Universal contact parameter of a strongly interacting Fermi superfluid

Centre for Atom Optics and Ultrafast Spectroscopy, ACQAO, SUT

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, \( \mathcal{I} \).

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.

\[
S_{\uparrow \downarrow}(k \gg k_F) = \mathcal{I} \frac{Nk_F}{k} \left( 1 - \frac{4}{\pi k a} \right)
\]

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.

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 \( \mathcal{I}/N k_F \). We have previously shown that \( S_{\uparrow \downarrow}(k \gg k_F) \) 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 (\( \sim 0.2 T_F \)) 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