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Molecular Probe of the BCS/BEC Crossover in ^{6}Li[1]

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We have used the broad Feshbach resonance in ^{6}Li to create a strongly-interacting Fermi gas and to study the crossover between a Bose-Einstein condensate (BEC) of diatomic molecules and a superfluid of paired fermions. The atoms are prepared in a two-spin component mixture that can be brought into a collisional resonance with a bound molecular state by tuning a magnetic field. A pure BEC of weakly-bound "dressed" molecules is created on the low-field side of the resonance. These dressed molecules are a hybridization of pairs of free atoms in the triplet channel and the bound state in the singlet channel. The details of this hybridization have significant implications for the nature of a Fermi superfluid near a Feshbach resonance as it determines the nature of the pairs; that is, whether they are small and molecular in character, or large extended objects akin to Cooper pairs. We use optical molecular spectroscopy to probe the molecular content of the many-body state at magnetic fields near the Feshbach resonance. The optical probe projects the closed, singlet-channel molecular character of the paired state onto a vibrational level of an excited molecule. We find that the molecular contribution in the crossover region can be $\sim$10%, which is much larger than expected. This large bare molecule fraction is seemingly unexplained by two-body physics. We expect that the large molecular content will have a significant effect on the properties of a resonant Fermi superfluid, including its critical temperature and excitation spectrum. We have also observed that the gas responds to the optical probe when the probe frequency is tuned to the bound-bound bare molecule transition, rather than to the transition from the dressed molecules. The latter transition frequency is magnetic field dependent, while the former is not. When driving the bound-bound transition, the condensate undergoes coherent oscillations as a function of the probe duration that persist for many ms. Although not fully understood, we believe that these oscillations are a collective response of the paired gas.

[1]Work done with K.E. Strecker, G.B. Partridge, R.I. Kamar, and M.W. Jack.