A white dwarf-neutron star relativistic binary model for soft gamma-ray repeaters

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ABSTRACT
A scenario for SGRs is introduced in which gravitational radiation reaction effects drive the dynamics of an ultrashort orbital period X-ray binary embracing a high-mass donor white dwarf (WD) to a rapidly rotating low magnetised massive neutron star (NS) surrounded by a thick, dense and massive accretion torus. Driven by GR reaction, sparsely, the binary separation reduces, the WD overflows its Roche lobe and the mass transfer drives unstable the accretion disk around the NS. As the binary circular orbital period is a multiple integer number \((m)\) of the period of the WD fundamental mode (Pons et al. 2002), the WD is since long pulsating at its fundamental mode; and most of its harmonics, due to the tidal interaction with its NS orbital companion. Hence, when the powerful irradiation glows onto the WD; from the fireball ejected as part of the disk matter slumps onto the NS, it is partially absorbed. This huge energy excites other WD radial \((\rho\text{-mode})\) pulsations (Podsiadlowski 1991, 1995). After each mass-transfer episode the binary separation (and orbital period) is augmented significantly (Deloye & Bildsten 2003; Alé cyan & Morsink 2004) due to the binary’s angular momentum redistribution. Thus a new adiabatic inspiral phase driven by GR reaction starts which brings the binary close again, and the process repeats. This model allows to explain most of SGRs observational features: their recurrent activity, energetics of giant superoutbursts and quiescent stages, and particularly the intriguing subpulses discovered by BeppoSAX (Feroci et al. 1999), which are suggested here to be overtones of the WD radial fundamental mode (see the accompanying paper: Mosquera Cuesta 2004b).

Key words: Binaries: close — gamma-rays: theory — relativity — stars: individual (SGR 1900+14) — stars: neutron — white dwarfs — stars: oscillations

1 ASTROPHYSICAL MOTIVATION
The giant outburst from SGR1900+14 on 27 August (1998), hereafter GRB980827, was an extraordinary event in many respects. Aside from the huge energy released \((E_{\text{out}} \geq 3 \times 10^{44} \text{ erg})\) on such a short timescale \((\sim 0.1 \text{ s})\), the clear identification in its light curve (and power spectral density) of a main pulsation period \((P \sim 5.16 \text{ s})\) and an accurately measure interpulse set \((\sim 1 \text{ s of interval})\), as discovered by BeppoSAX (Feroci et al. 1999), has challenged the current views on SGRs. This behavior, Feroci et al. (1999) advanced, is unexpected and quite difficult to explain in the magnetar view. According to the magnetar scenario (Thompson & Duncan 1995, 1996) the typical (crustal stored stress) energy of an outburst from an SGR source should be \(~ 10^{39} \text{ erg}\) (de Freitas Pacheco 1998) if one expects the source not to be destroyed by the explosion. Energies as \(E_{\text{out}}\) or higher can be obtained at the expense of destructing practically the whole crust of the NS undergoing the starquake (de Freitas Pacheco 1998) or through magnetic reconnection (Thompson & Duncan 1995, 1996; Woods et al. 1999). However, a NS with no crust is fully unstable, and should explode (Colpi, Shapiro & Teukolsky 1993). Consequently, the source could not repeat anymore.

The problems for the magnetar model do not stop there. After a burst phase in 1996, Marsden, Rothschild & Lingenfelter (1999, see also Harding, Contopoulos & Kazanas 1999; Murakami...
et al. 1999) found that the pulsar doubled its period derivative, ˙\(P\), which would suggest the pulsar magnetic field energy had augmented \(\sim 100\%\) during the outburst, what clearly opposes the magnetar scenario. They concluded that the SGRs spindown is due not to dipole radiation but to another mechanism. Thus, the ˙\(P\) could not be an estimate of the magnetic field strength, nor evidence for a magnetar. More recently, Rothschild, Marsden & Lingenfelter (2001) argued that the unexpected occurrence of most of the SGRs (and AXPs) in the denser phases of the interstellar medium effectively rules out the magnetar model for their origin, since in that model the NS endows a supercritical field as an intrinsic property, with no plausible relation to external environments. In addition to those shortcomings of the magnetar scenario, very recently P\'erez Mart\'inez et al. (2003) rose questions on the formation of the magnetar itself by invoking quantum-mechanical effects on the structural stability of the hypermagnetised star, while Rezzolla & Akhmedov (2004) demonstrated that a fundamental change in the magnetar scenario very recently

