Short-range correlations studied with unitarily transformed operators*

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Introduction

Short-range correlations in nuclei are of great interest for the theoretical understanding of nuclear matter at high densities. Experimental investigations for example in $(e, e'pp)$ and $(e, e'pn)$ reactions at large momentum transfer [1] illustrate that the momentum distributions for momenta larger than the Fermi momentum are dominated by tensor correlations. In a previous study [2] we investigated short-range correlations and momentum distributions in $A = 2, 3, 4$ nuclei using exact few-body wave functions. For heavier nuclei this is no longer feasible and one has to use other many-body approaches like the no-core shell model. It is however not possible to obtain converged results with bare interactions. One therefore employs unitary transformations to soften the Hamiltonian. Typical approaches are the unitary correlation operator method (UCOM) [3] or the similarity renormalization group (SRG).

Similarity Renormalization Group

In the SRG approach one solves the flow equation

$$\frac{d\hat{H}_\alpha}{d\alpha} = (2\mu)^2 \left[\left[\hat{T}_{\rm int}, \hat{H}_\alpha\right], \hat{H}_\alpha\right] \qquad (1)$$

with $\hat{H}_{\alpha=0} = \hat{H}$ to obtain an effective Hamiltonian $\hat{H}_\alpha$. With increasing flow parameter α the effective interaction becomes softer and the eigenstates $|\Psi_\alpha\rangle$ of the evolved Hamiltonian

$$\hat{H}_\alpha \left|\Psi_\alpha\right\rangle = E_\alpha \left|\Psi_\alpha\right\rangle \qquad (2)$$

contain less and less high-momentum components than the eigenstates $|\Psi\rangle$ of the bare Hamiltonian. To recover the high-momentum components one has to use effective density operators that are obtained using the same unitary transformation as for the Hamiltonian. For computational reasons the flow equation (1) is solved in two-body approximation which induces a dependence on the flow parameter for observables like the energies E_α and also the two-body densities. This dependence on α can be used to study the importance of the omitted higher body contributions.

Results

In Fig. 1 we show the two-body densities of the ^{4}He nucleus in momentum space obtained in no-core shell model calculations using SRG transformed Hamiltonians and bare density operators (top) and SRG transformed density operators (bottom). With the bare interaction the two-body densities contain high-momentum components caused by the short-range repulsion in the Argonne interaction. The significantly larger high momentum components in the S=1, T=0 channel are caused by the tensor force. With increasing α the high-momentum components in the wave function get smaller. By using the transformed density operators the high-momentum components can be recovered. Comparing the two channels we observe a striking difference in the momentum region between 1.5 and 3.0 fm^{-1}. Whereas the two-body densities in the S=1, T=0 channel are almost independent from α, the two-body densities in the S=0, T=1 channel show a significant α-dependence. This reflects many-body correlations in the wave function induced by the tensor force.

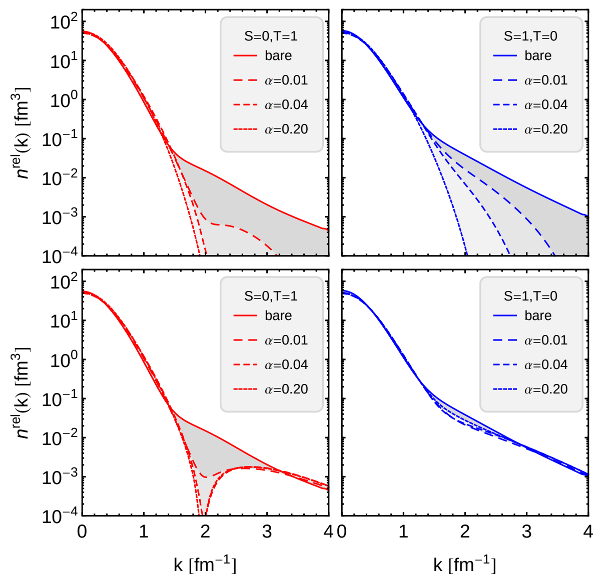

Figure 1: Two-body densities in momentum space for the S=0, T=1 and S=1, T=0 channels calculated with the eigenstates of SRG transformed AV8' Hamiltonians for flow parameters α of 0.01 fm^4, 0.04 fm^4 and 0.20 fm^4 using bare density operators (top) and effective density operators (bottom).

References

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* supported by Helmholtz Alliance EMMI