Inter-component correlations in few-fermion systems induced by a shape of an external confinement

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Abstract

In a one-dimensional two-component mixture of a few fermions having different mass, their spatial arrangement depends on a particular shape of external confinement. In a harmonic trap, the lighter component is split and push out of the trap, while the heavier component is located in the center. In contrast, in a flat box potential, the heavier component is split. In consequence, when the external trap adiabatically changes its shape, the ground-state of the few-fermion system undergoes a specific transition between these spatial orderings. It is known that the transition has many interesting properties similar to the properties of the quantum phase transitions. Here we analyze this transition from the inter-component correlations point of view.

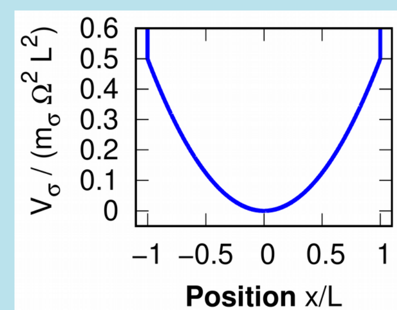
Hamiltonian:

$$\hat{\mathcal{H}} = \sum_{\sigma\in\{A,B\}} \int \mathrm{d}x\, \hat{\Psi}^\dagger_\sigma(x) \left[-\frac{\hbar^2}{2m_\sigma}\frac{\mathrm{d}^2}{\mathrm{d}x^2} + V_\sigma(x) \right] \hat{\Psi}_\sigma(x)$$

$$+ g \int \mathrm{d}x\, \hat{\Psi}^\dagger_A(x) \hat{\Psi}^\dagger_B(x) \hat{\Psi}_B(x) \hat{\Psi}_A(x)$$

$$V_\sigma(x) = \begin{cases} f(\lambda)\frac{m_\sigma\Omega^2}{2}x^2 & |x| < L \\ \infty & |x| \geqslant L \end{cases}$$

