A Detectable Gravitational-Wave Signal from SGR 1900+14 During the August 27, 1998 Superoutburst

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Abstract

The peculiar phenomenology of soft gamma-ray repeaters (SGRs) have been evidenced once again during the August 27, 1998 outburst from SGR 1900+14. Its powerful energy release could have make it possible for a gravitational-wave (GW) burst to be produced almost simultaneously with the γ-burst. Integrating in an unique scheme the most recent observational data on the energetics and timescales of the event, together with the strong-field relativistic gravity binary scenario [12] and the mechanism for triggering the GW and γ-rays signals as suggested recently [1,2], I have estimated the characteristics of the pulse for a wide range of reliable parameters of the model. I conclude that such a signal should have been detected even by the third generation of GW detectors in operation at the onset of the burst: ALLEGRO, EXPLORER, etc., as well as by LIGO, VIRGO and GEO-600 [3,4], were they operationals. Because of the fundamental impact for physics, and science in general, such a detection might have, an urgent search for evidences for or constraints on the occurrence of this event on archival data of such detectors is timely.

Key-words: Gamma-rays: theory; Stars: individual (SGR 1900+14); Gravitational waves; Detectors.

The detection of gravitational waves (GWs) is expected to be a breakthrough in modern physics, astrophysics and cosmology [3,4]. T o this purpose, the new generation of Earth-based interferometric (LIGO, VIRGO, GEO-600, TAMA-300, AIGO, etc.), and resonant-mass (TIGAs Network) observatories are expected to run into operation around 2002-2003, while the LISA space antenna is scheduled to fly near 2010 [3–5]. For all these capabilities to succeed in their tasks detailed studies of potential astrophysical and/or cosmological sources of GWs are strongly encouraged.

In this letter, I advance the suggestion that during the event on August 27, 1998 from SGR 1900+14 (GRB980827) a detectable GW pulse was emitted almost simultaneously with the overwhelming gamma-ray superoutburst around 4 milliseconds after its risetime (spectra with kT $\geq$ 300 keV $\longrightarrow$ burst energy flux $\geq 3.2\times10^{-2}$ erg cm^{-2} s^{-1}) [6]. As shown by Mazets et al. (1999) [6] using KONUS-WIND satellite observations of GRB980827, the total energy released was so huge, $E_\gamma \geq 10^{45}$ erg, that almost all the γ-ray detectors that observed the surge risetime got totally overloaded. Since any model based on NS crust strain stress and/or magnetic (reconnection) energy cannot afford this power release [24], then we argued in Refs. [12,7,8] that there is room in such an outburst for *accretion* to be the energy source of the event, perhaps an energy supply as high as 10^{47} erg as numerically computed by Fryer et al. (1998) [19] for the case of a NS-WD binary. Our claim is fundamented on predictions from a theory for generation of GW bursts from SGRs: the Mosquera Cuesta (1999) relativistic compact binary scenario [12,7,8]. Meanwhile, it is shown that de Freitas Pacheco's quadrupole oscillations in which the elastic stress energy stored in the NS crust triggers the pulse, as in the context of the magnetar model, is unable to put forward analogous predictions. The characteristics of the GW signals are computed using the WD-NS relativistic binary scenario for SGRs and found detectable by current observatories such as ALLEGRO, EXPLORER and NAUTILUS, which were operationals at the event onset, and also by the under construction interferometric detectors LIGO, VIRGO, GEO-600 and narrow-band TIGAs, etc.

