



PhD Thesis Defense **OLIVIER TIELEMAN** 'Ultracold atoms in optical lattices with long-range interactions and periodic driving'

OLIVIER TIELEMAN

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Friday March 8, 11:00. ICFO Auditorium

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Quantum Optics Theory

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This thesis contains theoretical research on ultracold quantum gases in spatially periodic potentials, featuring high-frequency periodic driving, long-range interactions, or both. The largest part features deep potentials where the behaviour of the gas is well-described by

quantum lattice models. The periodic driving is then integrated out to obtain effective time-independent descriptions. One project investigates emergent long-range interactions in a stationary, weak, spatially periodic potential, where a lattice theory is not appropriate.

In two short introductory chapters, the topics of ultracold atoms, optical lattice potentials, periodic driving, and long-range interactions, are sketched, without attempting to give a complete overview. Some experimentally relevant length and energy scales are given, but the main focus is on deriving and constructing theoretical descriptions of ultracold gases in various spatially and/or temporally periodic potentials.

The first project presented, is focused on how the single-particle spectrum of a Bose gas in a non-separable two-dimensional square lattice is affected by high-frequency periodic driving; the most striking conclusion is that under suitable circumstances, it develops two inequivalent minima, leading to finite-momentum Bose-Einstein condensation. Perturbative calculations indicate that local interactions induce spontaneous time-reversal symmetry breaking (TRSB) in such a system.

The second project investigates the interplay between kinetic frustration and long-range interactions in fermionic gases. Both a mean-field approximation and exact diagonalisations predict that such a system, studied in the more specific realisation of a weakly interacting dipolar fermionic gas in a 2D triangular lattice, also leads to spontaneous TRSB. Furthermore, a density wave could form at quarter filling, where the Fermi surface is perfectly nested. Perhaps more interesting yet, a spatially inhomogeneous TRSB pattern is predicted, confined to the low-density sublattice that emerges in the density wave.

The third project revolves around the question of supersolidity in the presence of a gauge field. Applying the Bogolyubov approximation to a variation of the extended Bose-Hubbard model, indicates that combining an artificial staggered magnetic field in a 2D square lattice with nearest-neighbour density-density interactions, not only leads to a supersolid with staggered vortices, but also induces an inhomogeneous distribution of the associated currents around the elementary plaquette.

In the fourth project, a one-dimensional Bose gas with strong local interactions in a weak lattice at incommensurate densities is shown to feature excitations corresponding to excess or deficit particles. The excitations interact repulsively at long distances, in spite of the fact that the underlying atoms themselves do not. As a consequence, the incommensurability of the density with the lattice can drive a transition to a density wave and even a supersolid.

The four above-mentioned research projects combine bosonic and fermionic gases, weak and strong interactions, perturbative and mean-field approximations, effective field theories and exact diagonalisations. The main overall conclusion is that long-range interactions and high-frequency periodic driving lead to a very diverse range of fascinating phenomena in ultracold lattice gases.

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