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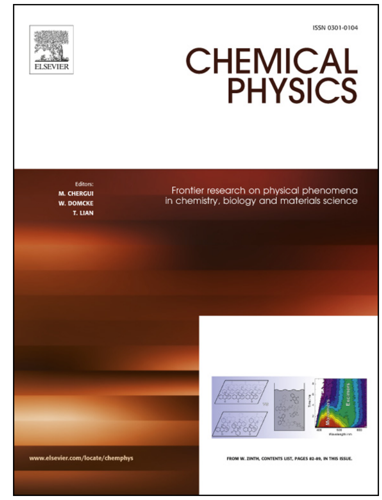

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Impact of the range of the interaction on the quantum dynamics of a bosonic Josephson junction

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Abstract

The out-of-equilibrium quantum dynamics of a bosonic Josephson junction (BJJ) with long-range interaction is studied in real space by solving the time-dependent many-body Schrdinger equation numerically accurately using the multiconfigurational time-dependent Hartree method for bosons. Having the many-boson wave-function at hand we can examine the impact of the range of the interaction on the properties of the BJJ dynamics, viz. density oscillations and their collapse, self trapping, depletion and fragmentation, as well as the position variance, both at the mean-field and many-body level. Explicitly, the frequency of the density oscillations and the time required for their collapse, the value of fragmentation at the plateau, the maximal and the minimal values of the position variance in each cycle of oscillation and the overall pace of its growth are key to our study. We find competitive effect between the interaction and the confining trap. The presence of the tail part of the interaction basically enhances the effective repulsion as the range of the interaction is increased starting from a short, finite range. But, as the range becomes comparable with the trap size, the system approaches a situation where all the atoms feel a constant potential and the impact of the tail on the dynamics diminishes. There is an optimal range of the interaction in which physical quantities of the junction are attaining their extreme values.

1. Introduction

The recent advancements in experimental techniques for interacting Bose gas have made it possible to study the quantum many-body dynamics in a highly controllable manner [1]. In this connection, the dynamics of many-body tunneling [2] is one of the most fundamental problem. A Bose-Einstein condensate (BEC) of interacting dilute Bose gas in a double well, which is generally referred to as a bosonic Josephson junction (BJJ) [3], provides a unique opportunity to study many-body tunneling dynamics. Naturally, the dynamics of BJJs have attracted a lot of attention both theoretically and experimentally [3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24]. Explicitly, Josephson oscillations [3, 5, 6, 19, 22, 23], collapse and revival cycles [4], self trapping (suppression of tunneling) [3, 4, 5, 6, 19], fragmentation [20] and more recently the variances and uncertainty product of the many-body position and momentum operators [21] have been studied. Note that while tunneling, self trapping and Josephson oscillations have some explanations at the mean-field level, the collapse and revival and fragmentation dynamics require many-body treatments like the Bose-Hubbard model [12] or even solving the full many-body Schrödinger equation [17, 25]. A universality has been predicted in the fragmentation dynamics in the sense that systems consisting of different numbers of particles fragment to the same value for the same mean-field interaction parameter [20]. However, it has been shown that even when the Bose-Hubbard model is apparently applicable, the full many-body Schrödinger equation can grab new features. For example, there is a symmetry in the Bose-Hubbard Hamiltonian with respect to repulsive and attractive interactions of equal magnitude. Such symmetry implies an equivalence between the time evolution of the survival probability and the fragmentation of a repulsive and an attractive BJJ with equal magnitude of the strength of the interaction. However, no such symmetry exists at the level of the full many-body Hamiltonian [18].

So far, only contact interactions between the atoms have been considered in the study of BJJs [17, 18, 20, 22, 23]. Actually, contact δ-interaction is widely used in the theoretical studies of trapped ultra-cold atomic gases [1]. However, in many recent experiments with the ultra-cold diploar atoms ^{52}Cr [26, 27], ^{164}Dy [28] and ^{168}Er [29], it has been shown that the short-range inter-particle interaction potential is not enough to account for the observed physics and an additional long-range term is needed to describe the overall two-body interaction, see also the reviews [30, 31]. It is also possible, in experiments, to tune the strength of the dipolar interactions including its sign by using a rotating polarizing field [32]. For a ^{52}Cr BEC, one can also use the Feshbach resonance to tune the s-wave scattering length [33], and this has already been used to enhance the dipolar effects in a BEC [34]. Naturally, the question arises what role the range of the interaction plays and how that affects our present understanding of the physics of an ultra-cold Bose gas.

To address these questions, several static properties includ-

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