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SOFT GAMMA-RAY REPEATERS AS WHITE DWARF-NEUTRON STAR RELATIVISTIC BINARIES

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ABSTRACT

Compelling evidence is accumulating against the picture suggesting that soft gamma-ray repeaters (SGRs) are *magnetars*. A scenario is introduced, in which gravitational radiation (GR) reaction effects drive the SGRs dynamics of an ultrashort orbital period X-ray binary embracing a mid-mass donor white dwarf (WD) to a rapidly rotating low magnetized high-mass neutron star (NS) surrounded by a thick dense massive accretion torus. Driven by GR, sparsely, the binary separation reduces and the WD overflows its Roche lobe, drives unstable the accretion disk around, and starts to pulsate radially due to the powerful irradiation from the fireball following the disk matter slumping onto the NS. This model allows to explain most of SGRs observational features, particularly the intriguing subpulses recently discovered by BeppoSAX, which are suggested here to be *overtones* of the WD radial fundamental mode. New γ-rays and X-rays satellites like CHANDRA, and the forthcoming generation of GR detectors such as LIGO, VIRGO, GEO-600 and TIGAs (burster phase) and LISA space observatory (orbital dynamics) may do their best so as to study SGRs evolution farther out of the weak-field regime, because these systems cannot be seen as binary radio pulsars.

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

1. INTRODUCTION

The spectacular superoutburst from SGR 1900+14 in August 27, 1998 evidenced a stable pulsation with period 5.16s (Hurley 1999a,b,c; Murakami et al. 1999; Mazets et al. 1999; Feroci et al. 1999). Since the modulation frequency is in the range of the other three SGRs studied before, Kouveliotou et al. (1999) and Hurley et al. (1999a,b,c) concluded that the observations provide strong support to the Duncan & Thompson (1992) and Thompson & Duncan (1995,1996) magnetar model for SGRs. They claimed the observed spindown rate of the pulse period, $\dot{P} = 1.1\times10^{-10}$ss^{-1}, may be explained by emission of dipolar radiation from an NS endowed with a very strong magnetic field $B \sim (2-8)10^{14}$G, a characteristic magnetic field strength inferred also from the spin down of the pulse period $P = 7.47$s of SGR 1806-20 (Kouveliotou et al. 1998).

However, the rapid risetime 0.25 s, energetics $E_{out} \geq 3\times10^{44}$ erg and subpulses seen by BeppoSAX (Feroci et al. 1999, see below) of the 27 August 1998 (GRB980827) powerful event are characteristics facing the magnetar view. According to the magnetar scenario (Thompson & Duncan 1995) the typical (crustal stored stress) energy of an outburst from an SGR source should be $\sim 10^{39}$erg (de Freitas Pacheco 1998) if one expects the source not to be destroyed by the explosion. Energies $\sim 10^{43}$erg 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; Woods et al. 1999).

The problems for the magnetar model do not stop there. Very recently Feroci et al. (1999) announced the discovery of an extremely regular interpulse set in the data of GRB980827 event from SGR 1900+14. The interpulses appear separated in time ~ 1.1s in between, with no lag. This behavior, the Feroci team (1999) advanced, is unexpected and quite difficult to explain in the magnetar framework. According to the magnetar model for SGRs, global seismic oscillations (Duncan 1998), pure shear deformation induced toroidal modes, ${}_lT_n$; with no radial components ($n = 0$ *overtones*) are expected to be produced in association with the onset of a new recurrence of a "soft" γ-ray repeater. Following Duncan (1998), these toroidal modes are easy to excite via starquakes because the restoring force is determined uniquely by the weak Coulomb forces of the crustal ions. *Overtones* are not allowed because that would require far too much energy so as to allow for the extremely short period ($\leq$ 1ms, or *lower*) oscillations to be excited. Unfortunately, the subpulses in the lightcurve (Power Spectral Density) of the burst from GRB980827 are clearly *overtones* of the fundamental frequency $f_0 = 0.194$ Hz (Feroci et al. 1999). As shown below, in our picture we are seeing the WD whole pulsation spectrum. Moreover, Marsden, Rothschild & Lingenfelter (1999a,b) found that after a burster phase in 1996 (see also Harding, Contopoulos & Kazanas 1999; Murakami et al. 1999) the pulsar doubled its period derivative, $\dot{P}$, 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 $\dot{P}$ could not be an estimate of the magnetic field strength, nor evidence for a magnetar. Then the issue is contentious: what are these objects?

