Study of finite nuclei and spindown properties of newborn neutron stars using Finite range Simple effective interaction

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In the absence of precise knowledge on nucleon-nucleon(NN) interaction, the model calculations have proved to be a reasonable alternative for the studies involving nuclear phenomena. An effective model needs to have the capability to predict reasonably the observables in the various domains of nuclear matter (NM) equation of state (EOS). In the context, we shall examine the predictability of the finite range Simple effective interaction(SEI) given by

$$\begin{aligned} v_{eff}(\vec{r}) &= t_0(1 + x_0 P_\sigma)\delta(\vec{r}) \\ &+ \frac{t_3}{6}(1 + x_3 P_\sigma)\left(\frac{\rho(\vec{r})}{1 + b\rho(\vec{r})}\right)^{\gamma}\delta(\vec{r}) \\ &+ (W + BP_\sigma - HP_\tau - MP_\sigma P_\tau)f(r) \end{aligned}$$

where, f(r) is the functional form of the finite range part, here considered to be of Gaussian one. Ten of the eleven parameters of SEI are determined from the experimental/empirical constraints resulting from the momentum and density dependence of the nuclear mean fields in NM of different kinds. The lonely NM interaction parameter together with the spin-orbit (SO) strength parameter are fixed to the binding energy (BE) of the two closed-shell nuclei, ^{40}Ca and ^{208}Pb [1]. The SEI with its parameters thus determined satisfies the Landau stability conditions $\sum_l f_l \approx 0$ and $\sum_l (f'_l + g_l - 2g'_l) \approx 0$.
The prediction of BE_s and charge radii of 620 even-even, both spherical and deformed, nuclei computed in the Hartree-Fock-Bogoulibov formulation are similar to those of any other model calculation [2]. The charge radii are reproduced better in quality than any other model prediction. The $1f_{5/2}$ and $2p_{3/2}$ single particle (s.p.) level crossing and magic character of A=78 in Ni-isotope chain, which is a topic of current interest [3, 4], is studied using SEI. From the spectroscopy study in Cu-isotopes [4] it has been ascertained that the $1f_{5/2} - 2p_{3/2}$ s.p. level crossing occurs for neutron number N=46. The computation of Ni-isotopes using SEI in the quasi-local density functional theory formulation predicts the $1f_{5/2} - 2p_{3/2}$ s.p. level crossing which depends on the NM incompressibility K as shown in Fig.1. The $1f_{5/2}$ and $2p_{3/2}$ s.p. level crossing occurs in ^{74}Ni for the EOS of SEI that has incompressibility value K=240 MeV. This is the value of K extracted from the study of giant excitation modes in finite nuclei [5]. The SEI EOS having K=240 MeV is used to calculate the ground state and excite state energies in Cu-isotopes. The spins of the Cu-isotopes are correctly predicted and first excitation energies are in good agreement with the experimental values similar in quality as obtained in the Monte-Carlo based larger shell-model calculation[6, 7]. The EOS is also used to examine other properties observed in exotic nuclei, such as, lowering of $1g_{7/2}$ level in N=51 isotones, reduction of SO-splittings at N=28 shell closure, weakening of Z=64 sub-magic structure for $N \sim 90$, isotopic shift in Pb- and Ra-isotopes, etc, and it produces qualitative results.

The EOS of SEI is now used to study the r-mode study in rotating neutron stars (NS)[8]. The EOS corresponding to K=240 MeV qualifies the two solar mass as well as the tidal deformability constraints. All new born young pulsar having an age around thousand years are found to have frequency as low as $\nu \lesssim 62$ Hz. The r-mode can be a possible spin-down mechanism that causes so low frequency. The

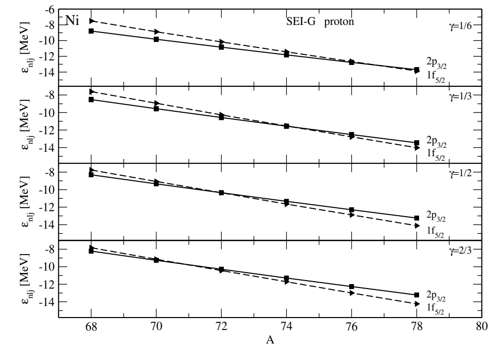

FIG. 1: Proton single-particle levels around the Fermi level in Ni isotopes from $A = 68$ to $A = 78$ computed with the SEI interaction for the four EoS.

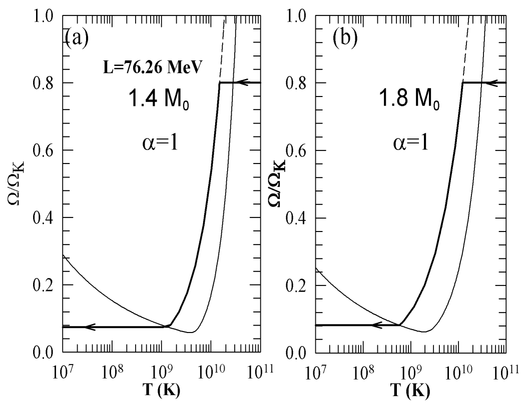

FIG. 2: The spin down path is shown inside the r-mode instability boundary for γ =1/2 with initial angular velocity $\Omega_i = 0.8\Omega_K$ for 1.4 and 1.8 $M_\odot$ NSs.

r-mode instability boundary has been calculated in the minimal model. However, the bulk viscosity has been evaluated taking into account the direct URCA (DU) processes. Using two NS mass models, $1.4M_\odot$ and $1.8M_\odot$, it has been shown that the spin-down period in case of the $1.8M_\odot$ NS is shorter than the $1.4M_\odot$ NS due to the effect of the DU processes. This is shown in Fig.2 in two panels for $1.4M_\odot$ and $1.8M_\odot$ NSs under the consideration that while born their temperature is of the order 10^{11} K. The spin-down features have been computed using the equations of motion together with the consideration that the spin-down occurs in a thermal steady state [9]. The resonance feature of the bulk viscosity is also examined and it is found that the modified URCA processes contributions are dominant. This resonance phenomenon is crucial to the equilibration processes of the oscillations produced in the event of two NS merger. The intensity of the gravitational waves (GW) emitted under r-mode mechanism have been calculated for the pulsars in the LMXB. The magnitude of the GW intensity obtained is in fair agreement with the results obtained in other calculations using APR interaction, and it shows that next generation GW detector is necessary to detect the GWs emitted under r-mode oscillation.

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