The f-mode and density dependence of symmetry energy

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Introduction

Any external or internal influence/perturbation can cause the fluid in a neutron star (NS) to oscillate resulting in a loss of equilibrium. However, restoring forces act to return the star to a state of equilibrium causing different modes of oscillation. The complex eigen frequencies corresponding to these oscillation modes, termed "quasi-normal modes" can be calculated in general relativity. Here, we solve the fluid perturbation equations to calculate the fundamental mode, called the f-mode, of quadrupolar oscillation.

The structure and bulk properties of NSs are determined by the pressure vs energy density relation or the equation of state (EOS) of beta-stable and charge neutral matter within these stars. Usually, the EOSs are characterised by a set of nuclear matter parameters (NMP) evaluated at the saturation density, ρ_0, that describes the symmetric nuclear matter part and the density dependence of the symmetry energy. The NMPs considered are the binding energy e_0, the incompressibility K_0, the skewness coefficient Q_0, the symmetry energy coefficient J_0, its slope L_0, and the curvature $K_{\rm sym,0}$. A central problem in nuclear physics and nuclear astrophysics is to constrain the EOS at high densities.

In this contribution, we present correlations of the f-mode frequencies with various NMPs. We have considered 35 different EOS's of which 23 correspond to non-relativistic mean field models based on the Skyrme interaction. The remaining 12 represent the two different variants of the relativistic mean field model (RMF) (see [1] for details). Most of these EOSs are consistent with the bulk properties of finite nuclei and infinite nuclear matter.

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Results and Discussion

The f-mode frequencies are obtained by solving the fluid perturbation equation along with the Tolman-Oppenheimer-Volkoff equations of stellar structure using the Cowling approximation (CA) where the metric perturbations are discarded [2] as well as from the fully general relativistic (GR) treatment [3, 4].

The linear correlation between a pair of quantities A and B are expressed using Pearson's correlation coefficient [5]

$$\mathrm{r(A,B)} = \frac{\sigma_{\rm AB}}{\sqrt{\sigma_{\rm AA}\sigma_{\rm BB}}}$$

with the covariance given by

$$\sigma_{AB} = \frac{1}{n}\sum_i A_i B_i - \left(\frac{1}{n}\sum_i A_i\right)\left(\frac{1}{n}\sum_i B_i\right),$$

where the index i runs over the number of models n. A correlation coefficient close to absolute unity signifies a strong linear relationship between the pair of quantities considered. We first asses uncertainties in values of the correlation coefficients by considering a large number of EOSs drawn randomly from our collection. We perform these calculations using different sample sizes.

Figure 1 shows the distribution of the correlation coefficient between the f-mode frequency and L_0 in a $1.4M_\odot$ NS for 1500 such samples. Each sample consists of 20 EOSs chosen at random from the 35 EOSs considered. We find a strong anti-correlation between the f-mode frequency and L_0 for both

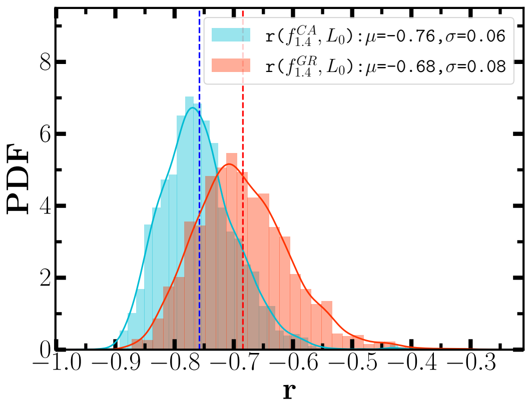

FIG. 1: The distributions of correlation coefficients, r, for $f_{1.4}$ with L_0 calculated using the CA (blue) and GR (red) in a $1.4M_\odot$ NS. The dashed vertical lines indicate the mean values.

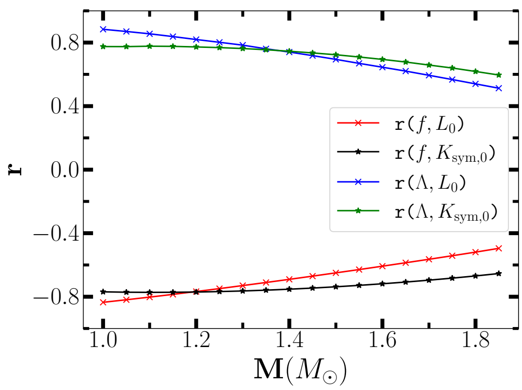

FIG. 2: Variations in the correlation coefficients, r,) for pairs of quantities indicated in the figure.

the CA and GR calculations. The mean value of the correlation coefficient does not change significantly with the number of EOSs used, but the standard deviation is affected marginally.

Considering all the EOSs, we found that f and Λ are strongly correlated with the slope of the symmetry energy curve, L_0, and its curvature, $K_{sym,0}$. As the f-mode frequency is proportional to the stellar average density, strong correlations with other NS observables such as its mass, M, and radius, R, are also suggested. We observe a strong anti-correlation between the f-mode frequency and the dimensionless tidal deformability Λ.

Figure 2 depicts the variation of the correlation coefficients with neutron star mass for calculations with 35 EOS models. Among the nuclear matter properties, we observe a strong correlation of L_0 and $K_{sym,0}$ with tidal deformability as well as with the f -mode frequency (anticorrelated). Interestingly the correlations observed are higher at lower masses for both L_0 and $K_{sym,0}$.

Summary and Conclusions

We have studied the dependence of the f-mode frequency on different nuclear matter properties. We observe that the f-mode frequency calculated for a $1.4M_\odot$ NS anticorrelates strongly with L_0 and $K_{sym,0}$. This dependence persists for calculations using both the Cowling and the general relativistic methods. Such anticorrelations are strong at lower masses for the pairs of quantities such as f-L_0, f-$K_{sym,0}$.

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