2. SGRS AS WD-NS RELATIVISTIC BINARIES: ORIGIN AND EVOLUTION DRIVEN BY GR REACTION

According to King & Ritter (1998) an interesting by-product of the massive case B evolution model of Cygnus X-2 is that binaries constituted by a massive WD ($M_{WD} \geq 1.0\mathrm{M}_\odot$) and massive rapidly rotating (*millisecond*) accretion spun up NS ($M_{NS} = 1.78 \pm 0.23\mathrm{M}_\odot$), with ultra-short orbital periods ($0.004 \leq P_f(d) \leq 0.02$) can exist for very massive WD companions. Systems with even more shorter, near tens of a second, depending on the common envelope efficiency parameter α_{CE}, can be formed (see also Ergma, Lundgren & Cordes 1997). 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 and/or ejection of the hydrogen-rich envelope of the red giant star ($\tau_{RG} \sim 10^4$yr) occurred once the neutron star is engulfed in a common-envelope evolutionary phase caused by shrinking of the orbit due to gravitational-wave (GW) 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 that this is why SGRs are surrounded by nebulae resembling supernovae remnants. The 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).

In this letter we suggest that SGRs are not related to magnetars, as opposed to claims by Kouveliotou et al. (1998,1999); Hurley et al. (1999a,b,c); Murakami et al. (1999); Mazets et al. (1999a,b); etc. Instead, it is shown that SGRs may be extremely close (tight) relativistic binaries with periods near *a few tens of seconds*[1], in which the rate of shrinking of the binary separation dominates over the massive WD rate of contraction below its equilibrium radius (Fryer et al. 1998b). During rather sparse catastrophic epochs ($\Delta T_{SGRs} \leq 10$yr) the WD starts to transfer mass onto a low-magnetized rapidly rotating massive NS ($2.0\mathrm{M}_\odot$), 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, slumps and inspirals onto the NS. The abrupt supercritical mass accretion onto the NS releases quasi-thermal powerful γ-rays (GRBs), a fireball to say, while triggers non-radial NS oscillations (GWs, 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 inside its deep interior and atmosphere and begins to pulsate at its fundamental mode and harmonics (*overtones*, see Table 1). The WD atmospheric temperature after being flared should be far too higher than the one for surface thermalization (Ergma, Lundgren & Cordes 1997) $T = ([L_{fireball}]/[4\pi R_{WD}^2 \sigma_{SB}])^{1/4} = 6.8 \times 10^7$K. Therefore, the star emits X-rays relatively hard. By the time its atmospheric temperature rolls down the Debye temperature $\Theta_D \sim 10^7$K due to reemission, the sudden *crust crystallization*[2] increases WD cooling rate because the surface specific heat is now due to *lattice vibrations* instead of thermal motions. Assuming $\sim 10\%$ of the trapped energy is quickly returned into space, the timescale for this transition to occur is (see Figure 1 of Feroci et al. 1999) $\tau_{cryst} \sim 0.1E/L|_{SGR1900+14} \sim 100$s. Then our view predicts: the very noticeable transition of the exponential *time constant* in GRB980827 lightcurve, around $\sim$ 80s after risetime, could be a signature of a crystallization phase transition of the WD crust.

