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Obj: Review report on the PhD thesis presented by the candidate Lami Suleiman

To whom it may concern:

The candidate Lami Suleiman presents a PhD thesis on astronuclear physics, entitled "Dense matter properties and neutron stars modelling".

The main motivations and the theoretical physics framework are well illustrated in the Introduction and are connected to the physics of neutron stars (NS), which are among the most exotic objects in the Universe: indeed, they present extreme and quite unique properties both in their macrophysics, controlled by the long-range gravitational and electromagnetic interactions, and in their microphysics, controlled by the short-range weak and strong nuclear interactions. Therefore, a comprehensive study of neutron stars requires expertise from disciplines that must work sinergically: high-energy astrophysics, general relativity, nuclear and hadronic physics, neutrino physics, QCD, physics of superfluids. The interdisciplinary nature of this study is clear in the dissertation presented by the candidate, which is well set in this new and thriving field of research, *astronuclear* physics. The newly born multi-messenger astronomy, with its more and more accurate observational precision, offers the possibility of exploring NS structure by comparing observations to nuclear models. This is the main goal of this dissertation.

After the Introduction, the dissertation contains a detailed discussion of the different approaches to the study of the equation of state (EoS) of NS matter, and the different constraints coming from nuclear physics and astrophysics, with special reference to the measurements of the NS mass, radius, tidal deformability, and moment of inertia. In this regard, the candidate shows that the construction of the NS EoS over the huge density range typical of these objects, about 14 orders of magnitude, may suffer of lack of precision in the interval where the transition from homogeneous matter (NS core) to clusterized matter (NS crust) takes place, due to the different nuclear models used over that interval and based on different theoretical frameworks. This may result in errors on macroscopic parameter's modelling and can be misleading in accepting or rejecting a nuclear model. This issue is not new, and this dissertation offers the opportunity to clarify this point. The discussion is rich of details and the conclusions clear, especially in view of the next generation of detectors. Moreover, accurate polytropic fits of modern equations of state for NS matter are presented, and this turns out to be very useful for research teams engaged in supernovae and binary neutron stars merging simulations. Both studies have been published in Physical Review C, one of the top-level peer review journals in astronuclear physics with high impact factor. In both cases Ms. Suleiman is the first author.

A further aspect treated in the dissertation regards neutron stars in low-mass binary systems, which are subject to accretion when material from the companion star accumulates on the surface. One usually assumes for the NS crust the so-called fully accreted crust approximation, although X-ray observations of some transient sources indicate that the original crust has not been completely replaced by accreted material. In the dissertation the candidate develops a new method to go beyond the fully accreted crust approximation and proposes a model of hybrid crust made of the original crust and of the accreted material crashing onto it. Important differences in the composition and energy sources for the fully accreted and hybrid crusts influence the cooling and transport properties. This study has been published in Astronomy & Astrophysics, an internationally recognized peer-review journal with high impact factor, and again the candidate is first author.

As far as cooling is regarding, this is the main subject of the last part of the dissertation, where the Direct and the Modified Urca processes for neutrino emission are discussed. In particular, the candidate Suleiman mainly discusses the derivation of the neutrino emissivity of the Modified Urca process at finite temperature, essential for the physics of proto-neutron stars and binary neutron star mergers. The chosen theoretical framework is the Thermal Quantum Field Theory, and the formalism is based on the thermal Green's functions. I found this part of the dissertation original, and very stimulating for future work. Though the theory has been developed starting from several approximations, its extension looks within reach and its perspectives very promising.

Summing up, I consider the doctoral thesis of Ms. Lami Suleiman to be a valuable contribution and to meet the criteria prescribed by the law for a doctoral dissertation. Therefore, I request that this dissertation be admitted to a public defense.

6/2/2023