Density and Spin Fluctuations in a Degenerate Fermi Gas

Christian Sanner, Edward Su, Aviv Keshet, Wujie Huang, Jonathon Gillen, Wolfgang Ketterle

MIT-Harvard Center for Ultracold Atoms, Research Laboratory of Electronics, and Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139

Abstract

We study density fluctuations in degenerate Fermi gases at different interaction strengths. For an ideal, noninteracting Fermi gas we observe Pauli suppression of density fluctuations (atom shot noise) for cold clouds deep in the quantum degenerate regime. Measuring the level of suppression provides sensitive thermometry at low temperatures. For a strongly interacting spin mixture through the BEC-BCS crossover, we use dispersive imaging to measure the relative density fluctuations between the two spin states. For a sample composed of molecules or of generalized Cooper pairs, we observe that the relative density fluctuations are strongly suppressed, while the fluctuations in total density increase or remain the same. This constitues a direct observation of pairing that does not rely on magnetic field ramps or on the interpretation of RF spectra. More generally, thermal fluctuations provide a natural method for measuring the response functions of a system, and should be useful for identifying interesting phases of atomic systems including itinerant ferromagnets, Mott insulators, and antiferromagnets.

Density Fluctuations

- atom positions uncorrelated
- full Poisson "shot noise" (variance in atom number equals atom number)

- atom positions highly correlated
- variance in atom number suppressed

Density Fluctuations and Compressibility

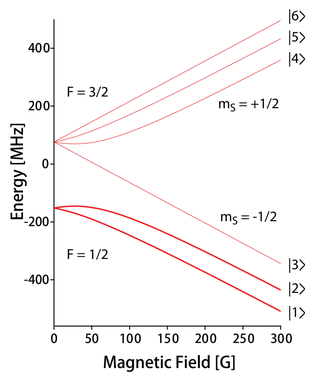
$$(\Delta N)^2 = \kappa(k_B T V)$$

Variance in atom number is proportional to temperature and compressibility $\kappa=(\partial n/\partial \mu)$

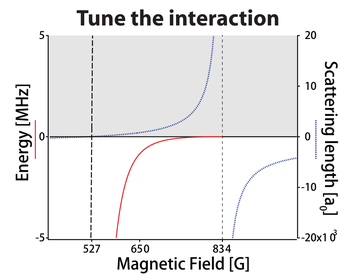
Experimental "Nuts and Bolts"

The atom and "Pseudo-Spin"

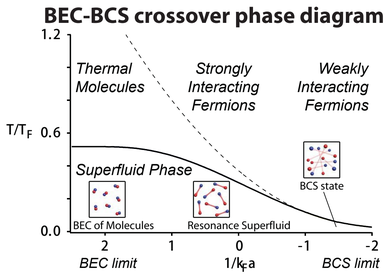
^{6}Li ground state $^2S_{1/2}$ hyperfine structure



Tune the interaction

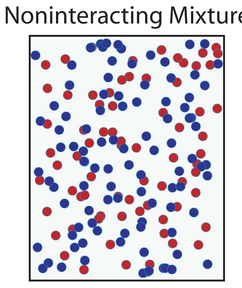


BEC-BCS crossover phase diagram



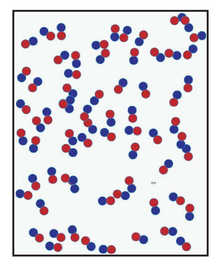
Spin (Relative Density) Fluctuations

Noninteracting Mixture



- no correlations between species
- relative density fluctuations equal to fluctuations in total density

Paired Mixture



- strong positive position correlations between atoms of different species
- relative fluctuations suppressed

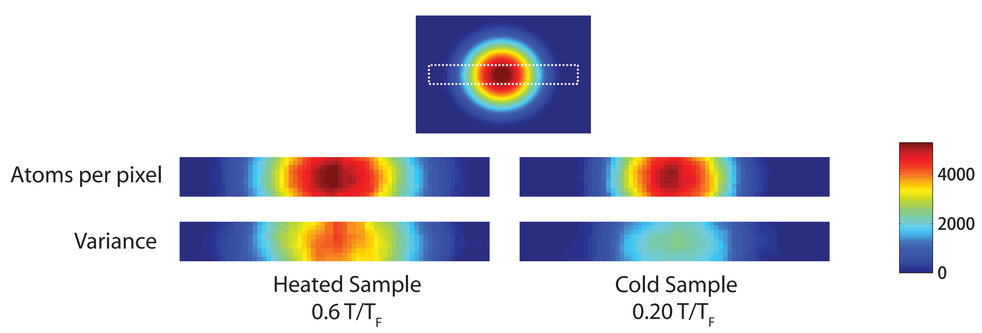
Spin Fluctuations and Spin Susceptibility

$$(\Delta M)^2 = \chi(k_B T V)$$

Variance in relative atom number is proportional to temperature and spin susceptibility $\chi=(\partial m/\partial H)$

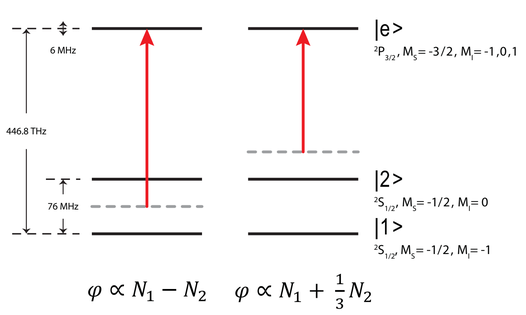
Spatially Resolved Density Fluctuations After Ballistic Expansion

Noise determined by looking at standard deviation of a given pixel over many otherwise identical shots.