The *transient* mass transfer rate from the WD onto the TDD during the "periastron passage" around the NS can be defined as (see Table 1 in Fryer et al. 1999) $\dot{M}_{disk}^{WD} \sim M_{Lost}^{WD}/\Delta t_{periastron} \sim 7.4 \times 10^{-2}\mathrm{M}_\odot\mathrm{s}^{-1}$. For the accretion rate from the TDD onto the NS, in general, one can use (Popham, Woosley & Fryer 1999) $t_{visc} \sim 4.0 \times 10^{-3}\alpha_{0.1}^{-1}M_{NS}^{-1/2}R_6^{3/2}$s, which leads to $\dot{M}_{disk} \sim M_{disk}/t_{visc} = 0.37\alpha_{0.1}M_{disk}M_{NS}^{1/2}R_6^{-3/2} = 5 \times 10^{-2}\mathrm{M}_\odot\mathrm{s}^{-1}$, where M_{disk} is the mass deposited at radius R (in units of 10^6 cm), and $t_{visc} \sim R^2/\nu = \alpha^{-1}(H/R)^{-2}\Omega_{\mathrm{K}}^{-1}$, with α, H and Ω_{K} the Shakura-Sunyaev parameter, disc height scale and Keplerian angular frequency, respectively.

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

$$\begin{aligned} R_{WD} &\simeq 10^4\left(\frac{M_{WD}}{0.7\ M_\odot}\right)^{-1/3}\left[1-\left(\frac{M_{WD}}{M_{Ch}}\right)^{4/3}\right]^{1/2} \\ &\qquad (\frac{\mu_e}{2})^{-5/3} = 4.8 \times 10^3\ km, \end{aligned} \tag{1}$$

where R_{WD} is the WD radius, $M_{WD} \sim 1.1\ \mathrm{M}_\odot$ the WD mass (to be justified below), $M_{Ch} = 1.44\ \mathrm{M}_\odot$ the Chandrasekhar mass limit, and $\mu_e \sim 2$ the molecular weight per electron. The orbital separation for which mass overflow commences is given by $a_0 = R_{WD}(0.6q^{2/3} + ln(1 + q^{1/3})/0.49q^{2/3})$, 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 a thick accretion disk around the NS. 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 time mass transfer starts is given by

$$\begin{aligned} a &= a_0\left(\frac{M_{WD} + M_{NS+Disk}}{M_{WD}^0 + M_{NS}^0}\right)\left(\frac{M_{WD}}{M_{WD}^0}\right)^{C_1}\left(\frac{M_{NS}}{M_{NS}^0}\right)^{C_2} \\ &\equiv (1 + \bar{d})a_0, \end{aligned} \tag{2}$$

where $\bar{d} \leq 1$, the superscript ^{0} stands for the states before Roche lobe overflowing and the values for the con-

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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: $10^3 - 10^6$ 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, $\sim$ 21s, but expected. Thus, it is likely that the orbital signature looked for remains embedded in the data subsets they are used for.

[2] Original idea of Professor John C. Miller (SISSA and Nuclear Laboratory Oxford U.).

stants C_1 and C_2 are $C_1 \equiv -2 + 2J_{Disk}B$ and $C_2 \equiv -2 - 2J_{Disk}$, with $B \sim 7 \times 10^{-2}$ the fraction of the WD mass that goes to the TDD formation. Furthermore, $M_{NS+Disk} \equiv B(M^0_{WD} - M_{WD}) + M^0_{NS}$ and $j_{eject} = 0$. The GW orbital angular momentum loss is $(dJ/dt)_{GW} = [32G^{7/2}/5c^5](M^{1/2}[M^2_{WD}M^2_{NS}/a^{7/2}])$.

