Continued Brightening of the Afterglow of GW170817/GRB 170817A as Being Due to a Delayed Energy Injection

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Abstract

The brightness of the multi-wavelength afterglow of GRB 170817A is increasing unexpectedly even \(\sim\)160 days after the associated gravitational burst. Here we suggest that the brightening can be caused by a late-time energy injection process. We use an empirical expression to mimic the evolution of the injection luminosity, which consists of a power-law rising phase and a power-law decreasing phase. It is found that the power-law indices of the two phases are 0.92 and \(\sim\)2.8, respectively, with the peak time of the injection being \(\sim\)110 days. The energy injection could be due to some kind of accretion, with the total accreted mass being \(\sim\)0.006 \(M_\odot\). However, normal fall-back accretion, which usually lasts for a much shorter period, cannot provide a natural explanation. Our best-fit decay index of \(\sim\)2.8 is also at odds with the expected value of \(-5/3\) for normal fall-back accretion. Noting that the expansion velocities of the kilonova components associated with GW170817 are 0.1–0.3 \(c\), we argue that there should also be some ejecta with correspondingly lower velocities during the coalescence of the double neutron star (NS) system. They are bound by the gravitational well of the remnant central compact object and might be accreted at a timescale of about 100 days, providing a reasonable explanation for the energy injection. Detailed studies on the long-lasting brightening of GRB 170817A thus may provide useful information on matter ejection during the merger process of binary neutron stars.

Key words: accretion, accretion disks – gamma-ray burst: individual (GRB 170817A) – methods: numerical – stars: neutron

1. Introduction

The first binary neutron star (NS) merger event was witnessed when the gravitational wave (GW) event GW170817 was detected by the advanced Laser Interferometer Gravitational-Wave Observatory (LIGO) and the Virgo Interferometer on 2017 August 17 (Abbott et al. 2017a). About 1.7 s later, a faint short gamma-ray burst (GRB) GRB 170817A was detected by Fermi Gamma-Ray Telescope and International Gamma-Ray Astrophysics Laboratory (INTEGRAL), which is considered to be associated with GW170817 (Abbott et al. 2017b; Goldstein et al. 2017; Savchenko et al. 2017). About \(\sim\)11 hr after the event, an optical counterpart was identified (a kilonova) and named AT2017gfo (Arcavi et al. 2017; Coulter et al. 2017; Drout et al. 2017; Kasen et al. 2017; Kasliwal et al. 2017; Pian et al. 2017; Smartt et al. 2017; Soares-Santos et al. 2017; Valenti et al. 2017), which verifies the hypothesis that \(r\)-process-induced kilonovae are associated with binary NS mergers (Li & Paczynski 1998; Rosswog 2005; Metzger et al. 2010; Metzger 2017), and confirms that at least some short GRBs originate from binary NS mergers (e.g., Eichler et al. 1989; Mészáros & Rees 1992; Narayan et al. 1992; Oechslin & Janka 2006; Nakar & Piran 2011, and see Berger 2014 for a recent review).

The isotropic energy of GRB 170817A is \(E_{\text{iso}} = (3.1 \pm 0.7) \times 10^{56}\) erg, and the isotropic peak luminosity is \(L_{\text{iso}} = (1.6 \pm 0.6) \times 10^{47}\) erg s\(^{-1}\). These numbers are several orders of magnitude lower than those of typical short GRBs (Abbott et al. 2017c; Goldstein et al. 2017; Zou et al. 2018). It implies GRB 170817A may originate from an off-axis relativistic jet (Xiao et al. 2017; Kathirgamaraju et al. 2018; Meng et al. 2018) or a cocoon expanding at a mildly relativistic speed (Abbott et al. 2017c; Gottlieb et al. 2017; Lazzati et al. 2017b; Murgia-Berthier et al. 2017; Piro & Kollmeier 2018). In the standard GRB fireball model, a highly collimated relativistic outflow interacts with the surrounding medium to produce broadband afterglow emission, which may be as luminous as \(L_{\text{X,iso}} > 10^{44}\) erg s\(^{-1}\) in X-rays at early stages for an on-axis observer (Racusin et al. 2011; Fong et al. 2015). However, for GRB 170817A, the luminosity of the early X-ray afterglow is quite faint, and is far less than \(10^{40}\) erg s\(^{-1}\) (Evans et al. 2017). Continued monitoring reveals that the X-ray afterglow began to rise to an observable level \(\sim\)10 days post-merger (Troja et al. 2017), and then the radio afterglow also became observable a week later (Hallinan et al. 2017). These observational features are highly consistent with a short GRB seen off-axis.

