The rotating frequency and GW strain amplitude from Nuclear Models

Shailesh K. Singh[1],* S. K. Biswal[1], M. Bhuyan[1], T. K. Jha[2], and S. K. Patra[1]
[1] *Institute of Physics, Bhubaneswar, India. and*
[2] *Department of Physics, BITS, Goa Campus, India.*

Introduction

About 96 percent mass-energy of the Universe is chargeless [1]. Thus, unlike electromagnetic radiation, it is difficult to get information from this huge part of cosmos either directly or indirectly. The only possible way to study this neutral part of the Universe is the gravitational wave (GW) radiation. The main disadvantage of the gravitational radiation is its production in laboratories.

The recently measured static mass of the neutron star (NS) [2] is quite massive than the earlier measured masses. To get a larger mass, one needs a stiff EOS, which again oppose the softer EOS of kaon production [3]. To make such a model in the same footing, extra interactions are needed as it is done in G1 and G2 parametrizations [4]. In this contribution, we have taken 20 different EOS's from both non-relativistic Skyrme and relativistic mean field (RMF) formalisms and calculate the gravitational wave strain amplitude (h_0) of rotating neutron star (RNS).

Calculations and Results

The 13 Skyrme parameter sets, used in the present calculation, are SGII, SkM*, RATP, SLy23a, SLy23b, SLy4, SLy5, SkT1, SkT2, KDE0v1, LNS, NRAPR, SkMP and the 7 RMF sets are G2, G1, NL3, TM1, FSU, L1 and SH which are collected in Ref. [5]. For neutron star, the neutron chemical potential exceeds the combined masses of the proton and electron. We use the well known Tolman-Oppenheimer-Volkoff (TOV) equations for the structure of a relativistic non-rotating spherical symmetric star, where the pressure and energy densities are the inputs. Another realistic approximation that when neutron star is rotating with static, axially symmetric in a spherical polar coordinate (t, r, θ, ϕ) considering as a perfect fluid, we can put the limit on the maximum rotation, i.e. Kepler frequency Ω_k [6]. We calculate the maximum mass (M) and radius (R) for non-rotating and rotating NS. Finally, h_0 is estimated by the following relation:

$$h_0 = \frac{16\pi^2 G}{c^4}\frac{\epsilon I_{zz}\nu^2}{r}, \tag{1}$$

where r is the distance of neutron star from the earth. After getting the mass, radius, other properties like Φ_{22}, ϵ, I_{zz} which are the input for the h_0 calculation of RNS.

We have noted down the maximum mass and the corresponding radius obtained from various parameter sets using TOV equations and given in Fig. 1(a). Again for RNS, we collected the M_{max} and R_{max} in Fig. 1(b). Here, we have given the result of pulsar J1614-2230 [2] as a standard reference shown by the horizontal strip (red color) and compared our results. Comparing the mass of static and rotational star, one can easily see that rotational neutron star mass is larger than the static one. As Demorest et al. [2] stated that the theoretical models should have the maximum mass more or near to $(1.97 \pm 0.04)M_\odot$, the Shapiro delay provides no information for the neutron star's radius and we can not put any constraint on the radius of neutron star. The non-relativistic model parameter LNS which is not comfortable in non-rotating case, but it is within the cut off region for rotating star.

From the figure, a large number of parameter sets, like FSU, SGII, SkM*, LNS, RATP and SkT2 are not crossing the horizontal strip, which is the experimental con-

*Electronic address: shailesh@iopb.res.in

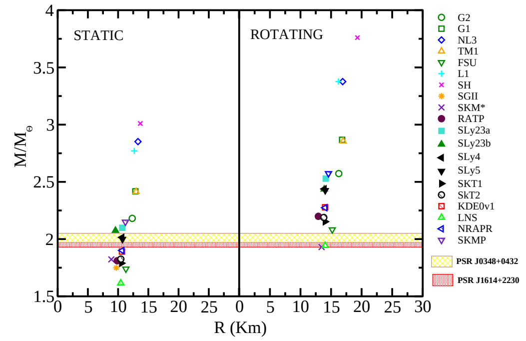

FIG. 1: Maximum mass ($M/M_{\odot}$) and radius R (km) of static and rotating neutron star obtained from TOV and RNS equations with various non-relativistic and relativistic model parameters.

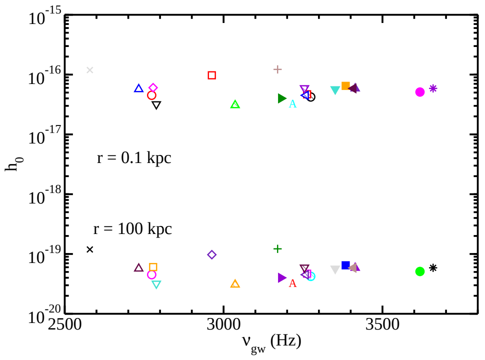

FIG. 2: The gravitational wave strain amplitude h_0 from various parameter sets.

straint on static/slowly rotating neutron star mass ($\frac{M}{M_{\odot}}$) [2]. To reproduce the recent star mass [2] (as the masses do not lie within the experimental strip) FSU [7] has been extended to IUFSU [8] to keep the prediction within the experimental constraint.

For a rotating neutron star, the gravitational wave amplitude h_0 is an experimental observable. We can observed it directly by specially designed experimental setups [9]. The gravitational wave is generated by rotation of an axially asymmetric NS. The wave strain amplitude h_0 can be measured by knowing the maximum mass and corresponding radius of a star. Apart from the mass and radius, the quadrupole moment Φ_{22}, moment of inertia along the rotation axis I_{zz}, ellipticity of the star due to rotation ϵ and rotational frequency ν_r are essential inputs for the estimation of the gravitational wave strain h_0 which is clear from the equation 1. We have given the GW strain amplitude with GW frequency ν_{gw} for two set of r. The value of r is very uncertain, in our calculations, we have taken two extreme range ($r = 0.1, 100$ kpc). The obtained results are shown in Fig. 2. The approximate upper limit of the h_0 is found 10^{-17} to 10^{-16} for $r = 0.1$ kpc and 10^{-20} to 10^{-19} for $r = 100$ kpc. One can easilly observe that the value of h_0 which is the fuction of rotational frequency, quadrupole moment and ellipticity, are almost consistent with all the considered models which show the model independency of the predictions. Our results will be very helpful in the respect of the prediction of future generations of GW detector families.

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