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Supporting Online Material for

Pairing Without Superfluidity:

The Ground State of an Imbalanced Fermi Mixture

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Materials and Methods

Figs. S1 to S3

References

Experimental details

1. **Determination of the atomic reference line:** For the data taken at the center of the $|1\rangle - |2\rangle$ Feshbach resonance the resonance frequency of the $|2\rangle - |3\rangle$ transition in the absence of atoms in state $|1\rangle$ was determined to be 81.700 MHz $\pm$ 1 kHz, corresponding to a magnetic field of about 833 G. The FWHM of a Lorentzian fit to the resonance peak was less than 1 kHz. These values reflect day to day fluctuations and correspond to a magnetic field stability better than 0.2 G. The resonance frequency of the $|2\rangle - |3\rangle$ transition on the BCS-side of the Feshbach resonance (Fig. 3) was 81.187 MHz $\pm$ 1 kHz (corresponding to a magnetic field of 936.5 G), determined in the absence of atoms in state $|1\rangle$.

2. **Rf pulse**: For all data a rf pulse of 2 ms was applied. This pulse duration is optimized in terms of precision and minimizing a dynamic response of the system during the rf pulse. For each spectrum the rf power was adjusted to give an adequate signal-to-noise ratio.

3. **Determination of the atom number fraction in state $|2\rangle$:** To obtain the atom number fraction $N_2/(N_1+N_2)$ two absorption images, one of the minority component in state $|2\rangle$ and the other of the majority component in state $|1\rangle$, were taken successively. The time-of-flight before the first absorption image as well as the delay time between the absorption

images were adjusted depending on the imbalance δ of the mixture, final temperature and the trapping frequency of the optical dipole trap. The time-of-flight before the absorption image of the minority varied between 200 μs and 8 ms, the delay time between the images was in the range of 500 μs and 2 ms.

4. **Imaging atoms transferred to state $|3\rangle$; Fig. 2A**: For the rf spectrum in Fig. 2A, T/T_F was increased by shortly switching off the optical dipole trap and allowing for subsequent equilibration before the rf pulse. The number of atoms transferred to state $|3\rangle$ was recorded for a better signal-to-noise ratio . The absorption image had to be taken within 200 μs after applying the rf pulse. After longer time-of-flight atoms in state $|3\rangle$ decayed through collisions. This precluded imaging atoms in state $|3\rangle$ at lower temperatures where longer time-of-flights were required before absorption imaging to avoid saturation.

5. **Weight of the atomic peak as function of imbalance**: The population imbalance affects the weight of the atomic peak in rf spectra obtained at the same T/T_F (compare Fig. 2D, S1C and S2B). As the imbalance decreases, the weight of the atomic peak increases. This is likely due to the higher relative temperature compared to the local binding energy in the the lower density region of the majority could. That effect will result in a higher fraction of unpaired atoms at small imbalances.

6. **Temperature determination**: Except for equal and nearly equal mixtures ($\delta < 20\%$), temperatures were determined from the *non-interacting* wings of the majority cloud after expansion (*S3*). In ref. (*S3*) it was found that for imbalances $\delta > 20\%$ the non-interacting wings of the majority cloud expand ballistically and are not affected by the hydrodynamic expansion of the interacting component. For equal or nearly equal mixtures the temperature T' was determined from a finite-temperature Thomas-Fermi fit to the whole density profile of the majority cloud.

7. **Clogston-Chandrasekhar limit**: The experimental value quoted of $\delta_{\mathbf{c,exp}} = 0.74(5)$ on resonance was obtained with the following probes for superfluidity: vortices and condensate fractions (*S2*), bimodal density distributions of the minority cloud in time-of-flight (*S3*). We would like to emphasize, that the previous experimental determination of the critical imbalance included a measurement of its *temperature dependence*, which was found to be weak at low temperatures (*S2*).

8. **Condensate fractions**: Condensate fractions were obtained as previously described in ref. (*S1*) and (*S2*). The samples were prepared as in the rf experiment, but the rf pulse was not applied. Instead the gas was released from the trap and the magnetic field was switched in 200 μs to 690 G, where the cloud expanded for several ms. Then the magnetic field was ramped in 1 ms to 720 G for absorption imaging. Condensate fractions were determined from bimodal fits to the minority component. Condensates were only observed when condensate fractions are explicitly stated (Fig. 4 of the letter).

References and Notes

S1. M. W. Zwierlein *et al.*, *Phys. Rev. Lett.* **92**, 120403 (2004).

S2. M. W. Zwierlein, A. Schirotzek, C. H. Schunck, W. Ketterle, *Science* **311**, 492 (2006).

