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A POSSIBLE CONNECTION BETWEEN FAST RADIO BURSTS AND GAMMA-RAY BURSTS

Bing Zhang
Department of Physics and Astronomy, University of Nevada Las Vegas, NV 89154, USA
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ABSTRACT

The physical nature of fast radio bursts (FRBs), a new type of cosmological transient discovered recently, is not known. It has been suggested that FRBs can be produced when a spinning supra-massive neutron star loses centrifugal support and collapses to a black hole. Here, we suggest that such implosions can happen in supra-massive neutron stars shortly (hundreds to thousands of seconds) after their births, and an observational signature of such implosions may have been observed in the X-ray afterglows of some long and short gamma-ray bursts (GRBs). Within this picture, a small fraction of FRBs would be physically connected to GRBs. We discuss possible multi-wavelength electromagnetic signals and gravitational wave signals that might be associated with FRBs, and propose an observational campaign to unveil the physical nature of FRBs. In particular, we strongly encourage a rapid radio follow-up observation of GRBs starting from 100 s after a GRB trigger.

Key words: gamma-ray burst: general – stars: black holes – stars: neutron

Online-only material: color figure

1. INTRODUCTION

Recently, a new type of cosmological transient, dubbed fast radio bursts (FRBs), was discovered (Lorimer et al. 2007; Thornton et al. 2013). These radio bursts have a typical duration of several milliseconds, high Galactic latitudes, and anomalously high dispersion measure (DM) values corresponding to a cosmological redshift z between 0.5 and 1 (Thornton et al. 2013). The inferred total energy release is 10^{38}–10^{40} erg, and the peak radio luminosity is $\sim 10^{43}$ erg s^{-1}. No detected electromagnetic counterpart was claimed to be associated with FRBs.

The physical nature of FRBs is unknown. Thornton et al. (2013) discussed several possibilities, and suggested that the event rate of FRBs ($R_{\rm FRB} \sim 10^{-3}\,{\rm gal}^{-1}\,{\rm yr}^{-1}$) is much higher than those of gamma-ray bursts (GRBs) and compact-star mergers, but could be consistent with those of soft gamma-ray repeater giant flares or core-collapse supernovae. Since the announcement of the discovery, several proposals have been made to interpret FRBs, including delayed collapses of supra-massive neutron stars to black holes (Falcke & Rezzolla 2013), special magnetar radio flares (Popov & Postnov 2007), mergers of double neutron stars (Totani 2013), mergers of binary white dwarfs (Kashiyama et al. 2013), and flaring stars (Loeb et al. 2013).

2. FRBs AS IMPLOSIONS OF NEW-BORN SUPRA-MASSIVE NEUTRON STARS

The millisecond duration τ points toward a small emission size for FRBs: $r_{\rm FRB} \sim c\tau \sim 3\times 10^7\,{\rm cm}\,(\tau/{\rm ms})$. The source of emission has to be limited to very compact objects involving neutron stars or black holes (white dwarfs may be marginally accommodated; Kashiyama et al. 2013). At such a small size, the brightness temperature of radio emission is extremely high, so the radiation mechanism must be coherent (Katz 2013).

Falcke & Rezzolla (2013) made a good case that a supra-massive neutron star collapsing into a black hole would be a likely source of FRBs. A supra-massive neutron star is initially sustained centrifugally by rapid rotation. As it gradually spins down, it would collapse into a black hole when centrifugal support no longer holds gravity. When the magnetic field "hair" is ejected as the event horizon swallows the neutron star, a strong electromagnetic signal in the radio band (which they call a "blitzar") is released. This is an FRB.

Falcke & Rezzolla (2013) suggested that such a delayed collapse would happen several thousand to a million years after the birth of the supra-massive neutron star. Here, we propose that a small fraction of such implosions could also happen shortly (hundreds to thousands of seconds) after the birth of the neutron star, and a signature of such implosions may have been observed in the early X-ray afterglow light curves of some GRBs.

