UNUSUAL CENTRAL ENGINE ACTIVITY IN THE DOUBLE BURST GRB 110709B

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ABSTRACT

The double burst, GRB 110709B, triggered Swift/BAT twice at 21:32:39 UT and 21:43:45 UT, respectively, on 9 July 2011. This is the first time we observed a GRB with two BAT triggers. In this paper, we present simultaneous Swift and Konus-WIND observations of this unusual GRB and its afterglow. If the two events are from the same physical origin, their different time-dependent spectral evolution suggest they must belong to different episodes of the central engine, which may be a magnetar-to-BH accretion system.

Subject headings: gamma-ray burst: general

1. INTRODUCTION

Gamma-Ray Bursts (GRBs) have been thought to be one-time events through both observation and theoretical understanding. The general picture of a GRB is as follows: (1) A “central engine” consisting of a rapidly rotating black hole (BH) and a nuclear-density accretion disk is formed from a progenitor system, which invokes either core-collapse of a massive star (Woosley 1993; MacFadyen & Woosley 1999, Fryer et al 2007) or merger of two compact stellar objects such as NS-NS or BH-BH (Paczynski 1986; Eichler et al 1989; Paczynski 1991; Narayan et al 1992). (2) A relativistically expanding ejecta, which is composed of many mini-shells with a wide-range of Lorentz factors, is launched by the central engine. Internal shocks (Rees & Mesz´a ro 1994) are formed during the collisions of those shells and produce the observed prompt GRB emission (mostly in Gamma-ray band). Observationally this is the phase when GRBs trigger gamma-ray band detectors. (3) The ejecta are further decelerated by an ambient medium (e.g, interstellar medium; ISM) and produce a long-term broad band afterglow through an external-forward shock (M´esz´a ro & Rees 1997a; Sari et al. 1998) and/or external-reverse shock (M´esz´a ro & Rees 1997a, 1999; Sari & Piran 1999a,b). (4) In some cases, the central engine can be restarted during the afterglow phase and X-ray flares are produced through dissipation of a late wind launched from a long-lasting central engine (Burrows et al 2005b; Zhang et al. 2006; Fan & Wei 2005; Ioka et al. 2005; Wu et al. 2005; Falcone et al. 2006; Romano et al. 2006; Lazzati & Perna 2007; see Zhang 2007 for review). Although X-ray flares are generally regarded to have the same physical origin as prompt emission, they release their energy mostly in the soft X-ray band.

GRB 110709B triggered the Burst Alert Telescope (BAT; Barthelmy et al. 2005) on-board Swift twice. Each of the triggers, separated by 11 minutes, consists of an otherwise typical long GRB light curve in the hard X-ray/gamma-ray band. X-ray observations during the second burst show that this event also produced bright soft X-ray emission. This provides a rare opportunity to conduct a detailed broad-band study of the central engine properties.

In this paper, we first report the Swift and Konus-WIND observations of GRB 110709B in §2. Then we present multi-wavelength spectroscopy and timing studies in §3. The physical implications on the central engine properties are discussed in §4. We draw our conclusions in §5.

2. OBSERVATIONS AND DATA ANALYSIS

2.1. Swift Data

GRB 110709B first triggered the Burst Alert Telescope (BAT; Barthelmy et al. 2005) on-board Swift at 21:32:39 UT on 9 July 2011 (Cummings et al 2011a). Swift slewed immediately to the burst. The two narrow field instruments, the X-ray Telescope (XRT; Burrows et al. 2005a) and the Ultraviolet Optical telescope (UVOT; Roming et al. 2005) on-board Swift began to observe the field at $T_0 + 80.5$ seconds and $T_0 + 91$ seconds, respectively, where $T_0$ is the BAT trigger time. A bright X-ray afterglow was localized at R.A. ($J2000$) = 10$^h$58$^m$37.08$^s$, Dec. ($J2000$) = $-23^\circ 27' 17''6$ with an uncertainty of 1.4$''$ (90% confidence, Beardmore et al. 2011). No reliable optical source was found within the XRT error circle (Holland et al 2011a,b).

Interestingly, at 21:43:25 UT on 9 July 2011, 11 minutes after the first trigger, the BAT was triggered again
and located a second event from the same location (Barthelmy et al. 2011). The second outburst has comparable intensity and light curve characteristics to the first outburst. Regarding the two outbursts as two episodes of a single burst, the separation (11 minutes) is the longest compared to other multi-episode bursts. In this paper, we use the term “double burst” to stress the unusual nature of this double-trigger GRB. We will use the term “the first sub-burst” to refer to the first outburst and “the second sub-burst” to refer to the second outburst. However, as we will show below, the two events are clearly related, indicating that they have the same physical origin.

