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as of 23-Mar-2023

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Final Report for Period Beginning 18-Oct-2013 and Ending 31-Aug-2020
Title: Fundamental Issues in Non-equilibrium Dynamics
Begin Performance Period: 18-Oct-2013
End Performance Period: 31-Aug-2020
Report Term: 0-Other
Submitted By: Cheng Chin
Email: cchin@uchicago.edu
Phone: (773) 702-7192
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STEM Degrees:

STEM Participants:

Major Goals: The Hulet group is exploring spin-charge separation in a one-dimensional (1D) interacting Fermi gas. Spin-charge separation is the prediction that the charge of an electron will exhibit a faster speed of sound than the spin part of the electron. This remarkable effect is one of the most distinct manifestations of strong correlated matter. Although qualitatively observed in condensed matter, quantitative confirmation of the Tomonaga-Luttinger Liquid (TLL) theory has not yet been achieved. Our goals are to measure the speed of sound of both the charge mode and the spin mode as a function of the strength of the repulsive interactions between spin-up and spin down fermions in order to test the TLL theory. We will use the Bragg spectroscopy method to measure the dynamic structure factor S(q, k) of both modes.

Ho group's major research goals are
(i) to study the dynamics of quantum gases in a variety of topological environments, including topological bands, quantum Hall systems, a variety of curved surfaces,
(ii) to study the dynamics of strongly stirred quantum gases,
(iii) to study cooling scheme for pushing out spin entropy.

Sachdev group aims to develop comprehensive theory of the transport properties of strange metals with connections to experimental observations. A variety of theoretical approaches are possible, including field theoretic, holographic, and SYK-type models. We will explore all methods with the aim of understanding the relationships between them.

Son group's goal of the research is to apply methods of quantum field theory to the few-body and many-body problems.

Ketterle group's major goal is to create new forms of matter and study their dynamics, including magnetic ordering and the dynamics of phase transitions between magnetically ordered phases.

Mueller Group has been pursuing six projects with interlocking goals. These include understanding the curious thermal properties of “Strange Metals”, discovering new paradigms for the evolution of order, and describing how dissipation works on a microscopic level.

Chin group investigated dynamics of Bose-Einstein condensates with modulated atomic interactions. Two main goals are 1. Understanding the complex correlations between jets emitted from the Bose condensates. 2. Modelling the atom number distribution in a jet based on the frame transformation from the inertial to accelerating frames. 3.

Developing a theoretical model to describe the jet formation dynamics.

Accomplishments: Sachdev group showed that a particular model of strange metal, built out of islands described by SYK models, and in the presence of mesoscopic disorder, could explain the remarkable linear-in-magnetic field magnetoresistance observed in the pnictides and the cuprates. We also developed a model of a strang metal using fractionalization, which model the onset of strange metal behavior at optimal doping in the cuprates.

Chin group observed a complex correlation patterns based on machine learning and pattern formation. The method allows us to identify as many as 8 correlated jets that form a turtle pattern. Goal 2: We developed a theoretical model to describe the thermal distribution of atom number in the emission which connects to the Hawking-Unruh radiation. This is a band new idea to simulate quantum effects in curved space time. 3. We collaborated with theorists to devise a code to simulate the dynamics of modulated Bose-Einstein condensates.

The Hulet group has succeeded in measuring the speed of the charge mode as a function of the strength of the repulsive interactions between two hyperfine sub-levels of the 6Li atom. The speed of sound of the charge mode agrees very well with TLL theory, and thus constitutes one half of our primary goal. For the charge mode, the Bragg pulse consists of two laser beams with frequency offset ◂. The frequency detuning from the 2P excited state must be large compared to the splitting between the two ground state hyperfine levels, so they respond equally to the Bragg probe. The spin-mode, on the other hand, is more difficult to measure because the Bragg beams must be detuned half way between the ground state hyperfine levels to be spin sensitive, and this near detuning with the excited state results in excessive spontaneous emission (heating).
We are currently developing an improved method, which utilizes the 2S-3P UV transition in lithium to reduce the rate of spontaneous emission. In addition, we have switched to using two ground-state hyperfine levels that are split by a greater frequency. We anticipate that these two modifications will reduce the spontaneous emission rate to an acceptable level.

Ketterle group demonstrated how to dress RF photons with adjustable recoil using periodic magnetic forces. This Floquet engineering of photons realizes a new scheme for spin-orbit coupling of atoms without near resonant light which causes heating by spontaneous light scattering. The group also demonstrated a new regime of superradiance with Bose-Einstein condensates when pumped by two laser beams. At low intensity, superradiance is suppressed, whereas at high intensity, it is enhanced, in agreement with theoretical predictions of an instability towards a supersolid phase.

Mueller Group: (1) We have discovered that a simple Boltzmann equation approach is capable of explaining the presence of strange metal behavior in fermions trapped by an optical lattice, indicating that in many cases the unusual thermal properties of these systems are simply a consequence of band structure and kinetic constrains on the allowed scattering processes. This result should be consequential. (2) We found that under many circumstances, Bose condensates develop new forms of order by first evaporating, then recondensing in the new configuration. This novel pathway may be relevant in other settings, such as the ordering of the early universe. (3) We came up with a novel way to model drag forces in Bose-Fermi mixtures, which accounts for experimental features which could not previously be explained.

Son group has considered the most general effective field theory for one-dimensional particle with contact interaction. We have shown that the physical scattering amplitude depends only on three parameters, which matches with the result a quantum mechanical treatment. With collaborators in Heidelberg, I have constructed the effective field theory of a vortex lattice, making use of the idea of particle-vortex duality. Finally, we continue to work on the problem of the theory of the half-filled Landau level

Ho group's results for Goal (i): In response to the recent experiments at NIST for constructing Yang monopole (in a five dimensional parameter space) in a Bose gas in a trap, our group has worked out general methods to construct Yang monopoles in lattice models and measure the so-called second Chern number. We have also showed that interaction effects can stretch the point monopole into an extended singular manifold. In addition, I have shown that how to create bosonic quantum Hall state from non-equilibrium processes of fermionic ones. Recently, we have studied the properties of quantum gases in curved surfaces, including BEC in cylindrical surfaces, potential scattering on a sphere, and the inflation of quantum gases in a rapidly expanding curved manifold.
Results for Goal (ii), in response to the recent experiment in Cambridge University which finds a power law behavior in momentum distribution of a strongly shaken BEC, I have studies the strong shaking of an ideal gases and have demonstrated how a power law emerge in this system.
Results for Goal (iii): We have come up with a way to squeeze out spin entropy in a Mott insulator, which will help

lowering the temperature of a doped antiferromagnetic phase to reach the superfluid phase.

Training Opportunities: Ho group: My group has three Ph.D students (Mr. Cheng Li, Miss Jiaxin Wu, and Mr. Waylon Chen) and one postdoc (Dr. Desmond Yin). They are partial supported by this MURI grant.

Mueller Group: Three undergraduate students and three graduate students have been receiving comprehensive personalized training in the craft of conducting theoretical research. This includes research design, numerical and analytical techniques, evaluating the significance of results, and both oral and written presentation.

Chin group: One Ph.D. student (Dr. Lei Feng) graduated with a Ph.D. degree and took the postdoc position at the University of Maryland. One postdoc (Dr. Jiazhong Hu) took a faculty position at Tsinghua University in China.

Hulet group: There are two graduate students, and a post-doc, Ruwan Senaratne, working on this experiment. One of the graduate students, Ya-Ting Yang is female, while the other, Danyel Cavazos, is Hispanic. This project is technologically and scientifically advanced, and thus provides a rich array of training opportunities.

Ketterle group: Our experiments provide excellent training opportunities for students qualifying them for a career in science and technology. One Ph.D. student (Jun-Ru Li) graduated and will become a postdoc at JILA, Boulder.

Son group: One Ph.D. student (Dr. Dung Xuan Nguyen) graduated and took the postdoc position at Oxford University.

Sachdev group: Wenbo Fu and Alex Thomson graduated with Ph. D. degrees, moving on to postdoctoral positions at UCSD and Caltech respectively.

