Many-body quantum physics of Josephson coupled Bose condensates

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Atomic Bose-Einstein condensates are intrinsic many-body quantum systems. Many-body quantum effects become significant in low-dimensional systems and systems with strict symmetry constraints, degeneracy, or strong interaction. Examples include low-dimensional quantum gases, spinor condensates, rapidly rotating systems, strongly interacting systems, and condensed atoms loaded into deep multi-well potentials. For condensates confined in multi-well potentials, such as double-well potentials and optical lattices, the Josephson tunneling links together the condensates in different wells and then establish the relative phase which could be measured in experiments.

By loading condensates into magnetic or optical double-well potentials, atomic interferometers have been demonstrated in several labs [1, 2, 3, 4], including the SUT node of ACQAO. Beyond the macroscopic quantum coherence, various many-body quantum effects such as coherence fluctuations, conditional tunneling, squeezing, and entanglement have been observed in experiments, and applications of these effects in modern quantum technology such as high-precision measurement [5] and quantum information processing have been discussed. Recently, we gave clear theoretical explanations for the full picture of the coherence fluctuations, the resonant tunneling and the interaction blockade [6].

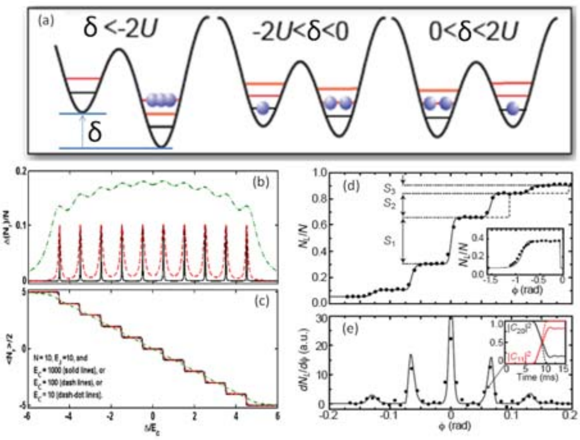

Fig. 1: Resonant tunneling and interaction blockade. (a) The schematic diagram, (b) and (c) Our theoretical prediction [6], (d) and (e) Experimental data from Bloch's group [7].

We introduce universal operators for characterizing many-body coherence without limitations on the system symmetry and total particle number N. We not only reproduce the results for both coherence fluctuations and number squeezing in symmetric systems of large N, but also reveal several peculiar phenomena that may occur in asymmetric systems and systems of small N. For asymmetric systems, we show that, due to an interplay between asymmetry and inter-particle interaction, the resonant tunneling and interaction blockade take place in sequence. The resonant tunneling and interaction blockade have been confirmed in Bloch's lab [7], and they may be used for counting atom numbers and creating single-atom devices with promising technology applications.

Our most recent studies deal with both mean-field and full quantum dynamics of symmetry-breaking transitions in Josephson coupled condensates. In particular, we explore the universal dynamical mechanisms and anomalous mean-field breakdown induced by symmetry breaking [8].

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