We processed the Swift/BAT data using standard HEASoft tools (version 6.11). As shown in Fig. 1 the first sub-burst lasted from \( T_0 - 28 \) seconds to \( T_0 + 55 \) seconds with \( T_{90,1st} = 55.6 \pm 3.2 \) seconds. The second sub-burst lasted from \( \sim T_0 + 550 \) seconds to about \( T_0 + 865 \) seconds with \( T_{90,2nd} = 259.2 \pm 8.8 \) seconds (Cummings et al. 2011b). There was no flux detectable in BAT from about \( T_0 + 180 \) seconds to about \( T_0 + 550 \) seconds. We extracted the BAT spectra in several slices. The lower panel in Fig. 1 shows the photon indices obtained by fitting the spectra with a simple power-law model. It is obvious that both sub-bursts have strong hard-to-soft spectral evolution. The photon indices range from \( \sim 1.25 \) to \( \sim 1.75 \). The BAT band (15-150 keV) fluences of the first and second sub-bursts are \( 8.95^{+0.29}_{-0.20} \times 10^{-6} \) erg cm\(^{-2}\) and \( 1.34^{+0.50}_{-0.74} \times 10^{-5} \) erg cm\(^{-2}\) respectively (see Fig. 2).

We processed the Swift/XRT data using our own IDL codes which employ the standard HEASoft analysis tools. For technical details please refer to Zhang et al. 2007. Fig. 3 shows the XRT light curve and spectral evolution. The prolonged and energetic flaring activity continues up to \( T_0 + 2000 \) seconds, which corresponds to the second sub-burst time period. The light curve after the flare can be fitted by a broken power-law with \( \alpha_1 = 0.98 \pm 0.08 \), \( \alpha_2 = 1.6 \pm 0.13 \) and a break time \( t_b = 5.9 \pm 4.1 \times 10^4 \) s. The X-ray spectrum can be fitted with an absorbed power-law with total column \( N_H = (2.14^{+0.22}_{-0.21} \times 10^{21}) \) cm\(^{-2}\) which includes the Galactic foreground \( N_H = 5.6 \times 10^{20} \) cm\(^{-2}\) (D’Elia et al. 2011). Strong spectral evolution was observed in the flare phase where the photon indices vary significantly from \( \Gamma \sim 0.9 \) to \( \Gamma \sim 2.6 \). The late time spectrum has no significant evolution with an average photon index \( \Gamma \sim 2.1 \). The total fluence in XRT band (0.3-10 keV) is \( 4.07 \pm 0.56 \times 10^{-6} \) erg cm\(^{-2}\) (see Fig. 2).

In order to check whether the break in XRT light curve is due to curvature caused by an incorrect reference time \( T_0 \) effect (e.g., Yamazaki 2009 and Liang et al. 2009, 2010), we plot the XRT light curve in reference to the trigger time of the second sub-burst. We find that the \( t_b \), \( \alpha_1 \) and \( \alpha_2 \) do not significantly change within 1-sigma range. We thus conclude that the break is intrinsic.

2.2. A Lensed Burst?

The similarity of the two sub-bursts raises the question of whether they could be produced by gravitational lensing of a single GRB located behind a foreground galaxy. To investigate this possibility, we examined Chandra observations of GRB 110709B at 14:15:04 UT on 23 July 2011 (day 14: 15.05 ks exposure time; Observation ID 12921) and at 19:50:34 UT on 31 October 2011 (day 114: 10 ks exposure time; Observation ID 14237). We downloaded the public Chandra data from the Chandra archive\(^{12}\) and processed them using the standard CIAO tools (version 4.3). The first Chandra observation has two X-ray point sources in the field of GRB 110709B, with nearly identical brightness \((3.7 \times 10^{-3} \text{ s}^{-1}, 0.2-8 \text{ keV})\) and separated by only 3.4 arcseconds (Fig. 4). Source 1 is located 0.67 arcseconds from the

