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# CONSTRAINTS ON THE HYPERON-SIGMA MESON COUPLING BY GW OBSERVATIONS

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The next generation of gravitational wave observatories are promissing candidates to make the first detections. Once the detection occurs the GW characteristics permit to extract some information about the gravitational wave source. In the present work we focus on waves produced by neutron stars which can give stringent constraints on the nuclear matter equation of state. The microscopic description is based on a non-linear field-theoretical model in order to construct such an equation of state. The model has free parameters, which from actual knowledge may not be pinned down by direct nuclear matter experiments. An important example is the hyperon-sigma meson coupling constant, currently determined by the spin-isospin SU(6) scheme. The coupling constant is of significant relevance for the structure of the equation of state, controlling its rigidity and, consequently, the properties of neutron stars and gravitational wave signals. We show, in this work, how one can constrain the hyperon-sigma meson coupling constant assuming the detection of a gravitational wave.

## 1. Introduction

A new window to the Universe is about to be opened. With the detection of gravitational waves, astrophysicists expect to have the answer to many questions, as well as new ones. With interferometric or resonant mass detectors, at low and high frequencies, we shall be able to see waves coming from coalescing binary systems, from a cosmological background, from catastrophic events etc.

Among the most promising sources of gravitational waves, neutron stars and black holes are the best candidates for a detection due to its high density characteristics. These objects emit waves in a very wide spectrum of frequencies determined by their quasi-normal modes of oscillation; and many works have been recently done to determine their characteristics (see the paper by Kokkotas for a review[1]). Black holes have a relative simple spectrum of quasi-normal modes determined basically by its mass and rotation frequency. Neutron star spectra are much more complex due to its internal characteristics. The still unrevealed internal structure of neutron stars is responsible for the wide spectrum of modes like the fundamental, the pressure, density, gravitational, torsional etc. Neutron star modes are determined by its mass, radius, rotation frequency and density distribution.

We analyze the case of a possible future detections made by these antennas in order to obtain information about its gravitational wave sources. We are specially concerned with the information we can extract from a neutron star detection. If values of mass and radius can be extracted with some accuracy, we could get additional information about the nuclear matter equation of state. The still obscure characteristics of nuclear matter, for example, the values of compression modulus or nucleon effective mass could be clarified. We could also get information about the hyperon-meson coupling constant.

We have already started this work in previous papers, as it can be found in the references,[2–5] where important results, concerning the gravitational wave detection and the relevant contributions to the better knowledge of the nuclear matter equation of state, were found.

This work is focused on the determination of a relation between the nuclear matter parameters of the present model, first presented in the work done by Taurines *et al.*,[6] and the frequency of the gravitational wave emitted by a neutron star f-mode, which basically depends on its mass-radius relation.

## 2. GW Observations

Many different scenarios are able to perturb and excite these stars, generating and emitting gravitational waves: orbiting or falling masses in the case of a companion,[7] structural rearrangements such as glitches, star quakes[8] or micro-collapses,[9,10] etc. All these mechanisms may excite quasi-normal modes, which have been largely studied in the last years.

While black holes oscillate due to its space-time structure perturbation, neutron stars may also oscillate due to its fluid perturbation. This difference implies that a neutron star may oscillate in many different modes and have a richer spectrum of oscillations. It is well known that different types of initial perturbations are more convenient to excite each of these modes.[11]

Benhar *et al.* have calculated the properties of the oscillation modes using a wide sample of equations of state.[12] As the main result, they have obtained empirical formulae for, among others, the frequency of the f- and first p-mode.

Our efforts on the study of quasi-normal modes were directed to a better comprehension of the w-mode, as can be seen in previous works.[3] We have also performed some analysis on a possible future detection that can be made by the Brazilian gravitational wave antenna, the Schenberg detector. The Schenberg bandwidth lies around 3.0–3.4 kHz. Such a small window in the huge garden of gravitational waves is curiously interesting, just because, once a detection is made, its characteristics frequency and damping time are immediately known. On a previous study[2] we have analyzed the detection of f- and p-modes by the Schenberg antenna.

## 3. Conclusions

We have seen the properties of gravitational waves emitted by the f-mode of neutron stars without getting into the problem of the excitation mechanism or event rate. We have performed this calculation for different values of the coupling parameters which turns possible a deep analysis in a future where gravitational waves shall be detected. The detection of frequencies above the value of 1.9 kHz would rule out coupling parameters greater then 0.2.

If gravitational waves are detected around 1.6–1.8 kHz it is necessary to have another kind of information about the source to describe the nuclear matter equation of state. Such information can be hidden in the gravitational wave, as the damping time, which can be analyzed in the same way we have done here or in

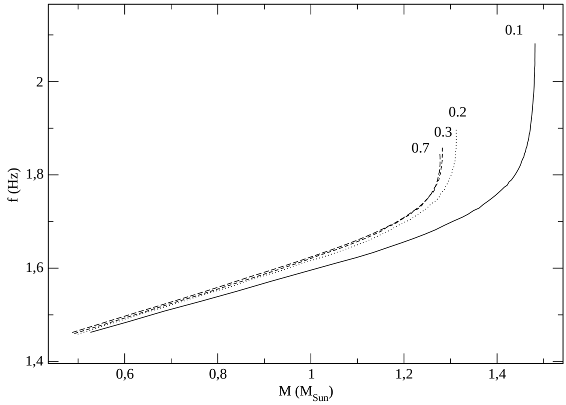


Fig. 1. The frequency of f-mode waves as a function of neutron star mass for different values of the coupling parameter $\alpha = 0.1$, 0.2, 0.3 and 0.7.

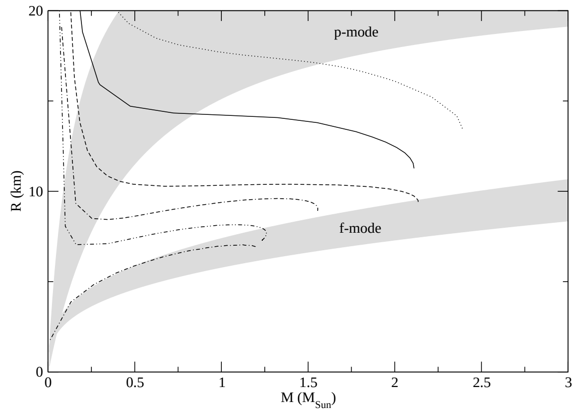


Fig. 2. Benhar empirical relations are the shaded regions representing the f- (lower) and first p-mode (upper). The results are compared, for the NL model, static (solid line) and rotating (dotted line) and the Taurines model with $K = 220$ MeV (dashed line). Quark stars with MIT model are plotted with $B = 60$ MeV/fm$^3$ (dot-double dashed line) and 100 MeV/fm$^3$ (dash-double dotted line) and CDM (dot-dashed line).

Ref. 2 or in another astrophysical observation using the Chandra or XMM-Newton space telescopes, or earth-based radio telescopes.

The study of neutron stars have shown important contributions to the better comprehension of nuclear matter equation of state and the gravitational wave astronomy seems to follow the same steps contributing to the better knowledge of general relativity, cosmology, astrophysics and the nuclear matter equation of state.

Our results can be summarized by the following two figures that describe the behavior of the f-mode frequency for each kind of model.

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