Neutron star and strange quark star binaries in the late inspiral phase

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1 Introduction

Coalescing neutron star binaries are considered among the strongest and most likely sources of gravitational waves to be seen by Advanced Virgo and LIGO interferometers (Abadie et al., 2010; Kim et al., 2004). The evolution of a binary system of compact objects is entirely driven by gravitational radiation and can be roughly divided into three phases: point-like inspiral, hydrodynamical inspiral and merger. Gravitational wave signal of the late inspiral or merger phase of such binaries could yield important information about the equation of state (EOS) of neutron stars (Read et al., 2009). It is worth mentioning that strange quark stars are currently considered as a possible alternative to neutron stars as compact objects. In 1971, Bodmer (Bodmer, 1971) remarked that matter consisting of deconfined up, down and strange quarks could be the absolute ground state of matter at zero pressure and temperature. If this is true objects made of such matter, the so-called strange stars could exist (Witten, 1984; Haensel et al., 1986; Alcock et al., 1986). Most of calculations were performed for equal-mass neutron star and strange quark star binaries (Taniguchi & Gourgoulhon, 2003; Oechslin et al., 2004; Bejger et al., 2005; Limousin et al., 2005; Gondek-Rosińska & Limousin, 2008; Taniguchi & Shibata, 2010). However the radio observations of neutron star binaries and population synthesis show that binaries with non-equal masses should be considered as well (Gondek-Rosińska et al., 2007; Osłowski et al., 2011). Numerical calculations have shown that the mass-ratio $q = M_1/M_2$, where $M_1 < M_2$ are component masses, has important impact on the evolution scenario. In particular, the mass and the radius of the disk created after the merger depends strongly on q (Rezzolla et al., 2010).

We present first results on non-equal strange star binaries as well the results for equal-mass binaries described by different EOSs.

2 Numerical models

We study the pre-coalescence stage within the Isenberg-Wilson-Mathews approximation (Baumgarte & Shapiro, 2003) of general relativity using a multi-domain spectral method. We construct sequences of quasi-equilibrium configurations with fixed baryon mass and decreasing separation. Such a sequence is expected to approximate well enough the true evolution of binary neutron stars, which is entirely driven by gravitational radiation. All calculations were performed by C++ LORENE library.[1]

[1] http://www.lorene.obspm.fr

3 Results and Conclusions

On the upper panel in Figure 1 we present the orbital angular frequency at the ISCO (Innermost Stable Circular Orbit), scaled with the gravitational mass as a function of the compaction parameter M/R for equal-mass neutron star and strange quark star binaries.

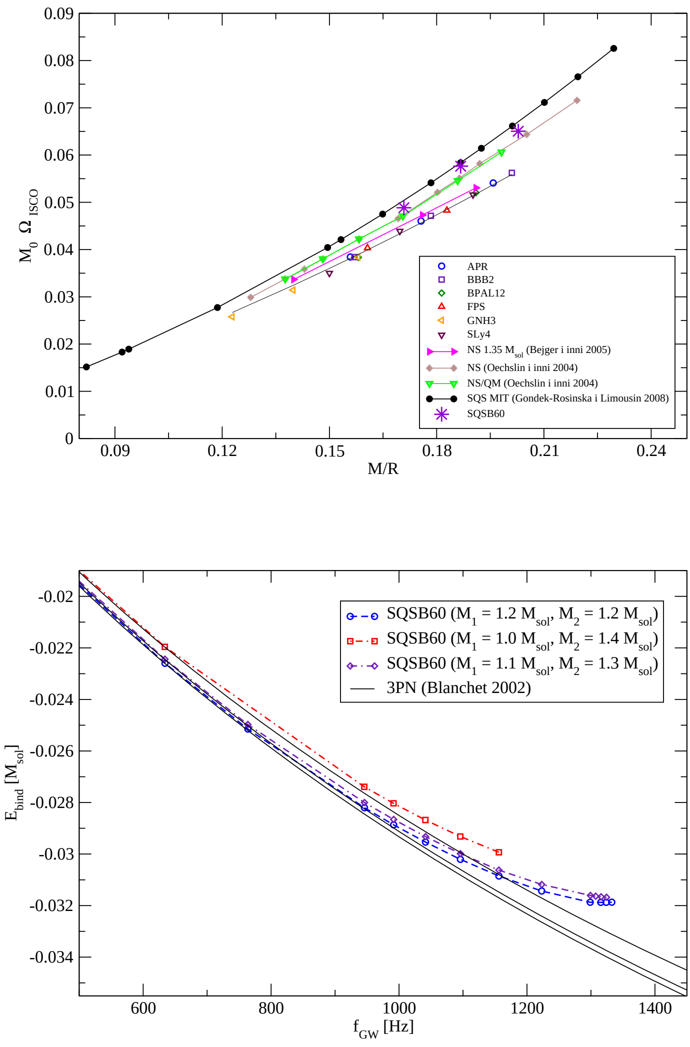

Fig. 1: *Upper panel:* Gravitational wave frequency at the ISCO (scaled with gravitational mass) versus the compaction parameter M/R for equal-mass neutron star and strange quark star binaries. The different symbols correspond to the numerical results taken by (Oechslin et al., 2004; Bejger et al., 2005; Gondek-Rosińska & Limousin, 2008; Taniguchi & Shibata, 2010). Stars correspond to our numerical results. *Bottom panel:* Binding energy versus frequency of gravitational waves along evolutionary sequences of nonequal-mass strange star binaries with a total mass of 2.4 $M_{\odot}$. The different symbols (squares, circles and diamonds) correspond to the numerical results. The solid black lines correspond to the 3rd post-Newtonian point masses approximation (Blanchet, 2002).

The frequency of gravitational waves at the ISCO depends systematically and strongly on the compaction parameter (for $M/R < 0.24$) for all considered models. This indicates that the ISCO is determined by the hydrodynamic instability and not by general relativistic effects. The higher the compactness of a star is, the higher the frequency of GW at the ISCO. Finally, the higher total mass of the system is the higher frequency of GW at ISCO.

On the bottom panel in Figure 1 we can see the binding energy of the system versus frequency of gravitational waves along evolutionary sequences of strange star binaries with a total mass 2.4 $M_{\odot}$ and mass ratio $q = M_1/M_2 = 1.0,\ 0.85,\ 0.71$. A turning point of binding energy along an evolutionary sequence indicates an orbital instability. The changes in binding energy correspond to the energy lost from the system via gravitational radiation. In the case where no turning point of binding energy occurs along the sequence is present, the mass-shedding limits the inspiral phase. In both cases, this defines the ISCO. The orbital frequency at the ISCO is a potentially observable parameter by the gravitational wave detectors. The differences in the evolution of binary strange stars and neutron stars stem from the fact that strange stars are principally bound by an additional force, strong interaction between quarks.

It is worth mentioning that for non-equal mass binaries a star of smaller mass could be tidally disrupted by a larger mass companion at large orbital separation, and than the frequency of gravitational waves could be smaller. The frequency of gravitational waves at the ISCO decreases with decreasing mass-ratio in strange star binaries. Moreover, the energy emitted by the system decreases with decreasing mass-ratio in strange quark star binary. Equal-mass binaries are the most efficient GW emitters.

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