SFB925 Highlights

Direct Observation of Chiral Order

The effect of quantum degeneracies can yield dramatic consequences in quantum many body systems, since tiny energy scales can decide, which quantum superposition state is actually realized in a system. The determination of this state requires phase information, which is often difficult to obtain in electronic condensed matter. In contrast, ultracold atomic gases provide a straight-forward technique to study phase coherence by matterwave interference.

We prepare bosonic atoms in the second band of a bipartite optical square lattice, where they condense into two inequivalent minima at the X_± points and form a metastable superfluid (see figure 1). When these minima are energetically nearly degenerate, the interaction energy, which is small compared to the kinetic energy of the atoms, determines the favored superposition state of the wave functions at the minima. A complex-valued coherent superposition with a fixed relative phase of $(\pm\,\pi)/2$ gives rise to local complex-valued superpositions of p-orbitals, which provide increased mode-volume compared to real-valued superpositions of p-orbitals. Thus, for repulsive interactions this state minimizes the interaction energy and resembles the ground state of the many-body system.

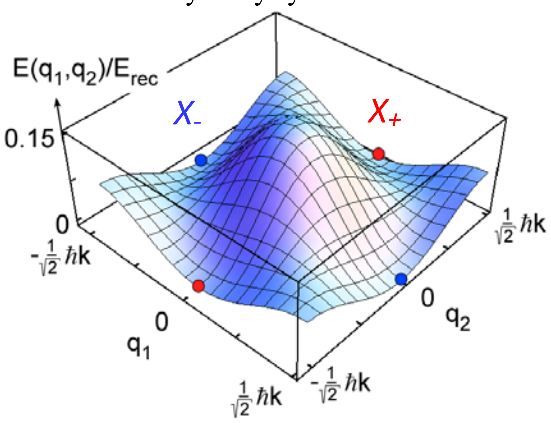

Fig. 1: Direct Observation of Chiral Order Atoms condense into two inequivalent condensation points X_± of the 2nd band.

Because information on phase relations is lost in standard absorption imaging, we conduct a matterwave interference experiment to determine the phase relation between the condensates. We employ a repulsive optical potential as a tunneling barrier between two perfectly aligned optical lattices. In both optical lattices, the atoms are excited to the second band and condense independently into the corresponding band minima. During time of flight, the condensates at the same condensation points in the two optical lattices interfere with each other, which results in interference gratings within the lowest order Bragg peaks. These interference gratings carry the desired phase information.

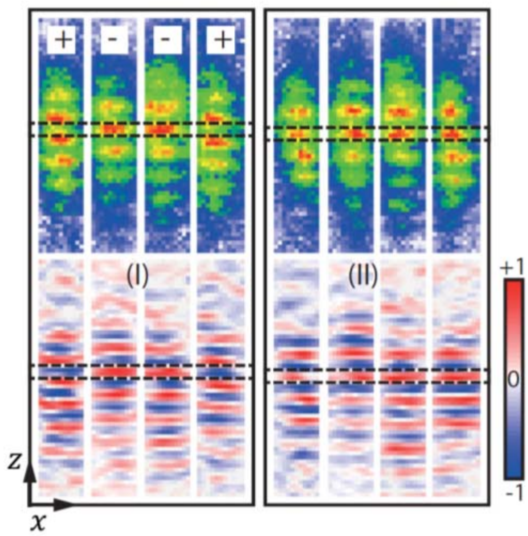

Fig. 2: Direct Observation of Chiral Order The two dominant results of the experiment: a phase difference of π (I) or 0 (II) between the Bragg peaks belonging to different condensation points. The upper row shows the raw data, which is repeated in the lower row after band pass filtering and normalization.

In the overwhelming part of experimental realizations, we encounter one of the two scenarios depicted in figure 2: The interference gratings of those Bragg peaks belonging to different condensation points are either completely correlated or anti-correlated. These two cases correspond to situations where in each of the two optical lattices either the same phase of (± π)⁄2 or phases with opposite sign between the condensates are chosen spontaneously. This finding clearly shows that the relative phase between the condensates only takes two fixed values, which is in perfect agreement with the formation of the complex-valued coherent superposition and the build-up of chiral order.

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