Properties of Gamma-ray Bursts Localized by the HETE−2 Satellite

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Abstract

The high energy transient explorer 2 (HETE−2) is a small spacecraft designed to detect and localize Gamma-ray bursts (GRBs) in wide field of view. HETE−2 have been localized about 20 GRBs per year. About 30% of localized GRBs have softer spectrum than that of ordinary GRBs, and they are classified in X-ray flash (XRF). We report features of XRFs detected by HETE−2 in this paper. A unique feature of the HETE−2 mission is real-time position alert system. We sent out four real-time position alerts in 2002, and sequential optical follow-up observations revealed unexpected behavior of optical transient within a few hours after the burst.

1. The High Energy Transient Explorer 2

Gamma-ray burst (GRB) is the most energetic phenomena in our universe. It has been found in the late 1960's by the Vela spacecraft (Klebesadel et al. 1973), however, it is still unknown what the GRB is. The high energy transient explorer 2 (HETE−2), launched on October 9, 2000, is a small spacecraft designed to study GRBs. The spacecraft is in an equatorial orbit at altitudes between 580 and 630 km, with an increnation angle of 2 degrees. The primary goal of HETE−2 is to determine the origin and nature of GRBs. This is accomplished through the simultaneous, broad-band observation in the soft X-ray, X-ray, and gamma-ray energy ranges, and the precise localization and identification of GRBs. The HETE−2 science instrument consists of a set of wide-field gamma-ray detectors (FREGATE) for energies of 8-400 keV, a wide-field X-ray imaging system (WXM, Shirasaki et al. 2000) for energies of 2-25 keV, and a wide-field soft X-ray imaging system (SXC) for energies of 0.5-10 keV.

Another prominent feature of the HETE−2 mission is its real-time position alert system shown in Fig.1. Since an optical transient associate with a GRB is fading very steeply, it is quite essential to observe the GRB position as quick as possible to detect an optical afterglow. HETE−2 is monitoring sky with wide field

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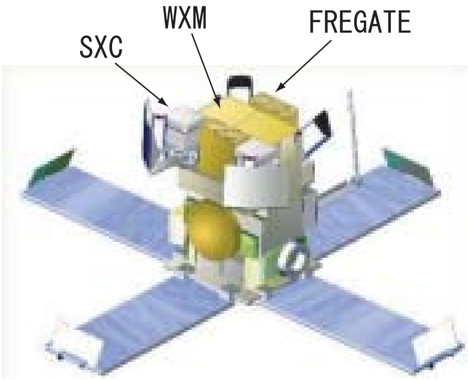

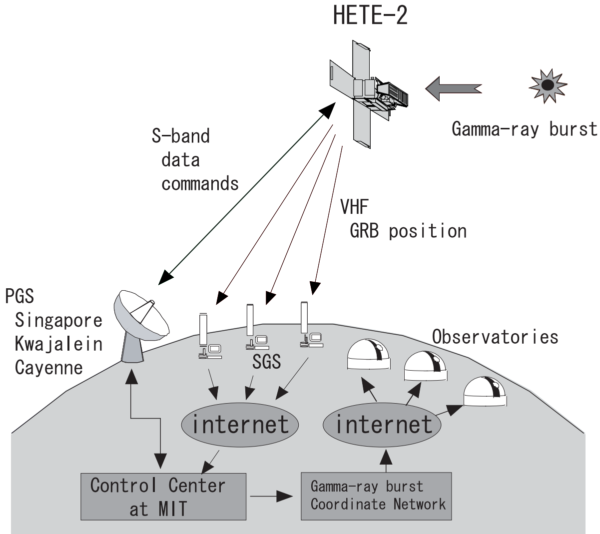

Fig. 1. [Left panel] The HETE−2 spacecraft carries aboard three science instruments, gamma-ray detector (FREGATE, 8-400 keV), Wide-field X-ray monitor (WXM, 2-25 keV), and soft X-ray camera (SXC, 0.5-10 keV). [Right panel] The HETE−2's burst alert system. When a GRB is detected by HETE−2, a summary of the collected burst data is sent to a series of listen-only ground stations distributed around the equator via VHF. These data are forwarded to MIT, where they are distributed to ground observers via the GRB Coordinates Network (GCN). The distribution takes a few 10 second.

of view of $80^\circ \times 80^\circ$. When a GRB is detected, HETE−2 calculates the position automatically with error of a few 10 arcminutes. The position data is, then, sent to the ground via VHF, and the data are distributed to ground observatories via the Gamma-ray Burst Coordinates Network (GCN, http://gcn.gsfc.nasa.gov/gcn/). The sequence takes only about a few 10 seconds from the burst trigger. Compare to the other GRB alert system such as BeppoSAX's, which took about a few hours $\sim$ one day to send out the position of GRB, our alert system enable us to observe the early, so that bright, stage of optical transient associate with the GRB where nobody has ever observed well.