Recent observations with Chandra revealed that the X-ray afterglow continued to increase unexpectedly until \(\sim\)110 days post merger (Margutti et al. 2017; Troja et al. 2017; Ruan et al. 2018). Ruan et al. (2018) further found that the radio emission brightened at approximately the same rate as that of the X-ray emission, which indicates that they share a common origin (see also Mooley et al. 2018). Later, Lyman et al. (2018) reported that the late-time optical afterglow of GRB 170817A was continuously brightening until 110 days after the merger. D’Avanzo et al. (2018) claimed that the X-ray and optical emission started to decrease \(\sim\)135 days post-merger according to their observations with XMM-Newton and Hubble Space Telescope (HST). However the X-ray brightness seems to be still rising even \(\sim\)153–164 days later, as hinted by the latest data from Chandra (Troja & Piro 2018), which was marginally consistent with the tendency of the radio data (Resmi et al. 2018). Most recently, Dobie et al. (2018) reported that the radio
The observed long-term brightening of the multiband afterglow disfavors the simple off-axis top-hat jet model (Lazzati et al. 2017c; Lyman et al. 2018; Margutti et al. 2018). It has been proposed that the structured jet model or the cocoon model could match the late-time behavior of GRB 170817A (Gottlieb et al. 2017; Granot et al. 2017; Lamb & Kobayashi 2017; Lazzati et al. 2017c; Wang & Huang 2017; Lyman et al. 2018; Mooley et al. 2018; Troja et al. 2018). A structured outflow with a highly relativistic inner core launched by the merger remnant may interpret the rising afterglow emission (Granot & Kumar 2003; Kumar & Granot 2003; Perna et al. 2003; Lazzati et al. 2004; Starling et al. 2005; Rezzolla et al. 2011). Alternatively, the brightening afterglow could arise from a wide-angle cocoon that breaks out at a mildly relativistic speed. Cocoons are widely believed to be involved in the collapsar model for long GRBs (Mészáros & Rees 2001; Ramirez-Ruiz et al. 2002; Lazzati & Begelman 2005; Pe’er et al. 2006). During the NS–NS merger process, a jet-cocoon structure could also be produced (Hotokezaka et al. 2013a; Rosswog 2013; Murguia-Berthier et al. 2014; Nagakura et al. 2014). In this case, the late afterglow emission is generated from the interaction between the cocoon and the interstellar medium (Nakar & Sari 2010; Duffell et al. 2015; Rezzolla & Kumar 2015; Lazzati et al. 2017a; Nakar & Piran 2017; Gottlieb et al. 2018). Additionally, a jet-less isotropic fireball expanding ahead of the kilonova ejecta may also be the cause of the observed brightening of GRB 170817A before ~100 days (Salafia et al. 2017; Salafia et al. 2018).

Except for the models mentioned above, it is also possible that the brightening features are caused by a continuous energy injection from the central engine. Energy injections can be due to various activities of the remnant central compact object after the merger. For example, the spinning down of a millisecond NS can supply enough energy for the external shock (Geng et al. 2018). The accretion of circumburst matter is another possibility (Murase et al. 2018). In fact, accretion of the fallback material is a very common process in many circumstances (e.g., Kumar et al. 2008b; Cannizzo et al. 2011). In a few previous studies on other GRBs, fall-back accretion by black holes (BHs) has been extensively discussed (Perna et al. 2006; Rosswog 2007; Kumar et al. 2008b; Zhang et al. 2008; Lee et al. 2009; Rossi & Begelman 2009). It can interpret some non-standard afterglow signatures, such as the X-ray plateaus and the optical bumps/rebrightnessings (e.g., Fan & Wei 2005; Wu et al. 2013; Geng et al. 2013; Laskar et al. 2015; Yu et al. 2015; Geng & Huang 2016). For GRB 170817A, if the central engine was restarted and capable of releasing energy over a long time, then the long-last brightening of the afterglow could be explained.

