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Gamma-ray burst afterglow plateaus and gravitational waves

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Abstract

The existence of a shallow decay phase in the early x-ray afterglows of gamma-ray bursts is a common feature. We discuss the possibility that such a feature is connected to the formation of a highly magnetized millisecond pulsar, pumping energy into the fireball via magnetic dipole emission, while undergoing a secular bar-mode instability. If this is the case, gravitational wave losses associated with the neutron star's ellipsoidal deformation, would affect the star's spin-down, possibly producing a gravitational wave signal detectable by the advanced LIGO and Virgo. Such a signal, being emitted in association with an observed x-ray light-curve plateau over relatively long timescales, could open a new interesting opportunity for multi-messenger studies to be carried out in coincidence with gamma-ray burst sources. We conclude that the hypothesis proposed here deserves further investigation.

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1. Introduction

Swift observations (Nousek *et al* 2006, Zhang *et al* 2006) have shown that long gamma-ray burst (GRB) x-ray light curves are often shaped in an initial steep decay, $F(t) \propto t^{\alpha}$ with $\alpha \sim -3$ (where $F(t)$ is the observed flux and t is the observer's time), followed by a shallow decay ($\alpha \gtrsim -0.5$; see figure 1) and finally by the so-called normal decay ($\alpha \sim -1.2$). The break times of the steep-to-shallow and shallow-to-normal decay transitions are usually observed at $100\ \mathrm{s} \lesssim t_{\mathrm{break},1} \lesssim 500\ \mathrm{s}$ and $10^3\ \mathrm{s} \lesssim t_{\mathrm{break},2} \lesssim 10^4\ \mathrm{s}$, respectively. During the

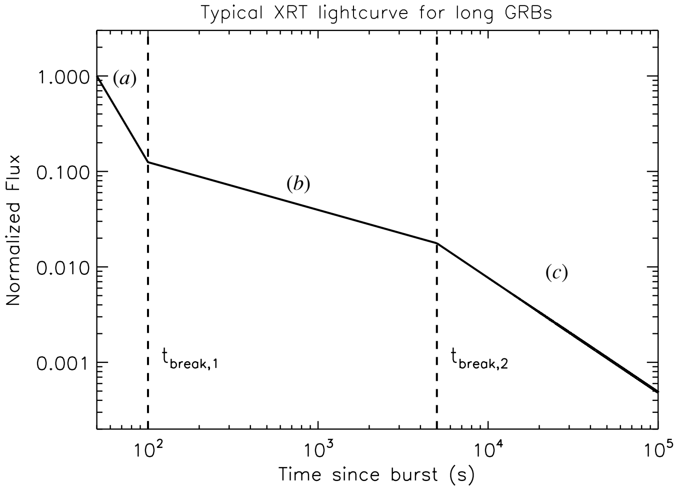

Figure 1. Cartoon representation of the typical light curve behavior observed by *Swift* XRT. (*a*): steep power-law decay phase with index $\alpha \sim -3.0$; (*b*): shallow or plateau phase with $\alpha \gtrsim -0.5$; (*c*): 'standard' power-law decay phase with index $\alpha \sim -1.2$. The steep-to-shallow and shallow-to-normal decay transitions occur at the break times $t_{\rm break,1} = 10^2$–10^3 s and $t_{\rm break,2} = 10^3$–10^4 s, respectively. See also Zhang *et al* 2006.

shallow-to-normal transition the spectral index does not change, and the decay slope after the break ($\alpha \sim -1.2$) is generally consistent with the standard afterglow model (Mészáros and Rees 1997, Sari *et al* 1998). The lack of spectral changes suggests that the shallow phase may be attributed to a continuous energy injection by a long-lived central engine, with progressively reduced activity (for a review see Zhang *et al* 2006 and references therein). Although it is still not clear if a typical 'steep–flat–steep' behavior does exist also in short GRB x-ray afterglows, the case of GRB 051221a does fit this scheme remarkably, with a plateau observed right in the middle of the afterglow decay (Soderberg *et al* 2006).