Results Dissemination: Results of the MURI program are broadly disseminated in workshops, conferences, meetings, seminar/colloquium talks. Manuscripts are published in scientific journal, accessible on eprint arXive and presented in international and domestic conferences, meetings, workshops, as well as seminar/colloquium talks.

Honors and Awards: Dam Son received the Dirac Medal of the ICTP
Subir Sachdev received the Dirac Medal of the ICTP and the Lars Onsager Prize (APS)

Protocol Activity Status:

Technology Transfer: Nothing to Report

PARTICIPANTS:

Participant Type: PD/PI
Participant: Cheng Chin
Person Months Worked: 1.00 **Funding Support:**
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Participant Type: Co PD/PI
Participant: Subir Sachdev
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Participant Type: Co PD/PI
Participant: Wolfgang Ketterle
Person Months Worked: 1.00 **Funding Support:**
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Participant Type: Co PD/PI
Participant: Erich Mueller
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Participant: Tin-Lun Ho
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Participant: Randall Hulet
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Volume: 1.0E+001 Issue: 1.2E+001 First Page #: 0
Date Submitted: Date Published:
Publication Location:
Article Title: Collisions of matter-wave solitons
Authors:
Keywords: Bose condensates, integrability
Abstract: Solitons are localized wave disturbances that propagate without changing shape, a result of a nonlinear interaction that compensates for wave packet dispersion. Individual solitons may collide, but a defining feature is that they pass through one another and emerge from the collision unaltered in shape, amplitude, or velocity, but with a new trajectory reflecting a discontinuous jump. This remarkable property is mathematically a consequence of the underlying integrability of the one-dimensional (1D) equations, such as the nonlinear Schrödinger equation, that describe solitons in a variety of wave contexts, including matter waves1,2. Here we explore the nature of soliton collisions using Bose–Einstein condensates of atoms with attractive interactions confined to a quasi-1D waveguide. Using real-time imaging, we show that a collision between solitons is a complex event that differs markedly depending on the relative phase between the solitons. By controlling the strength of the nonlinea
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Publication Identifier Type: DOI Publication Identifier: 10.1038/nature14223
Volume: 5.19E+002 Issue: 7.542E+00First Page #: 0
Date Submitted: Date Published:
Publication Location:
Article Title: Observation of antiferromagnetic correlations in the Hubbard model with ultracold atoms
Authors:
Keywords: Fermions, optical lattice, quantum magnetism
Abstract: Ultracold atoms in optical lattices have great potential to contribute to a better understanding of some of the most important issues in many-body physics, such as high-temperature superconductivity1. The Hubbard model—a simplified representation of fermions moving on a periodic lattice—is thought to describe the essential details of copper oxide superconductivity2. This model describes many of the features shared by the copper oxides, including an interaction driven Mott insulating state and an antiferromagnetic (AFM) state. Optical lattices filled with a two-spin-component Fermi gas of ultracold atoms can faithfully realize the Hubbard model with readily tunable parameters, and thus provide a platform for the systematic exploration of its phase diagram3,4. Realization of strongly correlated phases, however, has been hindered by the need to cool the atoms to temperatures as low as the magnetic exchange energy, and also by the lack of reliable thermometry5. Here we demonstrate spin-sen
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Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevLett.114.070403
Volume: 1.14E+002 Issue: 7.0E+000 First Page #: 0
Date Submitted: Date Published:
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Article Title: Compressibility of a Fermionic Mott Insulator of Ultracold Atoms
Authors:
Keywords: Mott insulator, fermions, optical lattice
Abstract: We characterize the Mott insulating regime of a repulsively interacting Fermi gas of ultracold atoms in a three-dimensional optical lattice. We use in situ imaging to extract the central density of the gas and to determine its local compressibility. For intermediate to strong interactions, we observe the emergence of a plateau in the density as a function of atom number, and a reduction of the compressibility at a density of one atom per site, indicating the formation of a Mott insulator. Comparisons to state-of-the-art numerical simulations of the Hubbard model over a wide range of interactions reveal that the temperature of the gas is of the order of, or below, the tunneling energy scale. Our results hold great promise for the exploration of many-body phenomena with ultracold atoms, where the local compressibility can be a useful tool to detect signatures of different phases or phase boundaries at specific values of the filling.
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Journal: Physical Review A
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevA.91.043601
Volume: 9.1E+001 Issue: 4.0E+000 First Page #: 0
Date Submitted: Date Published:
Publication Location:
Article Title: Local spin structure of large spin fermions
Authors:
Keywords: Fermi gas, spin
Abstract: We show that large spin fermions have very rich spin structures. The local spin order of a spin-f Fermi gas is a linear combination of 2 f (particle-hole) angular momentum states, L = 1, .., 2 f . L = 1, 2 represent ferromagnetic and nematic spin order, while L ? 3 are higher spin orders that have no analog in spin-1/2 systems. Each L spin sector is characterized as L pairs of antipodal points on a sphere. Model calculations show that some of these spin-orders have the symmetry of Platonic solid, and many of them have non-abelian line defects.
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Publication Identifier Type: DOI Publication Identifier: 10.1038/nphys3421
Volume: 0 Issue: 0 First Page #: 0
Date Submitted: Date Published:
Publication Location:
Article Title: Observation of Bose–Einstein condensation in a strong synthetic magnetic field
Authors:
Keywords: Adiabatic cooling, magnetic order, optical lattices
Abstract: Extensions of Berry's phase and the quantum Hall e?ect have led to the discovery of new states of matter with topological properties. Traditionally, this has been achieved using gauge ?elds created by magnetic ?elds or spin orbit interactions which couple only to charged particles. For neutral ultracold atoms, synthetic magnetic ?elds have been created which are strong enough to realize the Harper-Hofstadter model. Despite many proposals and major experimental e?orts, so far it has not been possible to prepare the ground state of this system. Here we report the observation of BoseEinstein condensation for the Harper-Hofstadter Hamiltonian with one-half ?ux quantum per latticeunit cell. The di?raction pattern of the super?uid state directly shows the momentum distributionon the wavefuction, which is gauge-dependent. It reveals both the reduced symmetry of the vectorpotential and the twofold degeneracy of the ground state. We explore an adiabatic many-body statepreparation protocol via t
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Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevA.92.013609
Volume: 9.2E+001 Issue: 1.0E+000 First Page #: 0
Date Submitted: Date Published:
Publication Location:
Article Title: Anomalous charge pumping in a one-dimensional optical superlattice
Authors:
Keywords: Adiabatic Transport, Chern Numbers, Topology, Optical Lattices
Abstract: We model atomic motion in a sliding superlattice potential to explore “topological charge pumping” and to find optimal parameters for experimental observation of this phenomenon. We analytically study the band structure, finding how the Wannier states evolve as two sinusoidal lattices are moved relative to one another, and relate this evolution to the center-of-mass motion of an atomic cloud. We pay particular attention to counterintuitive or anomalous regimes, such as when the atomic motion is opposite to that of the lattice. We propose a practical cold-atom experiment to detect this anomalous behavior. Through numerical simulations, we find that a negative adiabatic current and a nontrivial Chern number ?1 are readily measured.
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Publication Location:
Article Title: Collisionless spin dynamics in a magnetic field gradient
Authors:
Keywords: Kinetics, Magnetism, Spin Diffusion, Fermions
Abstract: We study the collisionless spin dynamics of a harmonically trapped Fermi gas in a magnetic field gradient. In the absence of interactions, the system evolution is periodic: the magnetization develops twists, which evolve into a longitudinal polarization. Recurrences follow. For weak interaction, the exchange interactions lead to beats in these oscillations. We present an array of analytic and numerical techniques for studying this physics.
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Publication Location:
Article Title: Quasiparticle dispersions and lifetimes in the normal state of the BCS-BEC crossover
Authors:
Keywords: BCS-BEC Crossover, Pseudogap
