Quantum solitons in one-dimensional spin-orbit coupled Bose-Bose mixtures

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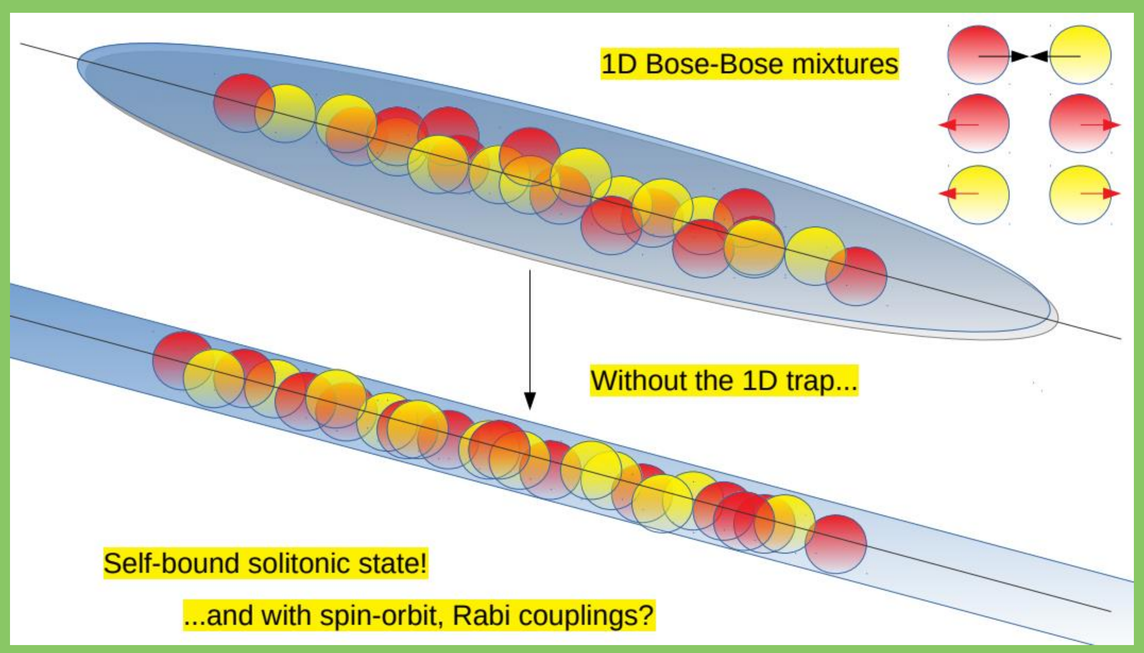
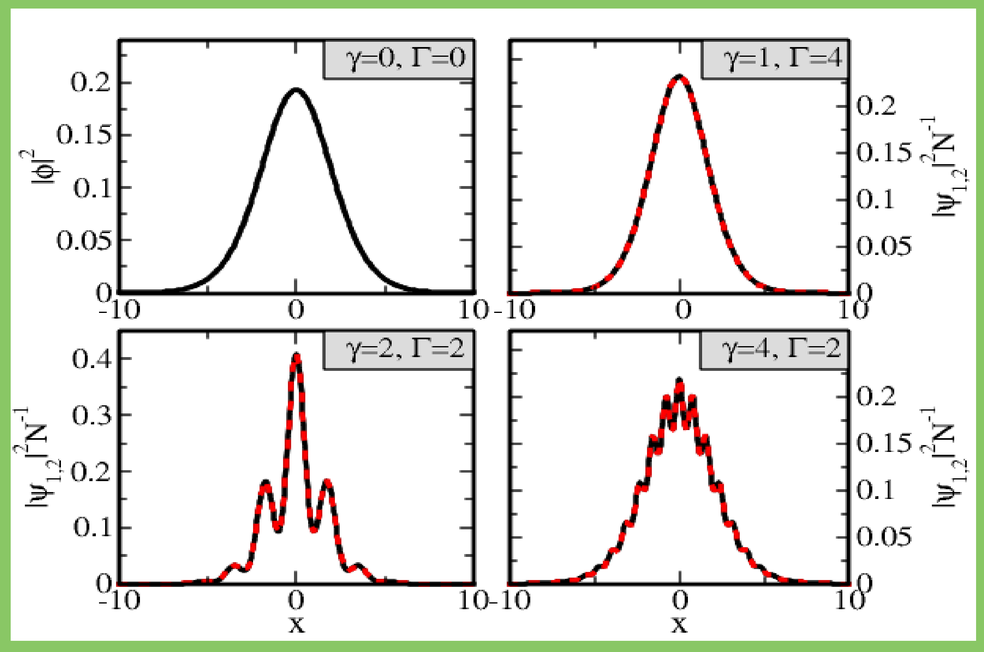


…from a single to a multipeak soliton



BOSE-BOSE MIXTURES IN 1D

Given a system of bosonic atoms in two different hyperfine levels, the beyond-mean-field energy density for a strictly **one-dimensional** mixture reads

$$\frac{E_{1D}}{L} = \frac{g}{2}(n_1 - n_2)^2 + \frac{\delta g}{4}(n_1 + n_2)^2 - \frac{2\sqrt{m}}{3\pi\hbar} g^{3/2}(n_1 + n_2)^{3/2}$$

with $\delta g = \sqrt{g_{11} g_{22}} + g_{12}$ and

Inter-species attraction

$$g_{12} < 0$$

Intra-species repulsion

$$g_{11} = g_{22} = g > 0$$

Differently from the 3D case, for $0 \lesssim \delta g \ll g$ an **attractive** beyond-mean-field term stabilizes a **repulsive** mean-field energy.

