Communal Pairing in Superconductors

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Introduction

A Fermi gas with an attractive interaction forms a superconducting state whose underlying components are Cooper pairs, as described by Bardeen, Cooper and Schrieffer [1] in the spin-balanced case and by Fulde and Ferrell, and Larkin and Ovchinnikov (FFLO) [2, 3], in the spin-imbalanced case. We propose a significant extension to FFLO theory by including correlations between all available fermions at the Fermi surface, making it energetically favorable to the FFLO superconducting state [4, 5]. We further supplement the analytical theory with numerical results obtained from ab initio Diffusion Monte Carlo (DMC) and Exact Diagonalisation (ED) calculations.

Methods

DMC The CASINO [6] Quantum Monte Carlo program was used to probe the ground state of Fermi gases of varying particle number by measuring the condensate fraction in momentum space.

ED Exact diagonalisation was performed on the same systems as DMC to provide a comparison between the expected condensate fraction distributions obtained via FFLO theory, communal pairing theory and the DMC results.

Conclusion

A spatially modulated superconducting gap is observed in DMC for the first time. Comparison to ED studies indicates that the ground state is most well-described by communal pairing theory rather than FFLO theory. The expected relationship between the ratio of the densities of states at the Fermi surfaces and the ratio of communal pairing indices, $N_\uparrow/N_\downarrow = \nu_\uparrow/\nu_\downarrow$ is verified, with evidence of higher order corrections.

