potential, leading in the long time limit to a steady state current. Time permitting I will also discuss the quench dynamics of the XXZ Heisenberg chain.

1Research supported by NSF Grant DMR 1410583

9:48AM A2.00004 Universal behavior after a quantum quench in interacting field theories

ADITI MITRA, New York University — The dynamics of an isolated quantum system represented by a field theory with O(N) symmetry, and in d=2 spatial dimensions, is investigated after a quantum quench from a disordered initial state to the critical point. A perturbative renormalization-group approach involving an expansion around d=4 is employed to study the time-evolution, and is supplemented by an exact solution of the Hartree-Fock equations in the large-N limit. The results show that the dynamics is characterized by a prethermal regime controlled by elastic dephasing where excitations propagate ballistically, and a light cone emerges in correlation functions in real space. The memory of the initial state, together with the absence of time-scales at the critical point, gives rise to universal power-law aging which is characterized by a new non-equilibrium short-time exponent. The dynamics of the entanglement following a quench is also explored, and reveals that while the time evolution of the entanglement entropy itself is not much different between a free bosonic theory and an interacting bosonic theory, the low-energy entanglement spectrum on the other hand shows clear signature of the non-equilibrium short-time exponent related to aging. This work was done in collaboration with Y. Lemosk (NYU), M. Tavora (NYU), A. Chiochetta (SISSA), A. Maraga (SISSA), and A. Gambassi (SISSA).

1Supported by NSF-DMR 1303177
interacting 1D systems [1] and in determining the asymptotic state after a quantum quench [5]. The talk concludes with a perspective on open questions concerning 2D systems and the numerical simulation of their nonequilibrium dynamics [6].


3 Supported by Deutsche Forschungsgemeinschaft (DFG) via FOR 801.

Monday, March 14, 2016 11:15AM - 2:15PM –
Session B50 DAMOP: Driven and Dissipative Atomic Systems Hilton Baltimore Holiday Ballroom 1 - Ryan Wilson, Joint Quantum Institute, University of Maryland

11:15AM B50.00001 Self-organization of atoms coupled to a chiral reservoir, ZACHARY ELDRIDGE, Univ of Maryland-College Park, DARRICK CHANG, ICFQ, Barcelona, ALEXEY GORSHKOV, Univ of Maryland-College Park — Recently, there has been increasing interest in the properties of confined light in the vicinity of tapered optical nanofibers. Interesting avenues have been suggested concerning cold atoms trapped on the fiber by evanescent light fields. It has been shown that the interaction between atoms coupled to this one-dimensional reservoir leads to equations of motion possessing self-organized stable solutions which exhibit striking many-body dynamics. Finally, it has also been observed that spin-orbit coupling due to the extreme confinement of the light leads to a directionality in the coupling to the fiber. In this paper we explore the implications of a chiral interaction on self-organization and show that the overall configuration exhibits similar behavior to the symmetric case but undergoes dramatic changes in some regions of parameter space. We also present proposals for experimental realizations of our model as well as signatures of chiral behavior.

11:27AM B50.00002 Novel Infrared Dynamics of Cold Atoms on Hot Graphene, SANGHITA SENGUPTA, VALERI KOTOV, DENNIS CLOUGHERTY, Univ of Vermont — The low-energy dynamics of cold atoms interacting with macroscopic graphene membranes exhibits severe infrared divergences when treated perturbatively. These infrared problems are even more pronounced at finite temperature due to the (infinitely) many flexural phonons excited in graphene. We have devised a technique to take account (resummation) of such processes in the spirit of the well-known exact solution of the independent boson model. Remarkably, there is also similarity to the infrared problems and their treatment (via the Bloch-Nordsieck scheme) in finite temperature “hot” quantum electrodynamics and chromodynamics due to the long-range, unscreened nature of gauge interactions. The method takes into account correctly the strong damping provided by the many emitted phonons at finite temperature. In our case, the inverse membrane size plays the role of an effective low-energy scale, and, unlike the above mentioned field theories, there remains an unusual, highly nontrivial dependence on that scale due to the 2D nature of the problem. We present detailed results for the sticking (atomic damping rate) rate of cold atomic hydrogen as a function of the membrane temperature and size. We find that the rate is very strongly dependent on both quantities.

11:39AM B50.00003 Periodically driven system coupled to a fermionic bath: A Keldysh approach, DONG E. LIU, Microsoft Research Station Q, ALEX LEVCHENKO, Department of Physics, University of Wisconsin-Madison, ROMAN M. LUTCHYN, Microsoft Research Station Q — We develop a Keldysh approach to study a time-periodically driven system with dissipation. We apply this approach to a periodically driven metallic system coupled to a normal metal and a superconducting bath. After integrating out the fermionic bath degrees of freedom and incorporating its effects exactly through self-energy, we find analytical solution for the steady state using the generalized P representation and expressing the master equation in the form of Fokker-Plank equation. A comparison shows a good match of the analytical and numerical solutions across different regimes. We investigate the quantum correlations in the steady state by solving the full master equation numerically, analyzing its second-order coherence, entanglement entropy and Liouvillian gap as a function of drive and detuning. This gives us insights into the nature of bistability and how the tunneling-induced bistability emerges in coupled cavities when going beyond a single cavity. We can understand much of the semiclassical physics in terms of the underlying phase space dynamics of a driven and damped classical pendulum. Furthermore, in the semiclassical analysis, we find steady state solutions with different number density in the two wells that can be considered an analog of double well self-trapped states.

12:03PM B50.00005 Non-equilibrium Steady-State Behavior in a Scale-Free Quantum Network, JIANSHI ZHAO, CRAIG PRICE, QI LIU, NATHAN GEMELKE, The Pennsylvania State University — We describe the nonequilibrium dynamics of a cold atomic gas held in a spatially random optical potential and gravity, subject to a controlled amount of dissipation in the form of an extremely slow dark-state laser cooling process. Reaching local kinetic temperature below the 100nK scale, such systems provide a novel context for observing the non-equilibrium steady-state (NESS) behavior of a disordered quantum system. For sufficiently deep potentials and strong dissipation, this system can be modeled by a self-organized version of directed percolation, and exhibits power-law decay of phase-space density with time due to the presence of absorbing clusters with a wide distribution of entropy and coupling rates. In the absence of dissipation, such a model cannot apply, and we observe the crossover to exponential loss of phase-space density. We provide measurements of the power-law decay constant by observing the non-equilibrium motion of atoms over a ten-minute period, consistent with $\gamma = 0.51 \pm 0.04$, and extract scaling of the absorbed number with dissipation rate, showing another power-law behavior, with exponent $0.5 \pm 0.2$ over two decades of optical excitation probability.
12:15PM B50.00006 Steady States in Fermionic Interacting Dissipative Floquet Systems. KARTHIK SEETHARAM, CHARLES BARDYN, Caltech, NETANEL LINDNER, Technion, MARK RUDNER, University of Copenhagen, GIL REFAEL, Caltech — The possibility to drive quantum systems periodically in time offers unique ways to deeply modify their fundamental properties, as exemplified by Floquet topological insulators. It also opens the door to a variety of non-equilibrium effects. Resonant driving fields, in particular, lead to excitations which can expose the system to heating. We previously demonstrated that the analog of thermal states can be achieved and controlled in a fermionic Floquet system in the presence of phonon scattering, spontaneous emission, and an energy filtered fermionic bath. However, interactions play an important role in thermalization and present additional sources of heating. We analyze the effects of weak interactions in the presence of dissipation and the role of coherences in determining the steady state of the driven system. Interactions generically create additional excitations and, in contrast to phonons, may sustain inter-Floquet-band coherences at steady state.

12:27PM B50.00007 How should we understand non-equilibrium many-body steady states?. MOHAMMAD MAGHREBI, ALEXEY GORSHKOV, University of Maryland — Many-body systems with both coherent dynamics and dissipation constitute a rich class of models which are nevertheless much less explored than their dissipationless counterparts. The advent of numerous experimental platforms that simulate such dynamics poses an immediate challenge to systematically understand and classify these models. In particular, nontrivial many-body states emerge as steady states under non-equilibrium dynamics. In this talk, I use a field-theoretic approach based on the Keldysh formalism to study nonequilibrium phases and phase transitions in such models. I show that an effective temperature generically emerges as a result of dissipation, and the universal behavior including the dynamics near the steady state is described by a thermodynamic universality class. In the end, I will also discuss possibilities that go beyond the paradigm of an effective thermodynamic behavior.

12:39PM B50.00008 Dissipation induced topological insulators: A recipe. MOSHE GOLSTEIN, Tel Aviv University, Israel — It has recently been realized that driven-dissipative dynamics, which usually tends to destroy subtle quantum interference and correlation effects, could actually be used as a resource. By proper engineering of the reservoirs and their couplings, one may drive a system towards a desired quantum-correlated steady state, even in the absence of internal Hamiltonian dynamics. An intriguing class of quantum phases is characterized by topology, including the quantum Hall effect and topological insulators and superconductors. Which of these noninteracting topological phases can be achieved as the result of purely dissipative Lindblad-type dynamics? Recent studies have only provided partial answers to this question. In this talk I will present a general recipe for the creation, classification, and detection of states of the integer quantum Hall and 2D topological insulator type as the outcomes of coupling a system to reservoirs, and show how the recipe can be realized with ultracold atoms and other quantum simulators. The mixed states so created can be made arbitrarily close to pure states, and the construction may be generalized to other topological phases.

12:51PM B50.00009 Engineering non-Hermitian optical potentials for Polariton Condensation. SAEED KHAN, Department of Electrical Engineering, Princeton University, LI GE, Department of Engineering Science and Physics, College of Staten Island, CUNY, HAKAN TURECI, Department of Electrical Engineering, Princeton University — We present a theoretical study of incoherently pumped exciton-polariton condensates in general cavity geometries, based on an analysis of the linear non-Hermitian modes of the (optical) pump induced potential. An analytical description is obtained for how the threshold pump power for condensation into a specific mode depends quantitatively on the relative spatial profiles of that mode and the pump. Specifically, we show that for a general pump profile, modes which best organize to balance the amplification from the pump against the repulsive pump potential achieve the lowest threshold power [1]. Reversing this idea, choosing the spatial profile of the pump provides control over which spatial mode condenses at lowest power. Our work hence provides a scheme to engineer non-Hermitian optical potentials for preferential polariton condensation into a specific mode, by an appropriate choice of pump profile. This approach has recently been used to achieve condensation in the flat band of a Lieb chain of micropillar cavities, where the flat band has energy above the ground state and hence cannot be studied in systems in thermal equilibrium [2].


1:03PM B50.00010 Collective phases of strongly interacting cavity photons. RYAN WILSON, United States Naval Academy, Annapolis, MD 21402, MICHAEL FOSS-FEIG, KHAN MAHMUD, MOHAMMAD HAFEZI, Joint Quantum Institute & Joint Center for Quantum Information and Computer Science, University of Maryland, College Park, MD 20742 — We study the steady state phases of the Bose-Hubbard model in the presence of dissipation and coherent driving, which in the limit of strong interactions maps onto a driven-dissipative XX spin-\(\frac{1}{2}\) model with transverse and longitudinal fields. Using a site-decoupled mean-field approximation, we identify phases with antiferromagnetic and spin density wave order, in addition to limit cycle phases, where oscillatory dynamics persist indefinitely. We also identify collective bistable phases, where the system supports two steady states among spatially uniform, antiferromagnetic, and limit cycle phases. We compare these mean-field results to exact quantum trajectories for one dimensional cavity arrays. The quantum results exhibit short-range antiferromagnetic and spin density wave order, in good qualitative agreement with the mean-field predictions. In the bistable regime, this system exhibits real-time collective switching between macroscopically distinguishable states. We present a clear physical picture for these dynamics, and establish a simple relationship between the switching times and properties of the quantum Liouvillian.

1:15PM B50.00011 Driven-dissipative bosons in open boundary and inhomogeneous cavity arrays. KHAN W. MAHMUD, University of Maryland, RYAN M. WILSON, United States Naval Academy, MICHAEL FOSS-FEIG, MOHAMMAD HAFEZI, University of Maryland — We study the driven-dissipative Bose-Hubbard model, which describes the physics of coherently pumped photonic cavity arrays as well as strongly interacting ultracold bosons in an optical lattice in a driven dissipative setting. We investigate many-body states and their quantum correlations on finite size lattices with open boundary conditions, a set up which is experimentally relevant. We show that the effects of hard boundaries on the steady-states are nontrivial, and explain the results in terms of finite system size excitations and the underlying phases of a thermodynamically large system. Furthermore, we explore the effects of trap inhomogeneity, such as an external harmonic trap, quantifying the breakdown of local density approximation for finite system size. We use a mixed state version of matrix product states algorithm for the numerical investigation.

1:27PM B50.00012 Flying over decades. JUDITH HOELLER, MENA ISSLER1, Graduate Student, ATAC IMAMOGLU, Professor — Levy flights haven been extensively used in the past three decades to describe non-Brownian motion of particles. In this presentation I give an overview on how Levy flights have been used across several disciplines, ranging from biology to finance to physics. In our publication we describe how a single electron spin ‘flies’ when captured in quantum dot using the central spin model. At last I motivate the use of Levy flights for the description of anomalous diffusion in modern experiments, concretely to describe the lifetimes of quasi-particles in Josephson junctions.

1Finished PhD at ETH in Spring 2015
1:39PM B50.00013 Multiple timescale analysis of dynamical evolution near two coalescing eigenvalues in open quantum systems. SAUVENN GARMON, Osaka Prefecture University, GONZALO ORDONEZ, Butler University — Recently the physics of coalescing eigenvalues at an exceptional point (EP) has been studied in a wide range of physical contexts, including open quantum systems. At an EP, at which eigenvalues coalesce the Hamiltonian can no longer be diagonalized but instead only reduced to a Jordan block of dimension N. In order to describe the survival probability P(τ) for an initially prepared state in the vicinity of two coalescing levels, we further subdivide the EP2 case into the EP2A and EP2B [1], where the EP2A involves the coalescence of two virtual bound states to form a resonance/anti-resonance pair and the EP2B occurs when two resonances collide to form two new resonances. We show that in the vicinity of the EP2B the usual exponential decay appearing for resonances on intermediate timescales is modified as P(τ) ∼ t^{-N/2}. However, the long-time evolution near the EP2B follows a 1/τ^2 power law decay. Meanwhile the evolution for the EP2A is non-exponential on all timescales, and may be strongly influenced by continuum threshold effects [2]. [1] S. Garmon, M. Gianfreda, and N. Hatano, Phys. Rev. A 92, 022125 (2015). [2] S. Garmon, T. Petrosky, L. Simine and D. Segal, Fortschr. Phys. 61, 261 (2013). [3] N. Hatano and G. Ordonez, J. Math. Phys. 55, 122106 (2014).

1:51PM B50.00014 Quantum Spontaneous Stochasticity. THEODORE DRIVAS, GREGORY EYINK, The Johns Hopkins University — Classical Newtonian dynamics is expected to be deterministic, but recent fluid turbulence theory predicts that a particle advected at high Reynolds-numbers by “nearly rough” flows moves nondeterministically. Small stochastic perturbations to the flow velocity or to the initial data lead to persistent randomness, even in the limit where the perturbations vanish! Such “spontaneous stochasticity has profound consequences for astrophysics, geophysics, and our daily lives. We show that a similar effect occurs with a quantum particle in a “nearly rough” force, for the semi-classical (large-mass) limit, where spreading of the wave-packet is usually expected to be negligible and dynamics to be deterministic Newtonian. Instead, there are non-zero probabilities to observe multiple, non-unique solutions of the classical equations. Although the quantum wave-function remains split, rapid phase oscillations prevent any coherent superposition of the branches. Classical spontaneous stochasticity has not yet been seen in controlled laboratory experiments of fluid turbulence, but the corresponding quantum effects may be observable by current techniques. We suggest possible experiments with neutral atomic-molecular systems in repulsive electric dipole potentials.

2:03PM B50.00015 Current-carrying quasi-steady states in a periodically driven many-body system. MARK RUDNER, Niels Bohr Institute, Copenhagen University, NETANEL LINNDNER, Technion, EREZ BERG, Weizmann Institute — We investigate many-body dynamics in a one-dimensional interacting periodically driven system, based on a partially-filled version of Thouless topologically quantized adiabatic pump. The corresponding single particle Floquet bands are chiral, with the Floquet spectrum realizing nontrivial cycles around the quasienergy Brillouin zone. For non-integrable filling the system is gapless; here the driving cannot be adiabatic and the system is expected to rapidly absorb energy from the driving field. We identify parameter regimes where scattering between Floquet bands of opposite chirality is exponentially suppressed, opening a long time window where the many-body evolution separates the occupations of the two chiral bands. Within this intermediate time regime we predict that the system reaches a quasi-steady state with uniform crystal momentum occupation within each Floquet band. This state furthermore carries a non-vanishing current given directly by the difference of densities in the right and left moving chiral bands. This remarkable behavior, which holds for both bosons and fermions, may be readily studied experimentally in recently developed cold atom systems.


11:15AM B52.00001 Exploring the Macroscopic Quantum Physics of Motion with Superfluid He-4. LAURA DE LORENZO, AARON PEARLMAN, KEITH SCHWAB, Caltech — We demonstrate the use of superfluid helium-4 as an extremely low loss optomechanical element. We form an optomechanical system with a cylindrical niobium superconducting TE_{011} resonator whose 40 cm
inner cylindrical cavity is filled with 4He. Coupling is realized via the variations in permittivity resulting from the density profile of the acoustic modes. Acoustic losses in helium-4 below 500 mK are governed by the intrinsic nonlinearity of sound, leading to an attenuation which drops as T

11:27AM B52.00002 Mechanical Resonance and Damping Properties of Gallium Nitride Nanowires in Selected-Area Growth Arrays Measured via Optical Bragg Scattering. JOHN HOULTON, Univ of Colorado - Boulder, M. D. BRUBAKER, K. A. BERTNESS, NIST Boulder, C. T. ROGERS, Univ of Colorado - Boulder — We report the use of optical Bragg scattering to measure the mechanical resonance frequencies and quality factors (Q) of gallium nitride (GaN) nanowires (NWs) in selected-area growth arrays. The GaN NWs are grown by catalyst-free molecular beam epitaxy on silicon (111) wafers. Hexagonal arrays of approximately 100 GaN NWs with pitch spacings of 400 - 1000 nm have been prepared. The NWs contained in such arrays have diameters ranging from 100-300 nm and lengths from 3 - 10 μm. A diode laser operating at 630 nm and 2 mW of optical power is used to perform Bragg scattering homodyne detection to passively read out the thermally induced Brownian mechanical motion of the NWs. The first order cantilever-mode mechanical resonance frequencies of these NWs have been measured to be between 2 - 12 MHz. We find that the optical output via Bragg scattered light allows the simultaneous detection of all lowest order mechanical resonances in a given array. Q factors ranging from 1,000 - 12,000 have been seen at room temperature and 10^{-5} Torr pressures. Qs as high as 25,000 have been seen at temperatures of 80 K. These results show that the narrow mechanical resonances observed in freely-grown GaN NWs can also be seen in NWs prepared via selected-area growth.

3We gratefully acknowledge funding via NIST MSE Grant # 1553451

11:41AM B52.00003 Boson-Coupled Ultracold Atoms as Non-Unique Solutions of the Classical Equations. THEODORE DRIVAS, GREGORY EYINK, The Johns Hopkins University — Classical Newtonian dynamics is expected to be deterministic, but recent fluid turbulence theory predicts that a particle advected at high Reynolds-numbers by “nearly rough” flows moves nondeterministically. Small stochastic perturbations to the flow velocity or to the initial data lead to persistent randomness, even in the limit where the perturbations vanish! Such “spontaneous stochasticity has profound consequences for astrophysics, geophysics, and our daily lives. We show that a similar effect occurs with a quantum particle in a “nearly rough” force, for the semi-classical (large-mass) limit, where spreading of the wave-packet is usually expected to be negligible and dynamics to be deterministic Newtonian. Instead, there are non-zero probabilities to observe multiple, non-unique solutions of the classical equations. Although the quantum wave-function remains split, rapid phase oscillations prevent any coherent superposition of the branches. Classical spontaneous stochasticity has not yet been seen in controlled laboratory experiments of fluid turbulence, but the corresponding quantum effects may be observable by current techniques. We suggest possible experiments with neutral atomic-molecular systems in repulsive electric dipole potentials.
11:39 AM B52.00003 Ultra-thin superconducting film coated silicon nitride nanowire resonators for low-temperature applications, ABHILASH SEBASTIAN, NIKOLAY ZHELEV, ROBERTO DE ALBA, JEEVAK PARPHI, Cornell University — We demonstrate fabrication of high stress silicon nitride nanowire resonators with a thickness and width of less than 50 nm intended to be used as probes for the study of superfluid $^3$He. The resonators are fabricated as doubly-clamped wires/beams using a combination of electron-beam lithography and wet/dry etching techniques. We demonstrate the ability to suspend (over a trench of depth ~8 m) wires with a cross section as small as 30 nm, covered with a 20 nm superconducting film, and having lengths up to 50 m. Room temperature resonance measurements were carried out by driving the devices using a piezo stage and detecting the motion using an optical interferometer. The results show that metalizing nano-mechanical resonators not only affects their resonant frequencies but significantly reduce their quality factor (Q). The devices are parametrically pumped by modulating the system at twice its fundamental resonant frequency, which results in observed amplification of the signal. The wires show self-oscillation with increasing modulation strength. The fabricated nanowire resonators are intended to be immersed in the superfluid $^3$He. By tracking the resonant frequency and the Q of the various modes of the wire versus temperature, we aim to probe the superfluid gap structure.

11:51 AM B52.00004 Optomechanics with superfluid He4 thin films, CHRISTOPHER BAKER, GLEN HARRIS, DAVID MCAUSLAN, YAUHEN SACHKOY, XIN HE, EOIN SHERIDAN, WÄRICK BOWEN, Univ of Queensland — Cavity optomechanics focuses on the interaction between confined light and a mechanical degree of freedom. Vibrational modes of superfluid helium-4 have recently been identified as an attractive mechanical element for cavity optomechanics, thanks to their ultra-low dissipation arising from superfluids viscosity free flow. Here we propose and demonstrate an approach to superfluid optomechanics based on femtogram thin films of superfluid helium condensed on the surface of a microscale microtoroid optical whispering gallery mode resonator. Excitations within the film, known as third sound, manifest as surface waves with a restoring force provided by the van der Waals interaction. We experimentally probe the thermodynamics of these superfluid excitations in real-time, and demonstrate both laser cooling and amplification of the thermal motion. In addition, we propose and demonstrate an entirely new approach to optical forcing based on the atomic recoil of superfluid helium-4. This technique utilizes the thermomechanical effect of superfluids, whereby frictionless fluid flow is generated in response to a local heat source. Using this technique, we achieve superfluid forces on a microrodot mechanical mode an order of magnitude greater than the equivalent radiation pressure force.

12:03 PM B52.00005 Strong coupling and parametric amplification in mechanical modes of graphene, JOHN MATHEW, Tata Institute of Fundamental Research, Mumbai, India, RAJ PATEL, Tata Institute of Fundamental Research, Mumbai, India, Birla Institute of Technology & Science, Pilani - K.K.Birla Goa Campus, India, ABHINANDAN BORAH, RAJAMANI VIJAYARAGHAVAN, MANDAR DESHMUKH, Tata Institute of Fundamental Research, Mumbai, India — We demonstrate strong dynamical coupling and parametric amplification in mechanical modes of a graphene drum using an all electrical configuration. Low tension in the system allows large electrostatic tunability of the modes thus enabling dynamic pumping experiments. In the strong coupling regime a red detuned pump gives rise to new eigenmodes having highly tunable mode splitting (cooperativity ~60) with coherent energy transfer. The coupling is also used to amplify the modes under the action of a blue detuned pump. In addition, self-oscillations and parametric amplification of the fundamental vibrational mode is demonstrated with a gain of nearly 3. The low mass and high frequency of these atomically thin resonators could prove useful for studying mode coupling in the quantum regime.

12:15 PM B52.00006 Observation of vacuum-enhanced electron spin resonance of optically levitated nanodiamonds, TONGCANG LI, THAI HOANG, JONGHOON AHN, JAEEHON BANG, Purdue University — Electron spins of diamond nitrogen-vacancy (NV) centers are important quantum resources for nanoscale sensing and quantum information. Combining such NV spin systems with levitated optomechanical resonators will provide a hybrid quantum system for many novel applications. Here we optically levitate a nanodiamond and demonstrate electron spin control of its built-in NV centers in low vacuum. We observe that the strength of electron spin resonance (ESR) is enhanced when the air pressure is reduced. To better understand this novel system, we also investigate the effects of trap power and measure the absolute internal temperature of levitated nanodiamonds with ESR after calibration of the strain effect. Our results show that optical levitation of nanodiamonds in vacuum not only can improve the mechanical quality of its oscillation, but also enhance the ESR contrast, which pave the way towards a novel levitated spin-optomechanical system for studying macroscopic quantum mechanics. The results also indicate potential applications of NV centers in gas sensing.

12:27 PM B52.00007 Piezo-optomechanical circuits, KRISHNA COIMBATORE BALRAM, MARCELO DAVANCO, ROBERT ILIC, KARTIK SRINIVASAN, NIST — Natl Inst of Stds & Tech — Coherent links between the optical, radio frequency (RF), and mechanical domains are critical for applications ranging from quantum state transfer between the RF and optical domains to signal processing in the acoustic domain for microwave photonics. We develop such a piezo-optomechanical circuit platform in GaAs, in which localized and interacting 1550 nm photons and 2.4 GHz phonons are combined with photonic and phononic waveguides. GaAs allows us to exploit the photoelastic effect to engineer cavities with strong optomechanical coupling $g_0/2\pi \approx 1.1$ MHz and the piezoelectric effect to couple RF fields to mechanical motion through surface acoustic waves, which are routed on-chip using phononic crystal waveguides. This platform enables optical readout of electrically-injected mechanical states with an average coherent intracavity phonon number as small as ~0.05 and the ability to drive mechanical motion with equal facility through either the optical or electrical channel. This is used to demonstrate a novel acoustic wave interference effect in which optically-driven motion is completely cancelled by electrically-driven motion, and vice versa. As an application of this, we present time-domain measurements of optically-controlled acoustic pulse propagation.1 Secondary Affiliation is Maryland Nanocenter, University of Maryland, College Park, MD

12:39 PM B52.00008 Magneto-optical coupling in whispering gallery mode resonators, JAMES HAIGH, Hitachi Cambridge Laboratory, Cambridge, CB3 0HE, UK, STEFAN LANGENFELD, NICHOLAS LAMBERT, JEREMY BAUMBERG, Cavendish Laboratory, Cambridge, University of Cambridge, Cambridge, CB3 0HE, UK, ANDREW RAMSAY, Hitachi Cambridge Laboratory, Cambridge, CB3 0HE, UK, ANDREAS NUNNENKAMP, ANDREW FERGUSON, Cavendish Laboratory, University of Cambridge, Cambridge, CB3 0HE, UK — We demonstrate that yttrium iron garnet microspheres support optical whispering gallery modes similar to those in non-magnetic dielectric materials. The direction of the ferromagnetic moment tunes the resonant optical frequency via the Voigt effect, dependent on the angle of the magnetization with respect to the plane of the whispering gallery mode. This parametric coupling of the magnetization to the optical mode may enable analogous experiments to those performed in cavity optomechanics. In addition, the Faraday effect couples the two ordinarily linear polarized modes, split by the geometrical birefringence due to the boundary conditions at the surface. This results in a polarization rotation of the light emitted from the cavity. Our results extend recent work on the strong coupling of microwave photons to magnetization dynamics in ultra-cold atom systems and an understanding of the magneto-optical coupling in whispering gallery modes, where the propagation direction rotates with respect to the magnetization, is fundamental to the emerging field of cavity optomagnonics. [arXiv:1510.06661].
great design flexibility toward multimode systems. We demonstrate this in Si optical mode in the slot and a mechanical breathing mode at the center of the mechanical beam. This structure has large optomechanical coupling rates and mechanics applications involve multiple interacting optical and mechanical modes. A key challenge in such systems is developing multimode platforms with both low mechanical and optical dissipations. A high Q-factor (≈10^9 at low pressure) of the fundamental mechanical mode at 74 kHz enabled direct measurement of thermal motion at room temperature, which holds an average displacement of 20 pm. Therefore, compound cavity systems can be employed as table-top, cost-effective displacement linear detectors. Furthermore, nonlinear optomechanical interactions could be observed, with new possibilities in the study of non-Markovian quantum properties at the mesoscale.

1:03PM B52.00010 Single photon frequency conversion and channelization based on microwave piezo-optomechanical devices. LINRAN FAN, CHANGLIN ZOU, MENNO POOT, RISHENG CHENG, HONG TANG, Yale University — Cavity optomechanics holds very promising potentials for quantum information processing, as it provides both a convenient method to manipulate photons and a platform to bridge different quantum system. Especially, the integration of microwave devices with cavity optomechanics draws great interest as such a hybrid platform can provide strong electrical actuation, ultra-sensitive optical readout, and parametric mechanical signal amplification simultaneously in a single device. This hybrid platform enables great functionalities in manipulating photons, and builds direct link between microwave photon and optical photon, which is important for future quantum network. Aluminum nitride (AlN) is ideal for such hybrid platform. Besides low optical and mechanical loss, AlN possesses strong piezoelectric effect, which gives rise to strong coupling between microwave cavities and mechanical resonators. We will present our recent progress in developing integrated AlN hybrid platform for photon manipulation, such as optical amplification and absorption, cascaded optical delay, single photon frequency shifting, etc.

1:15PM B52.00011 Displacement linear detection down to thermal fluctuations of a silicon nitride membrane with self-mixing technique. LORENZO BALDACCI, ALESSANDRO PANTANI, LUCA MASINI, ANDREA ARCANGELI, DANIEL NAVARRO URRIOS, NEST, Istituto Nanoscienze - CNR and Scuola Normale Superiore, ALESSANDRO TREDICUCCI, NEST, Istituto Nanoscienze - CNR and Dipartimento di Fisica E. Fermi, Universita’ di Pisa, SOULMAN RESEARCH GROUP TEAM — Active optomechanical systems exploit the interaction between photons and mechanical vibrations inside a laser cavity. A compound cavity made of a laser diode and an external vibrating reflector is a suitable platform, due to its ease of construction and coupling modulation. Here we use it as a linear displacement detector, by studying the motion of a silicon nitride suspended membrane as the external mirror of a near infrared laser diode. The membrane vibrations cause fluctuations in the laser optical power, which are collected by a photodiode and measured with a spectrum analyzer. The dynamics of the membrane driven by a piezo actuator was investigated in a homodyne configuration. The high Q-factor (≈10^8 at low pressure) of the fundamental mechanical mode at 74 kHz enabled direct measurement of thermal motion at room temperature, which holds an average displacement of 20 pm. Therefore, compound cavity systems can be employed as table-top, cost-effective displacement linear detectors. Furthermore, nonlinear optomechanical interactions could be observed, with new possibilities in the study of non-Markovian quantum properties at the mesoscale.

1:27PM B52.00012 Microwave cavity piezo-opto-mechanical resonators based on film thickness modes operating beyond 10 GHz. XU HAN, HONG TANG, Yale University — Micromechanical resonators, which support and confine microwave frequency photons on a scale comparable to optical wavelength, provide a valuable intermediate platform facilitating interactions among electrical, optical, and mechanical domains. High-frequency mechanical resonances ease the refrigeration conditions for reaching quantum mechanical ground state and also hold promise for practical device applications. However, efficient actuation of the highly stiff mechanical motions above gigahertz frequencies remains a challenging task. Here, we demonstrate a high-performance piezo-opto-mechanical resonator operating at 10.4 GHz by exploiting the acoustic thickness mode of an aluminum nitride micro-disk. In contrast to the in-plane mechanical modes, the thickness mode can be easily scaled to high frequencies with low mechanical and optical dissipations. A high f ·Q product of 1.9 × 10^12Hz is achieved in ambient air at room temperature. Moreover, strong piezoelectro-mechanical coupling can be achieved by coupling the optical mode with a microwave resonator, making it possible for coherent signal conversion. The thickness mode-based piezo-opto-mechanical resonators can be expected to serve as essential elements for advanced hybrid information networks.

1:39PM B52.00013 Slot-mode multimode optomechanical crystals with enhanced coupling and multimode functionality. KAREN GRUTTER, MARCELO DAVANCO, KARTIK SRINIVASAN, NIST - Natl Inst of Stds & Tech — A number of cavity optomechanics applications involve multiple interacting optical and mechanical modes. A key challenge in such systems is developing multimode platforms with both flexibility in the optical and mechanical designs and interactions as strong as those shown in single-mode systems. We thus present slot-mode optomechanical crystals, in which photonic and phononic crystal nanobeam separated by a narrow slot couple optomechanically. We pattern these beams to confine a low-loss optical mode in the slot and a mechanical breathing mode at the center of the mechanical beam. This structure has large optomechanical coupling rates and great design flexibility toward multimode systems. We demonstrate this in SiN slot-mode devices, with 980 nm optical modes coupling to mechanical modes at 3.4 GHz, 1.8 GHz, and 400 MHz. We use SiN tensile stress to shrink slot widths to 24 nm, greatly enhancing optomechanical coupling. Finally, with this platform, we develop multimode systems with three-beam geometries, in which two different mechanical modes couple to one optical mode and two different optical modes couple to one mechanical mode.

The authors acknowledge funding from DARPA (MESO) and the National Research Council Research Associateship Program

1:51PM B52.00014 Nonlinearly Coupled Superconducting Lumped Element Resonators. MICHELE C. COLLODO, ANTON POTOČNIK, ANTONIO RUBIO ABADAL, MINTU MONDAL, MARKUS OPPLIGER, ANDREAS WALLRAFF, Laboratory for Solid State Physics, ETH Zurich — We study SQUID-mediated coupling between two superconducting on-chip resonators in the microwave frequency range. In this circuit QED implementation, we employ lumped-element type resonators, which consist of Nb thin film structured into interdigitated finger shunt capacitors and meander inductors. A SQUID, functioning as flux dependent and intrinsically nonlinear inductor, is placed as a coupling element together with an interdigitated capacitor between the two resonators (cf. A. Baust et al., Phys. Rev. B 91 014515 (2015)). We perform a spectroscopic measurement in a dilution refrigerator and find the linear photon hopping rate between the resonators to be widely tunable as well as suppressible for an appropriate choice of parameters, which is made possible due to the interplay of inductively and capacitively mediated coupling. Vanishing linear coupling promotes nonlinear effects ranging from on-site to cross-Kerr interaction. A dominating cross-Kerr interaction related to this configuration is notable, as it induces a unique quantum state. In the course of analog quantum simulations, such elementary building blocks can serve as a precursor for more complex geometries and thus pave the way to a number of novel quantum phases of light.
203PM B52.00015 Microwave Reentrant Cavities for Quantum Devices, NATALIA C. CARVALHO, JEREMY BOURHILL, DANIEL CREEDON, MAXIM GORYACHEV, ARC Centre of Excellence for Engineered Quantum Systems, The University of Western Australia, SERGE GALLIQU, FEMTO-ST Institute, MICHAEL TOBAR, ARC Centre of Excellence for Engineered Quantum Systems, The University of Western Australia — A microwave reentrant cavity is a device able to provide a very sensitive high-Q microwave mode. Its design can be highly advantageous for electromechanical devices and quantum measurements. In this sense, a tunable device based on a narrow-gap superconducting reentrant cavity is under development. The resonant frequency is able to be fine-tuned over a range larger than 500 MHz at 10 mK with an electrical Q-factor of $10^5$. Such a cavity could possibly accommodate a transmon qubit to control and manipulate its quantum state. We are also working on the investigation of bulk acoustic wave (BAW) resonators in microwave reentrant cavities. BAW resonators offer a promising way to process quantum information through the coupling between microwaves and acoustic phonons. Thus, we are developing a device able to excite phonons through non-linearities and the piezoelectricity of the plano-convex quartz crystal. We will detail our experiments that work towards cooling gram scale phonon resonances to the quantum ground state.

1 Funded by ARC Grant No. CE110001013 (Australia) and National Counsel of Technological and Scientific Development (Brazil)

Monday, March 14, 2016 2:30PM - 5:30PM —
Session C50 DAMOP: Many-Body Localization in Atomic Systems 1 Hilton Baltimore Holiday Ballroom

1 - Bela Bauer, Microsoft Station Q

2:30PM C50.00001 Suppression and Revival of Weak Localization of Ultra-Cold Atoms by Manipulation of Time-Reversal Symmetry, ALAIN ASPECT, Institut d’Optique Palaiseau — In the early 1980’s, observation of a magneto-resistance anomaly in metallic thin films was attributed to the phenomenon of weak localization of electrons and to time-reversal symmetry breaking due to a magnetic field acting upon charged particles. We have observed weak localization of ultra-cold atoms in a 2D configuration, placed in a disordered potential created by a laser speckle. In order to manipulate time-reversal symmetry with our neutral atoms, we take advantage of the slow evolution of our system, and we observe the suppression and revival of weak localization when time reversal symmetry is cancelled and reestablished. References: K. Muller, J. Richard, V. V. Volkchov, V. Denechaud, P. Bouyer, A. Aspect, and V. Josse, “Suppression and Revival of Weak Localization through Control of Time-Reversal Symmetry,” Physical Review Letters 114 (20) (2015) and references in.

1 Work supported by the ERC Advanced Grant Quantatop

3:06PM C50.00002 Using subadditivity to reason about many-body localization on single disorder realizations, BRYAN CLARK, XIONGJIE YU, DAVID J. LUITZ, University of Illinois at Urbana Champaign — We investigate many-body localization in the presence of a single-particle mobility edge. By considering an interacting deterministic model with an incommensurate potential in one dimension, we find that the single-particle mobility edge in the noninteracting system leads to a many-body mobility edge in the corresponding interacting system for certain parameter regimes. Using exact diagonalization, we probe the mobility edge via energy resolved entanglement entropy (EE) and study the energy resolved applicability (or failure) of the eigenstate thermalization hypothesis (ETH). Our numerical results indicate that the transition separating area and volume law scaling of the EE does not coincide with the nonthermal to thermal transition. Consequently, there exists an extended nonergodic phase for an intermediate energy window where the many-body eigenstates violate the ETH while manifesting volume law EE scaling. We also establish that the model possesses an infinite temperature many-body localization transition despite the existence of a single-particle mobility edge. We propose a practical scheme to test our predictions in atomic optical lattice experiments which can directly probe the effects of the mobility edge.

3:18PM C50.00003 Many-Body Localization and Quantum Nonergodicity in a Model with a Single-Particle Mobility Edge, XIAOPENG LI, SRIRAM GANESHAN, J.H. PIXLEY, Univ of Maryland-College Park — We investigate many-body localization in the presence of a single-particle mobility edge. By considering an interacting deterministic model with a single-particle mobility edge in the noninteracting system leads to a many-body mobility edge in the corresponding interacting system for certain parameter regimes. Using exact diagonalization, we probe the mobility edge via energy resolved entanglement entropy (EE) and study the energy resolved applicability (or failure) of the eigenstate thermalization hypothesis (ETH). Our numerical results indicate that the transition separating area and volume law scaling of the EE does not coincide with the nonthermal to thermal transition. Consequently, there exists an extended nonergodic phase for an intermediate energy window where the many-body eigenstates violate the ETH while manifesting volume law EE scaling. We also establish that the model possesses an infinite temperature many-body localization transition despite the existence of a single-particle mobility edge. We propose a practical scheme to test our predictions in atomic optical lattice experiments which can directly probe the effects of the mobility edge.

1 JQI-NSF-PFC, AROAtomtronics- MURI, and LPS-CMTC, UMD supercomputing resources

3:30PM C50.00004 Early Breakdown of Area-Law Entanglement at the Many-Body Delocalization Transition, TRITHEP DEVAKUL, Princeton University, RAJIV SINGH, University of California, Davis — We introduce the numerical linked cluster expansion as a controlled numerical tool for the study of the many-body localization transition in a disordered system with continuous nonperturbative disorder. Our approach works directly in the thermodynamic limit, in any spatial dimension, and does not rely on any finite size scaling procedure. We study the onset of many-body delocalization through the breakdown of area-law entanglement in a generic many-body eigenstate. By looking for initial signs of an instability of the localized phase, we obtain a value for the critical disorder, which we believe should be a lower bound for the true value, that is higher than current best estimates from finite size studies. This implies that most current methods tend to overestimate the extent of the localized phase due to finite size effects making the localized phase appear stable at small length scales. We also study the mobility edge in these systems as a function of energy density, and we find that our conclusion is the same at all examined energies. Work based on Phys. Rev. Lett. 115, 187201.

3:42PM C50.00005 Exponential Orthogonality Catastrophe in Single-Particle and Many-Body Localized Systems, DONG-LING DENG, J. H. PIXLEY, XIAOPENG LI, Dept. of Physics, University of Maryland — We investigate the statistical orthogonality catastrophe (StOC) in single-particle and many-body localized systems by studying the response of the many-body ground state to a local quench. Using scaling arguments and exact numerical calculations, we establish that the StOC gives rise to a wave function overlap between the pre- and post-quench ground states that has an exponential decay with the system size, in sharp contrast to the well-known power law Anderson orthogonality catastrophe in metallic systems. This exponential decay arises from a statistical charge transfer process where a particle can be effectively “transported” to an arbitrary lattice site. We show that in a many-body localized phase, this non-local transport and the associated exponential StOC phenomenon persist in the presence of interactions. We study the possible experimental consequences of the exponential StOC on the Loschmidt echo and spectral function, establishing that this phenomenon might be observable in cold atomic experiments through Ramsey interference and radio-frequency spectroscopy.

3 We thank S.-T. Wang, Z.-X. Gong, Y.-L. Wu, J. D. Sau, and Z. Ovadyahu for discussions. This work is supported by LPS-MPO-CMTC, JQI-NSF-PFC, and ARO-Atomtronics-MURI. The authors acknowledge the University of Maryland supercomputing resources.
3:54PM C50.00006 Many-body localization effects in a disordered system coupled to a delocalized chain. KATHARINE HYATT, University of California - Santa Barbara, JAMES R. GARRISON, Univ of California - Santa Barbara, BELA BAUER, Station Q, Microsoft Research — The possibility of closed quantum systems that robustly violate quantum statistical mechanics has received a tremendous amount of interest in recent years. Using both numerical and analytical techniques, it has been established that weakly interacting disordered systems can be brought into a many-body localized regime, where the system does not conduct and does not equilibrate even for arbitrarily long times. The starting point for such a phase is usually taken to be an Anderson insulator where in the limit of vanishing interactions, all degrees of freedom of the system are localized. Here, we revisit this problem in a model where in the non-interacting limit, some degrees of freedom are localized while others remain delocalized. Such a system can be viewed as a model for a many-body localized system brought into contact with a small bath of a comparable number of degrees of freedom. We numerically study the effect of interactions on this system and find that generically, the entire system delocalizes. However, we find certain parameter regimes where results are consistent with localization of the entire system, an effect recently termed many-body proximity effect.

4:06PM C50.00007 Fractional transport and photonic sub-diffusion in aperiodic dielectric metamaterials. LUCA DAL NEGRO, YU WANG, SANDEEP INAMPUDI, Boston University, ECE Department — Using rigorous transfer matrix theory and full-vector Finite Difference Time Domain (FDTD) simulations in combination with Wavelet Transform Modulus Maxima analysis of multifractal spectra, we demonstrate all aperiodic dielectric metamaterial structures that exhibit sub-diffusive photon transport properties that are widely tunable across the near-infrared spectral range. The proposed approach leverages the unprecedented spectral scalability offered by aperiodic photonic systems and demonstrates the possibility of achieving logarithmic Sinai sub-diffusion of photons for the first time. In particular we will show that the control of multifractal energy spectra and critical modes in aperiodic metamaterials with nanoscale dielectric components enables tuning of anomalous optical transport from sub- to super-diffusive dynamics, in close analogy with the electron dynamics in quasi-periodic potentials. Fractional diffusion equations models will be introduced for the efficient modeling of photon sub-diffusive processes in metamaterials and applications to diffraction-free propagation in aperiodic media will be provided. The ability to tailor photon transport phenomena in metamaterials with properties originating from aperiodic geometrical correlations can lead to novel functionalities and active devices that rely on anomalous photon sub-diffusion to control beam collimation and non-resonantly enhance light-matter interaction across multiple spectral bands.

4:18PM C50.00008 Many-body localization protected quantum state transfer. CHRIS R LAUANN, University of Washington, NORMAN Y YAÖ, ASHVIN VISHWANATH, University of California, Berkeley — In thermal phases, the quantum coherence of individual degrees of freedom is rapidly lost to the environment. Many-body localized (MBL) phases limit the spread of this coherence and appear promising for quantum information processing. However, such applications require not just long coherence times but also a means to transport and manipulate information. We demonstrate that this can be done in a one dimensional model of interacting spins at infinite temperature. Our protocol utilizes protected qubits which emerge at the boundary between topological and trivial phases. State transfer occurs via dynamic shifts of this boundary and is shown to preserve quantum information. As an example, we discuss the implementation of a universal, two-qubit gate based upon MBL-protected quantum state transfer.

4:30PM C50.00009 Transport of Light in disordered random media. REGINE FRANK, Serin Physics Laboratory, E273 Department of Physics and Astronomy Rutgers University 136 Frelinghuysen Road Piscataway, NJ 08854-8019, USA, ANDREAS LUBATSCH, Georg-Simon-Ohm University of Applied Sciences, Nuremberg, Germany — The Anderson transition was originally proposed for electrons, however it has been soon searched for all kinds of waves in disordered media. This physics became extremely interesting with the application of high amplitude excitations, where the medium is supposed to respond with non-linear effects. In theory it is ever since a challenge to treat large random ensembles numerically, even if the medium is completely non-resonant or passive. We discuss in this talk transport of light with respect to a quantum field theoretical approach and we explain through comparison to other existing theories, what the advantages of state of the art theory in that field is, and why it is exciting.

4:42PM C50.00010 Many body localization in the presence of a single particle mobility edge. SUBROTO Mukerjee, RANJAN MODAK, Indian Institute of Science — In one dimension, noninteracting particles can undergo a localization-delocalization transition in a quasiperiodic potential. Recent studies have suggested that this transition transforms into a many body localization transition upon the introduction of interactions. It has also been shown that mobility edges can appear in the single particle spectrum for certain types of quasiperiodic potentials. Here we investigate the effect of interactions in models with such mobility edges. Employing the technique of exact diagonalization for finite-sized systems, we calculate the level spacing distribution, time evolution of entanglement entropy, optical conductivity and return probability to characterize the nature of localization. The localization that develops in the presence of interactions in these systems appears to be different from regular Many-Body Localization (MBL) in that the growth of entanglement entropy with time is linear (like in a thermal phase) but saturates to a value much smaller than the thermal value (like for MBL). All other diagnostics seem consistent with regular MBL.

