New perspectives on quantum geometry, superconductivity and Bose-Einstein condensation

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Superconductivity, superfluidity and Bose-Einstein condensation (BEC) are many-body phenomena where quantum statistics are crucial and the effect of interactions may be intriguing. Superconductors are already widely applied, but theoretical understanding of superconductivity and condensation in several real world systems is still a challenge, and superconductivity at room temperature remains a grand goal. We have recently discovered that superconductivity (superfluidity) has a connection to quantum geometry [1-3]. Namely, the superfluid weight in a multiband system has a previously unnoticed component, which we call the geometric contribution. It is proportional to the quantum metric of the band. Quantum metric is connected to the Berry curvature, and this allows to relate superconductivity with the topological properties of the band. Using this theory, we have shown that superconductivity is possible also in a flat band where individual electrons would not move. We show that, in a flat band, the salient features of superconductivity are actually given already by the two-body physics [3]. These results may be essential in explaining for instance the recent observation of superconductivity in bilayer graphene, and may eventually help realize superconductors at elevated temperatures.

Bose-Einstein condensation has been realized for various particles or quasi-particles, such as atoms, molecules, photons, magnons and semiconductor exciton polaritons. We have recently experimentally realized a new type of condensate: a BEC of hybrids of surface plasmons and light in a nanoparticle array [4]. The condensate forms at room temperature and shows ultrafast dynamics. We utilized a special measurement technique, based on formation of the condensate under propagation of the plasmonic excitations, to monitor the sub-picosecond thermalization dynamics of the system. This new platform is ideal for studies of differences and connections between BEC and lasing [5], and eventually also studies of topological phenomena due to the easy tunability of the array geometry and the system symmetries [6].

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