Pattern Formation, Vortex and Impurity Dynamics In Bose-Einstein Condensate

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Abstract

We unveil the spontaneous generation of vortex-bright-soliton structures in binary Bose-Einstein condensates with a small mass imbalance between the components. The system is confined in a two-dimensional (2D) harmonic trap. One of the two components has been segmented into two parts by a potential barrier. To trigger the dynamics the potential barrier is suddenly removed and subsequently, the segments perform a counterflow dynamics. Two scenarios involving the presence or absence of a singly quantized vortex at the center of the other non-segmented component are considered. In both cases, a relative phase difference of π exists between the segments of the initially segmented component. The number of vortex structures developed within the segmented component following the merging of its segments is found to depend on the presence of an initial vortex on the other component. Inspecting the dynamics of the angular momentum, we show that it can be transferred from one component to the other, and its transfer rate can be tuned by the strength of the inter-component interactions.

We examine the dynamics associated with the creation of a vortex in a Bose-Einstein condensate(BEC), from another nonrotating BEC. In order to do so, we utilize a two-photon Raman transition with Gaussian(G) and Laguerre-Gaussian (LG) laser pulses. In particular, we consider BEC of Rb atoms at their hyperfine ground states confined in a quasi-2D harmonic trap. Optical dipole potentials created by G and LG laser pulses modify the harmonic trap in such a way that density patterns of the condensates depend on the sign of the generated vortex during the Raman transition process. We investigate the significance of the Raman coupling parameter and the inter-component interaction during the population transfer, and on the final population of the rotating condensate.

We also present comprehensive studies of the star-shaped surface modes in a BEC. The two-dimensional surface modes with D_l symmetry, from quadrupole mode ($l = 2$) to heptagon mode ($l = 7$), are parametrically excited by modulating scattering length. This thesis demonstrates that the superfluid hydrodynamic instability under the periodic modulation can lead to these star-shaped excitations.. From the instability condition, we can measure the dispersion law of the elementary excitations of surface mode in a trapped superfluid system. The finite-size effect on the superfluids hydrodynamics is investigated and found to increase the natural angular frequencies of the patterns with decreasing particle number. We also elucidate the role of the modulation amplitude on the instability growth.

We further investigate the out-of-equilibrium many-body dynamics of two bosonic impurities immersed in a BEC. Here we apply a periodic driving of the confining potentials of the impurities. In particular, two driving schemes are explored. In one scheme, the system is driven only for two cycle of oscillations. The other formalism employs a continuous driving in the system throughout the dynamical process. A wide range from weak-to-strong driving frequencies are covered for both the schemes. Monitoring the single particle density, one-body correlation functions and center-of-mass oscillations, we analyze the response of the impurities to the periodic oscillation of their trap minimum and corresponding induced motion in the background BEC. The motion of the impurities within the bath can be either diffusive or localized depending on the driving frequency. Furthermore, impurities transfer energy to their background and become entangled with the latter. The degree of entanglement, inherent in the system, is analyzed and found to be significant in the long time dynamics of the system.

Key words: Bose-Einstein Condensate, Vortex, Lagueree Gaussian Beam, Pattern Formation, Impurities, Many-Body Dynamics

List of Publications

1. Interaction of a Laguerre-Gaussian beam with trapped Rydberg atoms, **Koushik Mukherjee**, Sonjoy Majumder, Pradip Kumar Mondal, Bimalendu Deb, **Journal of Physics B: Atomic, Molecular and Optical Physics, (2017)**

2. Transfer of orbital angular momentum superposition from asymmetric Laguerre-Gaussian beam to Bose-Einstein Condensate Subrata Das, Anal Bhowmik, **Koushik Mukherjee**, Sonjoy Majumder **Journal of Physics B: Atomic Molecular and Optical Physics 53 (2), 025302, (2019)**

3. Quench induced vortex-bright-soliton formation in binary Bose-Einstein condensates **K. Mukherjee**, S.I.Mistakidis, P.G. Kevrekidis, P. Schmelcher, **Journal of Physics B: Atomic, Molecular and Optical Physics 53 (5), 055302, (2020)**

4. Pulse-and continuously driven many-body quantum dynamics of bosonic impurities in a Bose-Einstein condensate **K. Mukherjee**, S.I. Mistakidis, S. Majumder, P. Schmelcher, **Physical Review A 101 (2), 023615, (2020).**

5. Parametrically excited star-shaped patterns at the interface of binary Bose-Einstein condensates, D.K. Maity, **K. Mukherjee**, S.I. Mistakidis, S. Das, P.G. Kevrekidis, S. Majumder, P. Schmelcher **Phys. Rev. A 102, 033320 (2020)**

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7. Induced interactions and quench dynamics of bosonic impurities immersed in a Fermi sea **K. Mukherjee**, S. I. Mistakidis, S. Majumder, P. Schmelcher, **Phys. Rev. A 102, 053317, (2020)**

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