

Extremely Bright GRB160625B with Short-Soft Precursor and long-hard extended emission: Hints for long-term evolution of the GRB Ejecta

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Abstract. In this paper, we focus on studying the high energy emission of GRB 160625B. The lightcurve of prompt emission is composed of three episodes: short-soft precursor, hard main burst, and possible long extended emission. The spectra of first and third episode can be fitted by a multi-color blackbody and cutoff power-law model, respectively. However, the spectrum of second episode was contributed by both multi-color blackbody and cutoff power-law. One can estimate the Lorenz factor of jet of first two episodes by invoking photosphere model as $\Gamma_0 \sim 175$ and 1694, respectively. It suggests that the ejecta of this case evolved from photosphere dominated initially to internal shock later. On the other hand, the optical emission is very bright during the second episode, which is likely a prompt optical emission. Finally, a more shallower normal decay segment appeared, which is consistent with standard external shock model.

Keywords. gamma rays: bursts; individual: GRB 160625B.

1. Introduction

The origin of gamma-ray burst (GRB) prompt emission is very important to understand and it is related with the ejecta composition, energy dissipation, particle acceleration, and radiation mechanism of GRB jet (Zhang 2011). However, its physical origin remains unclear even after more than forty years of study, e.g. what are the central engine and progenitors of GRBs? How does the ejecta evolve during prompt emission phase? What is the radiation mechanism of prompt emission and later afterglow. Several observational evidences support the existence of two types (black hole or magnetar) central engine and three types (photospheric, leptonic synchrotron or hadronic emission) of emission mechanisms in the relativistic jet are being actively discussed. From observational point of view, a small fraction of GRBs have a soft precursor emission before main burst, and tens seconds quiet phase between precursor and main burst. This was used to constraint the properties of central engine and progenitors. On the other hand, the thermal emission was detected during the prompt emission in several *Fermi* GRBs, such as GRB090902B (Ryde *et al.* 2010). The thermal emission in the prompt phase can be used to constrain the Lorenz factor of GRB jet. Moreover, the optical emission during the prompt emission (or roughly tracking gamma-ray emission) can constrain the emission site by requiring that the synchrotron self-absorption frequency is below the optical band if we assume that this optical emission is from the same emission region as gamma-rays.

GRB 160625B, one interesting case, was detected by *Fermi* Gamma-Ray Burst Monitor (GBM; Burns 2016), the Large Area Telescope (LAT), Konus-Wind, as well as *Swift* X-ray telescope (XRT). The optical and radio afterglows were also detected. More interesting, the optical emission is very bright, and can be compared to GRB 990123 and GRB 080319B. Multi-wavelength observations of this case could provide the opportunity to explore the physical origin of the GRB. Especially, the spectral properties of its prompt emission are quite similar to those of GRB 090902B, which was claimed to show evidence of thermal emission (Ryde *et al.* 2010). In this work, we perform the time-integrated spectral analysis for each part of the prompt emission of GRB 160625B, to obtain the characteristic of the thermal component and the evolution of ejecta, as well as the afterglow modeling analysis. In §2, we give the observations report and data analysis. The spectra fitting result with multi-color blackbody and afterglow model are presented in §3. Conclusions are drawn in §4.

2. Observations and Data Analysis

GRB 160625B triggered two times and one time during the prompt emission phase by *Fermi*/GBM (Burns 2016) and LAT (Dirirsa *et al.* 2016), respectively. The prompt emission lightcurve of this burst is composed of three parts: a short soft-precursor emission with duration about 1 second initially (part I), then a main extremely bright episode with a duration of about several ten seconds appeared after about 200 seconds since GBM first trigger (Batsch *et al.* 2016; Svinikin *et al.* 2016; part II), finally, one long weak emission is following the part II after 11 minutes (part III). Moreover, the *Swift* X-ray telescope (XRT) also observed the burst, and the X-ray lightcurve is from the UK *Swift* Science Data Centre at the University of Leicester. The optical telescopes (Pi of the Sky; Batsch *et al.* 2016) and Global MASTER-Crimea (Lipunov *et al.* 2016) also observed this case. All optical observations are extracted from GCN reports (Oates 2016; Kuroda *et al.* 2016; Troja *et al.* 2016; Mazaeva *et al.* 2016; Moskvitin 2016; Mazaeva *et al.* 2016; Guidorzi *et al.* 2016; Valeev *et al.* 2016; Bikmaev *et al.* 2016; Mazaeva *et al.* 2016). The optical lightcurve has a bright flare during the second episode, which is likely an optical prompt emission. Then, following a steep decay ($t^{-3.5}$), it transforms to normal decay segment after 10^4 second (Fig. 1). The X-shooter spectrograph observed the optical spectrum to measure the redshift $z = 1.406$ (Xu *et al.* 2016). The lightcurve is shown in Figure 1.

3. Spectra fitting and afterglow model result

We analyze the spectra of prompt emissions for the time slices of $-0.3 \sim 1.1$ s, $180 \sim 189$ s and $522 \sim 890$ s, which are corresponding to the parts *I*, *II* and *III* in Figure 1. Following Ryde *et al.* (2010), we used multi-color blackbody (mBB) model to fit the spectra of each parts. The first spectrum of part *I* can be well fitted by mBB model with $T_{\max} = 25.2 \pm 1.1$ keV, $q = 1.63 \pm 0.20$ and a goodness of reduced $\chi^2 = 387/120$. For part *II*, its spectrum is fit by multi-color blackbody combined with a cutoff power-law, one has $T_{\max} = 967 \pm 49$ keV, $q = 0.92 \pm 0.01$, photon index $\Gamma_{cut} = 1.33 \pm 0.02$ and a high-cut energy 14989 ± 1154 keV. For the third part, cutoff power-law and additional power-law model were used to fit the data. Best fit values are $\Gamma_{cut} = 1.64 \pm 0.04$ and a high-cut energy 692 ± 577 keV, and photon index $\Gamma_{pow} = 1.98 \pm 0.50$. The fitting results are shown in Fig. 2. One can estimate the Lorentz factor of jet of first two episodes by invoking photosphere model as $\Gamma_0 \sim 175$ and 1694 , respectively. On the other hand, we used standard afterglow model to fit both X-ray and optical data, and search for the best parameters distributions. We obtain $\epsilon_e = 0.14 \pm 0.06$, $\epsilon_B = (1.98_{-1.13}^{+1.53}) \times 10^{-7}$,