Newborn magnetars are among the progenitors proposed to account for shallow decays or plateaus observed in GRB light curves (Dai and Lu 1998, Zhang *et al* 2001, Fan and Dong 2006, Yu and Huang 2007). In the simplest version of the magnetar scenario, the end of the shallow decay is accompanied by an achromatic break. Recently, Panaitescu and Vestrand (2008) pointed out that the effects of a late-time energy injection may also be evident in some optical afterglows, around $30 - 10^4$ s after the trigger. Several cases of chromatic breaks have also been observed (e.g., Panaitescu 2008a), and additional mechanisms such as variable micro-physical parameters in the fireball shock front (Panaitescu *et al* 2006) or a structured jet model (e.g., Racusin *et al* 2008) can be invoked to explain such chromatic breaks. Anyhow, a larger sample of simultaneous optical-to-x-ray observations is needed to firmly asses the achromatic or chromatic behavior of breaks associated with the end of the shallow-decay phase. Independent support for the magnetar scenario comes from the case of SN2006aj-GRB 060218, which has suggested that the supernova-GRB connection may extend to a much broader range of stellar masses than previously thought, possibly involving two different mechanisms: a 'collapsar' for the more massive stars collapsing to a black hole (BH) and a newborn neutron star (NS) for the less massive ones (Mazzali *et al* 2006).

Previous studies have shown how magnetar dipole losses may indeed explain the flattening observed in GRB afterglows. Such studies have considered the magnetar's slow-down dominated by magnetic dipole losses, neglecting the contribution from the emission of gravitational waves (GWs, see Dai and Lu 1998, Zhang *et al* 2001, Fan and Dong 2006, Yu and Huang 2007), or considering it separately as a limiting case for a NS with constant eccentricity (Zhang and Mészáros 2001). Here we consider how GW losses might affect the spin-down of a magnetar left over after a GRB explosion, on the timescales that are characteristic of the shallow x-ray decays. Although the precise evolution of a newborn magnetar from birth up to timescales of $\sim 10^3$–10^4 s is difficult to predict or to follow with numerical simulations, we point out that among the possible evolutionary paths, one plausible and particularly interesting case to explore is that of a newborn NS which undergoes a secular bar-mode instability. While other scenarios are also possible, the interesting aspect of this particular one is that (i) GW observations would be facilitated by the presence of an electromagnetic signature to pinpoint the GW signal search and (ii) the detection of bar-mode like GWs in coincidence with a GRB x-ray plateau would be a smoking-gun signature of a magnetar pumping energy into the fireball, thus identifying the much-debated plateau mechanism. A point of interest for current analyses that GW detectors are carrying out (see, e.g., Acernese *et al* 2008, Abbott *et al* 2008a, 2008b) is that, in the scenario we discuss here, a different class of GW signals might be related to and searched for in coincidence with GRBs. Such signals would have a longer duration (10^3–10^4 s) and a different frequency evolution than the type of GW signals currently considered in association with GRBs.

Our discussion is organized as follows. In section 2, we describe how GRB afterglow plateaus are modeled in the context of the magnetar scenario. In section 3, we underline how, among the different mechanisms that can come into play, the high efficiency of the secular bar-mode instability is conducive to producing GW signals which are detectable also from relatively nearby extra-galactic sources. Moreover, it develops on timescales compatible with the observed durations of GRB plateaus. Section 4 discusses the general idea and some particular aspects of the scenario suggested here. Finally, in section 5 we summarize our conclusions, pointing out the importance of a further quantitative investigation of this topic.

2. GRB plateaus in the magnetar scenario

Although in the most popular progenitor scenarios GRB explosions end in the formation of a BH-debris torus system, it has been proposed that some progenitors may lead to a highly magnetized rapidly rotating pulsar (e.g., Usov 1992, Duncan and Thompson 1992, Thompson 1994, Yi and Blackman 1998, Blackman and Yi 1998, Dai and Lu 1998, Kluzniak and Ruderman 1998, Nakamura 1998, Spruit 1999, Wheeler *et al* 2000, Ruderman *et al* 2000, Levan *et al* 2006, Mereghetti 2008, Bucciantini *et al* 2009), with such a possibility being realized not only in the case of long GRBs associated with collapsars, but eventually also in scenarios relevant for short GRBs, such as NS binary mergers (Dai and Lu 1998 and references therein). Fast rotating highly magnetized pulsars may be associated with an energy input in the fireball for timescales significantly longer than the γ-ray emission, thus being relevant for explaining GRB afterglow plateaus (see Zhang and Mészáros 2001), as we recall in what follows.