Pacini’s spindown law appears when describing the electromagnetic interstellar medium efficiency parameter \(\alpha_{CE}\). Systems with \(\alpha_{CE}\) can exist for very massive WD companions. Systems with even more shorter, near tens of a second, depending on the common envelope efficiency parameter \(\alpha_{CE}\), can be formed (see also Podsiadlowski 1995, 2000; Ergma, Lundgren & Cordes 1997; Tauris, van den Heuvel & Savonije 2000). This view gives us some insight on the SGRs former evolution. Perhaps those systems come from a previous Thorne-Zytkow object in which a complete exhaustion or ejection of the hydrogen-rich envelope of the red giant star (lifetime \(\tau_{RG} \sim 10^4\) yr) occurred once the NS is engulfed

in a common-envelope evolutionary phase caused by shrinking of the orbit due to gravitational-wave (GW) radiation-reaction effects. This process leaves the giant companion’s bare Helium (or CNO) core, the WD, in a tight orbit with a rapidly spinning massive NS. We suggest this may explain why SGRs are surrounded by nebulae resembling supernovae remnants. The NS high mass being a consequence of the Thorne-Zytkow object latest stage, while the NS spin stems from its former LMXB evolution (van Paradijs 1995a,b). A similar evolutionary path was described by Ergma, Lundgren & Cordes (1997), see also Tauris, van den Heuvel & Savonije (2000). Ergma et al. showed that these systems may undergo a second mass transfer transient around periods of 5 minutes or less, being the source observed as an X-ray binary again. The final fate could be the binary coalescence. We also note that in the last few years a large number of systems of this sort have been discovered (Edwards & Bailes 2001; Tauris & Sennels 2000; Tauris, van den Heuvel & Savonije 2000), a large sample is collected in this reference; Deloye & Bildsten 2003, Ale\c{c}yan & Morsink 2004), and their formation have been modelled with great details (Ergma, Lundgren & Cordes 1997; Tauris, van den Heuvel & Savonije 2000). At this late stages GW dominate the binary dynamics and secularly shorten its period to those we suggest here.

| Period s | GR-Time a | Orb. Sep. b |
|----------|-----------|------------|
| 20.0     | 3.418     | 8252.0     |
| 22.0     | 4.407     | 8794.0     |
| 24.0     | 5.558     | 9319.0     |
| 26.0     | 6.881     | 9830.0     |
| 28.0     | 8.384     | 10330.0    |
| 30.0     | 10.08     | 10810.0    |
| 32.0     | 11.97     | 11290.0    |
| 34.0     | 14.07     | 11750.0    |
| 36.0     | 16.39     | 12210.0    |
| 38.0     | 18.93     | 12660.0    |
| 40.0     | 21.70     | 13100.0    |
| 42.0     | 24.72     | 13530.0    |
| 44.0     | 27.98     | 13960.0    |
| 46.0     | 31.51     | 14380.0    |
| 48.0     | 35.29     | 14790.0    |
| 50.0     | 39.35     | 15200.0    |
| 52.0     | 43.69     | 15600.0    |
| 54.0     | 48.32     | 16000.0    |
| 56.0     | 53.24     | 16390.0    |
| 58.0     | 58.46     | 16780.0    |
| 60.0     | 63.99     | 17170.0    |

\(a\) Computed using Peters & Mathews relation
\(b\) Computed using Kepler’s third Law