Abstract: We compute the spectral density in the normal phase of an interacting homogenous Fermi gas using a T-matrix approximation. We fit the quasiparticle peaks of the spectral density to BCS-like dispersion relations and extract estimates of a “pseudogap” energy scale and an effective Fermi wave vector as a function of interaction strength. We find that the effective Fermi wave vector of the quasiparticles vanishes when the inverse scattering length exceeds some positive threshold. We also find that, near unitarity, the quasiparticle lifetimes, estimated from the widths of the peaks in the spectral density, approach values on the order of the inverse Fermi energy. These results are consistent with the “breakdown of Fermi-liquid theory” observed in recent experiments.
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Article Title: Transverse collisional instabilities of a Bose-Einstein condensate in a driven one-dimensional lattice
Authors:
Keywords: Floquet, Driven System, Quasi-1D, Kinetics, Bose Condensate
Abstract: Motivated by recent experiments, we analyse the stability of a three-dimensional Bose-Einstein condensate (BEC) loaded in a periodically driven one-dimensional optical lattice. Such periodically driven systems do not have a thermodynamic ground state, but may have a long-lived steady state which is an eigenstate of a "Floquet Hamiltonian". We explore collisional instabilities of the Floquet ground state which transfer energy into the transverse modes. We calculate decay rates, finding that the lifetime scales as the inverse square of the scattering length and inverse of the peak three- dimensional density. These rates can be controlled by adding additional transverse potentials.
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Publication Location:
Article Title: Kinetics of Bose-Einstein condensation in a dimple potential
Authors:
Keywords: Kinetics, Trap Loading, Dimple Potential, Bose Condensate
Abstract: We model the dynamics of condensation in a bimodal trap, consisting of a large reservoir region, and a tight “dimple” whose depth can be controlled. Experimental investigations have found that such dimple traps provide an efficient means of achieving condensation. In our kinetic equations, we include two- and three-body processes. The two-body processes populate the dimple, and lead to loss when one of the colliding atoms is ejected from the trap. The three-body processes produce heating and loss. We explain the principal trends, give a detailed description of the dynamics, and provide quantitative predictions for time scales and condensate yields. From these simulations, we extract optimal parameters for future experiments.
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Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevA.90.023611
Volume: 9.0E+001 Issue: 2.0E+000 First Page #: 0
Date Submitted: Date Published:
Publication Location:
Article Title: Heating from continuous number density measurements in optical lattices
Authors:
Keywords: Measurement, Heating, Correlations, Optical Lattices
Abstract: We explore the effects of continuous number density measurement on atoms in an optical lattice. By integrating a master equation for quantum observables, we calculate how single-particle correlations decay. We consider weakly and strongly interacting bosons and noninteracting fermions. Even in the Mott regime, such measurements destroy correlations and increase the average energy, as long as some hopping is allowed. We explore the role of spatial resolution and find that the heating rate is proportional to the amount of information gained from such measurements.
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Date Submitted: Date Published:
Publication Location:
Article Title: Nondestructive imaging of an ultracold lattice gas
Authors:
Keywords: Nondestructive imaging, optical lattices
Abstract: We demonstrate the nondestructive imaging of a lattice gas of ultracold bosons. Atomic fluorescence is induced in the simultaneous presence of degenerate Raman sideband cooling. The combined influence of these processes controllably cycles an atom between a dark state and a fluorescing state while eliminating heating and loss. Through spatially resolved sideband spectroscopy following the imaging sequence, we demonstrate the efficacy of this imaging technique in various regimes of lattice depth and fluorescence acquisition rate. Our work provides an important extension of quantum gas imaging to the nondestructive detection, control, and manipulation of atoms in optical lattices. In addition, our technique can also be extended to atomic species that are less amenable to molasses-based lattice imaging.
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Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevLett.115.017202
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Date Submitted: Date Published:
Publication Location:
Article Title: Thermomechanical Two-Mode Squeezing in an Ultrahigh-
Authors:
Keywords: Parametric amplification, Noise squeezing
Abstract: We realize a nondegenerate parametric amplifier in an ultrahigh Q mechanical membrane resonator and demonstrate two-mode thermomechanical noise squeezing. Our measurements are accurately described by a two-mode model that attributes this nonlinear mechanical interaction to a substrate-mediated process which is dramatically enhanced by the quality factors of the individual modes. This realization of strong multimode nonlinearities in a mechanical platform compatible with quantum-limited optical detection and cooling makes this a powerful system for nonlinear approaches to quantum metrology, transduction between optical and phononic fields and the quantum manipulation of phononic degrees of freedom.
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Article Title: dc resistivity at the onset of spin density wave order in two-dimensional metals
Authors:
Keywords: spin-density wave, quantum criticality, strange metal
Abstract: The theory for the onset of spin density wave order in a metal in two dimensions flows to strong coupling, with strong interactions not only at the `hot spots', but on the entire Fermi surface. We advocate the computation of DC transport in a regime where there is rapid relaxation to local equilibrium around the Fermi surface by processes which conserve total momentum. The DC resistivity is then controlled by weaker perturbations which do not conserve momentum. We consider variations in the local position of the quantum critical point, induced by long-wavelength disorder, and find a contribution to the resistivity which is linear in temperature (up to logarithmic corrections) at low temperature. Scattering of fermions between hot spots, by short-wavelength disorder, leads to a residual resistivity and a correction which is linear in temperature.
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Article Title: Wess-Zumino-Witten Terms in Graphene Landau Levels
Authors:
Keywords: graphene antiferromagnetism
Abstract: We consider the interplay between the antiferromagnetic and Kekule valence bond solid orderings in the zero energy Landau levels of neutral monolayer and bilayer graphene. We establish the presence of Wess-Zumino-Witten terms between these orders: this implies that their quantum fluctuations are described by the deconfined critical theories of quantum spin systems. We present implications for experiments, including the possible presence of excitonic superfluidity in bilayer graphene.
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Article Title: Conformal field theories at nonzero temperature: Operator product expansions, Monte Carlo, and holography
Authors:
Keywords: holography, quantum Monte Carlo, quantum criticaliy
Abstract: We compute the non-zero temperature conductivity of conserved flavor currents in conformal field theories (CFTs) in 2+1 spacetime dimensions. At frequencies much greater than the temperature, $\hbar \omega \gg k_B T$, the ω dependence can be computed from the operator product expansion (OPE) between the currents and operators which acquire a non-zero expectation value at $T>0$. Such results are found to be in excellent agreement with quantum Monte Carlo studies of the O(2) Wilson-Fisher CFT. Results for the conductivity and other observables are also obtained in vector $1/N$ expansions. We match these large ω results to the corresponding correlators of holographic representations of the CFT: the holographic approach then allows us to extrapolate to small $\hbar \omega/(k_B T)$. Other holographic studies implicitly only used the OPE between the currents and the energy-momentum tensor, and this yields the correct leading large ω behavior for a large class of CFTs. H
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Publication Identifier Type: DOI Publication Identifier: 10.1007/JHEP06(2015)044
Volume: 2.015E+003 Issue: 6.0E+000 First Page #: 0
Date Submitted: Date Published:
Publication Location:
Article Title: Hydrodynamics on the lowest Landau level
Authors:
Keywords: hydrodynamics, lowest Landau level
Abstract: Using the recently developed approach to quantum Hall physics based on Newton-Cartan geometry, we consider the hydrodynamics of an interacting system on the lowest Landau level. We rephrase the non-relativistic fluid equations of motion in a manner that manifests the spacetime diffeomorphism invariance of the underlying theory. In the massless (or lowest Landau level) limit, the fluid obeys a force-free constraint which fixes the charge current. An entropy current analysis further constrains the energy response, determining four transverse response functions in terms of only two: an energy magnetization and a thermal Hall conductivity. Kubo formulas are presented for all transport coefficients and constraints from Weyl invariance derived. We also present a number of Streda-type formulas for the equilibrium response to external electric, magnetic and gravitational fields.
