Phase diagram of the integrable px+ipy fermionic superfluid

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The exact solution of the SU(2) pairing Hamiltonian with non-degenerate single particle orbits was introduced by Richardson in the early sixties, although largely forgotten till the last decade when is was rediscovered in an effort to describe the disappearance of superconductivity in ultrasmall grains. Since then Richardson's exact solution has been generalized to several families of exactly solvable Richardson-Gaudin models [1]. However, only rational family has been widely applied to mesoscopic systems where finite size effects play an important role. We have recently found an implementation of the hyperbolic family of the Richardson-Gaudin models to describe p-wave pairing [2]. Using this new tool we study the quantum phase diagram of a spinless Fermi gas in a 2D optical lattice with $p_x + ip_y$ pairing symmetry. Unlike the case of s-wave pairing, which has a smooth a crossover between BCS and BEC, p-wave pairing displays a quantum phase transition separating two gapped superfluid phases known as weak-pairing and strong-pairing. We make use of the exact solution for finite systems as well as mean-field BCS, which we show to be exact in the thermodynamic limit, to characterize the quantum phase transition and the properties of the two phases. As in the case of the BCS-BEC crossover of s-wave pairing [3], the exact wavefunction of the p-wave pairing Hamiltonian gives a beautiful insight into the nature of the quantum phase transition as well as into the structure of the Cooper pairs in the different phases. Moreover, it suggests the existence of an experimentally accessible characteristic length scale, associated with the size of the Cooper pairs, that diverges at the transition point, indicating that the phase transition is of a confinement-deconfinement type without local order parameter.

[1] J. Dukelsky, C. Esebbag, and P. Schuck. Phys. Rev. Lett. 87, 066403 (2001)

[2] S. Rombouts, J. Dukelsky, and G. Ortiz. Phys. Rev. B 82, 224510 (2010)

[3] G. Ortiz and J. Dukelsky, Phys. Rev. A 72, 043611 (2005)