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1 It is worth quoting that Kouveliotou’s team (1999) found (0.05 cycles) systematic departures of pulse phases from the best-fit ephemeris. Due to its potentiality, searches for an orbital period in the SGR 1900+14 August, 1998 observations were performed. They divided the data set in subsets of 400 seconds, and conducted searches in the range: \(10^{3} \quad 10^{9}\) s. No sinusoidal modulation was found. If our model is on the right track, the negative result is not surprising for a shorter period for the SGR 1900+14 binary, \(21.4 \leq \dot{P}_{GR}\) \(\leq 65\) s, but expected. Thus, it is likely that the orbital signature looked for remains embedded in the data subsets that were used for.
2.2 SGRs as interacting binaries

By the time the WD-NS relativistic binary reaches the critical separation transient mass transfer occurs.\(^2\) In a rather catastrophic episode, which repeats sparsely any: \(\Delta T_{\text{TDD}} \lesssim 10 \ \text{yr}\) (estimated below), the WD starts to transfer mass onto a low-magnetised rapidly rotating massive (2 \(M_{\odot}\)) NS, via the formation of a thick dense massive accretion disk (TDD) very close to the innermost stable circular orbit (ISCO). The disk becomes unstable due to gravitational runaway or Jeans instability, partially slumps and inspirals onto the NS. The abrupt supercritical mass accretion onto the NS releases quasi-thermal powerful \(\gamma\)-rays, a fireball to say, while triggers non-radial NS oscillations which emit fluid-mode GW (see Mosquera Cuesta et al. 1998). A parcel of the accretion energy illuminates with hard radiation the WD perturbing its hydrostatic equilibrium. The WD absorbs this huge energy at its interior and atmosphere and begins to radially pulsate (\(p\)-modes) in addition to its long before excited fundamental mode and higher harmonics (overtones: Podsiadlowski 1991, 1995), see Mosquera Cuesta (2004b), and Tables 14 below.

The accretion rate from the WD onto the TDD, to be replenished during the periastron passage \(\Delta T_{\text{TDD}}\) around the NS, can roughly be estimated from an idealized drop model in which we assume that the total mass contained in a sphere of radius equal to half the WD tidal height \(H_{\text{tide}}\) (Shapiro & Teukolsky 1983) drops onto the NS: \(H_{\text{tide}} = R_{\text{WD}} \left(\frac{M_{\text{NS}}}{3M_{\text{WD}}}\right)^{\frac{1}{3}} - 1\) \(\lesssim 1100\ \text{km}\). Using this, and a mean density \(\rho_{\text{WD}} = 4 \times 10^6\ \text{g cm}^{-3}\), we obtain the WD mass transfer rate

\[
\dot{M}_{\text{TDD}}^{\text{WD}} \sim \frac{M_{\text{WD}}^{\text{WD}}}{6 \times 10^{-10} M_{\odot}} \left(\frac{10^8 \text{s}}{\Delta T_{\text{TDD}}^{\text{WD}}}\right) \sim 6 \times 10^{-5} M_{\odot} \text{s}^{-1},
\]

where we have used results for \(R_{\text{WD}} \sim 4.7 \times 10^3\ \text{km}\) by Suh & Mathews (2000) and Eggleton’s theory (1983), see below.

Since essentially viscosity dominates the TDD hydrodynamics, in general one can estimate the viscous timescale (Frank, King & Raine 1992) for it to drive unstable the TDD as (Popham, Woosley & Fryer 1999)

\[
\Delta T_{\text{visc}} \sim \frac{R^2}{\nu} = \left(\frac{R^2}{H^2 \alpha \Omega_{\text{k}}}\right) \sim 4 \times 10^{-3} \frac{M_{\text{NS}}^{4/3} R_{\text{g}}^{1/3}}{\alpha_0 1},
\]

