Collective Excitation of Shell-Shaped BEC

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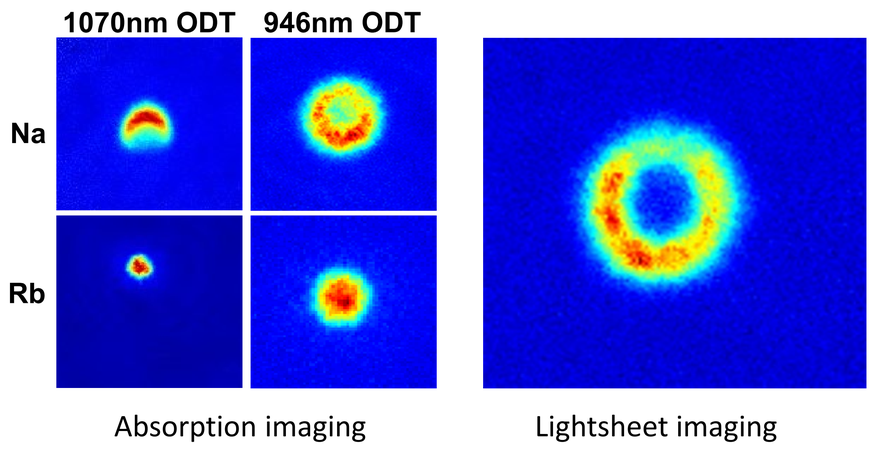
Introduction

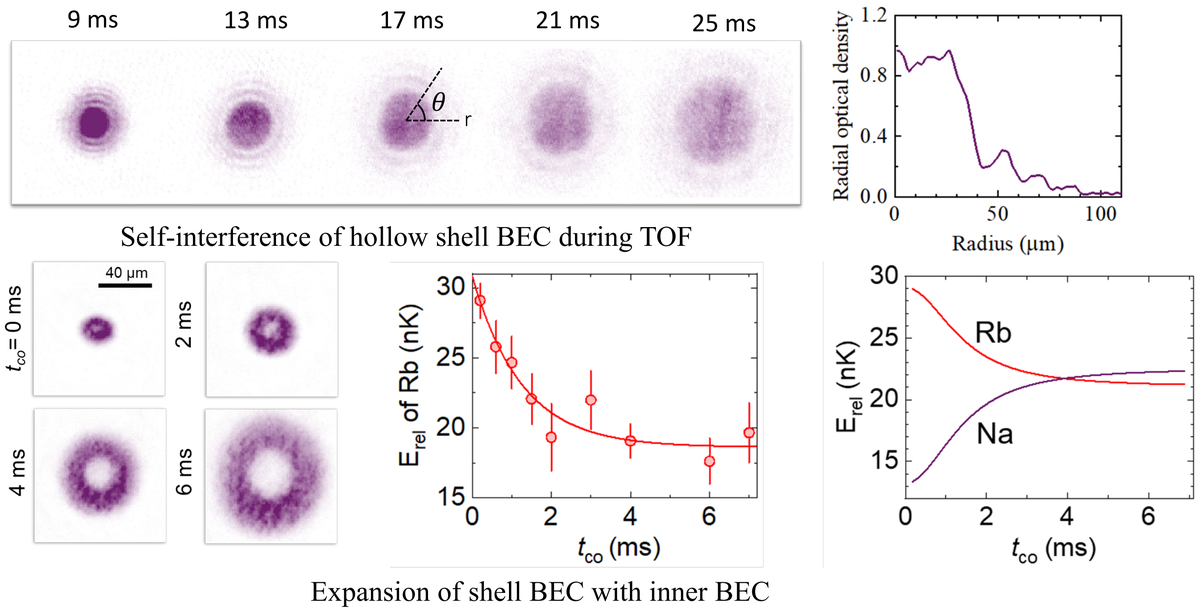
We study the hollowing transition of a shell-shaped Bose-Einstein condensate (BEC) with collective excitation. The shell's hollowness is controlled by tuning the interspecies interaction via a Feshbach resonance. We observe two monopole modes: in-phase and out-of-phase oscillations. The in-phase mode frequency stays constant, while the out-of-phase mode frequency changes, indicating the transition from a filled to a hollow condensate. This transition point depends on the species' number ratio. Our findings improve the understanding of topology changes in curved quantum gas systems and suggest new research directions in quantum many-body phenomena.