References

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Acknowledgements

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Schematics

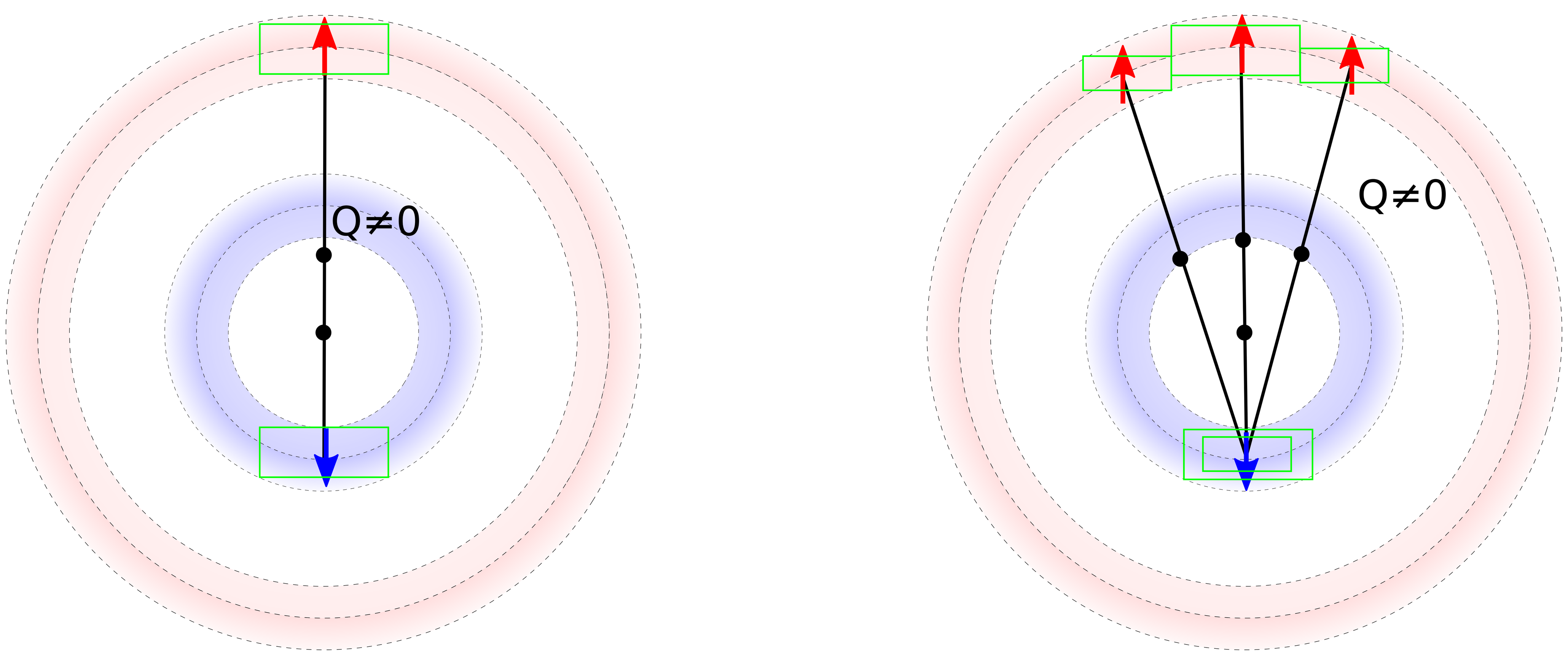

Figure 1: Pairing schematics for FFLO theory (left) and $(N_\uparrow, N_\downarrow) = (3, 1)$ communal pairing theory (right). The correlated states are limited by the spin-imbalance. In communal pairing, multiple majority fermions are correlated with the same minority species fermion, making fuller use of the majority Fermi surface. The pairing space decreases with offset from FFLO, limiting the values of $N_\uparrow$ and $N_\downarrow$.

Results

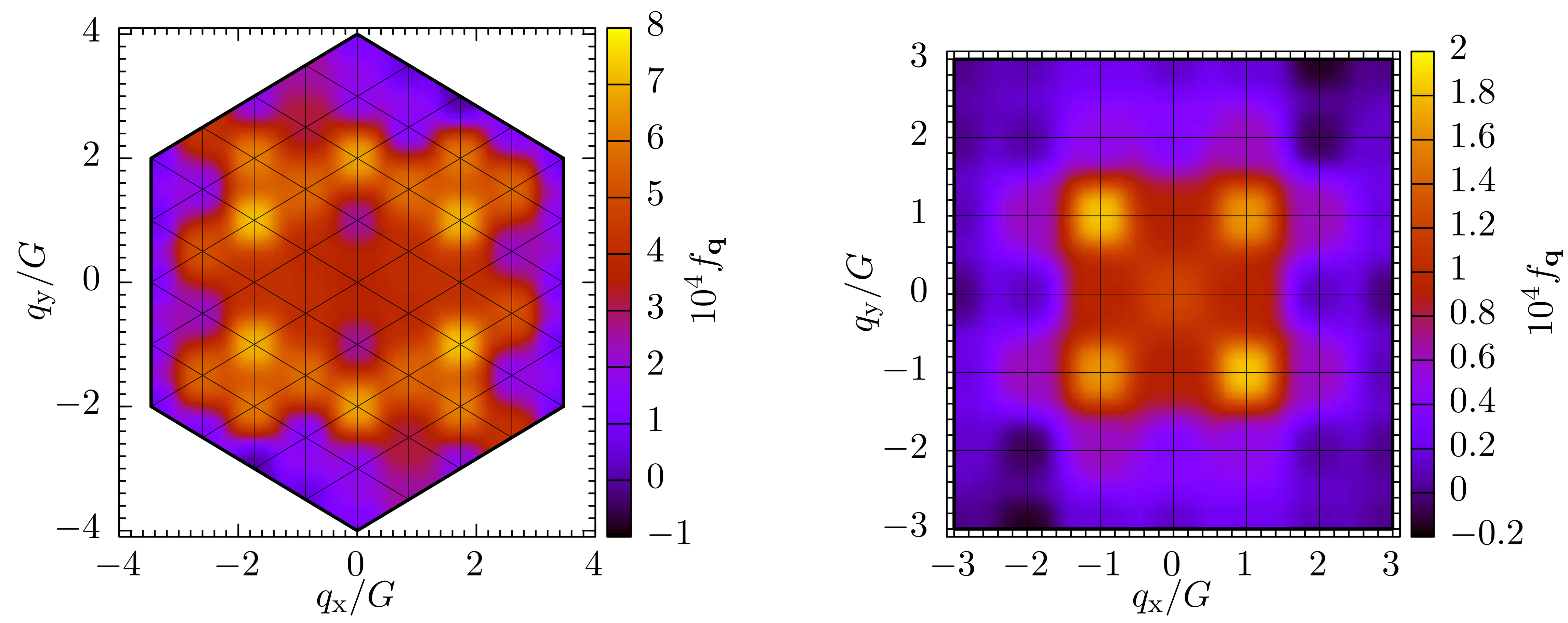

Figure 2: Condensate fraction as a function of pair momentum for a triangular (left) and (square) momentum space lattice. The ratio of the densities of states in momentum at the Fermi surface is $\nu_\uparrow/\nu_\downarrow = 2$. The condensate fraction exhibits the symmetry of the underlying lattice.

