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Exotic Matter and the Neutron Star EOS: Observational Signatures of Hyperons, Bosonic Dark Matter, and Quark Matter

The presence of dark matter in neutron stars is of growing interest due to its possible impact on their structure and observables. Among proposed candidates, the hypothetical sexaquark has emerged as a promising bosonic dark matter particle, potentially forming under extreme conditions in neutron star cores.
We investigate this scenario using a relativistic density functional approach, including hyperons (DD2Y-T model) for the hadronic phase, coupled to a deconfined quark phase described by a non-local Nambu-Jona-Lasinio model.
The phase transition is modeled through a smooth crossover, and sexaquark-baryon interactions
are introduced via an effective mass shift representing repulsion.
We assess whether this hybrid scenario, incorporating hyperons, bosonic dark matter, and deconfined quark matter,
is consistent with multi-messenger constraints from neutron stars. By scanning the parameter space,
we identify sexaquark masses that are consistent with mass-radius measurements and tidal deformability.
Our results show that the presence of the sexaquark softens the equation of state, enabling the model to satisfy both the radius and tidal deformability constraints around the canonical $1.4M_{\odot}$ neutron stars.
We incorporate all available NICER data, including PSR J0437-4715 and newly published PSR J0614-3329.
We find out that hybrid stars with sexaquark mass near 1900 MeV agree with all current observational limits, including HESS J1731-347 and PSR J0952-0607, representing the lightest and most massive known neutron stars.
Furthermore, we perform a Bayesian analysis, which yields a favored sexaquark mass range of 1885-1935 MeV, supporting the potential role of this exotic particle in the interiors of neutron stars.

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