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\(^{12}\) [http://cda.harvard.edu/chaser](http://cda.harvard.edu/chaser)
refined XRT position, within the refined XRT error circle. Both sources are within the XRT point-spread function (18 arcseconds Half-Power-Diameter), and the sum of their fluxes is consistent with the total XRT flux measured during the first epoch, while the flux of Source 1 is consistent with the extrapolation of the XRT light curve (Fig. 3). The field was unobservable by both Chandra and Swift from about 8 August 2011 until 28 October 2011. In the second Chandra observation, taken shortly after the field emerged from the Chandra Sun (pitch angle) constraint, Source 1 has vanished, while Source 2 is still present, with a slightly lower count rate of \(2.7 \times 10^{-3} \text{ s}^{-1} \) (0.2-8 keV), consistent with being a background X-ray source such as an AGN. The upper limit for the Source 1 flux is still consistent with the extrapolation of the XRT light curve (Fig. 3). The fact that Source 1 vanished while Source 2 did not clearly rules out any possibility that the double burst is due to gravitational lensing.

2.3. Konus-Wind Data

GRB 110709B triggered detector S1 of the Konus-WIND gamma-ray spectrometer (Aptekar et al. 1995) at 21:32:44.567 s UT on 9 July 2011 (Golenetskii et al 2011). Konus-WIND recorded the first sub-burst with high-resolution data. The \(T_{90}\) of the first sub-burst in Konus-WIND energy band (20 keV - 5 MeV) is 51.3 ± 7.6 s. The fluence in the same energy range is \(2.6 \pm 0.2 \times 10^{-5} \text{ erg cm}^{-2}\). The second sub-burst fell into a telemetry gap but was recorded by the instrument’s spare count rate measurement channel (Fig. 5). The overlap detection of the first sub-burst will allow a BAT+Konus-WIND multi-wavelength study.

3. MULTI-WAVELENGTH TIMING AND SPECTROSCOPY PROPERTIES

3.1. Joint Spectral Fit

As shown in Fig 5 the first sub-burst was simultaneously observed by Konus-WIND and Swift/BAT, so we are able to perform joint spectral fitting using the spectra of those two instruments. We divide the time period of the first sub-burst into 5 time slices. The exact time ranges of each slice are listed in Table 1. For the first four slices, the best fit model is a cut-off power-law (CPL, cutoffpl in Xspec 12). For the 5th slice, the best fit model is a simple power-law (PL, powerlaw in Xspec 12). The time-dependent fitting results are presented in Table 1. The time-integrated spectrum (3.594 s to 44.810 s) can also be fitted by a cut-off power-law model with \(\alpha = 1.17 \pm 0.04, E_p = 311^{+45}_{-38}\) and \(\chi^2/\text{dof} = 125/129\) (Fig. 6). The second sub-burst was simultaneously observed by Swift/BAT and Swift/XRT. Similarly with the first sub-burst, we are able to perform joint spectral fitting using the spectra of those two instruments. We divide the time period of the second sub-burst into 5 slices (listed in Table 1). We fit the spectrum of each slice using absorbed cut-off power-law model. An underlying simple power-law decaying component was also taken into account and subtracted using the same strategy as in Falcone et al 2007. The time-dependent fitting results are presented in Table 1. The time-averaged (550s to 1000 s) BAT+XRT spectra are well fitted by the absorbed cut-off power-law model with \(\alpha = 1.12 \pm 0.04, E_p = 116^{+9}_{-8}\) and \(\chi^2/\text{dof} = 687/679\) (Fig. 7).

The spectral evolution during the whole double burst shows an overall hard-to-soft trend. In Fig. 8 we plot the modeled spectral energy distribution in different time intervals, which demonstrates the intrinsic spectral shape evolution. Fig. 9 & 10 show the evolution of \(E_p\) and \(\alpha\) respectively. Although strong spectral evolution is exhibited by both sub-bursts, their time-dependent behaviors are very different. For example, as shown in Fig 9 the \(E_p\) of the first sub-burst decays to \(\propto t^{-0.13}\) while the \(E_p\) of the second sub-burst decays to \(\propto t^{-1.9}\) (or \(\propto t^{-0.31}\) if we shift reference time of the second sub-burst to its trigger time). The different time-dependent spectral of the two sub-bursts may suggest that the two sub-bursts are from different stages of the same central engine (see 4 for more discussions).