Consider a GRB powered by a central engine emitting both an initial impulsive energy input, E_{imp} (due to ν–$\overline{\nu}$ annihilation or magnetohydrodynamical processes, see e.g. MacFadyen and Woosley 1999, Popham *et al* 1999, Di Matteo *et al* 2002, Lee 2005, Oechslin and Janka 2006, Zhang and Dai 2009) and a continuous luminosity varying as a power-law with time, $L = L_0\left(\frac{t}{t_0}\right)^q$ (where t is the observer's time), which could be the case if the central engine is a pulsar. A self-similar blast wave is expected to form at $t > t_0$, where t_0 is the external shock deceleration time (e.g., Sari and Piran 1999). At different times, the total energy into the fireball may be dominated either by the initial impulsive term, or by the continuous injection one, whose contribution will scale as $E_{\rm inj} = \frac{L_0 t_0}{q+1}\left(\frac{t}{t_0}\right)^{q+1}$. The continuous energy injection term can dominate on the impulsive one for $t \gtrsim t_c$ (where $t_c \gtrsim t_0$ so that the self-similar solution has already developed), if $q > -1$ and $E_{\rm inj}(t_c) \sim E_{\rm imp}$. Generally speaking, one can write $t_c = \max\{t_0, t_0[(q+1)E_{\rm imp}/(L_0 t_0)]^{1/(1+q)}\}$ (Zhang and Mészáros 2001). In the particular case in which $L_0 t_0 \sim E_{\rm imp}$ then $t_c \sim t_0$ and the dynamics is dominated by the continuous injection as soon as the self-similar evolution begins. Note that the continuous injection may also have an additional characteristic timescale t_f at which the continuous injection power-law index $q > -1$ switches to $q < -1$. It is only for $t_c < t_f$ that the continuous injection has a noticeable effect on the afterglow light curve (Zhang and Mészáros 2001).

During the energy-injection dominated phase, the peak flux, peak frequency and cooling frequency of the synchrotron photons produced by the forward shock (Sari *et al* 1998) scale with time as $F_m \propto t^{1+q}$, $\nu_m \propto t^{-(2-q)/2}$, $\nu_c \propto t^{-(q+2)/2}$, respectively (Zhang and Mészáros 2001). Thus, in the case of a nearly constant energy supply, i.e. $q \sim 0$, one has $F_m \propto t$, $\nu_m \propto t^{-1}$, $\nu_c \propto t^{-1}$, respectively. These scalings allow one to compute the temporal indices of the afterglow light curve expected during the injection phase. Supposing to be in slow cooling, these are $F_\nu \propto t^{\alpha_1} = t^{(3-p)/2}$ for $\nu_m < \nu < \nu_c$ and $F_\nu \propto t^{\alpha_2} = t^{(2-p)/2}$ for $\nu > \nu_c$, where we have indicated with p the power-law index of the electron energy distribution in the shock front (Sari *et al* 1998). For $2 < p < 4$, one has $0.5 > \alpha_1 > -0.5$ at frequencies $\nu_m < \nu < \nu_c$ and $0 > \alpha_2 > -1$ at $\nu > \nu_c$, to compare with $\alpha \gtrsim -0.5$ observed during GRB afterglow plateaus. In the absence of energy injection, for the standard adiabatic fireball one would have $-3/4 > \alpha_1 > -9/4$ for $\nu_m < \nu < \nu_c$, and $-1 > \alpha_2 > -5/2$ at $\nu > \nu_c$, for the same range of p values. Thus, the presence of a pulsar pumping energy into the fireball at a nearly constant rate is expected to cause a flattening in the typical decay of the afterglow light curve, with $\alpha \gtrsim -0.5$, in agreement with *Swift* observations (see figure 1).

3. GWs by NS formation

In a rotating PNS, non-axisymmetric processes can yield to the emission of GWs with high efficiency (see, e.g., Kokkotas 2008 for a recent review). Among these, dynamical and secular instabilities are particularly promising. A dynamical instability arises from non-axisymmetric perturbations, and can be of two different types: the classical bar-mode instability and the more recently discovered low-$T/|W|$ bar-mode and one-armed spiral instabilities (e.g., Centrella *et al* 2001, Sajio *et al* 2002, Ott *et al* 2005, Baiotti *et al* 2007). In Newtonian stars, the classical $m = 2$ bar-mode instability is excited when the ratio $\beta = T/|W|$ of the rotational kinetic energy T to the gravitational binding energy $|W|$ is larger than $\beta_{\rm dyn} = 0.27$ (Chandrasekhar 1969). The instability grows on a dynamical timescale which is about one rotational period. If the bar persists for $\sim$ 10–100 rotation periods, then even signals from distances considerably larger than the Virgo Cluster are estimated to be detectable.