with \(\alpha\), \(H\) and \(\Omega_{\text{k}}\) the Shakura-Sunyaev parameter, disc height scale and Keplerian angular frequency, respectively. Thus a rough estimate of the mean NS accretion rate from the TDD reads

\[
\dot{M}_{\text{TDD}}^{\text{NS}} \sim \frac{M_{\text{WD}}^{\text{TDD}}}{\Delta T_{\text{visc}}} = 0.37 \alpha_0^4 M_{\text{NS}}^{4/3} M_{\text{WD}}^{1/2} R_{\text{g}}^{3/2},
\]

where \(\dot{M}_{\text{TDD}}^{\text{NS}} \sim 2 \times 10^{-5} M_{\odot} \text{s}^{-1}\) is the mass deposited at radius \(R_{\text{g}}\) (in units of 10^6 cm). Thus, we conjecture that giant outbursts from SGRs, like GRB980827, are triggered when a large part of the accretion torus plunges onto the NS.

Scaling these results for the difference in gravitational potential between a BH and a NS (\(\Phi_{\text{NS}}/\Phi_{\text{BH}} \sim 0.2\)), in coalescence with a WD (Kluźniak & Lee 1998; Kluźniak 1998), and using the Eq.(1) given by Mosquera Cuesta et al. (1998) to estimate the peak temperature achieved when the accreted matter crashes on the NS surface, we get

\[
T_{\text{peak}} = \left(\frac{G M_{\text{NS}} \dot{M}_{\text{TDD}}^{\text{NS}}}{4 \pi R_{\text{NS}}^2 \sigma_{\text{SB}}}\right)^{1/4} = 3.1 \times 10^{10}\ \text{K},
\]

or equivalently, \(T_{\text{peak}} = 2.1\ \text{MeV}\), and a total energy released during this transient is \(E_{\text{Burst}} >> 10^{44}\ \text{erg}\). Both results match very nicely the power emitted in GRB980827 (Mazets et al. 1999; Feroci et al. 1999). It also gets close to total energy that can be released in GRBs from galactic sources, as discussed by Fryer et al. (1998b).

2.3 A possible signature of a WD in SGR1900+14

The WD atmospheric temperature after being flared should be far much higher than the one for surface thermalization (Ergma, Lundgren & Cordes 1997)

\[
T = \left(\frac{L_{\text{fireball}}^{\text{SGR1900+14}}}{4 \pi R_{\text{WD}}^2 \sigma_{\text{SB}}}\right)^{1/4} = 6.8 \times 10^7\ \text{K},
\]

where

\[
L_{\text{fireball}}^{\text{SGR1900+14}} \equiv G M_{\text{NS}} \dot{M}_{\text{TDD}}^{\text{NS}} / R_{\text{NS}}^{\text{TDD}} \sim 10^{43-44}\ \text{erg s}^{-1}
\]

is the accretion luminosity, as given above. Therefore, the star emits X-rays relatively hard, and just in the band width of Rossi XTE, BeppoSAX, CHANDRA, XMM-NEWTON, INTEGRAL, etc. By the time its atmospheric temperature rolls down the Debye temperature \(\Theta_D \sim 10^7\ \text{K}\) due to reemission, the sudden crust crystallization increases the WD cooling rate because the surface specific heat is now due to lattice vibrations instead of thermal motions (Shapiro & Teukolsky 1983). Assuming \(\sim 10\%\) of the trapped energy is quickly returned into space, the timescale for this transition to occur is (see Table 1 and Figure 1 of Feroci et al. 1999)

\[
\tau_{\text{crys}} \sim \frac{0.1 E_{\text{Burst}}}{L_{\text{fireball}}^{\text{SGR1900+14}}} \sim 100\ \text{s}.
\]