Accepting that the WD orbit is circularized and the orbital period today is near the one for mass transfer to start at a_0, $P \sim 21\text{s}$[3] (see below), the timescale for the orbit to shrink due to effects of radiation of GWs is given by $\tau_{GRR} = (a_0^4/4\beta) \leq 100\text{yr}$, where $\beta \equiv (64G^3/5c^5)M_{WD}M_{NS}(M_{WD} + M_{NS})$. It is easy to see that if one wants the binary SGR to reenter a new unstable mass transfer transient, a very short reduction in the binary separation is required. Distance separation reduction of *a few* hundred km will yield a timescale compatible with the mean one observed for rebursting in most of the SGRs, i. e., $\tau_{rep} \leq 10\text{yr}$. Since after mass-shedding the orbit widens faster than the WD expands (WD recoils due to angular momentum conservation [gravothermal effect] and stops mass transfer), the GR timescale estimated above will determine the accretion rate onto the NS and the binary final merger will occur on this timescale. Consequently we can expect the system to repeat about 15 superoutbursts before the WD thermal runaway final explosion or tidal disruption. Driven by GR reaction effects the system is brought closer again in a timescale $\leq 10\text{yr}$, and the process described above restarts governing the binary dynamics leading to a new outburst. Each time the overall process reinitiates, replenishing of the disk around the NS raises up its temperature due to the huge amount of matter received from the WD, and also because NS tidal heating and compression occurs. This explains why SGRs glow in hard X-rays over some months before undergoing dramatic transients such as GRB980827 in SGR 1900+14, which we conjecture triggers when the torus plunges onto the NS.[4]

Scaling these results for the difference in gravitational potential between BH and NS ($\Phi_{NS}/\Phi_{BH} \sim 0.2$), in coalescence with a WD (Kluźniak & Lee 1998; Kluźniak 1998), and using the eq.(1) given by Mosquera Cuesta et al. (1998) for estimating the peak temperature achieved when the accreted matter crashes the NS surface, we get (see Mosquera Cuesta et al. 1998; 2000b for details) $T_{peak} = ([G/4\pi\sigma_{SB}]\beta_{acc}[M_{NS}\dot{M}_{disk}/R^3_{NS}])^{1/4} = 3.1 \times 10^{10}\text{K}$, or equivalently, $T_{peak} = 2.5\text{MeV}$, and the total energy released is $\geq 10^{45}\text{erg}$. Both results match very nicely the power emitted in GRB980827 (Mazets et al. 1999. See also the discussion on GRBs in Fryer et al. 1999b).

Any perturbation of the hydrostatic equilibrium of a canonical WD will grow on its dynamical timescale: $\tau_{inst} \sim (G\rho_{WD})^{-1/2}$. WD normal mode spectrum ($p-modes$) is obtained from the radial wavenumber k_r defined by (Montgomery & Winget 1999) $k_r^2 = (1/\sigma^2 c_s^2)(\sigma^2 - L_l^2)(\sigma^2 - N^2)$ with σ the mode angular frequency, c_s sound speed, $L_l^2 = l(l+1)c_s^2/r^2$ squared Lamb/acoustic frequency, r the radial variable, and N^2 Brunt-Väisälä frequency. For $p - modes$: $\sigma^2 > L_l^2, N^2$, and $\sigma \sim k_r\pi/\int_{r_1}^{r_2} dr/c_s$, where r_2, r_1 are the inner and outer turning points, respectively, at which $k_r = 0$ for a given σ.[5] If we use the picture being introduced here to explain the pulsation discovered in GRB980827 (Hurley 1999a; Kouveliotou 1999a; Murakami et al. 1999; Feroci et al. 1999), it is easy to see that the WD mass needed to produce pulsations with timescale of 5.16s is $\sim 1.1\text{M}_\odot$ (Montgomery & Winget 1999; Shapiro & Teukolsky 1983). The interpulses discovered by the Italian team of the BeppoSAX collaboration can also be explained in a simple manner (except that there are instrumental errors): they are a kind of WD *ringing overtones*. The amplitude of the pulsations will be severely reduced to tiny heights during the first evolutionary phase due to bulk viscous dissipation at the WD interior on a timescale $\tau_{visc} \sim (R^2_{WD}/<\nu_{WD}>) \sim 10^3\text{s}$.[6] This gives a timescale for the initial drastic reduction of the pulsational phase $\sim$ *a few minutes*, which is in agreement with the lightcurve evolution of GRB980827 from SGR 1900+14 (Hurley et al. 1999a,b,c; Murakami et al. 1999; Feroci et al. 1999). Here we have assumed the mean viscosity $<\nu_{WD}>= 10^{13}$ (cgs units), for canonical WD stars as those ones computed by Durisen (1973a,b). So the observed pulsations stem from a WD, not from a slowly rotating hyper-magnetized NS.