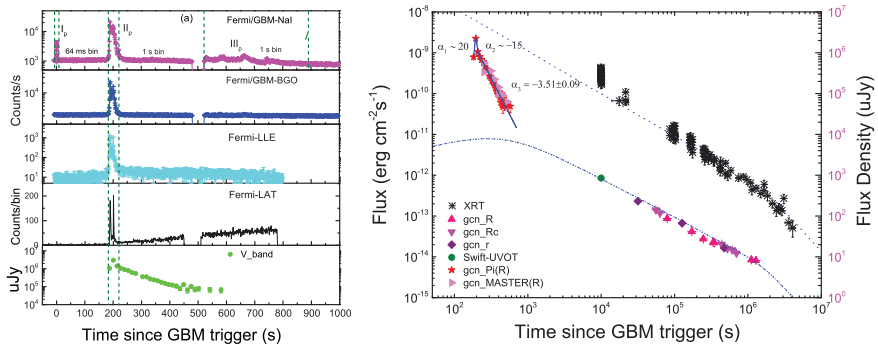


Figure 1. The *left panel*: illustrates the *Fermi* and optical observations of GRB 160625B. *Right panel*: The results of modeling the optical and X-ray afterglow light curves with the standard forward shock model.

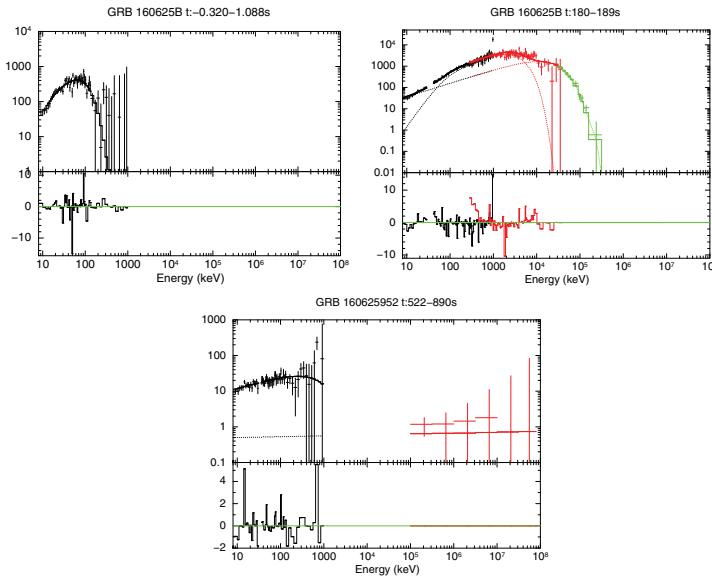


Figure 2. The spectra fitting by multi-color blackbody (part I), multi-color blackbody and cutoff power-law model (part II), and cutoff power-law model (part III). The unit of Y axis is $\text{erg cm}^{-2} \text{s}^{-1}$.

$n = 37_{-15}^{+14} \text{ cm}^{-3}$, $E_{K,\text{iso}} = (1.33_{-0.44}^{+0.40}) \times 10^{55} \text{ erg}$, $p = 2.17_{-0.06}^{+0.08}$. Here, we fixed the Lorenz factor as $\Gamma_0 \sim 1694$ in the second episode of prompt emission.

4. Discussion & Conclusion

GRB 160625A is an interesting case. Firstly, it triggered two times and one time during the prompt emission phase by *Fermi*/GBM and LAT, as well as Konus-Wind and other ground optical telescopes. It is the brightest case observed by Konus-Wind in the prompt emission phase, and has the highest isotropic energy ($E_{\gamma,\text{iso}} \sim 5 \times 10^{54} \text{ erg}$) measured by Konus-Wind for more than 21 years of its GRB observations. Secondly, the lightcurve of prompt emission is composed of three episodes: initial short-soft precursor emission (part I), hard main burst after about 200 seconds since GRB trigger (part II), and a weak long emission (part III). Thirdly, the optical emission is as bright as 8.04 magnitude

starting from second episode of prompt emission. We find that the spectra of the first and third episode can be fitted by a multi-color blackbody and cutoff power-law model, respectively. However, the spectra of the second episode shows contributions of both multi-color blackbody and cutoff power-law. One can estimate the Lorentz factor of jet of the first two episodes by invoking photospheric model as $\Gamma_0 \sim 175$ and 1694, respectively. This suggests that the photospheric emission is dominating initially, but the ejecta is not in interaction with interstellar medium, therefore there is no afterglow emission during this phase. Then, the photosphere emission is already present in the second episode, but the contribution of internal shock is more and more important. Finally, the internal shock is dominating in the third episode, no thermal component emission is needed. Moreover, the Lorentz factor of first short-soft emission is much lower than during the main burst phase. It is also supported that the photosphere emission is dominating earlier, and the internal shock is more and more important starting from the second episode. On the other hand, the optical emission is very bright during the second episode, which is likely a prompt optical emission. Then followed by a steep decay phase, which may be a tail emission of prompt optical, or due to reversed shock contribution. Finally, a more shallower normal decay segment appeared, which is consistent with standard external shock model.

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