Then our view predicts: the very noticeable transition of the exponential time constant in GRB980827 lightcurve, around \(\sim 80\ \text{~s}\) after risetime, could be a signature of a crystallization phase transition of the WD crust. We also stress that by using Eq.(2) some insight on the WD viscosity, over the event duration, could be inferred from a careful analysis of GRB980827 lightcurve of \(\sim 300\ \text{s}\). In this respect, a critical analysis of this lightcurve shows no evidence of a sinuosoidal modulation; the signature of occultation in the binary. Hence, the line-of-sight angle must satisfy \(i \geq 45^\circ\) for the system orbital features.
2.4 GWs at action

Assuming a polytropic model for the WD with $\Gamma = 5/3$, the mass-radius relation is given by (Eggleton 1983)

$$\frac{R_{WD}}{\frac{M_{WD}}{0.7 \ M_\odot}} \sim 10^3 \left[\frac{1}{\left(\frac{M_{WD}}{M_{Ch}}\right)^{4/3}}\right]^{1/2} \left[\frac{\mu_e}{2}\right]^{5/3},$$

(8)

where $R_{WD} = 4.8 \times 10^3$ km is the WD radius, $M_{WD} \sim 1.1 \ M_\odot$ the WD mass (justified in the related paper by Mosquera Cuesta 2004b), $M_{Ch} = 1.44 \ M_\odot$ (Chandrasekhar limit), and $\mu_e \sim 2$ the molecular weight per electron. The orbital separation for which mass overflow commences is given by (Eggleton 1983)

$$a_0 = R_{WD} \left[0.9q^{2/3} + \ln(1 + q^{1/3})/0.49q^{2/3}\right],$$

(9)

with $q \equiv M_{WD}/M_{NS}$ the mass ratio. Thus, we obtain $a_0 = 8.8 \times 10^3$ km.

Since the criterion for stable mass transfer is satisfied ($q \leq 2/3$), as the WD loses mass its orbit should widen to replace it just below its critical Roche lobe separation. This can be accomplished through the formation of the TDD around the NS in a timescale shorter than the periastron time

$$\Delta T_{TDD} \sim 2 \times \frac{R_{O_{WD}}}{V_{O_{orb}}} \sim \frac{8895 \ km}{5 \times 10^8 \ km \ s^{-1}} \sim 1.8 \ s,$$

(10)

which is shorter than the “periastron” passage time $\Delta T_{p-a} \sim 6 \ s$. The angular momentum lost by the WD (transferred to the TDD ‘stably’ orbiting the NS) is returned back to the orbit due to angular momentum conservation. Including angular momentum losses to the just formed accretion disk, the binary orbital separation by the mass transfer starts is given by (Podsiadlowski 1995)

$$a = a_0 \left[\frac{M_{WD} + M_{NS} + TDD}{M_{WD}^0 + M_{NS}^0}\right]^{C_1} \left[\frac{M_{NS}^0}{M_{NS}^0}\right]^{C_2} \left(1 + \frac{\bar{d}}{a_0}\right),$$

(11)

where $\bar{d} \leq 1$ (which means that the orbit can even double its size in this case), the superscript $^0$ stands for the states before Roche lobe overflowing and the values for the constants $C_1$ and $C_2$ are: $C_1 \equiv -2 + 2J_{TDD}B$, $C_2 \equiv -2 - 2J_{TDD}$, with $B \approx 7 \times 10^{-5}$ the fraction of the WD mass that goes to the TDD formation. Furthermore, $M_{NS+TDD} \equiv B(M_{WD}^0 - M_{WD}) + M_{NS}^0$, and no angular momentum is loss from the binary $J_{e\text{ffect}} = 0$. Assuming that the WD orbit is circular ($e \sim 0$: Pons et al. 2002) and the orbital period today is near the one for mass transfer to start at $a_0$, i.e., $P \sim 21 \ s^2$, the timescale for the orbit to shrink due to effects of radiation of GWs is given as

$$\tau_{GR} = \left(\frac{a_0^4}{43}\right) \approx 100 \ yr,$$

(12)

where

$$\beta \equiv \left(64C^3/5C^5\right)M_{WD}M_{NS}(M_{WD} + M_{NS}),$$

(13)

with the GWs orbital angular momentum loss by the system

$$(dJ/dt)_{GW} = \left[32C^7/5C^9\right](M_{NS}^1/[M_{WD}^2M_{NS}^2/\sqrt{7}]) \right].$$