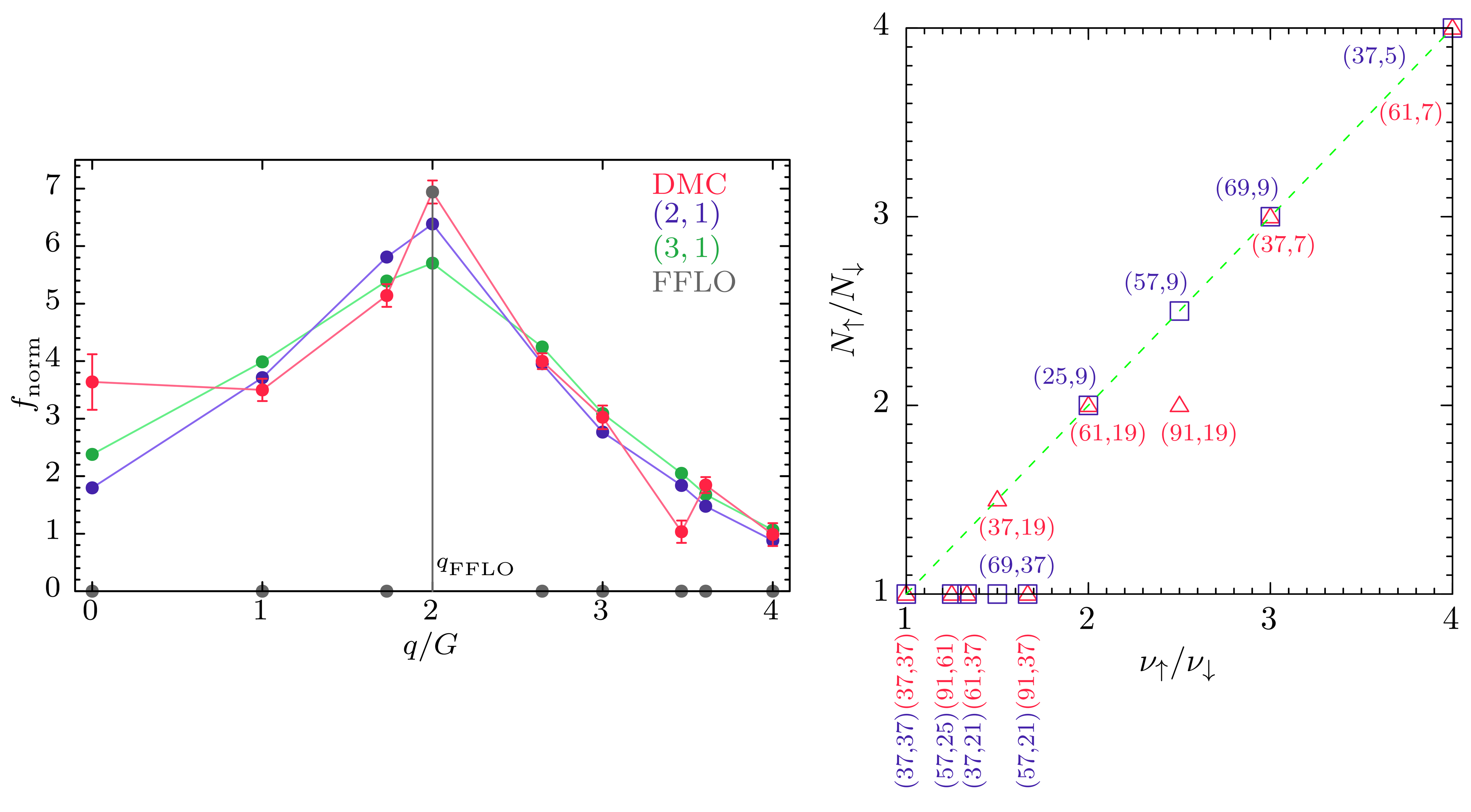

Figure 3: (Left) Condensate fraction as a function of magnitude of pairing momentum obtained from DMC and ED. A major peak is obtained at the expected FFLO pairing momentum with nonzero condensate fraction measured at a range of pairing momenta. Analysis of the weighted squared deviations indicate that the DMC results are best described by a $(N_\uparrow, N_\downarrow) = (2, 1)$ communal pairing state. (Right) Plot of the ratio of communal state indices against the ratio of the densitites of states in momentum for triangular and square momentum space lattices. Particle numbers are shown in brackets. The data is well described by theoretical predictions, $N_\uparrow/N_\downarrow = \nu_\uparrow/\nu_\downarrow$, with higher order corrections limiting $N_\uparrow/N_\downarrow$ when either is not a small integer.