4:54PM C50.00011 Energy Dependence and Scaling Property of Localization Length near a Gapped Flat Band. LI GE, College of Staten Island, CUNY, HAKAN TURECI, Princeton University — Using a tight-binding model for a one-dimensional Lieb lattice, we show that the localization length near a gapped flat band behaves differently from the typical Urbach tail in a band gap: instead of reducing monotonically as the energy E moves away from the flat band energy E_f, the presence of the flat band causes a nonmonotonic energy dependence of the localization length. This energy dependence follows a scaling property when the energy is within the spread (W) of uniformly distributed diagonal disorder, i.e. the localization length is only a function of (E-E_f)/W. Several other lattices are compared to distinguish the effect of the flat band on the localization length, where we eliminate, shift, or duplicate the flat band, without changing the dispersion relations of other bands. Using the top right element of the Green’s matrix, we derive an analytical relation between the density of states and the localization length, which shows light on these properties of the latter, including a summation rule for its inverse.

5:06PM C50.00012 Spatial and temporal localization of light in two dimensions. ROMAIN BACHELARD, Instituto de Fisica de So Carlos/Universidade de So Paulo — Despite decades of active research, punctuated by several contradictory experimental and theoretical claims, the mere existence of Anderson localization of light, a regime where light cannot propagate due to interference effects between randomly distributed scatterers, has not been demonstrated yet. Recent theoretical works suggest that the vectorial nature of light might actually prohibit localization. We here present a study on the scattering of light in two dimensions, a regime where both scalar or as a vectorial electromagnetic waves coexist. The scaling analysis reveals that although both kinds of wave present long-spatially bridged modes, only scalar ones do localize, supporting the theoretical claim in 3D. Yet we also observe a lack of correlation between lifetimes and localization length, calling for a differentiation between temporal (subradiant) and spatial (Anderson) localization. Finally, we discuss the implication of localization, following the original idea that the localization of the modes induces a metal to insulator transition, bringing transport to a halt. Indeed, in the case of light, the scattering is characterized by the presence of a few long-range (superradiant) modes, which appear to alter dramatically the transport properties.
5:18PM C50.00013 Anderson Localization in Degenerate Spin-Orbit Coupled Fermi Gas with Disorder\footnote{This work was carried out with the support of National Natural Science Foundation of China (No. 61275122).}

SHENG LIU, XIANGFA ZHOU, GUANGCAN GUO, YONGSHENG ZHANG, Univ. of Sci. & Tech. of China — Competition between superconductivity and disorder plays an essential role in understanding the metal-insulator transition. Based on the Bogoliubov-de Gennes equation, we studied an s-wave superconductor with both spin-orbit coupling and disorder are presented. With increasing the strength of disorder, the mean superconducting order parameter will vanish while the energy gap will persist which indicates that the system undergoes a transition from a superconducting state to a insulating state which can be conformed by calculating the inverse participation ratio. We also find that, if the strength of disorder is small, the superconducting order parameter and energy gap will decrease if we increase the strength of spin-orbit coupling and Zeeman field. In the large disorder limits, increasing the strength of spin-orbit coupling will increase the mean superconducting order parameter. This phenomena shows that the system is more insensitive to disorder if the spin-orbit coupling is presented. Numerical computing also shows that the whole system breaks up into several superconducting islands instead of being superconductive.

Monday, March 14, 2016 2:30PM - 5:30PM –
Session C52 DAMOP: Vortices, Rotation and Nonlinear Effects in BECs Hilton Baltimore Holiday
Ballroom 3 - Stephen Eckel, Joint Quantum Institute, University of Maryland

2:30PM C52.00001 Melting of Vortex Lattice in Bose-Einstein Condensate in Presence of Disorder\footnote{1 I would like to thank DST, India and BCUD SPPU, for financial assistance through research grants.}, BISWAJYOTI DEY, Department of Physics, SP Pune University, Pune 411007, India. — We study the vortex lattice dynamics in Bose-Einstein condensate (BEC) in presence of single impurity as well as random impurities or disorder. The single impurity is modeled by a Gaussian function while disorder is introduced in the system by a uniform random potential. Such potentials can be created experimentally by lasers. We solve the time-dependent Gross-Pitaevskii equation in two-dimensions using split-step Crank-Nicolson method. We first show that a single vortex can be pinned by an impurity. We then show that even a single impurity can distort the vortex lattice. For sufficiently strong impurity potential, the vortex lattice gets pinned to the impurity. We also show that a new type of giant hole with hidden vortices inside it can be created in the vortex lattice by a cluster of impurities. In presence of random impurity potential or disorder, the vortices get pinned at random leading to melting of the vortex lattice. We further show that the vortex lattice melting can also be induced by the pseudorandom potential generated by the superposition of two optical lattices. The absence of long-range order in the melted vortex lattice is demonstrated from the structure factor profile and the histogram of the distance between each pair of vortices.

2:42PM C52.00002 From Vortex Rings to Hopfions in 3d Bose-Einstein Condensates, PANAYOTIS KEVREKIDIS, UMass, Amherst — In this talk we report a number of recent results on three-dimensional topological states. Motivated by our earlier work on vortex rings, we develop a two-fold approach for studying vortex rings. We analytically and numerically explore their emergence through an instability from planar or ring dark soliton states in the small amplitude/weak nonlinearity limit. We also analytically and numerically explore the opposite, particle based limit of large density/large nonlinearity in the Thomas-Fermi regime. We connect these two analytically tractable limits through detailed numerical computations revealing the spectral and nonlinear stability of such states. We also explore a series of other states, including so-called Hopfions, and dark-soliton-shells examining both their regimes of stability in 3d atomic BECs, as well as their mechanisms and manifestations of dynamical instabilities.

2:54PM C52.00003 Equation of Motion of a Quantum Vortex, , TIMOTHY COX, University of British Columbia, PHILIP STAMP, University of British Columbia and the Pacific Institute of Theoretical Physics — Understanding the motion of vortices in quantum fluids is key to understanding the dynamics of such fluids. The motion of quantum vortices has long been understood in terms of the Hall-Vinen-Iordanski (HVI) equations. A fully quantum mechanical treatment of vortex motion in a two-dimensional Bose superfluid\cite{HVI} leads to a modified version of the HVI equations which include significant history dependent forces and a fluctuating noise force. The dynamics deviates from that described by the HVI equations when the frequency of motion is higher than the temperature. We describe the consequences of the memory and noise for the motion of a single superfluid vortex as well as the circumstances under which their effects should be experimentally observable. \cite{TSC} Thompson and Stamp, Phys Rev Lett. 108, 184501 (2012)

3:06PM C52.00004 Helicity in superfluids, HRIDESH KEDIA, DUSTIN KLECKNER, University of Chicago, DAVIDE PROMENT, University of East Anglia, WILLIAM T.M. IRVINE, University of Chicago — Ideal fluid flow conserves a special quantity known as helicity, in addition to energy, momentum and angular momentum. Helicity can be understood as a measure of the knottedness of vortex lines of the flow, providing an important geometric tool to study diverse physical systems such as turbulent fluids and plasmas. Since superfluids flow without resistance just like ideal (Euler) fluids, a natural question arises: Is there an extra conserved quantity akin to helicity in superfluids? We address the question of a "superfluid helicity" theoretically and examine its consequences in numerical simulations.

3:18PM C52.00005 Finite temperature and density depletion effects on persistent current state transitions and critical velocity of a toroidal Bose-Einstein condensate, AVINASH KUMAR, STEPHEN ECKEL, FRED JENDRZEJEWSKIL, Joint Quantum Institute, University of Maryland, GREITCHEN CAMPBELL, Joint Quantum Institute, University of Maryland, NIST — We study the decay of a persistent, quantized current state in a toroidal geometry. Our experiment involves trapping neutral $^{23}$Na atoms in an all optical “target trap” shaped potential. This potential consists of a disc surrounded by an annular potential. A current in a superfluid can be sustained only below a critical current. This critical current can be tuned by introducing a density perturbation which depletes the local density. The decay time of a persistent current state can also be controlled by enhancing fluctuations of the system thermally. We study the decay at four different temperatures between 30 nK and 190 nK. For each temperature we record the decay at four different perturbation strengths. We find that increasing the magnitude of the density depletion or the temperature leads to a faster decay, and have seen the decay constant change by over two orders of magnitude. We also studied the size of hysteresis loop between different current states as a function of temperature, allowing us to extract a critical velocity. We find that the discrepancies between the experimentally extracted critical velocity and theoretically calculated critical velocity (using local-density approximation ) decreases as the temperature is decreased.

\footnote{1 Now at University of Heidelberg}
3:30PM C52.00006 Finite-temperature energy landscapes in rotating ring BECs\textsuperscript{1} , BRENNAN COHELLEACH, CLAYTON HELLER, MARK EDWARDS, Georgia Southern Univ, STE\v{E}VE ECKERL, AVINASH KUMAR, CH\text{\v{A}}RLES CLARK, GRETCHE\text{\v{N}} CAMPBELL, Joint Quantum Institute — In a recent experiment conducted at NIST a ring Bose–Einstein condensate (BEC) was prepared in a unit angular momentum circulation state. A barrier was then slowly raised and left on for a variable hold time and then turned off. The final circulation of the BEC was studied as a function of hold time and barrier energy height. This procedure was carried out for several well–characterized non–zero temperatures. We have studied the energetics of this process under the assumption that a vortex is initially present in the center of the ring BEC and then travels out of the ring through the density notch created by the barrier. We have computed the energy per particle of the condensate system for a variable location of the vortex by solving the time–dependent Generalized Gross–Pitaevskii (GPP) equation in imaginary time. To account for finite–temperature we solved self–consistently for the condensate fraction as a function of temperature in thermal equilibrium for fixed total particle number. This yielded the non–condensate density which appears in the GGP affecting the energy of the vortex. We also modeled the dynamics of the vortex using the ZNG formalism.

\textsuperscript{1}Supported by NSF grants PHY–1413768 and ARO Atomtronics MURI

3:42PM C52.00007 Cold atoms in one-dimensional rings: a Luttinger liquid approach to precision measurement\textsuperscript{1} , STEPHEN RAGOLE, JQI, QuICs, and University of Maryland, JACOB TAYLOR, JQI, QuICs, University of Maryland, and National Institute of Standards and Technology — Recent experiments have realized ring shaped traps for ultracold atoms. We consider the one-dimensional limit of these ring systems with a moving weak barrier, such as a blue-detuned laser beam. In this limit, we employ Luttinger liquid theory and find an analogy with the superconducting charge qubit. In particular, we find that strongly-interacting atoms in such a system could be used for precision rotation sensing. We compare the performance of this new sensor to the state of the art non-interacting atom interferometry.

\textsuperscript{1}Funding provided by the Physics Frontier Center at the JQI and by DARPA QUASAR

3:54PM C52.00008 Resonant wavepackets and shock waves in an atomtronic SQUID\textsuperscript{1} , YI-HSIEH WANG, A. KUMAR, Joint Quantum Institute, F. JENDRZEJEWSKI, Ruprecht-Karls-Universität, RYAN M. WILSON, The United States Naval Academy, MARK EDWARDS, Georgia Southern University, S. ECKERL, G. K. CAMPBELL, CHARLES W. CLARK, Joint Quantum Institute — The fundamental dynamics of ultracold atomtronic devices are reflected in their phonon modes of excitation. We probe such a spectrum by applying a harmonically driven potential barrier to a \textsuperscript{23}Na Bose–Einstein condensate in a ring-shaped trap. This perturbation excites phonon wavepackets. When excited resonantly, these wavepackets display a regular periodic structure. The resonant frequencies depend upon the particular configuration of the barrier, but are commensurate with the orbital frequency of a Bogoliubov sound wave traveling around the ring. Energy transfer to the condensate over many cycles of the periodic wavepacket motion causes enhanced atom loss from the trap at resonant frequencies. Solutions of the time–dependent Gross–Pitaevskii equation exhibit quantitative agreement with the experimental data. We also observe the generation of supersonic shock waves under conditions of strong excitation, and collisions of two shock wavepackets.

\textsuperscript{1}Work supported by the U. S. Army Research Office Atomtronics MURI program.


4:06PM C52.00009 Anomalous hysteresis in a spinor atom–SQUID , RANCHU MATHEW, Joint Quantum Institute, University of Maryland, EITE TIESINGA, Joint Quantum Institute, National Institute of Standards and Technology and University of Maryland — Over the past few years, there has been a concerted effort at NIST studying the atomic analogue of a Superconducting Quantum Interference Device (SQUID) [Eckel S. et al., Nature (London) 506, 200 (2014)]. The atom–SQUID consists of a Bose–Einstein condensate (BEC) in a ring trap with a rotating external potential or weak link. The system displays persistent currents and hysteresis as a function of rotation rate. We investigate the effect of the spin degree of freedom of an atom and a rotating vector potential, which mixes spin sublevels, on the hysteresis pattern by performing a numerical analysis of the Gross–Pitaevskii equation. For a spinless BEC the the winding number of the BEC changes by one unit as the rotation of the potential is slowly changed beyond a critical value. In contrast, in a certain parameter regime for a spin BEC with a vector potential the winding number changes by two units instead of one. To explain this anomalous phenomenon, we calculate the energies of the two saddle–points of the mean–field energy functional, which mediate the transitions to states which differs by one and two units of winding number.

4:18PM C52.00010 Transport in a capacitive ultracold atomtronic circuit\textsuperscript{1} , MARK EDWARDS, BENJAMIN ELLER, Georgia Southern Univ, STEVE ECKERL, CHARLES CLARK, Joint Quantum Institute — A recent NIST experiment\textsuperscript{2} studied the transport of a gaseous Bose–Einstein condensate (BEC) confined in an atomtronic “dumbbell” circuit. The optically created condensate potential consisted of a tight harmonic potential in the vertical direction confining the BEC to a horizontal plane. The horizontal potential consisted of two cylindrical wells separated by a central barrier. We modeled this system with the Gross–Pitaevskii (GP) equation and found good agreement with the data provided that the confining potential is carefully reproduced. The GP simulations show behavior, not detectable in the experiment, that atoms can jump out of the dumbbell area after filling up the drain well. We also present the dependence of \(R\) and \(L\) on the channel shape.

\textsuperscript{1}Supported by NSF grants PHY–1413768 and ARO Atomtronics MURI


4:30PM C52.00011 Collective modes of trapped Bose–Einstein condensates undergoing adiabatic deformation from filled-sphere to thin-shell geometries\textsuperscript{1} , COURTNEY LANNERT, Smith College, KUEI SUN, The University of Texas at Dallas, KARMELA PADAVIC, SMITHA VISHVESHWARIA, University of Illinois at Urbana-Champaign — Collective modes of a trapped Bose–Einstein condensate (BEC) are closely related to the ground-state density profile and are experimentally measurable. They are particularly useful for characterizing a BECs three-dimensional structure that cannot be well resolved by the two-dimensional absorption imaging. In this context, it is essential to understand the signatures of collective modes of a BEC in various typical geometries and how they change with the geometry. Here, we study a BEC confined in a spherical trap that is tunable to shape the BEC to be a filled sphere, a thin shell, or any crossover stage between them. We employ hydrodynamic treatments and real-time simulations of the Gross–Pitaevskii equation to obtain the collective modes. We find a set of radial modes that can distinguish a sphere from a shell, and an oscillation frequency dip in a crossover region where the central density becomes low. We also explore the angular modes and find a crucial role of the shell BECs inner boundary, which the sphere BEC lacks. Our findings ought to help future experimental investigations on recently realized BECs in bubble-trap potentials.

\textsuperscript{1}Work supported by the National Science Foundation under award DMR-1243574
4:42PM C52.00012 Gravitational Effects on Collective Modes of Superfluid Shells, KARMELA PADAVIC, University of Illinois at Urbana-Champaign, KUEI SUN, The University of Texas at Dallas, COURTNEY LANNERT, Smith College, SMITHA VISHVESHWARA, University of Illinois at Urbana-Champaign — We study the effects of gravity on collective excitations of shell-shaped Bose-Einstein condensates (BECs). Superfluid shells are of general interest as examples of hollow geometries that can be produced in ultracold atoms in bubble-bump potentials or optical lattices. Our approach to analyzing superfluid shells is based on a Gross-Pitaevskii mean field theory and hydrodynamic equations derived from it. Considering a spherically symmetric BEC in general, there are distinct collective excitation spectra for the cases of a fully filled sphere and a very thin shell. Furthermore, an adiabatic change in the potential producing a slow transition from one geometry to the other shows a characteristic evolution. Given that in most realistic experimental conditions gravity cannot be neglected we investigate its effects on the equilibrium profile and the collective modes in the very thin shell limit. We analytically obtain the full excitation spectrum for the thin shell geometry and account for gravity perturbatively at length and energy scales that describe a stable matter-wave bubble. We find that gravity breaks spherical symmetry of the equilibrium density profile and affects the collective excitations by coupling adjacent modes in the angular direction.

4:54PM C52.00013 Classical and quantum dissipation of bright solitons in a bosonic superfluid, DMITRY K. EFIMKIN, Condensed Matter Theory Center, University of Maryland, United States, JOHANNES B. HOFMANN, Condensed Matter Theory Center, University of Maryland, United States and TCM Group, Cavendish Laboratory, University of Cambridge, United Kingdom, VICTOR GALITSKI, Joint Quantum Institute and Condensed Matter Theory Center, University of Maryland, United States — We consider the quantum dissipation of a bright soliton in a quasi-one-dimensional bosonic superfluid. The dissipation appears due to interaction of the soliton with Bogoliubov excitations, which act as a bath for the soliton. Using a collective coordinate approach and the Keldysh formalism, we derive a Langevin equation for the soliton motion which contains both a friction and a stochastic force. We argue that due to the integrability of the original problem, Ohmic friction is absent, rendering the dynamics non-Markovian. We furthermore show that the resulting friction can be interpreted as the backreaction of Bogoliubov quasiparticles emitted by an accelerating soliton, which represents an analogue of the Abraham-Lorentz force known in electrodynamics.

5:06PM C52.00014 Interacting multiple zero mode formulation for a dark soliton in a Bose-Einstein condensate, JUNICHI TAKAHASHI, YUSUKE NAKAMURA, YOSHIYA YAMANAKA, Waseda Univ. — The system of Bose-Einstein condensate (BEC) has a zero-mode (ZM) associated with the spontaneous breakdown of the global phase symmetry. However, to formulate the ZMs in quantum field theory for a finite-size system with spontaneous breakdown of symmetries is not trivial, for in the naive Bogoliubov theory one encounters difficulties such as phase diffusion, the absence of a definite criterion for determining the ground state, and infrared divergences. In order to remove this difficulty, we have recently proposed the new treatment of the ZM, which enable us to introduce a unique ground state in the ZM sector. Using this ground state, we have evaluated the quantum fluctuation for the phase of condensate. In this presentation, we consider an atomic BEC system with a dark soliton that contains two ZMs corresponding to spontaneous breakdown of the global phase and translational symmetries. In our treatment, the original non-linear interaction of the field operator brings us the interaction between the two ZMs. We evaluate the standard deviations of the ZM operators and see how the mutual interaction between the two ZMs affects them.


5:18PM C52.00015 Anomalous energetics and dynamics of moving vortices, LEO RADZIHOVSKY, Department of Physics, University of Colorado — Motivated by the general problem of moving topological defects in an otherwise ordered state and specifically, by the anomalous dynamics observed in vortex-antivortex annihilation and coarsening experiments in freely-suspended smectic-C films, I study the deformation, energetics and dynamics of moving vortices in an overdamped xy-model and show that their properties are significantly and qualitatively modified by the motion.

3supported by NSF through DMR-1001240, MRSEC DMR-0820579, and by Simons Investigator award from Simons Foundation

Tuesday, March 15, 2016 8:00AM - 11:00AM – Session E13 DAMOP: Exploring Topological Physics with Cold Atoms 309 -

8:00AM E13.00001 From Berry’s Phase to Wilson Lines in a Honeycomb Optical Lattice, MONIKA SCHLEIERSMITH, Department of Physics, Stanford University — I will report on methods for fully characterizing the topology and geometry of Bloch bands in optical lattices. Using a Bose-Einstein condensate as a momentum-resolved probe, we study a paradigmatic model system, the honeycomb lattice. Its salient features are two Dirac points, each producing a half-quantum of Berry flux similar to the magnetic flux of an infinitesimally narrow solenoid. We have detected this singular Berry flux by forming an Aharonov-Bohm-type interferometer in momentum space. Our technique is broadly applicable to mapping out the Berry curvature or directly measuring the Chern number of a single band. I will furthermore show how interband dynamics can reveal the matrix-valued Wilson line, the generalization of Berry’s phase to the multi-band setting. In the simple case where the Wilson line is path-independent and Abelian, it serves as a powerful tool for tomographic reconstruction of the band eigenstates. 1,2


8:36AM E13.00002 Geometric “charge” pumping with a Bose-Einstein condensate, IAN SPIELMAN, JQI, NIST and the University of Maryland — We realized a quantum “charge” pump for a Bose-Einstein condensate (BEC) in a novel bipartite magnetic lattice, whose bands are characterized by non-trivial topological invariants: the Zak phases. For each band, the Zak phase is determined by that band’s integrated Berry curvature, a geometric quantity defined at each crystal momentum. We probed this Berry curvature in a charge pump experiment by periodically and adiabatically driving the system. Unlike topological charge pumps in filled bands that yield quantized pumping, our BEC occupied just a single crystal band. Our magnetic lattice enabled us to observe this modulation by measuring the BEC’s magnetization. While our periodic drive shifted the lattice potential by one unit cell per cycle, the displacement of the BEC, solely determined by the underlying Berry curvature, was always less than the lattice’s displacement.
9:12AM E13.00003 Measuring Chern numbers in Atomic Gases: 2D and 4D Quantum Hall Physics in the Lab, NATHAN GOLDMAN, Université Libre de Bruxelles (ULB) — Optical-lattice experiments have recently succeeded in probing the geometry of 2D Bloch bands with cold neutral atoms. Beyond these local geometrical effects, which are captured by the Berry curvature, 2D Bloch bands may also display non-trivial topology, a global property captured by a topological invariant (e.g., the first Chern number). Such topological properties have dramatic consequences on the transport of non-interacting atoms, such as quantized responses whenever the bands are uniformly populated. In this talk, I will start with the first experimental demonstration of topological transport in a gas of neutral particles, which revealed the Chern number through a cold-atom analogue of quantum-Hall measurement. I will then describe how this Chern-number measurement could be extended in order to probe the topology of higher-dimensional systems. In particular, I will show how the second Chern number — an emblematic topological invariant associated with 4D Bloch bands — could be extracted from an atomic gas, using a 3D optical lattice extended by a synthetic dimension. Finally, I will describe a general scheme by which optical lattices of subwavelength spacing could be realized. This method leads to topological band structures with significantly enhanced energy scales, offering an interesting route towards the experimental realization of strongly-correlated topological states with cold atoms.


9:48AM E13.00004 Experimental Realization of the Harper-Hofstadter Model, COLIN KENNEDY, MIT — Extensions of Berry’s phase and the quantum Hall effect have led to the discovery of new states of matter with topological properties. Traditionally, this has been achieved using magnetic fields or spin-orbit interactions, which couple only to charged particles. For neutral ultracold atoms, synthetic magnetic fields have been created that are strong enough to realize the Harper-Hofstadter model. In this talk, I report on work studying Bose-Einstein condensation in the Harper–Hofstadter Hamiltonian with one-half flux quantum per lattice unit cell. The diffraction pattern of the superfluid state directly shows the momentum distribution of the superfluid in the Harper–Hofstadter potential. Additionally, by tuning the energy of the system, we are able to show the quantum control of the system.

10:24AM E13.00005 Topological Charge Pumping with Cold Atoms, YOSHIRO TAKAHASHI, Kyoto University — More than 30 years ago, Thouless considered an interesting phenomenon of quantum transport of an electron gas in an infinite one-dimensional periodic potential, driven in a periodic cycle. The charge pumped by this Thouless pump is a topological quantum number and does not depend on a smooth change of parameters. Importantly, this charge pumping shares the same topological origin as the integer quantum Hall effect. In spite of the importance in a topological quantum physics, this Thouless pump has never been realized in any system. In this study, we successfully realize the Thouless topological pump by exploiting the controllability of ultracold atoms in an optical superlattice. The charge pumping is detected as a shift of the center of mass of an atomic cloud measured with an interferometer.

8:00AM E45.00001 Charge dynamics and spin blockade in a hybrid double quantum dot in silicon1, ANASUA CHATTERJEE, MATIAS URDAMPILLETA, CHEUK CHI LO, JOHN MANSIR, London Centre for Nanotechnology, University College London, SYLVAIN BARRAUD, CEA-LETI, ANDREAS BETZ, M. FERNANDO GONZALEZ-ZALBA, Hitachi Cambridge Laboratory, JOHN J. L. MORTON, London Centre for Nanotechnology, University College London — Hybrid architectures combining donor atoms and quantum dots in silicon can take advantage of fast gate voltage based spin manipulations to form a hybrid singlet-triplet qubit, with access to the quantum memory offered by the nuclear spin of the donor via the hyperfine interaction. Additionally, spin buses using quantum dot chains could mediate the transfer of quantum information between long-lived donor spins. We present an approach to a novel hybrid double quantum dot by coupling a donor to an artificial atom in a CMOS-compatible nanotransistor. Using gate-based RF-reflectometry, we probe the charge stability of the system and its quantum capacitance. Through microwave spectroscopy, we find a tunnel coupling of 2.7GHz and characterize the charge dynamics, revealing a charge $g_1$ of 100ns. We also show spin blockade at the inderdot transition and investigate the spin dynamics, opening up the possibility to operate this coupled system as a singlet-triplet qubit and to coherently transfer spin information between the quantum dot and the donor electron and nucleus.

1We acknowledge support from the TOLOP project (FP7/318397), the EPSRC, ARC, and the UNDEDD project, the Royal Commission for the Exhibition of 1851 and the Royal Society.

8:12AM E45.00002 Controlling spin relaxation with a cavity, AUDREY BIENFAIT, SPEC, CEA-Saclay, JARRYD PLA, University College of London, YUIMARU KUBO, SPEC, CEA-Saclay, XIN ZHOU, Institute of Electronics, Microelectronics, and Nanotechnology, MICHAEL STERN, University of Bar Ilan, CHEUK LO, University College London, CHRISTOPHER WEIS, THOMAS SCHENKEL, Lawrence Berkeley National Laboratory, DENIS VION, DANIEL ESTEVE, SPEC, CEA-Saclay, JOHN MORTON, University College of London, PATRICE BERTET, SPEC, CEA-Saclay — Spontaneous emission of radiation is one of the fundamental relaxation mechanisms for a quantum system. For spins, however, it is negligible compared to non-radiative relaxation processes due to their weak coupling to the electromagnetic field. In 1946, Purcell realized [1] that spontaneous emission is strongly enhanced when the quantum system is placed in a resonant cavity - an effect now used to control the lifetime of systems with an electrical dipole [2]. Here, by coupling donor spins in silicon to a high quality factor superconducting microwave cavity of small mode volume, we reach the regime where spontaneous emission constitutes the dominant spin relaxation channel [3]. The relaxation rate is increased by three orders of magnitude when the spins are tuned to the cavity resonance, showing it can be engineered and controlled on-demand. Our results provide a novel way to initialize any spin into its ground state, with applications in magnetic resonance and quantum information processing. They also show for the first time an alteration of spin dynamics by quantum fluctuations, a step towards the coherent magnetic coupling of a spin to microwave photons. [1] E. M. Purcell, Phys. Rev. 1946, 69, 681.
the sample with a on-chip microstrip. We estimate the sensing volume and the minimum distinguishable number of electron spins to be \( \Omega \sim 0.1 \) and it has good agreement to the hyperbolic tangent law. We also successfully demonstrate EPR spectroscopy by applying a continuous microwave signal to a spectroscopy using a micrometer-sized dc-SQUID magnetometer. We measure temperature and in-plane magnetic field dependence of spin polarization ratio to characterize materials containing unpaired electrons. In the case of conventional EPR spectrometers, the resonance is detected as a change of microwave intensity of various encoded quantum dot spin-qubits to a microwave resonator via modulation of voltage gates. A dynamical coupling of tens of MHz can be achieved. Implications for entanglement sustained indefinitely. The achievable steady-state fidelities for entanglement and its scaling with the number of qubits are discussed for presently available superconducting quantum circuits. While the protocol is primarily discussed for a superconducting circuit architecture, it is ideally realized in any Cavity QED platform that permits controllable delivery of coherent electromagnetic radiation to specified locations.

Photonic entanglement has recently been shown to occur in the presence of cavity phonons in a hybrid Cavity Quantum Electrodynamics (QED) platform that permits controllable delivery of coherent electromagnetic radiation to specified locations.

Combining Rydberg hyperfine states of cesium atoms with superconducting circuit architectures provides an opportunity for highly sensitive and highly selective EPR spectroscopy. In this work, we demonstrate the first direct coupling of a nanoscale electron spin ensemble to a superconducting qubit in a single flux qubit. We observe a signal-to-noise ratio of 1 in a single echo \([3]\). We also demonstrate that the energy relaxation time of the spins is limited by spontaneous emission of microwave photons into the measurement line via the resonator \([4]\), which opens the way to on-demand spin initialization via the Purcell effect. These results constitute a first step towards circuit QED experiments with ultracold Rydberg atoms. These observations motivate the development of novel hybrid quantum computing architectures that combine superconducting circuits with Rydberg atoms to achieve highly sensitive EPR spectroscopy.

We report a new approach to implementing Rydberg atom-based quantum computing. This approach combines the strengths of Rydberg atoms and superconducting circuits to address challenges in existing hybrid qubit architectures. Our hybrid platform enables on-demand initialization, high-fidelity measurements, and high-gain signal detection. We demonstrate the feasibility of this approach by realizing a hybrid qubit that combines a superconducting qubit with a Rydberg atom. This hybrid platform provides a new route to realizing highly sensitive and highly selective EPR spectroscopy.
10:12AM E45.00010 Angular dependant micro-ESR characterization of a locally doped Gd$^{3+}$:Al$_2$O$_3$ hybrid system for quantum applications, I. S WISBY, NPL, UK & Royal Holloway, UK, S.E DE GRAAFF, NPL, UK, G R. GILL, J.M. ATLI, University of Surrey, UK, A. ADAMYAN, Chalmers University of Technology, S. E. KUBATKIN, Chalmers University of Technology, Sweden, P. J. MEESON, Royal Holloway, UK, A. YA. TZALENCHUK, NPL, UK & Royal Holloway, UK, T. LINDESTROM, NPL, UK — Rare-earth doped crystals interfaced with superconducting quantum circuitry are an attractive platform for quantum memory and transducer applications. Here we present a detailed characterization of a locally implanted Gd$^{3+}$ in Al$_2$O$_3$ system coupled to a superconducting micro-resonator, by performing angular dependent micro-electron-spin-resonance (micro-ESR) measurements at mK temperatures. The device is fabricated using a hard Si$_3$N$_4$ mask to facilitate a local ion-implantation technique for precision control of the dopant location. The technique is found not to degrade the internal quality factor of the resonators which remains above $10^7$ (1). We find the measured angular dependence of the micro-ESR spectra to be in excellent agreement with the modelled expectations, supporting the conclusion that the dopant ions are successfully integrated into their relevant lattice sites whilst maintaining crystalline symmetries. Furthermore, we observe clear contributions from individual microwave field components of our micro-resonator, emphasising the need for controllable local implantation. 1) Wisby et al. Appl. Phys. Lett. 105, 102601 (2014)

10:24AM E45.00011 Strong Coupling of a Donor Spin Ensemble to a Volume Microwave Resonator, BRENDON ROSE, ALEXEI TYRYSHKIN, STEPHEN LYON, Princeton University — We achieve the strong coupling regime between an ensemble of phosphorus donor spins (5e13 total donors) in highly enriched 28-Si (50 ppm 29-Si) and a standard dielectric resonator. Spins were polarized beyond Boltzmann equilibrium to a combined electron and nuclear polarization of 120 percent using spin selective optical excitation of the no-phonon bound exciton transition. We observed a spin ensemble-resonator splitting of 580 kHz ± 28 kHz in a cavity with a Q factor of 75,000 ($\kappa < \gamma < 100\kappa$ Hz where $\kappa$ and $\gamma$ are the external and internal resonator loss rates respectively). The spin ensemble has a long dephasing time (9 ps) providing a wide window for viewing the time evolution of the coupled spin ensemble-cavity system described by the Tavis-Cummings model The free induction decay shows repeated collapses and revivals revealing a coherent and complete exchange of excitations between the superradiant state of the spin ensemble and the cavity (about 10 cycles are resolved). This exchange can be viewed as a swap of information between a long lived spin ensemble memory qubit ($T_2 \approx 2$ ms) and a cavity

10:36AM E45.00012 Suppressing gate errors through extra ions coupled to a cavity in frequency-domain quantum computation using rare-earth-ion-doped crystal, SATOSHI NAKAMURA, HAY-ATO GOTO, MAMIKO KUJIRAOKA, KOICHI ICHIMURA, Corporate RD Center, Toshiba Corporation, QUANTUM COMPUTER TEAM — The rare-earth-ion-doped crystals, such as Pr$^{3+}$: Y$_2$SiO$_5$, are promising materials for scalable quantum computers, because the crystals contain a large number of ions which have long coherence time. The frequency-domain quantum computation (FDQC) enables us to employ individual ions coupled to a common cavity mode as qubits by identifying with their transition frequencies. In the FDQC, operation lights with detuning interact with transitions which are not intended to operate, because ions are irradiated regardless of their positions. This crosstalk causes serious errors of the quantum gates in the FDQC. When resonance conditions between eigenenergies of the whole system and transition-frequency differences among ions are satisfied, the gate errors increase. Ions for qubits must have transitions avoiding the conditions for high-fidelity gate. However, when a large number of ions are employed as qubits, it is difficult to avoid the conditions because of many combinations of eigenenergies and transitions. We propose new implementation using extra ions to control the resonance conditions, and show the effect of the extra ions by a numerical simulation. Our implementation is useful to realize a scalable quantum computer using rare-earth-ion-doped crystal based on the FDQC.

10:48AM E45.00013 Magneto-transport studies of a few hole GaAs double quantum dot in tilted magnetic fields, SERGEI STUDENIKIN, ALEX BOGAN, National Research Council of Canada, LISA TRACY, Sandia National Laboratories, LOUIS GAUDREAU, ANDY SACHRAIDA, MAREK KORKUSINSKI, National Research Council of Canada, JOHN RENO, TERRY HARGETT, Sandia National Laboratories — Compared to equivalent electron devices, single-hole spins interact weakly with lattice nuclear spins leading to extended quantum coherence times. This makes p-type Quantum Dots (QD) particularly attractive for practical quantum devices such as qubit circuits, quantum repeaters, quantum sensors etc. where long coherence time is required. Another property of holes is the possibility to tune their g-factor as a result of the strong anisotropy of the valence band. Hole g-factors can be conveniently tuned in situ from a large value to almost zero by tilting the magnetic field relative to the 2D hole gas surface normal. [1] In this work we explore high-bias magneto-transport properties of a p-type double quantum dot (DQD) device fabricated from a GaAs/AlGaAs heterostructures using lateral split-gate technology.[2] A charge detection technique is used to monitor number of holes and tune the p-DQD in a single hole regime around (1,1) and (2,0) occupation states where Pauli spin-blockaded transport is expected. Four states are identified in quantizing magnetic fields within the high-bias current stripe — three-fold triplet and a singlet which allows determining effective heavy hole g-factor as a function of the tilt angle from 90 to 0 degrees. [1] G. Ares et al., Phys.Rev. Lett. 110, 046602 (2013); [2] L. A. Tracy et al., App. Phys. Lett. 104, 123101 (2014).


11:15AM F2.00001 Floquet States: Anomalous topological phases and steady state engineering, GIL REFAEL, Caltech — Periodically driven quantum systems provide a novel and versatile platform for realizing topological phenomena. In my talk I’ll provide a brief introduction to the Floquet path to topological behavior. Next, I will concentrate on a remarkable Floquet state that has no static analog: A 2d system which has chiral edge states, alongside fully localized bulk orbitals. This unique situation serves as the basis for a new topologically-protected non-equilibrium transport phenomenon: quantized non-adiabatic charge pumping. We identify the bulk topological invariant that characterizes this new phase,which we dub the ‘anomalous Floquet Anderson Insulator’. In the second part of my talk, I will discuss recent results on stabilizing steady states in periodically driven fermionic semiconducting systems using bosonic and fermionic bath engineering.

11:51AM F2.00002 When do Floquet systems fail to heat?, ANUSHYA CHANDRAN, Perimeter Institute — Periodically driven quantum systems do not have a conserved energy. Thus, statistical mechanical lore holds that if they thermalize, it must be to infinite temperature. We will first show this holds in simple systems that satisfy the eigenstate thermalization hypothesis. I will then present recent results examining the signature of infinite temperature heating. The first is the bosonic O(N) model at infinite N, in which the steady states are paramagnetic and have non-trivial correlations. The second is the Clifford circuit model, which can fail to heat depending on the choice of circuit elements. The resulting steady states can then be localized or delocalized but not ergodic. Such models shed light on the nature of interacting Floquet localization.
12:27PM F2.00003 Floquet thermodynamics–nature of ensembles and order under periodic driving, ACHILLES LAZARIIDES, Max Planck Institute for the Physics of Complex Systems, Dresden — We study the long-time behaviour of many-body Floquet systems—closed quantum systems under temporally periodic driving, arguably the simplest deviation from equilibrium. We begin by showing that generically such interacting systems heat up and discuss the microscopic mechanism by which this happens. We then discuss two ways to prevent this: integrability and disorder. In the integrable case, a “periodic Gibbs ensemble” may be derived by maximising the entropy and shown to exactly describe the long-time steady state, while in the interacting disordered (many-body localised, or MBL) case, we identify the regime under which driving does not delocalise the system. We conclude by discussing the nontrivial steady-states achieved in interacting Floquet systems.

1:03PM F2.00004 Floquet engineering with ultracold fermions: From Haldane’s model of topological bands to spin-dependent lattices, MICHAEL MESSER, ETH Zurich — Periodically driving a system of ultracold fermionic atoms in an optical lattice allows for implementing a large variety of effective Hamiltonians through Floquet engineering. Using this concept we realize the Haldane model which is a fundamental example of a Hamiltonian exhibiting topologically distinct phases of matter. By loading non-interacting degenerate fermions in a periodically modulated honeycomb lattice we can implement and characterize the topological band structure. We explore the resulting Berry-curvatures of the lowest band and map out topological phase transitions connecting distinct regimes. Such a technique may be extended to also address internal degrees of freedom. By periodically modulating a magnetic field gradient we tune the relative amplitude and sign of the tunneling for different internal states. Thereby we experimentally realize spin-dependent effective Hamiltonians where one state can be pinned to the lattice, while the other remains itinerant. For each spin state, the differing band structure can be characterized either by measuring the expansion of an atomic cloud in the lattice, or by a measurement of the effective mass through dipole oscillations. Furthermore we use the tunability of ultracold atoms to investigate the role of interactions.

1:39PM F2.00005 Localization effects in periodically driven many-body systems1, FRANCOIS HUVE-NEERS, CEREMADE, Université Paris Dauphine — In this talk, I will discuss the emergence of quasi, or sometimes strictly, conserved quantities in periodically driven many-body quantum systems. In the particular case of a many-body localized Hamiltonian, characterized by a full set of local integral of motions (LIOMs), I will show that the driven system itself admits a full set of strictly conserved LIOMs, if the driving frequency is high enough. Moreover, I will show that the ideas developed in the context of driven systems can be generalized to describe the emergence of pre-thermal behavior in a wide class of both closed and driven systems.

References:
1Joint work with D. Ahanin, W. De Roeck, W. W. Ho


11:15AM F13.00001 New theoretical tools for quantum glasses, with and without quenched disorder, LOUK RADEMAKER, Univ of California - Santa Barbara — Even though most solid materials are disordered or glasslike, our understanding of such non-equilibrium phases of matter is meager. Our task is thus to develop new tools to understand the nature of quantum glasses. These can be characterized into two classes: with or without quenched disorder. Interacting spin or electron models with quenched disorder are known to exhibit many-body localization (MBL). We discuss a new method based on a Hilbert-space preserving RG scheme to find the integrals of motion for an interacting system. We used this approach to numerically study MBL phases and the corresponding transition. On the other hand, we discuss the possibility of self-generated electron glassiness in the absence of quenched disorder. Such structural quantum glasses, requiring geometric frustration and long-range interactions, are in many ways similar to the quenched disorder glasses. We will discuss the soft gap in the density of states, which is now related to short-range frozen density correlations. Using both numerical and analytic arguments we find Arrhenius-type slow relaxation and stretched exponential behavior.

References:

11:51AM F13.00002 Quench and Transport Dynamics in Disordered Atomic Hubbard Lattices1, BRIAN DEMARCO, Univ of Illinois - Urbana — I will give an overview of our experiments using ultracold atom gases trapped in optical lattices to probe transport, dynamics, and relaxation in disordered Hubbard models. By introducing disorder to naturally clean optical lattices using focused optical speckle, we realize variants of the disordered Bose- and Fermi-Hubbard models. In these systems, the distribution of Hubbard parameters is fully known, and the ratio of characteristic energy scales is completely tunable. I will discuss two measurements. In the first, we observe localization via transport measurements in the metallic regime of the Fermi-Hubbard model. We observe three phenomena consistent with many-body localization: localization at non-zero temperature, localization across a range of temperatures, and interaction-induced delocalization. These measurements show agreement with a mean-field theory in a limited parameter regime. In a separate experiment using bosonic atoms, we measure excitations following a quantum quench of disorder. Via comparison to state-of-the-art quantum Monte Carlo calculations that capture all aspects of the experiments—including all the particles—we show that the onset of excitations corresponds to the superfluid–Bose-glass transition. I will discuss how this behavior is reminiscent of the quantum Kibble-Zurek effect.

References:
1This work is funded by the NSF and ARO.
The role of weak interactions on the mobility-edge of strongly disordered electron systems. New insights into the nature of the mobility edge of a weakly correlated, disordered Anderson spectra will be presented within the typical medium dynamical cluster approximation (TMDCA). TMDCA systematically incorporates non-local spatial correlations (beyond the single-site approximations) treating the disorder to all orders and the interacting, non-local cluster self-energy up to second order in the perturbation expansion of the interactions, $U$. An arbitrary small interaction is found to lead to an exponential fast crossover of the sharp mobility edge that separates the localized and extended states in the non-interacting regime below the critical disorder strength $U_{c}^{\text{crit}} = 0$ whenever the chemical potential of the non-interacting typical density of states is below the mobility edge energy. This smearing of the mobility edge is ascribed to the inelastic scattering due to $U$. However, as the chemical potential, $\mu$, approaches the smeared edge, reduction of the phase space for scattering by $U$ causes the edge to once again become sharp. A concomitant pseudogap is found at energy, $\omega = 0$ independent of filling, which is linear rather than quadratic in $\omega$, due to the lack of momentum conservation. The method is demonstrated on realistic low-dimensional structures.

This work was supported by the Office of Naval Research through the Naval Research Laboratory and NSF DMR-1237565 and the NSF EPSCoR Cooperative Agreement EPS-1068397

Precise finite-temperature properties of disordered strongly-correlated electronic systems. The interplay between disorder and electronic interactions in quantum many-body systems is not well understood. Experiments with ultracold atoms on optical lattices hold a great promise for exploring the different competing phases that arise in these systems by simulating disordered quantum lattice models in the presence of interactions. However, these experiments often rely on precise and approximate-free results from numerical calculations for various static and dynamic properties of these models in order to characterize the experimental systems. In this talk, I will present recently obtained data for the thermodynamic properties and magnetic correlations of the disordered three-dimensional Hubbard model using the determinant quantum Monte Carlo. I will also discuss new techniques within the linked-cluster expansions that allow for fast and precise calculation of finite-temperature properties of disordered systems in the thermodynamic limit.

Properties of dirty bosons in disordered optical lattices. Disorder is ubiquitous in nature and its presence can lead to fascinating phenomena such as Anderson localization, Griffiths mechanisms and glassiness. These types of behavior have profound consequences on low temperature ordered phases that are difficult to study, particularly due to lack of controllable disorder. Recent advances in ultra-cold atomic systems have made it possible to make significant progress in overcoming such challenges – making direct comparisons with large scale Quantum Monte Carlo techniques a possibility. I will talk about the disordered Bose-Hubbard model and the equilibrium properties of the domains that arise in trapped systems. I will show how they correspond to phases and explore the consequences of finite temperature and strong correlations. These aspects will be used to explain the observations of experimental measurements. In particular, I will highlight results of a recent collaborative enterprise that show excellent agreement between theory and experiment.

The way to phase space crystals. A novel way to create a band structure of the quasienergy spectrum for driven systems is proposed based on the discrete symmetry in phase space. The system, e.g., an ion or ultracold atom trapped in a potential, shows no spatial periodicity, but it is driven by a time-dependent field. Under rotating wave approximation, the system can produce a periodic lattice structure in phase space. The band structure in quasienergy arises as a consequence of the n-fold discrete periodicity in phase space induced by this driving field. We propose explicit models to realize such a phase space crystal and analyze its band structure in the frame of a tightbinding approximation. The phase space lattice differs fundamentally from a lattice in real space, because its coordinate system, i.e., phase space, has a noncommutative geometry. The phase space crystal opens new ways to engineer energy band structures, with the added advantage that its properties can be changed in situ by tuning the driving fields parameters.

The role of weak interactions on the mobility-edge of strongly disordered electron systems. New insights into the nature of the mobility edge of a weakly correlated, disordered Anderson spectra will be presented within the typical medium dynamical cluster approximation (TMDCA). TMDCA systematically incorporates non-local spatial correlations (beyond the single-site approximations) treating the disorder to all orders and the interacting, non-local cluster self-energy up to second order in the perturbation expansion of the interactions, $U$. An arbitrary small interaction is found to lead to an exponential fast crossover of the sharp mobility edge that separates the localized and extended states in the non-interacting regime below the critical disorder strength $U_{c}^{\text{crit}} = 0$ whenever the chemical potential of the non-interacting typical density of states is below the mobility edge energy. This smearing of the mobility edge is ascribed to the inelastic scattering due to $U$. However, as the chemical potential, $\mu$, approaches the smeared edge, reduction of the phase space for scattering by $U$ causes the edge to once again become sharp. A concomitant pseudogap is found at energy, $\omega = 0$ independent of filling, which is linear rather than quadratic in $\omega$, due to the lack of momentum conservation. The method is demonstrated on realistic low-dimensional structures.

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12:03PM F50.00005 Statistical Transmutation in Periodically Driven Optical Lattices, TIGRAN SEDRAKyan, W. I. Fine Theoretical Physics Institute, University of Minnesota, Joint Quantum Institute, University of Maryland - College Park, Victor Galtiski, Joint Quantum Institute, University of Maryland - College Park. We show that bosons in a periodically driven two dimensional (2D) optical lattice may effectively exhibit fermionic statistics. The phenomenon is similar to the celebrated Tonks-Girardeau regime in 1D. The Floquet band of a driven lattice develops the moat shape, i.e., a minimum along a closed contour in the Brillouin zone. Such degeneracy of the kinetic energy favors fermionic quasiparticles. The statistical transmutation is achieved by the Chern-Simons flux attachment similar to the fractional quantum Hall case. We show that the velocity distribution of the released bosons is a sensitive probe of the fermionic nature of their stationary Floquet state.