(14)

It is easy to see that if one wants the SGR binary to reenter a new mass transfer transient, a very short reduction in the binary separation is required. Distance separation reduction (driven by GR reaction effects) of a few hundred km will yield a timescale compatible with the mean one observed for rebursting in most of the SGRs, i.e., $\Delta T_{re} \leq 10 \ yr$. Since after mass-shedding the orbit widens faster than the WD expands (i.e., WD recoils due to angular momentum conservation [gravothermal effect] and stops mass transfer), the angular momentum redistribution will prevent the binary merger to occur on this timescale $\tau_{GR}$. Consequently we can expect the system to repeat several superoutbursts before the WD thermal runaway final explosion or tidal disruption. We also highlight that the action of orbital gravitational stresses (powerful tides driven by the NS) may drive a sort of plate tectonics on the WD crust, a la Rothschild, Marsden & Lingenfelter (2001), which can provide enough energy so as to explain why SGRs glow in hard X-rays over some months before undergoing dramatic transients such as GRB980827 from SGR 1900+14. This prospective mechanism will be tackled elsewhere.

3 SGRs GW emission: A pathway to unravel their nature

Several GW signals of different nature are expected to be produced in the context of this picture for SGRs. During: a) the binary inspiral (detectable by the LISA antenna) with characteristic GW amplitude

$$h_c(f) = 3.2 \times 10^{-19} \left[\frac{\mu}{1 \ M_\odot}\right]^{5/3} \left[\frac{f}{3 \times 10^{-22} \ Hz}\right]^{2/3} \left[5.7kpc/D\right].$$

(15)

b) the inspiraling of a lump of matter that reaches the disk at a radius $R \sim 100 \ km$; the equilibrium distance from the NS, c) the plunging of the inner TDD, after crossing the ISCO, onto the millisecond NS. This will shake the NS and its (fluid-modes), d) WD non-radial pulsations, and e) the NS spinning or wobbling.

3 Note that an increase in orbital period by a factor of 3 (still consistent with our picture) would yield a time scale $\tau_{GR} \approx 8000 \ yr$ for the binary to coalesce driven by GW.
Some of them having characteristics so as to make it detectable even with today’s bars. For the sake of definiteness, we compute here the characteristics of the GW burst released during the brief inspiraling (timescale \( \Delta T_{\text{visc}} \equiv \Delta t \)) of a disk “blob” till finding the ISCO. The GW amplitude reads (Mosquera Cuesta et al. 1998)

\[
\frac{\Delta h}{\Delta t}^2 = \frac{4G}{c^3} \left( \frac{1}{L^2} \right) \frac{\Delta E_{\text{GW}}}{\Delta t},
\]

(16)

with the GW energy \( \Delta E_{\text{GW}} \equiv \Delta E_{\text{visc}} \). The GW luminosity

\[
\Delta L_{\text{GW}} \sim (G/5c^5) \left[ \dot{M}_{\phi}^2 \frac{W}{T_{\phi}} \frac{R_{\phi}^2}{T_{\phi}^4 \Delta T_{\text{visc}}^4} \right],
\]

(17)

where \( R_{\phi} = 7 \times 10^6 \) cm is the radius of gyration of the matter in the disk. This yields \( h_c = 1.5 \times 10^{-22} \) for a source distance of 5.7 kpc (Kouveliotou et al. 1999). The GW frequency is given by \( f_{\text{GW}} \sim 2 \times (\Delta T_{\text{visc}})^{-1} \sim 480 \) Hz. A GW signal such as this from SGR 1900+14 during the GRB980827 energetic outburst could have been detected by interferometers such as LIGO, VIRGO and GEO-600 were they operatives, but may be detected in the future. In passing, it’s worths to quote that since the conditions for GWs resonant excitation (Ferrari et al. 2000) of the stars’ fluid modes (mainly the WD, \( f_{\phi} \sim 4 \times f_0 \)) a continuous GWs emission could also be enhanced in this extremely close binary. This issue will be addressed elsewhere.