Since their discovery soft gamma-ray repeaters have been recognized as a very rare class among the high energy transient sources. Recent x-ray observations, however, have led some workers in the field to claim that its very nature has been unraveled [9,10]. Their conclusion is that these events are associated to a special class of highly magnetized slowly spinning neutron stars: the magnetars [11]. However, addressing the issue in the light of the new data (see Feroci et al. 1999 [17]; Marsden, Rothschild and Lingenfelter 1999 [18]; Murakami et al. 1999 [16]; Xiluoris and Lorimer 1999 [29]), we have argued [7,8] that there exist strong evidences for this not to be the case, and that the SGR 1900+14 event on August 27, 1998, leaves the magnetar scenario facing serious shortcomings. Instead, a model has been proposed elsewhere [1,7,8] in which the event can be pictured as stemming from a disc instability triggered by the replenishing of a highly dense accretion torus formed when a mid mass ($\sim$ 1.1 $M_\odot$) white dwarf star overflows its Roche lobe and becomes, supercritically, to transfer mass on to a massive ($\sim$ 2.0 $M_\odot$) high spin neutron star during a far short transient, in a very tight ultrashort orbital period x-ray binary [7,8]. It is also conjectured that the *few seconds* timescale of periodicity observed in most SGRs may be associated to hard x-ray radial pulsations of the white dwarf companion due to perturbations of its hydrostatic equilibrium induced by the neutron star powerful flare (*fireball*) emitted at the onset of the γ-rays surge [12,1,2,7,8].

Several spacecratfs observed the outburst on August 27, 1998 from SGR 1900+14 (see Figure 1). Hurley et al. [13,14] presented an accurate determination of the surge position on the sky based on high precision localization of the explosion source, throughout an analysis of the burst arrival times at Ulysses, GGS-Wind, RXTE and NEAR detectors [14], the same region from where they have previously discovered an x-ray pulsar [15].

The triangulation showed clearly that the signal is consistent with the quiescent x-ray source 19.0914+9.1919 (Julian efemeris). Murakami et al. [16] pursued accurate position localization of SGR 1900+14 outbursts, and evolution and pulse profile folding of the $\sim 5.16\ s$ period using ASCA satellite data. They found a noticeable increase of the pulse period, while claimed that the huge energy released in GRB980827 with serious difficulties could be fitted into the magnetar picture, and hence more observations of the spindown evolution are needed in order to settle this issue.

The strongest and longest ever detected explosion from SGR 1900+14, the August 27, 1998 event was also observed by Feroci et al. [17] using the Gamma-Ray Burst Monitor on board the BeppoSAX satellite. They discovered that the 5.16 s pulsations were observable from the very beginning of the outburst. Surprisingly, they also found that $\sim$ 34 s after the risetime a pattern of four subpulses and a dip, separated by $\sim$ 1.1 s between the main pulsations, were present. Unfortunately, due to energy band constraints [17] the BeppoSAX-GRBM was unable to follow up the GRB980827 risetime near its maximum.

Notwithstanding, due to the highest temporal and energy resolution of the KONUS-WIND satellite, a more interesting piece in the observations of GRB980827 comes from the Mazets team [6]. Among several other key characteristics observed with the KONUS-WIND satellite, they found that the number of additional counts needed to trigger the counting mechanism on the detector passed over the KONUS-WIND experiment in less than 4 ms, i. e., the event risetime was $< 4\ ms$. Overall, the quite unexpected issue was the burst evolution just the 4 ms following the risetime. No counts were detected during this interval in any window: G1 (15-50), G2(50-250) e G3(250-1000) keV (see Figure 2) [6]. Since their simulations of the detector response to higher intensities is well understood (see their Figure 4), they concluded that the radiation intensity was so huge that the count-rate channel got completely overloaded [6]. This fundamental piece of the observations deserves a more careful attention than have been payed till now. We will review it below in connection with the possible emission of a GW pulse in the event.

The possibility that SGRs could be powerful gravitational-wave emitters was independently advanced by Mosquera Cuesta et al. [2] and by de Freitas Pacheco [24]. In the Mosquera Cuesta (1999) [12] (see also Mosquera Cuesta et al. 1998 [2]) scenario for gravitational radiation from SGRs, there are at least two sequentially ways in which the gravitational waves can be produced. In one way of generation, the GW energy is released during the matter inspiraling near the innermost stable circular orbit, with time scale of $\sim$ a few seconds [8]. This signal could be detected by interferometers like LIGO, VIRGO and GEO-600. In the other mechanism the GW signal is generated when the first fragments of the torus encircling the NS slump onto it, driven by hydrodynamic instabilities, making it to vibrate with non-radial modes which are damped by GW emission. We argue these signals should have been catched up by ALLEGRO and EXPLORER detectors during the GRB980827 event. The γ-burst risetime (maximum emission) corresponds to the moment in which the first disc material (or more likely the whole torus) crashes the NS crust. Following Mazets et al. [6] key discovery, the GW timescale is assumed to be the necessary for the large collections of the slumping mass to hit the NS, i. e., $\sim$ 1 millisecond. As mentioned earlier, in the case of the slumping material, there exists still another possibility: the whole disc to plunge onto the NS with no fragmentation. In such a case, we expect relatively stronger GW and γ-pulses. We conjecture this might be the case from SGR 1900+14 on the August 27, 1998 superoutburst: the whole torus plunged onto the NS. As shown below the overall picture just described can be well-fitted into the observational data from GRB980827 (see Refs. [1,2,12] for details).