Three different GW signals are expected to be produced in the context of this picture for SGRs. During: a) the binary inspiral (detectable by the LISA antenna, see Mosquera Cuesta 2000b), b) the inspiraling of a lump of matter that reaches the disk at a radius $R \sim 100$ km, and c) when the disk inner matter plunges, after crossing the ISCO, onto the millisecond NS, shaking it. All of them having characteristics so as to make it detectable even with today's bars (this is shown elsewhere, Mosquera Cuesta 2000b). Here we compute the characteristics of the GW burst released during the brief inspiraling (timescale $t_{visc} \equiv \Delta t$) of a disk "blob" till finding the ISCO. The GW amplitude reads (Mosquera Cuesta et al. 1998, 2000a)

$$\left|\frac{\Delta h}{\Delta t}\right|^2 = \frac{4G}{c^3}\left(\frac{1}{D^2}\right)\frac{\Delta E_{GW}}{\Delta t}, \tag{3}$$

with the GW energy $\Delta E_{GW} \equiv \Delta L_{GW} \times t_{visc}$. The GW luminosity $\Delta L_{GW} \sim (G/5c^5)[\dot{M}^2_{disk}R^4_{giro}t^{-4}_{visc}]$, where $R_{giro} = 7\times10^6\text{cm}$ is the radius of gyration of the matter in the disk. This yields $h_c = 1.5\times10^{-20}$ for a source distance of 5.7 kpc (Kouveliotou et al. 1999). The GW frequency is given by $f_{GW} \sim 2 \times (t_{visc})^{-1} \sim 480$ Hz. A GW signal such as this from SGR 1900+14 during the energetic

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[3] Note that an increase in orbital period by a factor of 3 (still consistent with our picture) would yield the binary time scale $\sim$ 8000 yr, which is closer to the one inferred to from the SGRs magnetar model.

[4] Since the NS is rotating with a millisecond period, there will be enough rotational losses so as to account for the quiescent X-ray luminosity in SGRs: $L_{SGRs} \sim 10^{35}$ ergs^{-1} (Kouveliotou et al. 1999). Moreover, the existence of the massive TDD with a mass $\sim (4-10)\times 10^{-2}\text{M}_\odot$ guarantees that some radiation from the NS will be comptonized when hitting the torus. The dissipation of this energy keeps the disk hot enough for it to shine in the soft X-ray band (≤ 2)keV.

[5] Compare to the Shapiro & Teukolsky (1983) more elementary treatment of the hydrostatic perturbation of a WD, in which the spectra of WD normal modes is given by $\omega^2 = (2\pi G\rho_{WD}/3)[\Gamma_1(n^2 + 5n + 6) - 8]$, where the adiabatic index $\Gamma_1 \equiv \partial P_{WD}/\partial ln\rho_{WD}$, and $n = 0, 2, 4, ...$, being $n = 0$ the fundamental mode of pulsation.

[6] The full attenuation of the oscillations will be achieved on a much longer timescale via the *wave-leakage of radial modes* (see section 3).

