DOI: 10.15415/jnp.2015.31011

Properties of Rotating Neutron Star

SHAILESH K. SINGH[1*], S. K. BISWAL[1], M. BHUYAN1,T. K. JHA[2] AND S. K. PATRA[1]

[1]Institute of Physics, Bhubaneswar 751005, India.

[2]Department of Physics, BITS Pilani, K. K. Birla Goa Campus, India.

Email: shailesh@iopb.res.in

Received: May 7, 2015 | Revised: May 20, 2015 | Accepted: June 15, 2015

Published online: August 03, 2015

Abstract: Using the nuclear equation of states for a large variety of relativistic and non-relativistic force parameters, we calculate the static and rotating masses and radii of neutron stars. From these equation of states, we evaluate the properties of rotating neutron stars, such as rotational frequencies, moment of inertia, quadrupole deformation parameter, rotational ellipticity and gravitational wave strain amplitude. The estimated gravitational wave strain amplitude of the star is found to be~sim 10^{-23}.

Keywords: Relativistic and Non-relativistic mean field formalisms, equation of state, static and rotating neutron star, gravitational waves.

1. INTRODUCTION

Now-a-days analysis of gravitational wave (GW) sources and its application are very interesting area of research. Our universe has full of waves (gamma ray to microwave), which have their specific properties and having very interesting information about the source and surrounding. Mostly, all type of electromagnetic waves is generated from the charge source and as we know our universe have almost 96% are neutral. It means a lot of knowledge are hidden from us and gravitational waves are one of the possibility for explore the other side of knowledge. The observation of GW's is very not easy due to its non-interacting behavior and low frequency. There are so many dedicated experimental groups which are actively involved in detection of the GW. The main groups are LIGO (Laser Interferometer Gravitational Wave Observatory), LISA (Laser Interferometer Space Antenna) etc. situated on both ground and space. The main aim of these groups is to measure the GW polarization, quadrupole deformation, and ellipticity and strain amplitude of the gravitational waves. The theoretical estimation of the GW amplitude could

Journal of Nuclear Physics, Material Sciences, Radiation and Applications
Vol. 3, No. 1
August 2015
pp. 93–96

CHITKARA UNIVERSITY

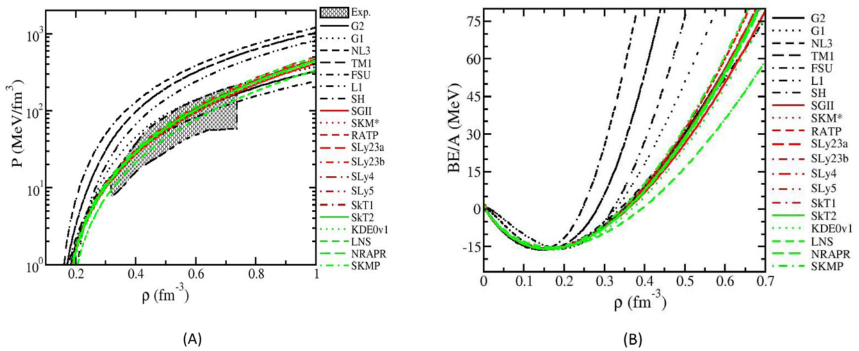

Figure 1: Binding energy per nucleon **(A)** and pressure density **(B)** with baryon density for 7 relativistic (G2, G1, NL3, TM1, FSU, L1, SH) and 13 non-relativistic (SGII, SKM*, RATP, SLy23a, Sly23b, Sly4, Sly5, SkT1, SkT2, KDE0v1, LNS, NRAPR, SKMP) parameters. These all parameters are summarized in [1].

provide important information for the experimentalists to set up their detectors for the detection of GW's strain amplitude.

2. RESULTS AND DISCUSSION

For, study the strain amplitude of the gravitational waves, we have taken the relativistic mean field and non-relativistic model parameter sets. In our study, we have taken static and rotating neutron star (NS) and find out the mass and radius in various forces. The NS are final state of collapsing start and then it goes to black hole due to its gravity. The GW's are the emitting source of the NS star and finally its gets cool down. Here, we analyzed the various properties of the NS like ellipticity (e), quadrupole deformation (PH) and moment of inertia (I). The main aim of our analysis is to find out the strain amplitude in different type of force parameter sets and finally put final limit on strain amplitude. These obtained results are very useful for the future experiments detectors. For our analysis, first we have solved the self-consistent equations and find out the equation of state for both relativistic and non-relativistic model. Here, we have given all EOS in figure 1, form the figure it is very clear all the force parameter followed the saturation properties (i.e. at saturation density BE/A is ~16 MeV) very nicely while at higher density results are diverted (mostly RMF forces). In this way we have taken varieties of parameters and trying to fix the gravitational strain amplitude. Most of the parameters are fitted to the saturation properties of symmetric nuclear matter like binding energy per nucleon (BE/A), effective mass of nucleons (M^*/M), incompressibility modulus (K_0) and symmetry energy E_{sym} at saturation density ρ_0. We have shown these empirical values in Table 1 of [1], where we will

