Stony Brook University
The Graduate School

Doctoral Defense Announcement

Abstract

Matter-wave dynamics in tailored optical and atomic lattices

By

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Quantum degenerate atomic gases offer a unique platform to emulate and study a myriad of important physical systems in a pristine environment, as well as a set of powerful tools for the coherent control of internal and external degrees of freedom. Here, we present experimental studies of strongly interacting bosonic mixtures in one-dimensional (1D) systems, where the mobility of one species is independently controlled with a state-selective optical lattice. By freezing out the tunneling of one species from a binary mixture, we study the formation of ``quantum emulsion" states, where immobile atoms serve as a static, random disorder for a more mobile species. We study the 1D superfluid-to-insulator transition in the presence of this disorder, and compare to the case of a pseudorandom quasi-crystal lattice. We observe enhanced localization in the more random potential, highlighting the important role of correlations in disordered systems. Through combined measurement of transport, localization, and excitation spectra, we also provide strong evidence for observation of a disordered, insulating quantum phase, the 1D Bose glass.

In a second experiment, we introduce a new experimental technique for the characterization of ultracold gases. In analogy to neutron diffraction from solids, we use atomic de Broglie waves to characterize the spatial structure of 1D Mott insulators, and to probe band-structure excitations of more weakly interacting 1D Bose gases. Elastic Bragg diffraction is used to non-destructively probe long-range order and on-site localization in a crystal of lattice-confined atoms. Furthermore, we use the diffraction of matter waves to detect the formation of forced antiferromagnetic ordering in an atomic spin mixture.

Lastly, we discuss experimental studies of the dynamical response of matter waves to periodically pulsed, disordered potentials. The matter waves undergo a localization-to-delocalization transition in momentum-space with an added incommensurate optical lattice, relating to a breakdown of dynamical localization. We also find that added spatial frequency noise inhibits ballistic momentum growth at a quantum resonance, i.e. when the pulse period matches a Talbot resonance.

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