Excited states of ultracold Bose atoms in double-well potential

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Abstract

We suggest a simple and robust scheme for creating the NOON state of interacting Bose atoms in a double-well potential.

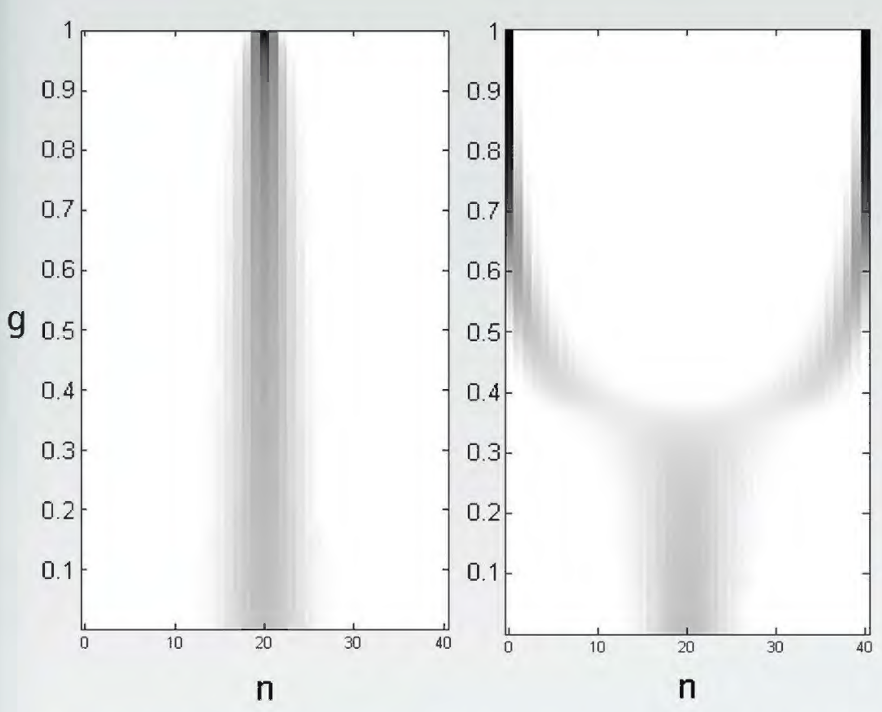
$$|NOON\rangle = \frac{1}{\sqrt{2}}(|N,0\rangle + |0,N\rangle)$$

The scheme consists of two steps. First, setting inter-atomic interactions to zero, we drive the system for a given time to excite the initial BEC of atoms into the highest state. Second, switching off the driving, we adiabatically increase the strength of atom-atom interactions and simultaneously decrease the inter-well tunneling rate. We also discuss fidelity of the final NOON state depending on the sweeping rate of the control parameter.

