Superflow instabilities of atomic fermion superfluids in an optical lattice

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We study the superfluid phase of the one-band attractive Hubbard model as a prototype of a strongly correlated fermionic superfluid on a lattice. We characterize its collective mode and compute the sound velocity and “roton” gap within a generalized random phase approximation (GRPA). At strong coupling, we perform a spin wave analysis of the appropriate pseudospin model, with our GRPA results matching onto the spin wave results. With our two-pronged understanding of the collective mode, we examine breakdown of superfluidity due to imposed supercurrent. We find several mechanisms of superflow breakdown - depairing, Landau or dynamical instabilities. The most interesting is a charge modulation dynamical instability distinct from those previously studied in Bose superfluids. The associated charge order can be of two types: (i) a commensurate checkerboard modulation driven by softening of the roton mode at the Brillouin zone corner, or (ii) an incommensurate modulation arising from flow-induced finite-momentum pairing of Bogoliubov quasiparticles. We map out a dynamical phase diagram showing critical flow momentum of the leading instability, and point out implications for experiments on cold atom superfluids in an optical lattice.

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