The direct detection of gravitational waves (GWs) will provide valuable astrophysical information about many celestial objects. The most promising sources for detection of GWs are neutron stars (NSs) and black holes. These objects emit waves in a very wide spectrum of frequencies determined by their quasi-normal modes oscillations. In this work we are concerned with the information we can extract from quasi-normal modes of the NSs when a candidate leaves its signature in a detector of resonant mass. With this goal we have verified the mass-radii relations and some informations about nuclear structure of NSs using the resonance frequencies of these detectors.

The quasi-normal modes: f-mode and p-mode

The NSs have a rich spectrum of frequencies because of its fluid perturbation that oscillates in many different modes. From the GW point of view the most important modes are the: fundamental mode (f-mode), the first pressure mode (p-mode), the first gravitational wave mode (w-mode) [1] and the r-modes [2]. In this work we are concerned in the f and p-mode. In ref [3] the authors have obtained an empirical formulæ for the frequencies of these two modes using a wide sample of equations of state:

$$\nu_f = 0.79(\pm 0.09) + 33(\pm 2) \frac{M}{M_\odot}$$ \hspace{1cm} (1)

$$\nu_p = \frac{1}{M} (-1.5(\pm 0.8) + 70(\pm 4) \frac{M}{M_\odot})$$ \hspace{1cm} (2)

where the mass and the radii are given in km (remember that $M_\odot = 1.477 \text{km}$), while $\nu_f$ and $\nu_p$ are given in kHz. In figure 1 we can see the 3-dimensional plots of these relations. For each frequency there is a surface in the mass-radius plane. The area of this surface represents an “interval” of possible NSs sequences that could detected. We noted that the sequences of the NSs in low frequencies do not point to objects which are compact enough to be identified as neutron star, a fact that occurs more sharply with models -f, where there is a divergence for frequencies near 0.79 kHz. With these graphics we can analyse a possible of detection of resonant mass antenna, but the analysis is easier with a projection 2-dimensional these graphics in figures 2 and 3.

In this figure we have applied the resonants mass detectors (RMDs) bandwidth into the empirical relations 1 and 2 and obtained the mass-radius diagram of the f and p-mode. These relations determine the candidates for a detection by the antennas. We also compare these relations with some NSs sequences of different models relativistic EqG: GM1, GM3, NL3, TM1, NWMNL, MIT, NIJ [4, 5] and also the models: NP, NPH and NPQH (these with and without 3)[6].

If the f-mode is identified on the Scheenberg and MiniGrail bandwidth (red region), the most probable source would correspond to a very compact object with radius smaller than 10 km. The models that fulfill this condition are models of strange quark stars[7], a fact that is confirmed when we compare with the sequence of the MITBag model (with bag constant $B/4\pi = 170$) and the NJL model. On the other hand the p-mode would only be expected to come from less compact NSs. On the bar detectors bandwidth (red region) there are no candidates of NSs emitting GWs for these modes.

How can we distinguish the f-mode in a putative detection? And how to determine the mass and radii of the star? The damping time is the response for these questions[7]. In ref.[3] the authors obtained an empirical relation for the f-mode damping time, described by:

$$\tau_f = \frac{R_\odot^3}{c\Delta f} \left[8.7 \pm 0.2 \times 10^{-2} + (-0.271 \pm 0.009) \frac{M}{M_\odot} \right]^{-1}$$ \hspace{1cm} (3)

Therefore applying the RMDs bandwidth on eq. 3 we can get the same diagram mass-radii, but doing a distinction as to the damping time. Results obtained by [7] show that on an interval of frequencies of 2.8-3.4Hz, for a signal coming from an object with $M \sim 1.0\, M_\odot$, the damping time would have a 0.06-0.10ns range.

Summary

1. RMDs bandwidth are on spectrum regions with a few (or none) candidates to NSs emitting GWs through their f and p-mode. However, the spherical detectors are on a region where the f-modes of very compact objects can be detected. Therefore, the MIT and NJL model would be the best candidates for these detectors.

2. The detection of the f and p-modes of NSs by bar detectors is unlikely, because their bandwidth are located in low frequencies.

References


Acknowledgements

This work was partially supported by FEDER and FCT (Portugal) under the projects POCI/FP/63918/2005 and PDC/T/FP/64707/2006. The CML, MM, RMM thank the financial support given by CAPES through the fellowship 2071/07-0 and the international cooperation program Capes-Grices between Brazil-Portugal.