Inspired by these works, we investigate the possibility that the continued brightening of the afterglow of GRB 170817A is due to some kind of energy injection from the central engine. We assume that the energy injection consists of a rising phase and a decreasing phase. The injection luminosity in each phase is taken as a power-law function of time. We compare our modeling results with the observations to derive the required characteristic injection luminosity and the power-law indices, and then discuss possible theoretical implications of the results. This Letter is organized as follows. In Section 2, the energy injection process is briefly introduced. Numerical results on the multiband afterglow light curves are presented and compared with the observational data in Section 3. Finally, we discuss and summarize our results in Section 4.

2. Model

Energy injections can be induced by various mechanisms, such as the spinning down of rapidly rotating NSs or some kinds of accretion. In different situations, the injection luminosity should also differ markedly. Among these processes, of special interest is the fall-back accretion of materials around newly born compact stars. For example, in the collapsar model for long GRBs, numerical simulations show that a significant portion of the ejected material of the extended stellar envelope will fail to escape. They will continuously fall back toward the central remnant, resulting in a long-lasting reactivation of the central engine (Kumar et al. 2008a). Similarly, fall-back processes has also been revealed by various simulations of double NS mergers (Rosswog 2007; Hotokezaka et al. 2013a). Considering these effects, we will use an empirical expression to approximate the varying luminosity of the energy injection in our study. We will then investigate the dynamics of the external shock under such an pointing-flux dominated injection, which should naturally deviate from that in the standard fireball model (Panaitescu et al. 1998).

2.1. Two Phases of the Energy Injection

After the merger of a binary NS system, the central remnant could be either a magnetized NS or a promptly formed BH, depending on the masses of the two NSs and the equation of state of supranuclear matter (Hotokezaka et al. 2013b; Piro et al. 2017). The remnant of GW170817 is still under debate (Shibata et al. 2017). Pooley et al. (2017) argued that the early X-ray data of GW170817 are better explained by a BH, rather than a hyper-massive NS. By considering the upper limits on the electromagnetic energy release and the ejecta mass during the binary NS merger of GW170817, Margalit & Metzger (2017) examined various equations of state for NSs, and derived the maximum mass limit of an NS as 2.17 $M_\odot$. A BH as the remnant of the merger is thus strongly indicated because the total mass of the two NSs as estimated from GW observations is significantly larger than the mass limit. Finally, the 1.7 s delay between the GRB and the GW signal may also support a BH born at the center. Here, for simplicity, we assume that a BH is formed at the center after GW170817. So, we do not consider the dipolar radiation from a rapidly rotating NS as the source for energy injection. Instead, we consider the energy extraction from the BH via some accretion process.

For a rotating BH with an accretion disk, the rotation energy could be extracted through the Blandford–Znajek mechanism (Blandford & Znajek 1977; Ghosh & Abramowicz 1997; Livio et al. 1999; Lee et al. 2000a, 2000b; Zhang & Mészáros 2002), which results in a Poynting-flux dominated outflow. The detailed luminosity profile for the Poynting-flux depends upon the exact accretion process. For a fall-back-like accretion, the accretion rate may initially increase with time (MacFadyen et al. 2001). After reaching a peak value, the accretion rate decreases with time as $\dot{M} \propto t^{-5/3}$ (Rees 1988; Chevalier 1989; MacFadyen et al. 2001; Rosswog 2007). In the case of GW170817, the accretion is surely not a constant process. The injection power should depend upon many parameters such as the mass ($M_{BH}$) and spin ($\dot{a}$) of the BH, the density and velocity...
distribution of the circumburst medium, and even the surrounding magnetic field (Zhang et al. 2008; Dai & Liu 2012; Wu et al. 2013; Yu et al. 2015; Chen et al. 2017). As a result, it is reasonable to assume that the injection luminosity profile should consist of two phases, a rising phase and a decreasing phase. Following the work of Geng et al. (2013), we take the injection luminosity profile as a broken power-law function (jointing the rising phase and the decreasing phase smoothly), i.e.,

$$L = L_p \left[ \frac{t}{t_p} \right]^{-\alpha_r} + \frac{1}{2} \left( \frac{t}{t_p} \right)^{-\alpha_d} \right]^{-1/s},$$

where $L_p$ is the peak luminosity at the peak time $t_p$, $\alpha_r$ and $\alpha_d$ are, respectively, the rising and decreasing index, and $s$ represents the sharpness of the peak. Figure 1 shows the injection luminosity profile used in our modeling.