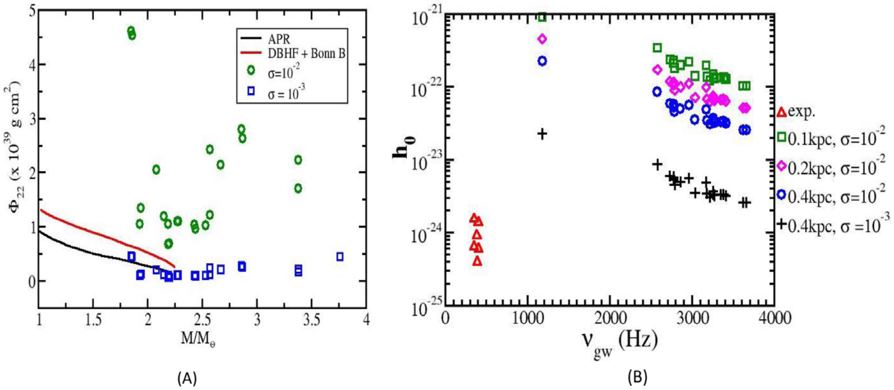

Figure 2: The quadrupole moment of NS for various parameters.

get all the parameter sets and their nuclear matter saturation properties. From figure 1, we get a very stiff equation of state (EOS) for SH parameter, which is one of the oldest RMF interaction and a soft EOS for LNS parameter, which is a successful set of SHF formalism. The rest of the EOS's for various parameter sets are between these two extremes. Our theoretical EOS for RMF and SHF results are compared with the most accepted experimental data of Danielewicz *et al.* 2 in Figure 1(B). From the figure, it is seen that all the EOS predicted with SHF formalism passes nicely through the experimental shaded region.

After getting the EOS in different parameter, it is very easy to find mass and radius of NS because only the EOS are the input for the RNS code (code for mass and radius of rotating neutron star). The other properties like quadrupole moment and moment of inertia which can be calculated by using this mass and corresponding radius for rotating NS in various parameters. For emission of GW, deformation is one of the necessary conditions. In figure 2, we have shown the quadrupole moment of NS for various parameters. The calculated results are compared with APR and theoretical results of DBHF + Bonn B which are shown in the figure 2 (A) by black and red color respectively. The quadrupole moments are also depends on the breaking stain of neutron crust which is responsible for the size and shape of the NS. For our calculation we have taken two set of σ values ($10^{-2,-3}$) and shown in the figure 2(A) by circle (green) and square (violet), respectively, for all the considered parameter sets. Hence, here we have taken the maximum mass and corresponding radius for the specific parameters so that our results are fall at higher mass side compare to the APR and DBHF + Bonn B results. For $\sigma = 10^{-2}$, calculated results are so much scattered while $\sigma = 10^{-3}$ are close to each other. Other observables like moment of inertia and ellipticity along with the formalism can be found in [1].

Before going to discuss the gravitational wave frequency ν_{gw} which is the double of the rotational frequency, we would like to see the rotational frequency $\nu_{rot} = \Omega_K/2\pi$ of neutron star. For a rotating neutron star, the gravitational wave amplitude h_0 is an experimental observable. We can observe it directly by specially designed experimental setup. The gravitational wave is generated by the rotation of an axially asymmetric neutron star. The wave strain amplitude h_0 can be measured by knowing the maximum mass and corresponding radius of a star. Its analytical feeling can be taken from the given equation:

$$h_0 = \frac{16\pi^2 G}{c^4} \frac{\in l_{zz} v^2{}_{rot}}{r}$$

where, G is universal gravitational constant, c is velocity of light, e is the ellipticity which is the proportional to the ratio of I_{zz} and quadrupole moment, ν_{rot} is rotational frequency and r is the distance between the source and observer. The results for different values of sigma and r are shown in the figure 2 (B). Apart from the mass and radius, h_0 is depending on the breaking strain of NS crust. It is a key quantity which controls the size of NS. The relation between gravitational wave strain amplitude and frequency ν_{gw} are shown in the figure 2 (B). In the calculations of quadrupole moment, we have taken two set of breaking strain of the neutron star crust $\sigma = 10^{-2}$, 10^{-3} and gravitational wave amplitude calculated with three sets of r (0.1, 0.2 and 0.4 kpc) which are the distances between the star and earth. So in this way, we have given the GW strain amplitude and frequency relation for four set of data as shown in the figure along with the experimental results. In our calculation, all gravitational frequencies come out more than 2700 Hz. We have noticed an important point here is that the gravitational wave strain amplitude decreases with increasing the r and decreases with the value of breaking strain of neutron star crust σ. Our results are close to the recent LIGO data. We have given these all data and citation in [1].

REFERENCES

[1] Shailesh K. Singh, S. K. Biswal, M. Bhuyan, T. K. Jha and S. K. Patra, arXiv:1312.5840.

[2] P. Danielewicz *et al*., Science 298, 1592 (2002). http://dx.doi.org/10.1126/science.1078070