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Journal: Physical Review Letters
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevLett.114.055301
Volume: 1.14E+002 Issue: 5.0E+000 First Page #: 0
Date Submitted: Date Published:
Publication Location:
Article Title: Roton-Maxon Excitation Spectrum of Bose Condensates in a Shaken Optical Lattice
Authors:
Keywords: Roton, Bose condensate, optical lattice
Abstract: We present experimental evidence showing that an interacting Bose condensate in a shaken optical lattice develops a roton-maxon excitation spectrum, a feature normally associated with superfluid helium. The roton-maxon feature originates from the double-well dispersion in the shaken lattice, and can be controlled by both the atomic interaction and the lattice modulation amplitude. We determine the excitation spectrum using Bragg spectroscopy and measure the critical velocity by dragging a weak speckle potential through the condensate—both techniques are based on a digital micromirror device. Our dispersion measurements are in good agreement with a modified Bogoliubov model.
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Journal: Science
Publication Identifier Type: DOI Publication Identifier: 10.1126/science.aaf9657
Volume: 354 Issue: 6312 First Page #: 606
Date Submitted: 7/14/17 12:00AM Date Published: 11/1/16 10:00AM
Publication Location:
Article Title: Universal space-time scaling symmetry in the dynamics of bosons across a quantum phase transition
Authors: L. W. Clark, L. Feng, C. Chin
Keywords: quantum phase transition, quantum critical dynamics, inflation
Abstract: The dynamics of many-body systems spanning condensed matter, cosmology, and beyond are hypothesized to be universal when the systems cross continuous phase transitions. The universal dynamics are expected to satisfy a scaling symmetry of space and time with the crossing rate, inspired by the Kibble-Zurek mechanism. We test this symmetry based on Bose condensates in a shaken optical lattice. Shaking the lattice drives condensates across an effectively ferromagnetic quantum phase transition. After crossing the critical point, the condensates manifest delayed growth of spin fluctuations and develop antiferromagnetic spatial correlations resulting from the sub-Poisson distribution of the spacing between topological defects. The fluctuations and correlations are invariant in scaled space-time coordinates, in support of the scaling symmetry of quantum critical dynamics.
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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Physical Review A
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevA.94.063646
Volume: 94 Issue: 6 First Page #:
Date Submitted: 7/14/17 12:00AM Date Published: 12/1/16 6:00AM
Publication Location:
Article Title: Exotic domain walls in Bose-Einstein condensates with double-well dispersion
Authors: Tongtong Liu, Logan W. Clark, Cheng Chin
Keywords: Bose-Einstein condensates, optical lattices, Topological defects
Abstract: We study the domain walls which form when Bose condensates acquire a double-well dispersion. Experiments have observed such domain walls in condensates driven across a Z2 symmetry-breaking phase transition in a shaken optical lattice. We derive a generic model to describe the dispersion and to compute the wave functions and energies of the domain walls. We find two distinct regimes which demand different physical pictures. In the weak-coupling regime, where interactions are weak compared to the kinetic-energy barrier, “density-wave domain walls” form that support an extended density wave and a series of phase steps. These features can be understood as the quantum interference between domains with distinct momenta. In the strong-coupling regime where interaction dominates, the system forms “phase domain walls” which have the minimum width allowed by the uncertainty principle and suppressed density modulation.
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Journal: Physical Review Letters
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevLett.118.220401
Volume: 118 Issue: 22 First Page #:
Date Submitted: 7/14/17 12:00AM Date Published: 5/1/17 5:00AM
Publication Location:
Article Title: Direct Lattice Shaking of Bose Condensates: Finite Momentum Superfluids
Authors: Brandon M. Anderson, Logan W. Clark, Jennifer Crawford, Andreas Glatz, Igor S. Aranson, Peter Scher
Keywords: Bose-Einstein condensates, optical lattices, Topological defects
Abstract: We address band engineering in the presence of periodic driving by numerically shaking a lattice containing a bosonic condensate. By not restricting to simplified band structure models we are able to address arbitrary values of the shaking frequency, amplitude, and interaction strengths g. For “near-resonant” shaking frequencies with moderate g, a quantum phase transition to a finite momentum superfluid is obtained with Kibble-Zurek scaling and quantitative agreement with experiment. We use this successful calibration as a platform to support a more general investigation of the interplay between (one particle) Floquet theory and the effects associated with arbitrary g. Band crossings lead to superfluid destabilization, but where this occurs depends on g in a complicated fashion.
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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 5-Submitted
Journal: arXive
Publication Identifier Type: Publication Identifier:
Volume: Issue: First Page #:
Date Submitted: 7/14/17 12:00AM Date Published:
Publication Location:
Article Title: Coherent inflationary dynamics for Bose-Einstein condensates crossing a quantum critical point
Authors: Lei Feng, Logan W. Clark, Anita Gaj, Cheng Chin
Keywords: Bose-Einstein condensates, optical lattices, Topological defects
Abstract: Quantum phase transitions, transitions between many-body ground states, are of extensive interest in research ranging from condensed matter physics to cosmology. Key features of the phase transitions include a stage with rapidly growing new order, called inflation in cosmology, followed by the formation of topological defects. How inflation is initiated and evolves into topological defects remains a hot debate topic. Ultracold atomic gas offers a pristine and tunable platform to investigate quantum critical dynamics. We report the observation of coherent inflationary dynamics across a quantum critical point in driven Bose-Einstein condensates. The inflation manifests in the exponential growth of density waves and populations in well-resolved momentum states. After the inflation stage, extended coherent dynamics is evident in both real and momentum space. We present an intuitive description of the quantum critical dynamics in our system and demonstrate the essential role of phase fluctu
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Journal: Physical Review A
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevA.95.053637
Volume: 95 Issue: 5 First Page #: 53637
Date Submitted: 8/1/17 12:00AM Date Published: 5/1/17 5:00AM
Publication Location:
Article Title: Core filling and snaking instability of dark solitons in spin-imbalanced superfluid Fermi gases
Authors: Matthew D. Reichl, Erich J. Mueller
Keywords: Solitons, Snake Instability, Superfluidity
Abstract: We use the time-dependent Bogoliubov–de Gennes equations to study dark solitons in three-dimensional spin-imbalanced superfluid Fermi gases. We explore how the shape and dynamics of dark solitons are altered by the presence of excess unpaired spins which fill their low-density core. The unpaired particles broaden the solitons and suppress the transverse snake instability. We discuss ways of observing these phenomena in cold-atom experiments.
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Journal: Physical Review Letters
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevLett.118.260402
Volume: 118 Issue: 26 First Page #: 260402
Date Submitted: 8/1/17 12:00AM Date Published: 6/1/17 5:00AM
Publication Location:
Article Title: Collective Modes of a Soliton Train in a Fermi Superfluid
Authors: Shovan Dutta, Erich J. Mueller
Keywords: Solitons, Collective Modes, FFLO
Abstract: We characterize the collective modes of a soliton train in a quasi-one-dimensional Fermi superfluid, using a mean-field formalism. In addition to the expected Goldstone and Higgs modes, we find novel long-lived gapped modes associated with oscillations of the soliton cores. The soliton train has an instability that depends strongly on the interaction strength and the spacing of solitons. It can be stabilized by filling each soliton with an unpaired fermion, thus forming a commensurate Fulde-Ferrell-Larkin-Ovchinnikov (FFLO) phase. We find that such a state is always dynamically stable, which paves the way for realizing long-lived FFLO states in experiments via phase imprinting.
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Journal: Physical Review A
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevA.94.053604
Volume: 94 Issue: 5 First Page #: 53604
Date Submitted: 8/1/17 12:00AM Date Published: 11/1/16 5:00AM
Publication Location:
Article Title: Nonequilibrium fractional Hall response after a topological quench
Authors: F. Nur Ünal, Erich J. Mueller, M. Ö. Oktel
Keywords: Quench, Hall Effect, Nonequilibrium
