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Determining the neutron star structure using narrow-band gravitational wave detector

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Introduction

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 pertubation that oscillates in many diferent modes. From the GW point of view the most important modes are the: **fundamental mode (f-mode)**, the **first pressure mode (p$_I$-mode)**, the **first gravitational wave mode (w$_I$-mode)** [1] and the **r-modes** [2]. In this work we are concerned in the f and p$_I$-modes. In ref [3] the authors have obtained an empirical formulae for the frequencies of these two modes using a wide sample of equations of state:

$$\nu_f = 0.79(\pm 0.09) + 33(\pm 2)\sqrt{\frac{M}{R^3}}, \tag{1}$$

$$\nu_p = \frac{1}{M}\left[-1.5(\pm 0.8) + 79(\pm 4)\frac{M}{R}\right], \tag{2}$$

where the mass and the radii are given in km (remember that $M_\odot \approx 1.477$km), while ν_f and ν_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-radii plane. The area of this surface represents an "interval" of possible NSs sequences that could detected. We note 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 mode-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 antena, but the analyse is easier with a projection 2-dimencional these graphics in figures 2 and 3.

In this figure we have applied the ressonants mass detectors (RMDs) bandwidth into the empirical relations 1 and 2 and obtained the mass-radii diagram of the f and p$_I$-modes. These relations determine the candidates for a detection by the antennas. We also compare these relations with some NSs sequences of different models of relativistic EoS: GM1, GM3, NL3, TM1, NLWNJL, MIT, NJL [4, 5] and also the models: NP, NPH and NPHQ (these with and without δ)[6].

If the f-mode is identified on the Schenberg 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 $B^{1/4} = 170$) and the NJL model. On the other hand the p$_I$-mode would only be expected to come from less compact NSs. On the bar detectors bandwidth (red region) there are no candidates of NSs emiting 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:

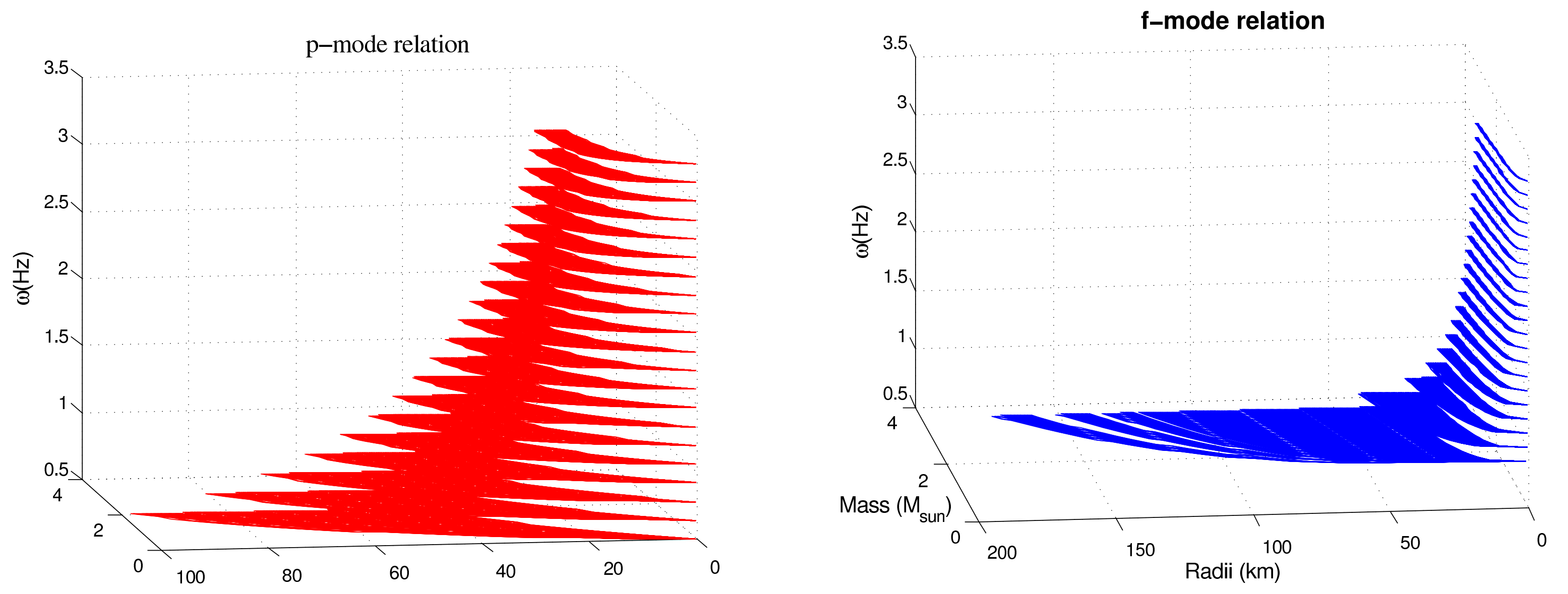

Figure 1: Mass-radii realations for the f-mode (right) and p$_I$-mode (left) for the different values of frequency.