### 2.2. Shock Dynamics

In our work, we use the generic dynamical equations to calculate the evolution of the GRB outflow (Huang et al. 1999, 2000), which can be conveniently used to calculate the afterglow light curves under various physical conditions (e.g., Huang et al. 2006; Kong et al. 2010; Geng et al. 2014; Li et al. 2015). However, note that when there is an energy injection of Poynting-flux, the dynamical equation for GRB ejecta should be modified.

Let us consider a GRB ejecta with the initial mass of $M_{ej}$, the bulk Lorentz factor of $\Gamma$ ($\Gamma = 1/\sqrt{1 - \beta^2}$, with $\beta c$ being its velocity), and a half-opening angle of $\theta_j$. The evolution of the bulk Lorentz factor of the forward shock can then be described by (e.g., Liu et al. 2010; Geng et al. 2013; Geng & Huang 2016),

$$\frac{d\Gamma}{dM} = -\frac{(\Gamma^2 - 1) - \frac{1 - \beta}{\beta} \Omega_j L(t) - R/c}{M_{ej} + 2(1 - \varepsilon) \Gamma M + \varepsilon M},$$

where $t_b$ is the time measured in the burst frame, $\Omega_j = (1 - \cos \theta_j)/2$ is the beaming factor of the jet, $\varepsilon$ is the radiative efficiency, and $m$ and $R$ are the swept-up mass and radius of the shock, respectively. According to Equation (2), the delayed energy injection with a luminosity of $L$ can change the evolution of $\Gamma$, thus the afterglow light curve should show a plateau or a re-brightening correspondingly.

### 3. Numerical Results

Considering the energy injection luminosity and the dynamical evolution as described in Section 2, we now calculate the multiband afterglow light curves for GW170817/GRB 170817A. In our calculations, the initial value of the bulk Lorentz factor is taken as $\Gamma_0 = 100$, a typical value for GRB outflow (e.g., Racusin et al. 2011). We fix the power-law index of the electron spectrum as $p = 2.2$, which has been derived from the spectrum of the brightening afterglow of GRB 170817A by some researchers (see Dobie et al. 2018; D’Avanzo et al. 2018; Margutti et al. 2018; Ruan et al. 2018 for details). According to the studies on the environment of short GRBs, the circumburst density is generally low, typically in the range of $\sim 10^{-3} - 10^{-2} \text{cm}^{-3}$ (Fong et al. 2015; Hallinan et al. 2017). We thus set the number density as $n = 1 \times 10^{-3} \text{cm}^{-3}$ in our calculations. Other parameters, such as $\theta_{obs}$, $\theta_j$, $E_{K,iso}$, $\varepsilon_e$, $\varepsilon_B$, $L_p$, $t_p$, $\alpha_r$, $\alpha_d$, and $s$ are free parameters. We derive them by comparing our theoretical light curves with observational data. Our fit results are plotted in Figures 1–3, and the derived parameter values are listed in Table 1. Generally, we find that our late-time energy injection model can well explain the multiband afterglow of GRB 170817A. The corresponding chi-square of the fit is $\chi^2 \approx 42.3$, with 22 degrees of freedom.

Figure 1 shows the evolution of the luminosity of the energy injection in our modeling. At early stages, the injection luminosity is a power-law function of time, $L(t) \propto t^{2.8}$. Then at late times, the luminosity decays with time as $L(t) \propto t^{-2.8}$. In Figure 2, we plot the bulk Lorentz factor versus time, where the dotted line corresponds to a jet without energy injection and the solid line corresponds to the jet with energy injection. From this figure, we see that the energy injection begins to affect the...
dynamics at about $\sim 10$ days. It increases the Lorentz factor significantly, so that the relativistic phase lasts for about $\sim 100$ days. Such a change in the dynamics will finally lead to a brightening in the multiband afterglow, as shown in Figure 3. In our calculations, we disregarded the lateral expansion of the ejecta. To examine the effect of lateral expansion, we have also calculated the evolution of the jet (also with the energy injection) by assuming that it expands laterally at the comoving sound speed. The result is plotted as the dashed line in Figure 2. We see that the difference between the dashed line and the solid line is very small, showing that this effect is not significant.

