Universal contact parameter 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 systems 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 and as such form model systems to study universal behaviours. In 2005 Shina Tan [1] developed several exact relations for two component Fermi gases in the BEC-BCS crossover, which connect the bulk thermodynamic properties to the microscopic parameters through a single short-range parameter known as the contact, $\mathcal{I}$.

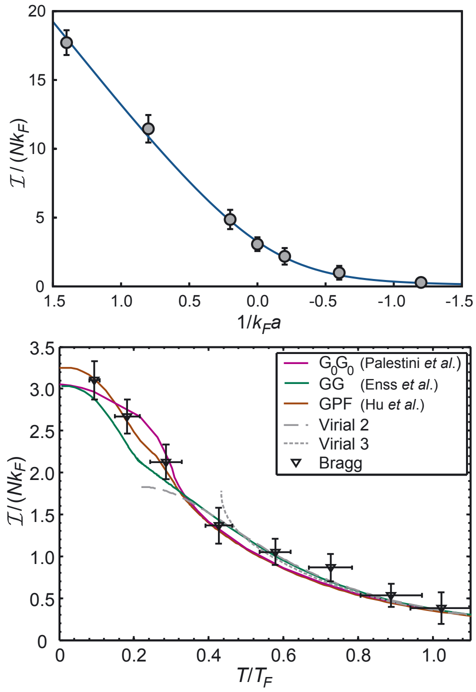

Figure 1: Universal contact parameter $\mathcal{I}$ measured as a function of (a) the interaction strength $1/(k_F a)$ and (b) the reduced temperature T/T_F at unitarity.

Previously, we have verified that pair correlations in a strongly interacting Fermi gas follow Tans universal law [2]. More recently, we have used the universal relation for the static structure factor below, to measure both the interaction and temperature dependence of the universal contact.

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

where N is the atom number, k_F is the Fermi wavevector, k is the probe wavevector 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 that $S_{\uparrow\downarrow}(k >> k_F)$ can be measured with high momentum transfer Bragg spectroscopy [3].

we can use the above equation to obtain the contact as shown in Fig 1(a) on the side. Also shown is a theoretical calculation based on a Gaussian pair fluctuation theory for strongly coupled Fermi gases [4]. The predictions and measurements agree very well. Figure 1(b) shows the temperature dependence of the contact in a unitary Fermi gas when $1/(k_F a) = 0$ [5]. Also shown in this figure are predictions based on the high temperature virial expansion (dashed lines) and three different strong-coupling theories, which deviate from each other near and below the critical temperature for superfluidity ($\sim 0.2T_F$) where T_F is the Fermi temperature [4]. While our data show good broad agreement with the theoretical calculations, we can not yet distinguish between the different calculations with our current experimental uncertainties.

References

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