1:15PM F50.00006 Driven impurity in an ultracold 1D Bose gas with intermediate interaction strength, Jean-Sebastien Caux, University of Amsterdam, Steve Simon, University of Oxford, Claudioio Castelnovo, University of Cambridge - We study a single impurity driven by a constant force through a 1D Bose gas using a Lieb-Liniger based approach. Our calculation is exact in the interaction amongst the particles in the Bose gas, and is perturbative in the interaction between the gas and the impurity. In contrast to previous studies of this problem, we are able to handle arbitrary interaction strength for the Bose gas. We find very good agreement with recent experiments [Phys. Rev. Lett. 103, 150601 (2009)].

12:27PM F50.00007 The anomalous Floquet-Anderson insulator as a non-adiabatic quantized charge pump, Paraj Titum, Institute for Quantum Information and Matter, Caltech, Pasadena, California 91125, USA, Erez Berg, The Weizmann Institute of Science, Rehovot, 76100, Israel, Mark S. Rudner, Niels Bohr International Academy and Center for Quantum Devices, University of Copenhagen, 2100 Copenhagen, Denmark, Gil Refael, Institute for Quantum Information and Matter, Caltech, Pasadena, California 91125, USA, Netanel H. Lindner, Physics Department, Technion, 320003 Haifa, Israel - Periodically driven quantum systems provide a novel and versatile platform for realizing topological phenomena. Among these are analogs of topological insulators and superconductors, attainable in static systems; however, some of these phenomena are unique to the periodically driven case. Here, we show that disordered, periodically driven systems admit an anomalous two dimensional phase, whose quasi-energy spectrum consists of chiral edge modes that coexist with a fully localized bulk – an impossibility for static Hamiltonians. This unique situation serves as the basis for a new topologically-protected non-equilibrium transport phenomenon: quantized non-adiabatic charge pumping. We provide explicit models which constitute a proof of principle for the existence of the new phase. Finally, we present evidence that the disorder-driven transition from the AAI to a trivial, fully localized phase is in the same universality class as the quantum Hall plateaux transition.

12:39PM F50.00008 Exact nonadiabatic steering of quantum particles between arbitrary instantaneous eigenstates of time-dependent Hamiltonians, Rafael Hipolito, Paul Goldbart, Georgia Institute of Technology - We consider a system governed by a Hamiltonian $H[R_n(t)]$ that depends on a set of parameters $R_n(t)$ that can be varied with time. We address the task of steering this system between a pair of eigenstates, one corresponding to $H[R_n(t)]$, the other to $H[R_f(t)]$. For any parameter history connecting $R_n(t)$ and $R_f(t)$, we formulate a measure of success with this task, based on a path-integral expression for the overlap between the time-evolved initial state (as driven by $H[R_n(t)]$) and the final state, which is obtained by integrating out the system degrees of freedom but which retains a dependence on the parameter history $R_f(t)$. We discuss various settings in which this program may be carried out with perfect accuracy, by optimizing the measure of success with respect to the parameter history. The task may be accomplished over timescales that are much shorter than simple adiabaticity would require and are on the order of the intrinsic timescale of the system dynamics. For illustration, we consider the example of a particle (possibly with internal freedoms) that is confined by a harmonic potential having time-varying center, curvature and squeezing parameters, for which we determine the parameter history required to steer the particle with perfect accuracy.

12:51PM F50.00009 Geodesic paths for quantum many-body systems, Michael Tomka, Tiago Souza, Steve Rosenberg, Michael Kolodrubetz, Anatoli Polkovnikov, Boston University - The quantum length is a distance between parameter-dependent eigenstates of an adiabatically driven quantum system. Its associated metric has many intriguing properties, for example it is related to the fidelity susceptibility, an important quantity in the study of quantum phase transitions. This quantity also appears as the leading adiabatic correction of the energy fluctuations of a quantum system and gives rise to a time-energy uncertainty principle and a geometric interpretation of time. The adiabatic response of an open quantum system can as well be expressed through this metric. Further, the quantum length introduces the notion of Riemannian geometry to the manifold of eigenstates and hence allows one to define geodesics in parameter space. We study the geodesics in parameter space of certain quantum many-body systems, emerging from this quantum distance. These geodesic paths provide a well-defined optimal control protocol on how to drive the systems parameters in time, to get from one eigenstate to another. Generating optimal evolution plays a central role in quantum information technology, adiabatic quantum computing and quantum metrology.

01:03PM F50.00010 Hysteresis of Current in Noninteracting Atomic Fermi Gases in Optical Ring Potentials, Mekena Metcalf, CHIH-CHUN CHIEN, CHEN-YEN LAI, Univ of California - Merced - Hysteresis is a ubiquitous phenomenon, which can be found in magnets, superfluids, and many-body systems. Although interactions are present in most systems exhibiting hysteresis, here we show the current of a non-interacting Fermi gas in an optical ring potential produces hysteresis behavior when driven by a time-dependent artificial gauge field and subject to dissipation. Fermions in a ring potential threaded with flux can exhibit a persistent current when the system is in thermal equilibrium, but cold-atoms are clean and dissipation for reaching thermal equilibrium may be introduced by an external, thermal bath. We use the standard relaxation approximation to model the dynamics of cold-atoms driven periodically by an artificial gauge field. A competition of the drive time and the relaxation time leads to hysteresis of the mass current, and work done on the system, as a function of the relaxation time, exhibits similar behavior as Kramers transition rate in chemical reaction and one-dimensional thermal transport.

1:15PM F50.00011 On Exact Solutions of Novel Multistate Landau-Zener Problems, Aniket Patra, Emil Yuzbashyan, Rutgers University - A multistate Landau-Zener (MLZ) Hamiltonian is used to model numerous non-equilibrium experiments involving cold atoms, showing that all the known MLZ problems either belong to the 2 × 2 Landau-Zener problem or belong to a family of mutually commuting Hamiltonians (that are polynomial in time). Based on this classification we identify previously unknown MLZ problems, explicitly obtain their solutions and discuss relevant experimental scenarios.

1:23PM F50.00012...
1:27PM F50.00012 Adiabaticity in a dimerised optical lattice site with increasing laser intensity

SCOTT TAYLOR, CHRIS HOOLEY, University of St Andrews, UK — Recent experiments attempting to simulate magnetic phenomena with cold atoms in optical lattices rely on systems of a few atoms in dimerised lattice sites. These atoms may be manipulated by deformations of the lattice potential, which often need to be adiabatic, but must also happen quickly. We consider such a system of two fermions in a time-dependent double well potential, described by a two-site Hubbard model with time-dependent hopping and interaction energies. The adiabaticity of the following process is analysed: the system is prepared in the ground state of a shallow potential, which is smoothly transformed to a deep potential over some period of time. Experimentally, this corresponds to ramping up the intensity of the lasers generating the lattice. We present numerical and analytical results, demonstrating principles to design fast, adiabatic ramp profiles.

1:39PM F50.00013 Non-equilibrium dynamics of a quantum gas in a box. ZORAN HADZIBABIC, University of Cambridge — For the past two decades harmonically trapped ultracold atomic gases have been used with great success to study both equilibrium and non-equilibrium many-body physics in a flexible experimental setting. Recently, we achieved the first atomic Bose-Einstein condensate in an essentially uniform potential of an optical-box trap, which has opened new possibilities for closer connections with other many-body systems and the theories that rely on the translational symmetry of the system. I will present our recent experiments on non-equilibrium phenomena in this system, including the study of the Kibble-Zurek dynamics of spontaneous symmetry breaking in a quenched homogeneous gas.

1:51PM F50.00014 Spin diffusion in ultracold spin-orbit coupled $^{40}$K gas, T. YU, M. W. WU, Univ of Sci & Tech of China — We investigate the steady-state spin diffusion for ultracold spin-orbit coupled $^{40}$K gas by the kinetic spin-Bloch equation approach. It is found that the behaviors of the steady-state spin diffusion are determined by three characteristic lengths in the system: the mean free path, the Zeeman oscillation length and the spin-orbit coupling oscillation length. It is further revealed that by tuning the scattering strength, the system can be divided into five regimes, in which the behaviors of the spacial evolution of the steady-state spin polarization shows different dependencies on the scattering strength, Zeeman field and spin-orbit coupling strength. These rich behaviors of the spin diffusions in different regimes are hard to be understood in the framework of the simple drift-diffusion model or the direct inhomogeneous broadening picture in the literature. However, almost all these rich behaviors can be well understood by means of our modified drift-diffusion model and/or modified inhomogeneous broadening picture. Specifically, several anomalous features of the spin diffusion are revealed, which are relevant to those obtained from both the simple drift-diffusion model and the direct inhomogeneous broadening picture.

2:15PM F50.00015 Prediction of the expansion velocity of ultracold 1D quantum gases for integrable models. ZHONGTAO MEI, University of Cincinnati, LEV VIDMAR, FABIAN HEIDRICH-MEISNER, Ludwig-Maximilians-Universitaet Muenchen, CARLOS BOLECH, University of Cincinnati — In the theory of Bethe-ansatz integrable quantum systems, rapidities play an important role as they are used to specify many-body states. The physical interpretation of rapidities going back to Sutherland is that they are the asymptotic momenta after letting a quantum gas expand into a larger volume rendering it dilute and noninteracting. We exploit this picture to calculate the expansion velocity of a one-dimensional Fermi-Hubbard model by using the distribution of rapidities defined by the initial state [1]. Our results are consistent with the ones from time-dependent quantum gas expand into a larger volume rendering it dilute and noninteracting. We exploit this picture to calculate the expansion velocity of a one-dimensional Fermi-Hubbard model by using the distribution of rapidities defined by the initial state [1].

Tuesday, March 15, 2016 2:30PM - 5:18PM –
Session H45 GQI DAMOP: Quantum Information with Ions, Photons and Spins 348 - Philipp Schindler, Innsbruck University

2:30PM H45.00001 Parallel transport gates in a mixed-species ion trap processor

JONATHAN HOME, ETH Zurich — Scaled up quantum information processors will require large numbers of parallel gate operations. For ion trap quantum processing, a promising approach is to perform these operations in separated regions of a multi-zone processing chip between which quantum information is transported either by distributed photonic entanglement or by deterministic shuttling of the ions through the array. However scaling the technology for controlling pulsed laser beams which address each of multiple regions appears challenging. I will describe recent work on the control of both beryllium and calcium ions by transporting ions through static laser beams. We have demonstrated both parallel individually addressed operations as well as sequences of operations. Work is in progress towards multi-qubit gates, which requires good control of the ion transport velocity. We have developed a number of techniques for measuring and optimizing velocities in our trap, enabling significant improvements in performance. In addition to direct results, I will give an overview of our multi-species apparatus, including recent results on high fidelity multi-qubit gates.

3:06PM H45.00002 Quantum information processing with long-wavelength radiation

DAVID MURGIA, Imperial College London, SEBASTIAN WEIDT, University of Sussex, JOSEPH RANDALL, Imperial College London, BOJERN LEKITSCH, SIMON WEBSTER, TOMAS NAVICKAS, ANTON GROUNDS, ANDREA RODRIGUEZ, ANNA WEBB, EAMON STANDING, University of Sussex, STUART PEARCE, IBRAHIM SARI, KIAN KIANG, HWANJIT RATTANASONTI, MICHAEL KRAFT, University of Southampton, WINFRIED HENSINGER, University of Sussex — To this point, the entanglement of ions has predominantly been performed using lasers. Using long wavelength radiation with static magnetic field gradients provides an architecture to simplify construction of a large scale quantum computer. The use of microwave-dressed states protects against decoherence from fluctuating magnetic fields, with radio-frequency fields used for qubit manipulation. I will report the realisation of spin-motion entanglement using long-wavelength radiation, and a new method to efficiently prepare dressed-state qubits and qutrits, reducing experimental complexity of gate operations. I will also report demonstration of ground state cooling using long wavelength radiation, which may increase two-qubit entanglement fidelity. I will then report demonstration of a high-fidelity-long-wavelength two-ion quantum gate using dressed states. Combining these results with microfabricated ion traps allows for scaling towards a large scale ion trap quantum computer, and provides a platform for quantum simulations of fundamental physics. I will report progress towards the operation of microchip ion traps with extremely high magnetic field gradients for multi-ion quantum gates.
3:18PM H45.00003 Controlled-phase gate for photons based on stationary light. IVAN IAKOPOV, Niels Bohr Institute, JOHANNES BORREGAARD, Harvard University, ANDERS S. SØRENSEN, Niels Bohr Institute — We propose a controlled-phase gate for optical photons based on an atomic ensemble coupled to a one-dimensional waveguide. When an ensemble of Λ-type atoms is subject to a standing wave control field, it creates a stationary light [1] effect where the ensemble develops a band gap for light propagation. For frequencies close to the band gap, the light-matter interactions are enhanced due to the reduced group velocity of the light pulses. Changing the internal state of one of the atoms, such that it behaves as an absorbing two-level atom instead of a transparent Λ-type atom, can change the scattering properties of the whole ensemble, switching it from being completely transmissive to being completely reflective. To realize a controlled-phase gate between photons, we store one of the photons inside the atomic ensemble (thereby changing the internal state of one of the atoms), scatter a second photon off the ensemble, and retrieve the first photon. Finally, we consider an application of the proposed controlled-phase gate — a quantum repeater.

References


3:30PM H45.00004 Photonic Quantum Logic with Narrowband Light from Single Atoms. ALLISON RUBENOK, University of Bristol, ANNEMARIE HOLDECZEK, OLIVER BARTER, JEROME DILLEY, PETER B. R. NISBET-JONES1, GUNNAR LANGFAH-KLABES, AXEL KUHN, University of Oxford, CHRIS SPARROW, University of Bristol, Imperial College London, GRAHAM D. MARSHALL, JEREMY L. O'BRIEN, KONSTANTINOS POULIOS2, JONATHAN C. F. MATTHEWS, University of Bristol — Atom-cavity sources of narrowband photons are a promising candidate for the future development of quantum technologies. Likewise, integrated photonic circuits have established themselves as a for-running contender in quantum computing, security, and communication. Here we report on recent achievements to interface these two technologies: Atom-cavity sources coupled to integrated photonic circuits. Using narrow linewidth photons emitted from a single 87Rb atom strongly coupled to a high-finesse cavity we demonstrate the successful operation of an integrated control-not gate. Furthermore, we are able to verify the generation of post-selected entanglement upon successful operation of the gate. We are able to see non-classical correlations in detection events that are up to three orders of magnitude farther apart than the time needed for light to travel across the chip. Our hybrid approach will facilitate the future development of technologies that benefit from the advantages of both integrated quantum circuits and atom-cavity photon sources.

3:42PM H45.00005 Scalable Boson Sampling with Noisy Components. TYLER KEATING, University of New Mexico, JOSEPH SLOTE, Carleton College, GOPIKRISHNAN MURALEDHARAN, EZEQUIEL CARRASCO, IVAN DEUTSCH, University of New Mexico — The goal of a Boson Sampler is to efficiently and scalably sample from a probability distribution that cannot be simulated efficiently on a classical computer, thus violating the Extended Church-Turing Thesis (ECTT). To properly falsify the ECTT, the physical device must do so even in the face of realistic noise. Scaling a Boson Sampler requires increasing quantities of a set of fixed-size components (beamsplitters, detectors, etc.), so it is natural to consider noise models that act on each component independently. We show that for any such model, the per-component noise need only decrease polynomially to keep the sampling problem hard. In this sense, Boson Sampling with noise is scalable. However, the same result applies to a number of other quantum information systems, including universal circuit-model quantum computers. Such devices are widely believed to require error correction in order to be truly scalable, even though polynomial reduction of per-component errors would allow them to work without error correction. This belief is consistent with the stricter requirement that error rates should be not just polynomially small, but constant in problem size. We conclude that a more precise definition of scalability with noise is needed to properly evaluate Boson Samplers.

4:06PM H45.00007 Experimental fault tolerant universal quantum gates with solid-state spins under ambient conditions.1 XING RONG, University of Science and Technology of China — Quantum computation provides great speedup over classical counterpart for certain problems, such as quantum simulations, prime factoring and database searching. One of the challenges for realizing quantum computation is to execute precise control of the quantum system in the presence of noise. Recently, high fidelity control of spin-qubits has been achieved in several quantum systems. However, control of the spin-qubits with the accuracy required by the fault tolerant quantum computation under ambient conditions remains exclusive. Here we demonstrate a universal set of logic gates in nitrogen-vacancy centers with an average single-qubit gate fidelity of 0.99995 and two qubit gate fidelity of 0.992. These high control fidelities have been achieved in the C naturally abundant diamonds at room temperature via composite pulses and optimal control method. This experimental implementation of quantum gates with fault tolerant control fidelity sets an important step towards the fault-tolerant quantum computation under ambient conditions.

We acknowledge support from Spanish Mineco Project FIS2012-33022, CAM Research Network QUITEMAD+ and EU FP7 FET-Open project PROMISE.

3:54PM H45.00006 Spin models and boson sampling1. JUAN JOSE GARCIA RIPOLL, Institute of Fundamental Physics, IFF-CSIC, Spain, BORJA PEROPADRE, ALAN ASPURU-GUZIK, Department of Chemistry and Chemical Biology, Harvard University — Aaronson & Arkhipov showed that predicting the measurement statistics of random linear optics circuits (i.e. boson sampling) is a classically hard problem for highly non-classical input states [1]. A typical boson-sampling circuit requires N single photon emitters and M photodetectors, and it is a natural idea to rely on few-level systems for both tasks. Indeed, we show that 2M two-level emitters at the input and output ports of a general M-port interferometer interact via an XY-model with collective dissipation and a large number of dark states that could be used for quantum information storage. More important is the fact that, when we neglect dissipation, the resulting long-range XY spin-spin interaction is equivalent [2] to boson sampling under the same conditions that make boson sampling efficient. This allows efficient implementations of boson sampling using quantum simulators & quantum computers. [1] S. Aaronson, A. Arkhipov, Proc. of the 43rd annual ACM symposium on Theory of computing (ACM, 2011) 333-342 [2] arXiv:1509.02703

1We acknowledge support from Spanish Mineco Project FIS2012-33022, CAM Research Network QUITEMAD+ and EU FP7 FET-Open project PROMISCE

4:18PM H45.00008 Universal Superadiabatic Geometric Quantum Gates in Nitrogen-Vacancy Centers. HUI YAN, ZHENGTAO LIANG, South China Normal University, SHILIANG ZHU, Nan Jing University — We propose a scheme to implement a universal set of quantum gates based on geometric phases and superadiabatic quantum control. The proposed quantum gates consolidate the advantages of both strategies for robust and fast. The diamond nitrogen-vacancy center system is adopted as a typical example to illustrate the scheme. We show those gates can be realized in a simple two-level configuration by appropriately controlling the amplitude, phase and frequency of just one microwave field. The robust and fast features are confirmed by comparing the fidelities of the proposed superadiabatic geometric phase gate with three other kinds of phase gates, replacing MAR16-2015-000077.
And this abstract can also go in the sorting categories 6.9 and 6.11.

4:42PM H45.00010 Saving entangled photons from sudden death in a single-mode fiber — Interplay of decoherence and dynamical decoupling. , MANISH K. GUPTA, CHENGLONG YOU, HWANG LEE, JONATHAN P. DOWLING, Hearne Institute of Theoretical Physics, Louisiana State Univ - Baton Rouge — We study the dynamics of decoherence in an optical fiber for the case of entangled photons. Such a study will allow us to increase the physical length of fiber for the transmission of entangled photon from the sources such as SPDC. We analytically derive the model for decoherence of entangled state photons in a single-mode fiber. We also show that entanglement lifetime can be increased with open loop control technique called dynamical decoupling.

5:06PM H45.00012 Optimizing Adiabaticity in NMR , JONATHAN VANDERMAUSE, CHANDRASEKHAR Ramanathan, Dartmouth College — We demonstrate the utility of Berry’s superadiabatic formalism for numerically finding control sequences that implement quasi-adiabatic unitary transformations. Using an iterative interaction picture, we design a shortcut to adiabaticity that reduces the time required to perform an adiabatic inversion pulse in liquid state NMR. We also show that it is possible to extend our scheme to two or more qubits to find adiabatic quantum transformations that are allowed by the control algebra, and demonstrate a two-qubit entangling operation in liquid state NMR. We examine the pulse lengths at which the fidelity of these adiabatic transitions break down and compare with the quantum speed limit.

Tuesday, March 15, 2016 2:30PM - 5:30PM — Session H50 DAMOP: Many-Body Localization in Atomic Systems II — Hilton Baltimore Holiday Ballroom

2:30PM H50.00001 Characterizing eigenstate thermalization via measures in the Fock space of operators. , XIAO-LIANG QI, PAVAN HOSUR, Stanford Univ — The eigenstate thermalization hypothesis (ETH) attempts to bridge the gap between quantum mechanical and statistical mechanical descriptions of isolated quantum systems. Here, we define unbiased measures for how well the ETH works in various regimes, by mapping general interacting quantum systems on regular lattices onto a single particle living on a high-dimensional graph. By numerically analyzing deviations from ETH behavior in the non-integrable Ising model, we propose quantities that we call the “n-weight” and the “n-distinguishability” to democratically characterize the average and the maximum deviations, respectively, for all operators residing on n sites. Along the way, we discover that complicated operators on average are worse than simple ones at distinguishing between neighboring eigenstates, contrary to the naive intuition created by the usual statements of the ETH that few-body (many-body) operators acquire the same (different) expectation values in nearby eigenstates at finite energy density.

2:42PM H50.00002 Dynamical Many-Body Localization in a System of Coupled Relativistic Kicked Rotors. , EFIM ROZENBAUM, VICTOR GALITSKI, University of Maryland, College Park — A periodically-driven rotor is a prototypical model that exhibits a transition to chaos in the classical regime and dynamical localization (related to Anderson localization) in the quantum regime. In a recent preprint, arXiv:1506.05455, Keser et al. considered a many-body generalization of coupled quantum kicked rotors, and showed that in the special integrable linear case, the dynamical localization survives interactions. By analogy with many-body localization, the phenomenon was dubbed dynamical many-body localization (DMBL). In the present work, we study a non-integrable model of coupled quantum relativistic kicked rotors. Our analysis of such coupled “kicked” Dirac equations indicates that DMBL can exist for generic, non-integrable systems. We also analyze quantum dynamics of the model, which for certain select values of model’s parameters exhibits highly unusual behavior — e.g., superballistic transport and peculiar spin dynamics.
3:06PM H50.00004 Many-body localization and thermalization in disordered Hubbard chains
, RUBEM MONDAINI, MARCOS RIGOL, The Pennsylvania State University — Recently, a lot of attention has been given to the aspects that lead isolated interacting quantum systems to thermalize. In the presence of disorder, however, the thermalization process fails resulting in a phenomena where transport is suppressed known as many-body localization. Unlike the standard Anderson localization for non-interacting systems, the delocalized (ergodic) phase is very robust against disorder even for moderate values of interaction. Another interesting aspect of the many-body localization phase is that under the time evolution of the quenched disorder, information present in the initial state may survive for arbitrarily long times. This was recently used as a probe of many-body localization of ultracold fermions in optical lattices with quasi-periodic disorder\[1\]. Here, we will use numerical results in one-dimensional Hubbard chains to show that this analysis may suffer from substantial finite-size effects. We will also compare different types of disorder to see how the ergodicity is affected\[2\].

1 M. Schreiber et al., Science, 349 842 (2015)

3:18PM H50.00005 Particle-hole symmetry, many-body localization, and topological edge modes\[1\], ROMAIN VASSEUR, UC Berkeley and Lawrence Berkeley National Laboratory, AARON J. FRIEDMAN, S.A. PARAMESWARAN, University of California, Irvine, ANDREW C. POTTER, UC Berkeley — We study the excited states of interacting fermions in one dimension with particle-hole symmetric disorder (equivalently, random-bond XXZ chains) using a combination of renormalization group methods and exact diagonalization. Absent interactions, the entire many-body spectrum exhibits infinite-randomness quantum critical behavior with highly degenerate excited states. We show that though interactions are an irrelevant perturbation in the ground state, they drastically affect the structure of excited states: even arbitrarily weak interactions split the degeneracies in favor of thermalization (weak disorder) or spontaneously broken particle-hole symmetry, driving the system into a many-body localized spin glass phase (strong disorder). In both cases, the quantum critical properties of the non-interacting model are destroyed, either by thermal decoherence or spontaneous symmetry breaking. This system then has the interesting and counterintuitive property that edges of the many-body spectrum are less localized than the center of the spectrum. We argue that our results rule out the existence of certain excited state symmetry-protected topological orders.

1 Supported by the Gordon and Betty Moore Foundation’s EPiQS Initiative (Grant GBMF4307 (ACP), the Quantum Materials Program at LBNL (RV), NSF Grant DMR-1455366 and UCOP Research Catalyst Award No. CA-15-327861 (SAP).

3:30PM H50.00006 Dynamical many-body localization in an integrable model, AVIN C. KESER, Condensed Matter Theory Center, University of Maryland, College Park, SRIRAM GANESHAN, Simon Center for Geometry and Physics, GIL REFAEL, Institute of Quantum Information and Matter, Caltech, VICTOR GALITSKI, Condensed Matter Theory Center and Joint Quantum Institute, University of Maryland, College Park — We investigate dynamical many-body localization and delocalization in an integrable system of periodically-kicked interacting bosons in one dimension. The linear-in-momentum Hamiltonian makes the Floquet evolution operator analytically tractable for arbitrary interactions. One of the hallmarks of this model is that strong disorder, leading to many-body localization, stabilizes SPT order at finite energy densities while also preventing arbitrary heating of the system.

3:42PM H50.00007 Dynamics of Hubbard-Band Quasiparticles in Disordered Optical Lattices\[1\], VITO SCAROLA, Virginia Tech, BRIAN DEMARCO, University of Illinois, Urbana-Champaign — Recent experiments use transport of degenerate Fermi gases in optical lattices (Kondov et al. Phys. Rev. Lett. 114, 083002 (2015)) to probe the interplay of disorder and strong interactions. These experiments find evidence for an intriguing insulating phase where quantum diffusion is completely suppressed by strong disorder. Quantitative interpretation of these experiments remains an open problem that requires inclusion of non-zero entropy, strong interaction, and trapping in an Anderson-Hubbard model. We construct a theory of dynamics of Hubbard-band quasiparticles tailored to trapped optical lattice experiments. We compare the theory directly with center-of-mass transport experiments of Kondov et al. with no fitting parameters. The close agreement between theory and experiments shows that the suppression of transport is only partly due to finite entropy effects. We argue that the complete suppression of transport is consistent with short-time, finite size precursors of Anderson localization of Hubbard-band quasiparticles. The combination of our theoretical framework and optical lattice experiments offers an important platform for studying localization in isolated many-body quantum systems.

1 V.W.S. acknowledges support from AFOSR under grant FA9550-11-1-0313

3:54PM H50.00008 Many-body localization and symmetry protected topology with ultracold Rydberg atoms , IONUT-Dragos Potirniche, Univ of California - Berkeley, Monika Schleier-Smith, Stanford University, Ashvin Vishwanath, Norman Yao, Univ of California - Berkeley — The interplay between quantum entanglement and symmetry-protected topological order has led to the classification of gapped, interacting, one dimensional quantum phases. A consequence of this classification is the existence of a diverse set of exactly solvable models, which serve as paradigmatic examples of various SPT orders. The experimental realization of such models has been hampered by the challenge of implementing tunable multi-body interactions. Recently, an alternate strategy has arisen: periodic driving. Indeed, it has been shown that the dynamics of a simple Floquet transverse-field Ising model can mirror that of the celebrated Haldane chain. However, as SPT order is expected only in the ground state while a driven system is expected to heat to infinite temperature, the ability to observe such Floquet SPT phases remains an open question. Here, we demonstrate that strong disorder, leading to many-body localization, stabilizes SPT order at finite energy densities while also preventing arbitrary heating of the system. Moreover, we propose a natural experimental implementation in a 1D optical lattice of ultracold Rydberg atoms.
4:06PM H50.00009 Probing Anderson localization of light via decay rate statistics in aperiodic Vogel spirals1, ARISTI CHRISTOFI, Department of Electrical and Computer Engineering, Boston University, 8 Saint Marys street, Boston, MA 02215 USA, FELIPE A. PINHEIRO, Universidade Federal do Rio de Janeiro, Rio de Janeiro-RJ, 21941-972, Brazil & University of Southampton, Highfield, Southampton SO17 1BJ, UK, LUCA DAL NEGRO, Department of Electrical and Computer Engineering & Photonics Center, Boston University, 8 Saint Marys street, Boston, MA 02215 USA — We systematically investigate the spectral properties of different types of two-dimensional aperiodic Vogel spiral arrays of pointlike scatterers and three-dimensional metamaterials with Vogel spiral chirality using rigorous Greens function spectral method. We considered an efficient T-matrix approach to analyze multiple-scattering effects, including all scattering orders, and to understand localization properties through the statistics of the Greens matrix eigenvalues. The knowledge of the spectrum of the Green matrix of multi-particle scattering systems provides important information on the character of light propagation and localization in chiral media with deterministic aperiodic geometry. In particular, we analyze for the first time the statistics of the eigenvalues and eigenvectors of the Green matrix and extract the decay rates of the eigenmodes, their inverse participation ratio (IPR), the Wigner delay times and their quality factors. We emphasize the unique properties of aperiodic Vogel spirals with respect to random scattering media, which have been investigated so far.

1This work was supported by the Army Research Laboratory under Cooperative Agreement Number W911NF-12-2-0023

4:18PM H50.00010 Anomalous transport in ergodic lattice systems1, YEVENY BAR LEV, DAVID R. REICHMAN, Columbia University — Many-body localization transition is a peculiar dynamical transition between ergodic and non-ergodic phases, which may occur at any temperature and in any dimension. For temperatures below the transition the system is nonergodic and localized, such that conductivity strictly vanishes at the thermodynamic limit, while for temperatures above the transition the system is thermal and conductive. In this talk I will present a comprehensive study of the dynamical properties of the ergodic phase in one and two dimensional generic disordered and interacting systems, conducted using a combination of nonequilibrium diagrammatic techniques and numerically exact methods. I will show that the ergodic phase, which was expected to be diffusive, exhibits anomalous transport regime for nontrivial times and explain how our findings settle with phenomenological theoretical models.

1 NSF-CHE-1648802

4:30PM H50.00011 Eigenstate Order in Floquet Systems, CURT VON KEYSERLINGK, SHIVAJI SONDHI, Princeton Univ — Recent work has introduced the notion of eigenstate order for many body systems and extended it to periodically driven, or Floquet, systems. I will discuss a set of results on possible phases in Floquet systems. These involve generalisations of topological insulators and superconductors as well as generalisations of interacting symmetry protected and topological phases of matter. Many body localisation plays an essential role in their realisation.

4:42PM H50.00012 Localization in systems with long-range interactions1, LEA SANTOS, Yeshiva University, USA, FRANCISCO PEREZ-BERNAL, Universidad de Huelva, Spain, FAUSTO BROGONOVI, GIUSEPPE CELARDO, Universita Cattolica del Sacro Cuore, Italy — In recent experiments with ion traps, long-range interactions were associated with the very fast propagation of excitations. Here, we show that, depending on the initial state, the evolution of these systems may actually be exceedingly slow. This is justified with the analysis of the density of states and structures of the eigenstates, and confirmed with numerical simulations of quench dynamics. The two sources of restricted dynamics that we discuss are: the presence of an excited state quantum phase transition and the onset of subspaces shielded from the effects of long-range interactions. Both scenarios can be tested experimentally.

1 NSF Grant No. DMR-1147430.

4:54PM H50.00013 Dynamics of a Many-Body-Localized System Coupled to a Bath, MARK FISCHER, MYKOLA MAKSYVENKO, EHUD ALTMAN, Weizmann Institute of Science — Coupling a many-body localized system to a dissipative bath necessarily leads to delocalization. Here we investigate the nature of the ensuing relaxation dynamics and the information it holds on the many-body localized state. To solve for the time evolution, we formulate the relevant Lindblad equation in terms of the local integrals of motion of the underlying localized Hamiltonian. This allows to map the quantum evolution deep in the localized state to tractable classical rate equations. We consider two different types of dissipation relevant to systems of ultra-cold atoms: particle loss and dephasing due to inelastic scattering on the lattice lasers. Only the first mechanism shows a pronounced effect of interactions on the relaxation of observables.

5:06PM H50.00014 Extended slow dynamical regime near the many-body localization transition, DAVID J. LUITZ, University of Illinois at Urbana-Champaign, NICOLAS LAFLORENCIE, FABIEN ALET, Laboratoire de Physique Théorique, IRSAMC, Université de Toulouse, CNRS — Many-body localization is characterized by a slow logarithmic growth of entanglement entropy after a global quantum quench while the local memory of an initial spin imbalance remains at finite time. We address the dynamics in the delocalized ergodic regime, where thermalization is expected. Using an exact Krylov space technique, the out-of-equilibrium dynamics of the random-field Heisenberg chain is studied up to L = 28 sites, starting from an initially unentangled high-energy product state. With such a global quench protocol, we study the time evolution of the entanglement entropy, as well as the spin density imbalance in contact with recent cold atom experiments. Within most of the delocalized phase, we unambiguously find a sub-ballistic entanglement growth $S(t) \propto t^{1/2}$ with a disorder-dependent exponent $\zeta \geq 1$, in contrast with the pure ballistic growth $\zeta = 1$ of clean systems. At the same time, anomalous relaxation is also observed for the spin imbalance $I(t) \propto t^{-\Delta}$ with a continuously varying disorder-dependent exponent $\Delta$, vanishing at the transition. This provides a clear experimental signature for detecting this non-conventional metallic state where transport is sub-diffusive.

5:18PM H50.00015 Effective localization potential of quantum states in disordered media1, FILOCHE MARCEL, Ecole Polytechnique, DOUGLAS N. ARNOLD, University of Minnesota, GUY DAVID, Université Paris-Sud, DAVID JERISON, Massachusetts Institute of Technology, SVITLANA MAYBORODA, University of Minnesota — The amplitude of localized quantum states in random or disordered media may exhibit long range exponential decay. We present here a theory that unveils the existence of a localization landscape that controls the amplitude of the eigenstates in any quantum system. For second order operators such as the Schrödinger operator, this localization landscape is simply the solution of a Dirichlet problem with uniform right-hand side [1]. Moreover, we show that the reciprocal of this landscape plays the role of an effective potential which finely governs the confinement of the quantum states. In this picture, the boundaries of the localization subregions for low energy eigenfunctions correspond to the barriers of this effective potential, and the long range exponential decay characteristic of Anderson localization is explained as the consequence of multiple tunneling in the dense network of barriers created by this effective potential. Finally, we show that the Weyl's formula based on this potential turns out to be a remarkable approximation of the density of states for a large variety of systems, periodic or random, 1D, 2D, or 3D. [1] M. Filoche and S. Mayboroda, Proceedings of the National Academy of Sciences of the USA 109, 14761 (2012).

1 NSF grant DMS-1418805, ANR Grant GEOMETRY ANR-12-BS01-0014, NSF Grant DMS-1069225, NSF CAREER Award DMS-1056004, NSF INSPIRE Grant.
2:30PM H52.00001 Hybrid atom-membrane optomechanics, PHILIPP TREUTLEIN, University of Basel, Department of Physics — We have realized a hybrid mechanical system in which ultracold atoms and a micromechanical membrane are coupled by radiation pressure forces. The atoms are trapped in an optical lattice, formed by retroreflection of a laser beam from an optical cavity that contains the membrane as a mechanical element. When we laser cool the atoms, we observe that the membrane is sympathetically cooled from ambient to millikelvin temperatures through its interaction with the atoms. Sympathetic cooling with ultracold atoms or ions has previously been used to cool other microscopic systems such as atoms of different species or molecular ions up to the size of proteins. Here we use it to efficiently cool the fundamental vibrational mode of a macroscopic solid-state system, whose mass exceeds that of the atomic ensemble by ten orders of magnitude. Our hybrid system operates in a regime of large atom-membrane cooperativity. With technical improvements such as cryogenic pre-cooling of the membrane, it enables ground-state cooling and quantum control of mechanical oscillators in a regime where purely optomechanical techniques cannot reach the ground state. References: A. Jöckel, A. Faber, T. Kampschulte, M. Korppi, M. T. Rakher, and P. Treutlein, Symphatic cooling of a membrane oscillator in a hybrid mechanical-atomic system, Nature Nanotechnology 10, 55 (2015). B. Vogell, T. Kampschulte, M. T. Rakher, A. Faber, P. Treutlein, K. Hammerer, and P. Zoller, Long distance coupling of a quantum mechanical oscillator to the internal states of an atomic ensemble, New J. Phys. 17, 043044 (2015). B. Vogell, K. Stannigel, P. Zoller, K. Hammerer, M. T. Rakher, M. Korppi, A. Jöckel, and P. Treutlein, Cavity-enhanced long-distance coupling of an atomic ensemble to a micromechanical membrane, Phys. Rev. A 87, 023816 (2013).

3:06PM H52.00002 Detecting continuous gravitational waves with a jug of superfluid, SWATI SINGH, University of Arizona, LAURA DELORENZO, ADAM PEARLMAN, Caltech, IGOR PIKOVSKI, ITAMP, MÍLEŠ BLENCOWÉ, Dartmouth College, KEITH SCHWAB, Caltech — We investigate the sensitivity to narrow band, continuous-wave strain fields of a kg-scale optomechanical system formed by the acoustic motion of superfluid helium-4 parametrically coupled to a super-conducting microwave cavity. This narrowband detection scheme is tunable through pressurization of the helium, thereby making both doppler tracking of astrophysical sources and tuning the detector on/off from the source possible. For reasonable experimental parameters, we find that gravitational metric strain fields from nearby pulsars could be detected with a few weeks of integration time.

3:18PM H52.00003 Measurement and Applications of Radiation Pressure1, DAKANG MA, JOSEPH GARRETT, JOSEPH MURRAY, JEREMY MUNDAY, University of Maryland, College Park, MUNDAY LAB TEAM — Light reflected off a material or absorbed within it exerts radiation pressure through the transfer of momentum. Measuring and utilizing radiation pressure have aroused growing interest in a wide spectrum of research fields. Micromechanical transducers and oscillators are good candidates for measuring radiation pressure, but accompanying photothermal effects often obscure the measurement. In this work, we investigate the accurate measurement of the radiation force on microcantilevers in ambient conditions and ways to separate radiation pressure and photothermal effects. Further, we investigate an optically broadband switchable device based on polymer dispersed liquid crystal which has potential applications in solar sails and maneuvering spacecraft without moving parts.

1The authors would like to thank NASA Early Career Faculty Award and NASA Smallsat Technology Partnership Award for their funding support.

3:30PM H52.00004 Real-time Measurement of Mechanical Fluctuations in Carbon Nanotube Resonators, IOANNIS TSIOUTSIOS, ALEXANDROS TAVERNARAKIS, JOHANN OSMOND, ICFO, Institut de Cincies Fotniques, Mediterranean Technology Park, 08860 Castelldefels, Barcelona, Spain, PIERRE VERLOT1, Universit Claude Bernard Lyon 1, UCBL, Domaine Scientifique de La Doua, 69622 Villeurbanne, France, ADRIAN BACTHOLD, ICFO, Institut de Cincies Fotniques, Mediterranean Technology Park, 08860 Castelldefels, Barcelona, Spain — Carbon nanotube resonators have been recently shown to hold an exceptional sensing potential, relying on their extremely low mass. As a consequence, they are also expected to transduce the fundamental thermal force into very large motion fluctuations. Recently, an increasing number of theoretical proposals have suggested that this property may strongly affect the vibrational behaviour of carbon nanotube resonators, which has so far remained unobserved. Here we report the first, real-time detection of the thermally-induced vibrations in carbon nanotube resonators with masses in the 10 ag range. We show that coupling singly-clamped carbon nanotubes to a focused electron beam enables the full access to their mechanical trajectories. Our detailed analysis demonstrates that our devices behave as linear harmonic oscillators undergoing thermally-driven Brownian motion. Our result establish the viability of carbon nanotube resonator technology at room temperature and paves the way towards the observing novel thermodynamics regimes in nanomechanics.

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3:42PM H52.00005 Testing quantum mechanics and quantum gravity with cavity optomechanics, DAVID VITALI, Physics Division, School of Science and Technology, University of Camerino — Cavity optomechanical setups represents a promising platform for testing quantum mechanics and its validity at a macroscopic scale. Here we present two different examples. We first show the result of an experiment which, by a high sensitive measurement of the free evolution of the nanomechanical resonator probed by an optical field, has improved by many orders of magnitude the bounds on commutator deformation parameters which characterize a wide class of approaches to quantum gravity. In the second case we propose an experiment able to discriminate unambiguously collapse models, postulating the existence of intrinsic noise which modifies quantum mechanics and is responsible for the emergence of macroscopic classicality, from standard environmental sources of decoherence. In particular, we show that the stationary state of a trapped nanosphere is particularly sensitive, under specific experimental conditions, to the interplay between the cavity size, the trapping frequency and the momentum diffusion induced by the collapse models, allowing to detect them even in the presence of standard environmental noises.

3:54PM H52.00006 Torque Magnetometry and Susceptometry using Split-Beam Optomechanical Nanocavities, TAYYABA FIRDOUS, Department of Physics and National Institute for Nanotechnology, University of Alberta, Canada, NATHANAEL WU, MARCELO WU, Department of Physics and Astronomy and Institute for Quantum Science and Technology, University of Calgary, Canada, FATEMEH FANI SANI, JOSEPH LOSBY, Department of Physics and National Institute for Nanotechnology, University of Alberta, Canada, PAUL BARCLAY, Department of Physics and Astronomy and Institute for Quantum Science and Technology, University of Calgary, Canada, MARK FREEMAN, Department of Physics and National Institute for Nanotechnology, University of Alberta, Canada — A large number of sensitive magnetometry methods are limited to cryogenic operation. We present a highly sensitive torque magnetometer using a photonic crystal optomechanical split-beam nanocavity operating in air at room temperature. The chip-based magnetometer is proficient for probing both the net magnetization and AC susceptibility of individual magnetic microstructures. This is demonstrated through the observation of nanoscale Barkhausen transitions in the magnetic hysteresis of a permalloy thin-film element. Control of the vector direction of the radio frequency drive allows detection of accompanying AC susceptibility terms.
4:06PM H52.00007 Appearance and disappearance of motional sideband asymmetry in measurement-based control of a mechanical oscillator. VIVISHEK SUDHIR, DALZIEL WILSON, RYAN SCHILLING, HENDRICK SCHUETZ, Ecole Polytechnique Federale de Lausanne, ANDREAS NUNNENKAMP, University of Cambridge, TOBIAS KIPPPENBERG, Ecole Polytechnique Federale de Lausanne — Measurement-based feedback provides an avenue to study the delicate interplay between the quantum correlations established during the process of measurement, and their progressive obfuscation when exposed to uncorrelated noise in the form of fundamental quantum fluctuations in the feedback path. Here we demonstrate this tradeoff using a feedback strategy whose objective is to cool a nano-mechanical oscillator close to its ground state. The correlations established due to the measurement are revealed in the appearance of motional sideband asymmetry. The latter, faithfully measured using an optical heterodyne interferometer with an imperfection ~17 dB below that at the standard quantum limit, increases to 6% as the oscillator is feedback cooled to an occupation of 15 phonons. Further increase in the gain of the feedback loop leads to a decrease in the asymmetry. This is due to the addition of unavoidable quantum fluctuations in a feedback amplifier – photon shot-noise amplified by a homodyne detector in our case.

4:18PM H52.00008 Enhanced nonlinear interactions in quantum optomechanics via mechanical amplification. NICOLAS DIDIER, Quantim team, INRIA Paris, MARC-ANTOINE LEMONDE, Atomistitut, Vienna University of Technology, AASHISH A. CLERK, Department of Physics, McGill University — A key challenge limiting truly quantum behaviour in optomechanical systems is the typically small value of the optomechanical coupling at the single-photon, single-phonon level. We present an approach for exponentially enhancing the single-photon coupling strength in an optomechanical system using only additional linear resources. It allows one to reach the quantum nonlinear regime of optomechanics, where nonlinear effects are observed at the single photon level, even if the bare coupling strength is much smaller than the mechanical frequency and cavity damping rate. Our method is based on using a large amplitude, strongly detuned mechanical parametric drive to amplify mechanical zero-point fluctuations and hence enhance the radiation pressure interaction. It has the further benefit of allowing time-dependent control, enabling pulsed schemes. For a two-cavity optomechanical setup, we show that our scheme generates photon blockade for experimentally accessible parameters, and even makes the production of photonic states with negative Wigner functions possible. We discuss how our method is an example of a more general strategy for enhancing boson-mediated two-particle interactions and nonlinearities. Preprint: arXiv:1509.09238.

4:30PM H52.00009 Quantum squeezing of a mechanical resonator. CHAN U LEI, AARON WEINSTEIN, California Institute of Technology, JUNHO SUH, Korea Research Institute of Standards and Science, EMMA WOLLMAN, KEITH SCHWAB, California Institute of Technology — Generating nonclassical states of a macroscopic object has been a subject of considerable interest. It offers a route toward fundamental test of quantum mechanics in an unexplored regime. However, a macroscopic quantum state is very susceptible to decoherence due to the environment. One way to generate robust quantum states is quantum reservoir engineering. In this work, we utilize the reservoir engineering scheme developed by Kronwald et al. [1] to generate a steady quantum squeezed state of a micronscale mechanical oscillator in an electromechanical system. Together with the backaction evading measurement technique [2], we demonstrate a quantum nondemolition measurement of the mechanical quadratures to characterize the quantum squeezed state. By measuring the quadrature variances of the mechanical motion, more than 3dB squeezing below the zero-point level has been achieved. [1] A. Kronwald, F. Marquardt, and A. A. Clerk, Phys. Rev. A 88, 063833 (2013). [2] J. Suh, A. J. Weinstein, C. U. Lei, E. E. Wollman, S. K. Steinek, P. Meystr, A. A. Clerk, and K. C. Schwab, Science 344, 1262 (2014).

4:42PM H52.00010 Quantum nondemolition measurement of a nonclassical state of a massive object. FLORENT LECOCQ, JEREMY CLARK, RAYMOND SIMMONDS, JOSE AUGMENTADO, JOHN TEUFEL, NIST - Boulder — By coupling a macroscopic mechanical oscillator to two microwave cavities, we simultaneously prepare and monitor a nonclassical steady state of mechanical motion [1]. In each cavity, correlated radiation pressure forces induced by two coherent drives engineer the coupling between the quadratures of light and motion. We first demonstrate the ability to perform a continuous quantum nondemolition measurement of a single mechanical quadrature at a rate that exceeds the mechanical decoherence rate, while avoiding measurement backaction by more than 13dB. Second, we apply this measurement technique to independently verify the preparation of a squeezed state in the mechanical oscillator, resolving quadrature fluctuations 20% below the quantum noise. [1] F. Lecocq, et al, ArXiv 1509.01629 (2015).