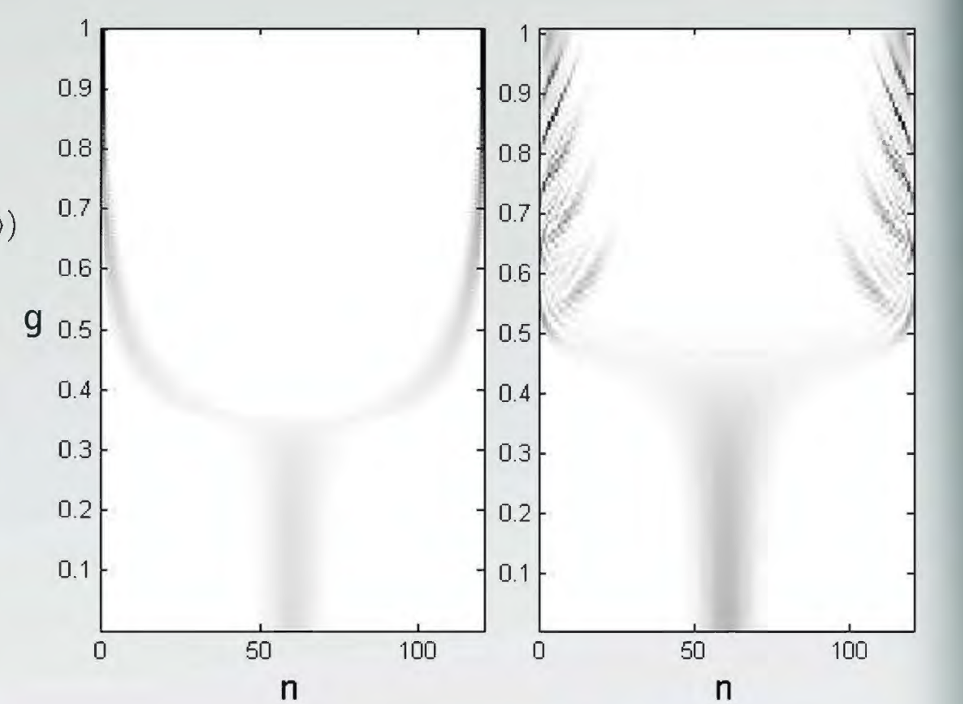
Eigenfunctions

$$|\psi_j\rangle = \sum_{n=0}^{N} c_n^{(j)} |N-n, n\rangle$$

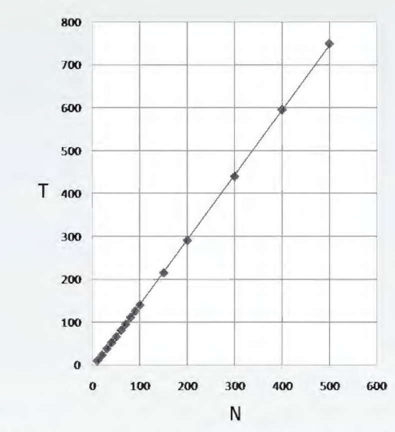
$$|\psi_0(g=1)\rangle = |N/2, N/2\rangle \qquad |\psi_N(g=1)\rangle = \frac{1}{\sqrt{2}}(|N,0\rangle + |0,N\rangle)$$



The ground (left) and most excited (right) states of the system as functions of the control parameter $g = UN/2J_0$. Squared moduli of the expansion coefficient over the Fock basis $|N-n, n\rangle$ are shown as a gray-scaled map.



Occupations of Fock states for finite sweeping rates of the control parameter $g = t/T$ with $T = 300\pi$ (left) and $T = 16\pi$ (right). The time is measured in units of the tunneling period h/J_0.

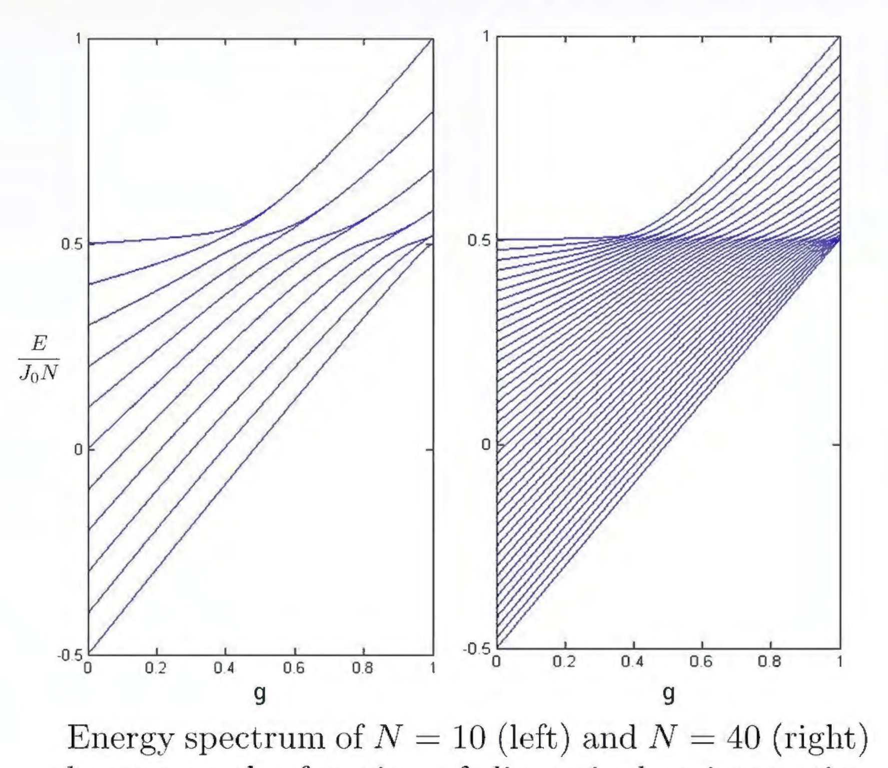


Duration T of the adiabatic passage which insures fidelity $|\langle\psi_N(T)|NOON\rangle|^2 = 0.99$, depending on the particle number N.

