

CHARGE PHASE DUALITY IN A FLUCTUATING ELECTROMAGNETIC ENVIRONMENT

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Circuits containing Josephson junctions are often understood in terms of a semi-classical, non-linear dynamics the Josephson phase. A reasonably complete understanding of the circuit electrodynamic has been achieved in many regimes, with good correspondence between theory and experiment – provided that the coupling to the dissipative electrodynamic of the junction environment is weak. This talk will report on our investigations of the strong coupling regime, where a semi-classical picture based on phase dynamics is not appropriate. Rather, we explain this strong coupling regime using a semi-classical charge dynamics which is exactly dual the phase dynamics.

PHASES OF DISORDERED FILMS NEAR A SUPERCONDUCTOR-
INSULATOR TRANSITION

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We investigate the possibility of a zero-temperature magnetic field-tuned superconductor-to-insulator transition in disordered thin films. This is an example of a quantum phase transition where an external parameter (i.e. the magnetic field) induces a transition from one quantum ground state to another, fundamentally different one. In our studies we were particularly interested in the possibility of a boson-dominated transition in which in the presence of a finite amount of quenched disorder, the ground state at low magnetic field is a vortex glass consisting of localized vortices and mobile Cooper pairs. As the magnetic field is raised, the phase fluctuations of the order parameter increase and ultimately drive the transition to a Bose-insulating phase, above a critical field H_c .

The different phases can be studied by measuring the resistivity and the Hall resistance as a function of temperature and magnetic field for a series of films of varying disorder. Isotherms of the resistivity cross at the temperature-independent transition, H_c , then peak at a higher field and decay slowly toward the normal state at the very highest fields. The peak in the resistivity appears to be activated and characterizes the strength of the insulating phase. We suggest that at the resistivity peak the film crosses over from a boson-dominated insulating phase at lower fields to a fermion-dominated insulating phase at higher fields, a result of an increased depairing rate, which suppresses the order-parameter amplitude and destroys the Bose-insulator. Despite the increased depairing rate, pairing susceptibility persists to the highest accessible fields, as the normal state does not appear to be fully recovered and a vestige of superconductivity remains. This interpretation is reinforced by measurements of the Hall resistance, which show zero resistance in the expected superconducting regime, finite resistance in the Bose-insulating regime, diverging resistance in the Fermi-insulating regime, followed by a peak at high fields that portends a return toward the normal state.

The phase transition itself can also be studied by carefully measuring the linear and dynamic resistance near the crossing point. As with all critical phenomena, the

ABSTRACTS

resistance is expected to scale with a reduced parameter and collapse onto a universal curve. The exponents describing the data collapse can thus be extracted, revealing insights into the universality class of the underlying transition.

**NON-EQUILIBRIUM DYNAMICS IN ULTRACOLD FERMIONIC AND
BOSONIC GASES**

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Ultracold atomic gases provide an excellent testing ground to study non-equilibrium dynamics. As the experimental parameters can be changed dynamically during the experiment the system's relaxation from non-equilibrium states can be observed. We report on experiments on the non-equilibrium dynamics of both fermionic and bosonic quantum gases. For fermionic atoms in a 3D optical lattice we investigate the behaviour of the system upon dynamic changes of the two-body scattering length using a Feshbach resonance. With bosonic atoms we experimentally study the formation of off-diagonal long-range order during Bose-Einstein condensation when a supercooled bosonic atom cloud evolves towards thermal equilibrium.

**TIME-DEPENDENT PHENOMENA IN ULTRACOLD ATOMS CONFINED
BY OPTICAL LATTICES**

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The good tunability of the system parameters in the experimental realization of ultracold atoms in optical lattices opens the possibility to investigate time dependent phenomena. We study the response of the ultracold atoms in the optical lattice to external time-dependent perturbations like the creation of a density perturbation or a periodic modulation of the lattice height. We calculate the time-evolution of the perturbed system using the adaptive time-dependent DMRG (density-matrix renormalization group) method.