We employ the following effective energy functional

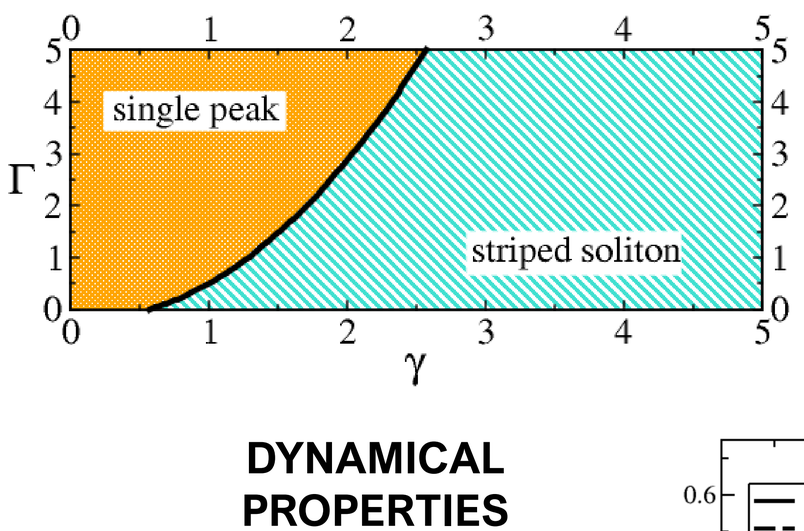
$$\mathcal{E} = \int dx \left\{ \frac{E_{1D}(|\psi_1|^2, |\psi_2|^2)}{L} + \sum_{j=1,2} \left[\frac{\hbar^2}{2m} |\partial_x \psi_j|^2 - (-1)^j i\gamma \psi_j^* \partial_x \psi_j - \Gamma \psi_j^* \psi_{3-j} \right] \right\}$$

Spin-orbit coupling — Rabi coupling

EFFECTIVE GPE IN 1D

$$\mu\psi_j = \left[-\frac{\hbar^2}{2m}\partial_x^2 + \frac{\delta g}{2}(|\psi_1|^2 + |\psi_2|^2) - (-1)^j g(|\psi_1|^2 - |\psi_2|^2) - \frac{\sqrt{m}}{\pi\hbar} g^{3/2}(|\psi_1|^2 + |\psi_2|^2)^{1/2} - (-1)^j i\gamma\partial_x \right] \psi_j - \Gamma\psi_{3-j}$$

We solve the coupled GPEs for $|\psi_1|^2 = |\psi_2|^2$, deriving the phase diagram for the transition **from a single peak to a multipeak** (striped) **soliton.**

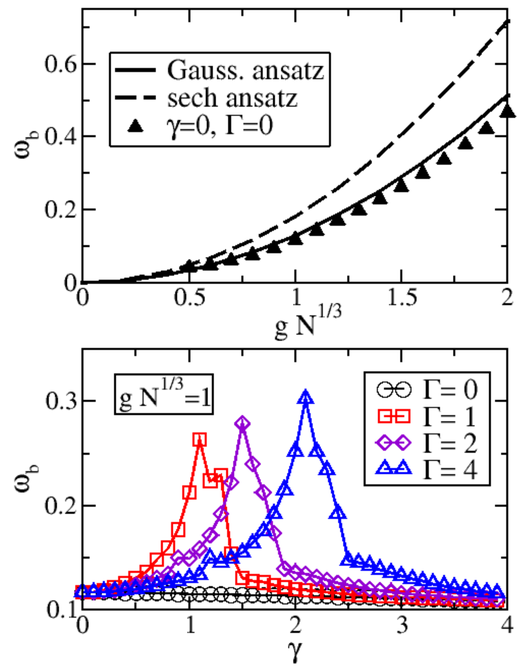


Tuning SO from lower to higher values of Rabi, we observe a larger number of peaks, with a finer spatial distribution and density displacement

DYNAMICAL PROPERTIES

Promoting the field to time-dependent quantities we investigate the collective excitations.

The peculiar behavior of the breathing mode frequency can be used to experimentally probe the transition.



References:
A. Tononi, Y. Wang, L. Salasnich, Quantum solitons in spin-orbit coupled Bose-Bose mixtures, Physical Review A, 99, 063618 (2019).

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