Energy spectrum

$$\widehat{H} = -\frac{J}{2}\left(\hat{a}_2^\dagger \hat{a}_1 + h.c.\right) + \frac{U}{2}(\hat{n}_1(\hat{n}_1 - 1) + \hat{n}_2(\hat{n}_2 - 1)), \qquad (1)$$

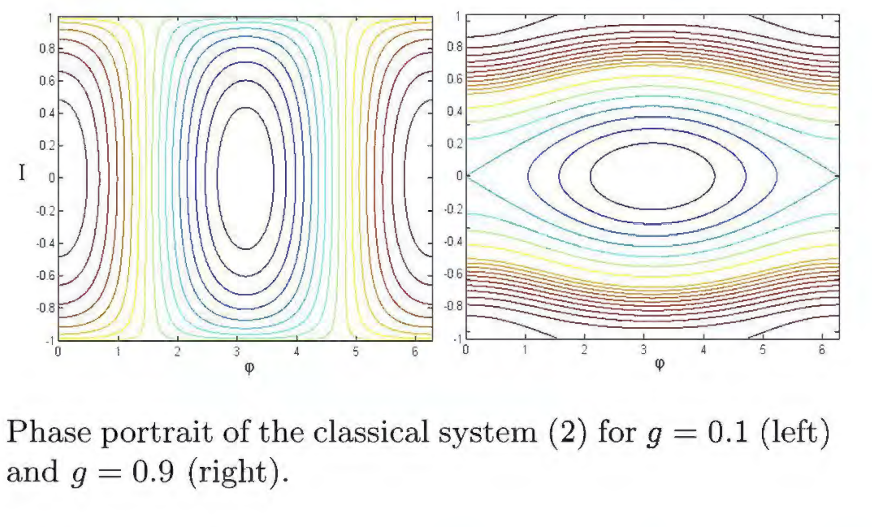
where J is the hopping matrix element, U is the microscopic interaction constant ($U > 0$), $\hat{a}$ and $\hat{a}^\dagger$ are the bosonic annihilation and creation operators in the left and right well of potential.



Energy spectrum of $N = 10$ (left) and $N = 40$ (right) bosons as the function of dimensionless interaction constant $g = UN/2J_0$. The hopping matrix element is $J = J_0(1 - g)$.

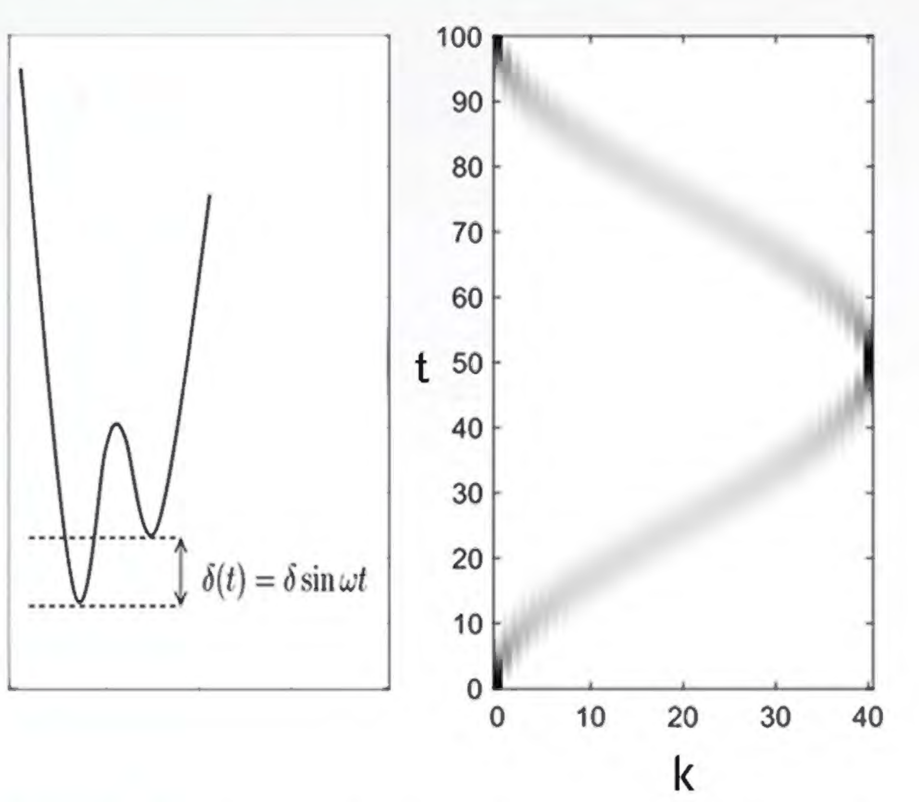
Semiclassical approach

$$\mathcal{H} = \frac{gI^2}{2} + J\sqrt{1 - I^2}\cos\varphi \qquad (2)$$



Phase portrait of the classical system (2) for $g = 0.1$ (left) and $g = 0.9$ (right).

Selective excitation



Periodically driven double-well potential (left) and populations of the eigenstates of (1) as the function of time (right). Parameters are $N = 40$, $g = 0$, $\omega = J_0/\hbar$, and $\delta = 0.01J_0$.

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