4:54PM H52.00011 Observation of Nonclassical Radiation Pressure Forces on a Mechanical Oscillator. JEREMY CLARK, FLORENT LECOCQ, RAYMOND SIMMONDS, JOSE AUGMENTADO, JOHN TEUFEL, NIST Boulder — Squeezed states of light are known to be useful for enhancing mechanical displacement sensing since they can be tailored to reduce the “photon counting noise” that limits the measurement’s noise floor. On the other hand, recent experiments in cavity optomechanics have reached measurement regimes where an interrogating light field exerts radiation pressure noise on a mechanical oscillator. One outstanding challenge has been to explore the intersection between such experiments. I will present data obtained using a superconducting cavity optomechanical system wherein a mechanical oscillator is driven by nonclassical radiation pressure imparted by squeezed microwave fields.

5:06PM H52.00012 Complex squeezing for force measurement beyond the standard quantum limit. SYDNEY SCHREPPLER, University of California, Berkeley, LUKAS BUCHMANN, Aarhus Universitet, JONATHAN KOHLER, University of California, Berkeley, NICOLAS SPETHMANN, University of California, Berkeley, Technische Universit Kaiserslautern, DAN STAMPER-KURN, University of California, Berkeley, Lawrence Berkeley National Laboratory — Squeezed quantum states are popular theoretical and experimental means of overcoming precision limits set by quantum mechanics. We identify “complex squeezing” as time delayed correlations that can in general not be measured using homodyne or heterodyne detection schemes, but nonetheless arise naturally in measurement devices such as optomechanical systems. In this case, the dispersive coupling between a mechanical element and an electromagnetic resonator causes real ponderomotive squeezing at frequencies away from mechanical resonance, but that squeezing becomes complex closer to resonance, where the system can be operated more sensitively for force detection. We describe a measurement protocol sensitive to complex squeezing and show how it can lead to enhanced sensitivity of force measurements using optomechanical oscillators.

5:18PM H52.00013 Frequency stabilization of single layer graphene oscillators through optical injection locking. SAMER HOURI, SANTIAGO CARTAMIL BUENO, Delft University of Technology, WARNER VENSTRA, Quantified Air — Single layer graphene (SLG) drum resonators offer exciting prospects as experimental testbeds for nonlinear dynamics. Recently, photo-thermal induced feedback effects leading to self-oscillations in graphene have been demonstrated [1]. In this paper we examine the phase jitter of self-oscillating SLG, and the means to improve the frequency stability through optical injection locking. The resonator consists of an SLG on top of a 10 micron diameter circular cavity with a cavity depth of 750 nm. By shining a 10 mW He-Ne laser the drum enters a regime of photo-thermally induced self-oscillation. The oscillating SLG suffers from a significant phase noise that can be directly observed in the time domain as random walk of the oscillation period. By applying a lock tone to the oscillator through the application of a modulated blue laser (405 nm), the SLG motion is then phase locked to the applied tone with more than an order of magnitude improvement in its coherence time. The injection locking is also studied as a function of lock signal detuning and power. [1] Barton, Robert A., et al. “Photothermal self-oscillation and laser cooling of graphene optomechanical systems.” Nano letters 12.9 (2012): 4681-4686.

1Presenting author
2Quantified Air, Lorentzweg 1, 2628 CJ Delft, The Netherlands
8:00AM K13.00001 Coexistence, Interfacial Energy and the Fate of Microemulsions of 2D Dipolar Bosons, MASSIMO BONNISENGI, University of Alberta — The superfluid-crystal quantum phase transition of a system of purely repulsive dipolar bosons in two dimensions has been the subject of a lot of theoretical study, mainly because of some intriguing predictions by Spivak and Kivelson (2004) regarding an exotic, intermediate “microemulsion” that should appear at low temperature between the crystal and the superfluid. We investigated this scenario by means of Quantum Monte Carlo simulations at zero temperature, determined freezing and melting densities, and estimated the energy per unit length of a macroscopic interface separating the coexisting crystal and superfluid phases. The results rule out quantitatively the microemulsion scenario for any physical realization of this system, given the exceedingly large predicted size of the bubbles. Reference: S. Moroni and M. Bonnineschi, Phys. Rev. Lett. 113, 240407 (2014)

8:36AM K13.00002 Quantum spin dynamics and entanglement in systems with long-range interactions1, ANA M REY, JILA, NIST and University of Colorado at Boulder — One of the fundamental goals of modern quantum sciences is to learn how to control and manipulate non-equilibrium many-body systems and use them to make powerful and improved quantum devices, materials and technologies. However, out-of-equilibrium systems are complex, typically strongly correlated and entangled, and thus to model them we are in an urgent need of new methodologies. In this talk I will discuss new theoretical methods that we have developed to investigate emergent non-equilibrium phenomena in driven-dissipative spin systems interacting via long-range interactions. I will show we can capture the dynamics of correlations and entanglement in close systems and the interplay between dissipation and entanglement in open quantum systems including spin-boson models. As a specific application I will discuss the use of our methods to model the spin dynamics exhibited by arrays of trapped ions with controllable long-range interactions. I will show that our predictions are consistent with recent experimental measurements. I will also discuss new protocols to diagnostic and characterize entanglement based on well-established NMR protocols

1This work is supported by NSF, ARO, AFOSR-MURI, and NIST

9:12AM K13.00003 Universal scaling of density and momentum distributions in Lieb-Liniger gases2, MARCOS RIGOL, The Pennsylvania State University — We present numerically exact results for the scaling of density and momentum distribution functions of harmonically trapped one-dimensional bosons with repulsive contact interactions. We consider systems in the continuum [1], and in the presence of a lattice [2,3], both in the ground state [1,2] and at finite temperature [1,3]. We use path integral quantum Monte Carlo with worm updates in calculations at finite interaction strengths, and the Bose-Fermi mapping in the Tonks-Girardeau limit. We first discuss the homogeneous case and, within the local density approximation, use it to motivate the scaling in the presence of a harmonic trap. For the momentum distribution function, we pay special attention to the high momentum tails and their $k^{-4}$ asymptotic behavior. When available, we compare our results to experimental measurements of the momentum distribution function of ultracold bosonic gases in two-dimensional optical lattices.

References:

1We acknowledge support from the National Science Foundation Grant No. PHY13-18303 and the Office of Naval Research

9:48AM K13.00004 Cooling Atomic Gases With Disorder1, RICHARD SCALETTAR, University of California, Davis — Cold atomic gases have proven capable of emulating a number of fundamental condensed matter phenomena including Bose-Einstein condensation, the Mott transition, Fulde-Ferrell-Larkin-Ovchinnikov pairing and the quantum Hall effect. Cooling to a low enough temperature to explore magnetism and exotic superconductivity in lattices of fermionic atoms remains a challenge. We propose a method to produce a low temperature gas by preparing it in a disordered potential and following a constant entropy trajectory to deliver the gas into a non-disordered state which exhibits these incompletely understood phases. We show, using quantum Monte Carlo simulations, that we can approach the Neel temperature of the three-dimensional Hubbard model for experimentally achievable parameters. Recent experimental estimates suggest the randomness required lies in a regime where atom transport and equilibration are still robust. Thereza Paiva, Ehsan Khatami, Shuxiang Yang, Valery Rousseau, Mark Jarrell, Juana Moreno, Randall G. Hulet, and Richard T. Scalettar, arXiv:1508.02613

1This work was supported by the NNSA SSA program.

10:24AM K13.00005 Diagrammatic Monte Carlo study of mass-imbalanced Fermi-polaron system, LODE POLLET, Department of Physics, LMU Munich — After a brief introduction and review of diagrammatic Monte Carlo, I present our results for the three-dimensional Fermi-polaron system with mass-imbalance, where an impurity interacts resonantly with a noninteracting Fermi sea whose atoms have a different mass. This method allows to go beyond frequently used variational techniques by stochastically summing all relevant impurity Feynman diagrams up to a maximum expansion order limited by the sign problem. The polaron energy and quasiparticle residue can be accurately determined over a broad range of impurity masses. Furthermore, the spectral function of an imbalanced polaron demonstrates the stability of the quasiparticle and allows to locate in addition also the repulsive polaron as an excited state. The quantitative exactness of two-particle-hole wave-functions is investigated, resulting in a relative lowering of polaronic energies in the mass-imbalance phase diagram. Tans contact coefficient for the mass-balanced polaron system is found in good agreement with variational methods. Mass-imbalanced systems can be studied experimentally by ultracold atom mixtures like $^6\text{Li}-^{13}\text{K}$. I will discuss some open questions and links with recent experiments.
8:00AM K45.00001 Hamiltonian simulation for improved state transfer and readout in cavity QED, FÉLIX BEAUDOIN, McGill University, ALEXANDRE-BLAIS, Université de Sherbrooke, WILLIAM A. COISH, McGill University — Quantum state transfer into a memory, state shuttling over long distances via a quantum bus, and high-fidelity readout are important tasks for quantum technology. Generating the Hamiltonians that realize these tasks is challenging in the presence of realistic couplings to an environment. Here, we use average Hamiltonian theory to design the desired Hamiltonians in cavity QED. In particular, we present a protocol for state transfer between a qubit and a cavity. This approach makes use of a controllable qubit-cavity coupling strength to achieve a high fidelity even in the presence of inhomogeneous broadening that is stronger than the qubit-cavity coupling strength. In addition, we design a time-averaged interaction that allows for an improved quantum nondemolition readout. These ideas can be applied to a controllable qubit-cavity coupling strength to achieve high fidelity even in the presence of inhomogeneous broadening that is stronger than the qubit-cavity coupling strength.

8:12AM K45.00002 Quantum efficiency of a double quantum dot microwave photon detector, CLEMENT WONG, MAXIM VAVILOV, Univ of Wisconsin-Madison — Motivated by recent interest in implementing circuit quantum electrodynamics with semiconducting quantum dots, we study charge transfer through a double quantum dot (DQD) capacitively coupled to a superconducting cavity subject to a microwave field. We analyze the DQD current response using input-output theory and determine the optimal parameter regime for complete absorption of radiation and efficient conversion of microwave photons to electric current. For experimentally available DQD systems, we show that the cavity-coupled DQD operates as a photon-to-charge converter with quantum efficiencies up to 80%.

8:24AM K45.00003 Optical-Fiber-Illuminated Response of a Superconducting Microwave Resonator Below 1 K, KRISTEN VOIGHT, J. B. HERTZBERG, S. K. DUTTA, J. E. HOFFMAN, J. A. GROVER, J. LEE, P. SOLANO, R. P. BURKOW, C. B. JOYD, J. R. ANDERSON, C. HUNT, F. C. WELLSTOOD, JQI and CNAM, Dept. of Physics, University of Maryland — As a step towards building a hybrid quantum system that couples superconducting elements to neutral atoms trapped on a tapered optical nanofiber, we have studied how the presence of the fiber dielectric and light scattered from a fiber affect the response of a translatable thin-film lumped-element superconducting Al microwave resonator that is cooled to 15 mK. The resonator has a resonance frequency of about 6 GHZ, a quality factor $Q \approx 10^6$, and is mounted inside a 3D Al superconducting cavity. An optical fiber is tapered to a 60 um diameter cavity and passes through two small holes in the 3D cavity such that it sits near the resonator. The 3D cavity is mounted on an x-z piezo-translation stage that allows us to change the relative position of the thin-film resonator and fiber. When the resonator is brought closer to the fiber, the resonance frequency decreases slightly due to the presence of the fiber dielectric. When 200 uW of 780 nm light is sent through the fiber, about 100 pW/mm is Rayleigh-scattered from the fiber. This causes a position-dependent illumination of the resonator, affecting its resonance frequency and Q. We compare our results to a model of the resonator response that includes the generation, diffusion, and recombination of quasiparticles in the resonator and find that the frequency response allows us to track the position of the fiber to within 10 um.

8:36AM K45.00004 Connecting trapped ions and quantum dots with photons, MICHAEL KOEHL, University of Bonn — Coupling individual quantum systems lies at the heart of building scalable quantum networks. Here, we report the first direct photonic coupling between a semiconductor quantum dot and a trapped ion and demonstrate that single photons generated by a quantum dot control the internal state of an Yb$^+$ ion. We ameliorate the effect of the sixty-fold mismatch of the radiative linewidths with coherent photon generation and a high-finesse fiber-based optical cavity enhancing the coupling between the single photon and the ion. The transfer of information presented here via the classical correlations between the $\sigma_z$ projection of the quantum-dot spin and the internal state of the ion provides a promising step towards quantum state-transfer in a hybrid photonic network.

9:12AM K45.00005 Encoding a Qubit into a Cavity Mode in Circuit-QED using Phase Estimation, BARBARA TERHAL, DANIEL WEIGAND, RWTH - Aachen — Gottesman, Kitaev and Preskill have formulated a way of encoding a qubit into an ancilla such that the qubit is protected against small shifts (translations) in phase space. The idea underlying this encoding is that error processes of low rate can be expanded into small shift errors. The qubit space is defined as an eigenspace of two mutually commuting displacement operators which act as large shifts/translations in phase space. We propose and analyze the approximate creation of these qubit states by coupling the oscillator to a sequence of ancilla qubits realizing the protocol of approximate phase estimation for a displacement operator. We analyze the performance of repeated and adaptive phase estimation as the experimentally most viable schemes given a realistic upper limit on the number of photons in the oscillator. We propose a physical implementation of the protocol using the dispersive coupling between an ancilla transmon qubit and a cavity mode in circuit-QED. We estimate that in a current experimental setup one can prepare a good code state from a squeezed vacuum state using 8 rounds of adaptive phase estimation lasting in total about 4 microseconds, with at least 80

9:24AM K45.00006 Long-distance entanglement of spin qubits via quantum Hall edge states, GUANG YANG, CHEN-HSUAN HSU, PETER STANO, RIKEN Center for Emergent Matter Science, Wako, Japan, JELENA KLINOVAJA, DANIEL LOSS, Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland — The implementation of a functional quantum computer involves entangling and coherent manipulation of a large number of qubits. For qubits based on electron spins confined in quantum dots, which are among the most investigated solid-state qubits at present, architectural challenges are often encountered in the design of quantum circuits attempting to assemble the qubits within the very limited space available. Here, we provide a solution to such challenges based on an approach to realizing entanglement of spin qubits over long distances. We show that long-range Ruderman-Kittel-Kasuya-Yosida interaction of confined electron spins can be established by quantum Hall edge states, leading to an exchange coupling of spin qubits. The coupling is anisotropic and can be either Ising-type or XY-type, depending on the spin polarization of the edge state. Such a property, combined with the dependence of the electron-spin susceptibility on the chirality of the edge state, can be utilized to gain valuable insights into the topological nature of various quantum Hall states.

9:36AM K45.00007 Entangling distant resonant exchange qubits via circuit quantum electrodynamics, VANITA SRINIVASA, Laboratory for Physical Sciences/University of Maryland, College Park, MD, JACOB M. TAYLOR, Joint Center for Quantum Information and Computer Science/Quantum Institute/National Institute of Standards and Technology, Gaithersburg, MD, CHARLES TAHAN, Laboratory for Physical Sciences, College Park, MD — Enabling modularity within a quantum information processing device relies on robust entanglement of coherent qubits at macroscopic distances. To address this challenge, we investigate theoretically a hybrid quantum system consisting of spatially separated resonant exchange qubits, defined in three-electron semiconductor triple quantum dots, that are coupled via a superconducting transmission line resonator. By analyzing three specific approaches drawn from circuit quantum electrodynamics and Hartmann-Hahn double resonance techniques for implementing resonator-mediated two-qubit entangling gates in both dispersive and resonant regimes, we show that methods for entangling superconducting qubits map directly to resonant exchange qubits. We also calculate the rate of relaxation via phonons for resonant exchange qubits in silicon triple dots and show that such an implementation is particularly well-suited to achieving the strong coupling regime. Our approach combines the robustness of encoded spin qubits in silicon with the rapid and robust long-range entanglement provided by circuit QED systems.
9:48AM K45.00008 Long distance coupling of resonant exchange qubits, MAXIMILIAN RUSS, GUIDO BURKARD, Department of Physics, University of Konstanz, D-78457 Konstanz, Germany — We investigate the effectiveness of a microwave cavity as a mediator of interactions between two resonant exchange (RX) qubits in semiconductor quantum dots (QDs) over long distances limited only by the extension of the cavity. Our interaction model includes the orthonormalized Wannier orbitals constructed from Fock-Darwin states under the assumption of a harmonic QD confinement potential. We calculate the qubit-cavity coupling strength $g_q$ in a Jaynes-Cummings Hamiltonian, and find that dipole transitions between two states with an asymmetric charge configuration constitute the relevant RX qubit-cavity coupling mechanism. The effective coupling between two RX qubits in a shared cavity yields a universal two-qubit SWAP gate with gate times on the order of nanoseconds over distances on the order of up to a millimeter. Funded by ARO through grant No. W911NF-15-1-0149.


10:00AM K45.00009 Injection locking of a semiconductor double-quantum-dot micromaser1, Y.-Y. LIU, J. STEHLIK, Department of Physics, Princeton University, M. J. GULLANS, J. M. TAYLOR, Joint Quantum Institute/NIST, J. R. PETTA, Department of Physics, Princeton University — Narrow linewidth lasers and masers are desirable for applications such as frequency standards and low-noise amplifiers. Recently we have demonstrated a double-quantum-dot (DQD) micromaser, which generates photons through single electron tunneling events. Charge noise couples to the DQD energy levels and results in a maser linewidth that is 100 times larger than the Schawlow-Townes prediction. We demonstrate linewidth narrowing by more than a factor of 10 using injection locking. The injection locking range is measured as a function of input power and shown to be in excellent agreement with the Adler equation. The position and amplitude of distortion sidebands that appear outside of the injection locking range are quantitatively examined. Our results show that this unconventional maser, which is impacted by strong charge noise and electron-phonon coupling, is well described by standard laser models.

1Supported by the National Science Foundation and the Gordon and Betty Moore Foundation’s EPiQS initiative through grant no. GBMF4535.

10:12AM K45.00010 Real-time tuning of a double quantum dot using a Josephson parametric amplifier1, J. STEHLIK, Y.-Y. LIU, Department of Physics, Princeton University, C. M. QUINTANA, Department of Physics, UC Santa Barbara, C. EICHLER, T. R. HARTKE, J. R. PETTA, Department of Physics, Princeton University — Josephson parametric amplifiers (JPAs)1 have enabled advances in readout of quantum systems. Here we demonstrate JPA-assisted readout of a cavity-coupled double quantum dot (DQD). Utilizing a JPA we improve the signal-to-noise ratio (SNR) by a factor of 2000 compared to the situation with the parametric amplifier turned off. At an interdot charge transition we achieve a SNR of 76 (19 dB) with an integration time $\tau = 400$ ns, which is limited by the linewidth of our cavity. By measuring the SNR as a function of $\tau$ we extract an equivalent charge sensitivity of $8 \times 10^{-5} \, e/\sqrt{\tau}$. We develop a dual-gate-voltage rastering scheme that allows us to acquire a DQD charge stability diagram in just 20 ms. Such rapid data acquisition rates enable device tuning in live “video-mode,” where the results of parameter changes are immediately displayed. Live tuning allows the DQD confinement potential to be rapidly tuned, a capability that will become increasingly important as semiconductor spin qubits are scaled to a larger number of dots.

1Research is supported by the Packard Foundation, ARO Grant No. W911NF-15-1-0149, DARPA QuEST Grant No. HR0011-09-1-0007, and the NSF (Grants No. DMR-1409556 and DMR-1420541).

10:24AM K45.00011 Investigating the level broadening of a semiconductor charge qubit in microwave emission measurements, A. STOCKKLAUSER, N. HEDRICH, V. F. MAISI, J. BASSET, K. CUJIA, C. REICHL, W. WEIGGSCHEDER, T. IHN, K. ENDSSLIN, A. WALLRAFF, ETH Zurich — We investigate a hybrid circuit quantum electrodynamics architecture in which a double quantum dot charge qubit is coupled to a nearby microwave cavity. The discussed experiments explore the emission of microwave radiation from a qubit. We study the dependence of the emission line width on the tunnel rates to the leads and identify this as the dominant contribution to the broadening of the qubit levels. For the explored bias conditions qubit decoherence is low in comparison. We extract the tunnel rates to the leads from the linewidth of the qubit spectrum when creating a coherent state in a magnetostatic mode. References [1] and [2] have enabled advances in the microwave domain to optical light required for quantum applications. In this talk, we present results on the observation of magnon number states in a superconducting qubit spectrum where we use a Josephson junction as the mediator of interactions between two quantum states with opposite magnetic moments.


10:36AM K45.00012 Observation of magnon number states in a superconducting qubit spectrum, DANY LACHANCE-QUIRION, Université de Sherbrooke, YUTAKA TABUCHI, SEICHIRO ISHINO, ATSUSHI NOGUCHI, TOYOFUMI ISHIKAWA, REKISHU YAMAZAKI, KOJI USAMI, RCAST, The University of Tokyo, YASUNOBU NAKAMURA, RCAST, The University of Tokyo, CEMS, RIKEN — A quantum transducer interfacing qubits in the microwave domain to optical light requires a quantum system interacting with photons of both frequency domains. Coherent interaction between collective excitations (magnons) in the ferrimagnetic insulator yttrium iron garnet (YIG) and a superconducting qubit through virtual microwave photons has recently been demonstrated [1]. In this talk, we present results on the observation of magnon number states in a superconducting qubit spectrum when creating a coherent state in a magnetostatic mode of a YIG sphere interacting dispersively with the qubit. The dispersive interaction strength of 1.2 MHz measured in the straddling regime is in good agreement with numerical simulations. Furthermore the probability distribution of magnon number states, recovered from the qubit spectrum, is compared with the Poisson distribution expected for a coherent state. Resolving magnon number states constitutes a first step toward encoding quantum information into a quantum state of a magnetostatic mode.

10:48AM K45.00013 Emergent Curved space induced by adiabatic approximation1, RAN CHENG, XIAOCHUAN WU, DI XIAO, Carnegie Mellon University — Berry curvature, serving as the imaginary part of quantum geometric tensor (QGT), gives rise to an effective Lorentz force to the dynamics of the adiabatic parameter. However, it is not clear whether the real part of QGT, the quantum metric, has any dynamical consequence as the Berry gauge force. We show in a general way that during an adiabatic process, the particle in a hybrid quantum system governed by an equation of motion second order in time is subject to an induced gravitational force. The adiabatic dynamics can be described by a geodesic equation as if the spacetime is curved by the quantum metric. As an example, we demonstrate the above result in a simple toy model.

This work was supported in part by DOE BES (No. DE-SC0012509) and AFOSR (No. FA9550-12-1-0479)

Wednesday, March 16, 2016 8:00AM - 11:00AM –
Session K50 DAMOP: Spin-Orbit Coupling and Artificial Gauge Fields Hilton Baltimore Holiday Ballroom
1 - Lauren Aycock, Joint Quantum Institute, University of Maryland

8:00AM K50.00001 Magnetic phases of spin-1 spin-orbit coupled Bose gases2, DANIEL CAMPBELL, RYAN PRICE, ANDIKA PUTRA, ANA VALDES-CURIEL, DIMITRIOS TRYPOGEORGOS, IAN SPIELMAN, Joint Quantum Institute, University of Maryland, College Park, Maryland, 20742, USA, SPIELMAN TEAM — We experimentally explore the magnetic phases present in a near-zero temperature spin-1 spin-orbit coupled atomic Bose gas. We observe ferromagnetic and unpolarized phases which are stabilized by the spin-orbit couplings explicit locking between spin and motion. In the limit of weak spin-orbit coupling, these phases are separated by a critical curve of 1st order quantum phase transitions, with an observed width as small as $h \times 1/f s$. These phase transitions give rise to long-lived metastable states.

This work was partially supported by the ARO’s atomtronics MURI, by the AFOSR’s Quantum Matter MURI, NIST, and the NSF through the PFC at the JQI

8:12AM K50.00002 Quantum double-exchange physics with ultracold atoms and synthetic gauge potentials1, JOHANNES SCHACHENMAYER, LEONID ISAEV, ANA MARIA REY, JILA, NIST and Dept. of Physics, University of Colorado Boulder — We study an interplay between local spin exchange and Néel antiferromagnetism in a two-band optical lattice. The lowest narrow band is half-filled and implements the magnetic background, while a higher band contains mobile objects. When the local spins are locked in a Néel state, the motion of itinerant atoms is hindered by exchange energy barriers and the system is a flat-band insulator. As we show, this picture breaks down when exchange interaction between local and mobile spins is comparable to an energy scale of the Néel state. In this regime, formation of singlets between local and itinerant spins gives rise to a metallic phase of mobile atoms dressed by the spin fluctuations. This state is characterized by coupled spin-charge excitations whose spin is transverse to the Néel vector. Our predictions can be realized with ultracold alkaline-earth fermionic atoms coupled to a laser-induced staggered magnetic field, which stabilizes the Néel order and controls the amount of quantum fluctuations of local spins. By tuning the strength of this laser coupling relative to the exchange interaction, one can either adiabatically drive the crossover between the flat-band insulator and correlated metal phases, or explore non-equilibrium spin-charge dynamics in quench experiments.

This work was supported by the NSF (PIF-1211914 and PFC-1125844), AFOSR, AFOSR-MURI, NIST and ARO individual investigator awards

8:24AM K50.00003 Interaction effects in cold gases in synthetic gauge fields1, THOMAS BLITIEWSKI, NIGEL COOPER, T.C.M. Group, Cavendish Laboratory, J.J. Thomson Avenue, Cambridge CB3 0HE, United Kingdom — There has been a long-standing goal to find ways to cause neutral atoms to experience synthetic gauge fields, extending the capabilities of ultracold gases as simulators of quantum many-body systems. Such gauge fields can mimic the effect of magnetic fields and generate topological energy bands. Recent proposals to generate synthetic gauge fields rely on time-dependent periodic forcing of the quantum system.

Interactions are of particular interest in these systems, as the interplay of time dependence and interactions can lead to inelastic scattering and the combined effect of synthetic gauge fields and strong correlations could lead to a variety of novel many-body phases of degenerate fermionic or bosonic atoms.

In the framework of Floquet Theory we study the effects of inelastic scattering induced by the intrinsic time dependence of the eigenstates and the elastic two-body interactions [1]. Specifically, we discuss this mechanism as a potential explanation of heating and band population dynamics in current experimental setups.


1EPSRC Grant No. EP/K030994/1

8:36AM K50.00004 Spin-Orbit Coupled Fermions in Harmonic Trap, DOGA MURAT KURKCUOGLU, Georgia Southern University, Georgia Inst of Tech — After the realization of artificial spin-orbit coupling in ultracold atoms experimentally, there is an interest in spin-orbit coupled systems in ultracold atoms. In this abstract, I will discuss the emergence of two-body bound states between two Fermi atoms in the presence of spin-orbit coupling and Zeeman fields. The fermions are assumed to have only two internal states and to have attractive contact (zero-ranged) interactions. We also add an isotropic three-dimensional harmonic trap to the system, since it is the experimentally relevant case. For such a system, I will describe the few-body solutions and the effective masses of the bound-states as a function of spin-orbit and Zeeman fields.

8:48AM K50.00005 Thermodynamics of interacting cold atomic Fermi gases with spin-orbit coupling1, SCOTT JENSEN, YORAM ALHASSID, CHRISTOPHER GILBRETH, Center for Theoretical Physics, Yale University — New physics is suggested with the prediction of novel phases in cold atom systems when a synthetic spin-orbit coupling is introduced. In particular, recent studies show that a new type of Bose-Einstein condensate, termed Rashba-BEC, is formed when a generalized Rashba spin-orbit term is present [1]. The Rashbon-BEC phase can be obtained by tuning the spin-orbit coupling strength even in the case of finite negative scattering length. This stands in contrast to the BCS-BEC crossover in the absence of spin-orbit coupling where a negative scattering length is associated with BCS physics, and its divergence signals the crossover. In our work we apply finite-temperature quantum Monte Carlo methods to a spherical Rashba spin-orbit coupled two-species Fermi gas with contact s-wave interaction in three dimensions. We will discuss the phase diagram for this system, and its crossover behavior from BCS to Rashbon-BEC.


This work was supported in part by the Department of Energy grant No. DE-FG-0291-ER-40608
9:00AM K50.00006 Spin-orbit coupling in the strongly interacting Fermi gas: an exact quantum Monte Carlo study¹, PETER ROSENBERG, HAO SHI, SIMONE CHIESA, SHIWEI ZHANG, College of William and Mary — Spin-orbit coupling (SOC) plays an essential role in a variety of intriguing condensed matter phenomena, including the quantum Hall effect, and topological insulators and superconductors. The recent experimental realization of spin-orbit coupled Fermi gases provides a unique opportunity to study the effects of SOC in a tunable, disorder-free system. Motivated by this experimental progress, we present here the first exact numerical results on the two-dimensional, unpeared, uniform Fermi gas with attractive interactions and Rashba SOC. Using auxiliary-field quantum Monte Carlo and incorporating recent algorithmic advances, we carry out exact calculations on sufficiently large system sizes to provide accurate results systematically as a function of experimental parameters. We obtain the equation of state, study the spin behavior and momentum distribution, and examine the interplay of SOC and pairing in real and momentum space. Our results help illuminate the rich pairing structure induced by SOC, and provide important guidance to future experimental efforts.

¹Supported by DOE SciDAC and NSF

9:12AM K50.00007 Melting of phase-stripes in Bose-Einstein condensates with synthetic spin-orbit coupling¹, ASLE SUDBO, PEDER GALTELAND, Norwegian Univ Tech (NTNU), EGOR BABAEEV, Royal Institute of Technology, Stockholm, Sweden — We study a two-component, density imbalanced Bose-Einstein condensate with density-density interactions and synthetic spin-orbit coupling, focusing on the impact of thermal fluctuations and density-density interactions on spin-orbit induced effects. We find that for intermediate density imbalance and small intercomponent density-density interactions, the ground state is non-uniform, represented by a striped state of modulated phases of the individual complex order parameter components. By using mean-field stability arguments, we calculate a critical value for the intercomponent density-density interaction, above which the non-uniform ground state collapses into a uniform single-component state. This is reproduced in Monte-Carlo simulations for intermediate values of the spin-orbit coupling. We also find that the non-uniform ground state is disordered by thermal fluctuations when heated, through a Berizinskii-Kosterlitz-Thouless unbinding of dislocation pairs. We argue that, to lowest order, the spin-orbit coupling can be seen as an effective Josephson-type locking of the phase difference $\theta_1 - \theta_2$, while simultaneously allowing the system to gain energy by modulating the phase sum $\theta_1 + \theta_2$.

¹Work supported by the Norwegian Research Council, the Swedish Research Council, and the National Science Foundation

9:24AM K50.00008 Pairing of fermions with unequal charges in an artificial magnetic field, NUR UNAL, Cornell Univ, M. O. OKTEL, Bilkent Univ — Artificial magnetic fields (AMFs) created for ultra cold systems depend sensitively on the internal structure of the atoms. In a mixture, each component couples to the AMF with a different charge. This enables the study of Bardeen-Cooper-Schrieffer pairing of fermions with unequal charges. We investigate the superconducting (SC) transition of a system formed by such pairs as a function of the field strength. We consider a homogenous two-component Fermi gas of unequal charges but equal densities with attractive interactions. We find that the phase diagram is altered drastically compared to the usual equal charge case. First, for some AMFs there is no SC transition and isolated SC phases are formed, reflecting the discrete Landau level (LL) structure. SC phases become reentrant both in AMF and temperature. For extremely high fields where both components are confined to their lowest LLs, the effect of the charge imbalance is suppressed. Charge asymmetry reduces the critical temperature even in the low-field semiclassical regime. We discuss a pair breaking mechanism due to the unequal Lorentz forces acting on the components of the Cooper pairs to identify the underlying physics.

9:36AM K50.00009 Spectrum of the Rashba spin-orbit coupled Hamiltonian with spin-dependent contact interaction in dimension three, RTYIS JURSENAS, Vilnius University, Institute of Theoretical Physics and Astronomy — The presentation provides functional analytic interpretation for the spectrum of the Rashba spin-orbit coupled Hamiltonian considered in the presence of the out-of-plane magnetic field. The impurity scattering is treated by means of a spin-dependent contact interaction. The research was inspired by a recently proposed technique [1, 2, 3] for producing the Rashba-type spin-orbit coupling for a three-dimensional ultracold atom. The analysis of the resolvent formula shows that, for nonzero spin-orbit coupling, the eigenvalues solve the transcendental equation. For small spin-orbit-coupling strength $\alpha$, the eigenvalues are derived analytically with the accuracy up to $O(\alpha^4)$. It is shown that there are no eigenvalues above the threshold no matter the form of a nonzero coupling parameter of contact interaction. When the lower branch of dispersion relation attains two minima, the eigenvalues are situated only below the threshold or above the minimum of the upper branch of dispersion relation; the upper bound of discrete states is also obtained. [1] B. M. Anderson et al, Phys. Rev. Lett. 111 (2013), 125301. [2] D. L. Campbell et al, Phys. Rev. A 84 (2011), 025602. [3] F. Jendrzejewski et al, Nature Physics 8 (2012), 398.

9:48AM K50.00010 Vortex line of spin-orbit coupled Fermi superfluid through BCS to BEC crossover, JUAN YAO, SHIZHONG ZHANG, The Univ of Hong Kong — Superfluid Fermi gases with spin-orbit interaction provides a unique opportunity to investigate possible effects of strong interaction in a topological superfluid. It has been suggested that with addition of Rashba-type spin-orbit coupling, a two-component Fermi gas with strong s-wave interaction can become a topological superfluid with zero-energy bound state at the core of the vortex. In this talk, I discuss the evolution of vortex structure in a spin-orbit coupled Fermi gas through the BCS-BEC crossover within Bogoliubov-de Gennes formalism. We find that the largest critical current occurs in the BEC side of the resonance, in contradiction to the usual crossover without spin-orbit coupling where it occurs at unitarity. Furthermore, we discuss the core structure of the vortex by calculating the spin and density distribution around the vortex.

¹Department of Physics and Centre of Theoretical and Computational Physics, The University of Hong Kong, Hong Kong, China

10:00AM K50.00011 Stripe phase and double-roton excitations in interacting spin-orbit-coupled spin-1 Bose-Einstein condensates, KUEI SUN, The University of Texas at Dallas, Richardson, Texas, USA, CHUNLEI QU, The University of Texas at Dallas, Richardson, Texas, USA and Università di Trento, Povo, Italy, YONG XU, The University of Texas at Dallas, Richardson, Texas, USA, YONGPING ZHANG, OIST Graduate University, Onna, Okinawa, Japan, CHUANWEI ZHANG, The University of Texas at Dallas, Richardson, Texas, USA — Spin-orbit (SO) coupling plays a major role in many important phenomena in condensed matter physics. However, the SO coupling physics in high-spin systems, especially with superfluids, has not been well explored because of the spin half of electrons in solids. In this context, the recent experimental realization of spin-orbit coupling in spin-1 Bose-Einstein condensates (BECs) has opened a completely new avenue for exploring SO-coupled high-spin superfluids. Nevertheless, the experiment has only revealed the single-particle physics of the system. Here, we study the effects of interactions between atoms on the ground states and collective excitations of SO-coupled spin-1 BECs in the presence of a spin-tensor potential. We find that ferromagnetic interaction between atoms can induce a stripe phase exhibiting two modulating patterns. We characterize the phase transitions between different phases using the spin-tensor density as well as the collective dipole motion of the BEC. We show that there exists a new type of double maxon-roton structure in the Bogoliubov-excitation spectrum, attributing to the third band minima of the SO-coupled spin-1 BEC. Our work could motivate further theoretical and experimental study along this direction.
10:12AM K50.00012 Finite temperature theory of spin-orbit coupled fermions in three dimensions in the presence of external Zeeman fields and tunable s-wave interactions, PHILIP POWELL, Lawrence Livermore National Laboratory, GORDON BAYM, University of Illinois at Urbana-Champaign, CARLOS SA DE MELO, Georgia Institute of Technology, Joint Quantum Institute — We develop a finite temperature theory of ultracold three-dimensional Fermi gases in the presence of artificial spin-orbit coupling, Zeeman fields, and tunable s-wave interactions. With the inclusion of quadratic fluctuations, we compute both the critical temperature for superfluidity and the population of bound and unbound fermions throughout the evolution from the Bardeen-Cooper-Schrieffer (BCS) to Bose-Einstein condensate (BEC) regimes. In particular, we show that in the BEC regime, spin-orbit coupling is capable of increasing the critical temperature relative to the no-field case, by inducing a triplet component to the superfluid order parameter, while decreasing the many-body effective mass. We also derive the time-dependent Ginzburg-Landau equation to sixth-order in the superfluid order parameter, and obtain explicit expressions for the coefficients of the effective theory valid across the entire evolution from BCS to BEC superfluidity.

10:24AM K50.00013 Entanglement of Vortex Lattices for Ultracold Bose Gases in a Non-Abelian Gauge Potential, SUZU-CHENG CHENG, Department of Optoelectric Physics, Chinese Culture University, Taiwan, ROC, T. F. JIANG, SHIH-DA JHENG, Institute of Physics, National Chiao Tung University, Taiwan, ROC, ATOMIC AND MOLECULAR PHYSICS TEAM, ATOMIC AND MOLECULAR PHYSICS TEAM — We develop a theory, referred to as the von Neumann lattice in a higher Landau level, for vortex lattices labelled by an integer number of flux quanta per unit cell in a higher Landau level. Using this lattice theory, we study the vortex lattice states of a pseudospin-1/2 ultracold Bose gas with contact interactions in a non-Abelian gauge potential. In addition to a uniform magnetic field, the Bose gas is also subjected to a non-Abelian gauge field, which creates an effect of the spin-orbit coupling to lift the spin degeneracy of the Landau levels. Because of interactions from the spin-orbit coupling, there are new degenerate points of the single particle spectrum due to the crossings of two Landau levels at certain coupling strengths. We show that interactions from the spin-orbit coupling force the nature and structure of the vortex lattice changing dramatically if the strength of the non-Abelian gauge field is increasing. We also find that the ground state of the vortex lattice at a degenerate point exhibits strong correlation and entanglement involving vortex lattices from different Landau levels. This entangled state builds the connection between two phases of vortex lattices during the first order phase transition of the adiabatic evolution.

10:36AM K50.00014 Baryon squishing in synthetic dimensions by effective SU(M) gauge fields, SUDEEP KUMAR GHOSH, UMESH K. YADAV, VIJAY B. SHENOY, Indian Institute of Science Bangalore — We investigate the physics of SU(M) symmetric interactions in the “synthetic dimensions” (Celi et al., PRL 112, 043001 (2014)) that provides a cold atom realization of the Hofstadter model. We show that this system is equivalent to particles (with SU(M) symmetric interactions) experiencing an SU(M) Zeeman field at each lattice site and a non-Abelian SU(M) gauge potential that affects their hopping. This equivalence brings out the possibility of generating non-local interactions between particles at different sites of the optical lattice. In addition, the gauge field induces a flavor-orbital coupling, which mitigates the “baryon breaking” effect of the Zeeman field. For M particles, concomitantly, the SU(M) singlet baryon which is site localized in the usual 1d optical lattice, is deformed to a non-local object (“squished baryon”). We conclusively demonstrate this effect by analytical arguments and exact (numerical) diagonalization studies. Our study promises a rich many-body phase diagram for this system. It also uncovers the possibility of using the synthetic dimension system to laboratory realize condensed matter models such as the SU(M) random flux model, inconceivable in conventional experimental systems. Reference: arXiv:1503.02301

3Work supported by CSIR, DST and DAE

10:48AM K50.00015 Cavity-Assisted Spin Orbit Coupling, CHUANZHOU ZHU, LIN DONG, HAN PU, Rice University — We consider a single ultracold atom trapped inside a single-mode optical cavity, where a two-photon Raman process induces an effective coupling between atom’s pseudo-spin and external center-of-mass (COM) motion. Without the COM motion, this system is described by the Jaynes-Cummings (JC) model. We show how the atomic COM motion dramatically modifies the predictions based on the JC model. We also investigated the situation when cavity pumping and decay are taken into account. We take a quantum Master equation approach to study this open system and again show how the cavity-induced spin-orbit coupling affects the properties of the system.


11:15AM L13.00001 A strongly interacting two-dimensional Fermi gas, SELIM JOCHIM, Heidelberg University — We will present our progress realizing two-dimensional superfluids with ultracold fermionic lithium atoms confined in a quasi two-dimensional potential. In this setting, a generic two-dimensional Fermi gas is realized with interactions tunable to any value within the short-range limit. We measured the phase diagram for this system and found the coherence properties to be decaying algebraically, a signature of the Beresinskii-Kosterlitz-Thouless phase which is expected for a homogeneous two-dimensional superfluid. We furthermore extracted from our data a the equation of state, which will be an important benchmark for many-body theories. We are currently working to transfer our fermionic atoms into an optical lattice potential. Our vision to realize exotic superfluidity in this system will be discussed.

11:51AM L13.00002 Experimental studies of spin-imbalanced Fermi gases in 2D geometries, JOHN THOMAS, North Carolina State University — We study the thermodynamics of a quasi-two-dimensional Fermi gas, which is not quite two-dimensional (2D), but far from three dimensional (3D). This system offers opportunities to test predictions that cross interdisciplinary boundaries, such as enhanced superfluid transition temperatures in spin-imbalanced quasi-2D superconductors, and provides important benchmarks for calculations of the phase diagrams. In the experiments, an ultra-cold Fermi gas is confined in an infrared CO2 laser standing-wave, which produces periodic pancake-shaped potential wells, separated by 5.3 μm. To study the thermodynamics, we load an ultra-cold mixture of N1 = 800 spin-up and N2 < N1 spin-down 6Li atoms into each well and image the individual cloud profiles as a function of interaction strength and spin imbalance N2/N1. The measured properties are in disagreement with 2D-BCS theory, but can be fit by a 2D-polaron gas model, where each atom is surrounded by a cloud of particle-hole pairs of the opposite spin. However, this model fails to predict a transition to a spin-balanced central region as N2/N1 is increased.

3Supported by the physics divisions of ARO, AFOSR, and NSF and by the Division of Materials Science and Engineering, the Office of Basic Energy Sciences, DOE.
12:27PM L13.00003 Fermi-to-Bose crossover in a trapped quasi-2D gas of fermionic atoms
ANDREY TURLAPOV, Institute of Applied Physics, Russian Academy of Sciences — Neither long-range order nor Bose condensation may appear in uniform 2D systems at finite temperature. Despite that, 2D superconductors, such as cuprates, are among the systems with highest critical temperatures. 2D quantum systems remain intriguing, and their understanding is incomplete despite huge progress seen in the recent decades. Ultracold atoms are a platform for studying 2D physics. Using tunability of atomic gases, we have realized a crossover between a 2D gas of Fermi atoms and a 2D gas of weakly-bound diatomic Bose molecules by varying s-wave interactions in the gas. Between these two asymptotic states, there is a regime of strong interactions, whose quantitative description is challenging, e.g., a mean field of Cooper pairs fails to describe the crossover even qualitatively, unlike in 3D gases. At the lowest achievable temperatures, \( \sim 10\% \) of the Fermi energy, the pressure is measured in the whole Fermi-to-Bose crossover and compared with the available theoretical models, including those which appeared over the last year. In the Fermi regime of weak interactions, the pressure is systematically above a Fermi-liquid-theory prediction, which maybe due to mesoscopic effects. Alternatively, this upshift is partially reproposed within a recent mean-field theory supplemented with fluctuations. On the Bose side of the crossover, the molecules easily condense, which is found in interferometric measurements. On one hand, such condensation is expected because the gas is held in a nearly harmonic trap, which favors condensation unlike the uniform space. On the other hand, each molecule is locally in a flat potential, which is the sum of the trap and the strong repulsive mean field, and this should inhibit the condensation.

1:03PM L13.00004 Quasi-condensation in trapped two-dimensional Fermi gases
BRANDON ANDERSON, James Franck Institute — It is well known that the Mermin-Wagner theorem prohibits true long range order 2D systems. Nevertheless, recent experiments [1,2] provide strong evidence that 2D Fermi gases undergo a form of pair condensation, along with aspects of BKT physics. In this talk we apply a BCS-BEC theory (which is compatible with the Mermin-Wagner theorem) to characterize the nature of pair (quasi-) condensation in 2D Fermi gases. Here we follow the same analysis and protocols of these recent experiments. We find a strong zero momentum peak in the pair momentum distribution which importantly occurs at a reasonably well defined onset temperature. We demonstrate that the resulting phase diagram, pair momentum distribution, and algebraic power law decay are compatible with the experiments throughout the continuum from BEC to BCS. Finally, we present sharp qualitative experimental signatures to test this physical picture. [1] Phys. Rev. Lett. 114. 230401 (2015) [2] Phys. Rev. Lett. 115. 010401 (2015) [3] Phys. Rev. Lett. (To be published.)

1:39PM L13.00005 BKT physics in trapped 2D Bose and Fermi gases
MARKUS HOLZMANN, LPMMC, CNRS and UJF, Grenoble — I will discuss superfluid and spatial coherence properties of two-dimensional trapped Fermi gases in the BEC-BCS crossover regime [1]. On the bosonic side, experimental data are in quantitative agreement with path-integral quantum Monte Carlo calculations of point like molecules up to large values of the interaction. Algebraic correlations in the first-order correlation function characterize the phase below the Kosterlitz-Thouless transition temperature. Whereas the inhomogeneous trapping potential introduces important quantitative modifications, the effective exponent of the power-law decay at the superfluid transition remains approximately constant for all interaction strengths in the BEC-BCS crossover regime. P.A. Murthy, I. Boettcher, L. Bayha, M. Holzmann, D. Kedar, M. Neidig, M.G. Ries, A.N. Wenz, G. Zuer, and S. Jochim, Phys. Rev. Lett. 115, 010401 (2015).

Wednesday, March 16, 2016 11:15AM - 1:51PM –
Session L50 DAMOP: Cold Atomic Gases: Precision Measurement and Few-Body Physics Hilton Baltimore Holiday Ballroom 1 - Shina Tan, Georgia Institute of Technology

11:15AM L50.00001 ABSTRACT WITHDRAWN –

11:27AM L50.00002 Atom interferometric measurement of “Big G” on the International Space Station
ELIZABETH ASHWOOD, DOGA MURAT KURKCUOGLU, MARK EDWARDS, Georgia Southern Univ, CHARLES CLARK, Joint Quantum Institute — Recent measurements of Newton’s universal gravitational constant (“Big G”) using atom interferometric methods have increased the uncertainty in the value of this important fundamental constant [1]. We have developed tools for rapid simulation and evaluation of atom interferometer (AI) schemes that can be implemented in the Cold Atom Laboratory to be deployed to the International Space Station (ISS) in 2017. We have approximated the solution of the rotating-frame Gross–Pitaevskii equation in both one and three dimensions by using the Lagrangian Variational Method (LVM). The LVM trial wave function is a sum of \( N \) Gaussian clouds and we have derived equations of motion for the centers, widths, and phase parameters of these clouds. These equations of motion can be rapidly solved for many different AI designs enabling the estimation of interferometer sensitivity and the effects of errors. We present two potential schemes for measuring “Big G” on the ISS. These include a Mach–Zehnder–like scheme as well as a design similar to a Foucault Pendulum.

