Quantum tunneling in a nonlinear matter wave interferometer

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Intrinsic interparticle interactions in atomic condensates lead to an interplay between dispersion and nonlinearity of matter waves, which supports a number of nontrivial collective excitations, including dark solitons in condensates with repulsive interactions. The recent experiments have demonstrated that such nonlinear excitations play an important role in atomic interferometers [1] based on BECs with repulsive atomic interactions, where they can be utilised to enhance the phase sensitivity of the devices. The construction of BEC interferometers involves time-dependent modifications of harmonic trapping potentials and the formation of dark solitons is associated with populating excited nonlinear eigenstates [2] of the confining trap.

The extensively explored mechanisms for population transfer between different eigenstates of a trapped BEC include non-adiabatic processes, Josephson tunneling, and Landau-Zener tunneling, which are also responsible for population transfer in linear systems. However, in a sharp contrast to linear systems, the quantum tunneling between different nonlinear eigenstates can be assisted by the nonlinear mean-field interaction even in the absence of crossing (and avoided crossing) of the energy levels. Up to now, this peculiar type of quantum tunneling remains poorly investigated.

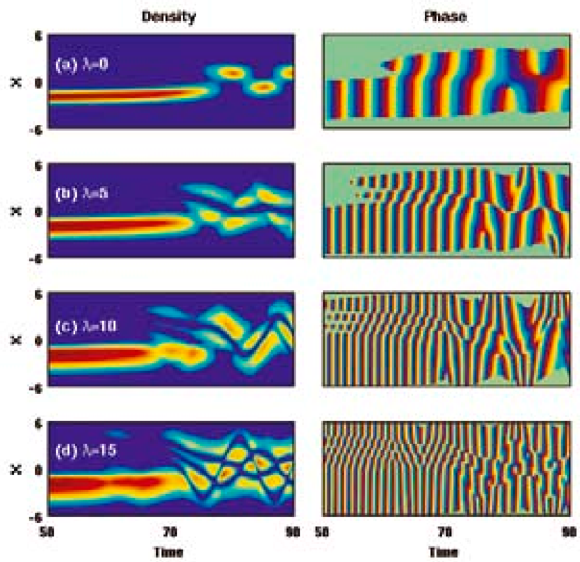

Figure 1: Evolution of the condensate density (left) and phase (right) for different values of the effective nonlinearity, showing that the number of dark solitons excited in the interferometer grows with increasing nonlinearity [3].

In this work we studied the intrinsic mechanism for the quantum tunneling assisted by repulsive mean-field interactions in a matter-wave interferometer [3]. We considered the dynamical recombination process of a BEC interferometer, in which a deep one-dimensional double-well potential is slowly transformed into a single-well harmonic trap. Our numerical simulations showed that multiple moving dark solitons are generated as a result of the nonlinearity-assisted quantum tunneling between the ground and excited nonlinear eigenstates of the system (see Fig. 1), and the qualitative mechanism is independent on the particular shape of the symmetric double-well potential. Furthermore, the number of the generated dark solitons is found to be highly sensitive to the strength of the effective nonlinearity. Finally, we demonstrated that the population transfer between different nonlinear eigenstates caused by the nonlinearity-assisted quantum tunneling can be quantified by a coupled-mode theory for multiple nonlinear eigenstates of the system.

References

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