Many-Body Effects in the Excitation Spectrum of Weakly-Interacting Bose-Einstein Condensates in One-Dimensional Optical Lattices

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In this work, we study many-body excitations of Bose-Einstein condensates (BECs) trapped in periodic one-dimensional optical lattices. In particular, we investigate the impact of quantum depletion onto the structure of the low-energy spectrum and contrast the findings to the mean-field predictions of the Bogoliubov-de Gennes (BdG) equations. Accurate results for the many-body excited states are obtained by applying a linear-response theory atop the MCTDHB (multiconfigurational time-dependent Hartree method for bosons) equations of motion, termed LR-MCTDHB. We demonstrate for condensates in a triple well that even weak ground-state depletion of around 1% leads to visible many-body effects in the low-energy spectrum which deviate substantially from the corresponding BdG spectrum. We further show that these effects also appear in larger systems with more lattice sites and particles, indicating the general necessity of a full many-body treatment.

References

[1] R Beinke, S Klaiman, L S Cederbaum, A I Streltsov and O E Alon, Phys. Rev. A **95**, 063602 (2017)

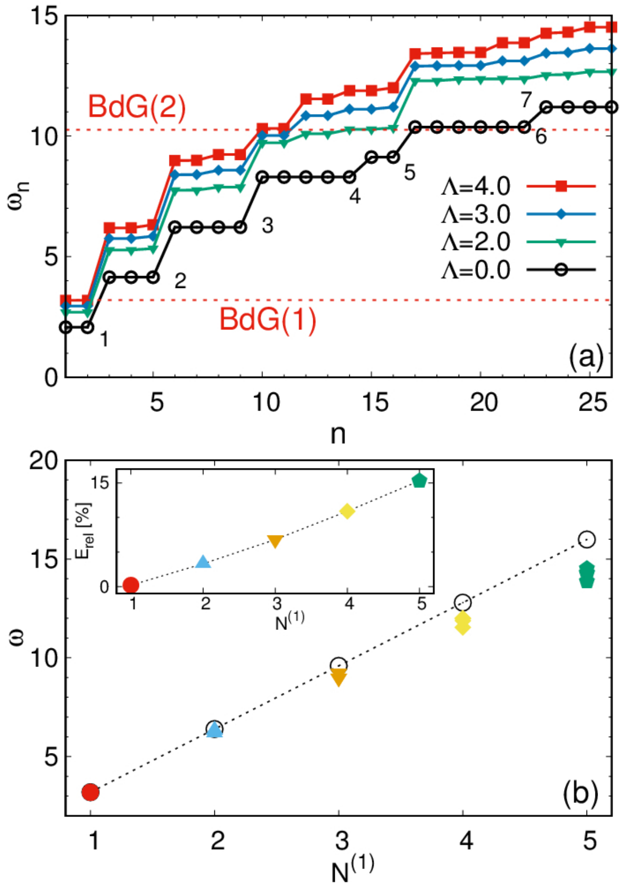

Figure 1: (a) Low-energy spectrum of many-body excited states for $N = 10$ bosons in a shallow triple well with depth $V_0 = 1.01\,E_R$ for different repulsion strengths Λ. The maximal degree of ground-state depletion is $f = 1.1\%$ for $\Lambda = 4.0$. By increasing Λ, the degeneracies between states of the same level are lifted and some levels change the order compared to the non-interacting case. The dotted red lines indicate the first two BdG lines for $\Lambda = 4.0$. (b) Comparison of the BdG approximation (open circles) with the LR-MCTDHB(7) many-body results (colored symbols) for the system of the uppermost curve in (a). The BdG approximation assigns too high excitation energies ω to all levels $N^{(1)}$ shown, and the deviation grows with $N^{(1)}$. Inset: Evolution of the relative error E_{rel}. Already for $N^{(1)} = 4$, E_{rel} exceeds 10%