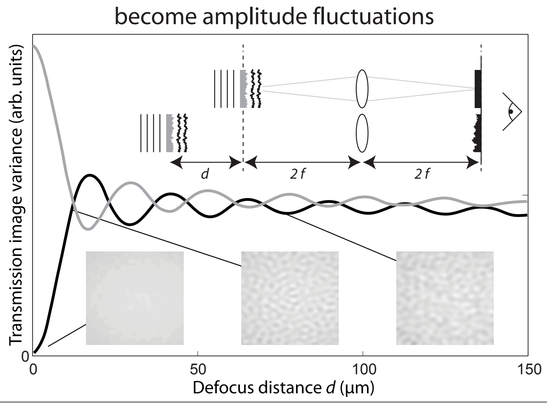
Measuring Spin Fluctuations In-Trap Using Dispersion

"Speckle Imaging"

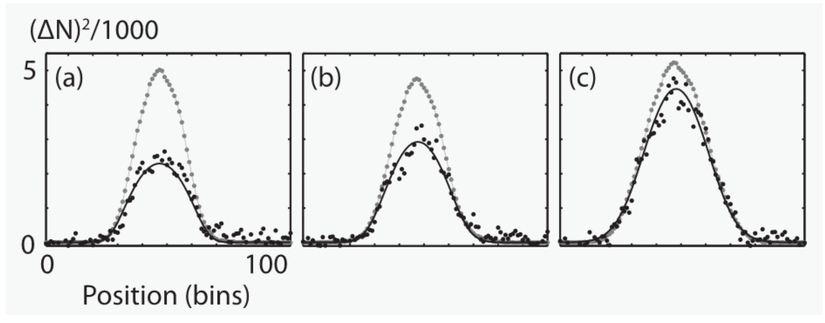


$\varphi \propto N_1 - N_2$ $\varphi \propto N_1 + \frac{1}{3}N_2$

After spatial propagation, phase fluctuations become amplitude fluctuations

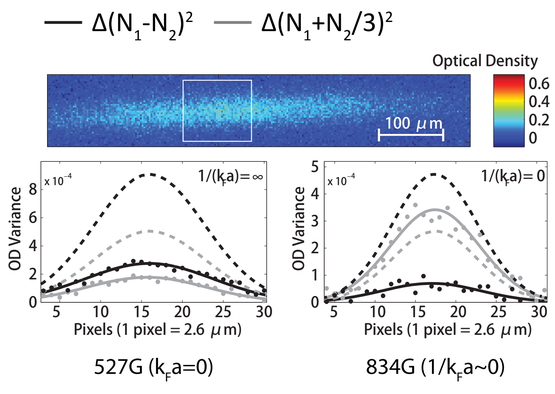


Temperature Dependence of Density Fluctuations



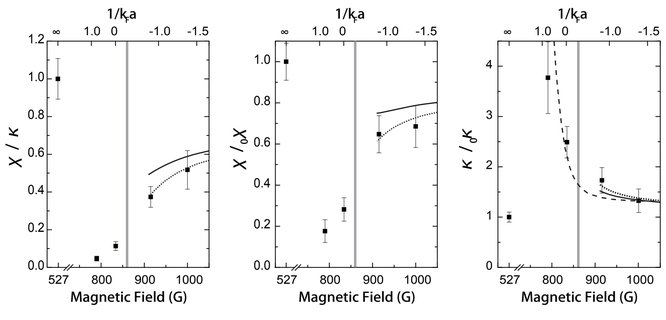
T/T_F = 0.23	T/T_F = 0.33	T/T_F = 0.60
50% suppression	40% suppression	15% suppression

Interaction Strength Dependence of Density Fluctuations



527G (k_Fa=0) 834G ($1/k_F$a~0)

Spin susceptibilities and compressibilities are extracted from spin and density fluctuations in agreement with theoretical preditions



Ongoing Projects and Outlook

1. Exploring itinerant ferromagnets in the repulsive interaction branch.
2. Building the next generation apparatus for optical lattice experiments.
3. Using noise measurements to characterize the phases (Mott insulators, antiferromagnets, ...) for fermions in optical lattices.

References

1. *Suppression of Density Fluctuations in a Quantum Degenerate Fermi Gas*, Phys. Rev. Lett. 105, 040402 (2010) Christian Sanner, Edward J. Su, Aviv Keshet, Ralf Gommers, Yong-il Shin, Wujie Huang, and Wolfgang Ketterle
2. *Speckle Imaging of Spin Fluctuations in a Strongly Interacting Fermi Gas*, Phys. Rev. Lett. 106, 010402 (2011) Christian Sanner, Edward J. Su, Aviv Keshet, Wujie Huang, Jonathon Gillen, Ralf Gommers, and Wolfgang Ketterle

$$$ from NSF, ONR, DARPA, OLE