**CURRENT-PHASE RELATION OF A SUPERCONDUCTING ATOMIC
POINT CONTACT**

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In a superconducting quantum point contact (QPC), Cooper pairs are thought to be transferred via a few channels that are characterized by a set of transmission coefficients. Indeed, the current-voltage characteristics and the current-phase relation of the single-channel QPC have been calculated as a function of the transmission coefficient. However, the experimental verification of the relation is yet to be done. We have made an experiment that allows to determine both the transmission coefficients and the current-phase relation: A device we made was a dc-SQUID composed of a superconducting atomic point contact and a tunnel junction, and the transmission coefficients and the current-phase relation of the point contact were determined by analyzing the I-V characteristics and the magnetic field dependence of the critical current, respectively. The current-phase relation became clearly non-sinusoidal when the transmission coefficients approached unity. In order for the quantitative explanation of the experimental results, we have to take into account the effect of the thermal fluctuation, and also have to assume a correction factor to the theory of the critical current. We also note that the SQUID behaves as a ratchet and the locking ratchet effect, i.e., the voltage rectification in the presence of ac current was really observed.

SUPERCONDUCTING FLUCTUATIONS IN JOSEPHSON JUNCTIONS

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At low temperatures, phase fluctuations give rise to fascinating behavior in small-scale superconducting links. The first example I will discuss is the idealized system of a Josephson point-contact connecting two infinite superconducting planes. Despite the quasi long-range order in the planes, the point-contact is resistive at all finite temperatures due to phase slips. This resistance is nearly activated with the energy barrier set by the stiffness in the planes. Following that I'll discuss the opposite limit of a thin long wire, partially normal and partially superconducting, that connects two finite leads. Phase fluctuations in the form of phase-slip dipoles decouple the normal and superconducting electronic fluids in the wire at low energies. This leads to the possibility of a Chakravarty-Schmid transition, tuned by the total resistance of the wire's normal-part.

**QUANTUM COHERENCE OF HARD-CORE-BOSONS AND FERMIONS:
EXTENDED, GLASSY AND MOTT PHASES**Ana Maria Rey^{1,2}, Indubala I. Satija^{2,3} and Charles W. Clark²¹ *ITAMP, Cambridge, MA, 02138, USA*² *NIST, Gaithersburg MD, 20899, USA and*³ *George Mason U., Fairfax, VA, 22030, USA*

Disorder has drastic effects in quantum systems of fermions and bosons. For non-interacting particles it leads to Anderson localization and to a metal-insulator transition. When interactions are present, the effects are even more drastic and the different phases induced by the interplay between disorder and interactions has been a topic of continuous theoretical interest. Cold atoms confined by a periodic lattice offer a unique laboratory to explore disordered systems in a controlled manner. In this talk I will discuss the use of Hanbury-Brown-Twiss interferometry (HBTI) to study various quantum phases of hard core bosons (HCBs) and ideal fermions confined in a one-dimensional lattice plus an additional quasi-periodic (QP) potential introduced to add pseudo-random disorder. I will show that in the localized phase, except for the sign of the peaks, both HCBs and ideal fermions exhibit identical interferometric patterns. We find that HBTI provides an effective method to distinguish Mott and glassy phases. On the other hand I will discuss the different behavior exhibited by HCBs and fermions in the extended phase. We find that the QP potential induces for HCBs a cascade of Mott-like band-insulator phases, in addition to the Mott insulator, Bose glass, and superfluid phases. At critical filling factors, the appearance of these insulating phases is heralded by a peak to dip transition in the interferogram, which reflects the fermionic aspect of HCBs. On the other hand, we find ideal fermions in the extended phase display various features characteristic of incommensurate structures such as devil's staircases and Arnold tongues.