Figure 3 illustrates our fit result for the multiband afterglow of GRB 170817A. We see that our model can well explain the multi-wavelength observational data. The derived parameters are also in reasonable ranges (see Table 1). In our calculations, an isotropic energy of $E_{K,\text{iso}} \approx 4.0 \times 10^{51}$ erg is used, which is comparable to that derived by Hallinan et al. (2017). The values of other normal parameters of the external shock, such as $\theta_j$, $\theta_{\text{obs}}$, are all in reasonable ranges as compared with those adopted in previous afterglow studies (Lyman et al. 2018; Mandel 2018; Margutti et al. 2018). In our theoretical light curves, the peak time of the afterglow is around 200 days. However, note that the exact peak time is actually mainly determined by the peak time of the energy injection ($t_p$). Therefore, this parameter could hopefully give us helpful information on the nature of the energy injection.

From the injection luminosity profile as illustrated in Figure 1, we can estimate the total accreted mass in the process. In principle, assuming that the potential energy of the accreted material is converted to the jet power at a particular ratio of $\eta$, we have

$$\eta G M_{\text{BH}} M_\bullet = \frac{1 - \cos \theta_j}{2} \frac{1}{1 + z} \int L(t) dt,$$

(3)

where $r_{\text{disc}}$ is the radius of the accretion disk around the BH and is taken as 10 times that of the Schwarchild radius ($2GM_{\text{BH}}/c^2$). Therefore, a total accreted mass of $M_\bullet \approx 0.006 M_\odot (t_j/0.1)^{-1} (M_{\text{BH}}/2.7 M_\odot)^{2/3}$ is needed in our scenario. This mass is not too large. It could come from the ejected material during the double NS merger process. As a comparison, the mass of the dynamical ejecta of double NS mergers is typically $\sim 10^{-3} - 10^{-2} M_\odot$ (Rosswog 2007; Bauswein et al. 2013; Holtokezaka et al. 2013a). It also does not conflict with the estimation of $M_{\text{ej}} \sim 10^{-3} - 10^{-2} M_\odot$ for the dynamical ejecta of GW170817 (Abbott et al. 2017d; Utsumi et al. 2017; Tanaka et al. 2017; Matsumoto et al. 2018). In a few recent studies, a more precise ejecta mass of $M_{\text{ej}} \sim 0.05 M_\odot$ was estimated when modeling the GW170817 kilonova (Cowperthwaite et al. 2017; Drout et al. 2017; Kasliwal et al. 2017; Kasen et al. 2017; Villar et al. 2017; Waxman et al. 2017). These studies also support the idea that there is enough material being ejected during the NS–NS merger.

4. Discussion and Conclusion

The X-ray, optical, and radio emission of the afterglow of GRB 170817A shows a steady rise until ~160 days after the merger. In this study, we suggest that the afterglow is produced by an off-axis jet with a delayed energy injection caused by some kind of accretion. By fitting the observed multiband light curves, we derived the required injection luminosity profile, which is composed of a power-law rising phase and a power-law decreasing phase. We show that our model can well explain the X-ray, optical, and radio light curves of GRB 170817A.

In our modeling, the peak time of the energy injection is about 110 days, and a total accreted mass of $\sim 6 \times 10^{-3} M_\odot$ is needed for the energy injection. How such an accretion can be achieved is thus a key issue. A possible solution is so-called fall-back accretion. The fall-back accretion process was first discussed by Colgate (1971). It is originally assumed to be

![Figure 3](image-url)

**Figure 3.** Our theoretical afterglow light curves as compared with the multiband observations of GRB 170817A. The solid lines represent the emission from the off-axis jet with the energy injection. As a comparison, the dotted lines show the same off-axis jet emission without any energy injections. The radio data points are taken from Alexander et al. (2017), Hallinan et al. (2017), Kim et al. (2017), Mooley et al. (2018), and Margutti et al. (2018). The X-ray data points are taken from Ruan et al. (2018), Lazzati et al. (2017), and D’Avanzo et al. (2018). The optical (in HST optical bands of F814W and F606W) data points are taken from Lyman et al. (2018) and Margutti et al. (2018). Note that the 1 keV upper limit shown as the black triangle is taken from Margutti et al. (2017).

