Supporting Online Material for

Pairing and Phase Separation in a Polarized Fermi Gas

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Materials and methods:

Our methods for producing a degenerate gas of fermionic ^{6}Li atoms (*1, 2*) and the realization of the BEC-BCS crossover at a Feshbach resonance (*3*) have been described previously. Approximately 3×10^6 atoms at a temperature $T \approx$ 6 μK are confined by an optical trap that is formed from a single focused infrared laser beam operating at a wavelength of 1080 nm. At an initial laser power of 2 W and with a $1/e^2$ beam radius of 26 μm, the trap depth is 90 μK and the corresponding radial and axial frequencies, υ_r and υ_z, are 4.3 kHz and 40 Hz, respectively. The atoms are prepared in the energetically lowest Zeeman sublevel, $F = ½$, $m_F = ½$, in a nearly uniform bias field of 754 G. A series of 100 saw-tooth frequency sweeps, centered near 76 MHz, create an incoherent spin mixture of the $F = ½$, $m_F = ½$ (state $|1\rangle$) and the $F = ½$, $m_F = -½$ (state $|2\rangle$) sublevels. These states interact via a broad Feshbach resonance located near 834 G (*4, 5*). The relative numbers of atoms in $|1\rangle$ and $|2\rangle$ can be controlled by changing the power of the rf sweeps, thereby creating a polarized gas. By adjusting the power to transfer roughly 50% of the population in each sweep, a state with exactly $P = 0$ should be formed at the end of the 100 sweep sequence. Polarizations with $P > 0$ are achieved using less rf power.

After preparation of the spin mixture, the atoms are evaporatively cooled by reducing the optical trap depth over a period of 750 ms. Since the *s*-wave scattering length *a* is large near the Feshbach resonance, the elastic collision rate is high and evaporation is efficient. Evaporation continues until the trap depth reaches a final value of ~0.6 μK. The magnetic field is ramped to a desired field within the crossover region during the final 100 ms of evaporation. For the case of $P = 0$ at 754 G, a molecular Bose-Einstein condensate (MBEC) is observed to form with no detectable thermal molecules. A small magnetic field curvature produced by the magnetic bias coils contributes significantly to the axial confining potential for the low optical trap depths needed for cooling to the lowest temperatures (*3*). To accurately characterize the axial potential at each field, we directly measure υ_z by observing the period of oscillation of an atomic cloud that has been "kicked" by a transient field generated with an external coil. At 830 G, we find $\upsilon_r = 350$ Hz and $\upsilon_z = 7.2$ Hz at the final trap depth.

States $|1\rangle$ and $|2\rangle$ are sequentially and independently imaged in the trap by absorption using a probe laser beam resonant with the $^2S_{1/2}$ to $^2P_{3/2}$ atomic transition specific to each state. The two probes are each 5 μs in duration and are separated in time by 215 μs, which is fast compared to the timescale of oscillation in both the radial and axial dimensions, as well as to the expansion rate associated with the Fermi energy of the system. Although the probe frequencies are separated by 77 MHz, which is large compared to the transition linewidth of 5.9 MHz, a slight heating of the radial dimension is observed in the second image. This heating is due both to off-resonant excitation and to the release of binding energy from the dissociation of the weakly bound pairs. The second mechanism is only important in the BEC regime and does not contribute for fields above 800 G, where the molecular binding energy is less than 1 μK. At such fields, the axial profile obtained by integrating out the remaining radial direction (as shown in Fig. 2 of the report) shows no dependence on the probing order. However, for fields below 650 G, radial heating in the second image is so severe as to prevent detection of the second state.

Due to decreasing evaporation efficiency with increasing P, there is a correlation between P and total atom number. Figure S1 shows that N_1 decreases by a factor of two from ~1.2×10^5 at $P = 0$ to ~6×10^4 at $P = 0.2$, but is relatively constant for $P > 0.2$.

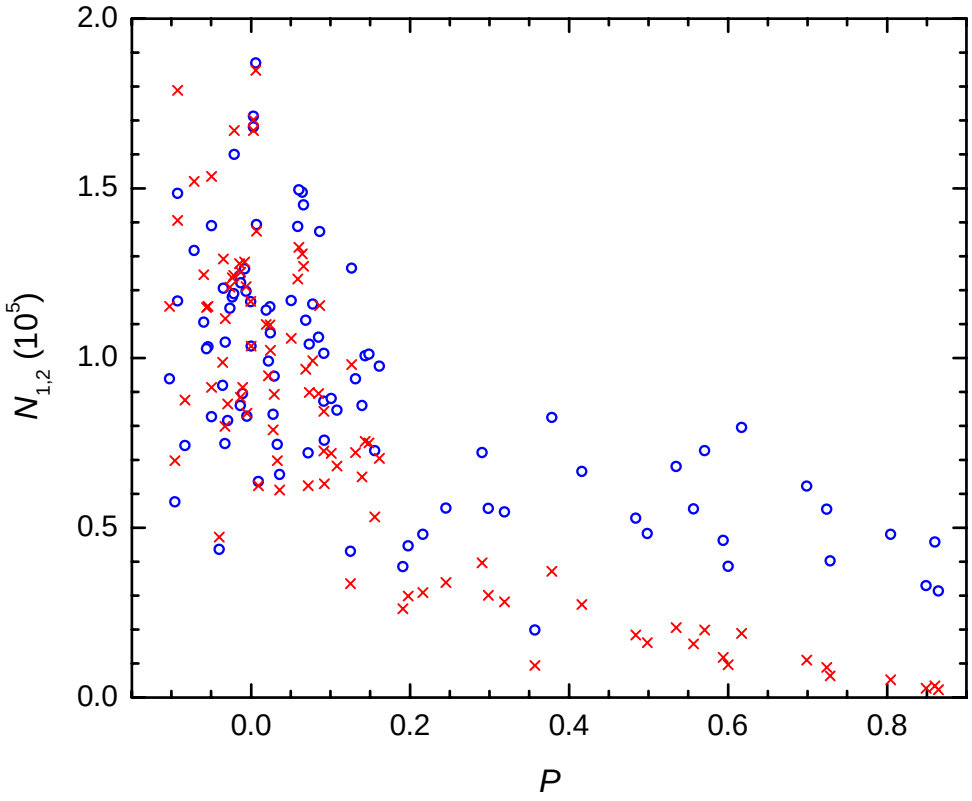

Fig. S1. N_1 and N_2 vs. P at 830 G. Open circles correspond to N_1 while crosses correspond to N_2. The correlation between N_1, N_2, and P, is attributed to decreasing evaporation efficiency in the optical trap for increasing polarization. For larger P values, smaller numbers result in increased relative uncertainties in P.

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