GRBs may originate from two types of progenitors: collapse of a massive star (e.g., Woosley 1993) and coelescence of two neutron stars (NS–NS merger) or one neutron star and one black hole (NS–BH merger) (e.g., Paczýnski 1986; Eichler et al. 1989). A large angular momentum and a strong magnetic field are essential to launch a jet (e.g., Rezzolla et al. 2011; Etienne et al. 2012). There are two types of plausible central engines: one is a promptly formed black hole (e.g., Popham et al. 1999), which accretes materials from the remnant with an extremely high accretion rate ($\sim(0.1$–$1)\,M_\odot\,{\rm s}^{-1}$); the other is a strongly magnetized (with surface magnetic field $\sim 10^{15}$ G) neutron star that is spinning near the break-up limit (millisecond rotation period) (e.g., Usov 1992). Our FRB model invokes the latter central engine.

Even without direct evidence, a magnetar central engine is inferred indirectly for some GRBs. A shallow decay phase (or "plateau," Figure 1 lower panel) in the early X-ray afterglow of most long GRBs may require continuous energy injection into the blast wave (Zhang et al. 2006), which would be consistent with a spinning-down neutron star engine (Dai & Lu 1998; Zhang & Mészáros 2001). An alternative explanation does not invoke a long-lasting central engine, but invokes a stratification of the ejecta Lorentz factor (Rees & Mészáros 1998). The degeneracy between the two models was broken when the so-called "internal plateaus" were discovered in the early X-ray afterglow light curves of some GRBs (Figure 1 upper panel) (Troja et al. 2007; Liang et al. 2007). These are X-ray plateaus followed by an extremely steep decay, with a decay index steeper

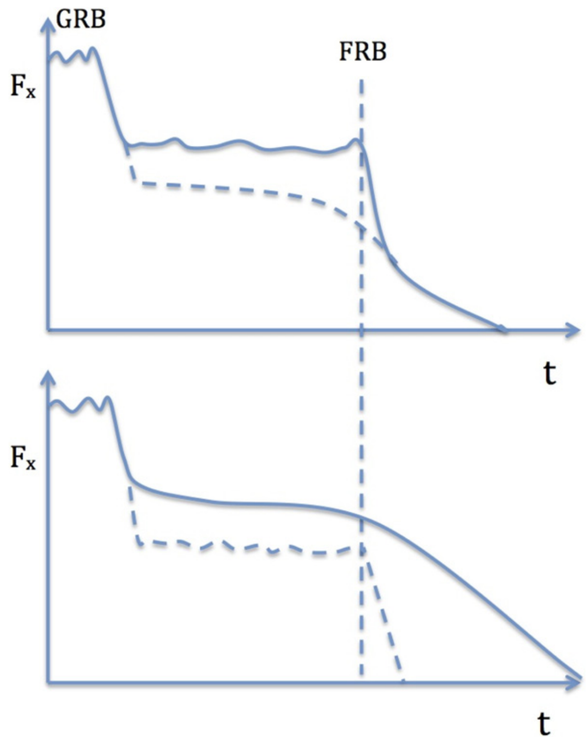

Figure 1. Schematic picture of the FRB/GRB connection. Two indicative X-ray afterglow light curves are presented. The upper panel shows an "internal plateau" with a nearly steady plateau emission followed by a very steep decay. The end of the plateau (or shortly after) may signal the collapse of the supra-massive magnetar into a black hole (dashed vertical line). We suggest this epoch as the emission epoch of an FRB. The external shock emission of these light curves (dashed curve) is buried below the internal plateau. The lower panel shows a "normal" plateau, which is dominated by the external shock emission. The end of the plateau may also coincide with the end of the magnetar energy injection, a fraction of which could be also due to magnetar implosion. The internal dissipation emission of these cases (dashed curve) is outshone by the external shock emission. The break time (or shortly after) of some of these normal plateaus could also coincide with an FRB.