### 4 DISCUSSION AND CONCLUSION

An observationally consistent scenario to explain the detected modulations from SGR 1900+14 is discussed in the accompanying paper by Mosquera Cuesta (2004b). In that paper is also provided a viable origin for the secular SGRs spindown, and for the up-and-down of their periods. Most of the results are collected in Table 2.

Related to those results, we stress that neither NS-NS nor NS-BH binaries can fit the observations of SGRs (Kouveliotou 1998, 1999; Hurley 1999a,b,c; Murakami et al. 1999; Feroci et al. 1999), since, even for the explosive lower mass limit of Colpi, Shapiro & Teukolsky (1993), \( M_{\text{NS}} \lesssim 0.09 \) M\(_\odot\), the oscillation frequency of its fundamental mode goes too high (McDermott, van Horn & Hansen 1987) due to the NS higher density, so as to explain the relative lower pulsation periods observed in SGRs (see Table 2). Moreover, since the maximum mass of a WD is limited to the Chandrasekhar mass: \( M_{\text{ch}} = 1.44 \) M\(_\odot\), we expect not to find SGRs with pulsation periods \( \lesssim 2.1 \) s (see Table 2). A prediction that agrees with current data, but that is not precluded by the magnetar model.

To conclude, the NS low magnetization in this model places it under the pulsar death line in the \( P - \dot{P} \) diagram, and hence turns SGRs undetectable as binary radio pulsars; a point confirmed by Xilouris et al. (1998). This fact makes the search for an optical and/or infra-red counterpart of SGRs with GEMINI or KECK a timely endeavour. Meanwhile, if our scenario proves correct, a prospective way to study these systems is through the new generation of X-rays telescopes like CHANDRA, XMM-Newton, INTEGRAL, etc., and GWs observatories such as LIGO, VIRGO, TAMA-300, GEO-600, the TIGAs Network (which may follow-up the burster phase) and LISA (which may follow-up the orbital dynamics and WD pulsations). When operatives, they will play a decisive role in deciphering the SGRs nature, as perhaps, new general relativistic astrophysical laboratories where WD-NS interacts farther out the weak-field regime.

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Table 3. Theoretical pulsation modes of a WD with \( m \approx 1.1 \) M\(_\odot\), (as computed by Montgomery & Winget 1999) versus the modulation spectrum from SGR 1900+14 on August 27 (1998) discovered by BeppoSAX. Also, SGRs pulsation periods and expected masses for the WD in the binary model.

| S.H.R. Overtones | Num. Model [Hz] | BeppoSAX [Hz] | Mismatch (%) | SGR | P [s] | Mass [M\(_\odot\)] |
|-----------------|----------------|---------------|-------------|-----|-----|---------------|
| l= 0, n = 1     | 0.1846         | 0.194         | 5.0         | 1900+14 | 5.16 | 1.1          |
| l= 1, n = 1     | 0.3898         | 0.389         | 0.2         | 0526-66 | 8.1  | 0.90         |
| l= 2, n = 2,3   | 0.7644, 0.7845 | 0.775         | 1.0, 1.23   | 1806-20 | 7.47 | 0.95         |
| l= 1, n = 3,3   | 0.9025, 1.0068 | 0.969         | 4.54, 3.78  | 1627-41 | 6.7  | 1.0          |
| l= 3, n = 1     | 1.0915         | 1.101         | 1.01        | 1456-21 | 3.4  | 0.55         |

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**Figure 1.** Prospectives for detectability by LISA of SGRs and their WD components in the relativistic binary model.

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