# Tidal effects in equal-mass binary neutron stars

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## Introduction

Gravitational waves (GWs) emitted by binary black hole inspiral and coalescence are done first time direct detection by advanced Laser Interferometer Gravitational-wave Observatory (aLIGO) detector. We may expect that the forthcoming aLIGO, VIRGO and KAGRA (LCGT) detectors will also detect gravitational waves emitted by binary neutron star is in a few years. It is understood that the late inspiral signal will be influenced by tidal interaction [1] between binary stars (NS-NS), which gives the important information about the equation-of-state(EOS) of matter at nuclear density. However, to extract such information, we need a theoretical gravitational waves template.

In present calculations, we evaluate the mass-radius (M-R) and tidal deformability of the single neutron star using four equation-of-states (EOSs) and then extend our study to the analysis of the gravitational waveform from binary neutron-stars at a distance of D=100 Mpc using the post-Newtonian (PN) theoretical templates TaylorT4 (TT4).

## Results and Discussion

When spherical star placed in a static external quadrupolar tidal field $\varepsilon_{ij}$ then the star will be deformed and quadrupole deformation will be the leading order perturbation . Such a deformation is defined as the ratio of the mass quadrupole moment of a star $Q_{ij}$ to the external tidal field $\varepsilon_{ij}$, given as:

$$\lambda = -\frac{Q_{ij}}{\varepsilon_{ij}} \tag{1}$$

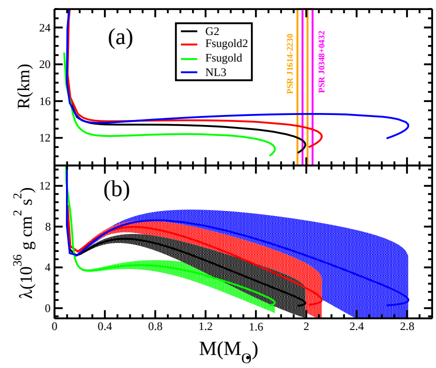


FIG. 1: (a)The mass-radius profile for the force parameters like G2, NL3,FSU and FSU2[2] used. (b) Tidal deformability $\lambda$ of a single neutron star as a function of the neutron-star mass for a range of EOSs. The estimate of uncertainties in measuring for equal mass binaries at a distance of D = 100 Mpc is shown for the Advanced LIGO detector in shaded area.

Specifically, the observable of the tidal deformability parameter $\lambda$ depends on the EOS via both the NS radius and a dimensionless quantity $k_2$, called the Love number:

$$\lambda = \frac{2}{3G} k_2 R^5 \tag{2}$$

and dimensionless tidal-deformability($\Lambda$) is related with the compactness parameter C=(M/R) as:

$$\Lambda = \frac{2k_2}{3C^5}, \tag{3}$$

where R is the radius of the (spherical) star in isolation. For a given EOS and a central density, one can calculate the M, R ,$k_2$, and $\lambda$ of a neutron stars by solving

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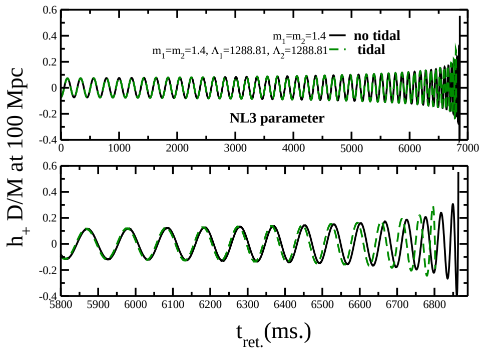


FIG. 2: Gravitational TT4 waveforms with and without tidal effect for the late inspiral phase. Gravitational waves(plus mode) is the order of $10^{-22}$ observed along the rotation axis( perpendicular to the orbital plane. D denotes the luminosity distance from the source to observer.

the Tolmann-Oppenheimer-Volkov (TOV) equation and the metric perturbations[1].

In Fig.1(a), we have taken four EOS to calculated the mass and radius of the neutron star. The M-R profile varies to a great extend over the choice of the parameter. For example, G2 predicts the maximum mass $1.98M_\odot$ of the neutron star, which matches well with the latest experimental observation. The tidal deformability $\lambda$ can be estimated experimentally. In Fig.1(b), $\lambda$ is seen to be very large for a star with mass $0.1M_\odot$. The large value of $\lambda$ is due to the large radius of this neutron-star. We noticed that $\lambda$ is very sensitive to the neutron-star radius. This quantity is directly affected by the EOSs. We found that $\lambda$ takes a wide range of values $\lambda \sim (3-8).10^{36} gcm^2s^2$ for a $1.4M_\odot$ neutron star with different EOSs. In the same Fig.1(b), we also displaced the uncertainty [error $\Delta\tilde{\lambda}$] for an equal-mass binary inspiral neutron star situated at a distance of 100 Mpc for aLIGO detector with tidal deformability $\lambda = 1.0\text{x}10^{42} gcm^2s^2$. Our results show that the error($\Delta\tilde{\lambda}$) increases with the total mass of the binary. To extract neutron-star properties from gravitational waves, it is necessary to prepare accurate theoretical waveform templates from binary neutron star coalescence. Here, we have used the post-Newtonian(PN) theory, when binaries at large orbital separation then the gravitational field is very weak. One can use the PN-theory which is essential perturbation of Newtonian dynamics, it is very successful for the solar system. But it is break-down for the strong gravitational field of the small orbital separation. Using TaylorT4[3] templates, we calculated the gravitational waveform of the equal-mass $1.4M_\odot$ binary star with and without tidal effects and results are shown in Fig.2. We noticed that tidal effect removes the ripples in the late stage of the inspiral.

## Summary and Conclusion

We have calculated the mass-radius and the tidal deformability $\lambda$ for a single neutron star using relativistic mean field EOSs. The aLIGO should be able to constrain the neutron stars deformability to $\lambda \leq 10$ x $10^{36} gcm^2s^2$, for a binary of $1.4M_\odot$ neutron stars at a distance 100 Mpc from the detector, using the portion of the signal with the GW frequencies less than 400 Hz. We also examined the tidal effect of the late stage of the binary neutron stars using PN-theory gravitational waveform templates.

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