COULOMB BLOCKADE AND COHERENT ELECTRON TRANSPORT IN
NANOWIRES UNDERGOING A SUPERCONDUCTOR-INSULATOR
TRANSITION

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To test the limits of superconductivity in one dimension we have fabricated a series of ultrathin homogeneous MoGe wires with diameters below ~ 10 nm using suspended carbon nanotube as templates. With decreasing diameter, nanowires display clear superconductor – insulator transition (SIT). In superconducting state, the nanowire resistance was found to follow the classical theory of thermally activated phase slips. In insulating state, zero-bias anomaly and temperature dependence of conductance are well described by the theory of weak Coulomb blockade of coherent single-electron transport. Within this interpretation a nanowire, which in our experiment is shorter than dephasing length, acts as a zero-dimensional coherent scatter. The capacitance extracted from theoretical fits quantitatively agrees with the capacitance between two electrodes connected to the opposite sides of the wire. Experiment suggests that the charge of the carriers changes from $1e$ for strongly insulating wires to $2e$ for weakly insulating wires that are close to the SIT.

INTERFERENCE AND COHERENCE IN 1-D BOSE-EINSTEIN-CONDENSATES

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Miniaturization and integration of atom-optical components on atom chips [1] allows to manipulate matter waves with high precision. Our exceptionally smooth atom chips potentials [2,3] allow the formation and manipulation of continuous 1 mm long condensates at strong transversal confinement in the order of ~ 10 kHz resulting in extreme aspect ratio up to >1000 .

In these smooth atom chip traps we employ RF induced adiabatic potentials [4] to split a 1d condensate along its long axis. Bringing the two split clouds together we can measure the interference between the two ensembles and study the coherence in the atom manipulation process [5]. In the talk we will present a detailed analysis of the RF induced potentials, the splitting process of the 1d condensate and study the coherence properties of the split 1d trapped cloud by interference.

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BADLY SUPERCONDUCTING WIRES

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We explore the properties of disordered superconducting wires approaching the one-dimensional limit. Our wires are made by evaporating indium-oxide on non-conducting inorganic nanotubes stretched across a gap. The deposited indium-oxide form a highly disordered amorphous superconductor. Under the application of a magnetic field the resistance of the wires exhibits reproducible periodic-oscillations, the like of which are usually associated with Superconducting Quantum Interference Devices (SQUIDs).

QUANTUM INTERFEROMETRY

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I'll talk about the possibility to interferometrically measure phase shifts with sensitivity bounded by the Heisenberg limit. The analysis is based on a Bayesian study of a BEC Mach-Zehnder interferometer. I'll focus on the dynamics of a non-linear beam splitter (the nonlinearity arising from the interatomic BEC interaction) and on some widely accepted old results which are not so acceptable, after all.

PROBING NUCLEAR SPINS IN DOUBLE QUANTUM DOTS

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When electrons are confined to small semiconductor quantum dots, they interact strongly via hyperfine interactions with lattice nuclear spins. We discuss how quantum control techniques, applied to the electronic degrees of freedom, allow for probing and manipulation of the nuclear spin degrees of freedom. Recent progress towards decoupling of electronic dynamics from nuclei as well as approaches for creating and probing non-equilibrium many-body states of nuclear spins will be presented.

DO NON-EQUILIBRIUM 1D BOSE GASES APPROACH EQUILIBRIUM?

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I will review the physics of 1D Bose gases, and describe recent experiments where trapped arrays of 1D Bose gases, each with hundreds of atoms, are excited to be far from equilibrium. Our observations extend from the intermediate to strong coupling limits. We observe negligible approach to equilibrium even after each atom has undergone thousands of collisions. When the gases are mutually coupled, so that the collisions have some 2D or 3D character, they readily equilibrate.

**ANDREEV REFLECTION AFFECTED BY DISORDER AND ELECTRON-
ELECTRON INTERACTIONS**

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We analyze the effect of electron-electron interactions on Andreev current and shot noise in diffusive hybrid structures composed of a normal metal attached to a superconductor via a weakly transmitting interface. We demonstrate that at voltages/temperatures below the Thouless energy of a normal metal Coulomb interaction yields a reduction of both Andreev current and its noise spectrum by a constant factor which essentially depends on the system dimensionality. For quasi-1d structures this factor scales with the number of conducting channels to the power $8/g$, where g defines a dimensionless conductance of a normal metal. At voltages above the Thouless energy the interaction correction to Andreev current and shot noise acquires an additional voltage dependence which turns out to be a power-law in the quasi-1d limit.