S3. M. W. Zwierlein, C. H. Schunck, A. Schirotzek, W. Ketterle, *Nature* **442**, 54 (2006).

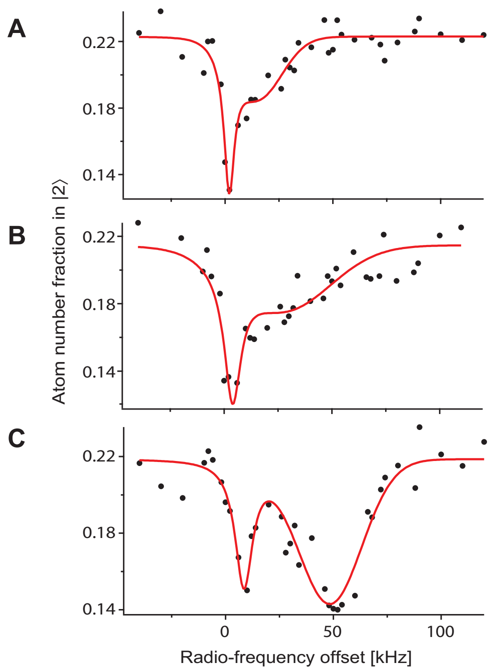

Fig. S1. Rf spectra of the minority component on resonance at 833 G. The spectra correspond to the open triangles shown in Fig. 1 of the letter and were obtained for the following parameters: A) $\delta = 0.55$, $E_F = h \times 230$ kHz, $T/T_F = 0.9$; The trapping frequencies for **A** were $\omega_r = 2\pi \times 3.4$ kHz and $\omega_a = 2\pi \times 76$ Hz. B) $\delta = 0.57$, $E_F = h \times 230$ kHz, $T/T_F = 0.5$; C) $\delta = 0.57$, $E_F = h \times 220$ kHz, $T/T_F = 0.25$. The trapping frequencies for **B** and **C** were $\omega_r = 2\pi \times 2.9$ kHz and $\omega_a = 2\pi \times 64$ Hz.

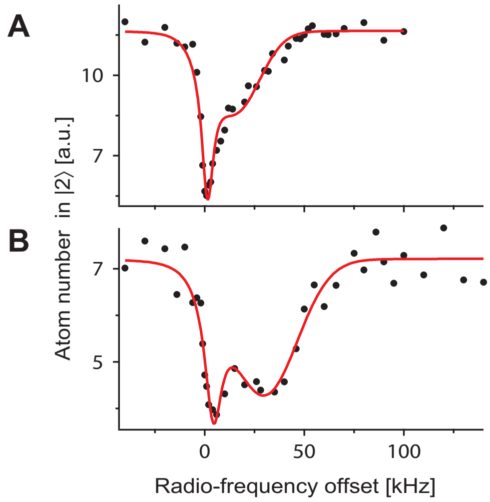

Fig. S2. Rf spectra of the minority component on resonance at 833 G. Since the majority component of the nearly equal mixture also suffered significant losses after the rf pulse (probably due to inelastic collisions), we report here the un-normalized atom number in state $|2\rangle$ as a function of the applied radio frequency. The spectra correspond to the open circles shown in Fig. 1 of the letter and were obtained for the following parameters: A) $\delta = 0.07$, $E_F = h \times 210$ kHz, $T'/T_F = 0.67$; B) $\delta = 0.07$, $E_F = h \times 180$ kHz, $T'/T_F = 0.34$. The trapping frequencies were $\omega_r = 2\pi \times 2.9$ kHz and $\omega_a = 2\pi \times 64$ Hz.

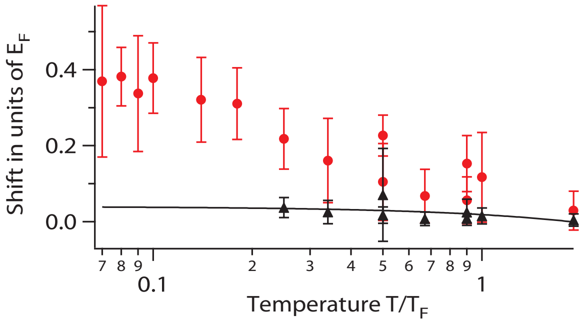

Fig. S3. Normalized shifts of the atomic peaks (black triangles) and pairing peaks (red circles) as a function of T/T_F (for equal mixture data as a function of T'/T_F). E_F (T_F) is the Fermi energy (temperature) of a non-interacting Fermi gas with the same number of atoms as the majority component. The black line is a linear fit to the atomic peak shifts. The error bars reflect the full width at half maximum of a Gaussian fit to the peaks.