Study of neutron star radius with skin thickness and slope parameter by using finite range effective interaction

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Introduction

Neutron stars are virtual laboratories for the physics and also natural testing grounds of our knowledge about the Equation of State (EOS) of dense neutron-rich nuclear matter under extreme conditions [1, 2].

The neutron star radius depends on density of neutron matter and controlled by properties of the nuclear force in particular by the density dependence of the nuclear symmetry energy $E_{sym}(\rho)$[3]. Estimation of the neutron star radius is more difficult than mass measurements. Various observations have recently utilized like 1) radius upper limits from rapidly rotating neutron stars, 2) estimate from the thermal emission of cooling neutron stars, including red-shifts, 3) estimate the properties of sources with bursts or thermonuclear explosions on their surfaces etc.

The Typel-Brown correlation indicates that the neutron skin thickness 'S' is linearly correlated with density derivative of $Esym(5\rho_0/8)$, whereas the Lattimer-Prakash correlation for the neutron star radius 'R' demonstrates a linear correlation between $R^{1/\alpha}$and density derivative of $Esym(3\rho_0/2)$. Also the density derivative of symmetry energies in two different densities is linearly correlated as in ref. [4]. This suggests a relationship between 'S' and 'R' as

$$S = \lambda + \mu R^{\frac{1}{\alpha}} , \qquad (1)$$

where λ, μ and α are some constants depends on neutron star mass.

The variation of neutron star radius with respect to neutron skin thickness of Pb^{208} is plotted for different sets of exchange strength parameters for finite rage effective interaction of Yukawa form given in ref [5] considering A$_1$) $E_{ex}{}^{l} = \frac{E_{ex}}{2}$ and A$_2$) $E_{ex}{}^{ul} = \frac{E_{ex}}{2}$ in Fig:1. In the same figure we compare our results for NL3, S271, Z271 interaction as in [6].

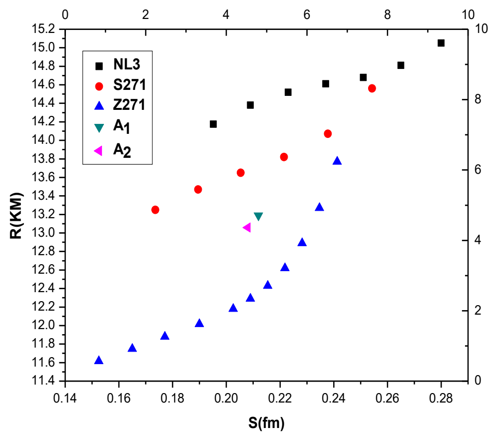

Fig. 1. Variation of 1.4 solar mass radius 'R' with respect to neutron skin thickness 'S' for NL3, S271, Z271 interaction [6]. Also star radius for A$_1$ (green) and A$_2$ (pink) by finite range effective interaction.

From Fig.1 we conclude that the radius of 1.4 solar mass neutron star varies as 11.61 km $<R_{1.4}<$15.05 km for the variation of skin thickness range 0.15 fm<S<0.28 fm. By using extended mass formula and finite range effective interaction, we have found that the values of 'S' is 0.212 fm for A$_1$ and 0.208 fm for A$_2$ as in [7]. The corresponding values of neutron star radius are 13.188 km and 13.059 km respectively which is consistent with the results obtained by other interaction or other model.

Symmetry energy parameters and neutron star radius

The crust of neutron stars bears some analogy with the neutron-skin of heavy nuclei. However, they show completely different behaviour on the slope parameter L. The neutron skin thickness usually increases with the increasing L as a result of the competition between the nuclear surface tension and the pressure difference of neutrons and protons. On the other hand, the thickness of neutron star crusts decreases with the increasing L as a result of the competition between the nuclear pressure and the gravitational binding.

To study the variation of neutron star radius with respect to L, we replace 'S' by L in our previous work [8, 9]

$$\sqrt{\frac{3}{5}}\left[\frac{2r_0}{3E_{sym}(\rho_0)}L\left(1-\chi\frac{K_{sym}}{2L}\right)\chi A^{1/3}\left(I-I_C\right) - \frac{e^2 z}{70\, E_{sym}(\rho_0)}\right] = \lambda + \mu R^{\frac{1}{\alpha}} \quad . \tag{2}$$

In Fig: 2 radius of 1.4 solar mass is plotted as a function of slope parameter L by using our interaction as well as for some other model or interaction for comparison.

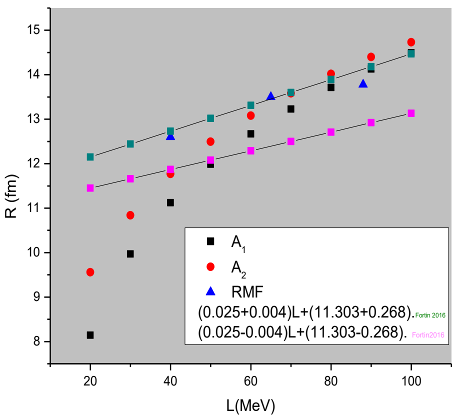

Fig. 2. Variation of neutron star radius with slope parameter L for A_1, A_2, RMF interaction and also linear regression Ref. in Fortin et al. [10].

The increasing nature of radius R with respect to slope parameter L is found and our results hold good for a particular range of L for both types of splitting which also constrain the range of L. For L=(40±10) MeV, the value of R is 9.96 km to 11.98 km for A1 and 10.84 km to 12.49 km for A2 where by using RMF model the variation is 11 km to 13 km and all these results are within the linear regression Ref. in Fortin et al.[10]. Hence it is found that the results obtained by using finite range effective interaction are consistent with the other results and also in between the range of upper and lower limits.

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