The August 27, 1998 event from SGR 1900+14 was so spectacular that most of the satellites that detected the explosion were fully saturated. This extraordinary γ-rays flux from the very early stages of the GRB980827 from SGR 1900+14 may be interpreted quite accordingly to the strong-field relativistic binary scenario for SGRs [2,12,1,7]. If one assumes that the Mosquera Cuesta above described model is correct, then the first time interval (0.35-0.8) s, i. e., *the γ-burst single wave* [6], may properly be correlated to the periastron passage of the WD around the NS during which mass transfer develops more supercritically ($\dot{M}_{acc} \geq 4 \times 10^{-2}\ M_\odot/s$) [19–21,2,12]. The risetime referred to earlier may correspond to the beginning of the abrupt accretion transient onto the NS, while the overloading radiation following it could have risen to a factor 6-7 times the KONUS-WIND G3 energy level (see details in Ref. [6]). It worths to recall that there was also a weak precursor in the soft window $\sim$ 0.45 s before the August 27, 1998 strong outburst to ensue. This transient may signalize the starting of the accretion phase onto the torus around the NS. Then, putting all these pieces in a consistent picture, it is now more than evident that something really catastrophic occurred around the first 0.6 seconds after the GRB980827 risetime (see Figures 1 and 2) [6].

According to the Mazets team observations [6] above, we can assume that at least a huge part of the total radiation energy from GRB980827 was released during a time interval $\sim$ 0.5-2.0 ms or on a timescale lower than this (see Figure 2, and its discussion by Mazets et al. [6]). We conjecture this superoutburst was most likely due to a supercritical accretion transient, as described above (see also Fryer et al. 1999 [19], Kluźniak and Lee 1988 [21], and Armitage and Livio 1999 [22]). In that case the GW characteristic amplitude and frequency are given by [2,12][1]

$$h_c = \left(\frac{4G}{c^3 D^2}\left[\Delta L_{GW}(\Delta t_{max})^2\right]\right)^{1/2} \tag{1}$$

where we assume $\Delta t_{max} \sim 1\ ms$ [6] as the time interval during which the maximum γ-emission occured. The GW luminosity is given by (see Mosquera Cuesta et al. [2,12] for details)

$$\Delta L_{GW} = K\left[\frac{G}{5c^5}\frac{\dot{M}^2_{acc} R^4_{giro}}{(\Delta t_{max})^4}\right], \tag{2}$$

with the constant $K \sim 1.1 \times 10^6$, $\dot{M}_{acc} \sim 7.5 \times 10^{-2} M_\odot/s$, and $R_{giro} \sim 50$ km; is the radius of gyration of the material in the torus (see Table 1). G and c are the gravitational constant and the velocity of light, respectively. Thus, we finally obtain

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[1] Below we shall address this issue and compare our theoretical computation to the view given by de Freitas Pacheco (1998) [24] since the NS in our binary picture is a millisecond spinning central source, a condition which closely match the discussion put forward by him, where a 8 ms rotating NS was envisioned as a likely source of the highest elastic stress energy, $\sim 10^{45}$ erg, released in transients such the August 27, 1998 event.