(A color version of this figure is available in the online journal.)

than −3, sometimes reaching −9. By contrast, most "normal" plateaus are followed by a decay with a decay index around −1, which is consistent with the external shock model of GRBs (e.g., Gao et al. 2013b, for a recent review of the external shock model of GRBs). The steepest decay allowed in the external shock model is defined by high-latitude emission of a relativistic ejecta (e.g., when the blast wave enters a density void), which has a decay slope $\alpha = -2 + \beta$ (convention $F_\nu \propto t^\alpha \nu^\beta$), which usually cannot be smaller than −3 (Kumar & Panaitescu 2000). The very steep decay following those internal plateaus therefore demands an internal dissipation mechanism (rather than the external shock emission) to account for the data (and hence, the plateaus gain their name). This demands that the central engine lasts much longer than the burst duration. The essentially constant X-ray luminosity during the plateau requires a steady central engine output, and a spinning-down magnetar naturally accounts for the data. Later, a systematic analysis revealed more internal plateaus (Lyons et al. 2010). Surprisingly, such a signature was also found in a good fraction of short GRBs (Rowlinson et al. 2010, 2013).

If one accepts that a millisecond magnetar is indeed operating in both long (Usov 1992; Bucciantini et al. 2009; Metzger et al. 2011) and short (Dai et al. 2006; Fan & Xu 2006; Metzger et al. 2008; Kiuchi et al. 2012) GRBs,[1] then the very steep decay at the end of internal plateaus suggests that the emission stops abruptly. It is difficult to turn off a rapidly spinning-down magnetar unless it collapses into a black hole. Simulations show that a rapidly spinning neutron star can have a threshold mass (for collapsing into a black hole) that is larger by 30%–70% (depending on the equation of state) than the maximum mass of a non-rotating neutron star (Bauswein et al. 2013). As a result, in a large parameter space, it is possible that a proto-millisecond magnetar born with a baryon mass somewhat larger than the maximum mass of a non-rotating neutron star may undergo rapid spindown within 10^3–10^4 s, and collapse into a black hole when it loses centrifugal support. The collapsing time may be near the dipole spindown timescale $\tau \sim 2 \times 10^3\,\mathrm{s}\, I_{45} B_{p,15}^{-2} P_{0,-3}^{2} R_6^{-6}$, where I, B_p, P_0, and R are the moment of inertia, surface magnetic field at the pole, initial spin period at birth, and radius of the neutron star, respectively, and the convention $Q_x = Q/10^x$ has been adopted in cgs units. This can happen both in massive-star core collapses (Troja et al. 2007) and NS–NS mergers (Zhang 2013; Gao et al. 2013a; Yu et al. 2013).

As a supra-massive neutron star collapses into a black hole, magnetic "hair" has to be ejected based on the no-hair theorem of black holes. The strong magnetic fields in the magnetar magnetosphere would reconnect and get detached from the event horizon and expelled in a catastrophic manner. The total energy in the magnetic field can be estimated as ($R_{\rm LC} \gg R$ is the light cylinder radius)

$$E_{\rm B} \simeq \int_R^{R_{\rm LC}} \left(B_p^2/8\pi\right)^2 (r/R)^{-6} 4\pi r^2 dr \simeq (1/6) B_p^2 R^3 = 1.7 \times 10^{47}\,\mathrm{erg}\, B_{p,15}^2 R_6^3. \quad (1)$$

This is much larger than the observed energy of FRBs. Only a small amount of this energy is adequate to power an FRB.

The conversion of a small fraction of this energy to radio emission energy invokes poorly known coherent radio emission mechanisms, such as coherent curvature radiation through "bunches" (Ruderman & Sutherland 1975; Falcke & Rezzolla 2013) or "maser"-like amplifications of plasma modes (e.g., Melrose et al. 2009). Here we assume that a certain coherent mechanism can operate during the hair-ejection process, and the observed $\nu_{\rm obs} = (1.2$–$1.5)$ GHz radio wave can escape the emission region.[2] It can reach the observer if it is not absorbed by the GRB blast wave in front of the FRB emission region. The comoving electron number density in the shocked ejecta region of the blast wave is $n' \simeq 1.8 \times 10^5\,\mathrm{cm}^{-3}\, L_{52} \Gamma_2^{-2} r_{17}^{-2}$ (L is the wind luminosity of the GRB, Γ the bulk Lorentz factor, and r the blast wave radius), which gives a comoving plasma frequency $\nu_p' = (n' e^2/\pi m_e)^{1/2} \simeq 3.8 \times 10^6\,\mathrm{Hz}\, L_{52}^{1/2} \Gamma_2^{-1} r_{17}^{-1}$, much smaller than the radio wave frequency in the comoving frame $\nu_{\rm obs}/\Gamma = (1.2$–$1.5) \times 10^7$ Hz. The density in the shocked circumburst medium region is even lower. So, the FRB emission can pass through the blast wave region and reach Earth. Overall,