3.2. \(E_p-E_{\gamma,\text{iso}}\) Relation and Implication for Redshift

There has been no redshift measurement for GRB 110709B, so the rest-frame peak energy, \(E_p/(1+z)\), and the isotropic energy, \(E_{\gamma,\text{iso}}\), are unknown. On the other hand, one can assume it has a redshift \(z_x\) and plot the corresponding \(E_p(z_x)\) and \(E_{\gamma,\text{iso}}(z_x)\) on the \(E_p - E_{\gamma,\text{iso}}\) (Amati relation; Amati et al 2002) diagram. The well-known Amati relation suggests that most long (or type II; Zhang et al 2009) bursts follow the \(E_p \propto E_{\gamma,\text{iso}}^{1/2}\) track (Amati et al 2002, Zhang et al 2009). Since GRB 110709B is obviously a long burst (especially with two long sub-bursts), in principal it should fall into the same track as other typical long (type II) bursts. In Fig. 11 we assign GRB 110709B onto the \(E_p - E_{\gamma,\text{iso}}\) diagram by assuming its redshift is in the range of \(z_x = 0.01-7\). It is...
Fig. 4.— Chandra (upper left: $T_0 + 14$ days; lower left: $T_0 + 114$ days) and Swift/XRT (upper right: $T_0 + 0$ day; lower right: $T_0 + 114$ days) images of 110709B. Black circles (radius=1.2”) indicate the Chandra source extraction regions at the locations of RA(J2000) = 10h58m37.121s, Dec(J2000) = −23°27′17.08″ and RA(J2000) = 10h58m37.003s, Dec(J2000) = −23°27′20.24″. The red circle is the enhanced XRT error circle (Beardmore et al 2011). The blue circle indicates the preliminary XRT error circle (based on the on-board centroid of the first 2.5 s of data) that was reported by Cummings et al 2011.

### TABLE 1

<table>
<thead>
<tr>
<th>Time interval</th>
<th>Model</th>
<th>$\alpha$</th>
<th>$E_p$ keV</th>
<th>$\chi^2$/dof</th>
<th>Inst.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(3.594,12.042)</td>
<td>CPL</td>
<td>1.00 ± 0.06</td>
<td>301 ± 77</td>
<td>127/128</td>
<td>BAT+KW</td>
</tr>
<tr>
<td>(12.042,20.230)</td>
<td>CPL</td>
<td>1.0 ± 0.06</td>
<td>272 ± 53</td>
<td>135/128</td>
<td>BAT+KW</td>
</tr>
<tr>
<td>(20.230,28.426)</td>
<td>CPL</td>
<td>1.1 ± 0.07</td>
<td>247 ± 46</td>
<td>156/128</td>
<td>BAT+KW</td>
</tr>
<tr>
<td>(28.426,36.618)</td>
<td>CPL</td>
<td>1.1 ± 0.08</td>
<td>258 ± 94</td>
<td>111/128</td>
<td>BAT+KW</td>
</tr>
<tr>
<td>(36.618,44.810)</td>
<td>PL</td>
<td>1.55 ± 0.05</td>
<td>–</td>
<td>132/129</td>
<td>BAT+KW</td>
</tr>
<tr>
<td>(3.594,44.810)</td>
<td>CPL</td>
<td>1.17 ± 0.04</td>
<td>311 ± 45</td>
<td>125/129</td>
<td>BAT+KW</td>
</tr>
<tr>
<td>(550,600)</td>
<td>CPL</td>
<td>0.80 ± 0.05</td>
<td>109 ± 15</td>
<td>363/303</td>
<td>BAT+XRT</td>
</tr>
<tr>
<td>(600,650)</td>
<td>CPL</td>
<td>0.82 ± 0.03</td>
<td>112 ± 9</td>
<td>360/418</td>
<td>BAT+XRT</td>
</tr>
<tr>
<td>(650,700)</td>
<td>CPL</td>
<td>0.92 ± 0.03</td>
<td>99 ± 8</td>
<td>343/365</td>
<td>BAT+XRT</td>
</tr>
<tr>
<td>(700,800)</td>
<td>CPL</td>
<td>1.22 ± 0.02</td>
<td>73 ± 16</td>
<td>438/456</td>
<td>BAT+XRT</td>
</tr>
<tr>
<td>(800,1000)</td>
<td>CPL</td>
<td>1.33 ± 0.02</td>
<td>71 ± 15</td>
<td>512/501</td>
<td>BAT+XRT</td>
</tr>
<tr>
<td>(550,1000)</td>
<td>CPL</td>
<td>1.12 ± 0.01</td>
<td>116 ± 8</td>
<td>687/679</td>
<td>BAT+XRT</td>
</tr>
</tbody>
</table>

*Error are given at the 1-sigma level.

interesting to note that, in order to let GRB 110709B fall into the long/Type II track, it apparently should have a redshift of $z_x \geq 0.3$. This may indicate that GRB 110709B is not a nearby event.

