Spectral Properties of "Classical" GRBs Seen by HETE-2 Satellite

A. Yoshida[1,2], Y. Nakagawa[1], T. Yamazaki[1], D. Takahashi[1], N. Kawai[2,3], T. Sakamot[2,3,6], M. Suzuki[3], R. Sato[3], Y. Urata[2,3], Y. Shirasaki[2,4], T. Tamagawa[2], K. Torii[2], M. Matsuoka[5], E. Fenimore[6], M. Galassi[6], D.Q. Lamb[7], C. Graziani[7], T. Donaghy[7], J-L Atteia[8], C. Barraud[8], J-F Olive[9], J-P Dezalay[9], M. Boer[9], K. Hurley[10], J.G. Jernigan[10], G. Ricker[11], J. Doty[11], J. Villasenor[11], Vanderspek[11], G. Crew[11], G. Prigozhin[11], G. Monnelly[11], N. Butler[11], S. Woosley[12] and HETE-2 Science Team

(1) Department of Physics, Aoyama Gakuin University, 5-10-1 Fuchinobe, Sagamihara, Kanagawa 229-8558, Japan
(2) The Institute of Physical and Chemical Research, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan
(3) Department of Physics, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro, Tokyo 152-8550, Japan
(4) National Astronomical Observatory of Japan, Mitaka, Tokyo 181-8588, Japan
(5) National Space Development Agency of Japan, 2-1-1 Sengen, Tsukuba, Ibaraki 305-8505, Japan
(6) Los Alamos National Laboratory MS D436, Los Alamos, NM 87545, USA
(7) Department of Astronomy and Astrophysics, University of Chicago, 5640 South Ellis Avenue, Chicago, IL 60637, USA
(8) Laboratoire d'Astrophysique, Observatoire Midi-Pyrénées, 31400 Toulouse, France
(9) C.E.S.R., Observatoire Midi-Pyrénées, 31028 Toulouse Cedex, France
(10) UC Berkeley Space Sciences Laboratory, Berkeley CA 94720-7450, USA
(11) Center of Space Research, Massachusetts Institute of Technology, Cambridge, MA 02139, USA
(12) Department of Astronomy and Astrophysics, UC Santa Cruz, 477 Clark Kerr Hall, Santa Cruz, CA 95064, USA

Abstract

The HETE-2 satellite can deliver a wide-band spectral data for GRBs, especailly in low-energy region such as "X-ray rich" GRB / X-ray Flash, pre- and post gamma-ray emission. GRB030328 is a long GRB displaying post-gamma-ray activity which might be a beginning of the afterglow detected by Chandra at the later epoch.

pp. 2693–2696

1. Introduction

In the past six years, we have learned much about gamma-ray bursts (GRBs) since the discovery of the afterglows in X-ray, optical and raidio bands. Thanks to accurate localizations by BeppoSAX, many rapid and late follow-up observations have provided means to research redshifts and host galaxies of GRBs. However, radiation mechanisms of burst itself and its central engine are rather poorly understood. Current studies do not seem to answer clearly how or when the transition comes out from prompt emissions during a burst to a succeeding afterglow in a longer wavelength. This may be partly due to the lack of wide band observation from X-rays to gamma-rays. There were several experiments aimed to observe GRB radiations below 20 keV, including the GRB Detector (GBD) on Ginga satellite. Recent results from WFC aboard BeppoSAX have reinforced the importance of X-ray observations. Major achievements by these lower energy observations have included post-burst activity (so-called “X-ray tails”), apparent “X-ray precursors”, and “X-ray rich GRBs”.

Three scientific instruments on the High Energy Transient Explorer 2 (HETE-2) satellite, Soft X-ray Camera (SXC), Wide-field X-ray Monitor (WXM) and French Gamma Telescope (FREGATE), can deliver observations in a wide energy band from 0.5 to 400 keV. As well as HETE’s unique capability of providing very rapid dissemination of accurate GRB localizations, a combination of WXM and FREGATE gives a wide band spectrum for the GRB prompt emission from ~ 2 to ~ 400 keV. This is almost the same energy band explored by GBD/Ginga and HETE can give better statistics without an uncertainty of incidence angles; i.e., an adequate detector response matrix is applicable for a burst localized with WXM/SXC. This is a great advantage especially for the study about lower energy photons. In this paper we report wide-band spectral studies of GRB prompt emissions especially focused on a very recent observation for a long GRB detected on March 28, 2003.

2. Observations, Data Analysis and Results

HETE-2 has localized 39 GRBs by the end of April 2003 since the launch in October 2000. About one third of them can be grouped in so-called X-ray Rich GRBs or X-ray Flashes which emit a large amount of X-ray radiation: $\log[S_X(2\text{–}30\,\mathrm{keV})/S_\gamma(30\text{–}400\,\mathrm{keV})] \geq -0.5$.

