Self-consistent extension of Dirac-Hartree-Bogoliubov density functionals from finite nuclei to neutron-star matter with thermodynamic consistency constraints

Authors: Guo, Mrs. Jun-Hua, Xie, Dr. Wen-Jie, Guo, Mr. Pei, Xie, Dr. Wen-Jie

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Abstract

Density-dependent covariant energy-density functionals provide a common framework for finite nuclei and neutron-star matter, but their extrapolation to supranuclear densities is not uniquely fixed by finite-nucleus data. We construct a finite-nucleus-protected high-density reshaping of the DD-ME2 functional in which the original low-density coupling functions are left unchanged, while selected high-density meson-nucleon couplings are modified in a thermodynamically consistent way. Direct Dirac-Hartree-Bogoliubov regression tests for representative spherical nuclei show that binding energies and charge radii are preserved within numerical precision. The dominant response is generated by the isoscalar-vector ω channel: moderate softening lowers the canonical radius and tidal deformability to $R_{1.4} = 12.19$ km and $\Lambda_{1.4} \simeq 470$, while preserving a maximum mass $M_{\max} = 2.35 M_{\odot}$. The simple isovector-vector ρ-channel reshaping considered here produces only a weak response in the symmetry sector, proton fraction, direct-Urca threshold, and bulk stellar observables. As a proof-of-concept statistical test, we perform a two-parameter Bayesian reweighting of the protected (f_V, f_{TV}) grid using NICER mass-radius posteriors and an event-level GW170817 tidal likelihood. The posterior favors a negative isoscalar-vector reshaping, with a marginal mode near $f_V = -0.043$, while leaving the present isovector reshaping weakly constrained.

Note: Figure translations are in progress. See original paper for figures.