Previous work [1]

- Created Shell-Shaped BEC by Utilizing the immiscibility of the two components BEC ($g_{NaRb} > \sqrt{g_{11}g_{22}}$) and overlap of center-of-mass under magic wavelength optical dipole trap ($\boldsymbol{m\omega^2 y = mg \rightarrow y = \frac{g}{\omega^2}}$)

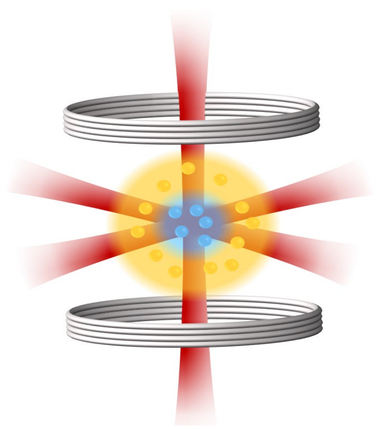


- Investigate the expansion dynamics of Shell-Shaped BEC

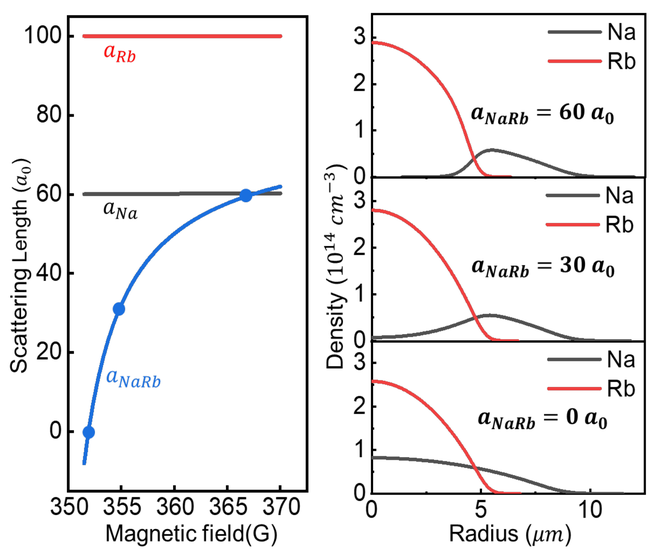


Collective Excitation of Shell-Shaped BEC [2]

- Setup: double BECs are trapped in an optical dipole trap formed by crossing three orthogonally propagating 946 nm laser beams to form an isotropic sample.

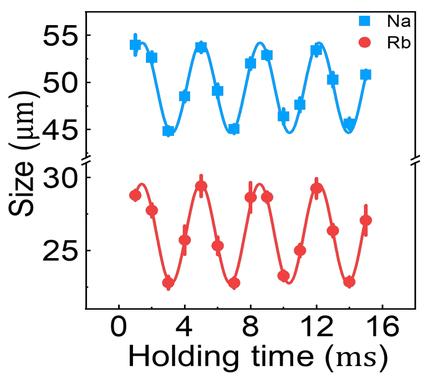


- Utilizing the tunability of interspecies scattering length near Feshbach resonance to explore collective excitation during hollowing transition

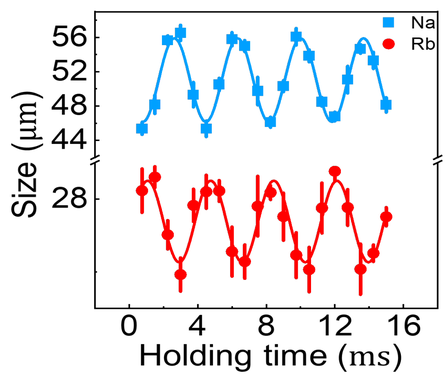


Collective excitation of shell BEC

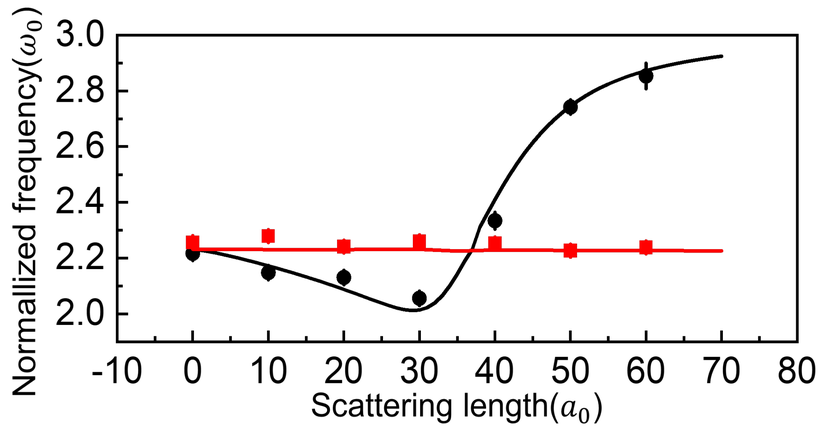
- Excite the in-phase mode by sinusoidally modulating trap potential (ω_0)