Abstract: We theoretically study the Hall response of a lattice system following a quench where the topology of a filled band is suddenly changed. In the limit where the physics is dominated by a single Dirac cone, we find that the change in the Hall conductivity is two-thirds of the quantum of conductivity. We explore this universal behavior in the Haldane model, and discuss cold-atom experiments for its observation. Beyond linear response, the Hall effect crosses over from fractional to integer values. We investigate finite-size effects, and the role of the harmonic confinement.
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Journal: Physical Review Letters
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevLett.117.235301
Volume: 117 Issue: 23 First Page #: 235301
Date Submitted: 8/1/17 12:00AM Date Published: 11/1/16 5:00AM
Publication Location:
Article Title: 1D to 3D Crossover of a Spin-Imbalanced Fermi Gas
Authors: Melissa C. Revelle, Jacob A. Fry, Ben A. Olsen, Randall G. Hulet
Keywords: superconductivity, Fermi pairing
Abstract: "We have characterized the one-dimensional (1D) to three-dimensional (3D) crossover of a two-component spin-imbalanced Fermi gas of 6Li atoms in a 2D optical lattice by varying the lattice tunneling and the interactions. The gas phase separates, and we detect the phase boundaries using in situ imaging of the inhomogeneous density profiles. The locations of the phases are inverted in 1D as compared to 3D, thus providing a clear signature of the crossover. By scaling the tunneling rate t with respect to the pair binding energy ?B, we observe a collapse of the data to a universal crossover point at a scaled tunneling value of tc = 0.025(7)."
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Journal: Science
Publication Identifier Type: DOI Publication Identifier: 10.1126/science.aal3220
Volume: 356 Issue: 6336 First Page #: 422
Date Submitted: 8/1/17 12:00AM Date Published: 4/1/17 5:00AM
Publication Location:
Article Title: Formation of matter-wave soliton trains by modulational instability
Authors: Jason H. V. Nguyen, De Luo, Randall G. Hulet
Keywords: Bose-Einstein condensates, solitons, quench
Abstract: "Nonlinear systems can exhibit a rich set of dynamics that are inherently sensitive to their initial conditions.One such example ismodulational instability, which is believed to be one of the most prevalent instabilities in nature. By exploiting a shallow zero-crossing of a Feshbach resonance,we characterize modulational instability and its role in the formation ofmatter-wave soliton trains from a Bose-Einstein condensate. We examine the universal scaling laws exhibited by the system and, through real-time imaging, address a long-standing question of whether the solitons in trains are created with effectively repulsive nearest-neighbor interactions or rather evolve into such a structure."
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Publication Identifier Type: DOI Publication Identifier: 10.1073/pnas.1608881113
Volume: 113 Issue: 34 First Page #: 9463
Date Submitted: 8/1/17 12:00AM Date Published: 8/1/16 5:00AM
Publication Location:
Article Title: Hydrodynamic theory of thermoelectric transport and negative magnetoresistance in Weyl semimetals
Authors: Andrew Lucas, Richard A. Davison, Subir Sachdev
Keywords: Weyl metals, gravitational anomalies, hydrodynamics
Abstract: We present a theory of thermoelectric transport in weakly disordered Weyl semimetals where the electron-electron scattering time is faster than the electron-impurity scattering time. Our hydrodynamic theory consists of relativistic fluids at each Weyl node, coupled together by perturbatively small inter-valley scattering, and long-range Coulomb interactions. The conductivity matrix of our theory is Onsager reciprocal and positive-semidefinite. In addition to the usual axial anomaly, we account for the effects of a distinct, axial-gravitational anomaly expected to be present in Weyl semimetals. Negative thermal magnetoresistance is a sharp, experimentally accessible signature of this axial-gravitational anomaly, even beyond the hydrodynamic limit.
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Journal: Physical Review B
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevB.95.075127
Volume: 95 Issue: 7 First Page #: 75127
Date Submitted: 8/1/17 12:00AM Date Published: 2/1/17 6:00AM
Publication Location:
Article Title: Shear viscosity at the Ising-nematic quantum critical point in two-dimensional metals
Authors: Andreas Eberlein, Aavishkar A. Patel, Subir Sachdev
Keywords: Strange metals, shear viscosity
Abstract: In an isotropic strongly interacting quantum liquid without quasiparticles, general scaling arguments imply that the dimensionless ratio (kB/?)?/s, where ? is the shear viscosity and s is the entropy density, is a universal number. We compute the shear viscosity of the Ising-nematic critical point of metals in spatial dimension d=2 by an expansion below d=5/2. The anisotropy associated with directions parallel and normal to the Fermi surface leads to a violation of the scaling expectations: ? scales in the same manner as a chiral conductivity, and the ratio ?/s diverges at low temperature (T) as T^(?2/z), where z is the dynamic critical exponent for fermionic excitations dispersing normal to the Fermi surface.
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Journal: Physical Review Letters
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevLett.118.036601
Volume: 118 Issue: 3 First Page #: 36601
Date Submitted: 8/1/17 12:00AM Date Published: 1/1/17 6:00AM
Publication Location:
Article Title: Holography of the Dirac Fluid in Graphene with Two Currents
Authors: Yunseok Seo, Geunho Song, Philip Kim, Subir Sachdev, Sang-Jin Sin
Keywords: graphene, thermal conductivity, holography
Abstract: Recent experiments have uncovered evidence of the strongly coupled nature of the graphene: the Wiedemann-Franz law is violated by up to a factor of 20 near the charge neutral point. We describe this strongly-coupled plasma by a holographic model in which there are two distinct conserved U(1) currents. We find that our analytic results for the transport coefficients for two current model have a significantly improved match to the density dependence of the experimental data than the models with only one current. The additive structure in the transports coefficients plays an important role. We also suggest the origin of the two currents.
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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Physical Review D
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevD.95.026009
Volume: 95 Issue: 2 First Page #: 26009
Date Submitted: 8/1/17 12:00AM Date Published: 1/1/17 6:00AM
Publication Location:
Article Title: Supersymmetric Sachdev-Ye-Kitaev models
Authors: Wenbo Fu, Davide Gaiotto, Juan Maldacena, Subir Sachdev
Keywords: supersymmetry, strange metals, holography
Abstract: We discuss a supersymmetric generalization of the Sachdev-Ye-Kitaev model. These are quantum mechanical models involving N Majorana fermions. The supercharge is given by a polynomial expression in terms of the Majorana fermions with random coefficients. The Hamiltonian is the square of the supercharge. The N=1 model with a single supercharge has unbroken supersymmetry at large N, but non-perturbatively spontaneously broken supersymmetry in the exact theory. We analyze the model by looking at the large N equation, and also by performing numerical computations for small values of N. We also compute the large N spectrum of "singlet" operators, where we find a structure qualitatively similar to the ordinary SYK model. We also discuss a N=2 version. In this case, the model preserves supersymmetry in the exact theory and we can compute a suitably weighted Witten index to count the number of ground states, which agrees with the large N computation of the entropy. In both cases, we discuss the
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Volume: 114 Issue: 8 First Page #: 1844
Date Submitted: 8/1/17 12:00AM Date Published: 2/1/17 6:00AM
Publication Location:
Article Title: Quantum chaos on a critical Fermi surface
Authors: Aavishkar A. Patel, Subir Sachdev
Keywords: Bose-Einstein condensates, matterwave, stimulated emission
Abstract: We compute parameters characterizing many-body quantum chaos for a critical Fermi surface without quasiparticle excitations. We examine a theory of N species of fermions at non-zero density coupled to a U(1) gauge field in two spatial dimensions, and determine the Lyapunov rate and the butterfly velocity in an extended random-phase approximation. The thermal diffusivity is found to be universally related to these chaos parameters i.e. the relationship is independent of N, the gauge coupling constant, the Fermi velocity, the Fermi surface curvature, and high energy details.
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Date Submitted: 8/1/17 12:00AM Date Published: 4/1/17 5:00AM
Publication Location:
Article Title: Thermoelectric transport in disordered metals without quasiparticles: The Sachdev-Ye-Kitaev models and holography
Authors: Richard A. Davison, Wenbo Fu, Antoine Georges, Yingfei Gu, Kristan Jensen, Subir Sachdev
Keywords: Thermoelectricity, strange metals, holography
Abstract: We compute the thermodynamic properties of the Sachdev-Ye-Kitaev (SYK) models of fermions with a conserved fermion number, Q. We extend a previously proposed Schwarzian effective action to include a phase field, and this describes the low temperature energy and Q fluctuations. We obtain higher-dimensional generalizations of the SYK models which display disordered metallic states without quasiparticle excitations, and we deduce their thermoelectric transport coefficients. We also examine the corresponding properties of Einstein-Maxwell-scalar theories on black brane geometries which interpolate from either AdS4 or AdS5 to an AdS2×?2 or AdS2×?3 near-horizon geometry. These provide holographic descriptions of non-quasiparticle metallic states without momentum conservation. We find a precise match between low temperature transport and thermodynamics of the SYK and holographic models. In both models the Seebeck transport coefficient is exactly equal to the Q-derivative of the entropy.
