Study of X-ray flares of GRB 071112C and GRB 080506 from near-infrared to X-ray band

Takeshi UEHARA[1], Makoto UEMURA[2], Koji S KAWABATA[2],
Yasushi FUKAZAWA[1], Ryo YAMAZAKI[1], Akira ARAI[1], Mahito SASADA[1],
Takashi Ohusugi[2], Tunefumi Mizuno[1], Masanori Ohno[3]

[1] Department of Physical Science, Hiroshima University, Kagamiyama 1-3-1, Higashi-Hiroshima 739-8526, Japan
[2] Astrophysical Science Center, Hiroshima University, Kagamiyama 1-3-1, Higashi-Hiroshima 739-8526, Japan
[3] Institute of Space and Astronautical Science, JAXA, 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, Japan
E-mail(TU): uehara@hep01.hepl.hiroshima-u.ac.jp

Abstract

We have observed two GRBs, GRB 071112C and GRB 080506, before the start of X-ray flares in the optical and NIR bands. In conjunction with published X-ray and optical data, we analyzed densely sampled light curves of the early afterglows and SEDs in the NIR to X-ray ranges. We found that the SEDs had a break between the UV and X-ray regions in the normal decay phase. No significant variation in the opticalNIR range was detected together with the X-ray flares, suggesting that the X-ray flares should be associated with a late internal shock. In addition, we found that two-component jets external shock model can also explain the observed variations of SEDs during the X-ray flares.

Key words: gamma rays:bursts — radiation mechnisims:nonthermal

1. Introduction

X-ray observations with the *Swift* satellite have discovered short flares in X-ray afterglows 10^{2-4} sec after GRBs, which are unexpected in the framework of the standard external shock model (1). It is very likely that they do not originate in external shocks that give rise to the afterglow emission, but in late-time internal shocks, if all previously observed X-ray flares are due to the same physical process(e.g. 2,3,4,5,6). No significant variation in optical was detected together with the X-ray flares. This behavior is explained by the model with late internal shocks (7). If the late internal shock model is correct, a GRB central engine must be alive longer than 1000 sec. Information on the age of the GRB central engine is very important to constrain the physical mechanism of GRBs. Although a umber of multi-wavelength observations have been done so far, they have not been well organized. Now, we are ready to study X-ray flares with prompt and multi-wavelength observations in the NIR—X-ray band. We discuss a model with two-component external shocks.

2. Observation and Results

We succeeded in observing X-ray flares in GRB 071112C and GRB 080506 simultaneously with three bands of the optical—NIR range by the KANATA telescope. We got 14- and 6-band photometric and X-ray data for those GRBs in conjunction with observations by the other telescopes and *Swift*. Our KANATA 1.5 m telescope, Higashi-Hiroshima Observatory, is equipped with a unique instrument, TRISPEC, capable of simultaneous optical-to-NIR imaging. We performed NIR—optical observations at the early phase of GRBs. Together with the X-ray and Gamma-ray data, we study GRBs (8). Observed optical spectral indexes were less than X-ray ones. If an afterglow in a normal decay phase is explained by the external shock model, SEDs should have a break between the UV and X-ray regimes in the normal decay phase. This is because the IR flux is less obscured than the UV flux.

In the X-ray flares, X-ray flux increased by 3 and 15 times, and the X-ray spectral index change from the normal decay phase. When the light curves become flare decay phase from normal decay phase, the electron distribution index change to 1.24 from 1.66 and to 2.92 from 2.70 for GRB 071112C and GRB 080506, respectively. No significiant variation (< 7 % and < 15 %) in the optical—NIR range was detacted together with the X-ray flares, respectively.