1Supported by NSF grants PHY–1413768 and ARO Atomtronics MURI

11:39AM L50.00003 Sensitivity improvements to the YbF electron electric dipole moment experiment
ISABEL RABEY, JACK DEVLIN, BEN SAUER, JONY HUDSON, MIKE TARBUTTON, ED HINDS, Imperial College London — The electron is predicted to have a small electric dipole moment (EDM). The size of this fundamental property is intimately connected to the breaking of time reversal symmetry (T) in nature. The Standard Model, which does include a small amount of T asymmetry, predicts the EDM to be too small to ever detect at \( d_e < 10^{-38} \) e.cm. However, many extensions of the Standard Model that suggest additional T-violation predict the electron’s EDM to be within a measurable regime of both current and proposed experiments. This talk describes our YbF electron EDM experiment and introduces some of the technical improvements made to our machine since the last measurement. We have increased the statistical sensitivity of our interferometer by increasing the number of YbF molecules that participate in the experiment and by increasing their detection probability. We demonstrate several hardware developments that combine laser, microwave and rf fields which, when applied to YbF, can pump six times more population into the initial measurement state. In the detection region we have used techniques developed for molecular laser cooling, including resonant polarisation modulation, to dramatically increase the number of scattered photons by a factor of 10. Combining all improvements, the statistical uncertainty of our measurement is expected to be reduced by a factor of ninety, allowing us to search for physics beyond the Standard Model and below the recent upper limit of \( d_e < 8.9 \times 10^{-29} \) e.cm.

12:03PM L50.00005 Two-dimensional atom localization via phase-sensitive absorption-gain spectra in five-level hyper inverted-Y atomic systems, ZHONGHU ZHU, WEN-XING YANG1. Department of Physics, Southeast University, Nanjing 210096, PR China, AI-XI CHEN, Department of Applied Physics, School of Basic Science, East China Jiaotong University, Nanchang 330013, PR China — High-precision measurement of an atomic position through a standing-wave field has been the subject of active research over the past few decades because of its potential applications in laser cooling and trapping of neutral atoms, such as atom nanolithography, Bose-Einstein condensation, and coherent patterning of matter waves. More recently, two-dimensional atom localization, achieved by applying two orthogonal standing-wave fields, has been studied extensively for its unique properties. For realizing high-precision two-dimensional atom localization, we explore two-dimensional atom localization based on phase-sensitive probe absorption and gain in a microwave-driven five-level hyper inverted-Y atomic system. Because of the spatial position-dependent atom-field interaction, two-dimensional atom localization can be achieved by the measurements of the probe absorption and gain spectra. It was clearly shown that the precision of two-dimensional atom localization is extremely sensitive to the detuning of the weak probe field, the intensities of the two control fields, and the relative phase of the driving fields. The main advantage of our proposed scheme is that the maximum probability of finding the atom at an expected position in one period of the standing-wave fields is 100%.

12:05PM L50.00007 Three-Body Effects in a Zero-Scattering-Length Condensate, LAWRENCE PHILLIPS, Heriot Watt University — When pairwise interactions between ultracold Bosons are set to zero using Feshbach resonance, the resulting condensate is well described by replacing the standard two-body contact interaction with a three-body pseudopotential and proceeding with Hartree-Fock theory in the usual way. We give a prescription for calculating the coupling constant appearing in the three-body pseudopotential, and use it to investigate the dependence of the zero-scattering-length dynamics upon the original two-body potential.

12:27PM L50.00008 Nonadiabatic calculations on hydrogen molecule, JACEK KOMASA, Adam Mickiewicz University, Poznan, KRZYSZTOF PACHUCKI, Warsaw University, Poland — Since its infancy quantum mechanics has treated hydrogen molecule as a test bed. Contemporary spectroscopy is able to supply the dissociation energy (\( D_0 \)) of H\(_2\) with the accuracy of 3.7 \( \times 10^{-4} \) cm\(^{-1}\), while current theoretical predictions are 10\(^{-4}\) cm\(^{-1}\) or less. Both the uncertainties are already smaller than the quantum electrodynamic (QED) effects contributing to \( D_0 \), which poses a particular challenge to theorists. Undoubtedly, in order to increase the predictive power of theory one has to not only account for the multitudes of the tiny relativistic and QED effects but, especially, significantly increase precision of the largest component of \( D_0 \)—the nonrelativistic contribution. We approach the problem of solving the Schroedinger equation, equipped with new methodology, with the target precision of \( D_0 \) set at the level of 10\(^{-7}\) cm\(^{-1}\).

12:51PM L50.00009 s-wave resonant short-range interactions in a d-dimensional finite volume, SHANGGUO ZHU, SHINA TAN, Georgia Inst of Tech — It has been known that the energy spectra of few or many particles with short-range interactions in a finite periodic box are shifted according to the size of the box. In particular, the two-body interaction in a three-dimensional box is described by Luscher's formulas. Here we study the energy of one particle scattered by a resonant s-wave short-range center in a d-dimensional finite volume. When \( d = 6 \), this one-body problem is mapped to the scattering of three particles in a three-dimensional box with a resonant three-body interaction.

1:03PM L50.00010 The Bosonic Kane-Mele Hubbard model, RAJIBIR NIRWAN1. Institute fur Theoretische Physik, Goethe-Universitat, 60438 Frankfurt/Main, Germany, IVANA VASIC, Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, 11080 Belgrade, Serbia, ALEXANDRU PETRESCU, Department of Electrical Engineering, Princeton University, Princeton, New Jersey 08544, USA, KARYN LE HUR, Centre de Physique Theorique, Ecole Polytechnique and CNRS, Universite Paris-Saclay, France, WALTER HOFSTETTER, Institut fur Theoretische Physik, Goethe-Universitat, 60438 Frankfurt/Main, Germany — We investigate the bosonic equivalent of the Kane-Mele model on the honeycomb lattice [1] including spin-orbit and interaction effects. This model is a generalization of the interacting bosonic Haldane model introduced in Ref. [2]. We also allow for an on-site interaction (coherent) term between the two species. We analyze the phase diagram using bosonic dynamical mean-field theory and analytical methods. In the Mott phase, a strong-coupling expansion is performed to investigate the magnetism and frustration effects. A connection is drawn with the quantum theory of an antiferromagnet on a triangular lattice in a magnetic field [3]. This model can be realized in ultra-cold atom systems with current technology. [1] C. L. Kane and E. Mele, Phys. Rev. Lett. 95, 226801 (2005). [2] I. Vasic, A. Petrescu, K. Le Hur and W. Hofstetter, Phys. Rev. B 91, 094502 (2015). [3] A. V. Chubukov and D. I. Golosov, J. Phys. Cond. Matt. 3 69 (1991).

1:replace MAR16-2015-003145
1:15PM L50.00011 Strong correlation effects in a two-dimensional Bose gas with quartic dispersion. JURAJ RADIC, STEFAN NATU, VICTOR GALITSKI, University of Maryland, College Park — We consider a two-dimensional Bose gas at zero temperature with an underlying quartic single-particle dispersion in one spatial direction. This type of band structure can be realized using the NIST scheme of spin-orbit coupling, in the regime where the lower band dispersion has the form \( k^4 + \frac{1}{4} k^2 \pm \ldots \). We numerically compare the ground state energies of the mean-field Bose-Einstein condensate (BEC) and various trial wave-functions, where bosons avoid each other at short distances. We discover that, at low densities, several types of strongly correlated states have an energy per particle \( \epsilon \), which scales with density \( n \) as \( \epsilon \propto n^{1/3} \), in contrast to \( \epsilon \propto n \) for the weakly interacting Bose gas. These competing states include a Wigner crystal, quasi-condensates described in terms of properly symmetrized fermionic states, and variational wave-functions of Jastrow type, where the latter has the lowest energy and describes a strongly-correlated condensate. Our results show that even for weakly-interacting bosons in higher dimensions, one can explore the crossover from a weakly-coupled BEC to a strongly-correlated condensate by simply tuning the single particle dispersion or density.

1:27PM L50.00012 Wave function anatomy of ultracold fermions in a double well: Attractive-pairing, Wigner-molecules, and entanglement. BENEDIKT B. BRANDT, CONSATNTINE YANNOULEAS, UZI LANDMAN, School of Physics, Georgia Institute of Technology — We report on exact benchmark configuration-interaction computational solutions of the many-body Hamiltonian, uncovering the spectral evolution, wave function anatomy, and entanglement properties of a few interacting ultracold fermions in the entire parameter range, including crossover from an single-well to a double-well confinement and a controllable energy imbalance between the wells. According to recent experiments, the two wells are taken as quasi-one-dimensional and both the linear and parallal configurations of them are considered. We demonstrate attractive pairing and formation of repulsive, highly correlated, ultracold Wigner molecules, associated with the emergence of Heisenberg spin chains. For two fermions, the entanglement measure of the von-Neumann entropy is used as a diagnostic tool for identifying maximally entangled two-qubit Bell states.

1 Supported by the Air Force Office of Scientific Research

Wednesday, March 16, 2016 2:30PM - 5:18PM — Session P50 DAMOP: Quenched Atomic Systems and Thermalization — Hilton Baltimore Holiday Ballroom

1 1:30PM L50.00013 Solvable Models for a Few Atoms in a Few One-Dimensional Wells. NATHAN HARSHMAN, Department of Physics, American University — This project identifies networks of one-dimensional, few-particle, few-models that can be smoothly connected by tuning trap shape and two-body interaction parameters. Solvable models within these networks are identified and analyzed by exploiting symmetries in few-body configuration space and phase space. In one-dimension, ordering permutation symmetry is particularly effective for generating new models. Ordering permutation symmetry is distinct from particle permutation symmetry and arises when there are similar regions in configuration space that are completely disconnected due to unitary interactions and/or infinite well barriers. Realistic experiments with a few atoms or with ultracold gases trapped in effectively one-dimensional wells are analyzed by comparison with nearby solvable models using approximation schemes like perturbation theory or variational methods. The transition from systems with a few particles in a few wells to systems with many particles in large lattices can be explored using these techniques.

2 2:30PM P50.00001 Prethermalization and exponentially slow energy absorption in periodically driven many-body systems. DMITRY ABANIN, WEN WEI HO, University of Geneva, Switzerland, WOJCIECH DE ROECK, KU Leuven, Belgium, FRANCOIS HUVÈNEERS, Université Paris-Dauphine, France — We establish some general dynamical properties of lattice many-body systems that are subject to a high-frequency periodic driving. We prove that such systems have a quasi-conserved extensive quantity \( H_\star \), which plays the role of an effective static Hamiltonian. The dynamics of the system (e.g., evolution of any local observable) is well-approximated by the evolution with the Hamiltonian \( H_\star \) up to time \( \tau_\star \), which is exponentially long in the driving frequency. We further show that the energy absorption rate is exponentially small in the driving frequency. In cases where \( H_\star \) is ergodic, the driven system prethermalizes to a thermal state described by \( H_\star \) at intermediate times \( t < \tau_\star \), eventually heating up to an infinite-temperature state at times \( t \sim \tau_\star \). Our results indicate that rapidly driven many-body systems generically exhibit prethermalization and very slow heating. We briefly discuss implications for cold atoms experiments which realize topological states by periodic driving.

3 2:42PM P50.00002 Universal aspects of thermalization after a quantum quench. JAMES R. GARRISON, University of California, Santa Barbara, TARUN GROVER, Kavli Institute for Theoretical Physics — A very fundamental problem in quantum statistical mechanics involves whether—and how—an isolated quantum system will thermalize at long times. The Eigenstate Thermalization Hypothesis (ETH) posits that when thermalization occurs, it occurs at the level of each individual energy eigenstate. In recent work [1], we examined an isolated quantum system that obeys ETH and identified the precise class of operators for which ETH is satisfied. Here, we use similar techniques to study the more general case of a time-evolved system after a quantum quench. Given a “typical” initial state, we investigate the class of operators that thermalize and the associated time scales, and remark on the similarities and differences compared with a single eigenstate at finite energy density. Possible experimental implications will be discussed. [1] J. R. Garrison and T. Grover, arXiv:1503.00729.

4 2:54PM P50.00003 Short- and long-time dynamics of isolated many-body quantum systems. MARCO TAVORA, Yeshiva University, JONATHAN TORRÈS-HERRERA, Universidad Autonoma de Puebla, Mexico, LEA FERREIRA DOS SANTOS, Yeshiva University — We show our results for the relaxation process of isolated interacting quantum spin chains in the integrable and chaotic regimes. The dynamics of the survival probability (the probability for finding the system still in its initial state at later times) and of few-body observables are analyzed. Different time scales are considered. While the short-time evolution is determined by the shape of the weighted energy distribution of the initial state, the long-time behavior depends on the bounds of the spectrum. Both numerical and analytical results are presented as well as comparisons with existing rigorous mathematical derivations. We consider initial states that can be prepared in experiments with cold atoms in optical lattices.

1 NSF Grant No. DMR-1147430.
3:06PM P50.00004 Temperature of a small quantum system as an internal property. JIAOZI WANG, WENGE WANG, Univ of Sci & Tech of China — Equilibration of small quantum systems is a topic of current interest both theoretically and experimentally. In this work, we study the extent to which a temperature can be assigned to a small quantum (chaotic) system as an internal property, but not as a property of any large environment. Specifically, we study a total system, which is composed of an Ising chain in a nonhomogeneous transverse field and an additional spin coupled to one of the spins in the chain. The additional spin can be used as a probe to detect local temperature of the chain. The total system lies in a pure state under unitary evolution and initial state of the chain is prepared in a typical state within an energy shell. Our numerical simulations show that the reduced density matrix of the probe spin approaches canonical states at different locations of the chain beyond a relaxation time, and the results are close to the theoretical prediction given by the statistical mechanics in the thermodynamic limit, namely $\beta = \frac{\ln \rho(E)}{\ln(E)}$ with $\rho(E)$ being the density of states. We also study effects due to finite size of the chain, including the dependence on initial state of the probe and difference of numerically-obtain temperature from theoretical results.

3:18PM P50.00005 Temporal fluctuations after a quantum quench: Many-particle dephasing. FLORIAN MARQUARDT, University of Erlangen-Nuremberg, THOMAS KIENDL, Free University Berlin — After a quantum quench, the expectation values of observables continue to fluctuate in time. In the thermodynamic limit, one expects such fluctuations to decrease to zero, in order for standard statistical physics to hold. However, it is a challenge to determine analytically how the fluctuations decay as a function of system size. So far, there have been analytical predictions for integrable models (which are, naturally, somewhat special), analytical bounds for arbitrary systems, and numerical results for moderate-size systems. We have discovered a dynamical regime where the decrease of fluctuations is driven by many-particle dephasing, instead of a redistribution of occupation numbers. On the basis of this insight, we are able to provide exact analytical expressions for a model with weak integrability breaking (transverse Ising chain with additional terms). These predictions explicitly show how fluctuations are exponentially suppressed with system size.

3:30PM P50.00006 Persistent Hall response after a quantum quench in Dirac systems. JUSTIN WILSON, JUSTIN SONG, GIL REFAEL, Caltech — The geometry and topology of quantum states play a central role in producing novel types of responses, such as the quantum anomalous Hall effect. These have featured prominently in topological materials in equilibrium as well as driven systems in the steady state. Here we unveil how quantum geometry yields radically new types of responses in systems far from equilibrium such as that realized in a quantum quench. To illustrate this, we consider quenches of two-band systems with spin-orbit coupling (e.g. Dirac systems). We find that quenching a time-reversal broken gap gives a Hall-type response that persists even at long times. Intimately tied to the quantum geometry of the underlying Hilbert space, the unconventional persistent Hall response yield clear signatures in quench protocols that can be implemented in cold atoms set-ups.

3:42PM P50.00007 Quantum Quenches in Arrays of Coupled Luttinger Liquids. ANDREW JAMES, ANDREW HALLAM, University College London, ROBERT KONIK, Brookhaven National Laboratory, ANDREW GREEN, University College London — Cold atom realisations of one dimensional interacting bosonic models are typically formed as large arrays of decoupled tubes. A low energy description of the individual tubes (including the Lieb-Liniger case) is provided by Luttinger liquid theory. Using matrix product state methods combined with integrability, we study the time evolution of an infinite array of coupled Luttinger Liquids, after a quantum quench in which interchain tunnelling is switched on to form a 2D system. We extract the time dependence of the density, bosonic modes, the Loschmidt echo and the entanglement entropy and consider possible implications for phase transitions in the coupled chain system. Our results are compared to perturbation theory and contrasted with simulations for coupled arrays of massive chains.

3:54PM P50.00008 Melting of a spin domain wall in the context of recent experiments on ultracold atoms. LEV VIDMAR, Penn State University, DEEPAK IYER, Bucknell University, MARCOS RIGOL, Penn State University — When a one-dimensional spin domain wall of the form $\uparrow \ldots \uparrow \uparrow \downarrow \ldots \downarrow \downarrow \ldots \uparrow \ldots \uparrow$ is melting, transverse spin correlations in the XX model exhibit a power-law decay in the melted region. This model can be mapped to hard-core bosons via Jordan-Wigner transformation. For hard-core bosons, these emerging power-law correlations correspond to singularities in the quasimomentum distribution at finite quasimomenta $+/\pi/2$, resulting in a dynamical quasicondensate with the emerging phase order consistent from the ground-state order. This phenomenon has been recently observed experimentally with ultracold bosons in optical lattices [1]. Here we study the emergence of correlations in melting domain walls for hard-core bosons, spinless fermions and the Fermi-Hubbard model at infinite onsite repulsion. In all cases, the density dynamics exhibit identical ballistic expansion, while the correlations show strikingly different features. References: [1] Vidmar et al, PRL 115, 175301 (2015)

4:06PM P50.00009 Spatio-temporal correlations after a quantum quench in the Bose-Hubbard model. MATTHEW FITZPATRICK, MALCOLM KENNETT, Simon Fraser University — The quench dynamics of the Bose-Hubbard model (BHM) has received considerable attention in recent years. Theoretically, it has proven challenging to study spatio-temporal correlations in the BHM in dimensions higher than one. We use the Schwinger-Keldysh technique and a strong-coupling expansion to develop a two-particle irreducible formalism that allows the study of spatio-temporal correlations in both the superfluid (SF) and Mott-insulating (MI) regimes during a quantum quench for dimensions higher than one. In this talk, we focus on quenches from the SF to the MI regime and present our numerical results for the evolution of two-time correlation functions. We relate our results to recent cold-atom experiments.

4:18PM P50.00010 Entanglement dynamics after a quantum quench in the O(N) model. YONAH LEMONIK, ADITI MITRA, New York University — The entanglement properties of quenched quantum systems is an active area of study, however results in dimensions other than $d=1$ are generally lacking. We remedied this by investigating the entanglement properties after a critical quench in the bosonic O(N) model in $d=3$, comparing our results to the free massless theory. We find that the evolution of the entanglement entropy for the free and interacting systems is nearly identical, as expected from a "quasi-particle" picture. However, the low-lying entanglement spectrum is controlled by the different non-equilibrium critical exponents of these two systems. Therefore we demonstrate that these critical exponents can be extracted by studying purely the entanglement in the system.

4:30PM P50.00011 Quench dynamics of 1D spin-imbalanced Fermi-Hubbard model. XIAO YIN, LEO RADZIENOVSKY, University of Colorado at Boulder — We study a non-equilibrium dynamics of a 1D spin-imbalanced Fermi-Hubbard model following a quantum quench of on-site interaction, using bosonization and exact analysis. By focusing on the evolution of singlet-, triplet-, density and magnetization correlation functions, we find that the evolution and the final state display a strong dependence on the initial state. Thus, we demonstrate that such quantum quench may be used as a new approach to identify and probe the 1D gapless analogue of the elusive FFLO state.

This work is supported by NSF-DMR 1303177.

3 supported by NSF through DMR-1001240 and by Simons Investigator award from Simons.
4:42PM P50.00012 Quenched dynamics of superconducting Dirac fermions on honeycomb lattice. MING LU, X. C. XIE1, International Center for Quantum Materials, School of Physics, Peking University, X.C. XIE’S GROUP TEAM — We study the BCS pairing dynamics for the superconducting Dirac fermions on honeycomb lattice after a sudden quench of pairing strength. We observe two distinct phases, one is the synchronized phase with undamped oscillations of pairing amplitude; the other phase has the pairing amplitude oscillates from positive to negative. The exact phase transition point is given by investigating the integrability of the system. Different from the previous work on normal superconducting fermions, which has three distinct phases, our results shows the absence of the Landau damped phase and over damped phase. Moreover, we present a linear analysis in the weakly quenched regime, showing that, in a rather long time scale, the dynamics can be approximated as the periodic oscillation with $2\Delta_0$ angular frequency along with the logarithmic decay of the pairing amplitude, in contrast of the $t^{-1/2}$ decay for the normal fermions, namely the Landau damped phase.

1The presenter’s advisor

4:54PM P50.00013 Preparation of Bose Einstein condensates in realistic trapping potentials for precision atom interferometry, KATERINE POSSO TRUJILLO, ERNST M. RASEL, NACEUR GAALOUL, Univ Hannover, QUANTUS TEAM — Preparation of Bose Einstein condensates in realistic trapping potentials for precision atom interferometry. Theoretical studies of the ground state and the dynamical properties of Bose Einstein condensates (BECs) are typically realized by considering the ensemble as being initially trapped by a harmonic potential. Dramatic discrepancies were found by comparing numerical results of the long-time expansion of BECs after being released from the harmonic trap, and measurements of the free evolution and delta-kick cooling (DKC) of a $^{87}$Rb BEC on large timescales of up to 2 s in micro-gravity (micro-g) environment such as those performed in the QUANTUS project from our group [1]. The modification in the dynamics of a $^{87}$Rb BEC with the application of DKC by using experimentally implemented trapping geometries and the effect of gravity have been studied. Three different configurations have been considered: atom chip-based potential, dipole trap and the time-averaged orbiting potential. Such discrepancies may be crucial in high precision atom interferometry experiments in micro-g and zero-g platforms in which the implementation of DKC is mandatory to achieve the long-expansion times required. [1] H. Minting et al., Phys. Rev. Lett. vol. 110 093602 (2013).

5:06PM P50.00014 Memory effects in noninteracting isolated systems from dynamical geometry transformations in ultracold quantum gases, CHEN-YEN LAI, CHIN-CHUN CHIEN, Univ of California - Merced — Memory effects have been of broad interest and particularly relevant in condensate matter systems where dynamical properties depend on history. Here we explore possibilities of observing memory effects in simple isolated quantum systems undergoing geometry transformations. By transforming into lattices supporting flat-bands consisting of localized states, memory effects could be observed in ultracold atoms in optical lattices due to different time scales of localized and mobile atoms. As an example, a triangular lattice into a Kagome or nested lattice, the system reaches a non-hyperbolic quasi-steady state. In the absence of interactions and dissipations, the emergence of steady states are highly nontrivial and crucial in identifying memory effects unambiguously. Moreover, when the lattices transform from a triangular lattice into a Kagome lattice with a flat band, history-dependent density distributions even in noninteracting systems can be observed in fermionic as well as bosonic systems. Rapid growth of cold atom technology and possibilities of various mechanisms for inducing memory effect promise interesting applications of novel quantum devices utilizing memory effect, especially in the thriving field of atomtronics. (arXiv:1510.08978)

Wednesday, March 16, 2016 2:30PM - 5:30PM – Session P52 DAMOP FIAP: Optomechanics and Hybrid Systems III: Fundamental Methods and Applications Hilton Baltimore Holiday Ballroom 3 - Chen-lung Hung, Purdue University

2:30PM P52.00001 A general framework for analyzing pulsed optomechanical systems, BASSAM HELOU, BELINDA PANG, HAIXING MIAO, YANBEI CHEN, Caltech — One difficulty in understanding driven optomechanical systems comes from keeping track of the continuum of input and output optical modes. Can we formulate a simpler description? In the case of optical pulses of finite duration, the answer is yes. The dynamics of the joint optical and mechanical system can be summarized by a finite number of generalized modes! On the other hand, the analysis of the entanglement structure between the mechanics and optics is more involved, but could be approximated by a simple and bounded structure. Our work has immediate applications to the quantum engineering of optomechanical setups. We rigorously justify the formalism used in proposals for arbitrary Fock state preparation, extend the proposals to more realistic setups, and propose additional state preparation and state transfer protocols.

2:42PM P52.00002 Quenched dynamics in optomechanical arrays, SADEGH RAEISI, VITTORIO PEANO, FLORIAN MARQUARDT, University of Erlangen-Nuremberg — Optomechanical arrays are a novel quantum system that provides a promising tool for exploring many-body physics. The tunability of optomechanical arrays can be exploited for studying the non-equilibrium dynamics. Despite the technological challenges, experimental implementation of simple one-dimensional systems seems feasible in the next few years. Here we focus on the non-equilibrium dynamics of one-dimensional optomechanical arrays and investigate the quench dynamics in these systems. In particular, we study the topological properties and phases of these one-dimensional optomechanical arrays.

2:54PM P52.00003 Correlated anomalous phase diffusion of sideband-excited phonons in an electromechanical resonator, XIAOSHUI DONG, FENGPEI SUN, JIE ZOU, Hong Kong University of Science and Technology, MARK DYKMAN, Michigan State University, HOBUN CHAN, Hong Kong University of Science and Technology — We study the phase fluctuations of self-sustained oscillations induced by dynamical backaction in a micromechanical resonator. The resonator has two vibrational modes with strongly differing frequencies and decay rates. The high-frequency mode acts as a phonon cavity mode, playing a similar role as photon modes in optomechanical systems. When sufficiently strong pumping is applied at the blue-detuned sideband of the cavity, the dynamical backaction leads to a parametric instability accompanied by self-sustained oscillations. We find that self-sustained oscillations are induced not only in the low frequency mechanical mode, but also in the high frequency cavity mode. The nonlinear nature of the backaction leads to hysteresis of this self-sustained oscillations. In each mode, the phase undergoes anomalous diffusion, where the mean square phase change in time follows a superlinear power law. The exponent of this power law is determined by the $1/f$-type intrinsic frequency noise of the resonator. Remarkably, the phase fluctuation of the two modes show near perfect anti-correlation, our findings show that self-sustained oscillations induced by dynamical backaction offer new opportunities of phase manipulation and investigation of fundamental properties of resonating.
for quantum sensing, quantum information processing with metamaterials.

Our proposal brings together two important contemporary realms of science – cold atom physics and metamaterial dark resonance physics to eliminate the absorption loss and demonstrate an all-optical and ultra-fast control over the photonic topological transition from a simple three-site model where we identify four different regimes of the gauge-field dynamics. Furthermore, we extend the discussion to a two-dimensional lattice. The mechanical oscillation phases determine the optomechanical setting allows for the most natural extension where the gauge field becomes dynamical. The mechanical oscillation phases determine the effective artificial magnetic field for the photons, and once these phases are allowed to evolve, they respond to the flow of photons in the structure. We discuss a simple three-site model where we identify four different regimes of the gauge-field dynamics. Furthermore, we extend the discussion to a two-dimensional lattice. Our proposed scheme could for instance be implemented using optomechanical crystals.

Significantly, optomechanical systems tend to synchronize either in-phase or anti-phase. We investigate how the synchronization behaviour is affected in the presence of (quantum) noise. Talitha Weiss, Andreas Kronwald, Stefan Walter, Florian Marquardt. Institute for Theoretical Physics, FAU Erlangen-Nuremberg — Synchronization is a phenomenon that appears in various natural and man-made systems. Optomechanical limit-cycle oscillators can synchronize when they are coupled to each other or to an external periodic force. Classically, in the absence of noise, different synchronization regimes can be identified. Notably, optomechanical systems tend to synchronize either in-phase or anti-phase. We investigate how the synchronization behaviour is affected in the presence of the fundamental quantum noise (arXiv:1507.06190). We find a regime where fluctuations drive transitions between the classical synchronization states and explore the quantum-to-classical crossover. Finally, we compare the effects of quantum noise to the effects of thermal noise.

3:30PM P52.00006 Stochastic dynamics and phase-field roughening in optomechanical oscillator arrays, Roland Lauter, University of Erlangen-Nuremberg, Aditi Mitra, New York University, Florian Marquardt, University of Erlangen-Nuremberg — We consider arrays of coupled optomechanical systems, each of which consists of a laser-driven optical mode interacting with a mechanical (vibrational) mode. For sufficiently strong laser driving, the mechanical modes can settle into stable finite-amplitude oscillations on a limit cycle. We study the collective classical nonlinear dynamics of the phases of these oscillators, which is effectively described by an extension of the well-known Kuramoto model. In this extended model, we study the effect of noise on the dynamics in the case of homogeneous-phase initial conditions. We analytically establish a connection to the physics of surface growth as described by the Kardar-Parisi-Zhang model. Simulations of one-dimensional arrays of our model indeed show roughening of the phase field and universal scaling of the phase-field width. In contrast to the continuum Kardar-Parisi-Zhang model, our model is a genuine lattice model. We discuss interesting effects due to this difference, including crossover timescales and the role of instabilities of the roughening process.

3:42PM P52.00007 Topological Transport of Light and Sound, Christian Brendel, Vittorio Peano, Michael Schmidt, Florian Marquardt, FAU Erlangen-Nuremberg — Since they exploit global features of a materials band structure, topological states of matter are particularly robust. Having already been observed for electrons, atoms, and photons, it is an outstanding challenge to create a Chern insulator of sound waves in the solid state. In this work, we propose an implementation based on cavity optomechanics in a photonic crystal. We demonstrate the feasibility of our proposal by means of an effective lattice model as well as first principle simulations. The topological properties of the sound waves can be wholly tuned in situ by adjusting the amplitude and frequency of a driving laser that controls the optomechanical interaction between light and sound. The resulting chiral, topologically protected phonon transport can be probed completely optically.

3:54PM P52.00008 ORIGIN AND IMPLICATIONS OF $A^2$-LIKE CONTRIBUTION IN THE QUANTIZATION OF CIRCUIT-QED SYSTEMS, Mohammad Moein Malekakhlagh, Hakan Tureci, Princeton Univ — It is known that the electromagnetic modal structure of a cavity is modified by placing an atom into it. In cavity QED, this phenomenon manifests itself through the appearance of the $A^2$-contribution, a gauge-dependent diamagnetic term. Despite the negligible effect in the case of atomic cavity QED systems, in recent superconducting circuit realizations [1] these corrections may be observable and have qualitative implications. In this talk [2], we revisit the canonical quantization of a circuit QED system consisting of a single superconducting transmon qubit coupled to a multimode superconducting microwave resonator. We introduce a new set of modes that properly satisfies current conservation in the entire circuit and discuss how in terms of this set of modes, light-matter coupling can deviate drastically from the previous theories in the literature. Finally, we present a sum rule for the dipole transition matrix elements of a multi-level transmon qubit which provides an upper bound for the possible light-matter coupling strengths. [1] Neereja M. Sundaresan, Yanbing Liu, Darius Sadri, Laszlo J. Szocs, Devin L. Underwood, Moein Malekakhlagh, Hakan E. Tureci, Andrew A. Houck, Phys. Rev. X 5, 021035 [2] Moein Malekakhlagh and Hakan E. Tureci, arXiv:1506.02773 (2015)

4:06PM P52.00009 Dynamical Gauge Fields in Optomechanics, Stefan Walter, Florian Marquardt, University of Erlangen-Nuremberg — Artificial gauge fields for neutral particles such as photons, recently attracted a lot of attention in various fields ranging from photonic crystals to ultracold atoms in optical lattices to optomechanical arrays. Here we point out that, among all implementations of gauge fields, the optomechanical setting allows for the most natural extension where the gauge field becomes dynamical. The mechanical oscillation phases determine the effective artificial magnetic field for the photons, and once these phases are allowed to evolve, they respond to the flow of photons in the structure. We discuss a simple three-site model where we identify four different regimes of the gauge-field dynamics. Furthermore, we extend the discussion to a two-dimensional lattice. Our proposed scheme could for instance be implemented using optomechanical crystals.

4:18PM P52.00010 Topologically Reconfigurable Atomic Lattice Quantum Metamaterial, Pankaj Jha, Michael Mrejen, Jeongmin Kim, Chihhui Wu, Yuan Wang, Univ of California - Berkeley, Yuri Rostovtsev, Univ of North Texas, Denton, Xiang Zhang, Univ of California - Berkeley — Metamaterials have attracted unprecedented attention owing to their exceptional light-matter interaction properties. However, harnessing metamaterial at single photon or few photon excitations is still a long way to go due to several critical challenges such as optical loss, defects to name a few. Here we introduce and theoretically demonstrate a novel platform toward quantum metamaterial, immune to aforementioned challenges, with ultra-cold neutral atoms trapped in an artificial crystal of light. Such periodic atomic density grating –an atomic lattice- exhibits extreme anisotropic optical response where it behaves like a metal in one direction but dielectric along orthogonal directions. We harness the interacting dark resonance physics to eliminate the absorption loss and demonstrate an all-optical and ultra-fast control over the photonic topological transition from a close to an open topology at the same frequency. Such atomic lattice quantum metamaterial enables dynamic manipulation of the decay rate of a quantum emitter by more than an order of magnitude. Our proposal brings together two important contemporary realm of science – cold atom physics and metamaterial for applications in both fundamental and applied science. Atomic lattice quantum metamaterial may provide new opportunities, at single or few photon level, for quantum sensing, quantum information processing with metamaterials.
4:30PM P52.00011 Optomechanical Quantum Correlation Thermometry  T. P. PURDY, Joint Quantum Institute/NIST, K. E. GRUTTER, M. I. DAVANCO, K. SRINIVASAN, Center for Nanoscale Science and Technology/NIST, J. M. TAYLOR, Joint Quantum Institute/NIST; Joint Center for Quantum Information and Computer Science/UMD — We present an optomechanical approach for producing accurate thermometry over a wide temperature range using quantum Brownian motion. Optical measurements induce quantum correlations in an optomechanical system when quantum-limited intensity fluctuations of a probe laser drive mechanical motion. The size of the correlations in the weak probe limit are dictated by the scale of individual phonons. We have recently measured optomechanical quantum correlations in the cross correlation spectrum between the amplitude and phase fluctuations of a single probe laser interacting with a silicon nitride optomechanical crystal. These correlations are independent of thermally-induced Brownian motion. However, Brownian motion does simultaneously produce much larger correlation signals between other optical quadratures. A comparison of the size of thermally-induced correlations to quantum correlations allows us to absolutely calibrate Brownian motion thermometry to the mechanical energy quantization scale.

4:42PM P52.00012 Energy decay measurements in graphene-based mechanical resonators  PETER WEBER, JOHANNES GÜTTINGER, ADRIEN NOURY, JOEL MOSER, ADRIAN BACHTOLD, ICFO - Institut de Ciencies Fotoniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain — Shrinking nanomechanical resonators has led to new record sensitivities in mass and force detection and has provided novel insights into the rich physics of mechanical nonlinearities. However, the high sensitivity and enhanced nonlinearities in ultra small resonators pose new challenges for the detection of motion. This has so far prevented a more detailed investigation of the energy decay, which is the key figure of merit for most technological and scientific applications. Here we present a method to carry out time-resolved energy decay measurements of few-layer graphene resonators. In the high vibration amplitude regime, we observe a strong deviation from previous energy decay measurements. Contrary to expectations, the exponential decay rate decreases abruptly at a few threshold amplitudes. At the lowest measured vibrational amplitude, the energy decay rate is weakest, corresponding to quality factors that can surpass 1 million.

5:06PM P52.00013 Demonstration of the reversed dissipation regime in cavity electromechanics  A.K. FEOFANOV, L.D. TOTH, N.R. BERNIER, T.J. KIPPENBERG, Ecole polytechnique federale de Lausanne — Cavity optomechanical phenomena, such as amplification, generation or optomechanically induced transparency, emerge due to a strong imbalance in the dissipation rates of the parametrically coupled electromagnetic and mechanical resonators. Here we explore experimentally for the first time the reversed dissipation regime where the mechanical energy relaxation rate exceeds the energy decay rate of the electromagnetic cavity. We demonstrate optomechanically induced modifications of the microwave cavity resonance frequency and decay rate as well as mechanically-induced amplification of the electromagnetic mode and self-sustained oscillations (maser action) with high spectral purity of emitted microwave tone.

5:18PM P52.00014 Ground state cooling of a nanomechanical resonator using electron transport in hybrid systems 1, GIANLUCA RASTELLI, PASCAL STADLER, WOLFGANG BELZIG, University of Konstanz — A still open challenge in nanoelectromechanical systems is the achievement of the quantum regime via active cooling and using electron transport. I will discuss active ground state cooling in a bottom-up device, viz. a carbon nanotube quantum dot suspended between two electric nano-contacts, and for two different coherent transport regimes: (i) spin-polarized current between two ferromagnets and (ii) sub-gap Andreev current between a superconductor and a normal metal. I will show that efficient ground state cooling of the resonator can be achieved for realistic parameters of the system and varying the transport parameters, e.g. gate voltage, magnetic field, etc. Finally I will discuss the signatures in the current-voltage characteristics of the non-equilibrium state of the nanoresonator.

5:44PM P52.00015 Laser cooling of a harmonic oscillator's bath with optomechanics  XUNNONG XU, Joint Quantum Institute, University of Maryland/National Institute of Standards and Technology, College Park, Maryland 20742, USA, JACOB TAYLOR2, Joint Quantum Institute, National Institute of Standards and Technology, Gaithersburg, Maryland 20899, USA — Thermal noise reduction in mechanical systems is a topic both of fundamental interest for studying quantum physics at the macroscopic level and for application of interest, such as building high sensitivity mechanics based sensors. Similar to laser cooling of neutral atoms and trapped ions, the cooling of mechanical motion by radiation pressure can take single mechanical modes to their ground state. Conventional optomechanical cooling is able to introduce additional damping channel to mechanical motion, while keeping its thermal noise at the same level, and as a consequence, the effective temperature of the mechanical mode is lowered. However, the ratio of temperature to quality factor remains roughly constant, preventing dramatic advances in quantum sensing using this approach. Here we propose an efficient scheme for reducing the thermal load on a mechanical resonator while improving its quality factor. The mechanical mode of interest is assumed to be weakly coupled to its heat bath but strongly coupled to a second mechanical mode, which is cooled by radiation pressure coupling to a red detuned cavity field. We also identify a realistic optomechanical design that has the potential to realize this novel cooling scheme.

1Zukunftscolleg of the University of Konstanz; DFG through SFB 767 and BE 3803/5.

1Joint Center for Quantum Information and Computer Science, University of Maryland, College Park, MD 20742, USA

Thursday, March 17, 2016 8:00AM - 11:00AM — Session R13 DAMOP: Atomtronics 309 - Mark Edwards, Georgia Southern University

8:00AM R13.00001 Magnon optics and thermodynamics in a degenerate spinor Bose gas  DAN STAMPER-KURN, Univ of California - Berkeley — At low temperature, spinor Bose gases form magnetically ordered superfluids. Like other magnetic materials, such a fluid supports magnons, the Nambu-Goldstone bosons corresponding to the spontaneous breaking of rotational symmetry. We have developed methods to produce and detect such excitations in a $^{87}$Rb F = 1 spinor Bose gas. I will discuss precise measurements of the magnon recoil energy using coherent magnon interferometry, the use of thermalized magnons to measure and lower the temperature of quantum gases, and the phenomenon of magnon condensation in a quantum gas.

8:36AM R13.00002 Atomtronics with Ultracold Bose Gases  HERWIG OTT, University of Kaiserslautern — Neutral atom systems can exhibit similar transport properties like solid state devices. For instance, a neutral atom current is induced by a difference in chemical potential very much in the same way as a voltage drives an electric current. Employing Bose-Einstein condensed atomic gases allows observing superfluid transport phenomena, thus drawing connections to superconductivity. With help of light fields, the atomic current can additionally be guided in engineered potential landscapes in which one can also incorporate tunneling junctions. Eventually, the different components and elements can be integrated in atomtronic circuits which shed light on fundamental transport properties of many-body quantum systems. In this talk, I will present two fundamental atomtronic devices. The first is the observation of negative differential conductivity, which occurs at a multidrome tunneling junction for ultracold atoms [1]. The second is the appearance of a DC Josephson current in a biased tunneling junction [2], which features bistable transport characteristics. I will discuss the prospects of these basic elements for more complex atomtronic circuits. References [1] R. Labouvie, B. Santra, S. Heun, Wimberger, and H. Ott “Negative Differential Conductivity in an Interacting Quantum Gas” Phys. Rev. Lett. 115, 050601 (2015). [2] R. Labouvie, B. Santra, Simon Heun, and H. Ott “Nonequilibrium steady states in a driven-dissipative superfluid” arXiv:1507.05007
9:12 AM R13.00003 Dynamics of quantum impurities in many-body systems of ultracold atoms...

9:48 AM R13.00004 Transport dynamics and dissipation in polariton ring condensates and cold atoms...

10:24 AM R13.00005 Driving transitions between quantized flow states in an atomtronic circuit...

Thursday, March 17, 2016 8:00 AM - 10:48 AM
Session R45 GQI DAMOP: Hybrid Quantum Systems III 348 - Guido Burkard, University of Konstanz, Germany

8:00 AM R45.00001 Investigations of a transmon-coupled nanoresonator in a CPW cavity...

8:12 AM R45.00002 Surface acoustic wave resonators in the quantum regime...

8:24 AM R45.00003 Cavity magnomechanics...

8:36 AM R45.00004 Continuous dynamical decoupling of a single diamond nitrogen-vacancy center spin with a mechanical resonator. 1...

We acknowledge research support from the Office of Naval Research.

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1 We acknowledge research support from the Office of Naval Research.
Towards a highly efficient quantum spin-photon interface for an NV centre based quantum network. Stefan Bogdanovic, Cristian Bonato, Suzanne Van Dam, Andreas Reiserer, Anne-Marie Zwerger, Ronald Hanson, Kavli Institute of Nanoscience Delft, Delft University of Technology, Quantum Transport Team — Nitrogen-vacancy (NV) centers in diamond recently emerged as promising candidates for realizing quantum information algorithms due to their remarkable versatility. The spin of these optically active defects can be entangled with their emitted photons, making them an excellent optical interface from the perspective of quantum communication. Recently, we have demonstrated the first building blocks of such networks, performing kilometer scale entanglement of two NV centers and teleportation of quantum information. (1) However, our current protocols are inefficient due to the low emission of NV centers resonant photons into the zero phonon line (ZPL). Here we present our efforts of coupling a single NV center emitter in a diamond membrane to a fiber-based Fabry-Perot microcavity with high finesse ($F > 10^4$) at cryogenic temperatures. This approach allows spectral tuning of the cavity resonance to the ZPL emission of the NV center, thereby significantly enhancing the resonant photon emission via Purcell effect. Furthermore, the bulk environment of the NV centers protects their spin properties against surface proximity effects, which is of crucial importance for quantum information processing applications. (1) B. Hensen et al., Nature 526, 682 (2015).

9:12AM R45.00007 Coupling a single InAs quantum dot to mechanical motion of a photonic crystal membrane. Samuel Carter, Allan Bracker, Naval Research Laboratory, Muin Kim, Sotera Defense Solutions, Inc., Chul Soo Kim, Maxim Zalalutdinov, Brennan Pursley, Naval Research Laboratory, Sophia Economou, Department of Physics, Virginia Tech, Cyprian Czarnecki, Cameron Jennings, Michael Scheibner, School of Natural Sciences, University of California, Merced, Daniel Gammon, Naval Research Laboratory — Coupling quantum mechanical systems to mechanical motion is attractive for fundamental science, quantum information applications, and sensing. Semiconductor quantum dots (QDs) embedded in suspended photonic crystal structures provide a versatile system for advances in this area. Flexural modes of the suspended membrane as well as localized mechanical modes surrounding optical cavities couple to QDs through strain, with the photonic crystal used to maximize collection of photons from QDs. We have performed high resolution spectroscopy of InAs QDs embedded in photonic crystal structures while optically driving mechanical motion. Using time-correlated photon counting, the strain-induced shift of the QD optical transitions is measured as a function of time. For QDs at the center of the membrane (along the growth direction), the strain is minimum, and the optical transitions shift by only a few µeV. For QDs shifted 30 nm from the center, the strain induces larger shifts of 50 µeV. Measurements in a magnetic field are being performed on charged QDs to determine the coupling of mechanical motion to electron and hole spin transitions.

9:24AM R45.00008 Inductive cooling in quantum magnetomechanics. 1. Erick Romero-Sanchez, University of Queensland, Jason Twamley, Macquarie University, Warrick P. Bowen, University of Queensland, Michael R. Vanner, University of Oxford — Coupling to light or microwave fields allows quantum control of the motion of a mechanical oscillator, and offers prospects for precision sensing, quantum information systems, and tests of fundamental physics. In cavity electromechanics ground state cooling has been achieved using resolved sideband cooling. Here we present an alternative approach based on a magnetomechanical system that inductively couples an LC resonator to a mechanical oscillator. The experimental setup consists of a micro cantilever with a pyramidal magnetic tip attached at the end of the beam. The sharp end of the magnetic tip is positioned close to the planar microfabricated inductor of the LC resonator. The displacement in the position of the end of the cantilever generates a change in flux through the coil inducing an electromotive force in the circuit. The current in the LC resonator generates a magnetic field, and then a force between the tip and the coil. When they are strongly coupled and the mechanical resonance frequency $\omega_m$ exceeds the electrical decay rate of the resonator $\gamma_r$, resolved sideband cooling can be used to cool the mechanics. We present estimations for the coupling rates and the experimental parameters required for these experiments.

1 E. Romero acknowledges to CONACyT

9:36AM R45.00009 Strain coupling of a mechanical resonator to a single quantum emitter in diamond 1. Kenneth Lee, Donghun Lee, Preeti Ovartchaypong, Ania Jayich, University of California Santa Barbara — Hybrid quantum devices are central to the advancement of several emerging quantum technologies, including quantum information science and quantum-assisted sensing. Here, we present a hybrid quantum device in which strain fields associated with resonant vibrations of a diamond cantilever dynamically modulate the energy and polarization dependence of the optical transitions of a single nitrogen-vacancy defect center in diamond. With mechanical driving, we observe optomechanical couplings exceeding 10 GHZ. Through resonant excitation spectroscopy, we quantitatively characterize the intrinsic strain environment of a single defect, and use this information to control the zero phonon line of the defect. Through microscopical measurements, we show that we are able to match the frequency and polarization dependence of the zero-phonon lines of two separate NV centers. The experiments demonstrated here mark an important step toward realizing a monolithic hybrid quantum device capable of realizing and probing the dynamics of non-classical states of mechanical resonators, spin-systems, and photons.