2. X-ray Rich GRB and X-ray Flash

HETE−2 has localized about 20 GRBs per year. Some of the localized GRBs have softer energy spectrum than that of ordinary GRBs. One of the examples, a burst occurred on February 13, 2001, is shown in Fig.2. A clear peak is seen in 2-25 kev and 5-10 keV band, however, there is no X-ray emission in 17 keV and higher energy band. In fact, this kind of burst has been found in the

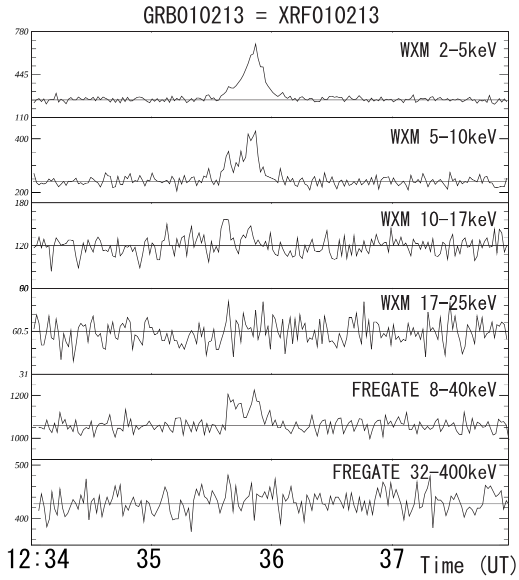

Fig. 2. Light curve of XRF010213; a typical XRF detected by HETE−2. A clear peak in 2-5 keV band is seen, however, nothing is seen in 17 keV and higher energy band. The burst has two peaks. The former one has harder energy spectrum than that of latter one. This spectral evolution is typical for ordinary GRB.

GINGA (Yoshida et al. 1989) and BeppoSAX missions, and the burst is called X-ray rich GRB or X-ray flash (XRF). To compare the BeppoSAX results (Heise et al. 2001), we define the XRF as the burst which has fluence ratio between γ-band (2-25 keV) and X-band (30-400 keV), $log(F_X/F_\gamma)$, larger than 0.3, where fluence is defined as time integrated flux during the burst. We found about 30% of localized GRBs by HETE−2 were XRFs. Since the XRFs localized by HETE−2 had high galactic latitudes, didn't have FRED(fast rise and exponential decay)-like light curves, and were not in a globular cluster, the XRFs were not the same as galactic X-ray bursts (XRBs).

It is well known that an energy spectrum of GRB has described by Band's function (Band et al. 1993); $N(E) = AE^\alpha e^{-E/E_0}$ for $E < (\alpha - \beta)E_0$, and $N(E) = BE^\beta$ otherwise. For observed value of α and β, νF_ν has a peak at E_p which is given by $E_p = E_0(2 + \alpha)$. This is the typical radiation energy of GRB. BATSE observation revealed that E_p localized around 200 keV. Figure 3. shows E_p distribution of detected GRBs (solid histogram) and localized ones (dotted) by HETE−2. The shaded histogram shows E_p distribution of XRFs. The interesting feature is E_p does not localize near 200 keV but spread into lower E_p region. Between GRB and XRF, there is a difference in E_p, but not in the spectral indices, α and β. This suggests that XRF is red-shifted GRB as shown in the

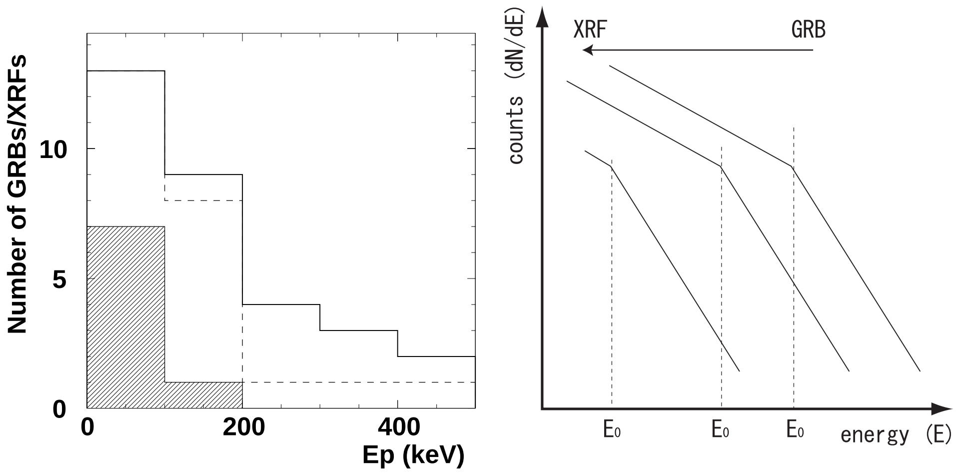

Fig. 3. [Left panel] E-peak distribution of localized GRBs. Hatched histogram shows the distribution of XRFs. XRF is defined as the burst whose fluence ration $log(F_X/F_\gamma) > 0.3$. XRF has lower E_p, but its spectral indices α and β are the same as those of ordinary GRB. [Right panel] One of the possible interpretations of XRF; Lorentz factor of XRF blast wave is lower than that of GRB.

left panel of Fig.3. One of the possible interpretations is that the Lorentz factor of blast wave from unknown central engine is lower than that of ordinal GRB. A detailed study is desired to reveal if XRF is a class of GRB.