At lower rotation rates, a star can become unstable to secular non-axisymmetric instabilities, driven by gravitational radiation or viscosity, usually called Chandrasekhar–Friedman–Schutz (CFS, Chandrasekhar 1970, Friedman 1978) instabilities. Neglecting viscosity, the CFS-instability is generic in rotating stars for both polar and axial modes. In the Newtonian limit, the $l = m = 2$ f-mode has the shortest growth time of all polar fluid modes ($\tau_{\rm GW} \sim$ 1s–(7×10^4) s for $0.24 \gtrsim \beta \gtrsim 0.15$, see Lai and Shapiro 1995) and becomes unstable when $\beta > 0.14$. The f-mode instability, also referred to as the secular bar-mode instability, is an excellent source of GWs. In the ellipsoidal approximation, Lai and Shapiro (1995) have shown that the non-axisymmetric pattern evolves radiating GWs sweeping through the advanced LIGO/Virgo sensitivity window (from 1 kHz down to about 100 Hz), which could become detectable out to a distance of more than 100 Mpc. Two recent hydrodynamical simulations (Shibata and Carino 2004, Ou *et al* 2004) have essentially confirmed this picture. Among axial modes, the $l = m = 2$ r-mode is an important member (see, e.g., Andersson 1998, Friedman and Schutz 1998, Lindblom *et al* 1998, Owen *et al* 1998, Lindblom and Owen 2002, Andersson and Kokkotas 2001, Andersson 2003, Bondarescu *et al* 2009). In the r-mode evolution, the bulk of the angular momentum of the star is radiated away by gravitational radiation during the saturation phase of the mode, which lasts for a timescale of the order of 1 year, and most of the contribution to the signal-to-noise ratio (SNR) that an interferometer can collect comes from such a phase (Owen *et al* 1998). Estimates based on matched filtering with an year-long waveform template give a SNR of 8 in the advanced detectors for a source located at a distance of 20 Mpc (Owen *et al* 1998). If the compact object is a strange star, such an instability is predicted to persist for a few hundred years (at a low amplitude) and, integrating data for a few weeks, could yield to an effective amplitude $h_{\mathrm{eff}} \sim 10^{-21}$ for galactic signals, at frequencies ~700–1000 Hz (Kokkotas 2008).

Mechanisms different from rotational instabilities, as the distortion of the star's shape caused by very high internal magnetic fields, can also be invoked as GW sources in newborn magnetars (e.g., Palomba 2000, Cutler 2002, Arons 2003, Stella *et al* 2005, Dall'Osso and Stella 2007, Dall'Osso *et al* 2008) and are typically estimated to be detectable by the advanced interferometers up to the Virgo Cluster (~20 Mpc).

4. GRB plateaus and GWs: multi-messenger signature of a magnetar?

On the long afterglow timescales that characterize the shallow x-ray decays, the energy injection into the fireball by a magnetar eventually surviving after the GRB explosion is expected to be mainly through electromagnetic dipolar emission (Zhang and Mészáros 2001). For what concerns GW losses, in light of what has been discussed in the previous section, the secular bar-mode instability is one of the most interesting processes, given its high efficiency in the production of GWs, and being its characteristic timescale τ_{GW} compatible with that of GRB plateaus.

A collapsing core rotating sufficiently fast can be secularly unstable but dynamically stable only if the rotation rate of the pre-collapse core lies in a narrow range. Since during the collapse β increases proportionally to R^{-1}, it is more likely that the core becomes first dynamically unstable ($\beta > \beta_{\mathrm{dyn}}$), evolving toward a nearly axisymmetric equilibrium state in a short dynamical timescale, with β decreasing below β_{dyn}, but possibly remaining above β_{sec} (see Lai and Shapiro 1995, and references therein). Due to gravitational radiation, the nearly axisymmetric core (secularly unstable Maclaurin spheroid) will evolve into a non-axisymmetric configuration (Riemann-S ellipsoid), on a secular dissipation timescale $\sim \tau_{\mathrm{GW}}$. While an initial dynamical unstable phase would possibly produce a GW burst during the GRB, the secular evolution takes place on longer timescales, thus being relevant for the shallow phase ($100\ \mathrm{s} \lesssim t \lesssim 10^4\ \mathrm{s}$) observed in GRB afterglows (see figure 1).

