



Novel non-trivial properties of Topological Quasiparticles from Bose-Einstein Condensates

ICFO researchers Zahra Jalali-mola, Tobias Grass, Valentin Kasper and Utso Bhattacharya, led by ICREA Prof. at ICFO Maciej Lewenstein report in *Physical Review Letters* on the stability of Bose Einstein Condensates, where Bogoliubov excitation modes have non-trivial topological properties.

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The discovery of topological band structures has given rise to an exciting and rapidly evolving field that blends concepts from topology and condensed matter physics by means of new materials with unique properties. The most prominent feature of topological insulators is their edge or surface states, which are topologically protected from backscattering. This protection means that these surface states are robust against impurities and imperfections, making them of great interest for potential applications in electronic devices.

Cold atomic systems, such as ultracold bosonic gases, have provided a fascinating platform for exploring topological properties in the realm of bosonic matter. These experiments have played a crucial role in advancing our understanding of topological band structures in a broad range of quantum systems. In some quantum systems, non-trivial topological features emerge due to the interactions between particles, rather than relying solely on the single-particle band structure. This means that the non-trivial topology is not initially present in the single-particle bands, but rather interactions induce topological properties in the many-body system. Degenerate flat bands are a prime example of this phenomenon realized in magic-angle twisted bilayer graphene. Flat bands are bands with zero or near-zero dispersion, and they can be generated by lattice structures or potentials. The interactions between particles, such as bosons or electrons, in these flat bands can give rise to exotic, interaction-driven topological states and other exotic many body phenomena such as unconventional superconductivity.

Optical lattices with Kagome geometries, which consist of a lattice structure resembling a hexagonal pattern of interconnected triangles, are known for hosting the lowest flat band via artificial gauge fields which is a potential candidate for topological properties in the presence of interactions. Nevertheless, the stability of Bose Einstein condensation in the lowest flat band is questionable due to the effects of zero-point fluctuations because of the suppression of kinetic energy in flat bands and the presence of many body interactions.

In a recent study published in *Physical Review Letters*, ICFO researchers **Zahra Jalali-mola, Tobias Grass, Valentin Kasper and Utso Bhattacharya**, led by ICREA Prof. at ICFO **Maciej Lewenstein** have reported on the stability of BEC in Kagome optical lattice in the lowest flat band, where the Bogoliubov excitation modes, as a result of broken time reversal symmetry in the Bogoliubov-de-Gennes Hamiltonian, have non trivial topological properties.

Flat band systems have attracted a lot of attention in the search for high temperature superconductors because they are actual hosts of strong interactions. In addition, their exotic quantum properties make them also ideal candidates to do research on quantum information and quantum simulation. Considering a flat-band system in the context of Bose condensates, the team of scientists has found that these interactions induce topological excitations. Furthermore, by tuning these interactions, there exists a topological phase transition emerging as different topological properties of the Bogoliubov excitations of different topological Chern numbers

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Figure Caption: Dispersion relation of Bogoliubov quasiparticles above the BEC condensate. The dispersion of the bulk and semi-finite configuration (limited along the y axis) Bogoliubov quasiparticles is shown in panels (a), and (b), respectively. The edge states between middle and highest energy band defined by the red and blue colors. The localization and chirality

of the edge states is depicted in the panel (c). Here, for the Bose Hubbard interaction $U/t=3$ and nearest neighbor interaction $V/t=0.6$ are assumed

. Zahra Jalalimola together with the ICFO-QOT group led by ICREA Prof. at ICFO Maria Lewenstein and with ex-ICFO members Tobias Grass and Valentin Kasper publishes this study in Phys. Rev. Lett. devoted to exotic topological properties of Bogoliubov Quasiparticles from Bose-Einstein Condensate in a Flat Band System