$$h_c = 1.7 \times 10^{-19}, \tag{3}$$

which implies a normalized GW amplitude $h_{min} = 5.4 \times 10^{-21}\mathrm{Hz}^{1/2}$, for a distance $D = 5.7$ kpc [23], while the GW frequency of the accretion induced pulse is $f_{GW} \sim 1$ kHz. It is quite likely that simultaneously with this signal an accompaning GW burst may be released due to precession of the ms spinning NS. In such a case, the corresponding frequency will be twice the rotation one, ~ 2 kHz, while its GW characteristic amplitude remains essentially as above. A GW signal such this could have been observed by the 6mK ALLEGRO detector operating with GW characteristics: $h_{min} = 1.0 \times 10^{-21}$ $\mathrm{Hz}^{-1/2}$ and $\mathrm{f}_{GW} \sim 900$ Hz, and the 3mK EXPLORER and NAUTILUS "twin" detectors running with GW characteristics: $h_{min} = 2.0 \times 10^{-20}$ $\mathrm{Hz}^{-1/2}$ and $[\mathrm{f}^1_{GW} \sim 908, \mathrm{f}^2_{GW} \sim 924]$ Hz resonance frequencies. The GW signal predicted could have also been observed by the interferometric observatories such as LIGO, VIRGO, GEO and the TIGAs xylophone (see Figure 3).

On the other hand, in the lines of the magnetar picture it has also been suggested that gravitational waves may be produced almost in coincidence with a very strong γ-ray burst during a recurrence activity of a SGR. Here we recast the GW characteristics computed under the assumption that the magnetar model is correct, following the lines of de Freitas Pacheco (1998) [24]. The gravitational waveform is given by Thorne (1969) [25]

$$h(t) = h_0 \exp\left(i\omega_n t - [t/\tau_n]\right) \tag{4}$$

where h_0 is the initial (characteristic) amplitude, ω_n the angular frequency of the n-mode and τ_n its characteristic damping time. The relation between the initial amplitude and the strain energy built in the neutron star crust is

$$h_0 = 2\left(\frac{GE}{c^3\tau_n}\right)^{1/2}\left[\frac{1}{D\omega_n}\right], \tag{5}$$

where the NS total energy, $E \sim 10^{45}$ erg [24], trapped in the NS, which is defined as

$$E = E_0 + \frac{1}{2}I\Omega^2(1-\epsilon) + W\epsilon^2 + B(\epsilon_0 - \epsilon)^2, \tag{6}$$

where the quantities I, Ω, B , W, ϵ and ϵ_0 are defined as the NS inertia tensor, angular frequency, stored elastic energy, gravitational potential energy, and actual and reference oblateness, respectively [24].

In Table 1 we have collected the general results for the GW signals derived using a reasonable parameter space [19,21,22]. One can see that for the accretion rates we have assumed, strikingly the third generation of GW detectors as well as the forthcoming ones may have "seen" this burst. Moreover, a close comparison between both the Pacheco's and ours estimated characteristic GW amplitudes shows that our view predicts a larger value. This is due to the fact that in our WD-NS binary model [1] the merging of the whole dense torus of matter or "blobs" [2] and the NS itself can be considered as a scaled-down version of the well-known NS-NS binary coalescence [26–28], for which GW amplitudes around $h_c \sim 10^{-19}$ $\mathrm{Hz}^{-1/2}$ for a distance ≤ 10 kpc are current figures. Clearly, this result means that the energy reservoir in the binary model is neatly larger than the one expected from the stored elastic stress energy in a NS crust on the lines of the magnetar scenario, and astonishingly agrees well with the energetics requirements of Mazets et al. (1999) [6]. To end, it worths to say that more detailed numerical simulations of these close WD-NS interactions are needed in order to settle the role of the accretion rate in determining the observability of the GW signal here predicted.

Because of its potential impact for physics, I strongly recommend a search for this signal in the detectors ALLEGRO and EXPLORER that were operationals during the superoutburst onset from SGR 1900+14 on August 27, 1998.

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TABLE I.

Characteristic GW properties of the signal emitted during the August 27, 1998 outburst from SGR 1900+14, computed on the framework of Ref. [1,2] for the system's parameter range described in the text. Also the respective ones calculated following the lines in Ref. [24].

