Correlations and Pair Formation in a Repulsively Interacting Fermi Gas

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

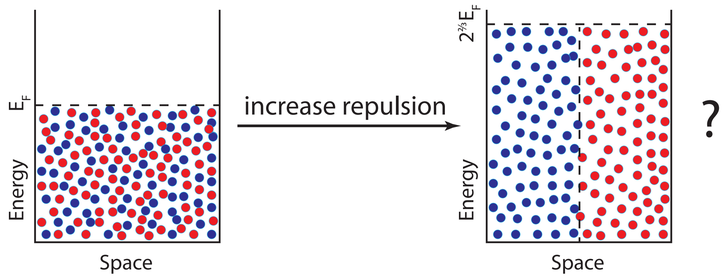
MIT-Harvard Center for Ultracold Atoms, Research Laboratory of Electronics, and Department of Physics, Massachusetts Institute of Technology, Cambridge, MA 02139

Abstract

A degenerate Fermi gas is rapidly quenched into the regime of strong effective repulsion near a Feshbach resonance. The spin fluctuations are monitored using speckle imaging and, contrary to a variety of theoretical predictions, the samples remain in the paramagnetic phase for arbitrarily large scattering length. Over a wide variety of interaction strengths a rapid decay into bound pairs is observed over times on the order of several inverse Fermi energy, preventing the study of equilibrium phases of strongly repulsive fermions. Our work suggests that a Fermi gas with strong short-range repulsive interactions does not undergo a ferromagnetic phase transition.

Itinerant Ferromagnetism

Question: Does a Fermi gas with sufficient strong short-range repulsion undergo a ferromagnetic phase transition?



Essentially kinetic energy competes with interaction energy
A fully polarized gas sets an upper limit of the total energy

Mean-Field description of the Stoner model

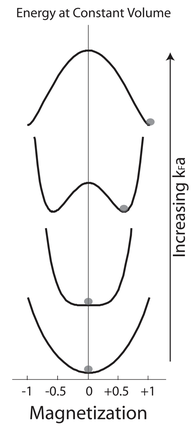
Magnetization: $\eta=(n_1-n_2)/(n_1+n_2)$
average density n per spin state

Minimize the total energy:

$$E=nVE_F\{(3/5)[(1+\eta)^{5/3}+(1-\eta)^{5/3}] +(4/3\pi)k_Fa(1+\eta)(1-\eta)\}$$

predicts a 2nd order phase transition at

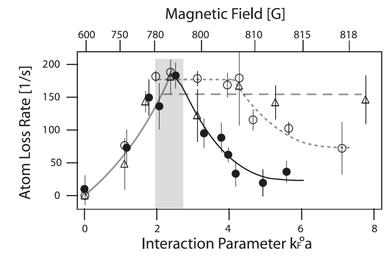
$$k_Fa=\pi/2$$



Previous work: indirect signatures of ferromagnetism

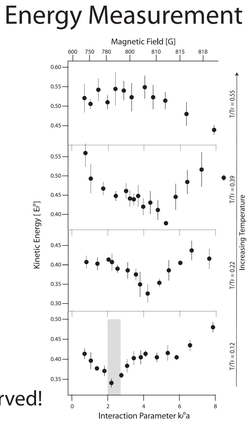
Gyu-Boong Jo et al.
Science 325, 1521

Atom Loss Measurement:



however ferromagnetic domains are never observed!

