Reconstruction of nuclear matter parameters from neutron star matter equation of state in a Bayesian approach

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The posterior distributions of nuclear matter properties are reconstructed using a Bayesian technique from the EoS of neutron star matter. Appropriate prior distributions are chosen to put constraints on lower-order parameters as imposed by the finite nuclei observables.The calculations are performed on two sets of pseudo data on the EoS whose real models are known.The accompanying uncertainties are also greater and the median values of second or higher order NMPs exhibit considerable variations from their true values.The following are the sources of these uncertainties: (i) the correlations among different NMPs and (ii) There is room for symmetry energy, neutron-proton asymmetry, and symmetric nuclear matter in the EoS, which spreads into the posterior distributions of the NMPs.

Introduction

The equation of state (EoS) of dense matter is greatly constrained by the bulk characteristics of neutron stars [1, 2].

Utilising the equation of state (EoS) for the neutron star matter that satisfies the criteria of β-equilibrium and charge neutrality, we use a Bayesian technique to reconstruct the marginalised posterior distributions(PDs) for the nuclear matter parameters (NMPs). For a given $\varepsilon(\rho, 0)$ and $J(\rho)$, one may use Eq.[1] of [3] to get the EoS for neutron star matter $\varepsilon(\rho, \delta)$. Using Eqs.[4] and [9] of [3], we create two sets of pseudo data for $\varepsilon(\rho, \delta)$ corresponding to the models M1 and M2 derived using NMPs from Table.[1] of [3] respectively.

Formalism

In the parabolic approximation, the nuclear component of the energy per nucleon for neutron star matter $\varepsilon(\rho, \delta)$ is stated as,

$$\varepsilon(\rho, \delta) \;=\; \varepsilon(\rho, 0) + J(\rho)\delta^2 + ..., \qquad (1)$$

where, $\delta = \left(\frac{\rho_n - \rho_p}{\rho}\right)$ with ρ_n and ρ_p being the neutron and proton densities, respectively. We use Taylor and $\frac{n}{3}$-expansions to reconstruct the nuclear matter parameters using a Bayesian approach of [3].

Results and Discussions

Models M1 and M2 are used in a Bayesian analysis for prior sets P1 and P2 (see [3]) The results can be summed up as follows: (i) the median NMP values in Table I show larger deviations from their true values; (ii) the uncertainties on the NMPs determined from the EoS of neutron star matter are several times larger for most of the NMPs; (iii) the uncertainties on the Z_0 and $Z_{\mathrm{sym},0}$ in Table I are considerably asymmetric about their median values. reflecting their non-Gaussian nature.

We now examine the uncertainties in the NMPs that could arise from the allowed variations in the $\varepsilon(\rho, 0)$, $J(\rho)$ and δ for a given $\varepsilon(\rho, \delta)$.In short, for a given $\epsilon(\rho, \delta)$, the values of $J(\rho)$, $\varepsilon(\rho, 0)$ and δ may have some leeway. For the NMPs, we employ the marginalised PDs to obtain 68% and 95% confidence intervals for $\varepsilon(\rho, \delta)$, $\varepsilon(\rho, 0)$ and $J(\rho)$. The results are plotted only for the M2-P2 case in Fig. 1. At a specific density, the value of $\varepsilon(\rho, \delta)$ (top) varies within a small bound, but, $\varepsilon(\rho, 0)$ (middle) and $J(\rho)$ (bottom) have larger uncertainties. Due to the non-Gaussian nature of higher-

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order NMPs, Table I and Fig.[5] of [3] show that the 95% confidence intervals for $\varepsilon(\rho,0)$ and $J(\rho)$ are slightly asymmetric compared to the ones for the 68%. Beyond 2ρ0, the dispersion in the values of $J(\rho)$ rises quickly with density. Spread in $J(\rho)$ at $4\rho_0$ is $\sim$ 36 MeV which increases to $\sim$ 160 MeV at $6\rho_0$, whereas, the spread in $\varepsilon(\rho,0)$ remains almost the same ($\sim$ 15 MeV) for the density in the range $4\rho_0$ to $6\rho_0$, For 68% confidence interval.

TABLE I: The EoS for the neutron star matter is used to recover the posterior distributions for each nuclear matter parameter simultaneously.

NMPs	M1-P1	M1-P2	M2-P1	M2-P2
ε_0	$-16.0^{+0.3}_{-0.3}$	$-16.0^{+0.3}_{-0.3}$	$-16.0^{+0.3}_{-0.3}$	$-16.0^{+0.3}_{-0.3}$
K_0	187^{+65}_{-56}	221^{+36}_{-28}	213^{+47}_{-40}	230^{+28}_{-25}
Q_0	-367^{+196}_{-220}	-471^{+113}_{-123}	-327^{+243}_{-198}	-412^{+159}_{-123}
Z_0	1518^{+258}_{-236}	1632^{+152}_{-157}	1307^{+1069}_{-1656}	1637^{+835}_{-1206}
J_0	$31.8^{+2.5}_{-2.6}$	$32.0^{+2.6}_{-2.7}$	$32.0^{+2.5}_{-2.5}$	$32.0^{+2.6}_{-2.4}$
L_0	52.8^{+25}_{-19}	55.5^{+17}_{-16}	$53.1^{+23.8}_{-19.3}$	$51.0^{+14.0}_{-13.9}$
$K_{\rm sym,0}$	-34^{+142}_{-178}	-108^{+76}_{-72}	-114^{+113}_{-138}	-106^{+70}_{-70}
$Q_{\rm sym,0}$	220^{+755}_{-563}	486^{+257}_{-264}	562^{+572}_{-488}	522^{+248}_{-241}
$Z_{\rm sym,0}$	807^{+1341}_{-1527}	100^{+876}_{-668}	-60^{+1944}_{-1921}	-323^{+1920}_{-1643}

It should be noted that the nuclear matter parameter has a number of other sources of uncertainty. These sources of uncertainties include (i) inter-correlations of NMPs corresponding to $\varepsilon(\rho,0)$ with the ones for $J(\rho)$, (ii) compensation in the change of $J(\rho)$ with the asymmetry parameter δ and $\varepsilon(\rho,0)$ in such a way that the EoS of neutron star matter remains more or less unaltered.

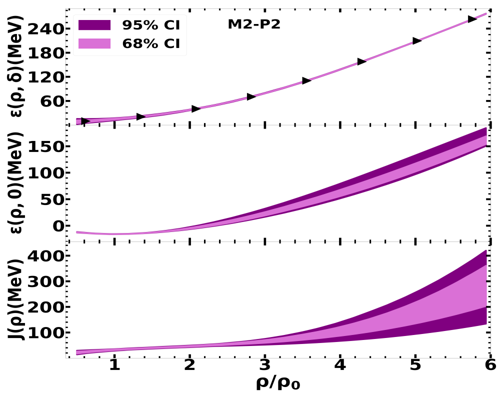

FIG. 1: Plots of 68% and 95% confidence intervals for the EoS for neutron star matter (top), the symmetric nuclear matter (middle), and the symmetry energy (bottom) as a function of scaled density with the prior set P2 for model M2 .

References

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