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Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevA.95.063605
Volume: 95 Issue: 6 First Page #: 63605
Date Submitted: 8/1/17 12:00AM Date Published: 6/1/17 5:00AM
Publication Location:
Article Title: Impurity and soliton dynamics in a Fermi gas with nearest-neighbor interactions
Authors: A.-M. Visuri, P. Törmä, T. Giamarchi
Keywords: Impurity, out of equilibrium, Luttinger liquid
Abstract: We study spinless fermions with repulsive nearest-neighbor interactions perturbed by an impurity particle or a local potential quench. Using the numerical time-evolving block decimation method and a simplified analytic model, we show that the perturbations create a soliton-antisoliton pair. If solitons are already present in the bath, the two excitations have a drastically different dynamics: The antisoliton does not annihilate with the solitons and is therefore confined close to its origin while the soliton excitation propagates. We discuss the consequences for experiments with ultracold gases.
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Publication Identifier Type: DOI Publication Identifier: 10.1140/epjst/e2016-60383-x
Volume: 226 Issue: 12 First Page #: 2763
Date Submitted: 8/1/17 12:00AM Date Published: 7/1/17 5:00AM
Publication Location:
Article Title: Relaxation dynamics of two coherently coupled one-dimensional bosonic gases
Authors: L. Foini, T. Giamarchi
Keywords: BEC, tunnelling, out of equilibrium
Abstract: In this work we consider the non-equilibrium dynamics of two tunnel coupled bosonic gases which are created from the coherent splitting of a one-dimensional gas. The consequences of the tunneling both in the non-stationary regime as well as at large time are investigated and compared with equilibrium results. In particular, within a semiclassical approximation, we compute correlation functions for the relative phase which are experimentally measurable and we observe a transient regime displaying oscillations as a function of the distance. The steady regime is very well approximated by a thermal state with a temperature independent of the tunneling strength.
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Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevLett.119.030403
Volume: 119 Issue: 3 First Page #: 30403
Date Submitted: 8/1/17 12:00AM Date Published: 7/1/17 5:00AM
Publication Location:
Article Title: Scanning Gate Microscope for Cold Atomic Gases
Authors: Samuel Häusler, Shuta Nakajima, Martin Lebrat, Dominik Husmann, Sebastian Krinner, Tilman Esslinge
Keywords: Quantum Gases, non-equilibrium
Abstract: We present a scanning probe microscopy technique for spatially resolving transport in cold atomic gases, in close analogy with scanning gate microscopy in semiconductor physics. The conductance of a quantum point contact connected to two atomic reservoirs is measured in the presence of a tightly focused laser beam acting as a local perturbation that can be precisely positioned in space. By scanning its position and recording the subsequent variations of conductance, we retrieve a high-resolution map of transport through a quantum point contact. We demonstrate a spatial resolution comparable to the extent of the transverse wave function of the atoms inside the channel and a position sensitivity below 10 nm. Our measurements agree well with an analytical model and ab initio numerical simulations, allowing us to identify a regime in transport where tunneling dominates over thermal effects. Our technique opens new perspectives for the high-resolution observation and manipulation of cold at
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Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevLett.117.255302
Volume: 117 Issue: 25 First Page #: 255302
Date Submitted: 8/1/17 12:00AM Date Published: 12/1/16 12:00PM
Publication Location:
Article Title: Anomalous Conductances in an Ultracold Quantum Wire
Authors: M. Kanász-Nagy, L. Glazman, T. Esslinger, E.?A. Demler
Keywords: Quantum Gases, non-equilibrium
Abstract: We present a scanning probe microscopy technique for spatially resolving transport in cold atomic gases, in close analogy with scanning gate microscopy in semiconductor physics. The conductance of a quantum point contact connected to two atomic reservoirs is measured in the presence of a tightly focused laser beam acting as a local perturbation that can be precisely positioned in space. By scanning its position and recording the subsequent variations of conductance, we retrieve a high-resolution map of transport through a quantum point contact. We demonstrate a spatial resolution comparable to the extent of the transverse wave function of the atoms inside the channel and a position sensitivity below 10 nm. Our measurements agree well with an analytical model and ab initio numerical simulations, allowing us to identify a regime in transport where tunneling dominates over thermal effects. Our technique opens new perspectives for the high-resolution observation and manipulation of cold at
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Journal: Physical Review Letters
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevLett.117.275301
Volume: 117 Issue: 27 First Page #: 275301
Date Submitted: 8/5/17 12:00AM Date Published: 12/1/16 6:00AM
Publication Location:
Article Title: Coherence Times of Bose-Einstein Condensates beyond the Shot-Noise Limit via Superfluid Shielding
Authors: William Cody Burton, Colin J. Kennedy, Woo Chang Chung, Samarth Vadia, Wenlan Chen, Wolfgang K
Keywords: atom interferometry, Bose Einstein condensatoin
Abstract: We demonstrate a new way to extend the coherence time of separated Bose-Einstein condensates that involves immersion into a superfluid bath. When both the system and the bath have similar scattering lengths, immersion in a superfluid bath cancels out inhomogeneous potentials either imposed by external fields or inherent in density fluctuations due to atomic shot noise. This effect, which we call superfluid shielding, allows for coherence lifetimes beyond the projection noise limit. We probe the coherence between separated condensates in different sites of an optical lattice by monitoring the contrast and decay of Bloch oscillations. Our technique demonstrates a new way that interactions can improve the performance of quantum devices.
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Publication Identifier Type: DOI Publication Identifier: 10.1038/nature21431
Volume: 543 Issue: 7643 First Page #: 91
Date Submitted: 8/5/17 12:00AM Date Published: 3/1/17 6:00AM
Publication Location:
Article Title: A stripe phase with supersolid properties in spin–orbit-coupled Bose–Einstein condensates
Authors: Jun-Ru Li, Jeongwon Lee, Wujie Huang, Sean Burchesky, Boris Shteynas, Furkan Ça?r? Top, Alan O. .
Keywords: supersolidity, spin-oribt coupling, Bose-Einstein condensatoin
Abstract: Supersolidity combines superfluid flow with long-range spatial periodicity of solids1, two properties that are often mutually exclusive. The original discussion of quantum crystals2 and supersolidity focused on solid 4He and triggered extensive experimental efforts3, 4 that, instead of supersolidity, revealed exotic phenomena including quantum plasticity and mass supertransport4. The concept of supersolidity was then generalized from quantum crystals to other superfluid systems that break continuous translational symmetry. Bose–Einstein condensates with spin–orbit coupling are predicted to possess a stripe phase5, 6, 7 with supersolid properties8, 9. Despite several recent studies of the miscibility of the spin components of such a condensate10, 11, 12, the presence of stripes has not been detected. Here we observe the predicted density modulation of this stripe phase using Bragg reflection (which provides evidence for spontaneous long-range order in one direction).
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Volume: 117 Issue: 18 First Page #: 185301
Date Submitted: 8/5/17 12:00AM Date Published: 10/1/16 5:00AM
Publication Location:
Article Title: Spin-Orbit Coupling and Spin Textures in Optical Superlattices
Authors: Junru Li, Wujie Huang, Boris Shteynas, Sean Burchesky, Furkan Ça?r? Top, Edward Su, Jeongwon Lee
Keywords: spin-orbit coupling, Bose-Einstein condensation, superlattices
Abstract: We propose and demonstrate a new approach for realizing spin-orbit coupling with ultracold atoms. We use orbital levels in a double-well potential as pseudospin states. Two-photon Raman transitions between left and right wells induce spin-orbit coupling. This scheme does not require near resonant light, features adjustable interactions by shaping the double-well potential, and does not depend on special properties of the atoms. A pseudospinor Bose-Einstein condensate spontaneously acquires an antiferromagnetic pseudospin texture, which breaks the lattice symmetry similar to a supersolid.
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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Physical Review A
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevA.97.043630
Volume: 97 Issue: 4 First Page #:
Date Submitted: 9/5/18 12:00AM Date Published: 4/1/18 12:00AM
Publication Location:
