Study of correlation between tidal deformability of neutron Star and nuclear matter parameters

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Introduction

The interior of the neutron star (NS) is inaccessible to direct observations, due to extremely small size($\sim$ 10 km) and relatively large distance from Earth. However, the NS observables such as mass, radius, and tidal deformability Λ are theoretically linked to the NS equation of state (EoS). This can be used to explore the properties of the interior of NS.

The EoS can be constructed from Taylor series expansion of the EoS about the saturation density ρ_0, where the expansion coefficients are the nuclear empirical parameters. In the present work we mainly focus on the slope and incompressibility of symmetry energy, namely L_0 and $K_{sym,0}$.

$$E(\rho, \delta) = E_{is}(\rho) + \delta^2 E_{iv}(\rho) \qquad (1)$$

Here, E_{is} is the SNM term and E_{iv} is the correction term for the deviation from SNM, ρ is the number density, and $\delta = (\rho_n - \rho_p)/(\rho_n + \rho_p)$ is the asymmetry parameter, where ρ_n and ρ_p are the neutron and proton umber densities respectively. The δ values $\delta = 0$ and $\delta = 1$ corresponds to symmetric nuclear matter (SNM) and pure neutron matter (PNM). The E_{is} and E_{iv} in Eq. (1) can also be Taylor expanded in terms $x = (\rho - \rho_0)/(3\rho_0)$:

$$E_{is}(\rho) = E_0 + \frac{1}{2}K_0 x^2 + \frac{1}{3!}Q_0 x^3 + \frac{1}{4!}Z_0 x^4 + ...$$

$$E_{iv}(\rho) = J_0 + L_0 x + \frac{1}{2}K_{sym,0}x^2 + \frac{1}{3!}Q_{sym,0}x^3 + \frac{1}{4!}Z_{sym,0}x^4 + ...$$

$E_0, K_0, J_0, L_0, K_{sym,0}$ etc. are the nuclear matter parameters (NMPs) evaluated at ρ_0. The correlation between these NMPs and the tidal deformability $\Lambda_{1.4}$ for NS with mass $1.4M_\odot$ sheds some light on how the $\Lambda_{1.4}$ is influenced by the properties of the EoS. Recently, several investigations have been carried out to explore the possibility of the correlations of $\Lambda_{1.4}$ with various NMPs. The conclusions drawn in these studies are at variance [5]. In Ref. [1], the calculations are performed using a meta model and has found the correlation between L_0 and $\Lambda_{1.4}$to be 0.63 while Ref. [2] reports a correlation of 0.03 and Ref. [3] has reported correlation as strong as 0.91. These correlations are quite sensitive to the choice of the distributions of NMPs. The nature of correlations strongly depends on whether or not the NMPs are appropriately constraint by the available data on the bulk properties of finite nuclei and empirical values of NMPs at the ρ_0.

In the present contribution we perform a systematic study of correlations of $\Lambda_{1.4}$ with L_0 and $K_{\rm sym,0}$ for correlated and uncorrelated distributions of NMPs which are minimally constrained by the low density EOS for the PNM obtained by the chiral effective field theoretical model.

Methodology

We consider the uniform or gaussian priors, assuming higher uncertainty in our understanding of the values of NMPs and no correlation among the NMPs. These priors are taken to be exactly same as the ones considered in Ref. [4]. The posterior distributions of NMPs are obtained by subjecting the EOS for the PNM obtained using Taylor expansion to the pseudo data which

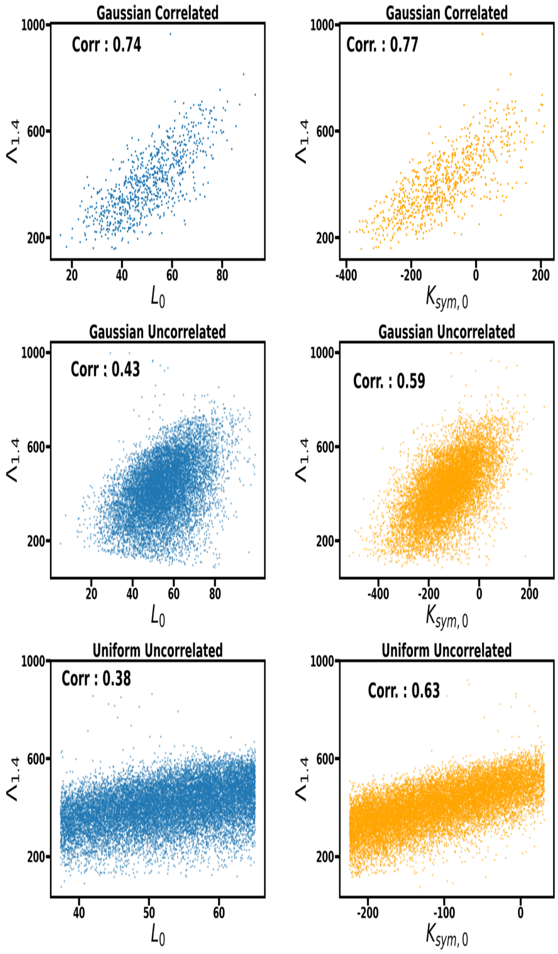

FIG. 1: Scatter plot for tidal deformability $\Lambda_{1.4}$ with L_0 and $K_{sym,0}$ for three different distributions of NMPs.

corresponds to the one obtained by a chiral effective field theoretical model. These NMPs are correlated due to the constraints imposed by the pseudo data. Mostly, the NMPs are having Gaussian distributions and we refer them as GC, i.e., Gaussian and Correlated. Using them, we construct marginalized distributions of NMPs which are Gaussian, but, uncorrelated and are referred as GU. We also construct Uniform Uncorrelated (UU) distributions of NMPs with the help of parameters of GU such that they vary over $\mu - \sigma$ to $\mu + \sigma$, where, μ and σ correspond to the mean and standard deviation for the GU. Using the UU, GU and GC distributions of NMPs, we construct the EoS and use them to solve the Tolman-Oppenheimer-Volkoff (TOV) equations to obtain the mass, radius and tidal deformability. Then, we calculate the Pearson's correlation coefficient r for $\Lambda_{1.4}$ with L_0 and $K_{\text{sym},0}$.

Results

In Fig. 1 we display the scatter plot for $\Lambda_{1.4}$ with L_0 and $K_{\text{sym},0}$, indicating the dependence of the correlations on the choice of distributions of NMPs. The numerical values of the correlations are indicated in the figure. We find that the correlation between the tidal deformability $\Lambda_{1.4}$ and slope of symmetry energy L_0 and $K_{sym,0}$ are sensitive to the type of distribution of NMPS. It is clearly evident, if the NMPs are not appropriately constrained, they yield quite weak correlations. For instance, the $\Lambda_{1.4}$ - L_0 correlation is quite weak for the case of UU ($r \sim 0.38$) which becomes quite strong for the GC ($r \sim 0.74$). Inclusion of correlations among the NMPs as imposed by the pseudo data remarkably increase the correlations of $\Lambda_{1.4}$ with the L_0 and moderately with $K_{sym,0}$.

Summary and Conclusion

We have studied the sensitivity of the correlation between the tidal deformability $\Lambda_{1.4}$ and the NMPs. We find that the correlations among NMPs, as imposed by the physical constraints, are responsible for the strong correlations of $\Lambda_{1.4}$ with L_0 and $K_{sym,0}$.

References

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