Universal thermodynamics of strongly interacting Fermi gases

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Experiments on ultra-cold Fermi gases at micro-Kelvin temperatures are revolutionizing many areas of physics. Their exceptional simplicity allows tests of many-body theory in areas long thought to be inaccessible. The broad Feshbach resonance in gases of ^{6}Li and ^{40}K has already permitted the examination of the strongly interacting regime — the so-called unitarity limit, which leaves the inter-atomic distance as the only relevant length scale. At this point, the gas is expected to exhibit a universal thermodynamic behaviour, independent of any microscopic details of the underlying interactions. Substantial experimental efforts have been carried out to verify the existence of universality, though so far there has been no conclusive confirmation. This situation has dramatically improved in the most recent thermodynamic measurements on strongly interacting Fermi gases of ^{40}K and ^{6}Li atoms[1], which allow accurate estimates of temperature. These ground-breaking investigations provide a precise measurement, accurate to the level of a few percent, which is an exceptional accuracy in this challenging field of ultra-low temperature physics.

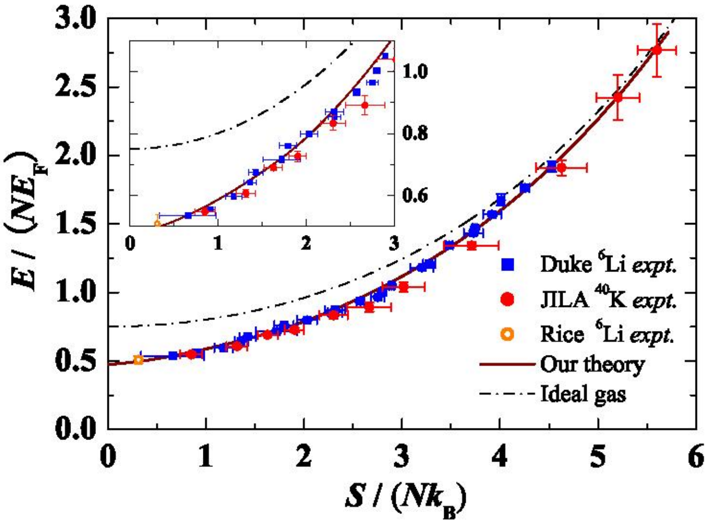

Figure 1: **Illustration of the universal thermodynamics of a strongly interacting Fermi gas**.

We analyze all the available experimental data from three laboratories on the entropy-energy relation of two different strongly interacting trapped Fermi gases, and compare this directly with a single universal theoretical prediction. We use a diagrammatic approach based on functional path-integrals together with the local density approximation to treat the inhomogeneous trap. Below the superfluid transition, our calculations include pairing fluctuations, which are important in the strongly interacting regime, due to the onset of molecule formation. This approach is described in detail elsewhere[2]. We demonstrate a quantitative test of these thermodynamic predictions by comparing experimental results on both types of atom with a single theoretical curve, as shown in Fig (1). The fit uses no adjustable parameters.

This provides clear evidence for universality.

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[1] G. B. Partridge et. al., "Pairing and phase separation in a polarized Fermi gas", *Science* **311**, 503-505 (2006); J. T. Stewart et. al., "Potential energy of a ^{40}K Fermi gas in the BCS-BEC crossover", *Phys. Rev. Lett.* **97**, 220406 (2006); L. Luo et. al., "Measurement of the entropy and critical temperature of a strongly interacting Fermi gas", http://arxiv.org/abs/cond-mat/0611566 (2006).

[2] H. Hu, X.-J. Liu, and P. D. Drummond, " Equation of state of a superfluid Fermi gas in the BCS-BEC crossover", *Europhys. Lett.* **74**, 574-580 (2006); H. Hu, X.-J. Liu, and P. D. Drummond, "Temperature of a trapped unitary Fermi gas at finite entropy", *Phys. Rev. A* **73**, 023617 (2006).