3. Real-time Position Alert and Follow-up Observations

HETE's real-time position alert enables us to observe properties of optical transient just after GRBs detection. HETE−2 sent out four real-time position alerts in 2002. On October 4 (GRB021004), a position alert was sent out 48 seconds after the burst just in middle of the burst (∼100-sec duration). With the quick position alert, a robotic telescope Oschin/NEAT detected optical afterglow 9 minutes after the burst trigger (Fox et al. 2002) at R∼15.5. A sky map of the position alert and optical afterglow of GRB021004 is shown in Fig.4. The quick alert followed by the prompt identification of the optical afterglow allowed us to make dense observations in the early stage of the burst. A redshift of the burst was also measured from spectroscopic observation to be z=2.328 (Mirabal et al. 2002). The light curve of the optical afterglow shown in Fig.5. In general, decay of optical light curve is well descrived by simple power-low. However, there was unusual bump around 0.1 days after the burst. There are many explanaions of this bump (Lazatti et al. 2002, Kobayashi et al. 2003), and interesting discussions

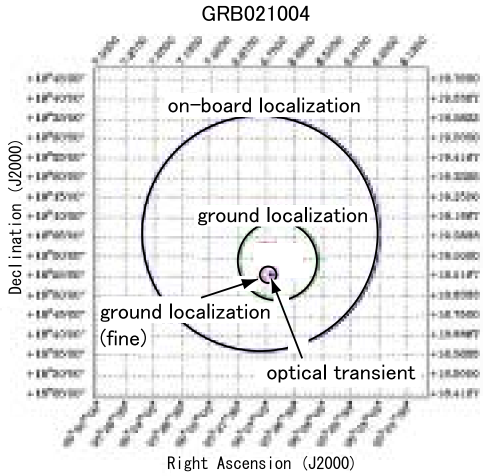

Fig. 4. The skymap of the GRB021004. HETE−2 sent out the position calculated onboard 48 second after the burst was detected, just in middle of the burst duration. We refined the position with downloaded data TBD minutes after the burst. Bright optical transient was detected 9 minutes after the burst.

about the burst environment continue.

Another interesting case is GRB021211. The prompt position alert was sent out 22 seconds after the burst trigger. In this case, a bright (R∼14.5) transient was detected by a robotic telescope KAIT (Li et al. 2002) 108 seconds after the trigger. However, the optical transient faded quite steeply. Two hours after the burst, it became R∼22.5. In a half of GRBs ever localized, optical afterglow have not detected. Such burst is called "dark GRB", and nobody knew if an afterglow is associate with the burst before GRB021211. A discovery of the steeply decaying afterglow with GRB021211 unveiled the "dark GRB". Without our prompt position alert, we never found this type of steeply decaying optical transient, because it is difficult to find fainter object than that of R<18-20 with small telescope which is mainly dedicated for hunting GRB transients.

4. Summary

HETE−2 is a small spececraft to study GRBs. About 30% of localized GRBs are classified into the XRF which has lower E_p than that of ordinary GRB. Our spectral analysis revealed that XRF is the GRB whose blast wave has lower Lorentz factor. HETE's real-time position alert system enables us to observe an

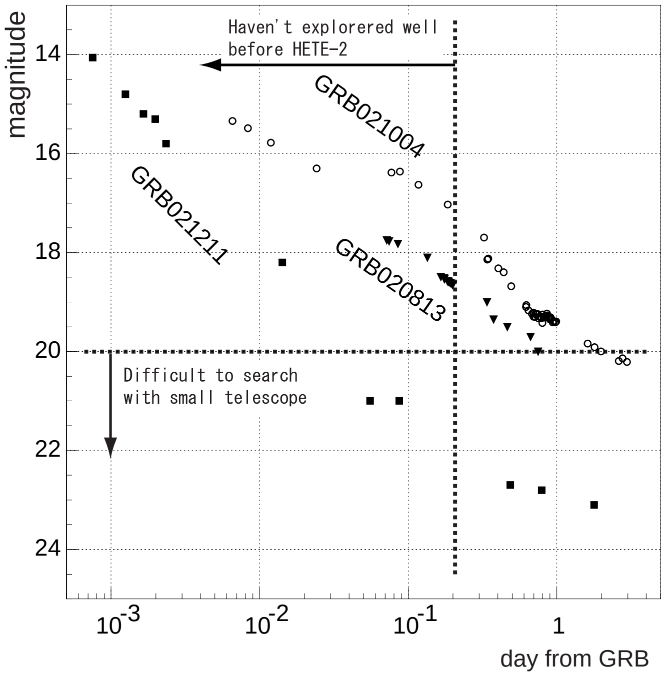

Fig. 5. The light curves of optical afterglows. The region before 0.2 days after the burst had not been explorered well, and it is very difficult to detect optical afterglow in the region of $R > 20$ with small telescopes. HETE's prompt position alert and sequential follow-up observations revealed that unexpected behavior of light curves within a few hours after the burst trigger.

early stage of optical afterglow. In GRB021211, a steeply decaying afterglow was observed, and it unveiled the dark GRB.

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