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Peer Review

# Review of: "General Features of the Stellar Matter Equation of State From Microscopic Theory, New Maximum-Mass Constraints, and Causality"

**Mohamed Nouh**[1]

1. National Research Institute of Astronomy and Geophysics, Helwan, Egypt

Using microscopic chiral effective field theory (EFT) as a basis, this work investigates the neutron star equation of state (EoS) and extends it into high-density regimes by introducing maximum-mass constraints and causality. The authors use polytropic extensions and speed-of-sound parametrisations to guarantee compatibility with observable constraints, such as PSR J0952-0607 (2.35 $M_{\odot}$), since ab initio theories are only trustworthy at normal densities. While stronger extensions are required to sustain the most massive neutron stars, the research indicates that softer EoS models meet microscopic expectations. Higher-mass neutron stars cool quickly as a result of increased neutrino emission, according to cooling models, and surface temperatures are largely determined by the chemical makeup of the envelope. The study emphasises the significance of three-nucleon forces (3NFs), but it also points out irregularities at $N^3LO$ because of regularisation problems. The authors stress that at very high densities, phase transitions or exotic matter might appear and affect the form of the EoS. In contrast to the more flexible phenomenological relativistic mean-field (RMF) models, ab initio models give more robust limitations based on nuclear physics.

This paper presents a well-structured and scientifically rigorous analysis of the neutron star equation of state (EoS), integrating microscopic nuclear theory, astrophysical constraints, and neutron star cooling models. The methodology is solid, particularly in its use of chiral effective field theory (EFT), polytropic extensions, and causality constraints. The discussion is comprehensive, covering both low-density nuclear interactions and high-density phenomenological extensions, making it relevant to both nuclear physicists and astrophysicists.

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This work effectively blends microscopic theory, causality constraints, and astrophysical evidence to improve the neutron star equation of state (EoS). However, more advances may be achieved by combining more sophisticated three-nucleon force (3NF) models with adequate regularization to assure consistency at higher chiral orders (N3LO and beyond). Additionally, although the work used polytropic and speed-of-sound parametrizations, alternate techniques, such as density-functional methods or machine-learning-based EoS reconstructions, might yield deeper insights. Future studies should also concentrate on comprehensive neutron star cooling models, including superfluid gaps, medium effects, and short-range correlations, to increase agreement with observable thermal luminosities. Furthermore, to further refine high-density EoS behaviour, gravitational wave constraints from neutron star mergers should be included. Last but not least, expanding the study to include hybrid stars with phase transitions or quark matter may assist in answering outstanding issues about the stability and composition of ultra-dense matter.

## Declarations

**Potential competing interests:** No potential competing interests to declare.