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Beyond Current Limitations: A New Approach to the Neutron Star Equation of State

The neutron star equation of state (EOS) remains one of the fundamental challenges in nuclear astrophysics, with current modeling approaches facing distinct limitations. Phenomenological models, while successful in reproducing nuclear and astrophysical constraints, suffer from inherent model dependencies in their parametrizations. These dependencies can introduce biases in posterior distributions when constraining neutron star properties from observational data, potentially affecting our interpretation of multi-messenger observations. Model-independent and agnostic frameworks attempt to overcome these limitations through increased flexibility, but this comes at the cost of reduced physical interpretability and increased systematic uncertainties. The tension between flexibility and physical consistency presents a fundamental challenge: how can we develop EOS models that are both sufficiently flexible to capture diverse astrophysical constraints and physically motivated enough to provide meaningful insights into dense matter?
We present a new framework that addresses these challenges by combining the strengths of both approaches. Our method maintains theoretical consistency while achieving the flexibility necessary for modern astrophysical applications. By carefully constructing a framework that respects fundamental nuclear physics principles without being overly restrictive, we demonstrate improved performance in capturing current observational constraints across the full neutron star mass range.
This work suggests that next-generation EOS modeling can move beyond the traditional dichotomy between phenomenological and agnostic approaches, offering new pathways for leveraging multi-messenger observations to constrain the properties of matter at extreme densities.

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