	WD-NS Binary Model		
$\dot{M}_{[M_\odot/s]}$	GW Amplitude	GW Frequency	GW Observatory
10^{-3}	2.2×10^{-23}	1 kHz	LIGO/VIRGO/TIGAs
10^{-2} [21, 20, 2]	2.2×10^{-21}	*idem*	LIGO/VIRGO/TIGAs
7.5×10^{-2} [19]	1.7×10^{-19}	*idem*	ALLEGRO/EXPLORER
	Pacheco's Magnetar Scenario		
Model	GW amplitude	NS Mass [M$_\odot$] - Radius [km]	Source Distance [kpc]
O	2.7×10^{-22}	1.45 - 12.84	0.8
N	0.3×10^{-22}	1.57 - 13.82	1.0
M	1.6×10^{-22}	1.44 - 15.79	1.2

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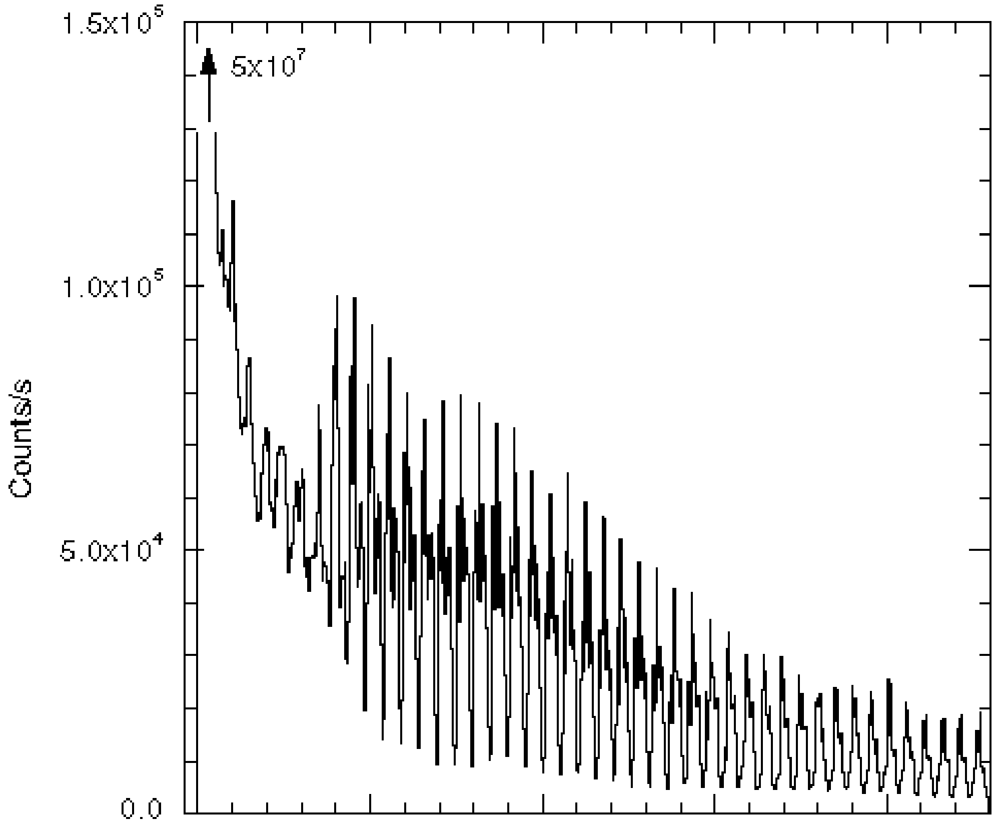

FIG. 1. First T-T$_0$ seconds initial evolution of the SGR 1900+14 August 27, 1998 superoutburst.