Article Title: Effective-field theory for one-dimensional nonrelativistic particles with contact interaction
Authors: Soke Yuen Yong, Dam Thanh Son
Keywords: 1-dimensional systems, Fermi gases
Abstract: We consider a field theory describing interacting nonrelativistic particles of two types, which map to each other under time reversal, with pointlike interaction. We identify an alternative type of interaction which depends on the relative velocity between the particles. We compute the renormalization-group running of the coupling constants and find a fixed point and a fixed line. We show that the scattering amplitudes can be expressed in terms of three parameters. The result matches with a quantum-mechanical analysis and represents the most general pointlike interaction consistent with unitarity and time-reversal invariance.
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Journal: Physical Review A
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevA.97.033825
Volume: 97 Issue: 3 First Page #:
Date Submitted: 9/6/18 12:00AM Date Published: 3/1/18 6:00AM
Publication Location:
Article Title: Coherent generation of photonic fractional quantum Hall states in a cavity and the search for anyonic quasiparticles
Authors: Shovan Dutta, Erich J. Mueller
Keywords: Anyons, Cavity Quantum Electrodynamics, Polaritons, Quantum States of Light
Abstract: "We present and analyze a protocol in which polaritons in a noncoplanar optical cavity form fractional quantum Hall states. We model the formation of these states and present techniques for subsequently creating anyons and measuring their fractional exchange statistics. In this protocol, we use a rapid adiabatic passage scheme to sequentially add polaritons to the system, such that the system is coherently driven from n- to (n+1)-particle Laughlin states. Quasiholes are created by slowly moving local pinning potentials in from outside the cloud. They are braided by dragging the pinning centers around one another, and the resulting phases are measured interferometrically. The most technically challenging issue with implementing our procedure is that maintaining adiabaticity and coherence requires that the two-particle interaction energy V0 be sufficiently large compared to the single-polariton decay rate ?, V0/??10N^2lnN, where N is the number of particles in the target state. While th
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Publication Type: Journal Article Peer Reviewed: Y **Publication Status:** 1-Published
Journal: Physical Review Letters
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevLett.119.220401
Volume: 119 Issue: 22 First Page #:
Date Submitted: 9/6/18 12:00AM Date Published: 11/1/17 12:00AM
Publication Location:
Article Title: Dissociation of One-Dimensional Matter-Wave Breathers due to Quantum Many-Body Effects
Authors: Vladimir A. Yurovsky, Boris A. Malomed, Randall G. Hulet, Maxim Olshanii
Keywords: soliton, Bose-Einstein condensate, quantum
Abstract: We use the ab initio Bethe ansatz dynamics to predict the dissociation of one-dimensional cold-atom breathers that are created by a quench from a fundamental soliton. We find that the dissociation is a robust quantum many-body effect, while in the mean-field (MF) limit the dissociation is forbidden by the integrability of the underlying nonlinear Schrödinger equation. The analysis demonstrates the possibility to observe quantum many-body effects without leaving the MF range of experimental parameters. We find that the dissociation time is of the order of a few seconds for a typical atomic-soliton setting.
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Journal: Physical Review A
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevA.96.051603
Volume: 96 Issue: 5 First Page #:
Date Submitted: 9/6/18 12:00AM Date Published: 11/1/17 5:00AM
Publication Location:
Article Title: Observation of two-beam collective scattering phenomena in a Bose-Einstein condensate
Authors: Ivana Dimitrova, William Lunden, Jesse Amato-Grill, Niklas Jepsen, Yichao Yu, Michael Messer, Thoma
Keywords: superradiance, Bose-Einstein condensate
Abstract: Different regimes of collective light scattering are observed when an elongated Bose-Einstein condensate is pumped by two noninterfering beams counterpropagating along its long axis. In the limit of small Rayleigh scattering rates, the presence of a second pump beam suppresses superradiance, whereas at large Rayleigh scattering rates it lowers the effective threshold power for collective light scattering. In the latter regime, the quench dynamics of the two-beam system are oscillatory, compared to monotonic in the single-beam case. In addition, the dependence on power, detuning, and atom number is explored. The observed features of the two-beam system qualitatively agree with the recent theoretical prediction of a supersolid crystalline phase of light and matter at large Rayleigh scattering rates.
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Journal: Physical Review X
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevX.7.031047
Volume: 7 Issue: 3 First Page #:
Date Submitted: 9/6/18 12:00AM Date Published: 9/1/17 5:00AM
Publication Location:
Article Title: Quantum Butterfly Effect in Weakly Interacting Diffusive Metals
Authors: Aavishkar A. Patel, Debanjan Chowdhury, Subir Sachdev, Brian Swingle
Keywords: quantum chaos, diffusive metals
Abstract: We study scrambling, an avatar of chaos, in a weakly interacting metal in the presence of random potential disorder. It is well known that charge and heat spread via diffusion in such an interacting disordered metal. In contrast, we show within perturbation theory that chaos spreads in a ballistic fashion. The squared anticommutator of the electron field operators inherits a light-cone like growth, arising from an interplay of a growth (Lyapunov) exponent that scales as the inelastic electron scattering rate and a diffusive piece due to the presence of disorder. In two spatial dimensions, the Lyapunov exponent is universally related at weak coupling to the sheet resistivity. We are able to define an effective temperature-dependent butterfly velocity, a speed limit for the propagation of quantum information, that is much slower than microscopic velocities such as the Fermi velocity and that is qualitatively similar to that of a quantum critical system with a dynamical critical exponent
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Journal: Physical Review D
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevD.96.106008
Volume: 96 Issue: 10 First Page #:
Date Submitted: 9/6/18 12:00AM Date Published: 11/1/17 10:00AM
Publication Location:
Article Title: Thermal diffusivity and chaos in metals without quasiparticles
Authors: Mike Blake, Richard A. Davison, Subir Sachdev
Keywords: fractionalization, strange metals
Abstract: We describe the phases of a solvable t-J model of electrons with infinite-range, and random, hopping and exchange interactions, similar to those in the Sachdev-Ye-Kitaev models. The electron fractionalizes, as in an `orthogonal metal', into a fermion f which carries both the electron spin and charge, and a boson ?. Both f and ? carry emergent ?2 gauge charges. The model has a phase in which the ? bosons are gapped, and the f fermions are gapless and critical, and so the electron spectral function is gapped. This phase can be considered as a toy model for the underdoped cuprates. The model also has an extended, critical, `quasi-Higgs' phase where both ? and f are gapless, and the electron operator ?f? has a Fermi liquid-like 1/? propagator in imaginary time, ?. So while the electron spectral function has a Fermi liquid form, other properties are controlled by ?2 fractionalization and the anomalous exponents of the f and ? excitations. This `quasi-Higgs' phase is proposed as a toy model
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Journal: Physical Review B
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevB.96.205123
Volume: 96 Issue: 20 First Page #:
Date Submitted: 9/6/18 12:00AM Date Published: 11/1/17 5:00AM
Publication Location:
Article Title: Quantum quench of the Sachdev-Ye-Kitaev model
Authors: Andreas Eberlein, Valentin Kasper, Subir Sachdev, Julia Steinberg
Keywords: quantum chaos, diffusive metals
Abstract: We study scrambling, an avatar of chaos, in a weakly interacting metal in the presence of random potential disorder. It is well known that charge and heat spread via diffusion in such an interacting disordered metal. In contrast, we show within perturbation theory that chaos spreads in a ballistic fashion. The squared anticommutator of the electron field operators inherits a light-cone like growth, arising from an interplay of a growth (Lyapunov) exponent that scales as the inelastic electron scattering rate and a diffusive piece due to the presence of disorder. In two spatial dimensions, the Lyapunov exponent is universally related at weak coupling to the sheet resistivity. We are able to define an effective temperature-dependent butterfly velocity, a speed limit for the propagation of quantum information, that is much slower than microscopic velocities such as the Fermi velocity and that is qualitatively similar to that of a quantum critical system with a dynamical critical exponent
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Journal: Physical Review B
Publication Identifier Type: DOI Publication Identifier: 10.1103/PhysRevB.98.075150
Volume: 98 Issue: 7 First Page #:
Date Submitted: 9/6/18 12:00AM Date Published: 8/1/18 10:00AM
Publication Location:
Article Title: Z2 fractionalized phases of a solvable, disordered t-J model
Authors: Wenbo Fu, Yingfei Gu, Subir Sachdev, Grigory Tarnopolsky
