Cooling and Trapping Neutral Atoms

RLE Groups
Atomic, Molecular and Optical Physics Group; MIT-Harvard Center for Ultracold Atoms

Academic and Research Staff
Professor Wolfgang Ketterle, Professor David E. Pritchard

Visiting Scientists and Research Affiliates
Jae Hoon Choi, Ralf Gommers, David Weld

Graduate Students
Caleb Cristensen, Gyu-Boong Jo, Aviv Keshet, Ye-ryoung Lee, Patrick Medley, Hiro Miyake, Christian Sanner, Edward Su, Tout Wang, Wujie Huang

Undergraduate Students
Dylan Rankin, Gregory Lau

Support Staff
Joanna Keseberg

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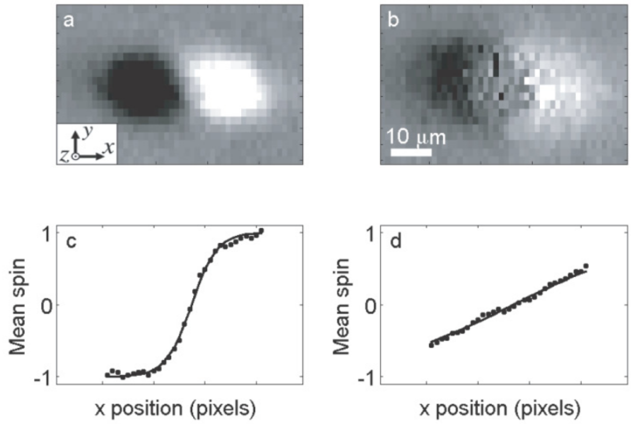
Overview
Our results in the past year reflect our focus on strongly interacting quantum gases. Our longer term goal is the study of magnetic properties of two-component gases including spin ordering and magnetic phase transition. This year, we made progress in developing novel detection and cooling techniques.

1. Spin Gradient Thermometry for Ultracold Atoms in Optical Lattices

A major goal of current research with ultracold atoms in optical lattices is the realization of magnetic ordering. This requires temperatures on the order of the second order tunneling rate, J2/U where U is the interaction energy and J the tunneling amplitude. Such temperatures are about ten times less than 1 nk, the lowest temperature reached thus far in optical lattices. Additional cooling methods will be needed to reach this very interesting temperature scale. However, even to assess current methods, new methods of low-temperature thermometry of the Mott insulator are needed.

We have demonstrated a novel, simple and direct method of thermometry using a magnetic field gradient which works in a two-component Mott insulator [1]. The two states are assumed to have different magnetic moments, and are thus pulled towards opposite sides of the trapped sample by the gradient. At zero temperature, the spins will segregate completely with a sharp boundary (a small width due to superexchange coupling is negligible). At finite temperature, spin excitations will result in an increase in the width of the domain wall which is proportional to the temperature.

We developed this method in a system of ultracold rubidium atoms. We observed the lowest measured temperature in a Mott insulator thus far, 1 nK, indicating that the system has reached the quantum regime, where insulating shells are separated by superfluid layers. The interface between the two components of the Mott insulator provide new opportunities beyond thermometry: It can be used to study relaxation processes, and to realize a two dimensional layer with spontaneous transverse magnetization at very low temperature.

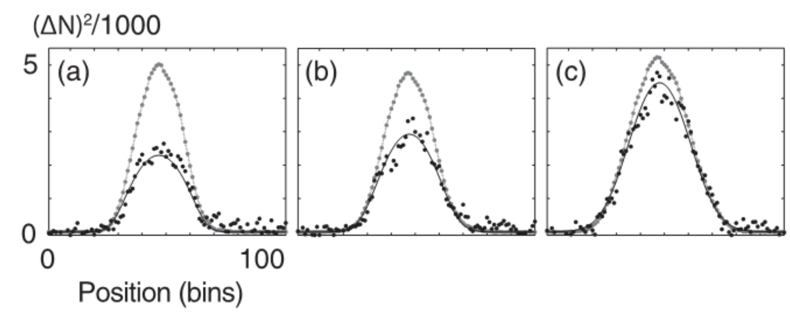


Images used for spin gradient thermometry. Data on the left were taken at a lower optical trap depth than data on the right resulting in a lower temperature (52 nk vs. 296 nk). The upper panels are images of the spin distribution, created by subtracting the image of atoms in the |1,1> state from the image of the |2,2> atoms. The lower panels show the mean spin versus x position.

2. Suppression of Density Fluctuations in a Quantum Degenerate Fermi Gas

Systems of fermions obey the Pauli exclusion principle. Processes that would require two fermions to occupy the same quantum state are suppressed. In recent years, several classic experiments have observed different manifestations of Pauli suppression in Fermi gases. Here we study density profiles of an ideal Fermi gas and observe Pauli suppression of density fluctuations (atom shot noise) for cold clouds deep in the quantum degenerate regime.

The development of a technique to sensitively measure density fluctuations was motivated by the connection between density fluctuations and compressibility through the fluctuation-dissipation theorem. In this study, we validate our technique for determining the compressibility by applying it to the ideal Fermi gas [2, 3]. In future work, it could be extended to interesting many-body phases in optical lattices which are distinguished by their incompressibility including the band insulator, Mott insulator, and also the antiferromagnet for which spin fluctuations, i.e., fluctuations of the difference in density between the two spin states are suppressed. Furthermore, measuring the level of suppression provides sensitive thermometry at low temperatures.



Comparison of observed variances (black dots) with a theoretical model (black line) and the observed atom number (gray), at three different temperatures (a, b, and c), showing 50, 40, and 15% suppression of density fluctuations. .Noise thermometry is implemented by fitting the observed fluctuations, resulting in temperatures T/T_F of 0:23, 0:33, and 0:60, in good agreement with temperatures obtained by fitting the shape of the expanded cloud.

References

1. D.M. Weld, P. Medley, H. Miyake, D. Hucul, D.E. Pritchard, and W. Ketterle, Phys. Rev. Lett. **103**, 245301 (2009).

2. T. Müller, B. Zimmermann, J. Meineke, J.-P. Brantut, T. Esslinger, and H. Moritz, Phys. Rev. Lett. **105**, 040401 (2010).

3. C. Sanner, E.J. Su, A. Keshet, R. Gommers, Y.-i. Shin, W. Huang, and W. Ketterle, Phys. Rev. Lett. **105**, 040402 (2010).

Publications

Papers (in refereed journals) and major book chapters

1. C. Sanner, E.J. Su, A. Keshet, R. Gommers, Y. Shin, W. Huang, and W. Ketterle: *Suppression of Density Fluctuations in a Quantum Degenerate Fermi Gas* Phys. Rev. Lett. **105**, 040402 (2010).

2. D.M. Weld, P. Medley, H. Miyake, D. Hucul, D.E. Pritchard, and W. Ketterle: *Spin gradient thermometry for ultracold atoms in optical lattices.* Phys. Rev. Lett. **103**, 245301 (2009).

Theses

Gyu-Boong Jo, "Quantum Coherence and Magnetism in Bosonic and Fermionic Gases of Ultracold Atoms", Ph.D. Thesis, Department of Physics, MIT, January 2010

Andre Schirotzek, "Radio-Frequency Spectroscopy of Ultracold Fermi Gases", Ph.D. Thesis, Department of Physics, MIT, January 2010

Patrick Medley, "Thermometry and Cooling of Ultracold Atoms in an Optical Lattice", Ph.D. Thesis, Department of Physics, MIT, June 2010