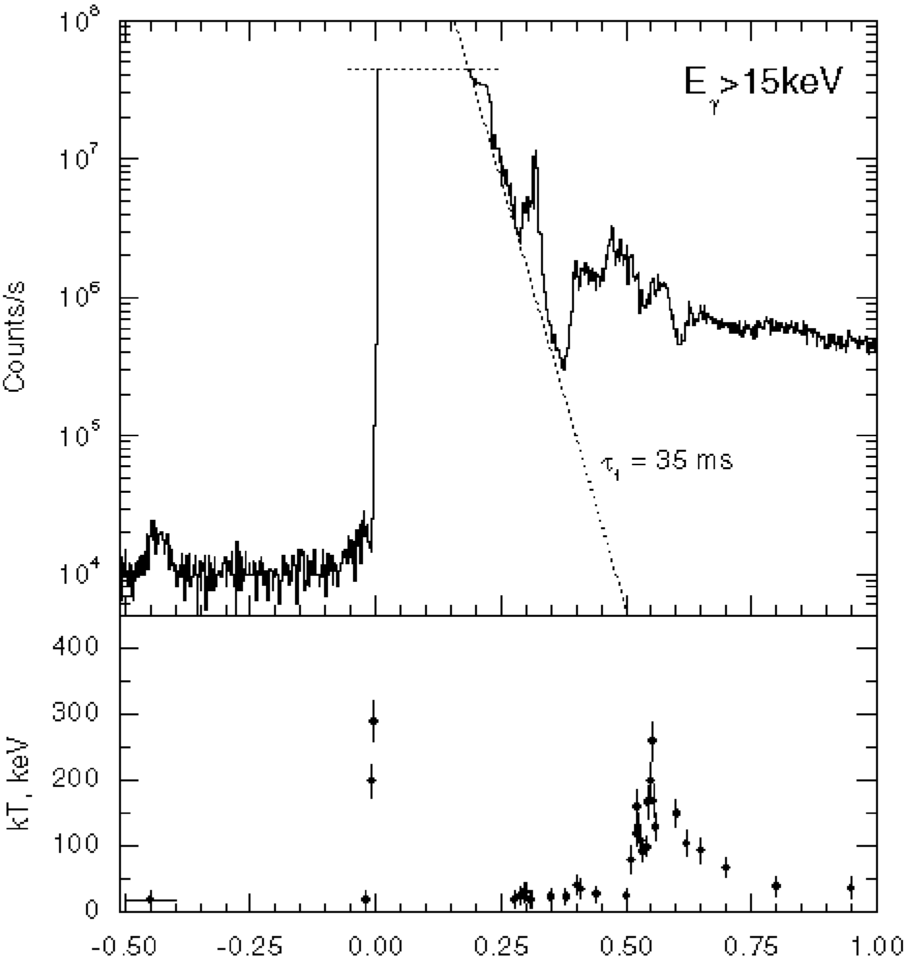

FIG. 2. First T-T_0 seconds initial evolution of the SGR 1900+14 August 27, 1998 superoutburst.