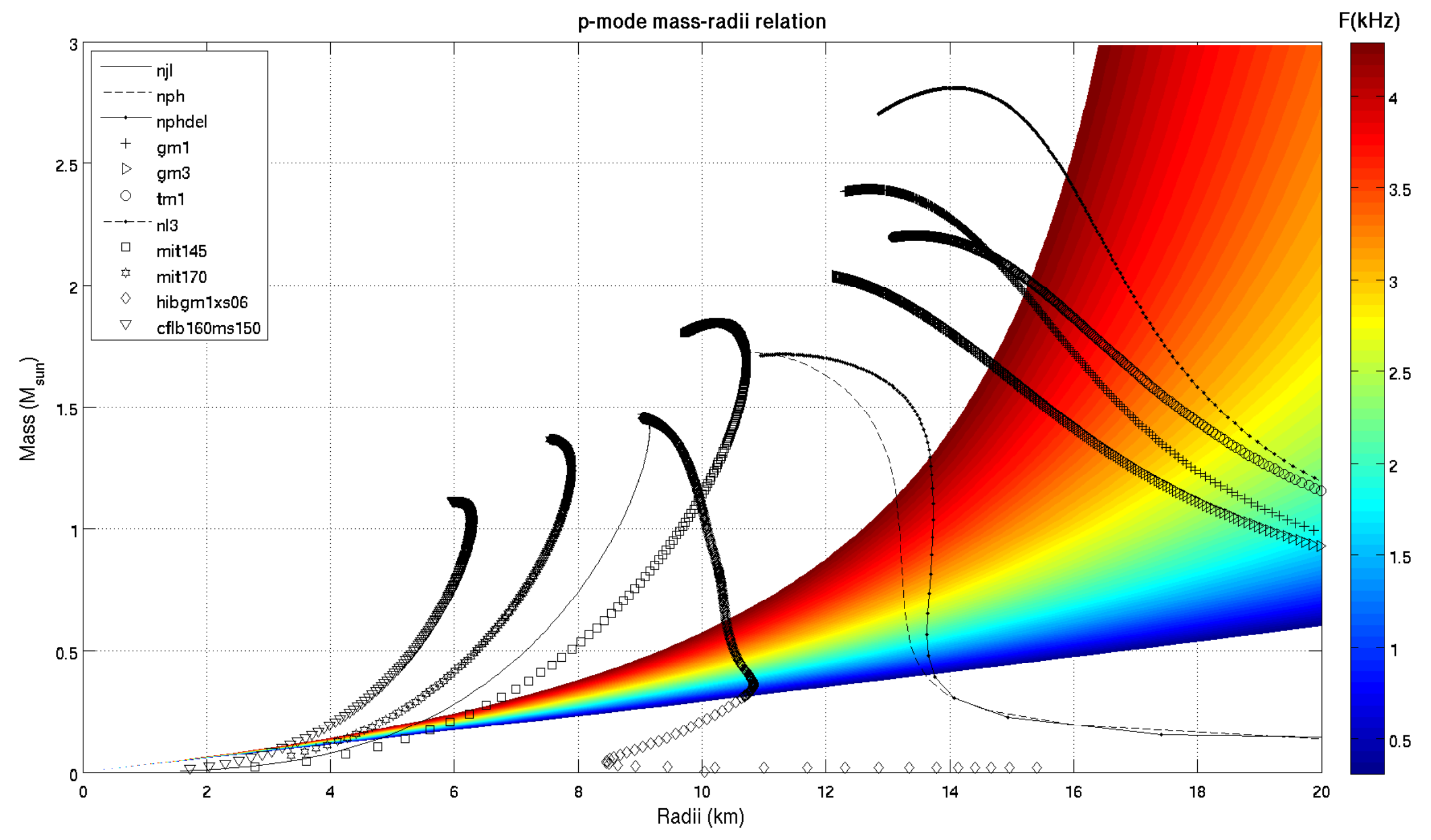

Figure 2: Projection 2-dimensional of the relations 1 abtained by Benhar *et al* for the mass-radii relation of the p$_I$-mode. We compare with some models of relativistcs EoS. The differents colors identify the differents fraquencies.