The NS evolution under the effect of gravitational radiation can in principle be studied using the full dynamical equations of ellipsoidal figures (Chandrasekhar 1969), including gravitational radiation reaction. However, since τ_{GW} is generally much longer than the dynamical time of the star, the evolution is quasi-static and proceeds along an equilibrium sequence of Riemann-S ellipsoids (Lai and Shapiro 1995). The f-mode grows to a large nonlinear amplitude, modifying the star from an axisymmetric shape to a rotating ellipsoid, that becomes a strong emitter of GWs until the star is slowed-down toward a stationary state called Dedekind ellipsoid, i.e. a non-axisymmetric ellipsoid with internal flows but with a stationary (non-radiating) shape in the inertial frame.

In what follows, we make some order-of-magnitude estimates aimed at showing that the possibility of having a GRB afterglow plateau associated with a secularly unstable newborn magnetar deserves to be analyzed in more detail. Consider a Maclaurin spheroid with mass $M = 1.4\ M_\odot$, $\beta = 0.20$ (about in the middle of the range $0.14 < \beta < 0.27$ for the secular instability), and polytropic index $n = 1$. Let us denote with R_0 the radius of the spherical polytrope with the same mass, and set $R_0 = 20$ km as a reasonable value for a newborn NS. The mean radius of the secularly unstable spheroid is then $R \sim \sqrt{1.785} \times 20\ \text{km} = 26.7$ km (see table 2 and equation (3.27) in Lai, Rasio and Shapiro 1993). For a magnetar, a typical polar magnetic field strength is $\sim 10^{14}$ G, so assuming flux conservation we can set $B = (20\ \text{km}/26.7\ \text{km})^2 10^{14}$ G. If the magnetic field does not substantially modify the NS dynamics, such a magnetar evolves following a sequence of Riemann-S ellipsoids, as described in Lai and Shapiro (1995). For $\beta = 0.20$, the total energy emitted during the secular evolution is of the order of $6 \times 10^{-3} \times \text{G M}^2/R_0 \sim 10^{51}$ ergs (see figure 3 in Lai and Shapiro 1995). On a timescale of the order of few $\tau_{\rm GW}$, which we can roughly estimate as $t_{\rm GW} \sim (3\text{–}6) \times \tau_{\rm GW} \sim (1\text{–}2) \times 10^3$ s, where $\tau_{\rm GW} \simeq 2 \times 10^{-5}\ \text{s}\,[M/(1.4\ M_\odot)]^{-3}\,[R_0/(10\ \text{km})]^4\,(\beta - \beta_{\rm sec})^{-5} \sim 335$ s (Lai and Shapiro 1995), the star evolves along the Riemann-S sequence, eventually reaching a final stationary football configuration. Since the circulation is conserved in the evolution (Lai and Shapiro 1995), the rotational frequency of the fluid particles on the star's surface stays nearly constant around its maximum value $\Omega_M \sim 800\pi(R/26.7\ \text{km})^{-3/2}$ Hz (see equation (2.2) in Lai and Shapiro 1995) until the final Dedekind state is reached. In a time $t_{\rm GW}$, assuming the magnetic field is tied to fluid particles on the NS surface (see e.g. Baym *et al* 1969), about $E_{\rm dip} = L_{\rm dip} t_{\rm GW} \sim (3-6) \times 10^{50}$ ergs of the total energy is emitted through dipole losses, with $L_{\rm dip} = \left[\Omega_M^4 B^2 R^6/(6c^3)\right]$ (Shapiro and Teukolsky 1983), remaining nearly constant around a value of $L_{\rm dip} \sim 3 \times 10^{47}$ ergs s^{-1}. As seen in section 4, a constant luminosity supply into the fireball can explain GRB afterglow plateaus. Considering a GRB with impulsive energy $E_{\rm imp} \lesssim 10^{50}$ ergs, which is typical of long low-luminosity GRBs, or else of short GRBs, an afterglow plateau would become visible in its light curve after about $t \sim 300$ s, and would have a duration of $\gtrsim t_{\rm GW}$, in agreement with current observations. Suppose that during the NS evolution toward a stationary football configuration no more than half the energy is emitted through magnetic dipole radiation, the signal emitted in GWs should still be detectable by the advanced interferometers up to distances of the order of $\sim$100 Mpc (see Lai and Shapiro 1995).

BATSE results show that about 3% of short GRBs are expected to be within 100 Mpc (Nakar *et al* 2006), which translates into ∼1–2 short GRBs per year in the Swift (∼10 short GRB per year) plus GBM (GLAST - ∼1/4 of ∼200 GRBs per year) sample. As far as low-luminosity long GRBs, two of them (980425 and 060218) were already observed at distances of ∼40 Mpc and ∼130 Mpc, and their local rate ($\gtrsim 200$ Gpc^{-3} yr^{-1}) is expected to be much higher than that of normal bursts (1 Gpc^{-3} yr^{-1}, e.g. Virgili *et al* 2009). Despite the fact that these considerations are to be intended as order-of-magnitude estimates, however they show that energies and timescales of the process are such that a more detailed exploration of the possible connection between GRB afterglow plateaus and bar-like GW signals would be worthwhile.