1 This work was supported with grants from the AFOSR, NSF and DARPA

9:48AM R45.00010 Microwave-frequency electromechanical resonators incorporating phononic crystals. K. J. Satzinger, G. Peairs, A. Vainsencher, University of California, Santa Barbara, A. N. Cleland, University of Chicago — Piezoelectric micromechanical resonators at gigahertz frequencies have been operated in the quantum limit, with quantum control and measurement achieved using superconducting qubits. However, experiments to date have been limited by mechanical dissipation, due to a combination of internal and radiative losses. In this talk, we explore the incorporation of phononic crystals into resonator designs. In phononic crystals, periodic patterning manipulates the acoustic band structure of the material. Through appropriately chosen geometries, these periodic patterns lead to full acoustic bandgaps which can be used to greatly reduce radiation losses from resonant structures. Alternatively, the crystal geometry can be manipulated to allow isolated modes within the bandgap, giving fine control over the spatial structure of the resonator modes. In this talk, we will describe the design, fabrication, and measurement of resonators with phononic crystals.
10:00AM R45.00011 Superconducting-circuit quantum heat engine with frequency resolved thermal baths, PATRICK P. HOFER, JEAN-RENÉ SOUQUET, AASHISH A. CLERK, McGill University — The study of quantum heat engines promises to unravel deep, fundamental concepts in quantum thermodynamics. With this in mind, we propose a novel, realistic device that efficiently converts heat into work while maintaining reasonably large output powers. The key concept in our proposal is a highly peaked spectral density in both the thermal baths as well as the working fluid. This allows for a complete separation of the heat current from the working fluid. In our setup, Cooper pairs tunnelling across a Josephson junction serve as the working fluid, while two resonant cavities coupled to the junction act as frequency-resolved thermal baths. The device is operated such that a heat flux carried entirely by the photons induces an electrical current against a voltage bias, providing work.

10:12AM R45.00012 Strong nonlinearity of mesoscopic vibrational modes induced by electron-phonon coupling, KIRILL MOSKOVTSLEV, M. I. DYNAMAN, Michigan State University — We show that the electron-phonon coupling can lead to a strong nonlinearity of vibrational modes in semiconductor nano- and micro-resonators. For typical mode frequencies, the electron distribution adiabatically follows lattice strain. Therefore strain leads to redistribution of the electron density over the valleys of the conduction band. It also leads to the onset of a spatial charge. The parameter that controls the distribution is the ratio of the deformation potential to the electron chemical potential or temperature. It is $\sim 10^3$ for many semiconductors of interest even when they are heavily doped. Therefore the change of the electron distribution is strongly nonlinear in the strain. As a consequence, the stress induced by the electron-phonon coupling is also strongly nonlinear. We have found the vibration nonlinearity parameters for $n$-doped Si and calculated the amplitude dependence of the frequencies of several low-lying Si resonator modes with account taken of their spatial structure. The results are compared with the recent experimental data that shows strong effect of doping on the vibration nonlinearity.

10:24AM R45.00013 Novel High Cooperativity Photon-Magnon Cavity QED, MICHAEL TOBAR, JEREMY BOURHILL, NIKITA KOSTYLEV, MAXIM G. DANIEL CREDON, School of Physics, University of Western Australia, ARC Centre of Excellence for Engineered Quantum Systems — Novel microwave cavity resonators are presented, which couple photons and magnons in YIG spheres in a super- and ultra-strong way at around 20 mK in temperature. Few/Single photon couplings (or normal mode splitting, 2g) of more than 6 GHz at microwave frequencies are obtained. Types of cavities include multiple post reentrant cavities, which co-couple photons at different frequencies with a coupling greater that the free spectral range, as well as spherical loaded dielectric cavity resonators. In such cavities we show that the bare dielectric properties can be obtained by polarizing all magnon modes to high energy using a 7 Tesla magnet. We also show that at zero-field, collective effects of the spins significantly perturb the photon modes. Other effects like time-reversal symmetry breaking are observed.

10:36AM R45.00014 Cavity QED with ferromagnetic magnons in a small YIG sphere, DENGKE ZHANG, Beijing Computational Science Research Center, XIN-MING WANG, Research Center of Laser Fusion, CAEP, TIE-FU LI, Institute of Microelectronics, Tsinghua University, XIAO-QING LUO, Beijing Computational Science Research Center, WEIDONG WU, Research Center of Laser Fusion, CAEP, FRANCO NORI, Center for Emergent Matter Science, RIKEN. J. Q. YOU, Beijing Computational Science Research Center — Hybridizing collective spin excitations in ferromagnetic crystals and a cavity with high cooperativity provides a new research subject in the field of cavity quantum electrodynamics and can also have potential applications to quantum information. In contrast to spin ensembles based on dilute paramagnetic impurities, these spins are strongly exchange-coupled and have a much higher density. Here we report a direct observation of the strong coupling between magnons and microwave photons at both cryogenic and room temperatures by using the same small yttrium-iron-garnet (YIG) ferromagnetic sphere in a 3D copper cavity. We observed strong couplings of the same cavity mode to both ferromagnetic-resonance (FMR, uniform precession) and a magnetostatic (MS, non-uniform precession) mode in the quantum limit at 22 mK. Then, at room temperature, we observed a strong coupling of the cavity mode to the FMR mode with slightly increased damping rate. This reveals the robustness of the FMR mode against temperature. However, the coupling to MS mode disappears at room temperature and numerically simulations show that this is due to a drastic increase of the damping rate of the MS mode. Our work unveils quantum-coherence properties of the magnons.

Thursday, March 17, 2016 8:00AM - 11:00AM —

Session R50 DAMOP: Quantum Gases in Reduced Dimension, Ladders, and other Novel Geometries

Hilton Baltimore Holiday Ballroom 1 - M. Rigol, Pennsylvania State University

8:00AM R50.00001 Exploring Quantum Many-Body Spin Dynamics with Truncated Wigner Methods, JOHANNES SCHACHENMAYER, JILA, NIST & Department of Physics, University of Colorado, Boulder — Recent experiments in atomic, molecular, and optical physics offer controlled and clean environments to experimentally study non-equilibrium dynamics of large many-body quantum spin models with variable range interactions. Thus, efficient computation of such dynamics is of great importance. While in one dimension, time-dependent density matrix renormalization group methods (t-DMRG) have proven effective under certain conditions, computing dynamics in higher dimensional systems remains an outstanding challenge. Recently we formulated the discrete truncated Wigner approximation (DTWA), a semiclassical method based on the truncated Wigner approximation (TWA) that has been proven to be surprisingly accurate in predicting quench dynamics in high-dimensional lattices with up to tens of thousands of quantum spins. Here, we introduce the DTWA and show how it can compute time-evolution of quantum states in experiments that engineer spin-models with polar molecules in optical lattices or with ions in two-dimensional Penning traps. We show, how the DTWA can provide results for the time-evolution of classical and quantum correlations in quench experiments in regimes where other numerical methods are generally unreliable. We report on progress of how to incorporate higher order corrections to the method, and how to adapt it to systems with both spin and bosonic degrees of freedom.

8:36AM R50.00002 A Quantum Dipolar Spin Liquid, NORMAN YAO, Department of Physics, UC Berkeley, MICHAEL ZALETEL, Station Q, Microsoft Research, DAN STAMPER-KÜRN, ASHVIN VISHWANATH, Department of Physics, UC Berkeley — Quantum spin liquids are a new class of magnetic ground state in which spins are quantum mechanically entangled over large distances. Motivated by recent advances in the control of polar molecules, we consider that dipolar interactions between $S=1/2$ moment states can stabilize spin liquids on the triangular and kagome lattices. In the latter case, the moments spontaneously break time-reversal, forming a chiral spin liquid with robust edge modes and emergent semions. We propose a simple route toward synthesizing a dipolar Heisenberg antiferromagnet from lattice-trapped polar molecules using only a single pair of rotational states and a constant electric field.

8:48AM R50.00003 Intrinsic topological superfluidity — fluctuations and response, K LEVIN, CHIEN-TE WU, BRANDON ANDERSON, RUFUS BOYACK, James Franck Institute — Recent interest in topological superconductivity is based primarily on exploiting proximity effects to obtain this important phase. However, in cold gases it is possible to contemplate “intrinsic” topological superfluidity produced with a synthetic spin-orbit coupling and Zeeman field. It is important for such future experiments to establish how low in temperature one needs to go to reach the ordered phase. Similarly, it will be helpful to have a probe of the normal (pseudogap) phase to determine if the ultimate superfluid order will be topological or trivial. In this talk, we address these issues by considering fluctuation effects in such a superfluid, and calculate the critical transition temperature and response functions. We see qualitative signatures of topological superfluidity in spin and charge response functions. We also explore the suppression of superfluidity due to fluctuations, and importantly find that the temperature scales necessary to reach topological superfluidity are reasonably accessible [1]. [1] Phys. Rev. B 92, 134523 (2015)
Phase diagrams of spinor bosons in two-leg ladders.\(^1\)  

JERÓNIMO SILVA VALENCE, ROBERTO FRANCO, Universidad Nacional de Colombia, MARCOS SERGIO FIGUEIRE, Universidade Federal Fluminense — In the last, years different experimental groups have reported the realization of atomic ladders in the presence of a homogeneous flux [Nat. Phys. 10, 588 (2014)]. These experiments have motivated theoretical calculations on 2-leg ladders with spinless bosons under magnetic fields [PRB 91, 140406(R) (2015)]. In this paper, we consider spinor boson atoms with spin \(S=1\), such as Rb and Na. Gases of these atoms can be described by the spinor Bose-Hubbard Hamiltonian which has three terms: the kinetic energy, local density-density interaction and local spin-dependent term. Using DMRG, we study \(S=1\) bosons on 2-leg ladders, taking into account both antiferromagnetic and ferromagnetspin interaction. When both legs are ferromagnetic or antiferromagnetic, we obtained Mott insulator and superfluid phases, similar to the one-dimensional case, but the insulator areas decrease due to the additional kinetic term. The even-odd asymmetry is still observed in the antiferromagnetic case. However, when the local spin interaction has a different sign on each leg, charge density waves for densities 3/2 and 5/2 appear. The Mott insulator phase for density 1 (2) correspond to the antiferromagnetic-leg (ferromagnetic-leg).

\(^1\) Colciencias (grant No. FP4482-057-2015)

XY-sliding phases — mirage of the Renormalization Group\(^1\), STEVEN VAYL, ANATOLY KUKLOV, VADIM OGANESYAN, CSI and the Graduate Center, CUNY — The so-called sliding XY phases in layered systems are predicted to occur if the one loop renormalization group (RG) flow renders the interlayer Josephson coupling irrelevant, while each layer still features broken U(1) symmetry\(^2\). In other words, such a layered system remains essentially two-dimensional despite the presence of inter-layer Josephson coupling. We have analyzed numerically a layered system consisting of groups of asymmetric layers where the RG analysis predicts sliding phases to occur. Monte Carlo simulations of such a system have been conducted in the dual representation by Worm Algorithm\(^3\) in terms of the closed loops of J-currents\(^4\) for layer sizes varying from 4×4 to 640×640 and the number of layers — from 2 to 40. The resulting flow of the inter-layer XY-stiffness has been found to be inconsistent with the RG prediction and fully consistent with the behavior of the 3D standard XY model where the bare inter-layer Josephson coupling is much smaller than the in-layer stiffness. This result emphasizes the importance of the compactness of the U(1) variable for 2D to 3D transformation.

\(^1\) This work was supported by the NSF grant PHY1314469
\(^3\) N.V.Prokof'ev, B.V.Svidunov, PRL 87.160601(2001)
\(^4\) M.Wallin, et al., PRBB49.12115(1994)

Dimensional phase transition from 1D behavior to a 3D Bose-Einstein condensate , AXEL PELSTER, DENIS MORATH, DOMINIK STRABEL, SEBASTIAN EGGERT, Univ Kaiserslautern, Germany — The emergence of new properties from low-dimensional building blocks is a universal theme in different areas in physics. The investigation of transitions between isolated and coupled low-dimensional systems promises to reveal new phenomena and exotic phases. Interacting 1D bosons, which are coupled in a two-dimensional array, are expected to exhibit an unusual variety of states. In this talk, we present experimental results obtained on a system which illustrates the concept of a dimensional phase transition. However, recent experiments using ultracold gases have shown a surprising discrepancy between theory and experiment [1] and it is far from obvious if the power laws from the underlying 1D theory can predict the transition temperature and order parameter correctly for all interaction strengths. Using a combination of large-scale Quantum Monte-Carlo simulations and mean-field calculations, we show that the behavior of the ordering temperature as a function of inter-chain coupling strength does not follow a universal powerlaw, but also depends strongly on the filling. [1] A. Vogler, R. Labouvie, G. Barontini, S. Eggert, V. Guarrera, and H. Ott, Phys. Rev. Lett. 113, 215301 (2014)

Solving a quantum many-body problem by experiment , THOMAS SCHWEIGLER, Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien; VALENTIN KASPER, Institut für Theoretische Physik, Universität Heidelberg, SEBASTIAN ERNE, BERNHARD RAUER, TIM LANGEN, Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, THOMAS GASENZER, Kirchhoff-Institut für Physik, Universität Heidelberg, JÜRGEN BERGES, Institut für Theoretische Physik, Universität Heidelberg, JÖRG SCHMIDEMAYER, Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien — We experimentally study a pair of tunnel-coupled one-dimensional atomic superfluids, which realize the quantum sine-Gordon massive Thirring models relevant for a wide variety of disciplines from particle to condensed-matter physics. From measured interference patterns we extract phase correlation functions and analyze if, and under which conditions, the higher-order correlation functions factorize into the fundamental ones, which allows us to perform our experimental measurements, detecting the relevant quasiparticles, their interactions and the topologically distinct vacua. Our method provides comprehensive insights into a non-trivial quantum field theory and establishes a general method to analyze quantum many-body systems through experiments. The method is also used to investigate the non-equilibrium dynamics following a quench in the tunnel-coupling between the superfluids.

Meissner and Laughlin Phases in bosonic Ladders , ALEXANDRU PETRESCU, Princeton University, Department of Electrical Engineering, MARIE PIRAUD, Department of Physics and Arnold Sommerfeld Center for Theoretical Physics, Ludwig-Maximilians-Universität München, IAN MCCulloch, ARC Centre for Engineered Quantum Systems, School of Mathematics and Physics, The University of Queensland, ANATOLY KUKLOV, Ludwig-Maximilians-Universität of Munich, VADIM OGANESYAN, CSI and the Graduate Center, CUNY — The so-called sliding XY phases in layered systems are predicted to occur if the one loop renormalization group (RG) flow renders the interlayer Josephson coupling irrelevant, while each layer still features broken U(1) symmetry. In other words, such a layered system remains essentially two-dimensional despite the presence of inter-layer Josephson coupling. We have analyzed numerically a layered system consisting of groups of asymmetric layers where the RG analysis predicts sliding phases to occur. Monte Carlo simulations of such a system have been conducted in the dual representation by Worm Algorithm in terms of the closed loops of J-currents for layer sizes varying from 4×4 to 640×640 and the number of layers — from 2 to 40. The resulting flow of the inter-layer XY-stiffness has been found to be inconsistent with the RG prediction and fully consistent with the behavior of the 3D standard XY model where the bare inter-layer Josephson coupling is much smaller than the in-layer stiffness. This result emphasizes the importance of the compactness of the U(1) variable for 2D to 3D transformation.

Phase diagrams of spinor bosons in two-leg ladders,\(^1\)  

JERÓNIMO SILVA VALENCE, ROBERTO FRANCO, Universidad Nacional de Colombia, MARCOS SERGIO FIGUEIRE, Universidade Federal Fluminense — In the last, years different experimental groups have reported the realization of atomic ladders in the presence of a homogeneous flux [Nat. Phys. 10, 588 (2014)]. These experiments have motivated theoretical calculations on 2-leg ladders with spinless bosons under magnetic fields [PRB 91, 140406(R) (2015)]. In this paper, we consider spinor boson atoms with spin \(S=1\), such as Rb and Na. Gases of these atoms can be described by the spinor Bose-Hubbard Hamiltonian which has three terms: the kinetic energy, local density-density interaction and local spin-dependent term. Using DMRG, we study \(S=1\) bosons on 2-leg ladders, taking into account both antiferromagnetic and ferromagnetic spin interaction. When both legs are ferromagnetic or antiferromagnetic, we obtained Mott insulator and superfluid phases, similar to the one-dimensional case, but the insulator areas decrease due to the additional kinetic term. The even-odd asymmetry is still observed in the antiferromagnetic case. However, when the local spin interaction has a different sign on each leg, charge density waves for densities 3/2 and 5/2 appear. The Mott insulator phase for density 1 (2) correspond to the antiferromagnetic-leg (ferromagnetic-leg).

\(^1\) Colciencias (grant No. FP4482-057-2015)
10:12AM R50.00010 Entanglement entropy of the ground state of the Lieb-Liniger model, C. M. HERDMAN, P.-N. ROY, University of Waterloo, ROGER MELKOE, University of Waterloo and Perimeter Institute for Theoretical Physics, ADRIAN DEL MAESTRO, University of Vermont — We consider the entanglement between two spatial subsystems in the Lieb-Liniger model of contact interacting bosons in continuous space in one dimension. Using a continuous-space ground state path integral quantum Monte Carlo method, we numerically compute the Rényi entropy of the reduced density matrix of the subsystem as a measure of entanglement. Our numerical algorithm is based on the replica method previously introduced by the authors, which we have extended to efficiently study large spatial subsystems using a ratio approach. We confirm a logarithmic scaling of the Rényi entropy with subsystem size that is expected from conformal field theory and compute the non-universal sub-leading constant for interaction strengths ranging over several orders of magnitude. In the strongly interacting limit, we find agreement with the known free fermion result.

10:24AM R50.00011 Diagrammatic Monte Carlo study of Fermi-polaron systems, PETER KROISS, LODE POLLET, Department of Physics, Arnold Sommerfeld Center for Theoretical Physics and Center for NanoScience, Ludwig-Maximilians-University Munich — We apply the diagrammatic Monte Carlo approach to three-dimensional Fermi-polaron systems with mass-imbalance, where an impurity interacts resonantly with a noninteracting Fermi sea whose atoms have a different mass. This method allows to go beyond frequently used variational techniques by stochastically summing all relevant impurity Feynman diagrams up to a maximum expansion order limited by the sign problem. Polaron energy and quasiparticle residue can be accurately determined over a broad range of impurity masses. The quantitative exactness of two-particle-hole wave-functions is investigated, resulting in a relative lowering of polaronic energies in the mass-imbalance phase diagram. The application of the method to two-dimensional Fermi-polaron systems is presented.

10:36AM R50.00012 Recent developments in auxiliary-field quantum Monte Carlo methods for cold atoms, HAO SHI, PETER ROSENBERG, ETTORE VITALI, SIMONE CHIESA, SHIWEI ZHANG, College of William and Mary — Exact calculations are performed on the two-dimensional strongly interacting, uni-polarized, uniform Fermi gas with a zero-range attractive interaction. We describe recent advances in auxiliary-field quantum Monte Carlo techniques, which eliminate an infinite variance problem in the standard algorithm, and improve both acceptance ratio and efficiency. The new methods enable calculations on large enough lattices to reliably compute ground-state properties in the thermodynamic limit. An equation of state is obtained, with a parametrization provided, which can serve as a benchmark and allow accurate comparisons with experiments. The pressure, contact parameter, condensate fraction, and pairing gap will be presented. The same methods are also applied to obtain exact results on the two-dimensional strongly interacting Fermi gas in the presence of Rashba spin-orbit (SOC), providing insights on the interplay between pairing and SOC.

Thursday, March 17, 2016 11:15AM - 2:03PM — Session S45 GQI DAMOP: Atomic, Molecular and Optical Quantum Information and Metrology

11:15AM S45.00001 Quantum Rabi Model in Quantum Technologies, JULIEN PEDERNALES, URTZI LAS HERAS, LUCAS LAMATA, University of the Basque Country, Spain, ENRIQUE SOLANO, University of the Basque Country and IKERBASQUE, Spain — We will discuss how to simulate a wide range of regimes of the Quantum Rabi Model (QRM) in quantum platforms as trapped ions and circuit QED. Directly accessible regimes of the QRM correspond to a very narrow set of values of the ratio between the coupling strength and the characteristic frequencies of the system, typically in the strong coupling regime or in the perturbative zone of the ultrastrong coupling regime. However, with analog and digital quantum simulation techniques we can access the most elusive regimes of the QRM. Recent theoretical developments have disclosed a plethora of physical phenomena appearing at these previously unexplored regimes of the QRM, making its experimental implementation timely and of high interest.

11:27AM S45.00002 What can we learn from the dynamics of entanglement and quantum discord in the Tavis-Cummings model?1, JULIANA RESTREPO, Universidad Antonio Nario, BORIS A. RODRIGUEZ, Universidad de Antioquia — We revisit the problem of the dynamics of quantum correlations in the exact Tavis-Cummings model. We show that many of the dynamical features of quantum discord attributed to dissipation are already present in the exact framework and are due to the well known non-linearies in the model and to the choice of initial conditions. Through a comprehensive analysis, supported by explicit analytical calculations, we find that the dynamics of entanglement and quantum discord are far from being trivial or intuitive. In this context, we find states that are indistinguishable from the point of view of entanglement and distinguishable from the point of view of quantum discord, states where the two quantities give opposite information and states where they give roughly the same information about correlations at a certain time. Depending on the initial conditions, this model exhibits a fascinating range of phenomena that can be used for experimental purposes: the exchange of manifold or dissipation, tunable entanglement states and states with a counterintuitive sudden birth as the number of photons increase. We furthermore propose an experiment called quantum discord gates where discord is zero or non-zero depending on the number of photons.

11:39AM S45.00003 ABSTRACT WITHDRAWN —

11:51AM S45.00004 Robust quantum state transfer with suppressed parametric noise, MENGZHENG ZHANG, CHANGLING ZOU, LIANG JIANG, Yale University — For opto-electro-mechanical transducers, there are undesirable parametric processes that introduce parametric noise, which will limit the fidelity of the transferred quantum state. To overcome this imperfection, we propose a quantum state transfer scheme with squeezed input states and measurement dependent compensation to eliminate the parametric noise from the quantum state transfer. Besides parametric noise, we also investigate the sensitivity of our scheme to thermal noise, signal frequency detuning and imperfect impedance matching, and show a good quantum state fidelity and applicability to quantum state transfer.

nanometer accuracy, a regime where the storage capacity could exceed $10^{17}$ bytes/cm$^3$ with the aid of super resolution microscopy techniques already employed to discriminate between NVs with sub-diffraction, preserves information written on different planes of the diamond crystal and thus serves as a platform for three-dimensional storage. Substantial enhancement allows us to transition from binary to multi-valued encoding, which translates into a significant storage capacity boost. Finally, we show that our technique initialize the NV charge state, which has an immediate impact on the center's light emission properties. Here, we use two-color microscopy in NV-rich, type-1b focus of widespread attention for applications ranging from quantum information processing to nanoscale metrology. Of great utility is the ability to optically interplay between photo-excited carriers and atomic defects in the diamond lattice. Further, by using the NV as a local probe, we map the relative fraction redistribution of charge. We uncover the formation of various spatial patterns of trapped charge, which we semi-quantitatively reproduce via a model of the

This is due to the challenges posed by diamond as host material for defects, as well as the attractive properties of SiC. In this density functional theory work, we study the spin-1 system of the negatively charged NV-center in SiC in two polytypes: 3C-SiC and 4H-SiC. The calculated zero phonon line for the excited state of the defect is in telecom range (0.90 eV), making it a very good candidate for quantum technologies. This work provides basic ingredients required to understand the physics of this color center at a quantitative and qualitative level. We also design quantum information applications, such as a spin-photon interface and three-dimensional memory.

We acknowledge support from NSERC, INTRIQ, CIFAR and the Walter C. Sumner Foundation.

12:15PM S45.00006 Maximal adaptive-decision speedups in quantum-state readout$^1$, BENJAMIN D’ANJOU, LOUTFI KURET, LILIAN CHILDRESS, WILLIAM A. COISH, McGill University — The average time $T$ required for high-fidelity readout of quantum states can be significantly reduced via a real-time adaptive decision rule. An adaptive decision rule stops the readout as soon as a desired level of confidence has been achieved, as opposed to setting a fixed readout time $t_f$. The performance of the adaptive decision is characterized by the “adaptive-decision speedup” $t_f/T$. In this work, we reformulate this readout problem in terms of the first-passage time of a particle undergoing stochastic motion. This formalism allows us to theoretically establish the maximum achievable adaptive-decision speedups for several physical two-state readout implementations. We show that for two common readout schemes (the Gaussian latching readout and a readout relying on state-dependent decay), the speedup is bounded by $4$ and $2$, respectively, in the limit of high single-shot readout fidelity. We experimentally study the achievable speedup in a real-world scenario by applying the adaptive decision rule to a readout of the nitrogen-vacancy-center (NV-center) charge state. We find a speedup of $\approx 2$ with our experimental parameters. Our results should lead to immediate improvements in nano-scale magnetometry based on spin-to-charge conversion of the NV-center spin.

We acknowledge support from the National Science Foundation through grant NSF-1314205.

12:27PM S45.00007 Negatively-charged NV-center in SiC: Electronic structure properties, PRATIBHA DEV, Dept. of Physics and Astronomy, Howard University, Washington, D.C., SOPHIA ECONOMOU, Dept. of Physics, Virginia Tech, Blacksburg, Virginia — Deep defects with high-spin states in semiconductors are promising candidates as solid-state systems for quantum computing applications. The charged NV-center in diamond is the best-known and most-studied defect center, and has proven to be a good proof-of-principle structure for demonstrating the use of such defects in quantum technologies. Increasingly, however, there is an interest in exploring deep defects in alternative semiconductors such as SiC. This is due to the challenges posed by diamond as host material for defects, as well as the attractive properties of SiC. In this density functional theory work, we study the spin-1 system of the negatively charged NV-center in two polytypes: 3C-SiC and 4H-SiC. The calculated zero phonon line for the excited state of the defect is in telecom range (0.90 eV), making it a very good candidate for quantum technologies. This work provides basic ingredients required to understand the physics of this color center at a quantitative and qualitative level. We also design quantum information applications, such as a spin-photon interface and three-dimensional memory.

We acknowledge support from NSERC, INTRIQ, CIFAR and the Walter C. Sumner Foundation.

12:39PM S45.00008 Optical patterning of trapped charge in nitrogen-doped diamond$^1$, SID-DHARTH DHOMKAR, HARISHANKAR JAYAKUMAR, DANIELA PAGLIERO, ABDELGHANI LARAOUI, REMUS ALBU, City College of New York-CUNY, NEIL MANSON, MARCUS DOHERTY, Australian National University, JACOB HENSHAW, CARLOS MERILES, City College of New York-CUNY, Graduate Center-CUNY — The nitrogen-vacancy (NV) center in diamond is emerging as a promising platform for solid-state quantum information processing and nanoscale metrology. Of interest in these applications is the manipulation of the NV charge state, which can be attained by optical illumination. Here we use two-color optical microscopy to investigate the dynamics of NV photo-ionization, charge diffusion, and trapping in type-1b diamond. We combine fixed-point laser excitation and scanning fluorescence imaging to locally alter the concentration of negatively charged NVs and to subsequently probe the corresponding redistribution of charge. We uncover the formation of various spatial patterns of trapped charge, which we semi-quantitatively reproduce via a model of the interplay between photo-excited carriers and atomic defects in the diamond lattice. Further, by using the NV as a local probe, we map the relative fraction of positively charged nitrogen upon localized optical excitation. These observations may prove important to various technologies, including the transport of quantum information between remote NVs and the development of three-dimensional, charge-based memories.

We acknowledge support from the National Science Foundation through grant NSF-1314205.

12:51PM S45.00009 Towards High Density 3-D Memory in Diamond$^1$, JACOB HENSHAW, City College of New York-CUNY, Graduate Center-CUNY, SIDDHARTH DHOMKAR, City College of New York-CUNY, CARLOS MERILES, City College of New York-CUNY, Graduate Center-CUNY, HARISHANKAR JAYAKUMAR, City College of New York-CUNY — The nitrogen-vacancy (NV) center in diamond is presently the focus of widespread attention for applications ranging from quantum information processing to nanoscale metrology. Of great utility is the ability to optically initialize the NV charge state, which has an immediate impact on the center’s light emission properties. Here, we use two-color microscopy in NV-rich, type-1b diamond to demonstrate fluorescence-encoded long-term storage of classical information. As a proof of principle, we write, reset, and rewrite various patterns with 2-D binary bit density comparable to present DVD-ROM technology. The strong fluorescence signal originating from the diffraction-limited bit volume allows us to transition from binary to multi-valued encoding, which translates into a significant storage capacity boost. Finally, we show that our technique preserves information written on different planes of the diamond crystal and thus serves as a platform for three-dimensional storage. Substantial enhancement in the bit density could be achieved with the aid of super resolution microscopy techniques already employed to discriminate between NVs with sub-diffraction, nanometer accuracy, a regime where the storage capacity could exceed $10^{17}$ bytes/cm$^3$.

We acknowledge support from the National Science Foundation through grant NSF-1314205.
1:15PM S45.00011 Single molecule spin resonance spectroscopy and imaging by diamond-sensor. JIANGFENG DU, University of Science and Technology of China — Single-molecule magnetic resonance spectroscopy and imaging is one of the ultimate goals in magnetic resonance and will have great applications in a broad range of scientific areas, from life science to physics and chemistry. The spin of a single nitrogen vacancy (NV) center in diamond is a highly sensitive magnetic-field sensor, which has been proposed for detection of single molecules or nanoscale targets. We and co-workers have successfully obtained the first single-protein spin resonance spectroscopy under ambient conditions [1], high-resolution vector microwave imaging [2], and realized atomic-scale structure analysis of single nuclear-spin clusters in diamond [3]. Moreover, we have tried to improve the quantum control technique and succeed to achieve fault-tolerant universal quantum gates [4]. As the last part, I will briefly introduce our most recently work on single protein imaging in situ in cell. References: [1] Fazhan Shi, et al., Science, 347, 1135 (2015) [2] Pengfei Wang, et al., Nature Commu., 6, 6631 (2015) [3] Fazhan Shi, et al., Nature Physics, 10, 21 (2014) [4] Xing Rong, et al., Nature Commu., In press (2015)

1:27PM S45.00012 Beating the Shot-Noise Limit with Partially-Distinguishable Photons. PATRICK M. BIRCHALL, JAVIER SABINES-CHESTERKING, JEREMY L. OBRICH, HUGO CABLE, JONATHAN C. F. MATTHEWS C. F. MATTHEWS, Centre for Quantum Photonics, University of Bristol — Quantum metrology promises high-precision measurements beyond the capability of any classical techniques. This has the potential to be an integral part of investigative techniques, utilised across all areas of science and technology. However, all sensors must be able to operate despite imperfections to be of practical use. Proposals for photonic quantum sensors typically exploit quantum interference between photons which are perfectly indistinguishable, but achieving this indistinguishability can be a major technical challenge in practice, in particular with immature but promising approaches to producing source-sound correlable partially-distinguishable photons. We circumvent this challenge by harnessing the inherent partially distinguishable nature of quadrature fluctuations. This allows for an asymptotic field-average, which is deterministic and fully specified by a single temporal boundary condition. In contrast, a quantum electromagnetic field is irreducibly stochastic, such that only its average corresponds to a classical field for large ensembles of measurements. Such a field-average may be further refined by a second temporal boundary condition, which can compose fundamentally different classical fields in the same classical averaging limit. To demonstrate this, we consider an ensemble of coherent laser pulses that interact with identically prepared test charges before being collected at an intensity meter. Isolating only the pulses with zero collected intensity reveals a nonzero average classical force on the charge from those pulses. The charge is affected with no light collected. PACKED IN S50.00017 Multi-Branch Spin Chain Models for Strongly interacting Spinor Fermi and Bose gases in One-Dimension. LI YANG, HAN PU, Rice Univ — By mapping a 1D spinor Fermi or Bose gases wavefunction to a direct product of a spinless fermion wavefunction and a spin chain wavefunction, we obtain a spin-charge coupling Hamiltonian which is a multi-branch spin chain model. The charge part of this model are p-wave contacts for two dimensional quatum gas. YICAI ZHANG, The University of Hong Kong, ZHENHUA YU, Institute for Advanced Study, Tsinghua University, SHIZHONG ZHANG, The University of Hong Kong — The s-wave contact has played an important role in our understanding of the strongly interacting Fermi gases. Recently, theoretical and experimental work has shown that two similar contacts exist for a p-wave interacting Fermi gas in three-dimensions. In this work, we extend the considerations to two dimensional spinless Fermi gas and derive exact results regarding the energy, momentum distributions and in particular, shifts of monopole frequency in a harmonic trap. Asymptotic formula for the frequency shift is given at high temperature via virial expansion and this can be checked by future experiments. The resulted spin chain models are studied by exact numerical methods such as Matrix Product States. Other than harmonic trap we also considered traps with high-$m$ impurity, which can not be approximated by local density approximation.

Thursday, March 17, 2016 11:15AM - 2:15PM – Session S50 DAMOP: Strongly Interacting Bose and Fermi Gases Hilton Baltimore Holiday Ballroom 1 - Johannes Hofmann, Cavendish Laboratory 11:15AM S50.00001 P-wave contacts for two dimensional quatum gas, YICAI ZHANG, The University of Hong Kong, ZHENHUA YU, Institute for Advanced Study, Tsinghua University, SHIZHONG ZHANG, The University of Hong Kong — The s-wave contact has played an important role in our understanding of the strongly interacting Fermi gases. Recently, theoretical and experimental work has shown that two similar contacts exist for a p-wave interacting Fermi gas in three-dimensions. In this work, we extend the considerations to two dimensional spinless Fermi gas and derive exact results regarding the energy, momentum distributions and in particular, shifts of monopole frequency in a harmonic trap. Asymptotic formula for the frequency shift is given at high temperature via virial expansion and this can be checked by future experiments.

11:27AM S50.00002 Multi-Branch Spin Chain Models for Strongly interacting Spinor Fermi and Bose gases in One-Dimension. LI YANG, HAN PU, Rice Univ — By mapping a 1D spinor Fermi or Bose gases wavefunction to a direct product of a spinless fermion wavefunction and a spin chain wavefunction, we obtain a spin-charge coupling Hamiltonian which is a multi-branch spin chain model. The charge part of this model are p-wave contacts for two dimensional quatum gas. LI YANG, HAN PU, Rice Univ — By mapping a 1D spinor Fermi or Bose gases wavefunction to a direct product of a spinless fermion wavefunction and a spin chain wavefunction, we obtain a spin-charge coupling Hamiltonian which is a multi-branch spin chain model. The charge part of this model are p-wave contacts for two dimensional quatum gas. YICAI ZHANG, The University of Hong Kong, ZHENHUA YU, Institute for Advanced Study, Tsinghua University, SHIZHONG ZHANG, The University of Hong Kong — The s-wave contact has played an important role in our understanding of the strongly interacting Fermi gases. Recently, theoretical and experimental work has shown that two similar contacts exist for a p-wave interacting Fermi gas in three-dimensions. In this work, we extend the considerations to two dimensional spinless Fermi gas and derive exact results regarding the energy, momentum distributions and in particular, shifts of monopole frequency in a harmonic trap. Asymptotic formula for the frequency shift is given at high temperature via virial expansion and this can be checked by future experiments.
11:39AM S50.00003 ABSTRACT WITHDRAWN

11:51AM S50.00004 Efimov correlations in strongly interacting Bose gases, JOHANNES HOFMANN, University of Cambridge, MARCUS BARTH, Technische Universität Muenchen — A series of recent hallmark experiments have demonstrated that Bose gases can be created in the strongly interacting unitary limit in the non-degenerate high-temperature regime. These systems display the three-body Efimov effect, which poses a theoretical challenge to compute observables including these relevant three-body correlations. In this talk, I shall present our results for the virial coefficients, the contact parameters, and the momentum distribution of a strongly interacting three-dimensional Bose gas obtained by means of a virial expansion up to third order in the fugacity, which takes into account three-body correlations exactly. Our results characterize the non-degenerate regime of the interacting Bose gas, where the thermal wavelength is smaller than the interparticle spacing but the scattering length may be arbitrarily large. In addition, we provide a calculation of the momentum distribution at unitarity, which displays a universal high-momentum tail with a log-periodic momentum dependence - a direct signature of Efimov physics. In particular, we provide a quantitative description of the momentum distribution at high momentum as measured by the JILA group [Makotyn et al., Nat. Phys. 10, 116 (2014)]. Our results allow the spectroscopy of Efimov states at unitarity.

12:03PM S50.00005 Competing order parameters in Fermi systems with engineered band dispersion, CHIEN-TE WU, RUFUS BOYACK, BRANDON ANDERSON, K LEVIN, James Franck Institute — We explore a variety of competing phases in 2D and 3D Fermi gases in the presence of novel dispersion relations resulting from a shaken optical lattice. We incorporate spin imbalance along with attractive interactions. In 3D, at the mean field level we present phase diagrams reflecting the stability of alternative order parameters in the pairing (including LOFF) and charge density wave channels. We perform analogous studies in 2D, where we focus on the competition between different paired phases. Important in this regard is that our 2D studies [1] are consistent with the Mermin Wagner theorem, so that, while there is competition, conventional superfluidity cannot occur. [1] C.-T. Wu, B. M. Anderson, R. Boyack, and K. Levin, arXiv:1509.00897 (to be published in Phys. Rev. Lett.)

12:15PM S50.00006 Spectral function and dark continuum of the resonant Fermi Polaron, OLGA GOULKO, UMass Amherst, ANDREY MISCHENKO, RIKEN Center for Emergent Matter Science (CEMS), NIKOLAY PROKOFEV, BORIS SVISTUNOV, UMass Amherst — The Fermi polaron is a strongly imbalanced Fermi gas and quasi-particles. Experiments probe its spectral function, which is directly linked to many physical properties. We present the first numerical results for the polaron spectral function with controlled error bars, obtained from first principles with diagrammatic Monte Carlo and analytic continuation. The spectral function exhibits a narrow ground state peak and another broad peak at positive energy, which are separated by a region of extremely low spectral weight. This “dark continuum” surprisingly starts to emerge in the absence a small parameter, around $k_Fa \sim 1$, and quickly broadens into a gap-like structure deeper on the BEC side. We confirm that the dark continuum is indeed physical and not an artefact of approximate calculations and establish a controlled upper bound on its integrated weight.

1Acknowledgment partial support from Institute for Complex Adaptive Matter (ICAM).

12:27PM S50.00007 Finite Temperature Response of a 2D Dipolar Bose Gas at Different Dipolar Tilt Angles, PENGTAO SHEN, KHANDKER QUADER, Kent State University — We calculate finite temperature (T) response of a 2D Bose gas, subject to dipolar interaction, within the random phase approximation (RPA). We evaluate the appropriate 2D finite-T pair bubble diagram needed in RPA, and explore ranges of density and temperature for various dipolar tilt angles. We find the system to exhibit a collapse transition and a finite momentum instability, signaling a density wave or striped phase. We construct phase diagrams depicting these instabilities and resulting phases, including a normal Bose gas phase. We also consider the finite-T response of a quasi-2D dipolar Bose gas. We discuss how our results may apply to ultracold dense Bose gas of polar molecules, such as $^4$K$^{39}$Rb, that has been realized experimentally.

1NSF-DMR-1506547.

11:29PM S50.00008 Strengthening Supersolids with Disorder in the Extended Bose-Hubbard Model, FEI LIN, Washington and Lee University, THOMAS MAIER, Oak Ridge National Lab, VITO SCAROLA, Virginia Tech — The extended Bose-Hubbard model captures the essential properties of a wide variety of physical systems including ultracold atoms and molecules in optical lattices, Josephson junction arrays, and narrow band superconductors. It exhibits a rich phase diagram including a supersolid phase where a lattice solid coexists with a superfluid. We use quantum Monte Carlo to map out the phase diagram of the extended Bose-Hubbard model on the simple cubic lattice where the supersolid is expected. We find that the supersolid is very delicate because unexpected phase separated states compete with the supersolid. We add disorder to the extended Bose-Hubbard model and find that the supersolid phase is enhanced by disorder as phase separation is suppressed. Our results establish optimal regimes for observing supersolids and therefore have important implications for their observation.

11:51PM S50.00009 p-wave superfluid shells for trapped fermions with population imbalance, AMMAR KIRMANI, KHANDKER QUADER, MAXIM DZERO, Kent State University — We present the phase diagram for a p-wave fermionic superfluid with imbalanced populations in a potential trap. We find shells of various superfluid phases, whose realization is determined by the parameters of a trap. In order to compute the resulting phase diagram, we use weak-coupling BCS theory together with the local density approximation in which the effect of the trapping potential is accounted for by a spatially inhomogeneous chemical potential. We compare our phase diagram with the one found for the trapped population imbalanced p-wave fermionic superfluid [Lin, Yi & Duan, Phys. Rev. A 74, 031604R (2006)], and also point out key differences with results for the population imbalanced p-wave case in the absence of a trap [Liao, Popescu & Quader, Phys. Rev. B 88, 134507 (2013)].

11:03PM S50.00010 Quantum Criticality of the Two-dimensional Bose Gas with the Lifshitz dispersion, CONGJUN WU, JIANDA WU, UC San Diego — Bosonic systems with the synthetic spin-orbit coupling and Zeeman field can be tuned into a quantum Lifshitz point exhibiting the $q^d$-dispersion. They are fundamentally different from the conventional ones with the $q^d$-dispersion, and are also connected to quantum frustrated magnets. We set up a generic quantum $q^d$-theory at the Lifshitz point and investigate quantum critical behaviors at both zero and finite temperatures following the perturbative renormalization group method. Controlled by different fixed points, various physical quantities exhibit significantly different scalings from those of the conventional bosonic systems, exhibiting rich quantum critical physics in different interaction and temperature ranges.
1:15PM S50.00011 Equation of state of ultracold fermions in the 2D BEC-BCS crossover, IGOR BOETTCHER, Department of Physics, Simon Fraser University, Burnaby, British Columbia V5A 1S6, Canada, LUCA BAYHA, DHHRUV KEDAR, PUNEET MURTHY, MATHIAS NEIDIG, MARTIN RIES, ANDRE WENZ, GERHARD ZUERN, SELIM JOCHIM, Physikalisches Institut, Heidelberg University, D-69120 Heidelberg, Germany, TILMAN ENNS, Institute for Theoretical Physics, Heidelberg University, D-69120 Heidelberg, Germany — We report the experimental measurement of the equation of state of a two-dimensional Fermi gas with attractive s-wave interactions throughout the crossover from a weakly coupled Fermi gas to a Bose gas of tightly bound dimers as the interaction strength is varied. We demonstrate that interactions lead to a renormalization of the density of the Fermi gas by several orders of magnitude. We compare our data near the ground state and at finite temperature to predictions for both fermions and bosons from Quantum Monte Carlo simulations and Luttinger-Ward theory. Our results serve as input for close-to-equilibrium dynamics and transport in the two-dimensional system.

1:27PM S50.00012 Fluctuation theory of Rashba Fermi gases: Gaussian and beyond1, VJAY B. SHENOY, Indian Institute of Science Bangalore, JAYANTHA P. VYASANAKERE, Tumkur University — Fermi gases with generalized Rashba spin orbit coupling induced by a synthetic gauge field have the potential of realizing many interesting states such as rashbon condensates and topological phases. Here we address the key open problem of the fluctuation theory of such systems and demonstrate that beyond-Gaussian effects are essential to capture finite temperature physics of such systems. We obtain their phase diagram by constructing an approximate non-Gaussian theory. We conclusively establish that spin-orbit coupling can enhance the exponentially small transition temperature ($T_c$) of a weakly attracting superfluid to the order of Fermi temperature, paving a pathway towards high $T_c$ superfluids.

1Work supported by CSIR, DST, DAE and IUSSTF

1:39PM S50.00013 Superfluidity and BCS-BEC crossover of ultracold atomic Fermi gases in mixed dimensions1, LEIFENG ZHANG, QIJIN CHEN, Zhejiang University — Atomic Fermi gases have been under active investigation in the past decade. Here we study the superfluid and pairing phenomena of a two-component ultracold atomic Fermi gas in the presence of mixed dimensionality, in which one component is confined on a 1D optical lattice whereas the other is free in the 3D continuum. We assume a short-range pairing interaction and determine the superfluid transition temperature ($T_c$) and the phase diagram for the entire BCS-BEC crossover, using a pairing fluctuation theory which includes self-consistently the contributions of finite momentum pairs. We find that, as the lattice depth increases and the lattice spacing decreases, the behavior of $T_c$ becomes very similar to that of a population imbalance Fermi gas in a simple 3D continuum. There is no superfluidity even at $T = 0$ below certain threshold of pairing strength in the BCS regime. Nonmonotonic $T_c$ behavior and intermediate temperature superfluidity emerge, and for deep enough lattice, the $T_c$ curve will split into two parts. Implications for experiment will be discussed. References: 1. Q.J. Chen, Ioan Kosztin, B. Janko, and K. Levin, Phys. Rev. B 59, 7083 (1999).


1Work supported by NSF of China and the National Basic Research Program of China

1:51PM S50.00014 Bose polarons in the strongly interacting regime,1 MING-GUANG HU, MICHAEL VAN DE GRAAFF, DHHRUV KEDAR, ERIC CORNELL, DEBORAH JIN, JILA, NIST and CU-Boulder — Impurities immersed in and interacting with a Bose-Einstein condensate (BEC) are predicted to form quasiparticle excitations called Bose polarons. I will present experimental evidence of Bose polarons in cold atoms obtained using radio-frequency spectroscopy to measure the excitation spectrum of fermionic 40K impurities interacting with a BEC of 87Rb atoms. We use an interspecies Feshbach resonance to tune the interactions between the impurities and the bosons, and we take data in the strongly interacting regime.

1This work is supported by NSF, NASA and NIST

2:03PM S50.00015 Self consistent theories of superfluid density and collective modes in BCS-BEC, RUFUS BOYACK, BRANDON ANDERSON, CHIEN-TE WU, KATHRYN LEVIN, James Franck Inst — Establishing fully self consistent and sum rule compatible response functions in strongly correlated Fermi superfluids has been a historically challenging subject. In this talk, we present recent progress pertaining to response functions in many-body Fermi systems. We note that even in strict BCS theory, the textbook derivation of density and current response functions in the gradient expansion breaks certain conservation laws such as the compressibility sum rule. To include additional contributions that preserve all expected conservation laws, we show how to exploit Ward identities within two different t-matrix schemes. In this way we address the density-density response (including collective modes) and the superfluid density. Finally, we characterize approximations made in the literature where some consistency requirements have been dropped.