3. Discussion

Here, we propose an alternative model with external shocks for the X-ray flare. We consider two-component jets external shock model. One component originates from the main shell that produces the normal afterglow. The other originates from a delayed shell, which is responsible for the X-ray flare. A sharp decay of the X-ray flare is expected with the emission from the delayed shell if it follows the temporal variation of SEDs same as the external shock model for the normal afterglow. The delayed shell is required to generate a prominent X-ray flare by the external shock. The delayed shell could generate a prominent X-ray flare in a condition that it passes a region containing enough interstellar medium, for example, the opening angle of the delayed shell is larger than that, or the axis of the delayed shell is off to that of the main jet. Such conditions were originally proposed to explain "X-ray flashes", which are analogous to GRBs except for their for their softer emission and less energetics (9). Piro et al. (2005) and Galli & Piro (2006) also proposed a model similar to ours, in which the X-ray flare was reproduced by a collision of the delayed shell and a reverse shock region. Here, we consider a model with two-component forward shock emissions. We discuss whether the observed SED variation during the X-ray flares can be explained with this model.

We discuss possible parameters for the two-component jest external shock model which reproduces the observed SED variations. We introduce an additional emission source to the normal afterglow component. The radiation from this emission source is synchrotron emission from an external shock whose typical and cooling frequencies are represented by ν'_m and ν'_c. As mentioned in §2, the SEDs are expected to have ν_c between the UV and X-ray regimes.

For example, in case S1, the X-ray and optical flux densities of the normal decay component, $F_{\rm n,X}$ and $F_{\rm n,O}$ are related as;

$$F_{\rm n,X} = F_{\rm n,O} \left(\frac{\nu_c}{\nu_{\rm O}}\right)^{-\frac{p-1}{2}} \left(\frac{\nu_{\rm X}}{\nu_c}\right)^{-\frac{p}{2}}. \quad (1)$$

Here, we assumed an SED predicted by the standard external shock model (4). Similarly, the optical and X-ray flux densities of the X-ray flare component, $F_{\rm flare,O}$ and $F_{\rm flare,X}$ are related as;

$$F_{\rm flare,O} = F_{\rm flare,X} \left(\frac{\nu'_c}{\nu_{\rm X}}\right)^{-\frac{p'}{2}} \left(\frac{\nu_{\rm O}}{\nu'_c}\right)^{-\frac{p'-1}{2}}, \quad (2)$$

where p' is the electron distribution index of the X-ray flare component. We define ratios of the flare to the normal fluxes in the X-ray and optical bands as

$$A = F_{\rm flare,X}/F_{\rm n,X}, \quad (3)$$

$$a = F_{\rm flare,O}/F_{\rm n,O}. \quad (4)$$

Using Eqs. (1), (2), (3), and (4), we obtain

$$\nu_c = \left(\frac{a}{A}\right)^2 10^{3(p-p')}\nu'_c, \quad (5)$$

where we take $\nu_{\rm X}/\nu_{\rm O} \approx 10^3$. In this case S1, the cooling frequency of the flare component, ν'_c, is assumed to lie between $\nu_{\rm O}$ and $\nu_{\rm X}$. Given this fact, and substituting observed quantities summarised into Eq. (5), we derive the condition for the cooling frequency of the normal afterglow component as $\nu_c < 1 \times 10^{15}$ and $< 4 \times 10^{11}$ Hz for GRB 071112C and GRB 080506, respectively. These conditions must be compatible with the previously derived result that ν_c is between the NIR and X-ray bands. For GRB 071112C, both conditions are consistent with each other, so that the present two-component external shock model can reproduce the observed SED variations in case S1. On the other hand, for GRB 080506, two independent conditions give no overlapping allowed regions for ν_c, so that the case S1 fails to explain the observed result.

$\nu_c$can be also constrained by the observed amplitudes of the X-ray flares in the two-component external shock model. This restriction for ν_c depends on the SED profile, in particular, on the relationship between ν'_m and ν'_c, the observation frequencies of $\nu'_{\rm O}$ and $\nu'_{\rm X}$. Possible conditions for the X-ray flare component are divided into five cases in the slow cooling regime ($\nu'_m < \nu'_c$) and five cases in the fast cooling regime ($\nu'_c < \nu'_m$) . The conditions were limited to those ten cases because we considered a fading phase of the X-ray flare, that is, $\nu'_m < \nu_{\rm X}$ or $\nu'_c < \nu$ for the slow or fast cooling regime, respectively.

The two-component jets external shock model in the other nine cases were also evaluated like the above example about case S1. The observed SED variations can be reproduced in most cases for both GRB 071112C and GRB 080506.

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