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Superfluidity and Geometry of Flat Bloch Bands

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Correlated many-body states of fermions moving in a lattice are at the root of many fascinating phenomena in condensed matter, which are at present still poorly understood. The main example in this sense is high-Tc superconductivity. Understanding the low energy properties of a system ofmany fermions in a lattice, even in its simplest realization, the Fermi-Hubbard model, is challenging both from the conceptual and the computational point of view [1]. Therefore it is of paramount importance to find ways to simplify the problem. One possibility is to consider lattices with flat bands, that is Bloch bands with vanishing bandwidth (infinite effective mass). In the case of flat band models it is possible to obtain remarkable exact results. For example Mielke and Tasaki have rigorously proved that a maximally polarized ferromagnet is the unique ground state (up to rotations) for a half-filled flat band in a repulsive Hubbard model [2]. On the other hand we have focused on the attractive case, motivated by the expectation that the diverging density of states of a flat band should boost the superconductive critical temperature [3]. We find that the ground state is well described by the BCS wavefunction [6], whereas the normal state of a flat band superconductor is very different from a Fermi liquid and in this sense similar to the pseudogap phase of high-Tc superconductors. Indeed we provide evidence that only pairs of particles are mobile in a flat band in the presence of interactions, while unpaired particles remain localized [9]. We have also related the superfluid weight of a flat band superconductor to geometric and topological invariants of the band structure, respectively the quantum metric and the Chern number [4-8]. In particular we find that the superfluid weight of a flat band is bounded from below by the Chern number. Our results are not limited to the attractive case since in the flat band limit a superconductor can be mapped exactly into a ferromagnet of the Mielke and Tasaki type [5,6]. Ultracold gases are the most promising platform to verify these predictions, but our results are potentially important also for solid state superconductors.

References

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