Thursday, March 17, 2016 11:15AM - 2:15PM — Session S52 DAMOP: Photonic Topological Materials Hilton Baltimore Holiday Ballroom 3 - Xiaopeng Li, Joint Quantum Institute, University of Maryland

11:15AM S52.00001 The Science and Applications of Photonic Topological Insulators: From Robust Delay Lines to Non-Reciprocal Metawaveguides1, GENNADY SHVETS, The University of Texas at Austin — Electromagnetic (EM) waves propagating through an inhomogeneous medium inevitably scatter whenever the mediums electromagnetic properties change on the scale of a single wavelength. This fundamental phenomenon constrains how optical structures are designed and interfaced with each other. Our theoretical work indicates [1] that electromagnetic structures collectively known as photonic topological insulators (PTIs) can be employed to overcome this fundamental limitation, thereby paving the way to ultra-compact photonic structures that no longer have to be wavelength-scale smooth. Here I present the first experimental demonstration of a photonic structure that supports topologically protected surface electromagnetic waves (TPSWs) that are counterparts to the edge states between two quantum spin-Hall topological insulators in condensed matter. Unlike conventional guided EM waves that do not benefit from topological protection, TPSWs are shown to experience reflections-free time delays when detoured around sharply-curved paths, thus offering a unique paradigm for wave buffers and delay lines. I will also discuss how the photonic analogs of the quantum Hall and valley-Hall topological insulators can be realized and interfaced with each other. [1] T. Ma et. al., “Guiding Electromagnetic Waves around Sharp Corners: Topologically Protected Photonic Transport in Metawaveguides”, Phys. Rev. Lett. 114, 127401 (2015).

1This work was supported by the National Science Foundation (NSF) Award PHY-1415547 and the Air Force Office of Scientific Research grant number FA9550-15-1-0075
Moreover, we will demonstrate that continuous photonic media with the time-reversal symmetry can be topologically characterized by a $\mathbb{Z}$.

Photonic crystals have revolutionized light-based technologies during the last three decades. Notably, it was recently discovered that the light propagation in atom-surface interactions. This work is supported in part by DOE, DARPA, and AFOSR.

Topological photonics: an observation of Landau levels for optical photons, NATHAN SCHINE, Univ of Chicago, ALBERT RYU, ARIEL SOMMER, JONATHAN SIMON, University of Chicago — Creating photonic materials with nontrivial topological characteristics has seen burgeoning interest in recent years; however, a major route to topology, a magnetic field for continuum photons, has remained elusive. We present the first experimental realization of a bulk magnetic field for optical photons. By using a non-planar ring resonator, we induce an image rotation on each round trip through the resonator. This results in a Coriolis/Lorentz force and a centrifugal anticonfining force, the latter of which is cancelled by mirror curvature. Spatial- and energy- resolved spectroscopy tracks photonic eigenstates as residual trapping is reduced, and we observe photonic Landau levels as the eigenstates become degenerate. We will discuss the conical geometry of the resulting manifold for photon dynamics and present a measurement of the local density of states that is consistent with Landau levels on a cone.

Topological photonics: an observation of Landau levels for optical photons, NATHAN SCHINE, Univ of Chicago, ALBERT RYU, ARIEL SOMMER, JONATHAN SIMON, University of Chicago — Creating photonic materials with nontrivial topological characteristics has seen burgeoning interest in recent years; however, a major route to topology, a magnetic field for continuum photons, has remained elusive. We present the first experimental realization of a bulk magnetic field for optical photons. By using a non-planar ring resonator, we induce an image rotation on each round trip through the resonator. This results in a Coriolis/Lorentz force and a centrifugal anticonfining force, the latter of which is cancelled by mirror curvature. Spatial- and energy- resolved spectroscopy tracks photonic eigenstates as residual trapping is reduced, and we observe photonic Landau levels as the eigenstates become degenerate. We will discuss the conical geometry of the resulting manifold for photon dynamics and present a measurement of the local density of states that is consistent with Landau levels on a cone.

Topological crystalline insulators in photonic systems, JIANXIAO ZHANG, MIKAEL RECHTSMAN, CHAO-XING LIU, Pennsylvania State Univ — Topological crystalline insulators are a class of materials with a bulk energy gap and edge or surface modes, which are protected by crystalline symmetry, at their boundaries. These modes are protected by crystalline symmetry. We map this one-dimensional system to a two-dimensional lattice model with opposite magnetic fields, as well as opposite Chern numbers, in its even and odd mirror parity subspaces, thus corresponding to a topological insulator mirror. Furthermore, we test how sensitive and robust edge modes depend on their mirror parity by performing time dependent evolution simulation of edge modes in a photonic setting with realistic experimental parameters.

Topological photonics: an observation of Landau levels for optical photons, NATHAN SCHINE, Univ of Chicago, ALBERT RYU, ARIEL SOMMER, JONATHAN SIMON, University of Chicago — Creating photonic materials with nontrivial topological characteristics has seen burgeoning interest in recent years; however, a major route to topology, a magnetic field for continuum photons, has remained elusive. We present the first experimental realization of a bulk magnetic field for optical photons. By using a non-planar ring resonator, we induce an image rotation on each round trip through the resonator. This results in a Coriolis/Lorentz force and a centrifugal anticonfining force, the latter of which is cancelled by mirror curvature. Spatial- and energy- resolved spectroscopy tracks photonic eigenstates as residual trapping is reduced, and we observe photonic Landau levels as the eigenstates become degenerate. We will discuss the conical geometry of the resulting manifold for photon dynamics and present a measurement of the local density of states that is consistent with Landau levels on a cone.

Topological Photonics for Continuous Media, MARIO SILVEIRINHA, University of Coimbra — Photonic crystals have revolutionized light-based technologies during the last three decades. Notably, it was recently discovered that the light propagation in photonic crystals may depend on some topological characteristics determined by the manner how the light states are mutually entangled. The usual topological classification of photonic crystals explores the fact that these structures are periodic. The periodicity is essential to ensure that the underlying wave vector space is a closed surface with no boundary. In this talk, we prove that it is possible calculate Chern invariants for a wide class of continuous bianisotropic electromagnetic media with no intrinsic periodicity. The nontrivial topology of the relevant continuous materials is linked with the emergence of edge states. Moreover, we will demonstrate that continuous photonic media with the time-reversal symmetry can be topologically characterized by a $\mathbb{Z}_2$ integer. This novel classification extends for the first time the theory of electronic topological insulators to a wide range of photonic platforms, and is expected to have an impact in the design of novel photonic systems that enable a topologically protected transport of optical energy.

This work is supported in part by Fundacao para a Ciencia e a Tecnologia grant number PTDC/EEI-TEL/4543/2014.

1:15PM S52.00009 Robust topological states in Parity-time (PT) symmetric photonic lattices
ANDREW HARTER, YOGESH JOGLEKAR, Indiana University Purdue University Indianapolis (IUPUI) — We consider generalized Aubry-Andre models, which support topological states and are experimentally realizable in integrated waveguide lattices, in the presence of balanced gain and loss. When the gain-loss strength exceeds a threshold set by the nearest neighbor tunneling, the non-Hermitian, PT-symmetric Hamiltonian of this system undergoes PT breaking transition. We investigate the interplay between the PT-breaking transition, tuned by the gain-loss strength, and topological transitions between different states with Chern numbers. We show, due to sub-lattice-localization property of the topological edge states in these models, these edge states remain robust across the PT-breaking transition. We present the consequences of this result for light-propagation in such materials, obtained via both tight-binding model and beam-propagation method.

1:27PM S52.00010 Exciting Reflectionless, Unidirectional Edge Mode in BiaNTisotropic Metalswaveguide Using Rotating Dipole Antenna.
BO XIAO, THOMAS ANTONSEN, EDWARD OTT, STEVEN ANLAGE, Univ of Maryland-College Park, TŽUHSHUAN MA, GENNADY SHVETS, University of Texas Austin — Electronic chiral edge states in Quantum Hall Effect systems has attracted a lot of attention in recent years because of its unique directonality and robustness against scattering from disorder. Its electromagnetic counterpart can be found in photonic crystals, which is a material with periodic dielectric constant. Here we present the experimental results demonstrating the unidirectional edge mode inside a bi-anisotropic meta-waveguide [1] (BMW) structure. It is a parallel plate waveguide with metal rods placed in a hexagonal lattice. Half of the rods are attached to the top plate while the other half are attached to the bottom plate creating a domain wall. The edge mode is excited by two loop antennas placed perpendicular to each other within one wavelength, generating a rotating magnetic dipole that couples to the left or right-going mode. The transmission measurement are taken along the BMW boundary and shows high transmission only around the edge, thus confirming the presence of an edge mode. We also demonstrated that very high directivity can be achieved when the input amplitude and phase of the two loop antennas are tuned properly. [1] T. Ma, A. B. Khanikaev, S. H. Mousavi, And G. Shvets, Phys. Rev. Lett. 114, 127401 (2015).

1:39PM S52.00011 Angle-Resolved Mid-Infrared Spectroscopy of Gyroid Photonic Crystals
EMIL T. KHABIBOULLINE, SIYING PENG, Applied Physics, California Institute of Technology, PHILIP HON, Nanophotonics and Metamaterials Laboratory, Northrop Grumman Aerospace Systems, RUNYU ZHANG, Department of Materials Science and Engineering, UIUC, HONGJIE CHEN, Applied Physics, California Institute of Technology, LUKE A. SWEATLOCK, Nanophotonics and Metamaterials Laboratory, Northrop Grumman Aerospace Systems, PAUL BRAUN, Department of Materials Science and Engineering, UIUC, HARRY A. ATWATER, Applied Physics, California Institute of Technology — Photonic topological insulators form a new class of materials with exciting properties. Theory has indicated that gyroid photonic crystals are photonic topological insulators. In this paper, we experimentally characterize the photonic properties of gyroid photonic crystals at mid-infrared wavelengths, using angle-resolved spectroscopy with coherent light from a quantum cascade laser tuned from 7.7 μm to 11.1 μm and focused onto a 100 μm × 100 μm spot. From measurements of reflection and transmission spectra over incidence angles, we construct the band structure of the photonic crystals. In this study, the photonic crystals are single and double gyroid made of amorphous silicon, with unit cell size of 5 μm, sitting on an intrinsic silicon substrate. Simulations predict band gaps for the single gyroid and Weyl points for the double gyroid. We compare results of angle-resolved spectroscopy experiments with simulations for nanofabricated gyroid structures and discuss the topological features observable in angle-resolved scattering.

1:51PM S52.00012 Squeezing as a route to photonic analogues of topological superconductors
MARTIN HOUDE, McGill Univ, VITTORIO PEANO, CHRISTIAN BRENDEL, FLORIAN MARQUÄRDT, University of Erlangen-Nurnberg, AASHISH CLERK, McGill Univ — There has been considerable recent interest in studying topological phases of photonic systems. In many cases the resulting system is described by a quadratic particle-conserving Hamiltonian which is directly equivalent to its fermionic counterpart. Here, we consider a class of photonic topological phases where this correspondence fails: photonic systems where particle-number non-conserving terms break time-reversal symmetry. We show that these phases support protected edge modes which facilitate chiral inelastic and elastic transport channels. We also discuss the possibility of quantum amplification using these edge states. Our system could be realized in a variety of systems, including nonlinear photonic crystals, superconducting circuits and optomechanical systems.

2:03PM S52.00013 Gyroid photonic crystal with Weyl points: synthesis and mid-infrared photonic characterization
SIYING PENG, EMIL KHABIBOULLINE, Applied Physics, California Institute of Technology, RUNYU ZHANG, Department of Materials Science and Engineering, UIUC, HONGJIE CHEN, Applied Physics, California Institute of Technology, PHILIP HON, LUKE SWEATLOCK, Nanophotonics and Metamaterials Laboratory, Northrop Grumman Aerospace Systems, PAUL BRAUN, Department of Materials Science and Engineering, UIUC, HARRY ATWATER, Applied Physics, California Institute of Technology — Gyroid photonic crystals are degenerate energy states resulting from crossings of linear bands in 3D momentum space. Unlike their 2D counterparts, Weyl points are bulk degenerate states that are stable to weak perturbation. The topological surface states associated with Weyl points exhibit unidirectional backscattering-immune transport. Double gyroid photonic crystals with parity-breaking perturbation are predicted to possess Weyl points. We designed and synthesized single and double gyroid mid-IR photonic crystals composed of a-Si. We characterized them by mid-IR spectroscopy. We observed 100% reflection at 8 μm, in agreement with the predicted photonic bandgap seen in full-wave EM simulations. As the unit cell size of single gyroids changes to 6 μm, we observed a 20% decrease in reflection at 8 μm, which could be explained by the addition of states appearing within the bandgap of our simulation of double gyroids. We use angle-resolved mid-IR spectroscopy with a QCL to characterize Weyl points.

Thursday, March 17, 2016 2:30PM - 5:30PM –
Session V50 DAMOP: Quantum Gases in Optical Lattices Hilton Baltimore Holiday Ballroom 1 - B. Svistunov, University of Massachusetts Amherst
2:30PM V50.00001 Phase diagram of ferromagnetic spinor bosons in an optical lattice under an external magnetic field. KOHAKU H. Z. SO, Department of Physics, University of Tokyo, MASAHTO UEDA, Department of Physics, University of Tokyo, and RIKEN Center for Emergent Matter Science (CEMS) — Recently, cold atoms with spin degrees of freedom have attracted considerable interest because of the possibility they offer of modelling quantum magnetism and exploring the interplay between spatial and spin degrees of freedom. While spinor bosons with antiferromagnetic interaction loaded in optical lattices have been widely studied in this context because of their properties such as an even-odd effect in the superfluid to Mott-insulator transition, those with ferromagnetic interaction have not been studied extensively. However, mean-field analysis in the continuum systems suggests that the competition between an external magnetic field and the ferromagnetic interaction could give rise to new and rich phases. We have studied ferromagnetic spinor bosons in an optical lattice under an external magnetic field. Using the decoupling mean-field approximation, we have obtained a rich ground-state phase diagram, in which, in addition to the well-known Mott-insulator and superfluid phases, polar and broken-axisymmetry superfluid phases arise. We also found that the transition between broken-axisymmetry superfluid phase and other phases is a first-order one across some part of the phase boundary, in remarkable contrast to the case without external magnetic fields.

1 JSPS KAKENHI (No. 26287088, No. 15H05855), JSPS ALPS

2:42PM V50.00002 Unconventional Bose-Einstein Condensations of Two-species Bosons in the p-orbital Bands in Optical Lattice. JHIH-SHIH YOU, Department of Physics, Harvard University, I-KANG LIU, Department of Physics and Graduate Institute of Photonics, National Chianghua University of Education, DAW-WEI WANG, Physics Department and Physics division, National Center for Theoretical Sciences, National Tsing-Hua University, SHIH-CHUAN GOU, Department of Physics and Graduate Institute of Photonics, National Chianghua University of Education, CONGJUN WU, Department of Physics, University of California, San Diego — We investigate the unconventional Bose-Einstein condensations of two-species mixture with p-wave symmetry in the second band of a bipartite optical lattice. Different from the single-species case, the two-species boson mixture exhibits two non-equivalent complex BECs in the intraspecies-interaction-dominating regime, with one breaking time-reversal symmetry while the other not. When the interspecies interaction is tuned across the SU(2) invariant point, the system undergoes a quantum phase transition toward a real-valued checkerboard state characterized by a staggered spin density structure. An experimental scheme for phase measurement is presented. Finally, we will show strong coupling analysis on anti-Hund’s rule, Mott-insulating states and the superfluid.

2:54PM V50.00003 Phase diagram of strongly attractive p-orbital fermions on optical lattices. THEJA DE SILVA, Augusta University — We examine a system of doubly degenerate p-orbital polarized fermions on a two-dimensional square lattice with a strong on-site interaction. For strong attractive interactions at the half filling density limit, a four-site square plaquette interaction term is generated from the directional tunneling dependence of p-orbitals. By treating both on-site interaction and the four-site square plaquette interaction term in fourth order perturbation theory, we derive an effective Hamiltonian for the system. Then we map the resulting effective particle Hamiltonian into an effective spin-Hamiltonian and study the phase diagram of the system by using a variational mean field approach and a linear spin-wave theory. Further, we discuss the experimental signatures of the resulting phases within the context of current cold-atom experimental techniques.


3:18PM V50.00005 Magnetic-field-tunable Kondo effect in alkaline-earth cold atoms. LEONID ISAEV, ANA MARIA REY, JILA, NIST and Department of Physics, University of Colorado Boulder — We study quantum magnetism and emergent Kondo physics in strongly interacting fermionic alkaline-earth atoms in an optical lattice with two Bloch bands: one localized and one itinerant. For a fully filled narrow band (two atoms per lattice site) we demonstrate that an applied magnetic field provides an efficient control of the ground state degeneracy due to the field-induced crossing of singlet and triplet state of the localized atomic pairs. We exploit this singlet-triplet resonance, as well as magnetically tunable interactions of atoms in different electronic states via the recently-discovered inter-orbital Feshbach resonance, and demonstrate that the system exhibits a magnetic field-induced Kondo phase characterized by delocalization of local singlets and a large Fermi surface. We also determine the phase diagram of the system by using a variational mean field approach and a linear spin-wave theory. Further, we discuss the experimental signatures of the resulting phases within the context of current cold-atom experimental techniques.

1 Work supported by NSF of China and the National Basic Research Program of China

3:30PM V50.00006 Cooling a Band Insulator with a Metal: Fermionic Superfluid in a Dimerized Holographic Lattice. ARUJIT HALDAR, VIJAY B. SHENOY, Indian Institute of Science Bangalore — A cold atomic realization of a quantum correlated state of many fermions on a lattice, eg. superfluid, has eluded experimental realization due to the entropy problem. Here we propose a route to realize such a state using holographic lattice and confining potentials. The potentials are designed to produce a band insulating state (low heat capacity) at the trap center, and a metallic state (high heat capacity) at the periphery. The metal “cools” the central band insulator by extracting out the excess entropy. The central band insulator can be turned into a superfluid by tuning an attractive interaction between the fermions. Crucially, the holographic lattice allows the emergent superfluid to have a high transition temperature – even twice that of the effective trap temperature. The scheme provides a promising route to a laboratory realization of a fermionic lattice superfluid, even while being adaptable to simulate other many body states. Reference: Scientific Reports 4, 6665 (2014).

1 Work supported by CSIR, DST and DAE

3:30PM V50.00006 Cooling a Band Insulator with a Metal: Fermionic Superfluid in a Dimerized Holographic Lattice. ARUJIT HALDAR, VIJAY B. SHENOY, Indian Institute of Science Bangalore — A cold atomic realization of a quantum correlated state of many fermions on a lattice, eg. superfluid, has eluded experimental realization due to the entropy problem. Here we propose a route to realize such a state using holographic lattice and confining potentials. The potentials are designed to produce a band insulating state (low heat capacity) at the trap center, and a metallic state (high heat capacity) at the periphery. The metal “cools” the central band insulator by extracting out the excess entropy. The central band insulator can be turned into a superfluid by tuning an attractive interaction between the fermions. Crucially, the holographic lattice allows the emergent superfluid to have a high transition temperature – even twice that of the effective trap temperature. The scheme provides a promising route to a laboratory realization of a fermionic lattice superfluid, even while being adaptable to simulate other many body states. Reference: Scientific Reports 4, 6665 (2014).

1 Work supported by CSIR, DST and DAE
3:42PM V50.00007 Dirac and Weyl Rings in Three Dimensional Cold Atom Optical Lattices. YONG XU, CHUANWEI ZHANG, The University of Texas at Dallas. Recently three dimensional topological quantum materials with gapless energy spectra have attracted considerable interests in many branches of physics. Besides the celebrated example, Dirac and Weyl points which possess gapless point structures in the underlying energy dispersion, the topologically protected gapless spectrum can also occur along a ring, named Dirac and Weyl nodal rings. Ultra-cold atomic gases provide an ideal platform for exploring new topological materials with designed symmetries. However, whether Dirac and Weyl rings can exist in the single-particle spectrum of cold atoms remains elusive. Here we propose a realistic model for realizing Dirac and Weyl rings in the single-particle band dispersion of a cold atom optical lattice. Our scheme is based on previously experimentally already implemented Raman coupling setup for realizing spin-orbit coupling. Without the Zeeman field, the model preserves both pseudo-time-reversal and inversion symmetries, allowing Dirac rings. The Dirac rings split into Weyl rings with a Zeeman field that breaks the pseudo-time-reversal symmetry. We examine the superfluidity of attractive Fermi gases in this model and find Dirac and Weyl rings in the quasiparticle spectrum.

3:54PM V50.00008 The Detection of Massive Goldenstone (Higgs) Mode in Two-Dimensional Ultra-cold Atomic Lattice Systems. LONGXIAO LIU, KUN CHEN, University of Massachusetts, Amherst; University of Science and Technology of China, YONG XU, CHUANWEI ZHANG, The University of Texas at Dallas. With a combination of worm-algorithm Monte Carlo simulations and asymptotically exact analytics, we accurately characterizing the growing linearly with time. However in the disordered paramagnet, the motion of the vacancy becomes highly nontrivial, and no exact solution to this outstanding problem is known. This scenario is referred to as the Higgs amplitude mode, near the Superfluid-to-Insulator quantum critical point (QCP) in a system of two-dimensional ultra-cold bosonic atoms in optical lattices. The spectral function of the amplitude response is obtained by analytic continuation of the kinetic energy correlation function calculated by Monte Carlo methods. Our results enable a direct comparison with the recent experiment \cite{M. Endres, T. Fujkuro, D. Pekker, M. Cheneau, P. Schaus, C. Gross, E. Demler, S. Kehr, and I. Bloch, Nature 487, 454-458 (2012)}, and demonstrate a good agreement for temperature shifts induced by lattice modulation. Based on our numerical analysis, we formulate the necessary conditions in terms of homogeneity, detuning from the QCP and temperature in order to reveal the massive Goldstone resonance peak in spectral functions experimentally. We also propose to apply a local modulation at the trap center to overcome the inhomogeneous broadening caused by the parabolic trap confinement.

4:06PM V50.00009 Evolution of the Hofstadter butterfly in a tunable optical lattice. MEHMET O. OKTEL, Bilkent Univ, NUR UNAL, Cornell Univ, FIRAT YILMAZ, Bilkent Univ. Advances in realizing artificial gauge fields on optical lattices promise experimental detection of topologically non-trivial energy spectra. Self-similar fractal energy structures, known as Hofstadter butterflies, depend sensitively on the geometry of the lattice, as well as the applied magnetic field \cite{[1]}. The recent demonstration of an adjustable lattice geometry \cite{[2]}, Nature 483, 302-305 (2012)} is expected to enable the study of Hofstadter butterflies that can be obtained in such an adjustable lattice, and find three qualitatively different regimes. We show that the existence of Dirac points at zero magnetic field does not imply the topological equivalence of spectra at finite field. As the real-space structure evolves from the checkerboard to the honeycomb lattice, two square lattice Hofstadter butterflies merge to form a honeycomb lattice butterfly in a topologically non-trivial way, as it is accomplished by sequential closing of infinitely many gaps. We discuss the evolution of topological properties with topological lattice geometry by calculating the Chern numbers and comment on the validity of simulating graphene in such an adjustable lattice. \cite{[1]} F. Yilmaz, F. Nur Unal, and M. O. Oktel, Phys. Rev. A 91, 063628 (2015).

4:18PM V50.00010 Proposals for quantum simulating simple lattice gauge theory models using optical lattices. JIN ZHANG, University of California, Riverside; JUDAH UNMUTH-Yockey, University of Iowa; ALEXEI BAZAVOV, University of California, Riverside; YANNICK MEURICE, University of Iowa; SHAN-WEN TSAI, University of California, Riverside. We derive an effective spin Hamiltonian for the (1+1)-dimensional Abelian Higgs model in the strongly coupled regime by integrating out the link variables. With finite spin truncations, the Hamiltonian can be matched with a 1-dimensional two-species Bose Hubbard model in the strong-coupling limit that can be implemented with cold atoms on an optical lattice. We study the phase diagram of the original Abelian Higgs model with Monte Carlo simulation and Tensor Renormalization Group methods. The results show a crossover line which terminates near the Kosterlitz-Thouless transition point. The effective quantum Hamiltonian is also studied with the DMRG method, and we find that they have a similar behavior. We discuss practical experimental implementations for our quantum simulator. Species-dependent optical lattices and ladder systems with double-well potentials are considered. We show how to obtain each of the interaction parameters required in the Bose-Hubbard model that we obtained, and confirm the possibility of tuning these interactions to the region in which our mapping is valid. We emphasize that this proposal for quantum simulating a gauge theory uses a manifestly gauge-invariant formulation and Gauss’s Law is therefore automatically satisfied.

3Supported by DoD ARO under Grant No. W911NF-13-1-0119 and by the NSF under Grants No. DMR-1411345

4:30PM V50.00011 Topological Nodal-Line Superfluid in Spin-Orbit Coupled Cold Atomic Systems. WEN-YU HE, DONG-HUI XU, TONG ZHOU, K. T. LAW, Hong Kong University of Science and Technology, HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY COLLABORATION. Topological nodal line superconductivity or superfluidity is a fascinating topological gapless phase which hosts bulk Weyl ring degeneracy in the quasiparticle excitation spectrum and supports Majorana zero bound modes with a large density of states at the edge. In this work, based on the experimental realized 1D spin orbit coupling, we show the emergence of topological nodal line superfluid phase in Fermionic atoms trapped in 3D cubic optical lattice when the s wave pairing field is introduced through Feshbach resonance between the two atomic hyperfine spin states. The nodal line degeneracy is further found to evolve into Weyl nodes once another component of spin orbit coupling field enters to break the chiral symmetry. The momentum resolved radio frequency spectroscopy is suggested to manifest the topological nodal line superfluid phase.

4:42PM V50.00012 Vacancy dynamics in the paramagnetic environment. JOHAN CARLSTROM, BORIS SVISTUNOV, NIKOLAY PROKOFIEV, Bilkent Univ, MEHMET O. OKTEL, Bilkent Univ, NUR UNAL, Cornell Univ, FIRAT YILMAZ, Bilkent Univ. The nodal line degeneracy is further found to evolve into Weyl nodes once another component of spin orbit coupling field enters to break the chiral symmetry. The momentum resolved radio frequency spectroscopy is suggested to manifest the topological nodal line superfluid phase.

4:54PM V50.00013 Scratched-XY Universality and Phase Diagram of Disordered 1D Bosons in Optical Lattice. ZHIYUAN YAO, Department of Physics, University of Massachusetts, Amherst, MA 01003, USA; LODEN POLLETT, Department of Physics, Arnold Sommerfeld Center for Theoretical Physics and Center for NanoScience, University of Munich, Theresienstrasse 37, 80333 M, NIKOLAY PROKOFIEV, BORIS SVISTUNOV, Department of Physics, University of Massachusetts, Amherst, MA 01003, USA — The superfluid-insulator quantum phase transition in a 1D system with weak links belongs to the so-called scratched-XY universality class, provided the irrenormalizable exponent $\gamma$ characterizing the distribution of weak links is smaller than $2/3$. With a combination of worm-algorithm Monte Carlo simulations and asymptotically exact analytics, we accurately trace the position of the scratched-XY critical line on the ground-state phase diagram of bosonic Hubbard model at unity filling. In particular, we reveal the location of the tricritical point separating the scratched-XY criticality from the Giamarchi-Schulz one.

\[\text{Supported by DoD ARO under Grant No. W911NF-13-1-0119 and by the NSF under Grants No. DMR-1411345}\]
bosons in optical lattices.

Using this method we have figured out the phase diagram of the xxz model on the anisotropic triangular lattice which can be realized by hardcore Monte Carlo, this algorithm allows the systematic switching of DMRG states between different model parameters, which is very efficient for solving convergence problems. To overcome this problem we have now successfully developed a parallel tempering DMRG algorithm. Similar to parallel tempering in quantum Monte Carlo, this algorithm allows the systematic switching of DMRG states between different model parameters, which is very efficient for solving convergence problems. We explore quantum many–body systems formed by molecules in doublet sigma (\(2\Sigma\)) states, with both electric dipole moments and electron spin \(S = 1/2\), but without electronic orbital momentum. The Hamiltonian for doublet sigma molecules includes molecular rotation terms, spin–rotation interaction, hyperfine terms including both spin–spin and nuclear electric quadrupole interactions, and molecular dipole–dipole interactions. The complete control of the molecular quantum states can be accomplished by applying electric and magnetic fields to molecules trapped in optical lattices. We provide the complete theoretical treatment for experimentally relevant doublet sigma molecules such as SrF and CaF and discuss the associated single–body and many–body physics.

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**Friday, March 18, 2016 8:00AM - 11:00AM**

**Session X2 DCMP DAMOP: Recent Advances in Many Body Localization**

**Ballroom II - Christopher Laumann, University of Washington**

### 8:00AM X2.00001 A rigorous result on many-body localization

JOHN IMBRIE, University of Virginia — The mathematical theory of many-body localization is in its infancy. Lack of thermalization is associated with the existence of a complete set of quasi-local integrals of motion. I will discuss a proof that a particular one-dimensional spin chain with random local interactions exhibits many-body localization. The proof depends on a physically reasonable assumption that limits the amount of level attraction in the system. In a KAM-style construction, a sequence of local unitary transformations is used to diagonalize the Hamiltonian and connect the exact many-body eigenfunctions to the original basis vectors. This provides an explicit construction of integrals of motion via convergent expansions.

### 8:36AM X2.00002 Many-body localization: Entanglement and efficient numerical simulations

FRANK POLLMANN, Max Planck Institute for the Physics of Complex Systems — Many-body localization (MBL) occurs in isolated quantum systems when Anderson localization persists in the presence of finite interactions. To understand this phenomenon, the development of new efficient numerical methods to find highly excited many-body eigenstates is essential. In this talk, we will discuss two complimentary approaches to simulate MBL systems: First, we introduce a variant of the density-matrix renormalization group (DMRG) method that obtains individual highly excited eigenstates of MBL systems to machine precision accuracy at moderate to large disorder. This method explicitly takes advantage of the local spatial structure and the low entanglement which is characteristic for MBL eigenstates. Second, we propose an approach to directly find an approximate compact representation of the diagonalizing unitary by using a variational unitary matrix-product operator.

### 9:12AM X2.00003 Dynamical Response of Many-Body Localized Systems

VEDIKA KHEMANI, Princeton University — Many-body localization (MBL) is the long sought-after generalization of Anderson localization to interacting systems. Many-body localized systems fail to thermalize, and display a variety of novel properties and phases that have no equilibrium analog. In this talk, I will review our rapidly evolving understanding of the MBL phase before describing the eigenstate properties and dynamical response of these phases in some detail. In particular, I will show how a slow local perturbation surprisingly induces a highly non-local charge response despite the localized nature of the phase. This effect lies beyond linear response theory and has implications for numerous fields, including topological quantum computation in quantum Hall systems and quantum control in disordered environments. I will also discuss the low-frequency Kubo conductivity of MBL systems, and discuss the crossover from the linear to the non-linear response regime with an emphasis on the time-scales and amplitudes of the drive.

### 9:48AM X2.00004 Universal dynamics across many-body localization phase transition

MAKSYM SERBYN, Univ of California - Berkeley — Many-body localization allows quantum systems to evade thermalization owing to the emergence of extensive number of local conserved quantities [1,2]. Many-body localized (MBL) systems exhibit universal dynamics, qualitatively distinct from dynamics in ergodic systems. In this talk I will survey recent progress in understanding the properties of the MBL phase, which follow from the picture of local conserved quantities. In particular, I will discuss the power-law relaxation of local observables [3], which gives an experimentally observable signatures of the MBL phase. In the second part of my talk, I will demonstrate how the delocalization transition can be probed by characterizing the breakdown of local conservation laws. Using statistics of matrix elements of local operators, I will introduce an analogue of many-body Thouless conductance which probes the response of the system to local perturbations [4]. Its scaling allows one to locate the MBL transition, and predicts the onset of logarithmically slow transport at the MBL transition, consistent with results from the renormalization group [5,6]. In addition, I will demonstrate how the properties of matrix elements govern the crossover of the level statistics across the MBL transition, and relate to the dynamics in the ergodic phase. I will conclude by discussing experimental implications and open challenges in understanding the MBL transition.

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Many-body localisation of interacting fermions in a quasi-random optical lattice. IMMANUEL BLOCH, Max Planck Institute of Quantum Optics — We experimentally observe many-body localization (MBL) of interacting fermions in a one-dimensional quasi-random optical lattice. We identify the many-body localization transition through the relaxation dynamics of an initially-prepared charge density wave. For sufficiently weak disorder the time evolution appears ergodic and thermalizing, erasing all remnants of the initial order. In contrast, above a critical disorder strength a significant portion of the initial ordering persists, thereby serving as an effective order parameter for localization. The stationary density wave order and the critical disorder value show a distinctive dependence on the interaction strength, in agreement with numerical simulations. We also present recent results on the fate of an MBL system upon coupling to the environment through photon scattering or by coupling identical 1d systems. Finally, progress to observe MBL in a 2d setting of interacting bosons will be presented that can provide a new route for identifying and characterizing the MBL phase transition.

Entanglement area law for long-range interacting systems, ZHEXUAN GONG, MICHAEL FOSS-FEIG, Joint Quantum Institute, FERNANDO G.S.L. BRANDAO, Microsoft Research, ALEXEY V. GORSHKOV, Joint Quantum Institute — Area laws for entanglement provide crucial insight into the low-energy behavior of many-body systems and are intimately connected to the efficiency of classical computational methods. For 1D systems, an area law was rigorously proven for ground states of gapped Hamiltonians with local interactions and for states with exponentially decaying correlations. In the presence of long-range interactions, the proof of an area law for gapped ground states becomes much more challenging because long-range interactions can change the effective dimensionality of the system and introduce correlations decaying slower than an exponential. Based on recent theoretical advances that reveal strong remnants of locality in quenched systems with power-law decaying interactions, we prove an area law for a large class of gapped Hamiltonians with long-range interactions. As an intermediate step, we prove tight bounds on the decay of ground-state correlations.

A System For High Flexibility Entangling Gates With Trapped Ions, ALISTAIR MILNE, CLAIRE EDMUNDS, SANDEEP MAVADIA, TODD GREEN, MICHAEL BIERCUK, Univ of Sydney — Trapped ion qubits may be entangled via coupling to shared modes of motion using spin-dependent forces generated by optical fields. Residual qubit-motional coupling at the conclusion of the entangling operation is the dominant source of infidelity in this type of gate. For synchronously entangling increasing numbers of ions, longer gate times are required to minimise this residual coupling. We present a scheme that enables the state of each qubit to be simultaneously decoupled from all motional modes in an arbitrarily chosen gate time, increasing the gate fidelity and scalability. This is achieved by implementing discrete phase shifts in the optical field moderating the entangling operation. We describe an experimental system based on trapped ytterbium ions and demonstrate this scheme for two-qubit entangling gates on ytterbium ion pairs.

Phase-modulated spin-motional decoupling with trapped ions, CLAIRE EDMUNDS, ALISTAIR MILNE, SANDEEP MAVADIA, TODD GREEN, MICHAEL BIERCUK, Univ of Sydney — We present a technique to minimize residual spin-motional entanglement after a phonon-mediated entangling gate in trapped $^{171}$Yb$^+$ ion qubits. Phonon-mediated gates, such as the Mølmer-Sørensen gate, engineer spin-spin entanglement by coupling the qubits to their collective modes of motion. Consequently, a major experimental limitation is residual motional entanglement at the conclusion of the gate, resulting in a degradation of the final spin state purity. Our work utilizes phase-modulated pulse sequences to decouple the qubits from multiple motional modes simultaneously at a variable gate time. In addition, we extend this technique to the suppression of time-dependent noise using concatenated gate sequences, which allows for the recovery of a higher purity spin state. Using a single, experimentally controllable modulation parameter we are able to achieve more optimal quantum control in these gate sequences.

The effect of electrode surface roughness on the motional heating rate of electromagnetic trapped ions, KUAN-YU LIN, GUANG HAO LOW, ISAAC CHUANG, Massachusetts Inst of Tech-MIT — Electric field noise is a major source of motional heating in trapped ion quantum computation. While it is well known that this noise is influenced by trap electrode geometry in patch potential and surface adsorbate models, this has only been analyzed for smooth surfaces. We investigate the dependence of electric field noise on the roughness of surface electrodes by deriving a Greens function describing this roughness, and evaluating its effects on adsorbate-surface binding energies. At cryogenic temperature, surface roughness is found to exponentially enhance or suppress heating rate, depending on the density distribution of surface adsorbates. Our result suggests that heating rates can be tuned over orders of magnitude by careful engineering of electrode surface profiles.

Universal critical phenomena of the cloud → crystal phase transition in the Paul trap: Powerlaws, DANIEL WEISS, YUNSEONG NAM, REINHOLD BLMEI, Wesleyan University — $N$ charged particles, simultaneously stored in a radio-frequency (rf) Paul trap, exhibit deterministic heating. Depending on the damping ($\gamma$) imparted to the system, these particles can exist in multiple phases, the most commonly found being the cloud and crystal phases. With a small $\gamma$, the particles exhibit gas-like behavior, where the heating and cooling equilibrate and a stable cloud results. For larger $\gamma$, the damping overcomes the heating and the particles are forced into the crystalline state. We explore the cloud → crystal transition as a critical phenomenon. We find that the transition occurs at a critical value $\gamma_c$ of the damping constant $\gamma$. We find that as a function of $N$, $\gamma_c$ scales approximately like an iterated log law. We also present a universal power law, $\gamma_c \propto (\gamma - \gamma_c)^{-\beta}$, $\gamma > \gamma_c$, $\beta > 0$, independent of both $N$ and the Paul trap parameter $a$, depending only on the Paul trap parameter $q$, that describes the number of cycles necessary for the system to crystalize as a function of $\gamma - \gamma_c$.

9:00AM X50.00006 Ion-crystal metamorphoses in the Paul trap, VARUN URSEKAR, YUN SEONG NAM, REINHOLD BLMEI, Wesleyan Univ — We construct a generalized time-independent pseudo potential to describe the crystal morphologies and transitions between them for a three-ion Coulomb-interacting system in a Paul trap. The derivation of this pseudo potential extends a similar method that was already successfully constructed for the two-ion case to the case of three ions. Our method is based on keeping second-order micro-motion terms in the derivation of the pseudo potential. The resulting improved pseudo potential predicts ion-crystal morphologies that are corroborated by numerical simulations but are not captured by the standard pseudo potential. We provide a general method for extending this improved pseudo potential to a system of $N$ Coulomb-interacting ions in a Paul trap.
9:12AM X50.00007 Storage of multiple single-photon pulses emitted from a quantum dot in a solid-state quantum memory. — JIAN-SHUN TANG, ZONG-QUAN ZHOU, YI-TAO WANG, CHUAN-FENG LI, GUANG-CAN GUO, University of Science and Technology of China — Quantum repeaters are critical components for distributing entanglement over long distances in presence of unavoidable optical losses during transmission. Stimulated by Duan-Lukin-Cirac-Zoller protocol, many improved quantum-repeater protocols based on quantum memories have been proposed, which commonly focus on the entanglement-distribution rate. Among these protocols, the elimination of multi-photons (multi-photon-pairs) and the use of multimode quantum memory are demonstrated to have the ability to greatly improve the entanglement-distribution rate. Here, we demonstrate the storage of deterministic single photons emitted from a quantum dot in a polarization-maintaining solid-state quantum memory; in addition, multi-temporal-mode memory with 1, 20 and 100 narrow single-photon pulses is also demonstrated. Multi-photons are eliminated, and only one photon at most is contained in each pulse. Moreover, the solid-state properties of both sub-systems make this configuration more stable and easier to be scalable. Our work will be helpful in the construction of efficient quantum repeaters based on all-solid-state devices.

9:24AM X50.00008 Towards the coupling of single photons from dye molecules to a photonic waveguide. — CLAUDIO POLISSEN, KIANG WEI KHO, KYLE MAJOR, SAMUELE GRANDI, SEBASTIEN BOISSER, JAESUK HWANG, ALEX CLARK, EDWARD HINDS, Imperial College London — Single photons are very attractive for quantum information processing given their long coherence time and their ability to carry information in many degrees of freedom. A current challenge is the efficient generation of single photons in a photonic chip in order to scale up the complexity of quantum operations. We have proposed that a dibenzoterrylene (DBT) molecule inside an anthracene (AC) crystal could couple lifetime-limited indistinguishable single photons into a photonic waveguide if deposited in its vicinity. In this talk I describe the recent progress towards the realization of this proposal. A new method has been developed for evaporating AC and DBT to produce crystals that are wide and thin. The crystals are typically several microns across and have remarkably uniform thickness, which we control between 20 and 150 nm. The crystal growth is carried out in a glove bag in order to exclude oxygen, which improves the photostability of the DBT molecules by orders of magnitude. We image the fluorescence of single DBT molecules using confocal microscopy and analyse the polarization of this light to determine the alignment of the molecules. I will report on our efforts to control the alignment of the molecules by aligning the host matrix with the substrate.

9:36AM X50.00009 Ultra-Low Power Cross-Phase Shifts using Metastable Xenon in a High-Finesse Cavity. — GARRETT HICKMAN, TODD PITTMAN, JAMES FRANSON, University of Maryland, Baltimore County — Many important applications in quantum information and quantum communications make use of weak single-photon nonlinearities. These nonlinearities have been produced using a number of methods, but they generally require a complicated experimental setup. We demonstrate a relatively simple system for producing ultra-low power cross-phase modulation, by using metastable xenon as the nonlinear medium within an optical cavity. Using metastable xenon prevents the degradation of optical surfaces which typically occurs with the use of alkali vapors such as rubidium. We produce phase shifts of up to 10 mrad using 4.5-fJ control pulses. We discuss the performance of this system and outline the planned improvements that will allow the cavity to produce single-photon phase shifts on the order of 1 mrad.

This work was supported in part by DARPA DSO Grant No. W31P4Q-12-1-0015 and by NSF Grant No. PHY-1402708.

9:48AM X50.00010 Electric-Field Noise above a Thin Dielectric Layer on Metal Electrodes. — MIUR KUMPH, IBM, CARSTEN HENKEL, Universitaet Potsdam, PETER RABL, TU Wien, MICHAEL BROWNNTU, The University of Hong Kong, RAINER BLATT, University of Innsbruck — The electric-field noise above a layered structure composed of a planar metal electrode covered by a thin dielectric is evaluated and it is found that the dielectric film considerably increases the noise level, in proportion to its thickness. Importantly, even a thin (mono) layer of a low-loss dielectric can enhance the noise level by several orders of magnitude compared to the noise above a bare metal. Close to this layered surface, the power spectral density of the electric field varies with the inverse fourth power of the distance to the surface, rather than with the inverse square, as it would above a bare metal surface. Furthermore, compared to a clean metal, where the noise spectrum does not vary with frequency (in the radio-wave and microwave bands), the dielectric layer can generate electric field noise which scales in inverse proportion to the frequency. For various realistic scenarios, the noise levels predicted from this model are comparable to those observed in trapped-ion experiments. Thus, these findings are of particular importance for the understanding and mitigation of unwanted heating and decoherence in miniaturized ion traps.

10:00AM X50.00011 Carving complex many-atom entangled states by single-photon detection. — JIAZHONG HU, WENLAN CHEN, YIHENG DUAN, BORIS BRAVERMAN, HAO ZHANG, VLADAN VULETIC, Massachusetts Inst of Tech-MIT. — We propose a versatile and efficient method to generate a broad class of complex entangled states of many atoms via the detection of a single photon. For an atomic ensemble contained in a strongly coupled optical cavity illuminated by weak single- or multi-frequency light, the atom-light interaction entangles the atomic ensemble by aligning the molecules by aligning the host matrix with the substrate.

10:12AM X50.00012 Exponentially small dependence of the Q-function on quantum coherence. — R. A. BREWSTER, J. D. FRANSON, University of Maryland Baltimore County — We show that the Husimi Q-function has an exponentially small dependence on the relative phase of a Schrödinger cat state, as might be expected from its definition. This raises the question as to whether or not the Q-function provides a complete description of the coherence of quantum states. We calculate the Q-function for a cat state and then invert it by first calculating the Glauber-Sudarshan P-function using a Fourier transform, which can then be used to calculate the state itself. This process is shown to multiply the small phase-dependent terms in the Q-function by an exponentially large factor as needed in order to obtain the original state once again. This exponential factor is strongly degraded by decoherence, such as by amplification of the original state.

10:24AM X50.00013 Generation and multi-pass propagation of a squeezed vacuum field in hot Rb vapor. — MI ZHANG, College of William and Mary, R. NICHOLAS LANNING, ZHIHAO XIAO, JONATHAN P. DOWLING, Louisiana State University, IRINA NOVIKOVA, EUGENIY E. MIKHAILOV, College of William and Mary — We study a squeezed vacuum field (with reduced quantum noise level) generated in hot Rb vapor via the polarization self-rotation effect. By propagating the strong laser beam through a vapor cell once, we were able to achieve a noise suppression of 1.5-2 dB below shot noise. Our previous experiments showed that the amount of observed squeezing may be limited by the contamination of the squeezed vacuum output with higher-order spatial modes, also generated inside the cell. Here, we investigate whether or not the squeezing can be improved by making the light interact several times with a less dense atomic ensemble. We carry out a comparison of various conditions, e.g., injection power, atomic density, passing numbers etc., and studied their effect on squeezing level and the spatial structure of the output squeezed vacuum field. We believe(or show) optimization of the conditions can lead to higher achievable squeezing which would be very useful for precision metrology and quantum memory applications.

This project is supported by AFOSR grant FA9550-13-1-0098.
10:36AM X50.00014 Bright Single Photon Emitter in Silicon Carbide. BENJAMIN LIENHARD, TIM SCHROEDER, SARA MOURADIAN, FLORÍAN DOLDE, Massachusetts Inst of Tech-MIT, TOAN TRONG TRAN, IGOR AHARONOVICH, University of Technology Sydney, Australia, DIRK ENGLUND, Massachusetts Inst of Tech-MIT — Efficient, on-demand, and robust single photon emitters are of central importance to many areas of quantum information processing. Over the past 10 years, color centers in solids have emerged as excellent single photon emitters. Color centers in diamond are among the most intensively studied single photon emitters, but recently silicon carbide (SiC) has also been demonstrated to be an excellent host material. In contrast to diamond, SiC is a technologically important material that is widely used in optoelectronics, high power electronics, and microelectromechanical systems. It is commercially available in sizes up to 6 inches and processes for device engineering are well developed. We report on a visible-spectrum single photon emitter in 4H-SiC. The emitter is photostable at both room and low temperatures, and it enables 2 million photons/second from unpatterned bulk SiC. We observe two classes of orthogonally polarized emitters, each of which has parallel absorption and emission dipole orientations. Low temperature measurements reveal a narrow zero phonon line with linewidth < 0.1 nm that accounts for more than 30% of the total photoluminescence spectrum. To our knowledge, this SiC color emitter is the brightest stable room-temperature single photon emitter ever observed.

