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Clustering and two-body correlations within extended density functional approaches

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The formation of nuclear clusters constitutes an essential feature for the construction of global and unified equation-of-state (EoS) for nuclear matter. They emerge as many-body correlations, which can be attributed to the nucleon-nucleon (NN) interaction, and exist at sub-saturation densities in nuclear matter.

Phenomenological models that make use of energy density functionals (EDFs) offer a convenient approach to account for the presence of these bound states of nucleons when clusters are introduced as additional degrees of freedom. However, these models are constructed in such a way that clusters dissolve when the density approaches the nuclear saturation density, so that only nucleons survive as independent quasi-particles at higher densities. These models reveal thus inconsistencies with recent findings that evidence the existence of sizeable NN short-range correlations (SRCs) even at larger densities.

In our work, we propose a novel approach which allows, within the EDF framework, for an explicit treatment of SRCs at supra-saturation densities, by using effective quasi-clusters immersed in dense matter as a surrogate for correlations. Our idea is to embed the SRCs within generalized relativistic energy density functionals through the introduction of suitable in-medium modifications of the cluster properties. As a first exploratory step, the example of a quasi-deuteron in a relativistic mean-field model with density dependent couplings is explored. A full covariant and self-consistent scheme, based on the two-body Dirac equations, is moreover proposed to explicitly determine the many-body wave function of the quasi-deuteron in the medium.

Some parameterizations of the cluster mass shift at zero temperature, as constrained by experimental results for the effective deuteron fraction in nuclear matter near saturation and by microscopic many-body calculations in the low-density limit, are derived for all baryon densities. Novel effects on some thermodynamic quantities, such as the matter incompressibility, the symmetry energy and its slope, are finally discerned.

Implications in the widest scope of astrophysical applications are envisaged and the impact of these studies for general aspects of reactions dynamics, such as the clustering processes emerging in heavy-ion collisions, will be also discussed.

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