Josephson currents in superfluids and supersolids

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Supersolidity is a state of matter where coexist superfluidity and crystalline order. Despite the first theoretical prediction dates back to 1969, it has been observed for the first time in a dipolar quantum gas in 2019. In a supersolid dipolar quantum gas, the interplay between the interactions in the gas creates a self-induced density modulation in it. We show that this density dips behave as effective Josephson weak links among nearby clusters of atoms. This system can show the characteristic dynamics of a bosonic Josephson junction, for relatively long times and with a surprisingly weak coupling with other dynamical modes. Small amplitude excitations induce Josephson-like oscillations of the clusters' relative phase and population imbalance with the distinctive $\pi/2$ shift of the Josephson effect. Increasing the initial population imbalance beyond a critical value, the system crosses over a macroscopic quantum self-trapping regime with unbalanced population oscillations and running phase. We base our predictions on a many-mode model, supported by 3D numerical simulation of an extended Gross-Pitaevskii equation with the addition of first-order quantum fluctuations. Collaboration with the experimental group in Pisa led by prof. Modugno validates the theory, observing Josephson oscillations and measuring their frequencies. In addiction, we propose and demonstrate an innovative method to measure the superfluid fraction of a supersolid based on the Josephson effect. The result quantitatively demonstrates the existence of the supersolid as an intermediate phase between superfluids and crystals, measuring for the first time a sub-unity superfluid fraction.