It should be noted that in a real situation where magnetic field instabilities and viscosity effects are also present, the relevant timescales may be altered. A secularly evolving bar can last up to a timescale of the order of 10^3 s, as far as viscosity or magnetic field-induced instabilities do not substantially modify the dynamics. Viscosity may play a role on the secular evolution when the PNS has cooled to below ∼1 MeV (e.g. Lai and Shapiro 1995, Lai

2001). The time required for the pulsar to cool below such temperature was estimated as a few hundreds of seconds by Lai (2001). In the case of a GRB explosion, a less rapid cooling is expected due to continuous in-fall and jet emission (a heating source which was absent in e.g. Lai 2001), so that we may assume that the bar survives at least until the end of the electromagnetic plateau (i.e. $t \sim 10^3$ s). Magnetic effects are notoriously difficult to predict (see, e.g., Shibata and Karino 2004) and in general require making heuristic assumptions. Our hypothesis would require making the plausible assumption that magnetic instabilities are less efficient at spinning-down the bar than GW emission and magnetic dipole losses.

Finally, some considerations are required on the fate of the bar after the final stationary football configuration (Dedekind) is approached. In such a configuration, the pattern speed is null while fluid particles on the star's surface are spinning at a frequency still of the order of Ω_M (since the gravitational radiation driven evolution conserves circulation). When the final Dedekind state is reached, we do not know what the fate of the bar is. As Lai and Shapiro (1995) have underlined, while the star approaches a Dedekind ellipsoid the gravitational evolution timescale increases, eventually becoming comparable to the viscous dissipation one. When this happens, the star is expected to be driven along a nearly-Dedekind sequence to become a Maclaurin spheroid, since this is the only final state that does not radiate GWs or dissipate energy viscously. The addition of magnetic dipole losses would speed up such evolution, and further spin-down the final Maclaurin state. We thus expect to have the dipole luminosity $L_{\rm dip}$ also decreasing accordingly. Correspondingly, the energy injected into the fireball will start decreasing (eventually entering in the $q < -1$ phase, see section 2), and the afterglow plateau is expected to end, with the light curve turning back to the temporal decay expected in the absence of continuous energy injection. In view of these considerations, and for the purpose of this paper, we have limited our discussion to show that the properties of the electromagnetic plateau, even assuming that the bar survives only until the Dedekind state is reached, are in agreement with those typically observed in GRBs.

5. Conclusion

We have discussed the scenario of a newly formed magnetar left over after a GRB explosion, undergoing a secular bar-mode instability and pumping energy into the fireball. Following the formulation by Lai and Shapiro (1995), we have shown that for reasonable values of the physical parameters, the typical timescales and luminosities of GRB afterglow plateaus may be reproduced. With respect to previous studies, here we are making the new hypothesis that a magnetar left over after a GRB explosion could be secularly unstable, and thus a GW signal may exist in association with an observed electromagnetic plateau. If the left-over magnetar is secularly stable and spinning down only through dipole emission, an afterglow plateau could still be present (as shown in Zhang and Mészáros 2001). However, the interesting aspect of the scenario we are proposing is that the detection of bar-mode like GWs in coincidence with a GRB x-ray plateau would be a smoking-gun signature of a magnetar pumping energy into the fireball, thus identifying the much-debated plateau mechanism. Given that several alternative scenarios have been invoked to explain the afterglow flattening, which are *not* expected to be associated with GW signals (see, e.g., Panaitescu 2008b), this would represent a significant step forward in our understanding of GRB physics. Moreover, identifying the presence of a magnetar would confirm that not all GRB explosions necessarily lead to the prompt formation of a BH.

In conclusion, although there are considerable uncertainties about the evolutionary path of newborn magnetars, this order-of-magnitude analysis indicates that the scenario proposed here is a plausible and interesting possibility, connecting an efficient GW emission process to a distinctive electromagnetic signature. In view of the impending commissioning of the advanced LIGO and Virgo, we thus consider it worthwhile to further explore this hypothesis theoretically (Corsi and Mészáros 2009) so as to evaluate the level of attention that matched electromagnetic-GW data searches related to this scenario might deserve.

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