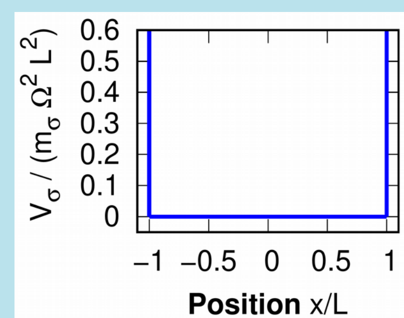
$$\frac{m_B}{m_A} = \frac{40}{6}$$



$f(0)=1$

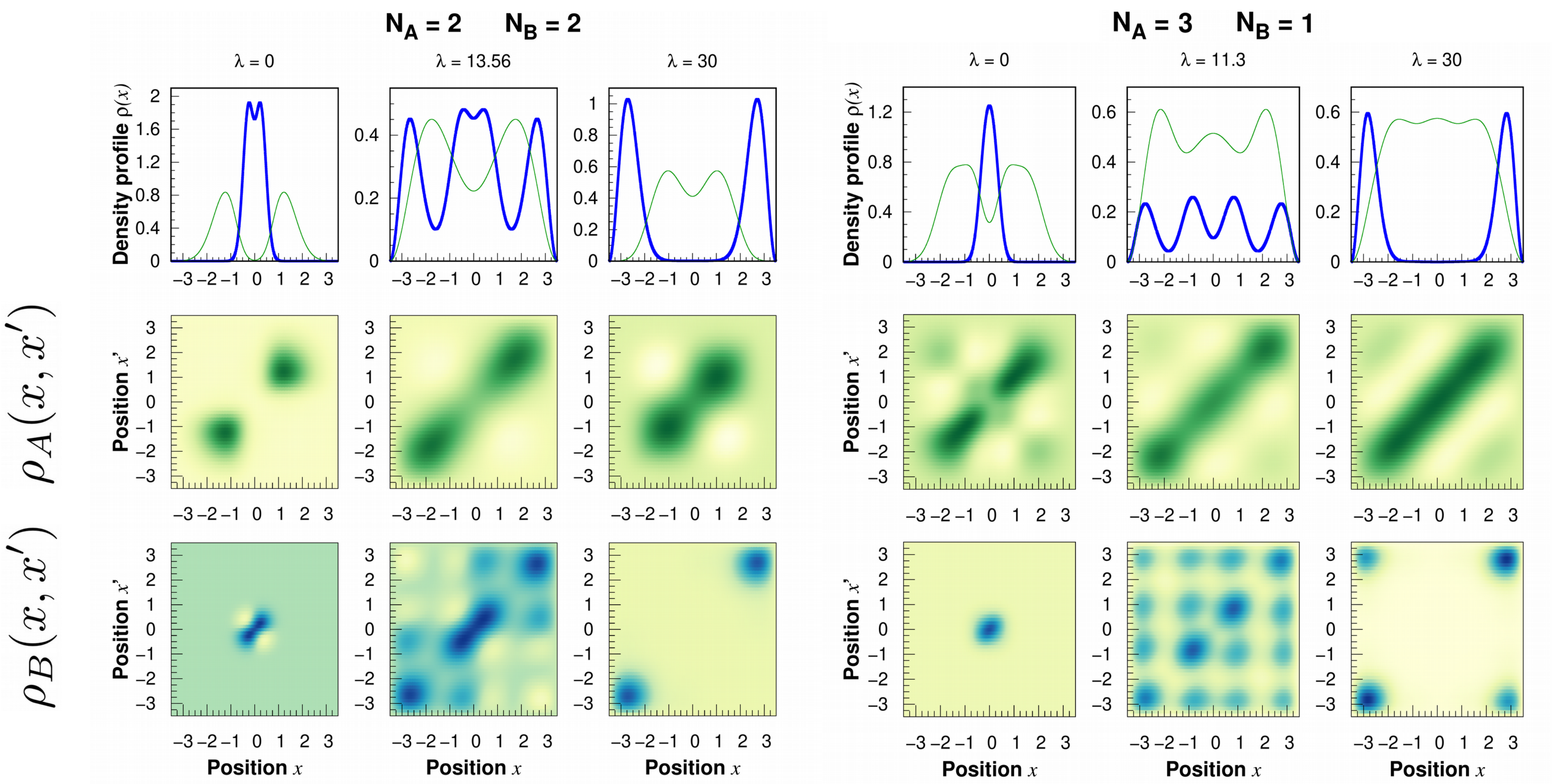
$\downarrow$

$f(\infty)=0$



Single-particle reduced density matrix:

$$\rho_\sigma(x,x') = \langle \mathtt{G}|\hat{\Psi}^\dagger_\sigma(x)\hat{\Psi}_\sigma(x')|\mathtt{G}\rangle$$



Intra-component von Neumann entropies:

$$\mathcal{S}_\sigma = -\sum_i \chi_{\sigma i} \ln \chi_{\sigma i} \qquad \rho_\sigma(x, x') = \sum_i \chi_{\sigma i} \eta^*_{\sigma i}(x) \eta_{\sigma i}(x')$$

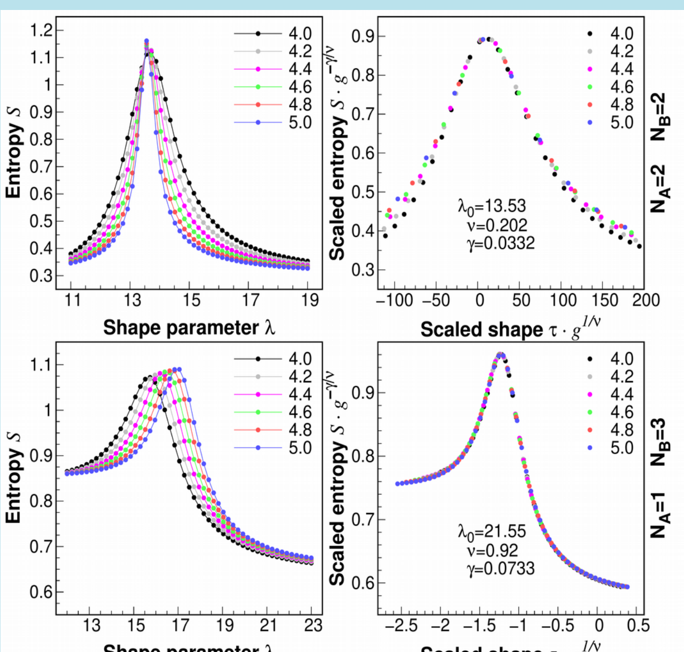
Inter-component von Neumann entropy:

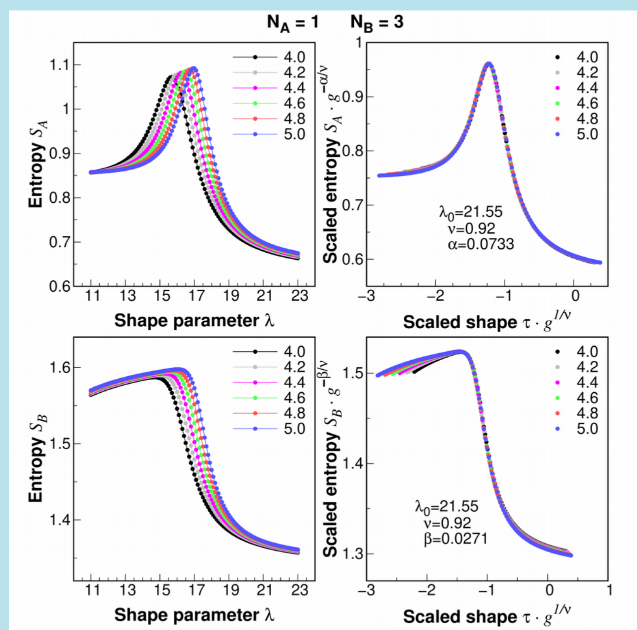
$$\mathcal{S} = -\mathrm{Tr}_A\left[\hat{\Gamma}_A \ln(\hat{\Gamma}_A)\right] = -\mathrm{Tr}_B\left[\hat{\Gamma}_B \ln(\hat{\Gamma}_B)\right] \qquad \hat{\Gamma}_\sigma = \mathrm{Tr}_{\sigma'} |\mathtt{G}\rangle\langle\mathtt{G}|$$

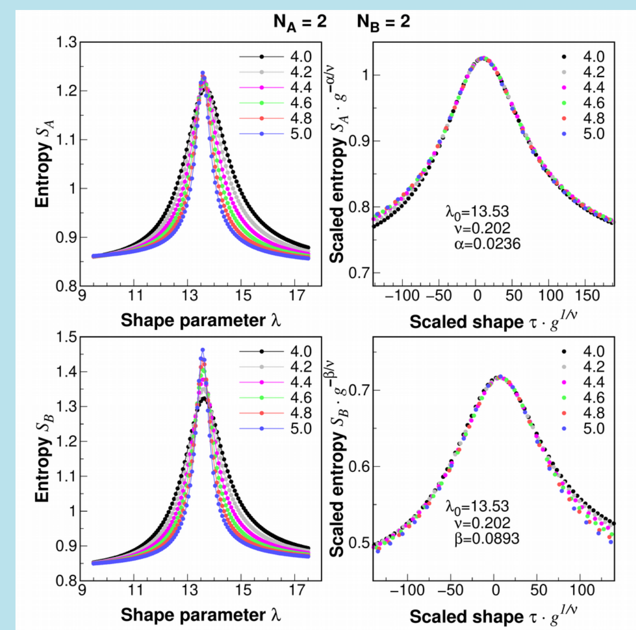
Finite-size scaling:

$$\mathcal{S}_A(\lambda, g) = g^{\alpha/\nu} \mathbf{S}_A(g^{1/\nu}\tau) \qquad \mathcal{S}(\lambda, g) = g^{\gamma/\nu} \mathbf{S}(g^{1/\nu}\tau)$$

$$\mathcal{S}_B(\lambda, g) = g^{\beta/\nu} \mathbf{S}_B(g^{1/\nu}\tau)$$







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