Keywords: fractionalization, strange metals
Abstract: We describe the phases of a solvable t-J model of electrons with infinite-range, and random, hopping and exchange interactions, similar to those in the Sachdev-Ye-Kitaev models. The electron fractionalizes, as in an `orthogonal metal', into a fermion f which carries both the electron spin and charge, and a boson ?.
Both f and ? carry emergent ?2 gauge charges. The model has a phase in which the ? bosons are gapped, and the f fermions are gapless and critical, and so the electron spectral function is gapped. This phase can be considered as a toy model for the underdoped cuprates. The model also has an extended, critical, `quasi-Higgs' phase where both ? and f are gapless, and the electron operator ?f? has a Fermi liquid-like 1/? propagator in imaginary time, ?. So while the electron spectral function has a Fermi liquid form, other properties are controlled by ?2 fractionalization and the anomalous exponents of the f and ? excitations. This `quasi-Higgs' phase is proposed as a toy model
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Journal: Nature Physics
Publication Identifier Type: DOI Publication Identifier: 10.1038/s41567-017-0011-x
Volume: 14 Issue: 3 First Page #: 269
Date Submitted: 1/27/20 12:00AM Date Published: 12/1/17 6:00AM
Publication Location:
Article Title: Coherent inflationary dynamics for Bose–Einstein condensates crossing a quantum critical point
Authors: Lei Feng, Logan W. Clark, Anita Gaj, Cheng Chin
Keywords: Inflation, Bose-Einstein condensate
Abstract: Quantum phase transitions, transitions between many-body ground states, are of extensive interest in research ranging from condensed matter physics to cosmology. Key features of the phase transitions include a stage with rapidly growing new order, called inflation in cosmology, followed by the formation of topological defects. How inflation is initiated and evolves into topological defects remains a hot debate topic. Ultracold atomic gas offers a pristine and tunable platform to investigate quantum critical dynamics. We report the observation of coherent inflationary dynamics across a quantum critical point in driven Bose-Einstein condensates. The inflation manifests in the exponential growth of density waves and populations in well-resolved momentum states. After the inflation stage, extended coherent dynamics is evident in both real and momentum space. We present an intuitive description of the quantum critical dynamics in our system and demonstrate the essential role of phase fluctu
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Volume: 121 Issue: 24 First Page #:
Date Submitted: 1/27/20 12:00AM Date Published: 12/1/18 6:00AM
Publication Location:
Article Title: Density Waves and Jet Emission Asymmetry in Bose Fireworks
Authors: Han Fu, Lei Feng, Brandon M. Anderson, Logan W. Clark, Jiazhong Hu, Jeffery W. Andrade, Cheng Ch
Keywords: Bose Fireworks, Jet structure
Abstract: A Bose condensate, subject to periodic modulation of the two-body interactions, was recently observed to emit matter-wave jets resembling fireworks [Nature (London) 551, 356 (2017)]. In this Letter, combining experiment with numerical simulation, we demonstrate that these “Bose fireworks” represent a late stage in a complex time evolution of the driven condensate. We identify a “density wave” stage which precedes jet emission and results from the interference of matter waves. The density waves self-organize and self-amplify without breaking long range translational symmetry. This density wave structure deterministically establishes the template for the subsequent patterns of the emitted jets. Moreover, our simulations, in good agreement with experiment, address an apparent asymmetry in the jet pattern, and show that it is fully consistent with momentum conservation.
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Date Submitted: 1/27/20 12:00AM Date Published: 1/1/19 6:00AM
Publication Location:
Article Title: Correlations in high-harmonic generation of matter-wave jets revealed by pattern recognition
Authors: Lei Feng, Jiazhong Hu, Logan W. Clark, Cheng Chin
Keywords: Bose fireworks, Bose condensation
Abstract: Correlations in interacting many-body systems are key to the study of quantum matter. The complexity of the correlations typically grows quickly as the system evolves and thus presents a challenge for experimental characterization and intuitive understanding. In a strongly driven Bose-Einstein condensate, we observe the high-harmonic generation of matter-wave jets with complex correlations as a result of bosonic stimulation. Based on a pattern recognition scheme, we identify a pattern of correlations that reveals the underlying secondary scattering processes and higher-order correlations. We show that pattern recognition offers a versatile strategy to visualize and analyze the quantum dynamics of a many-body system.
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Volume: 9 Issue: 2 First Page #:
Date Submitted: 1/27/20 12:00AM Date Published: 4/1/19 5:00AM
Publication Location:
Article Title: Superresolution Microscopy of Cold Atoms in an Optical Lattice
Authors: Mickey McDonald, Jonathan Trisnadi, Kai-Xuan Yao, Cheng Chin
Keywords: Superresolution, Optical lattice
Abstract: Superresolution microscopy has revolutionized the fields of chemistry and biology by resolving features at the molecular level. In atomic physics, such a scheme can be applied to resolve the atomic density distribution beyond the diffraction limit and to perform quantum control. Here we demonstrate superresolution imaging based on the nonlinear response of atoms to an optical pumping pulse. With this technique, the atomic density distribution can be imaged with a full-width-at-half-maximum resolution of 32(4) nm and a localization precision below 500 pm. The short optical pumping pulse of 1.4???s enables us to resolve fast atomic dynamics within a single lattice site. A by-product of our scheme is the emergence of moiré patterns on the atomic cloud, which we show to be immensely magnified images of the atomic density in the lattice.
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Journal: Nature Physics
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Volume: 15 Issue: 8 First Page #: 785
Date Submitted: 1/27/20 12:00AM Date Published: 5/1/19 5:00AM
Publication Location:
Article Title: Quantum simulation of Unruh radiation
Authors: Jiazhong Hu, Lei Feng, Zhendong Zhang, Cheng Chin
Keywords: Unruh radiaiton, Hawking Radiation, Bose condensation
Abstract: The exploration of quantum phenomena in a curved spacetime is an emerging interdisciplinary area at the interface between general relativity1,2,3,4, thermodynamics4,5,6 and quantum information7,8. One famous prediction in this field is Unruh thermal radiation3—the manifestation of thermal radiation from a Minkowski vacuum when viewed in an accelerating reference frame. Here, we report the experimental observation of a matter field with thermal fluctuations that agree with Unruh's predictions. The matter field is generated within a framework for the simulation of quantum physics in a non-inertial frame, based on Bose–Einstein condensates that are parametrically modulated9 to make their evolution replicate the frame transformation. We further observe long-range phase coherence and temporal reversal of the matter-wave radiation, hallmarks that distinguish Unruh radiation from its classical counterpart.
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Volume: 20 Issue: 8 First Page #: 083030
Date Submitted: 1/27/20 12:00AM Date Published: 8/1/18 5:00AM
Publication Location:
Article Title: Rewiring stabilizer codes
Authors: Kristina R Colladay, Erich J Mueller
Keywords: quantum information
Abstract: We present an algorithm for manipulating quantum information via a sequence of projective measurements. We frame this manipulation in the language of stabilizer codes: a quantum computation approach in which errors are prevented and corrected in part by repeatedly measuring redundant degrees of freedom. We show how to construct a set of projective measurements which will map between two arbitrary stabilizer codes. We show that this process preserves all quantum information. It can be used to implement Clifford gates, braid extrinsic defects, or move between codes in which different operations are natural.
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Journal: Physical Review A
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Volume: 99 Issue: 5 First Page #:
Date Submitted: 1/27/20 12:00AM Date Published: 5/1/19 5:00AM
Publication Location:
Article Title: Collective dynamics and atom loss in bright-soliton matter waves
Authors: Daniel Longenecker, Erich J. Mueller
Keywords: soliton, Bose condensate
Abstract: Motivated by recent experiments, we model the dynamics of bright solitons formed by cold gases in quasi-1D traps. A dynamical variational Ansatz captures the far-from-equilibrium excitations of these solitons. Due to a separation of scales, the radial and axial modes decouple, allowing for closed-form approximations for the dynamics. We explore how soliton dynamics influence atom loss and find that the time-averaged loss is largely insensitive to the degree of excitation. The variational approach enables us to perform high precision calculations of the critical atom number (i.e., the maximum number of atoms that can exist in a single soliton before the attractive forces overwhelm quantum pressure, leading to collapse).
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Signature: Cheng Chin
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