### 3.3. Spectral Lag

Spectral lags, which are caused by the fact that softer Gamma-ray photons usually arrive later than hard photons, are always observed in long (type II) GRBs (Norris et al 2000; Gehrels et al 2006; Liang et al 2006; Zhang et al 2009), but are typically negligible for short (type I) GRBs (Norris & Bonnell 2006; Zhang et al 2009). For the first sub-burst, we extracted 64ms-binned light curves in the following four BAT energy bands: 15−25 keV, 25−50 keV, 50 − 100 keV and 100 − 150 keV and the following three Konus-WIND bands: 25−95 keV, 95 − 380 keV and 380 − 1435 keV. Then, using the CCF (cross-correlation function; Norris et al 2000) method, we calculate the lags between any two light curves in above energy bands. The uncertainty of lags are estimated by Monte Carlo sim-
Fig. 5.— Multi-wavelength light curve for the prompt emission phase of GRB 110709B. Different color indicate different instruments as follows: Magenta: Konus-WIND; blue: Swift/BAT; red: Swift/XRT. The pulse width evolution with energy, namely the pulses in softer band tend to be broader, are similar with other GRBs (e.g., Romano et al. 2006).

ulation (see e.g., Peterson et al. 1998). We found that all those lags are consistent with zero. For the second sub-burst, we extracted 64ms-binned light curves in the same four BAT energy bands as mentioned above and three XRT energy bands: 0.3 – 1 keV, 1 – 4 keV and 4 – 10 keV. Again, no significant lags were found between any two of those energy bands. In Fig 12 we plot the luminosity-lag diagram by assuming the double burst is at redshift 0.1 – 7.0, where the upper limits of lags are defined as the temporal resolution (64 ms) of the light curves that we used to calculated lags. The zero lag for GRB 110709B is puzzling since it conflicts with the fact that it is a long burst, which in principle should exhibit spectral lags. One possible reason is that GRB 110709B might be a high redshift (i.e., z ≥ 2.0) burst with higher intrinsic luminosity so an intrinsic short lag is expected and might be undetectable. This is consistent with the non-detection of optical afterglow as described in §3.4.

One puzzling feature of GRB 110709B is that there is no optical counterpart or host galaxy observed by UVOT or any other ground telescopes. Furthermore, no cataloged extragalactic galaxy was found within 1’ radius in the NASA/IPAC Extragalactic Database (NED). Using the optical afterglow upper limits reported by Fong & Berger (2011), we plot the optical-to-X-ray SED at T−T0 = 3.2 hours and T−T0 =4.1 days in Fig. 13. The corresponding βOX are > 0.75 and > 0.71 for the two epochs. Since bursts with βOX > −0.5 are defined as “dark” (Jakobsson et al. 2004, Greiner et al. 2011), GRB 110709B is clearly an unusual dark burst with an extreme positive βOX. Furthermore, the EVLA detection of radio counterpart of GRB 110709B gives further support that GRB 110709B is a dark burst (Zauderer & Berger 2011). The absence of the optical observation may indicate a high redshift origin (Fong & Berger 2011) or very different radiation mechanisms between the X-ray and optical components (D’Elia & Stratta, 2011).

3.4. A Dark Burst?

4. IMPLICATIONS FOR THE CENTRAL ENGINE
Long-term central engine activities have been proved by the commonly detected X-ray flares which occur at hundreds of seconds after the burst trigger. This double burst GRB 110709B suggests that the long-term active central engine not only powers X-ray flares but also can power a second burst. Generally speaking, in order to produce a second “burst” as is observed in GRB 110709B, the central engine must restart with comparable or even larger energy. This is challenging for the following popular theoretical X-ray flare models:

- **Fragmentation in the massive star envelope.** The collapse of a rapidly rotating stellar core leads to fragmentation (King et al 2005). If the delayed accretion of fragmented debris leads a second burst, the debris must have comparable mass with the materials in the initial major accretion.

- **Fragmentation in the accretion disk.** Fragmentation in the accretion disk can power X-ray flares in both short and long GRBs (Perna et al 2006). In order to power a second burst instead of X-ray flares, the total mass of the fragmented outer part of the disk must be comparable to the initial disk mass.
**Magnetic barrier around the accretor.** Proga & Zhang (2006) argued that a magnetic barrier near the black hole may act as an effective modulator of the accretion flow. The delayed outflow can power the X-ray flares. This model, however, is difficult to apply to the double burst mainly because it predicts that the late time accretion mass/rate is much lower and thus can not power the gamma-ray energy.