1 Within the magnetar central engine model, a short GRB may be produced through a brief accretion phase (Metzger et al. 2008), a brief differentially rotating phase (Fan et al. 2013), or a rapid phase transition phase (e.g., Dai & Lu 1998).

2 We note that the condition that the observed frequency is above the plasma frequency defined by the Goldreich & Julian (1969) density is not required, since a force-free pulsar magnetosphere is charge-separated. In fact, the 400 MHz "core" radio emission from the pulsar polar cap region (Rankin 1983) is below the plasma frequency defined by the Goldreich–Julian density, but is observed.

the magnetic bubble associated with this FRB ejection, with total energy described by Equation (1), would accelerate and convert the energy to kinetic form. This energy is, however, small compared with the GRB energy, so it would not leave a noticeable imprint in the GRB afterglow light curve.

Since a sharp drop at the end of an "internal X-ray plateau" marks a sudden cessation of the central engine, we suggest that the break time (or shortly after) is the epoch when an FRB is emitted (Figure 1).

3. FRBs WITH AND WITHOUT GRBs

The observed FRB event rate ($R_{\rm FRB} \sim 10^{-3}\,{\rm gal}^{-1}\,{\rm yr}^{-1}$) is almost 3 orders of magnitude higher than that of long GRBs, which is $R_{\rm GRB} \sim$ several $10^{-6}\,{\rm gal}^{-1}\,{\rm yr}^{-1}$ at cosmological distances. So the scenario discussed above cannot account for all FRBs. *Only a small fraction of FRBs could be associated with GRBs.* Also, since not all GRBs would have a supra-massive millisecond magnetar as the central engine, *not all GRBs would be associated with FRBs*.

What is the nature of the majority of FRBs? We first consider the possibility that they are similar to GRB-associated FRBs but viewed at an off-jet angle. Even though these events may marginally account for the event rate (Frail et al. 2001), the FRBs (even if generated) are most likely not detectable. For massive-star (long) GRBs, it is believed that a more isotropic supernova should accompany the GRB, which would screen any radio signal from the central engine. Compact-star (short) GRBs may be more transparent. An internal X-ray plateau due to magnetar wind dissipation would have a near isotropic emission pattern, which could be observed without a short GRB association (Zhang 2013). However, any FRB emission would still be absorbed by the ejecta launched during the merger process, which has a mass of at least $10^{-4}\,M_\odot$ (e.g., Freiburghaus et al. 1999; Rezzolla et al. 2010; Hotokezaka et al. 2013). At about 1000 s (typical time at the end of internal plateaus; Rowlinson et al. 2010, 2013), this ejecta has traveled a distance $r \sim 0.2c \times 1000\,{\rm s}\,t_3 = 6 \times 10^{12} t_3$ cm. With a width $\Delta \sim 10^7$ cm, the mass density of the ejecta is $\rho = M/(4\pi r^2 \Delta) \sim 4.4 \times 10^{-4}\,{\rm g\,cm^{-3}} M_{-3} t_3^{-2} \Delta_7^{-1}$. Assuming an average atomic number Z for the ejecta, the electron number density is $n_e \sim 2.6 \times 10^{20} \chi Z^{-1} M_{-3} t_3^{-2} \Delta_7^{-1}\,{\rm cm^{-3}}$, where χ is the ionization fraction. The plasma frequency is $\nu_p \sim 1.5 \times 10^{14}\,{\rm Hz}\,\chi^{1/2} Z^{-1/2} M_{-3}^{1/2} t_3^{-1} \Delta_7^{-1/2}$, which is $\gg \nu_{\rm obs}$ for a reasonable ionization fraction χ. So the FRB emission would be blocked by the ejecta. Such an off-axis FRB may be still observable if the ejecta has a "filling" factor less than unity, so that the FRB emission can be visible at certain solid angles. Nonetheless, this off-axis model can at most account for a small fraction of FRBs not associated with GRBs.