10:48AM X50.00015 Ring-shaped Wigner crystals of trapped ions at the microscale. HAOKUN LI, ERIK URBAN, CRYSTAL NOEL, ALEXANDER CHUANG, YANG XIA, BÖRGE HEMMERLING, YUAN WANG, XIANG ZHANG, HARTMUT HAEFFNER, University of California, Berkeley — Trapped ion crystals are ideal platforms to study many-body physics and quantum information processing, with both the internal electronic states and external motional degree-of-freedom controllable at the single quantum level. In contrast to conventional, finite, linear chains of ions, a ring topology exhibiting periodic boundary conditions and rotational symmetry opens up a new directions to diverse topics. However, previous implementations of ion rings result in small aspect ratios (<0.07) of ion-electrode distance to ring diameter, making the rotational symmetry of the ion crystals prone to stray electric fields from imperfections of the trap electrodes, particularly evident at low temperatures. Here, using a new trap design with a 60-fold improvement of this aspect ratio, we demonstrate crystallization of $^{40}$Ca$^+$ ions in a ring with rotational energy barriers comparable to the thermal energy of Doppler laser cooled ion crystals. When further reducing the rotational energy barriers, we observe delocalization of the ion rings. With this result, we enter a regime where quantum topological effects can be studied and novel quantum computation and simulation experiments can be implemented.

Friday, March 18, 2016 8:00AM - 11:00AM Session X52 DAMOP: Atomic Physics: New Frontiers I Hilton Baltimore Holiday Ballroom 3 -

8:00AM X52.00001 Comparison between two models of time-dependent absorption of matter waves$^1$. MAXIMILIEN BARBIER, Northumbria University, UK, MATHIEU BEAU, University of Massachusetts Boston, USA, and Dublin Institute for Advanced Studies, Ireland, ARSENI GOUSSEV, Northumbria University, UK — The interaction between an atom and a laser might give rise to transitions between two, or more, internal states of the atom. Such processes can be efficiently described within the framework of matter wave absorption, in which the laser beam is mimicked by an absorbing barrier. In this talk we present a quantitative comparison between two models describing the interaction between a non-relativistic quantum particle and a thin time-dependent absorbing barrier. The first model represents the barrier by time-dependent discontinuous matching conditions imposed on both the matter wave function of the particle and its spatial derivative. The second model treats the particle as a spinor submitted to a time-dependent off-diagonal $\delta$-potential. We show the two models to be in excellent agreement in a semiclassical regime. Reference: M. Barbier, M. Beau, A. Goussev, arXiv:1510.06996, Phys. Rev. A (in press).

8:12AM X52.00002 Bell Experiment with Classical Optical Fields$^2$, BETHANY LITTLE, XIAO-FENG QIAN, JOHN HOWELL, J. H. EBERY, University of Rochester — We theoretically and experimentally explore the implications of entanglement in statistically classical optical fields$^3$. The description of these fields in terms of polarization and amplitude degrees of freedom can take a non-separable form which employs a mathematical description of entanglement often associated with quantum phenomena. By subjecting these optical fields to a Bell analysis, we examine the role of entanglement in marking the quantum-classical boundary. We report a value of the Bell parameter greater than $B = 2.54$, many standard deviations outside the limit $B = 2$ established by the Clauser-Horne-Shimony-Holt Bell inequality$^4$. This suggests that Bell violation has less to do with quantum theory than previously thought, but everything to do with entanglement.

$^1$EPSRC Grant No. EP/K024116/1
$^2$University of Rochester Research Award, NSF PHY-1203931, NSF PHY-1505189, and NSF/INSPIRE PHY-1539859

8:24AM X52.00003 Non-equilibrium Transport of Light. CHIAO-HSUAN WANG, JQI/UMD/QuICS, JACOB TAYLOR, JQI/NIST/QuICs — Non-equilibrium Transport of Light The thermalization of light under conditions of parametric coupling to a bath provides a robust chemical potential for light$^1$. We study non-equilibrium transport of light using non-equilibrium Green’s function approach under the parametric coupling scheme, and explore a potential photonic analogue to the Landauer transport equation. Our results provide understandings of many-body states of photonic matter with chemical potential imbalances. The transport theory of light paves the way for quantum simulation and even practical applications of diode-like circuits using quantum photonic sources in the microwave and optical domain.


8:36AM X52.00004 Determination of Zak phase by reflection phase in 1D photonic crystals. WENSHENG GAO, HKUST, MENG XIAO COLLABORATION, CHETING CHAN COLLABORATION, WINGYIM TAM TEAM — For a one-dimensional (1D) periodic system with inherent mirror symmetry, the value of the geometric "Zak" phase in a bulk band is related to the sign of reflection phase for wavelengths inside the bandgaps sandwiching the bulk band. We designed an interference setup which allows us to measure the reflection phase of 1D photonic crystal fabricated for the optical range, and this in turn enabled us to determine the Zak phases of the bands. We then found interface states whose existence can be traced to the topological properties of the bandgaps and the geometric phases of the bulk bands. (accepted by optics letters)

8:48AM X52.00005 Experimental Apparatus for the Observation of the Topological Change Associated with Dynamical Monodromy. DANIEL SALMON, M. PERRY NEREM, SETH AUBIN, JOHN DELOS, William & Mary Coll. — Monodromy means once around a path, therefore systems that have non-trivial monodromy are systems such that, when taken around a closed circuit in some space, the system has changed state in some way. Classical systems that exhibit non-trivial Hamiltonian monodromy have action and angle variables that are multivalued functions. A family, or loop, of trajectories of this system has a topological change upon traversing a monodromy circuit. We present an experimental apparatus for observing this topological phase. A family of particles moving in a cylindrically symmetric champagne-bottle potential exhibits non-trivial Hamiltonian monodromy. At the center of this system is the classically forbidden region. By following a monodromy circuit, a loop of initial conditions on one side of the forbidden region can be made to evolve continuously into a loop that surrounds the forbidden region. We realize this system using a spherical pendulum, having at its end a permanent magnet. Magnetic fields generated by coils can then be used to create the champagne-bottle potential, as well as drive the pendulum through the monodromy circuit.
9:00AM X52.00006 Topological Charge Screening in Disordered Aharonov-Bohm Wavefunctions. ALEXANDER HOUSTON, JOHN HANNAY, ALEXANDER TAYLOR, MARK DENNIS, University of Bristol — Free electrical charges are typically subject to screening relations. For example, in ionic fluids and Coulomb gases there is screening (both global and local) of the electrical charges, described by the first and second Stillinger-Lovett sum rules [1]. A topological analogy governs the statistical behaviour of the nodal points in Gaussian random superpositions of plane waves. These nodal points are integer topological charges, i.e. vortices and antivortices of the complex wavefunction, whose sign is that of the phase circulation. Such superpositions are known to model high energy eigenfunctions in the presence of wave chaos [2], and display topological charge screening in the bulk [3]. We investigate how these screening relations are affected by the introduction of a magnetic flux line [4], which may be fractional in strength. We find that the global screening relation is broken, with the average total topological charge of the vortices given by the flux strength, and that the local screening of the flux itself shows unexpected features. [1] F. H. Stillinger and R. Lovett, J. Chem. Phys. 49, 1991-94 (1968) [2] M. V. Berry, J. Phys. A 10, 2083-91 (1977) [3] M. V. Berry and M. R. Dennis, Proc. R. Soc. A 456, 2059-79 (2000) [4] Y. Aharonov and D. Bohm, Phys. Rev. 115, 485-91 (1959)

9:12AM X52.00007 Synthetic gauge flux and Weyl points in acoustic systems.1. MENG XIAO, stanford university, WEN-JIE CHEN, WEN-YU HE, C. T. CHAN, the Hong Kong University of Science and Technology — We consider acoustic systems comprising a honeycomb lattice in the xy plane and periodic along the z direction. As k is a good quantum number here, for each fixed k, this system can be treated as a reduced two-dimensional system. By engineering the interlayer coupling in the z-direction, we show that we can realize effective inversion symmetry breaking and staggered synthetic gauge flux in the reduced two-dimensional system. The realizations of chiral edge states for fixed values of k are direct consequences of the staggered gauge flux. And we then show that the synthetic gauge flux is closely related to the Weyl points in the three-dimensional band structure.

1This work was supported by the Hong Kong Research Grants Council (grant no. AoE/P-02/12)

9:24AM X52.00008 Atomic collisions, inelastic indeed. HERVE BERCEGOL, GWENAEL FERRANDO, ROLAND LEHOUQC, CEA — At the turn of the twentieth century, a hot controversy raged about the ability of Boltzmann’s framework to take care of irreversibility. The so-called Loschmidt’s paradox progressively faded with time during the last hundred years, due to the predictive efficiency of statistical mechanics. However, one detail at the origin of the controversy – the elasticity of atomic collisions – was not completely challenged. A semi-classical treatment of two atoms interacting with the vacuum zero-point field permits to predict a friction force acting against the rotation of the pair of atoms [Bercegol H. & Lehoucq R., Phys. Rev. Lett. 115, 090402 (2015)]. By its form and its level, the calculated torque is a candidate as a physical cause for diffusion of energy and angular momentum, and consequently for entropy growth. It opens the way to a revision of the standard vision of irreversibility. This presentation will focus on two points. First we will discuss the recent result in a broader context of electromagnetic interactions during microsopic collisions. The predicted friction phenomenon can be compared to and distinguished from Collision-Induced Emission and other types of inelastic collisions. Second we will investigate the consequences of the friction torque on calculated trajectories of colliding atoms, quantifying the generation of dimers linked by dispersion forces.

9:36AM X52.00009 Hydrogen Dissociation in Generalized Hartree-Fock Theory: Breaking the diatomic bond.1 JONATHAN JERKE, Texas Southern University, SAMINA MASOOD, University of Houston Clear Lake, CJ TYMCZAK, Texas Southern University — Generalized Hartree Fock theory predicts molecular Hydrogen dissociation without correlation. A variational Gaussian-Sinc linear superposition is the basis of 50 calculations with 3-4 significant digits of quality. The spin singlet covalent bond spontaneously breaks into a pair of uncorrelated doublets at atomic separation of 1.22 Angstroms. Quantum spin numbers and energetic comparison with Configuration Interaction theory—correlation—point to a first order phase transition in the molecular Hydrogen bond without correlation.

1Welch Foundation (Grant J-1675), the ARO (Grant W911NF-I-3-I-0162), the Texas Southern University High Performance Computing Center (http://hpcc.tsu.edu/); Grant PHY-1126251 and NSF-CREST CRCN project (Grant HRD-137732)

9:48AM X52.00010 Stretching of Picosecond Laser Pulses with Uniform Reflecting Volume Bragg Gratings. SERGIY MOKHOV, CREOL - the College of Optics and Photonics, Univ. of Central Florida — It is shown that a uniform reflecting volume Bragg grating (VBB) can be used as a compact monolithic stretcher of high-power picosecond laser pulses in cases when chirped Bragg gratings with an appropriate chirp rate are difficult to fabricate. A chirp-free reflected stretched pulse is generated of almost rectangular shape when incident short pulse amplitudes and beam quality, and tolerance to high power. Obtained pulses of several tens of picoseconds can be amplified by standard methods which are about 10% after taking into account the spectral narrowing of the reflected emission. We believe that the relatively low energy efficiency of the proposed stretching method is due to the mode competition of the Bragg reflection. The typical expected theoretical value of diffraction efficiency is about 10% for uniform gratings. In the numerical treatment we used the analytic expression for diffraction efficiency, which incorporates incident pulse duration, grating thickness, and amplitude of refractive index modulation, enabling an optimum selection of the grating for pulse stretching. The typical expected theoretical value of diffraction efficiency is about 10% for uniform gratings. In the numerical treatment we used the analytic expression for diffraction efficiency, which incorporates incident pulse duration, grating thickness, and amplitude of refractive index modulation, enabling an optimum selection of the grating for pulse stretching. The typical expected theoretical value of diffraction efficiency is about 10% for uniform gratings. In the numerical treatment we used the analytic expression for diffraction efficiency, which incorporates incident pulse duration, grating thickness, and amplitude of refractive index modulation, enabling an optimum selection of the grating for pulse stretching. The typical expected theoretical value of diffraction efficiency is about 10% for uniform gratings. In the numerical treatment we used the analytic expression for diffraction efficiency, which incorporates incident pulse duration, grating thickness, and amplitude of refractive index modulation, enabling an optimum selection of the grating for pulse stretching. The typical expected theoretical value of diffraction efficiency is about 10% for uniform gratings. In the numerical treatment we used the analytic expression for diffraction efficiency, which incorporates incident pulse duration, grating thickness, and amplitude of refractive index modulation, enabling an optimum selection of the grating for pulse stretching. The typical expected theoretical value of diffraction efficiency is about 10% for uniform gratings. In the numerical treatment we used the analytic expression for diffraction efficiency, which incorporates incident pulse duration, grating thickness, and amplitude of refractive index modulation, enabling an optimum selection of the grating for pulse stretching. The typical expected theoretical value of diffraction efficiency is about 10% for uniform gratings. In the numerical treatment we used the analytic expression for diffraction efficiency, which incorporates incident pulse duration, grating thickness, and amplitude of refractive index modulation, enabling an optimum selection of the grating for pulse stretching. The typical expected theoretical value of diffraction efficiency is about 10% for uniform gratings. In the numerical treatment we used the analytic expression for diffraction efficiency, which incorporates incident pulse duration, grating thickness, and amplitude of refractive index modulation, enabling an optimum selection of the grating for pulse stretching. The typical expected theoretical value of diffraction efficiency is about 10% for uniform gratings. In the numerical treatment we used the analytic expression for diffraction efficiency, which incorporates incident pulse duration, grating thickness, and amplitude of refractive index modulation, enabling an optimum selection of the grating for pulse stretching.

10:00AM X52.00011 Ablation-cooled material removal with ultrafast bursts of pulses. F. MER ILDAY, F. MER ILDAY, Department of Electrical and Electronics Engineering, Bilkent University, Ankara, Turkey, C. KERSE, H. KALAYCIOGLU, P. ELAHI, Department of Physics, Bilkent University, Turkey, S. YAVAS, FiberLAST, Inc., Ankara, Turkey, M. ASIK, Nanotechnology and Nanomedicine Department, Hacettepe University, Turkey, H. HOOGLAND, R. HOLZWARTH, Department of Physics, University of Erlangen-Nuremberg, Germany — Use of femtosecond pulses allows precise and thermal-damage-free material removal with broad applications. However, its potential is limited by low material removal speeds and complexity of the required lasers. The laser complexity arises from the high pulse energy threshold for ablation. Physics of the laser-material interaction precludes a straightforward scaling up of the removal rate by using more powerful lasers due to shielding and collateral damage from heat accumulation. Here, we exploit ablation cooling, a technique used in aerospace engineering since 1950s, to circumvent this limitation. We apply rapid successions of pulses from specially developed lasers to ablate the target material before the residual heat deposited by previous pulses diffuse away from the interaction region. This constitutes a new physical regime of laser-material interactions, where heat removal due to ablation is comparable to conduction. Proof-of-principle experiments demonstrate reduction of required pulse energies by 1000x, while simultaneously increasing efficiency and speed by 10x.
10:12AM X52.00012 Formation of ultrashort pulses from monochromatic XUV radiation via interaction with a medium of IR-dressed He atoms. TIMUR AKHMEDZHANOV, Texas A&M University and Institute for Quantum Studies and Engineering, College Station, TX, VLADIMIR ANTONOV, Institute of Applied Physics of the Russian Academy of Sciences, Nizhny Novgorod, Russia, OLGA KOCAROVSKAYA, Texas A&M University and Institute for Quantum Studies and Engineering, College Station, TX — Trains of high intensity ultrashort XUV pulses could find a lot of applications. Recently, a mechanism of high efficiency formation of a train of XUV pulses from quasi-monochromatic XUV field was suggested [Opt. Lett. 36, 2296 (2011)]. XUV field propagates through the medium of atoms, which are space-time modulated by IR field. The field scattered by modulated atoms contains sidebands of incident XUV field frequency and, for properly chosen parameters, train of ultrashort pulses is formed at the output of the medium. In this contribution, we study formation of ultrashort pulses in the medium of He atoms. Contrary to our recent work [Phys. Rev. A 91, 023830 (2015)], IR field is chosen to be weak enough, so that pulses are formed due to modulation of excited atomic levels, rather than tunnel ionization. The suggested method allows to form train of pulses with high efficiency and can be scaled to He-like ions in order to get even shorter pulses.

10:24AM X52.00013 Chiral Molecular Optical Response to Nano-Shaped Light1. PRASOON SAURABH, Univ of California - Irvine, VLADIMIR CHERNYAK, Wayne State University, JEREMY ROUXEL, SHAUL MUKAMEL, Univ of California - Irvine — Chiral linear optical signals are an important spectroscopic tool for biomolecules and chemical sensing applications. Exact expressions are derived which express these signals as a convolution of a non-local linear susceptibility of matter with a non-local intrinsic property of the electric field. The chiral response can be enhanced and optimized using nano-optical fields with strong spatial variation. The approach is based on a gauge invariant formulation using the minimal coupling Hamiltonian. The multipolar expansion is avoided and all multipoles are naturally incorporated. We apply these expression to achiral (planar) and chiral (dihedral angle of 45°) bi-phenyl as a physically intuitive illustration.

1The support of National Science Foundation (Grant No. CHE-1361516) and the Chemical Sciences, Geosciences and Biosciences Division, Office of Basic Energy Sciences, Office of Science, U.S. Dept. of Energy (award DE-FG02-4ER15571)

10:36AM X52.00014 Study of Rydberg blockade mediated optical non-linearity in thermal vapor1. ARUP BHOWMICK, Senior Research Fellow, ASHOK MOHAPATRA, Reader-F — We demonstrate Rydberg blockade by coupling to Rydberg state via two-photon excitation in rubidium thermal vapor. The probe beam coupling to the D2 transition was blue detuned by 1.3 GHz and a coupling beam was scanned to excite the atoms to Rydberg state via two-photon transition (S1/2 → nS1/2). The dispersion of the probe beam is modified due to the 2-photon excitation and is measured using an optical heterodyne detection technique in the experiment. We have observed that the dispersion of the probe beam depends linearly on atomic vapor density while coupling to a Rydberg state with principal quantum number, n = 30. However, density dependent suppression of the dispersion is observed while coupling to the Rydberg state with n = 60. Since the dispersion of the probe beam due to 2-photon excitation depends on the Rydberg population, the density dependent suppression is explained by introducing the concept of blockade. The blockade radius is measured to be about 2.2 μm which is consistent with the scaling due to Doppler width of the 2-photon resonance in thermal vapor. Our result promises the realization of single photon source and strong single photon non-linearity based on Rydberg blockade in thermal vapor.

1National Institute of Science Education and Research

10:48AM X52.00015 'Relativistic' corrections to the mass of a plucked guitar string. MICHAEL KOLODRUBETZ, Univ of California - Berkeley, ANATOLI POLKOVNIKOV, Boston University — Quantum systems respond non-adiabatically when parameters controlling them are ramped at a finite rate. If the parameters themselves are dynamical for instance the position of a box that defines the boundary of a quantum field the feedback of these excitations gives rise to effective Newtonian equations of motion for the parameter. For the age old problem of photons in a box, this correction gives rise to a mass proportional to the energy of the photons. We show that a similar correction arises for a classical guitar string plucked with energy E; moving clamps at the ends of the string requires inertial mass m = 2E/c2, where c is the speed of sound. This quasi-relativistic effect should be observable in freshman physics level experiments. We then comment on how these simple methods have been readily extended to treat problems such as rams and quenches of strongly-interacting superconductors and dynamical trapping near a quantum critical point.

Friday, March 18, 2016 11:15AM - 2:15PM — Session Y1 DCMP DAMOP: Orbital Angular Momentum of Light and Matter Ballroom I - Charles Clark, NIST

11:15AM Y1.00001 Ghost imaging with entangled photons and orbital angular momentum. MILES PADGETT, University of Glasgow — We utilise the position and orbital angular momentum (OAM) correlations between the signal and idler photons generated in the down-conversion process to obtain ghost images of a phase object. By using an OAM phase filter, which is non-local with respect to the object, the ghost images exhibit isotropic edge-enhancement. The strong spatial correlations between the signal and idler photons generated by spontaneous parametric downconversion have been widely utilised in many different imaging systems. The use of a scanning single element detector to recover the spatial information in the signal and idler beams fundamentally limits the detection efficiency of the imaging system to a maximum of 1/N where N is the number of pixels in the image. Our approach overcomes this limitation by replacing the scanning detector by an intensified CCD camera, therefore detecting all photons irrespective of their position within the image. Using a camera in this way, coupled with the OAM edge-enhancement and image reconstruction techniques allows us to obtain images of phase objects with an average of fewer than one photon per image pixel.

11:51AM Y1.00002 Twisting Neutron Waves1. DMITRY PUSHIN, IQC, University of Waterloo — Most waves encountered in nature can be given a “twist”, so that their phase winds around an axis parallel to the direction of wave propagation. Such waves are said to possess orbital angular momentum (OAM). For quantum particles such as photons, atoms, and electrons, this corresponds to the particle wavefunction having angular momentum of lh along its propagation axis. Controlled generation and detection of OAM states of photons began in the 1990s, sparking considerable interest in applications of OAM in light and matter wavefronts. OAM states of photons have found diverse applications such as broadband data multiplexing, massive quantum entanglement, optical trapping, microscopic quantum state determination and teleportation, and interferometry. OAM states of electron beams have been used to rotate nanoparticles, determine the chirality of crystals and for magnetic microscopy. Here I discuss the first demonstration of OAM control of neutrons. Using neutron interferometry with a spatially incoherent input beam, we show the addition and conservation of quantum angular momenta, entanglement between quantum path and OAM degrees of freedom. Neutrons based quantum information science heretofore limited to spin, path, and energy degrees of freedom, now has access to another quantized variable, and OAM modalities of light, x-ray, and electron beams are extended to a massive, penetrating neutral particle. The methods of neutron phase imaging demonstrated here expand the toolbox available for development of phase-sensitive techniques of neutron imaging.

1Financial support provided by the NSERC Create and Discovery programs, CERC and the NIST Quantum Information Program is acknowledged.


transformation measurements. The method can be extended to other types of waves. Specifically, we have recently used it to determine the acceleration of an electron.

Determine the topological charge up to a value of 10. The same concept of astigmatic transformation was then used to unveil the acceleration of an electron beam that preserves its shape while propagating along parabolic trajectory, have drawn significant attention recently both in light optics and in electron optics experiments. In contrast to other methods, such as the phase shifter method, our method is based on the fundamental properties of the OAM for the vortex beams and the nodal trajectory acceleration coefficient for the Airy beam. Here we demonstrate a straightforward method to determine these quantities by astigmatic Fourier transform of the beam. For electron beams in a transmission electron microscope, this transformation is easily realized using the condenser and objective stigmators, whereas for light beams this can be achieved using a cylindrical lens. In the case of Laguerre-Gauss vortex beams, it is already well known and is an application of vortex transformation.

The Airy beam is a special class of beams that carry orbital angular momentum (OAM). We generated a series of electron vortex beams and managed to determine the topological charge up to a value of 10. The same concept of astigmatic transformation was then used to unravel the acceleration of an electron Airy beam. The shape of astigmatic-transformed depends only on the astigmatic coefficient and on the acceleration coefficient. The method was experimentally verified by generating electron Airy beams with different known acceleration parameters, enabling direct comparison to the deduced values from the astigmatic transformation measurements. The method can be extended to other types of waves. Specifically, we have recently used it to determine the acceleration of an optical Airy beam and the topological charge of so-called Airy-vortex light beam, i.e. an Airy light beam with an embedded vortex.

1:39PM Y1.00005 Unveiling orbital angular momentum and acceleration of light beams and electron beams1, ADY ARIE, Tel-Aviv University — Special beams, such as the vortex beams that carry orbital angular momentum (OAM) and the Airy beam that preserves its shape while propagating along parabolic trajectory, have drawn significant attention recently both in light optics and in electron optics experiments. In contrast to other methods, such as the phase shifter method, our method is based on the fundamental properties of the OAM for the vortex beams and the nodal trajectory acceleration coefficient for the Airy beam. Here we demonstrate a straightforward method to determine these quantities by astigmatic Fourier transform of the beam. For electron beams in a transmission electron microscope, this transformation is easily realized using the condenser and objective stigmators, whereas for light beams this can be achieved using a cylindrical lens. In the case of Laguerre-Gauss vortex beams, it is already well known and is an application of vortex transformation.

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1This work was supported by DIP and the Israel Science Foundation.

Friday, March 18, 2016 11:15AM - 1:15PM — Session Y50 DAMOP: Fluctuation-Induced Forces Hilton Baltimore Holiday Ballroom 1 - Jeremy Munday, University of Maryland

11:15AM Y50.00001 Nanoscale Radiative Heat Transfer between Graphene Ribbon Arrays1, ZHUOMIN ZHANG2, XIANGLEI LIU3, Georgia Institute of Technology — Near-field radiative heat transfer between two graphene sheets can exceed that between blackbodies due to surface plasmons excited by the graphene sheet. This study shows that, by patterning a single layer of graphene sheet into ribbons, a giant enhancement of the near-field radiative heat flux, by more than one order of magnitude higher than that between two graphene sheets, can be achieved. The mechanism lies in that when the graphene sheet is patterned into an array of ribbons, the closed circular dispersion of graphene plasmons is opened to become hyperbolic, leading to broadband singularities of density of states. Extremely high-k evanescent waves can now couple with hyperbolic graphene plasmons. Exact numerical simulations are used by combining the scattering theory and rigorous coupled-wave analysis. Furthermore, effective medium calculations are used to support the arguments and provide clear physical insights. The findings from this study may open promising pathways for highly efficient thermal management, energy harvesting, and subwavelength thermal imaging.

1This work was supported by the Department of Energy, Office of Science, Basic Energy Sciences (DE-FG02-06ER46343).

1Professor

2PhD student

11:27AM Y50.00002 Failure of local FDT in fluctuation-induced interactions. DIEGO DALVIT, Los Alamos National Laboratory, FRANCESCO INTRAVAIA, Max-Born Institute, Germany, RYAN BEHUNIN, Yale University, CARSTEN HENKEL, University of Potsdam, Germany — Fluctuation-induced interactions (e.g., quantum friction, near-field heat transfer, and non-equilibrium Casimir forces) the local fluctuation-dissipation theorem (FDT) is widely used without much justification. Here, we report the failure of the local FDT in a specific example of quantum friction of an atom moving at constant velocity above a surface. A generalized non-equilibrium FDT is derived, which contains a contribution akin to the local FDT and an additional one corresponding to a velocity-dependent current term. We show that in the low-velocity limit the frictional force arising from the current term is of the same order of magnitude as that predicted by the local FDT, which underestimates the total force by almost 50 percent.

11:39AM Y50.00003 Fluctuation-Induced Interactions in external magnetic fields: Casimir force and Radiative Heat Transfer, RAUL ESQUIVEL-SIRVENT, Univ Nacl Autonoma de Mexico — Thermally induced electromagnetic fields give rise to the Casimir force and the near field heat transfer between two bodies separated by a gap. These phenomena are described by Rytov theory of fluctuating electromagnetic fields and both the Casimir force and the near field heat transfer depend on the local dielectric function of the bodies. In this work, we present a theoretical calculation on the modulation of fluctuation-induced interactions in the presence of an external magnetic field. The system consists of two parallel plates separated by a gap d. Each plate is isotropic and has a local dielectric function. Applying an external magnetic field parallel to the plates, in the so called Voigt configuration, the plates become anisotropic. In particular, we consider plates of InSb. For the Casimir force the two plates are kept at the same temperature and the external field reduces the magnitude of the force. Similarly if the two plates are kept at different temperature the near field radiative heat transfer is modulated by the magnitude of the external magnetic field. The results are extended to semiconducting quantum wells. In both cases, the excitation of magnetoplasmons provides an explanation for the observed effect.

11:51AM Y50.00004 Short distance expansion for fluctuation induced interactions, THORSTEN EMIG, CNRS and MIT, GIUSEPPE BIMONTE, Universita’ di Napoli Federico II — Fluctuation induced interactions become most prominent in close to proximity to surfaces. Examples include van der Waals and Casimir forces, heat transfer, and spectral shifts for atoms and molecules. In many situations, the surfaces are curved or structured which makes the computation of the interaction in general complicated. Here we present a versatile and powerful approach to this problem which is based on a derivative expansion. It applies to distances much smaller than the radii of surface curvature. Explicit results include orientational effects for anisotropic particles, thermal effects, and spectral modifications.
12:03PM Y50.00005 Unified boundary conditions and Casimir forces for fields with arbitrary spin

ROBERT BENNETT, University of Freiburg, ADAM STOKES, University of Leeds — The electromagnetic Casimir effect is well-known and has been extensively studied for the last half-century. This attractive force between parallel plates arises from the imposition of boundary conditions upon the fluctuating spin-1 photon field, so a natural further question is whether fields of different spin can cause similar forces when confined in the same way. However, so far it has not been clear what the appropriate boundary conditions for physically-confined spinor fields may be. Here we present work that generalises the physically well-motivated electromagnetic boundary conditions to fields of arbitrary spin, thus arriving at physically reasonable boundary conditions and Casimir forces for a selection of interesting fields. For example, the so-called ‘bag model’ boundary conditions from nuclear physics emerge from our generalised boundary condition as a special case, as do the linearised gravity boundary conditions suggested in a remarkable recent proposal concerning possible measurement of gravitonic Casimir forces.

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12:15PM Y50.00006 Measurement and control of electrostatic patch potentials

JOSEPH L. GARRETT, JEREMY N. MUNDAY, University of Maryland, College Park — Electrostatic patch potentials hinder many precision measurements, particularly measurements of the Casimir force. Despite the improved force sensitivity achieved over the last decade, only recently have attempts been made to measure and quantify the effects of patch potentials. Here we present an analysis of patch potentials measured by Kelvin probe force microscopy (KPFM) and discuss methods to control these potentials (e.g., humidity, material choice, etc.).

1Department of Physics, Institute for Research in Electronics and Applied Physics
2Electrical and Computer Engineering, Institute for Research in Electronics and Applied Physics

12:27PM Y50.00007 An experimental apparatus for Casimir torque measurements

DAVID A. T. SOMERS, JEREMY N. MUNDAY, Univ of Maryland-College Park — We have developed an experiment to measure the Casimir torque. In our experiment, a solid birefringent crystal causes a nematic liquid crystal director to rotate such that the extraordinary axes are aligned. A transparent and isotropic dielectric spacer layer is used to separate the two birefringent materials and an all-optical technique is used for detection. In this talk, we report on the progress of this experiment.

12:39PM Y50.00008 Parameterization of lattice spacings for lipid multilayers in ionic solutions

HORIA PETRACHE, Indiana University Purdue University Indianapolis, MERRRELL JOHNSON, Indiana University Purdue University Fort Wayne, DANIEL HARRIES, The Hebrew University of Jerusalem, SOENKE SEIFERT, Argonne National Laboratory — Lipids, which are molecules found in biological cells, form highly regular layered structures called multilamellar lipid vesicles (MLVs). The repeat lattice spacings of MLVs depend on van der Waals and electrostatic forces between neighboring membranes and are sensitive to the presence of salt. For example, addition of salt ions such as sodium and potassium makes the MLVs swell, primarily due to changes in electrical polarizabilities. However, a more complicated behavior is found in some ionic solutions such as those containing lithium ions. Using x-ray scattering, we show experimentally how the interactions between membranes depend on the type of monovalent ions and construct parameterizations of MLVs swelling curves that can help analyze van der Waals interactions.

12:51PM Y50.00009 Johnson-Nyquist Noise Coupling Formulation of Near-Field Heat Transfer for 1D Conductors

MIKA PRUNNILA, SAMPO LAAKSO, DAVID GUNNARSSON, VTT Technical Research Centre of Finland — Near-field heat transfer has been formulated using different levels of theoretical sophistication and complexity ranging from fluctuational electrodynamics to quasi-static Coulomb interaction description. Our goal is to find a simple description for the near-field heat transfer between coupled 1D electron systems (conductors). We will show that by considering distributed Johnson-Nyquist voltage sources, arising from the dissipative part of the electron systems’ response, a compact fundamental formula for the near-field heat transfer can be found. We will describe the details of the derivation and discuss the regime of validity of our approach. Several special cases will be considered and experimental configurations will be discussed. The presented analysis is especially suitable for closely spaced graphene ribbons and nanowires. We will also show that by including inductive responses, which are necessary at high frequencies, speed of light emerges in the heat flow formula, thereby showing the link between fundamental physical quantities/constants and near-field heat transfer in coupled 1D systems. Our formulation also provides the possibility to use different boundary conditions for the physical system and this enables design of near-field heat transfer circuits.

1:03PM Y50.00010 ABSTRACT WITHDRAWN —
11:27AM Y52.00002 Broken selection rule in the quantum Rabi model. GUILLERMO ROMERO, University of Santiago de Chile, POL FORN-DIAZ, University of Waterloo, C. J. P. M HARMANS, TU Delft, ENRIQUE SOLANO, University of the Basque Country, HANS MOOIJ, TU Delft — We report the spectroscopic observation of a resonant transition that breaks a selection rule in the quantum Rabi model, implemented using an LC resonator and a superconducting qubit. The eigenstates of the system consist of a superposition of bare qubit-oscillator states with a relative sign. In the limit of low qubit-oscillator coupling strength, the matrix element between excited eigenstates of different sign is very small in presence of an oscillator drive, establishing a sign-preserving selection rule. Here, our qubit-resonator system operates in the ultrastrong coupling regime, where the coupling strength is 10% of the resonator frequency, allowing sign-changing transitions to be activated and, therefore, detected. This work shows that sign-changing transitions are an unambiguous, distinctive signature of systems operating in the ultrastrong coupling regime of the quantum Rabi model. These results pave the way to further studies of sign-preserving selection rules in multimode and multiphoton models.

11:39AM Y52.00003 ”Magnetic” refrigeration in synthetic quantum magnets. MICHAEL ZALETEL, Station Q, Microsoft Research, NORMAN YAO, Department of Physics, UC Berkeley — The advent of ultracold atomic systems has promised to expand upon our understanding of strongly correlated quantum ground states; by contrast to their material cousins, cold atomic experiments benefit from unique tools such as direct optical imaging and tunable short- and long-range interactions. However, despite advances in coherent quantum control, ultracold atoms remain much too hot. Although sub-nanokelvin temperatures are the norm in experiments, the entropy of the system remains extensively far above the ground state. One strategy to combat this is to shift the entropy elsewhere for example, placing a gapless system near a gapped system can effectively ”cool” the latter. In this talk, we will demonstrate that typical atomic systems can act as their own coolant. As an example, we consider a 1D optical lattice geometry where spin-1 atoms interact via a generic AKLT-type Hamiltonian. We will discuss why decreasing the density of atoms in one region is sufficient cool the complementary portion of the system to the ground state, wherein coherent edge dynamics are observed.

11:51AM Y52.00004 Dissipative topological insulator with fractional winding number and single edge state. TONY LEE, Indiana University-Purdue University Indianapolis (IUPUI) — Photonic experiments offer an opportunity to find novel topological states. We consider a one-dimensional tight-binding model in the presence of gain and loss as well as long-range hopping. The system is described by a non-Hermitian Hamiltonian with PT symmetry and exceptional points. The unique feature of the model is that the Hamiltonian encircles an exceptional point in momentum space, leading to novel topological features. The winding number has a fractional value 1/2 because the Brillouin zone has a periodicity of 4pi instead of 2pi. There is only one edge state due to the coalescence of eigenvectors. The edge state is topologically protected by a chiral symmetry but disappears when the bulk gap closes. We also discuss experimental realization with optical waveguides.

12:03PM Y52.00005 Simulating the Generalized Gibbs Ensemble (GGE): A Hilbert space Monte Carlo approach. VINCENZO ALBA, SISSA — By combining classical Monte Carlo and Bethe ansatz techniques we devise a numerical method to construct the Truncated Generalized Gibbs Ensemble (TGGE) for the spin-1/2 isotropic Heisenberg (XXX) chain. The key idea is to sample the Hilbert space of the model with the appropriate GGE probability measure. The method can be extended to other integrable systems, such as the Lieb-Liniger model. We benchmark the approach focusing on GGE expectation values of several local observables. As finite-size effects decay exponentially with system size, moderately large chains are sufficient to extract thermodynamic quantities. The Monte Carlo results are in agreement with both the Thermodynamic Bethe Ansatz (TBA) and the Quantum Transfer Matrix approach (QTM). Remarkably, it is possible to extract in a simple way the steady-state Bethe-Gaudin-Takahashi (BGT) roots distributions, which encode complete information about the GGE expectation values in the thermodynamic limit. Finally, it is straightforward to simulate extensions of the GGE, in which, besides the local integral of motion (local charges), one includes arbitrary functions of the BGT roots. As an example, we include in the GGE the first non-trivial quasi-local integral of motion.

12:15PM Y52.00006 Minimally entangled typical thermal states versus matrix product purifications for the simulation of equilibrium states and time evolution. MORITZ BINDER, THOMAS BARTHEL, Duke Univ — We compare matrix product purifications and minimally entangled typical thermal states (METTS) for the simulation of equilibrium states and finite-temperature response functions of strongly correlated quantum many-body systems. For METTS, we highlight the interplay of statistical and DMRG truncation errors, discuss the use of self-averaging effects, and describe schemes for the computation of response functions. We assess the computation costs and accuracies of the two methods for critical and gapped spin chains and the Bose-Hubbard model. For the same computation cost, purifications yield more accurate results than METTS except for temperatures well below the systems energy gap. (Phys. Rev. B 92, 125119 (2015))

12:27PM Y52.00007 Interacting Bose gas confined in a Kronig-Penney potential. O. A. RODRIGUEZ, Postgrado en Ciencias Físicas, UNAM, M. A. SOLÍS, Instituto de Física, UNAM — We analyze the effect of the 1D periodic Kronig-Penney potential, composed of barriers of width \( b \) and separated a distance \( a \), over an interacting Bose gas. At \( T = 0 \), the Gross-Pitaevskii equation is solved analytically in terms of the Jacobi elliptic functions for repulsive or attractive interaction between bosons. By applying the boundary conditions for periodic solutions as well as the normalization of the wave function, we arrive to a set of nonlinear equations from which we obtain the density profile and the chemical potential of the condensate as a function of the particle momentum. The profiles for attractive and repulsive interactions are compared with that of the non-interacting case. For attractive interaction we are able to observe a pronounced spatial localization in the middle of every two barriers. We reproduce the well known results when the Kronig-Penney potential becomes a Dirac Comb.

We acknowledge partial support from grants PAPIIT IN111613 and CONACyT 221030.

12:39PM Y52.00008 Concept of contact spectrum and its applications in atomic quantum Hall states. MINGYUAN HE, SHAO-LIANG ZHANG, HON-MING CHAN, QI ZHOU, Department of Physics, The Chinese University of Hong Kong — A unique feature of ultracold atoms is the separation of length scales, \( r_0 \ll k_F^{-1} \), where \( k_F \) and \( r_0 \) are the Fermi momentum characterizing the average particle distance and the range of interaction between atoms respectively. For \( s \)-wave scattering, Shina Tan discovered that such diluteness leads to universal relations, all of which are governed by contact, among a wide range of thermodynamic quantities. In this talk, I will show that the concept of contact can be generalized to an arbitrary partial-wave scattering. Contact of all partial-wave scatterings form a contact spectrum, which establishes universal thermodynamic relations with notable differences from those in the presence of \( s \)-wave scattering alone. Moreover, such a contact spectrum has an interesting connection with a special bipartite entanglement spectrum of atomic quantum Hall states, and enables an intrinsic probe of these highly correlated states using two-body short-ranged correlations.

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and present-day cosmic observables. The following set of the three smallest integers:

\([-1, 0, 1]\)

are associated with each physical entity investigated as a frequency equivalent. They are listed as follows: twice the maximum energy of a cosmic ray, 1; the Bohr radius, 4/5; Rydberg's constant, 2/3; twice the peak spectral radiance of cosmic microwave background radiation, 3/2; Planck's constant, 0; the Sun's galactic radius, -1/2; the Sun's galactic period, -2/3; Hubble's constant, -3/4; the dimension of the observable ray, 3/2; the base identity of the neutron, 1; the Bohr radius, 4/5; Rydberg's constant, 2/3; twice the peak spectral radiance of cosmic microwave background radiation, 3/2; Planck's constant, 0; the Sun’s galactic radius, -1/2; the Sun’s galactic period, -2/3; Hubble's constant, -3/4; the dimension of the observable universe, -4/5; and twice the gravitational binding energy of the electron in hydrogen, -1. When viewed in the physically equivalent frequency domain, the neutron partitions an abundance of physical constants from the very small to the very large.

1:03PM Y52.0010 Quantum memory and phase gate in Optical cavities based on EIT

D. W. CHAKERES, CELSO VILLAS-BÔAS, Federal University of São Carlos — In this work we investigate theoretically the implementation of an optical quantum memory in a system composed by a single atom, trapped in a high finesse optical cavity. In order to analyse the feasibility of implementing a quantum memory in the atom-cavity system based on the EIT phenomenon, we investigated in detail which parameter configuration the memory efficiency is optimized considering the two different setups. Our results shows that for a asymmetric one-sided cavity, which is the experimental setup commonly used to observe the EIT effect, the memory efficiency value saturates at about 8.5%. Meanwhile, for an one-sided cavity, we observe for a sufficiently high value of the coupling constant g, the efficiency has its maximum value increased considerably, close to 100%. However, this experimental setup is not suitable to observe cavity-EIT in the transmission spectrum, being necessary another kind of experiment, such as measurements phase difference field that leaves the cavity induced by the control field. Considering this configuration we also showed the implementation of a quantum phase gate based on the same nonlinear effect, where the pulse probe can experience a phase shift on the order of π, due to the presence or absence of a control pulse.

1:27PM Y52.0012 Application of axiomatic formal theory to the Abraham–Minkowski controversy

MICHAEL CRENSHAW, USArmy AMRDEC — Continuum electrodynamics is an axiomatic formal theory whose axioms are the macroscopic Maxwell equations. We demonstrate that valid theorems of the formal theory are inconsistent with conservation laws and with special relativity because continuum electrodynamics allows transformations of the Maxwell equations that constitute an improper tensor transformation that changes the conservation properties, the relativity properties, and the space-time embedding of the coupled equations of motion. The inconsistencies are resolved by a reformulation of physical principles in a flat non-Minkowski material spacetime in which the timelike coordinate corresponds to ct/n. Applying Lagrangian field theory, we derive equations of motion for the macroscopic electric and magnetic fields in a simple dielectric medium. We construct a new formal theory of continuum electrodynamics and we derive a tensor energy-momentum continuum theory that trivially resolves the century-old Abraham–Minkowski momentum controversy. We derive the theory of special relativity in a dielectric, including the material Lorentz factor and the material Lorentz transformation. We derive the momentum of a polariton in the context of material special relativity to confirm the resolution of the Abraham–Minkowski debate.

1:39PM Y52.0013 Particle beams carrying orbital angular momentum, charge, mass and spin

TEUNTEJ TJSUEN, H Wills Physics Laboratory, University of Bristol, ARMEN HAYRAPETYAN, JOERG GOETTE, Max Planck Institute for the Physics of Complex Systems, Dresden, MARK DENNIS, H Wills Physics Laboratory, University of Bristol — Electron beams carrying vortices and angular momentum have been of much experimental and theoretical interest in recent years. In addition, optical vortex beams are a well-established field in optics and photonics. In both cases, the orbital angular momentum associated with the beams axial vortex has effects on the overall spin of the beam, due to spin-orbit interactions. A simple model of these systems are Bessel beam solutions (of either the Dirac equation or Maxwell equations) with a nonzero azimuthal quantum number, which are found by separation in cylindrical coordinates. Here, we generalize this approach, considering the classical field theory of Bessel beams for particles which are either massive or massless, uncharged or charged and of a variety of different spins \((0, \frac{1}{2}, 1, \ldots)\). We regard the spin and helicity states and different forms of spin-orbit terms that arise. Moreover, we analyse the induced electromagnetic field when the particles carry charge. Most importantly, this unified field theory approach leads to the prediction of effects for vortex beams of neutrons, mesons and neutrinos.

1:51PM Y52.0014 Harmonic Fractions and an Integer Power Law to Demonstrate a Relationship of the Neutron to the Properties of Hydrogen and Cosmic Observables

D. W. CHAKERES, Department of Radiology, The Ohio State University, Columbus, OH, 43210, R. VENTO, Retired, Columbus State Community College, Columbus, OH, 43215, D. I. PANCHENKO, J. A. TOBAR, S. S. MOSES, V. M. ANDRIANARIJAONA, Department of Physics, Pacific Union College, Angwin, CA, 94508 — Power laws and harmonic oscillator systems represent a ubiquitous relationship among many physical phenomena. This study demonstrates a close power law relationship of the annihilation frequency of the neutron, approximately 2.27 \(10^{23}\) Hz, when used as a dimensionless base, to fundamental quantum properties of hydrogen and present-day cosmic observables. The following set of the three smallest integers: \([-1, 0, 1]\), and the set of partial harmonic fractions: \((3/2, 1/2, 2/3, -3/4, 4/5)\), are associated with each physical entity investigated as a frequency equivalent. They are listed as follows: twice the maximum energy of a cosmic ray, 3/2; the base identity of the neutron, 1; the Bohr radius, 4/5; Rydberg's constant, 2/3; twice the peak spectral radiance of cosmic microwave background radiation, 1/2; Planck's constant, 0; the Sun's galactic radius, -1/2; the Sun's galactic period, -2/3; Hubble's constant, -3/4; the dimension of the observable universe, -4/5; and twice the gravitational binding energy of the electron in hydrogen, -1. When viewed in the physically equivalent frequency domain, the neutron partitions an abundance of physical constants from the very small to the very large.
Branching ratio, transition frequency and lifetime measurements in $^{88}\text{Sr}^+$ with trapped ions

HELENA ZHANG, MICHAEL GUTIERREZ, GUANG HAO LOW, ISAAC CHUANG, Massachusetts Inst of Tech-MIT — Precise measurements of atomic properties, such as branching ratios and transition frequencies and lifetimes, are important in the study of astrophysical objects as well as verification of relativistic many-body theories. We report on a new measurement of the branching ratio of the $^5P_{1/2}$ and $^5P_{3/2}$ states in $^{88}\text{Sr}^+$ to $10^{-4}$ fractional uncertainty, a $10^3$ times improvement over current results, using ions confined in a Paul trap. Using a fiber frequency comb and pulsed spectroscopy, we measure the absolute frequencies of the $5S_{1/2} - 5P_{1/2}$ and $5S_{1/2} - 5P_{3/2}$ transitions to within 200 kHz, previously only known to tens of MHz. By fitting the fluorescence curve of the ion with optical Bloch equations, we obtain a new measurement for the lifetime of the $^5P_{1/2}$ and $^5P_{3/2}$ states without using a pulsed laser source.

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