On the other hand, the long quiescent gap between the two sub-bursts leads us to re-think the 2-stage fallback collapsar scenario that has been used to interpret GRB precursors (Wang & Mészáros, 2007). In that scenario, the precursor is produced by a weak jet formed during the initial core collapse, possibly related to MHD processes associated with a short-lived proto-neutron star, while the main burst is produced by a stronger jet fed by fallback accretion onto the black hole resulting from the collapse of the neutron star. We found that the assumed proto-neutron star rotational energy of few $10^{51}$ ergs in Wang & Mészáros, 2007 would also be sufficient, when
beaming is taken into account, to power the first sub-burst of GRB 110709B. In fact, simple estimates indicate that maximally rotating proto-neutron stars could reach rotational energies as high as several $10^{52}$ erg. Here, we propose a magnetar-to-BH scenario as follows:

(1) A magnetar is formed and produces the first sub-burst by releasing its rotation energy via electromagnetic and gravitational radiation in $\sim 10 - 20$ seconds (rest frame). A magnetar, rather than a lower field neutron star, is required not only to produce the high luminosity ($L_{\gamma, \text{iso}} \sim 10^{52}$ erg s$^{-1}$) and $E_{\gamma, \text{rest}}$ ($\sim 0.6$-1 MeV) of the first sub-burst (Zhang & Mészáros, 2001; Metzger et al. 2011), but also to overcome the ram pressure of the fallback matter (Wang & Mészáros, 2007). For a typical magnetar with proto-neutron star radius $R_{\text{PNS}} \sim 50$ km and mass $M_0 \sim 1.4 M_\odot$, the ram pressure can be written as

$$P_{\text{ram}} = \frac{M_{\text{ej}}}{4\pi R_{\text{PNS}}^2} \simeq 5 \times 10^{26} M_\odot M_{\text{ej}}^{1/2} (R_{\text{PNS}}/60\text{ km})^{-5/2} \text{ erg s}^{-1},$$

where $v_{\text{ff}} = (2GM/R_{\text{PNS}})^{1/2}$ is the free-fall velocity and $M_{\text{ej}}$ is the mass infalling rate in units of $M_\odot$ s$^{-1}$. The magnetic field pressure can be written as $P_B = B_j^2/8\pi \simeq 4 \times 10^{26} B_j^2/15 \text{ erg s}^{-1}$. Comparing the two, one can get $B_j \gtrsim 10^4 G$. Such a magnetized jet internally dissipates and powers the observed gamma-ray emission (e.g. Zhang & Yan 2011; Metzger et al. 2011).

(2) After the magnetar slows down, the magnetic outflow stresses decrease, so the ram pressure of the infalling matter becomes dominant. Thus the activity of the magnetar is suppressed during the accretion process. The accretion onto the magnetar does not lead to GRB emission, since the hot NS likely launches a dirty neutrino-driven wind with heavy baryon loading. In order to form a BH, a total accreting mass of $1 M_\odot$ is needed. Assuming a redshift $z=1$, the accretion rate is about $\dot{M} \sim \frac{M_{\text{ej}}}{4\pi R_{\text{PNS}}^2 (1+z)^2} \simeq 0.004 M_\odot$/s, which is consistent with theoretical predications in the supernova fallback scenario (see e.g., MacFadyen et al. 2001).

(3) The accretion finally leads the magnetar to collapse to a black hole. The second sub-burst is produced either from a baryonic or a magnetic jet. The spectrum will be softer either because the accretion leads the gas near the central engine to be more baryon-loaded so that the jet is slower or because the pre-existing channel from the first sub-burst may not have time to close so that the wide channel results in a slower jet and a softer spectrum. The spectral evolution of two stages would be expected to be different, since they are due to different physical process. These model features appear to be in concordance with the observed facts (see Fig. 2).

5. CONCLUSION

GRB 110709B is the first GRB with two Swift/BAT triggers. Although separated by 11 minutes, the continuous spectral evolution of the two sub-bursts indicates that they may originate from the same central engine, which apparently requires extreme two-step activities that may be related to magnetar-to-BH accretion. On the other hand, we determined that GRB 110709B may be a high-z event according to its absence of optical observation together with the extreme $\beta_{\text{OX}}$, zero lags and (assumed) consistency to the Amati-relation.

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