This leaves the conclusion that most FRBs are implosions with a much longer delay (thousands to million of years; Falcke & Rezzolla, 2013). The environment is clean. The FRBs, once generated, can escape the source and reach Earth. However, since the magnetic field strength is typically several 10^{12} G, the total energy of the explosion is smaller by 5–6 orders of magnitude than Equation (1). This energy would be converted to kinetic energy of an outflow and then drive an "afterglow" of the FRB. Due to low baryon contamination, this outflow can reach a high Lorentz factor. However, due to its low energetics, the afterglow would be too faint to be detectable. According to the synchrotron external shock model of GRBs (e.g., Mészáros & Rees 1997; Sari et al. 1998; Gao et al. 2013b), the peak spectral density of the afterglow is directly proportional to the energy of the fireball, which can be scaled as $F_{\nu,\max} = 1.1 \times 10^{-6}\ \mu{\rm Jy}\, E_{42} n^{1/2} \epsilon_{B,-2}^{1/2} D_{28}^{-2} [(1+z)/2]$. The deceleration time is short, $t_{\rm dec} = (3E/16\pi n m_p \Gamma_0^8 c^5)^{1/3} \simeq 0.1\,{\rm s}\, E_{42}^{1/3} \Gamma_{0,2}^{-8/3} [(1+z)/2]$. The characteristic synchrotron frequency is $\nu_m = 4.3 \times 10^{11}\,{\rm Hz}\, E_{42}^{1/2} \epsilon_{e,-1}^2 \epsilon_{B,-2}^{1/2} t_1^{-3/2} [(z+1)/2]^{1/2}$. Here, E is the total energy in the blast wave, n is the ambient proton number density, ϵ_e and ϵ_B are fractions of the shocked energy that are distributed to electrons and magnetic fields, respectively, Γ_0 is the initial Lorentz factor, t is the observer time, and D is the luminosity distance. Even for a magnetar with a total energy budget $E \sim 2 \times 10^{47}$ erg (Equation (1)), the peak flux density can only reach $F_{\nu,\max} \sim \mu$Jy at $z = 0.5$. The deceleration time is $t_{\rm dec} \sim 3$ s, and the 1.3 GHz light curve reaches the peak (μJy) at around 340 s after the FRB.

Since the X-ray internal plateau was detected in a good fraction of short GRBs, and since the NS–NS merger has been regarded as a top candidate to power short GRBs, our picture suggests that some FRBs are also associated with gravitational wave bursts (GWBs) due to NS–NS mergers. Our picture is different from Totani (2013), who suggested that all FRBs are associated with NS–NS mergers. In his picture, an FRB is generated due to the interaction of the magnetospheres of the two neutron stars, while in our picture, it happens hundreds to thousands ofseconds after the merger. As a result, the FRB signal in our picture would be blocked by the ejecta launched during the merger in a large solid angle, so that the rate of FRB/GWB associations in our picture is much less than that of Totani (2013).

4. MULTI-WAVELENGTH/MULTI-MESSENGER OBSERVATIONAL CAMPAIGN TO UNVEIL THE NATURE OF FRBs

Within the framework delineated in this paper, one would consider the following strategies to unveil the nature of FRBs.

1. Since some GRBs may have generated an FRB 10^2–10^4 s after the GRB trigger, a prompt radio follow-up of GRBs would be essential to verify or rule out our proposal. The fraction of long GRBs that show an internal plateau is low, i.e., ∼3% (H.-J. Lü & B. Zhang 2013, in preparation), so the chance of catching an internal plateau would be low. However, an internal plateau is observable only if the external shock emission is relatively weak (Figure 1). Many "normal" plateaus could be also related to magnetars, since their decay slopes and spectral indices are consistent with being due to energy injection of a millisecond magnetar (H.-J. Lü & B. Zhang 2013, in preparation). The end of the plateau could be interpreted as the spindown timescale of a magnetar, some of which may be related to implosion. These normal plateaus would outshine the internal plateaus if the afterglow level is high. One would then expect that a fraction of normal plateaus would also be accompanied by FRBs at the end of the plateaus (or shortly after). The fraction of these magnetar-candidate normal plateaus can be up to ∼60% of the long GRB population (H.-J. Lü & B. Zhang 2013, in preparation). For short GRBs, it seems that the chance of catching an internal plateau is much higher (Rowlinson et al. 2013), although the end of the plateau is earlier (hundreds of seconds). In the past, radio follow-up observations of GRBs have been carried out much later, partially because of the technical challenge for rapid slewing but also partially because of the lack