**Table 1**

| Parameter                  | Value  |
|----------------------------|--------|
| $\theta_{\text{obs}}$ (degree)$^a$ | 23.4   |
| $\theta_j$ (degree)        | 11.0   |
| $E_{K,\text{iso}}$ (erg)$^b$ | $4.0 \times 10^{51}$ |
| $\epsilon_e$              | 0.025  |
| $\epsilon_B$              | 0.0045 |

**Injection Parameter**

| Parameter       | Value        |
|-----------------|--------------|
| $I_p$ (erg s$^{-1}$) | $3.2 \times 10^{44}$ |
| $t_p$ (days)    | 110.0        |
| $\alpha_x$      | 0.92         |
| $\alpha_d$      | -2.8         |
| $s$             | 0.38         |

**Notes.**

$^a$ $\theta_{\text{obs}}$ is defined as the angle between the line of sight and the jet axis.

$^b$ $E_{K,\text{iso}}$ is the initial isotropic kinetic energy of the ejecta.
related to supernovae. Later, it became evident that fall-back accretion could also play an important role in the collapsar model for long GRBs (Chevalier 1989; Kumar et al. 2008a; Zhang et al. 2008; Geng et al. 2013; Wu et al. 2013). It is interesting to note that evidence for fall-back accretion during binary NS mergers that produce short GRBs has also been suggested. In fact, for short GRBs, even if a small mass of $\sim 10^{-5} - 10^{-4} M_\odot$ is accreted after the NS–NS merger, it would be sufficient to power a bright afterglow (Metzger et al. 2010). Some possible examples include short GRB 060729 (Cannizzo et al. 2011) and short GRB 130603B (Hotokezaka et al. 2013b; Kisaka & Ioka 2015). It is possible that fall-back accretion and the related energy injection may be a common process among short GRBs.

However, for the brightening of the afterglow of GRB 170817A, normal fall-back accretion maybe cannot provide a natural explanation, as our best-fit parameters seem at odds with a fall-back interpretation. In general, during the double-NS merger process, one would expect the fall-back accretion to peak on about the dynamical timescales of the least-bound material, which would be less than $\sim 100$ ms or so. More detailed investigation also shows that the normal fall-back accretion usually does not last for a long period (Rosswog 2007). Additionally, our best-fit slope for the late-time segment of the luminosity profile is $\alpha_t \sim -2.8$. This value is also inconsistent with the value of $-5/3$ expected for normal fall-back accretion. We thus need to look for a mechanism other than normal fall-back accretion for the energy injection in GRB 170817A.

We note that a bright kilonova has been found to be associated with GW170817. The kilonova is composed of “blue,” “purple,” and “red” components. Their expanding velocities are typically in the range of 0.1c–0.3c, and their total mass can be as large as $\sim 0.08 M_\odot$ (Villar et al. 2017). The material of these kilonova components undoubtedly should be ejected from the binary NS merger. But because their velocities are too large, they could not be accreted during the afterglow stage. However, we could imagine that there should also be many slower materials ejected during the process. Their velocities are significantly higher than those of the initial fall-back materials, but they are still bound by the gravity of the central BH. They could be accreted at a much later stage, i.e., about 110 days later, providing a source for the late energy injection as required in our modeling. Note that according to our calculations, a total accreted mass of $\sim 6 \times 10^{-3} M_\odot$ is needed for the energy injection. This value is much less than the total mass of the observed kilonova components. It is also consistent with the typical mass range of the dynamical ejecta estimated by a few other authors ($\sim 10^{-4} - 10^{-2} M_\odot$), Rosswog 2007; Rossi & Begelman 2009; Hotokezaka et al. 2013a; Rosswog 2013; Just et al. 2015; Kisaka & Ioka 2015).

Energy extraction from a rotating BH through the Blandford–Znajek mechanism is usually assumed to be in the form of a Poynting flux. In this case, macroscopic magnetic field may present in the external shock and may play an important role in our energy injection model. A possible consequence is that the induced afterglow emission is likely to be polarized to some extent. However, it is also possible that the injected energy does not need to be in the form of a Poynting flux in a realistic case. It may simply re-energize the external shock and increase the afterglow brightness. Consequently, no polarization will be expected in the brightening stage. Polarization observations can help to discriminate between these two cases. More observations on the late-time afterglows of short GRBs should be conducted in the future.

In our calculations, although we have assumed that the central engine of GRB 170817A is a BH, an NS as the central remnant still cannot be ruled out. A newly born NS accompanied by an accretion disk may also play a similar role in injecting energy into the external shock (Zhang & Dai 2008; Dai & Liu 2012). To produce a comparable brightness, the total accreted mass may need to be slightly larger to ensure a similar potential energy release.

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