Kinetic Energy Measurement



It triggered a vigorous discussion

- Conduit and Simons (2009): nonequilibrium dynamics
- Zhai (2009): local anticorrelations
- Pilati et al (2010) and Chang et al (2010): Quantum Monte Carlo
- Pekker et al (2010): competition between magnetism and pairing
- Zhang (2011): molecular formation and decay
- Barth and Zwerger (2011): Tan relations
- Zhou et al (2011): Scattering length approximation

and others…

Two key improvements in this work

1. Fast switching of interactions
   10 times faster in the mangetic field jump
2. Direct measurement of Spin Fluctuations
   using Speckle Imaging: ref. PRL 106, 010402
   look for diverging signals around phase transition

Experiment Scheme

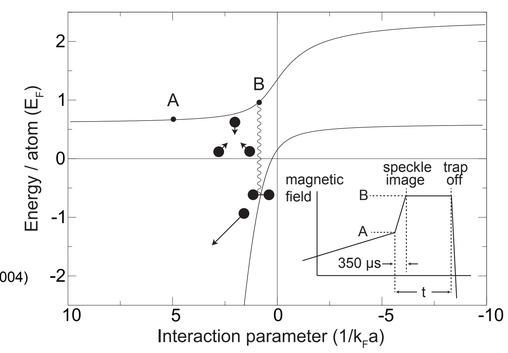
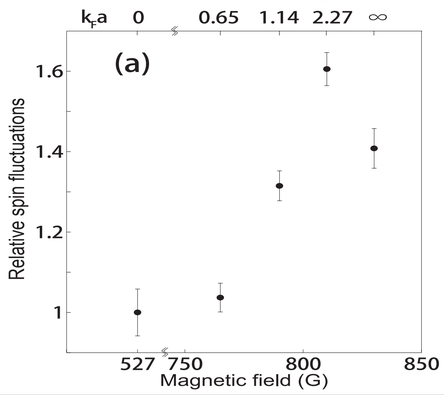


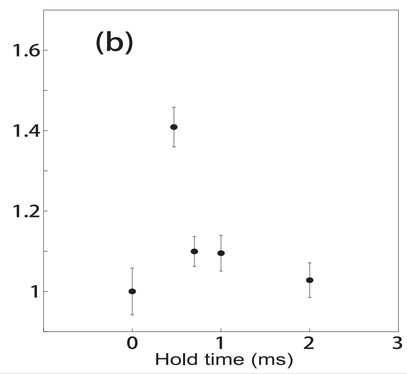
figure adapted from
L.Pricoupenko et al. (PRA 2004)

Searching for significant increase on spin fluctuations

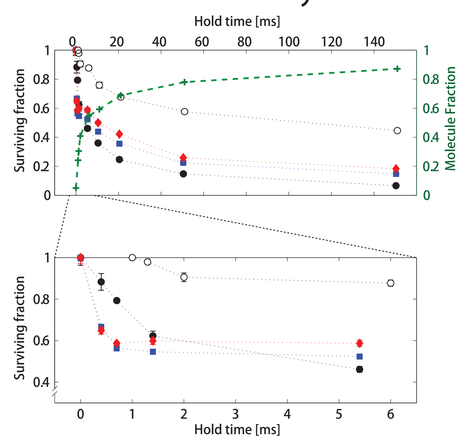
Spin Fluctuations vs. Magnetic Fields



Spin Fluctuations vs. Hold Times



Fast Decay of the Unbound Atom Population



closed symbols: normalized number of free atoms
circles (black) at 790G with $k_Fa = 1.14$
squares (blue) at 810G with $k_Fa = 2.27$
diamonds (red) at 818G with $k_Fa = 3.5$

open symbols: total number of atoms including those bound in Feshbach molecules
open circles at 790G with $k_Fa = 1.14$

green crosses show the molecule fraction

Time Scales

Fermi time: $\hbar/E_F = 45$ μs

field ramp time (typical): 350 μs

atom loss rate (typical): 1000 [1/s]

Conclusion

1. No significant increase in spin fluctuations is observed over a wide parameter space of a strongly repulsive Fermi gas using speckle imaging.

2. The fast formation of molecules and the accompanying heating makes it impossible to study such a gas in equilibrium, confirming predictions of a rapid conversion of the atomic gas to pairs.

3. An ultracold gas with strong short range repulsive interactions near a Feshbach resonance remains in the paramagnetic phase.

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)
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3. *Correlations and Pair Formation in a Repulsively Interacting Fermi Gas*, to be published.

$$$ from NSF, ONR, DARPA, OLE