Universal structure of a strongly interacting Fermi superfluid

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Universality is a remarkable property of strongly interacting systems of fermions. For sufficiently strong interactions, all dilute Fermi gases behave identically on a scale given by the average particle separation. Ultracold Fermi gases in the Bose-Einstein condensate (BEC) to Bardeen-Cooper-Schrieffer (BCS) superfluid crossover display such universality, although their universal properties are not exactly known. In 2005 Shina Tan [1] developed several elegant exact relations for the BEC-BCS crossover, which connect the bulk thermodynamic properties to the microscopic parameters using a single short-range parameter known as the contact, $\mathcal{I}$.

Using Tan's result for the pair correlation function, we have derived a universal relation for the spin-up/spin-down static structure factor, $S_{\uparrow\downarrow}$, of a Fermi gas in the BEC-BCS crossover [2].

$$S_{\uparrow\downarrow}(q >> k_F) = \frac{\mathcal{I}}{4Nk_F}\frac{k_F}{q}\left(1 - \frac{4}{\pi q a}\right), \tag{1}$$

where N is the atom number, k_F is the Fermi wavevector, q is the momentum and a is the s-wave scattering length. Apart from some factors which we can easily determine, this depends only on the dimensionless contact $\mathcal{I}/Nk_F$. We have previously shown how $S_{\uparrow\downarrow}(q >> k_F)$ can be measured with high momentum transfer Bragg spectroscopy [3].

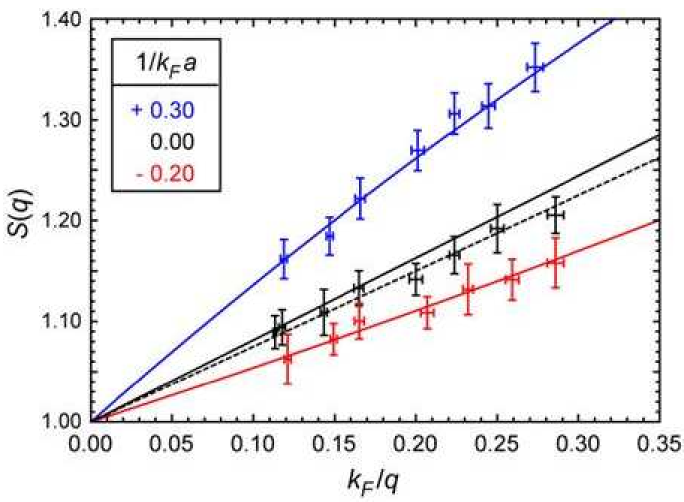

Figure 1: Universal behaviour of the static structure factor of a strongly interacting Fermi superfluid

We have performed Bragg spectroscopy on a strongly interacting ultra-cold ^{6}Li Fermi gas in a balanced mixture of the lowest two spin states to test Eq. (1). To extract the absolute value of the static structure factor we integrate measured Bragg spectra over all Bragg frequencies and normalise them according to the f-sum rule [2]. Multiple Bragg spectra are taken at three different values of the dimensionless interaction parameter $1/(k_F a)$ = 0.3, 0.0, -0.2, and $S(q)$ is plotted versus k_F/q. The data closely follow the exact prediction shown by the solid lines. The dashed line is a straight line fit to the unitarity data which has a slope of 0.75 ± 0.03, slightly below the $T = 0$ prediction of 0.81, due to reduced pairing at finite temperature.

Our new Tan relation is seen to accurately describe $S(q)$ on both sides of the Feshbach resonance. Pair correlations are not only universal but follow a simple power law dependence. These results verify Tan's predictions linking microscopic and bulk properties of these gases and provide the first measure of the contact $\mathcal{I}$.

References

[1] S. Tan, Ann. Phys. **323**, 2952 (2008).

[2] H. Hu, E. D. Kuhnle, X. J Lui, P. Dyke, M. Mark, P. D. Drummond, P. Hannaford, and C. J. Vale, submitted to Nature (2010).

[3] G. Veeravalli, E. Kuhnle, P. Dyke, and C. J. Vale, Phys. Rev. Lett **101**, 250403 (2008).