of theoretical motivation (the predicted radio afterglow peaks days to weeks after a GRB trigger). The possible FRB/GRB connection proposed here hopefully would give more impetus for prompt radio follow-up of GRBs.

2. Most FRBs are not supposed to be associated with GRBs. Many of these will be discovered with future wide-field array searches (e.g., Trott et al. 2013). Broadband follow-up observations of these FRBs are encouraged. Possible detections may be made if a small fraction of these FRBs are associated with off-axis GRBs, which may be possible for NS–NS mergers leaving behind broadband (afterglow and merger-nova) signals powered by a pre-collapsing magnetar (Zhang 2013; Gao et al. 2013a; Yu et al. 2013). For most FRBs, the afterglow would be too weak to detect, unless they are very nearby (peak flux μJy at $z = 0.5$ for a magnetar).
3. Nearby short GRBs with FRBs would be accompanied by GWBs, both before the short GRB (in-spiral signal), between the short GRB and the FRB (e.g., secular bar-mode instability of the supra-massive neutron star), and shortly after the FRB (ring-down). Advanced LIGO/Virgo may be able to detect these signals if the source is close enough. Some FRBs may be also associated with GWBs without a short GRB association, if the ejecta filling factor of NS–NS mergers is not too large.

5. SUMMARY

Along the line of Falcke & Rezzolla (2013), who proposed that FRBs can be produced when a supra-massive neutron star loses centrifugal support and collapses into a black hole, here we suggest that a small fraction of such implosions can happen shortly (10^2–10^4 s) after the formation of a supra-massive neutron star, which could produce an FRB around an X-ray break time following some GRBs, both long and short (Figure 1). Not all GRBs could make FRBs, but a good fraction could. We therefore suggest a prompt radio follow-up observation for GRBs, and suggest that observations as early as 100 s after GRB triggers would be useful. If observations cover the period when the X-ray plateau (both "internal" and "normal"; Figure 1) is observed, a detection or non-detection of an FRB at the end of the plateau (or shortly after) would greatly constrain the nature of FRBs. Most FRBs are not supposed to be associated with GRBs. In any case, some faint signals are predicted, and multi-wavelength follow-up observations of FRBs may lead to detection of these signals under optimistic circumstances.

After posting the first version of this paper to arXiv, I was informed (A. van der Horst 2013, private communication) that the suggested FRB/GRB association may have been detected. In a conservative paper where the authors reported an upper limit of early radio afterglow flux, Bannister et al. (2012) reported two FRB-like events following two long GRBs, at an epoch close to what is predicted in this paper. Further dedicated observations are needed to unveil the rich GRB/FRB association phenomenology.

