Equation State of Asymmetric Nuclear Matter & Studies on Properties of Neutron Star

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Introduction

The nuclear equation of state (EoS), a cornerstone of nuclear physics, continues to be a formidable challenge. By synergizing insights from astrophysical observations and heavy-ion experiments, researchers aim to construct a more comprehensive model of the nuclear EoS, thereby advancing our understanding of the properties of nuclear matter (NM) under extreme conditions. The phenomenological effective forces, finite range Simple Effective Interaction (SEI) [1] is used to study the saturation properties of nuclear matter, Neutron star (NS) phenomenology, and finite nuclei behavior under extreme conditions of density and isospin asymmetry.

Simple Effective Interaction

SEI which has been developed by Behera and his collaborators [1] is a simplest possible parameterization of finite-range effective interaction has the following form:

$$V_{eff} = t_0(1+x_0P_\sigma)\delta(r) + \frac{t_3}{6}(1+x_3P_\sigma)\left(\frac{\rho(\mathbf{R})}{1+b\rho(\mathbf{R})}\right)^\gamma \delta(r) + (W + BP_\sigma - HP_\tau - MP_\sigma P_\tau)f(r).$$

where $f(r)$ represents a short-range interaction of conventional form such as Yukawa ($\frac{e^{-r/\alpha}}{r/\alpha}$), Gaussian ($e^{-r^2/\alpha^2}$) or exponential ($e^{-r/\alpha}$).

Result & discussions

Neutron-rich nuclei may exhibit new phenomena, such as the disappearance of the standard magic numbers and the appearance of new magic numbers. All of these new scenarios provide an excellent testing ground for the various nuclear models available in the scientific literature. The purpose of this study is to demonstrate that the effect of the monopole component of the central part of the nucleon-nucleon interaction is significant and can significantly influence the behaviour of the single-particle (s.p.) levels along isotopic or isotonic chains, masking the monopole effects originating from the spin-orbit and tensor parts of the nucleon-nucleon interaction. To emphasise these facts, the exotic Ni isotopes between ^{68}Ni and ^{78}Ni have been considered, as different measurements performed on Cu isotopes imply a crossing at $N = 46$ between the unoccupied $2p_{3/2}$ and $1f_{5/2}$ single-particle proton levels, which is the result extracted from the experiment [2, 3]. It has been asserted in prior literature that the aforementioned crossing can be reproduced using Skyrme forces and Gogny interaction by adding a tensor term. It is shown in Fig.[1], that in case of the Gaussian form of SEI (SEI-G) interaction with an incompressibility value $K(\rho_0)$=240 MeV, there is no requirement of explicit inclusion of a tensor part, unlike the case in Gogny and Skyrme forces. The SEI model's consistent preservation of Z=28 and N=50 magic numbers strengthens its potential as an effective nuclear interaction [4].

While SEI calculation has been successful in explaining numerous exotic scenarios within neutron-rich nuclei, there are instances where sole reliance on mean-field descriptions proves inadequate for replicating experimental data, even in a qualitative sense. Our findings reveal that the experimentally observed behavior of specific energy gaps in the Sn-isotopes, N=82 [5], and N=51 isotonic chains can be qualitatively explained by incorporating a short-range tensor term alongside the standard spin-orbit interaction in the SEI-G(γ= 0.42) model [6] as illustrated in Fig. [2].

The SEI EoS has been extensively employed to study the global correlation be-

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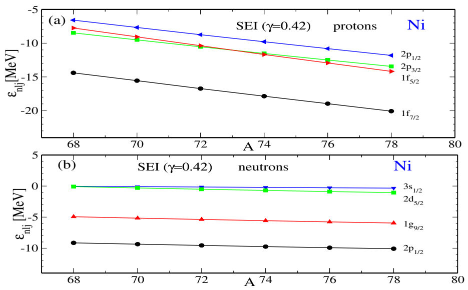

FIG. 1: (a) Proton (b) Neutron single-particle levels around the Fermi level for Ni isotopes computed with the SEI-G($\gamma = 0.42$) EoS.

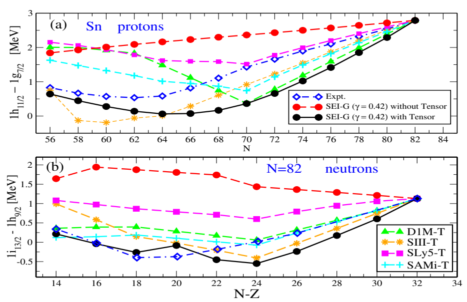

FIG. 2: Energy differences between the proton s.p. levels in Sn isotopes in panel (a) and the neutron s.p. levels in N=82 isotonic chain in panel (b), with and without tensor interaction. The experimental data are taken from Ref.[5].

tween charge radii differences in mirror nuclei (ΔR_{CH}), and neutron skin thickness (ΔR_{np}). A linear correlation between them is observed, which confirms the trends previously found in Skyrme forces and in Chiral effective field theory calculations in the low-energy limit. From the charge radii difference in mirror pair along with the neutron star radius extracted from NICER data analysis of the heaviest-mass pulsar PSR J0740+6620 [7] and GW170817 event of a binary NS merger within the LIGO/VIRGO collaboration [8], the slope parameter of the nuclear symmetry energy, L is constrained to lie in the range of $70 \le L \le 100$ MeV. In this range of L, the tidal deformability $\Lambda^{1.4}$=190^{+390}_{-120} extracted from the GW170817 event at 2σ level is well reproduced by the SEI-G($\gamma = 0.42$) EoS [9], as shown in Fig.[3] by the vertical yellow bands. In order to verify the applicability of the SEI in the domain of high density neutron rich matter the recent NS phenomenology associated with

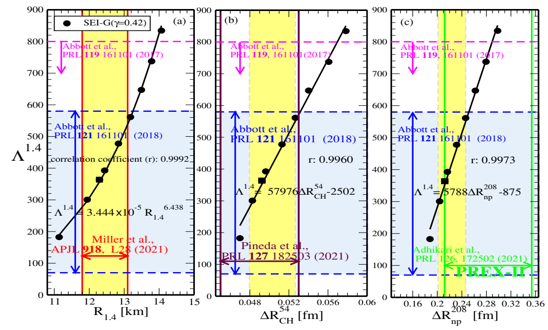

FIG. 3: Predictions of SEI-G(γ=0.42) for the tidal deformability, $\Lambda^{1.4}$, in 1.4M$_\odot$ NSs shown in filled black circles versus (a) the radius $R_{1.4}$ of 1.4M$_\odot$ NSs, (b) charge radii difference ΔR^{54}_{CH} of the ^{54}Ni-^{54}Fe mirror pair, and (c) neutron skin thickness ΔR^{208}_{np} in ^{208}Pb.

binary NS merger and gravitational redshift (Z_{surf}) have been computed using the Yukawa form of SEI (SEI-Y) EoSs [10]. The compactness C_{max} of the maximum mass NS predicted by the SEI-Y EoSs could predict the threshold mass M_{th} for prompt collapse that satisfies the minimum threshold mass constraint assessed from the binary masses in GW170817 event.

Summary

The SEI EoS is found to give satisfactory account of the higher-order nuclear matter saturation properties, finite nuclei properties, and various Neutron star phenomenology.

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