Table 1

Theoretical pulsation frequency spectrum of a WD with 1.1 $M_\odot$, as computed by Montgomery & Winget (1999), versus the modulation spectrum from SGR 1900+14 on 27 August, 1998 observed by the Feroci Team (1999). 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	0.70
l= 2,0, n = 2,3	0.7644, 0.7845	0.775	1.0, 1.23	1806-20	7.47	0.80
l= 1,2, n = 3,3	0.9025, 1.0068	0.969	4.54, 3.78	1627-41	6.7	0.95
l= 1, n = 4	1.1430	1.161	1.55			

outburst on August 27, 1998 could have been detected by interferometers such as LIGO, VIRGO and GEO-600 were they operationals. In passing, it worths to quote that since the conditions for resonant excitation of both stars' fluid modes (mainly the WD) a continuous gravitational wave emission could also be enhanced in this extremely close binary. This issue will be addressed elsewhere (Mosquera Cuesta 2000b).

3. DISCUSSIONS AND CONCLUSIONS

The SGR 1900+14 spin down observed by Kouvelioutou et al. (1999) and the pulse period increase found by Murakami et al. (1999); Marsden, Rothschild & Lingenfelter (1999) and Harding, Contopoulos & Kazanas (1999) may be explained as follows: because the WD is a gravothermal (degenerate) system, as soon as it loses mass when overflowing its Roche lobe its negative specific heat forces it to expand until a new dynamical equilibrium radius is found. Then, the next stage of pulsation should occur with a slightly longer period compared to the previous one. As a result, the pulse period increases.

Thus, the rate of variation of the viscously attenuated pulsation timescale, $\tau_{pulse} = 5.16$s, over the timescale to dissipate the absorbed energy $\sim 10^{44}$erg via *wave-leakage* for *radial modes*[7], $\tau_{w-l} \sim 10^3$yr, gives us the observed spindown rate in SGR 1900+14 (here we assume this the dominant source available to the WD)

$$\left(\frac{\partial \tau_{pulse}}{\partial \tau_{w-l}}\right) \equiv \frac{5.16 \text{ s}}{3.17 \times 10^{10} \text{ s}} = 1.63 \times 10^{-10} \text{ ss}^{-1}. \quad (4)$$

In our view this is the origin of those important time variations. Discrepancies might be caused by the differences in the WD model used (see Table 1). Moreover, in a realistic star the frequencies of the overtones depend on the WD matter EOS and the degree of core crystallization. Changes in pulsation (fundamental) periods of $\sim$ a few percent are expected to occur once lattice crystallization onsets while the harmonics (overtones) remain almost unchanged (Montgomery & Winget 1999). We also emphasize that the conclusion by Mazets et al. (1999) "... the processes accounting for emission of the narrow initial pulse and the long pulsating tail in both SGR 0526-66 and 1900+14 *are separated in the source not only on time but in space...*" is quite clearly realized in the picture introduced here, i. e., the NS releases the superoutburst while the WD the subsequent tail of pulsations. Rephrasing de Freitas Pacheco (1998) on magnetars: any model based on magnetic field energy stored in the NS crust would have the same difficulties in explaining both events.

To conclude, the NS low magnetization leads it under the pulsar death line making it SGRs undetectable as binary radio pulsars, a point confirmed by Xilouris et al. (1998). Overall, since almost (if not) all SGRs are enshrouded by intervening galactic dust and gaseous nebulae, any optical observations of the quite hot ($\sim$ 15000K) WD are prevented. Therefore, the best way to study these systems is via the new generation of X-rays telescopes like CHANDRA, and GW observatories such as LIGO, VIRGO, the TIGAs Network and LISA. When operational, they will play a important role in deciphering the SGRs nature. If this scenario is correct, then new more critical relativistic astrophysical laboratories will be available to study general relativity outside the weak-field approximation.

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[7] Physical support for the figures have been used here comes from the detailed numerical calculations of pulsation periods for DA and DB WDs given by Hansen, Winget & Kawaler (1985), where timescales for dissipation of energies such as the one absorbed by the WD in this scenario are estimated for wave-leakage via unstable radial modes with e-folding timescale $\tau_D \sim 10^3$yr, for nonadiabatic driving of the mode with energy 10^{44}erg.

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