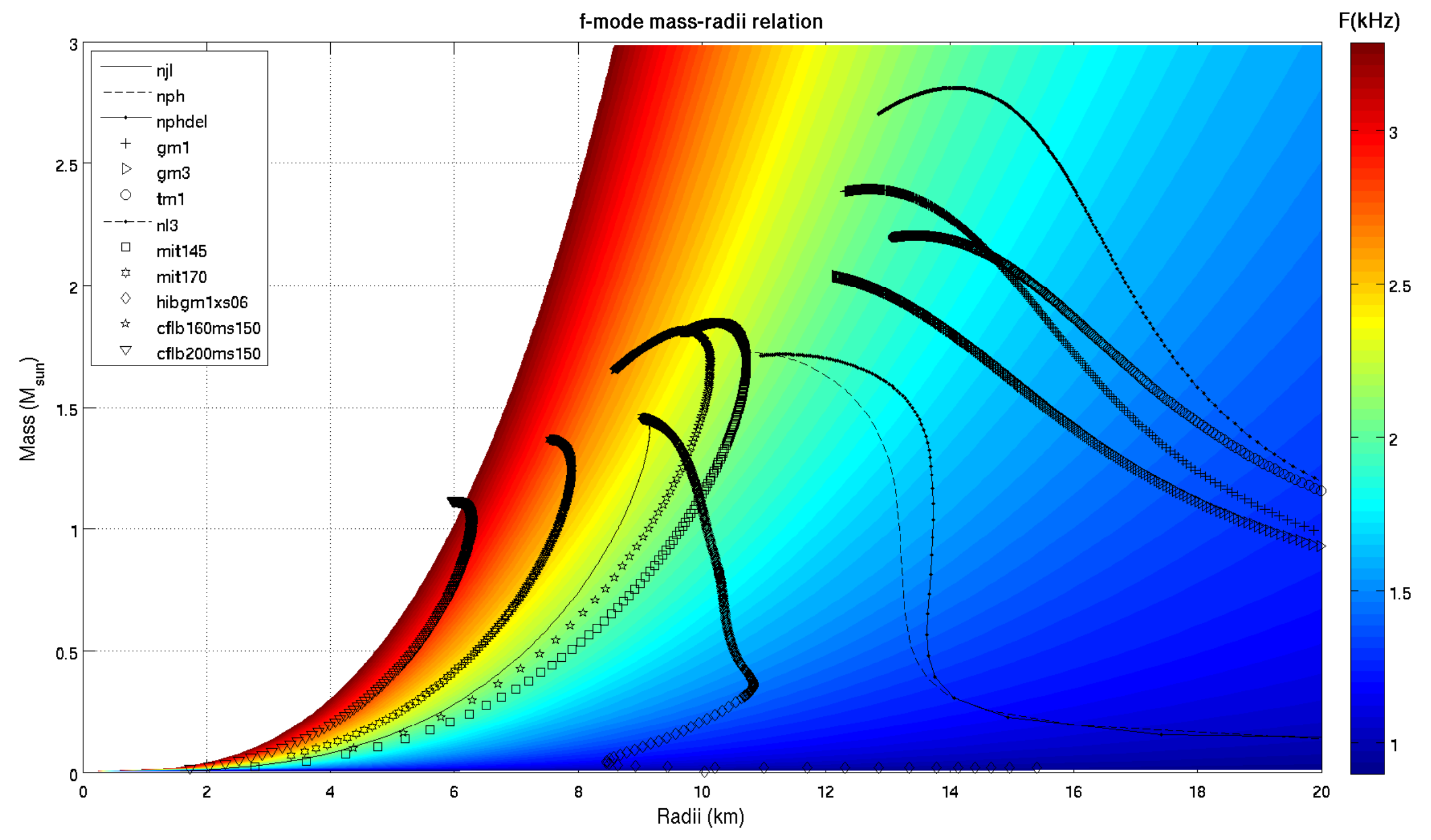

Figure 3: Projection 2-dimensional of the relations 1 abtained by Benhar *et al* for the mass-radii relation of the f$_I$-mode.

$$\tau_f = \frac{R^4}{cM^3}\left[(8.7 \pm 0.2)\cdot 10^{-2} + (-0.271 \pm 0.009)\frac{M}{R}\right]^{-1}. \tag{3}$$

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 $M \sim 1.0M_\odot$ the damping time would have a 0.06-0.10s range.

Summary

1. RMDs bandwidth are on spectrum regions with a few (or none) candidates to NSs emiting GWs through their f and p$_I$-modes. However, the Spherical detectors are on a region where the f-modes of very compact objects can be detected. Therefore, the MIT and NJL models would be the best candidates for these detectors.
2. The detection of the f and p$_I$-modes of NSs by bar detectors is unlikely, because their bandwidth are located in low frequencies.

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