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Machine Learning Applied to Quark Stars and Neutron Stars: From Observations to EoS

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In this work, we generate a wide range of equations of state (EoS) for both quark matter and nucleonic matter. For nucleonic matter, we use the metamodeling approach due to its simplicity. The EoS generated using metamodeling must satisfy certain physical constraints: it must be causal, its symmetric properties must fall within experimental values, and it must support approximately 2 solar masses.

The EoS for quark matter is given by the MIT bag model, which here is considered a toy model. The only constraint is the bag value, as it must lie within the stability range for strange matter. The constraint of supporting \(\sim 2\) solar masses was not imposed on strange matter.

By solving the TOV equations for the generated EoSs, we obtained a dataset containing mass (\(M\)), radius (\(R\)), energy density, pressure, and model parameters. This dataset is used to train the model \cite{Krastev2024, Wu2024} and properly solve the inverse problem—i.e., given \(M\) and \(R\), determining the corresponding energy density, pressure, and model parameters. This approach is essential for obtaining information about the microscopic features from the observed M-R relations, such as those for PSR J0030+0451 and PSR J0740+6620.

To validate our trained model, we used the \(M\)-\(R\) relation for the MIT bag model extracted from the literature and verified that the bag value is in good agreement with the value reported in the paper. For nucleonic matter, before training the model, we removed two \(M\)-\(R\) relations—each corresponding to one EoS—from the dataset. These were later used to verify whether key model parameters.

Krastev2024: P.˜G.˜Krastev, A Deep Learning Approach to Extracting Nuclear Matter Properties from Neutron Star Observations," \textit{Symmetry}.
Wu2024: Z.˜Wu and D.˜Wen,From masses and radii of neutron stars to EOS of nuclear matter through neural network," Chin. Phys. C \textbf{48}, no.2, 024101 (2024) [arXiv:2312.15629 [nucl-th]].

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