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REFERENCES

Bannister, K. W., Murphy, T., Gaensler, B. M., & Reynolds, J. E. 2012, ApJ, 757, 38
Bauswein, A., Baumgarte, T. W., & Janka, H.-T. 2013, PhRvL, 111, 131101
Bucciantini, N., Quataert, E., Metzger, B. D., et al. 2009, MNRAS, 396, 2038
Dai, Z. G., & Lu, T. 1998, PhRvL, 81, 4301
Dai, Z. G., Wang, X. Y., Wu, X. F., & Zhang, B. 2006, Sci, 311, 1127
Eichler, D., Livio, M., Piran, T., & Schramm, D. N. 1989, Natur, 340, 126
Etienne, Z. B., Paschalidis, V., & Shapiro, S. L. 2012, PhRvD, 86, 084026
Falcke, H., & Rezzolla, L. 2013, A&A, submitted (arXiv:1307.1409)
Fan, Y.-Z., & Xu, D. 2006, MNRAS, 372, L19
Fan, Y.-Z., Yu, Y.-W., Xu, D., et al. 2013, ApJL, 779, L25
Frail, D. A., Kulkarni, S. R., Sari, R., et al. 2001, ApJL, 562, L55
Freiburghaus, C., Rosswog, S., & Thielemann, F.-K. 1999, ApJL, 525, L121
Gao, H., Ding, X., Wu, X.-F., Zhang, B., & Dai, Z.-G. 2013a, ApJ, 771, 86
Gao, H., Lei, W.-H., Zou, Y.-C., Wu, X.-F., & Zhang, B. 2013b, NewAR, 57, 141
Goldreich, P., & Julian, W. H. 1969, ApJ, 157, 869
Hotokezaka, K., Kiuchi, K., Kyutoku, K., et al. 2013, PhRvD, 87, 024001
Kashiyama, K., Ioka, K., & Mészáros, P. 2013, ApJL, 776, L39
Katz, J. I. 2013, arXiv:1309.3538
Kiuchi, K., Kyutoku, K., & Shibata, M. 2012, PhRvD, 86, 064008
Kumar, P., & Panaitescu, A. 2000, ApJL, 541, L51
Liang, E.-W., Zhang, B.-B., & Zhang, B. 2007, ApJ, 670, 565
Loeb, A., Shvartzvald, Y., & Maoz, D. 2013, arXiv:1310.2419
Lorimer, D. R., Bailes, M., McLaughlin, M. A., Narkevic, D. J., & Crawford, F. 2007, Sci, 318, 777
Lyons, N., O'Brien, P. T., Zhang, B., et al. 2010, MNRAS, 402, 705
Melrose, D. B., Rafat, M. Z., & Luo, Q. 2009, ApJ, 698, 115
Mészáros, P., & Rees, M. J. 1997, ApJ, 476, 232
Metzger, B. D., Giannios, D., Thompson, T. A., Bucciantini, N., & Quataert, E. 2011, MNRAS, 413, 2031
Metzger, B. D., Quataert, E., & Thompson, T. A. 2008, MNRAS, 385, 1455
Paczýnski, B. 1986, ApJL, 308, L43
Popham, R., Woosley, S. E., & Fryer, C. 1999, ApJ, 518, 356
Popov, S. B., & Postnov, K. A. 2007, arXiv:0710.2006
Rankin, J. M. 1983, ApJ, 274, 333
Rees, M. J., & Mészáros, P. 1998, ApJL, 496, L1
Rezzolla, L., Baiotti, L., Giacomazzo, B., Link, D., & Font, J. A. 2010, CQGra, 27, 114105
Rezzolla, L., Giacomazzo, B., Baiotti, L., et al. 2011, ApJL, 732, L6
Rowlinson, A., O'Brien, P. T., Metzger, B. D., Tanvir, N. R., & Levan, A. J. 2013, MNRAS, 430, 1061
Rowlinson, A., O'Brien, P. T., Tanvir, N. R., et al. 2010, MNRAS, 409, 531
Ruderman, M. A., & Sutherland, P. G. 1975, ApJ, 196, 51
Sari, R., Piran, T., & Narayan, R. 1998, ApJL, 497, L17
Thornton, D., Stappers, B., Bailes, M., et al. 2013, Sci, 341, 53
Totani, T. 2013, PASJ, 65, L12
Troja, E., Cusumano, G., O'Brien, P. T., et al. 2007, ApJ, 665, 599
Trott, C., Tingay, S. J., & Wayth, R. B. 2013, ApJ, 776, L16
Usov, V. V. 1992, Natur, 357, 472
Woosley, S. E. 1993, ApJ, 405, 273
Yu, Y.-W., Zhang, B., & Gao, H. 2013, ApJL, 776, L40
Zhang, B. 2013, ApJL, 763, L22
Zhang, B., Fan, Y. Z., Dyks, J., et al. 2006, ApJ, 642, 354
Zhang, B., & Mészáros, P. 2001, ApJL, 552, L35