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Nuclear equation of state from nuclear experiments and neutron star observations

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The Equation of State (EoS) is crucial for understanding the structure of compact objects such as neutron stars. In the conservative hypothesis of a purely nucleonic composition of neutron star matter, the EoS is fully determined in terms of the so-called nuclear matter parameters (NMPs), which, in principle, can be determined from nuclear theory and experiments, though with error bars. However, present constraints from nuclear data are typically limited to (i) independent analyses of different data sets with limited control over the quality of the simultaneous reproduction of different observables and (ii) independent inferences of single NMPs with limited knowledge of the correlations among parameters.

The main objective of our work is to progress on both limitations. Specifically, we build a reliable probability distribution of the whole set of nuclear matter parameters and investigate the correlations between them using a combined Bayesian inference of a large set of EoS-sensitive nuclear structure data. We then use this distribution to compute the static properties of neutron stars.

To compute a wide selection of precisely measured nuclear observables over the nuclear chart (binding energies, charge radii, spin-orbit splittings, giant resonance energies, dipole polarizability, parity-violating scattering), we employ the hfbcs-qrpa [1] code with standard Skyrme functionals. While ground state properties of nuclei require negligible computational time, observables linked to nuclear response, which are expected to be sensitive to specific nuclear bulk properties are computationally more demanding. In Metropolis sampling, evaluating on the fly is time-consuming, so we resorted to the MADAI package [2], an emulator software for Bayesian inference with slow models.

The final result is a 10-dimensional multivariate probability distribution for the NMPs. Marginalizing the distribution over all parameters but one allows to compare with previous simpler analyses in the literature. The talk will present such a critical comparison and the final predictions on some selected static properties of neutron stars.

We will, in particular, show that the constraints from nuclear experiments are well compatible with the theoretical predictions for infinite pure neutron matter from ab initio modeling, and those constraints additionally indicate the existence of interesting structures in the density dependence of the sound speed in neutron stars.

[1] G. Colò, X. Roca-Maza, arXiv:2102.06562v1 [nucl-th]

[2] MADAI Collaboration (Models and Data Analysis Initiative) https://madai.phy.duke.edu/indexdc37dc37.html?page_id=445

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