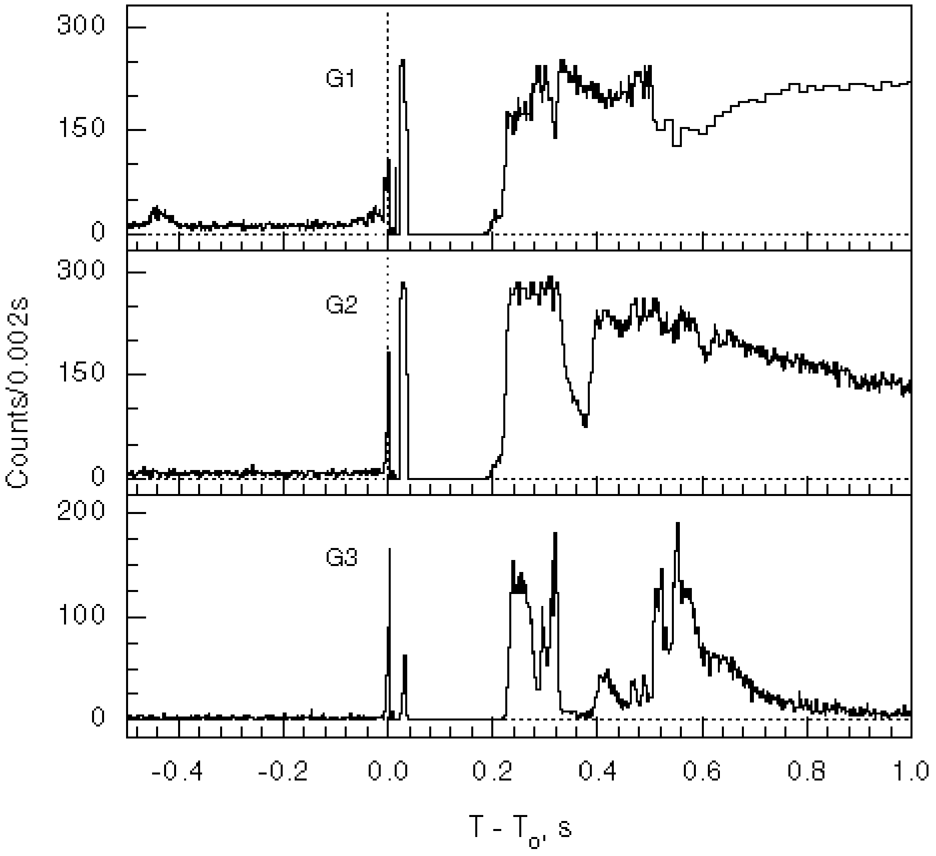

FIG. 3. The plot shows how the additional counts needed to generate a trigger arrives to KONUS-WIND spectrometers in less than 4ms, i. e., the outburst intensity rises abruptly. 4ms after risetime there were no counts detected in any window implying the radiation intensity got so high in such a brief time interval that the count-rate channel was fully overloaded.

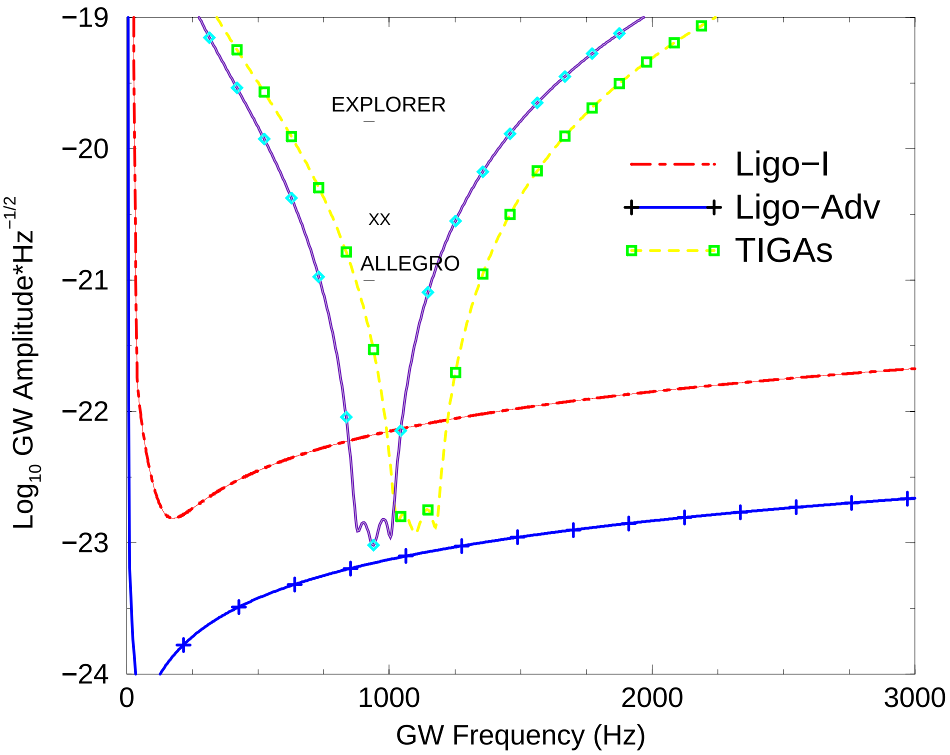

FIG. 4. The GW characteristic amplitude and frequency of the event, symbol XX, generated during the giant outburst on August 27, 1998 from SGR 1900+14 according to the relativistic binary model, versus strain burst sensitivities of the operational GW detectors ALLEGRO (–) and EXPLORER (–), and the prospectives for LIGOs and TIGAs.