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The amplitude mode at the superfluid-mott insulator transition

DAVID PEKKER, Caltech

We study a two dimensional gas of repulsively interacting bosons in the presence of both an optical lattice and a trap using optical lattice modulation spectroscopy. The strongly interacting superfluid supports two types of low energy modes associated with the symmetry breaking at the phase transition: gapless phase (Goldstone) modes and gapped amplitude (Anderson-Higgs) modes. Both experimentally and in theoretical simulations lattice modulation spectroscopy shows an onset of absorption at a frequency associated with the amplitude mode gap, followed by a broad absorption peak at higher frequencies. From the simulations, we learn that energy is being absorbed by various amplitude modes, which inside a trap resemble the modes of a (gapped) drum. Our main results are: (1) despite coupling to the phase modes, modulation spectroscopy shows a sharp absorption onset at the frequency associated with the amplitude mode gap; (2) as we approach the Mott transition the gap softens and finally disappears at the transition point; (3) in the weak coupling regime, deep in the superfluid phase, the amplitude mode disappears.