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Dynamics of Bose-Einstein condensates and wave chaos

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ABSTRACT

Ultracold atoms and Bose-Einstein condensates (BECs) have evolved to one of the most experimentally controllable and tunable systems, through an enormous experimental progress in manipulating, cooling, and trapping techniques. To utilize ultracold atoms and BECs in future quantum metrology schemes, a detailed knowledge of their dynamics is necessary. We study theoretically the dynamics of ultracold atoms and BECs in typical one-dimensional trap geometries with external potentials. The external potentials range from harmonic traps with defects, to periodic, aperiodic and disorder potentials. Disorder potentials are especially interesting in connection with Anderson localization. We investigate the dynamics of BECs within the Gross-Pitaevskii equation (GPE) which is equivalent to a nonlinear Schrödinger equation. The GPE plays an important role in the description of BECs and is strictly valid only for the dynamics of the condensate. The GPE does not take into account any excitations out of the condensate, i.e. depletion.We investigate the properties of the GPE and find that for some parameter ranges of the above potentials the solutions of the GPE exhibit wave chaos as measured by the exponential divergence of nearby wave functions in Hilbert space. The emergence of strong local random fluctuations leads to the hypothesis that wave chaos is closely connected to depletion.We utilize the multiconfigurational time-dependent Hartree for bosons (MCDTHB) method to give a numerical proof for the connection between wave chaos of the GPE and depletion of the condensate. It is shown that the validity of the GPE is limited by the appearance of wave chaos. Despite a strong depletion of the condensate, coarse-grained observables such as the width of the atom cloud are well reproduced within the GPE. Accordingly, experimental results for these coarse-grained observables may agree well with the predictions of the GPE although the system does not correspond to a pure BEC. The found depletion mechanism can be detected experimentally by investigation of local fluctuations or higher-order coherence.