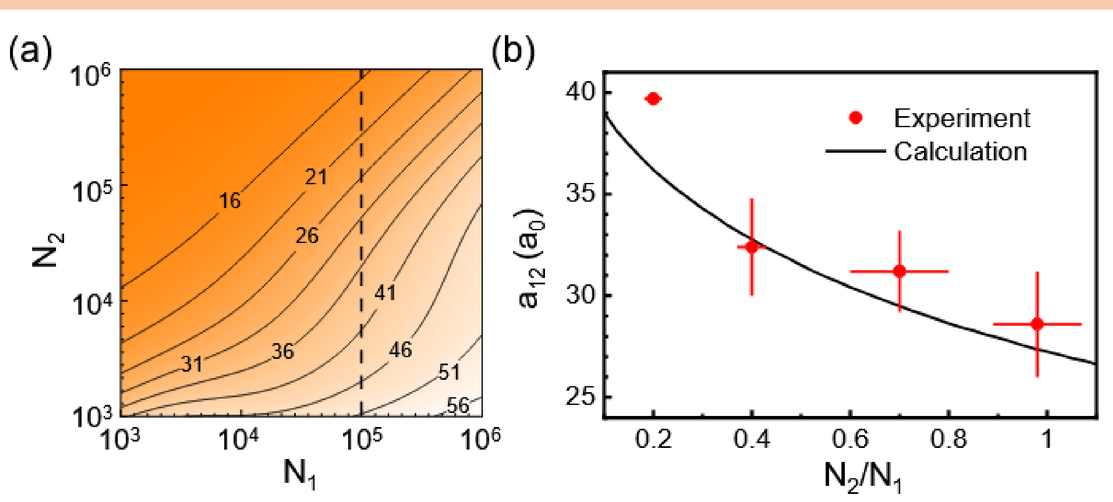
- Excite the Out-of-phase mode by modulating interspecies interaction (a_{12})



- In-phase spectrum remain unchanged during hollowing transition, out-of-phase signifies the hollowing transition points



Number of Particles Dependence of Critical a_{12}



Out-of-Phase mode

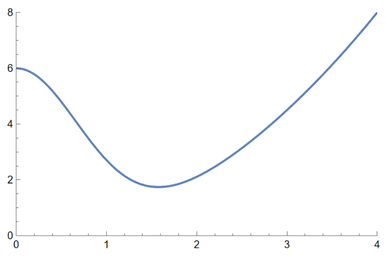
- Variational Method [3]

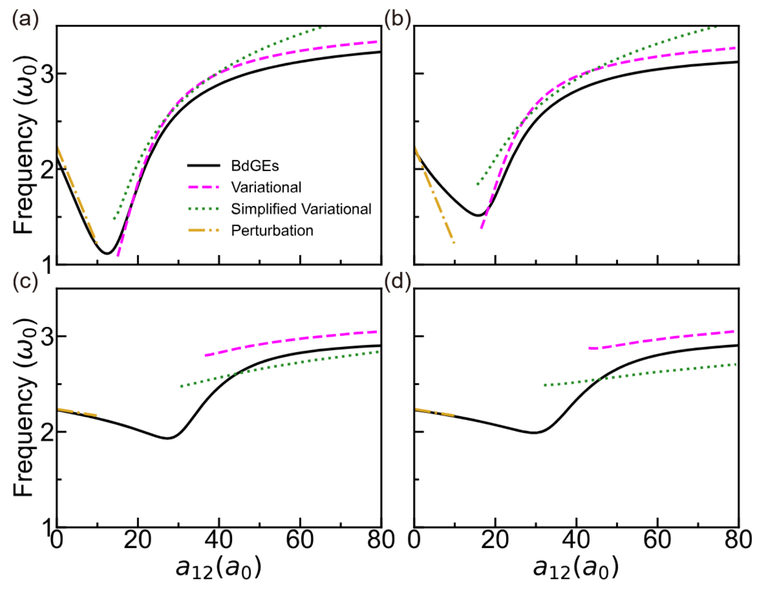
$$\mathcal{L} = \int \left[\sum_i \left(\frac{i\hbar}{2} \left(\psi_i^* \frac{\partial \psi_i}{\partial t} - \psi_i \frac{\partial \psi_i^*}{\partial t} \right) - \frac{\hbar^2}{2m_i} |\nabla \psi_i|^2 - V_i |\psi_i|^2 - \frac{g_{ii}}{2} |\psi_i|^4 \right) - g_{12} |\psi_1|^2 |\psi_2|^2 \right] d^3 r$$

$$\psi_1(r,t) = \frac{\sqrt{N_1}}{\sqrt{2\pi^{3/2}\sigma_1(2r_c^2 + \sigma_1^2)}} e^{-\frac{1}{2}\left(\frac{r-r_c}{\sigma_1}\right)^2} e^{i\beta_0 m_1 r/\hbar + i\beta_1 m_1 (r-r_c)^2/(2\hbar)}$$

- Effective Potential $V_{\text{eff}}(r) = \frac{1}{2} m_1 \omega_0^2 r^2 + g_{12} n_2(r)$

- COM + Width Oscillations





References:

[1] Jia, Fan, et al. Expansion dynamics of a shell-shaped Bose-Einstein condensate. Phys. Rev. Lett 129.24 (2022): 243402.

[2] Zerong, Huang, et al. Collective excitation of shell-shaped Bose-Einstein condensate. (PRR Accepted) (2025)

[3] Lannert, C., Wei, T.-C. & Vishveshwara, S. Dynamics of condensate shells: Collective modes and expansion. *Phys. Rev. A* **75**, 013611 (2007)