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A unified equation of state for neutron stars and proto-neutron stars

In this work, we aim to study the interior properties of isolated, non-accreting, and non-rotating (proto-)neutron stars. For this purpose, the meta-modeling technique was employed to compute the properties of nuclear matter, while the inhomogeneities in the crust were characterized using a compressible liquid drop model. Furthermore, the equation of state was consistently calculated in a unified manner under the nucleonic hypothesis. Within a Bayesian study, we investigated the impact of different constraints from nuclear physics and astrophysical data on the equation of state of cold neutron stars. Notably, the results of our Bayesian analysis suggest that the nucleonic hypothesis remains compatible with all current data from neutron-star observations provided by the NICER and LIGO-Virgo collaborations. The non-spherical structures of nuclei in the innermost region of the crust, known as pasta phases, and the uncertainties associated with their properties were thoroughly investigated. Particularly, we demonstrated that both the bulk and surface terms have a significant impact on the prediction of the pasta-phase properties. Finally, we studied the inner crust of proto-neutron stars in the liquid phase. In particular, we demonstrated that the translational free energy has important effects on the crust composition. At high densities and temperatures, the one-component plasma approximation becomes less reliable, and the coexistence of different nuclear species in a multi-component plasma approach has been considered, thus allowing us to consistently calculate the so-called impurity parameter, needed for neutron-star cooling simulations. The formalism and numerical tools developed in this work could be further extended for future studies, such as investigating phase transitions in the core and calculating transport properties of the crust.

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