In GRB studies, the Band function is useful to represent spectra. It is a smoothly connected power laws given by

$$
\begin{aligned}
N(E) &= AE^{\alpha}\, exp(-E/E_0) &&\text{for } E \leq (\alpha-\beta)E_0 \\
N(E) &= BE^{\beta} &&\text{for } E \geq (\alpha-\beta)E_0
\end{aligned}
$$

$$\text{where}\quad B = A\Big((\alpha-\beta)E_0\Big)^{(\alpha-\beta)} \exp(\beta-\alpha)$$

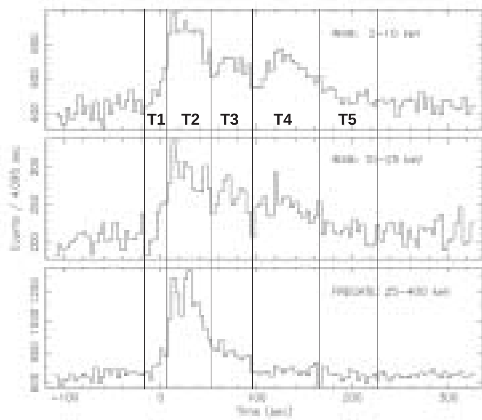

Fig. 1. The light curve of GRB030328

This function is also useful to derive the peak energy E_{peak} of the νF_{ν} distribution. The conversion is that $E_{peak} = (\alpha + 2)E_0$.

Spectral studies using the HETE sample of GRBs, X-ray Rich GRBs and X-ray Flashes indicate a smooth distribution of their properties such as E_{peak}, photon index, and X-ray/gamma-ray fluence, S_X / S_{γ}. Hence it suggests a common origin of these phenomena. Detailed discussions are given elsewhere [1,2].

Recently, HETE-2 observed a long GRB on March 28, 2003 (GRB030328). The burst triggered FREGATE at 11:20:58.35 UT. Based on the HETE localization, an optical afterglow was found, and the redshift of $z = 1.52$ from absorption features. Fig. 1 shows the light curve of this burst taken by WXM (2-10, 10-25 keV) and FREGATE (25-400 keV). It displays a hard-to-soft evolution over a burst as commonly seen in GRBs. The burst lasted very long; T_{90} (the duration which involves 90% energy) is 316 ± 3 s in 2-25 keV band. More noteworthy are much soft X-ray activities seen after the cease of pulses in 25-400 keV. A separate broad peak is appeared in a period labeled T_4 as well as decaying tail ("X-ray tail") in T_5 interval. This kind of "post gamma-ray" activity was reported from GBD/Ginga observations [3].

We made time-resolved spectra for five regions labeled T_1 to T_5. The Band function is employed as a functional form for $T_1 \sim T_4$ and gives acceptable fits for $T_1 \sim T_3$ but a single power-law (E^{β}) is good enough for T_4 (no more parameter is necessary). The power-law model also results a good fit for T_5. For these fits we assumes the galactic absorption with the line of sight column density of $5 \times 10^{20}\,\mathrm{cm}^{-2}$. Table 1 summarizes the best-fit parameters.

From the March 29.112 to March 30.278, a Chandra LETGS observation was conducted for 94.0 ksec. Butler et al. reported an X-ray afterglow of a flux of $\sim 1.9 \times 10^{-13}\,\mathrm{ergs\,cm^{-2}\,s^{-1}}$ [4]. The spectrum of the source was represented as an absorbed power-low with the photon index of 1.7 ± 0.2. This spectrum is

Table 1. Summary of fitting.

Region	$-\alpha$	$-\beta$	E_{peak} (keV)	χ_r^2/dof
T_1	$0.57^{+0.30}_{-0.44}$	$1.53^{+0.16}_{-0.13}$	$61.7^{+43.1}_{-22.1}$	1.12/156
T_2	$0.70^{+0.05}_{-0.06}$	$1.69^{+0.08}_{-0.06}$	$112.2^{+12.9}_{-11.5}$	0.96/300
T_3	$0.83^{+0.11}_{-0.14}$	$1.70^{+0.11}_{-0.09}$	$68.0^{+17.3}_{-15.1}$	1.04/188
T_4	—	$1.74^{+0.06}_{-0.06}$	—	0.85/151
T_5	—	$1.77^{+0.39}_{-0.34}$	—	1.15/102

fully consistent with our results for T_4 and T_5. It might suggest that a broad peak in T_4 would be the start of the X-ray afterglow (an external shock). Assuming the beginning time of T_4 as an origin, we can plot a time versus flux curve using the data in T_4, T_5 and from the Chandra observation (Fig. 2). The three data points are on a simple power-law relation $\propto t^{-1.4}$. This seems consistent with a hypothesis that the broad peak at T_4 is a smooth extrapolation of the X-ray afterglow.

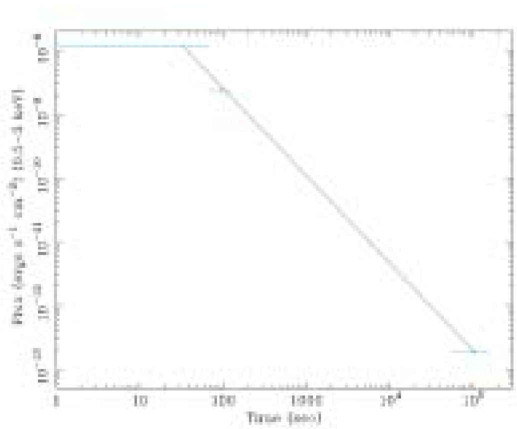

Fig. 2. Flux of the last peak and the afterglow as a function of time since the beginning of T_4. The solid line indicates $t^{-1.4}$.

3. References

1. Baarraud, C. et al. 2003, A & A 400, 1021
2. Sakamoto, T. et al. 2003, ApJ submitted
3. Yoshida, A. et al. 1989, PASJ, 41, 509
4. Butler, N. et al. 2003, GCN Circ. 2076