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THE GAMMA-RAY BURST ALERT SYSTEM AND THE RESULTS OF HETE-2

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Abstract. *HETE-2* (High Energy Transient Explorer Satellite 2) is a small Explorer-class satellite designed to detect gamma-ray bursts (GRBs), localize them in real time and distribute the burst coordinates to ground observers within minutes of burst detection. As of August 2003, *HETE-2* had localized 47 GRBs, and 19 localizations had led to the detection of X-ray, optical or radio afterglows. The prompt position alert enables researchers to probe the nature of so-called "dark bursts" – GRBs for which no optical afterglow has been found despite accurate localizations. Bursts localized by *HETE-2* can be observed more promptly, when the afterglow is intrinsically brighter; thus, afterglows can be detected for bursts which would have otherwise been considered as "dark". In one case of a "dark" burst observed by *HETE-2*, the optical afterglow was found to be intrinsically faint, and its flux declined rapidly. In another case, the optical emission was likely extinguished by the dust in the vicinity of the GRB source.

X-ray rich GRBs or X-ray flashes (XRFs) are found to have many properties in common with classical GRBs, suggesting that they are a single phenomenon. However, optical identification of XRFs has been difficult, perhaps because the counterparts are intrinsically faint; prompt localizations from *HETE-2* will help observers identify optical counterparts to XRFs.

The bright afterglows of GRB 021004 and GRB 030329 were observed in unprecedented detail by telescopes around the world; GRB 030329 was subsequently identified with SN 2003dh, a Type Ic supernova. Consequently, strong evidence for the connection of long GRBs with core-collapsed supernovae was found.

Key words: gamma-rays: bursts – X-rays: flashes – stars: supernovae

1. INTRODUCTION

Before the launch of *HETE-2* we had several open questions concerning GRBs (van Paradijs et al. 2000). Their solution depends on how promptly the locations of GRBs are distributed to multiwavelength observers for further detailed observations. *Beppo-SAX* detected many burst afterglows, but their earliest observations were several hours after the burst explosion (Costa et al. 1997, Feroci et al. 1998). Now *HETE-2* is unfolding the afterglow science after 30 s from explosion (Ricker et al. 2002).

About half of GRBs localized by *Beppo-SAX* did not show bright optical afterglows, but *HETE-2* is finding some new reasons for dim or dark afterglows. A supernova connection with GRBs had remained somewhat doubt before *HETE-2* (van Paradijs et al. 2000), but at present this doubt is extinguished. Energy fluences of X-ray rich GRBs or X-ray flashes (XRFs) are biased to the X-ray region. Although the XRFs had not been optically identified with *Beppo-*

SAX (Heise et al. 2001), *HETE-2* has led to the identification of their optical counterparts. This paper describes performance of *HETE-2* and the remarkable results initiated by this mission.

2. INSTRUMENTS AND PERFORMANCE OF HETE-2

Three main instruments of *HETE-2* are fabricated by international collaboration (Ricker et al. 2002; *HETE-2* home page). The NaI(Tl) scintillation counter (FREGATE) which detects and triggers on bursts is provided by French CESR group (Atteia et al. 2002). A wide field X-ray monitor (WXM) with coded masks is provided by collaborators of Japanese RIKEN and LANL of U.S.A. (Shirasaki et al. 2003), while soft X-ray cameras (SXC) with CCDs and coded masks are provided by MIT of U.S.A. (Villasenor et al. 2002). *HETE-2* operations are run by MIT, supported by many collaborators at several institutes. The WXM can determine the burst location with accuracy of $10'$ or better, while the SXC can determine the location with accuracy of $50''$ or better by acting as a "vernier" on the WXM localization.

Since *HETE-2* has an equatorial orbit, commanding and data collection are well covered with three primary ground stations at sites along the equator. Prompt distribution of burst coordinates is made possible with 13 listen-only "burst alert stations" distributed around the equator. Burst-alert stations receive the localization data calculated automatically by the onboard computer and then send the information via Internet to MIT; from there, the data are relayed to the GCN at GSFC. More precise localizations are calculated on the ground once the full burst data set is received; these are also sent via Internet after a delay of 30–90 minutes. *Beppo-SAX* had to perform the calculation for a burst position on ground and thus the alert was delayed by several hours or more.

Currently, the observation efficiency of GRBs is about 50 %, and the number of localization of GRBs is stationary at a rate of 20–25 GRBs per year. Over time, the *HETE-2* localization delay has become shorter with more experience of the operation. The shortest case of location alert among so far observed bursts is 22 s for GRB 021211 (Crew et al. 2002). An optical transient of GRB 021211 was discovered in 60 s, and its light curve was followed, showing that the optical transient decayed faster than ordinary bursts (Fox et al. 2003a).

3. SOME RESULTS INITIATED BY HETE-2

3.1. Supernova connection with GRB

In the *Beppo-SAX* era it was suspected that GRB 980425 might be associated with SN 1998bw, despite the uniqueness of the result (Galama et al. 1998). The optical transient was found a few weeks after burst of GRB 980425, but it showed an unusual optical light curve different from those of ordinary GRBs. An apparent luminosity of the GRB for z=0.008 of SN 1998bw was also as low as 10^{-6} times that of a typical GRB.

HETE-2 has since detected a monster burst, GRB 030329 (Vanderspek et al. 2003). Its location was distributed 72 min after the burst; an optical transient was discovered two minutes later (Peterson & Price 2003, Torii 2003). The early 10-day optical light curve of GRB 030329 shows a zig-zag decay profile which is similar to ordinary GRBs such as GRB 021004 (Fox et al. 2003b). Optical spectroscopic observations revealed a huge type Ic supernova with z=0.168. The spectrum of the optical transient (i.e., SN 2003dh) was quite similar to that of SN 1998bw (Hjorth et al. 2003), where SN 1998bw is named as a hypernova, a massive core-collapsed supernova, and has been well studied (Iwamoto et al. 1998, Woosley et al. 1999). Thus *HETE-2* has established that this monster burst is connected to supernova, and this connection might be common for other long and hard GRBs.

3.2. Dark GRBs, X-ray rich GRBs and XRFs

An interesting result was obtained in GRB 030115 (Kawai et al. 2003) which was identified by the infrared *JHK* passbands (Kato et al. 2003, Levan et al. 2003). After decay of this IR source it was found that its host galaxy was visible in the *R* band with WIYN and Subaru telescopes (Garnavich 2003, Tsuru et al. 2003). This suggests that GRB 030115 was surrounded by very thick matter within the host galaxy, but the associated galaxy is not heavily reddened. This kind of GRBs would have been categorized as a dark GRB before the *HETE-2* era.

Optical afterglows have not been found for more than half of the well located GRBs despite early and deep follow-up observations. X-ray observations of them to date are consistent with all long GRBs having X-ray afterglows, but the optical afterglows of some of them are found to be intrinsically dim. Near-real time optical follow-up observations of an X-ray rich gamma-ray burst GRB 021211 showed that its afterglow was bright at R$\sim$14 mag at t$\sim$100 s after the burst, but quickly faded and was very much fainter at t$\geq$60 min than those observed previously (Wozniak et al. 2002). Without the prompt localization of *HETE-2*, the optical transient would not have been discovered, and thus this GRB would have been categorized as a dark GRB.

HETE-2 has the ability to trigger on and localize XRFs, which show larger fluences in the 2–30 keV X-ray band than in the 30–400 keV band, and can carry out detailed studies of their properties. The softest event detected by *HETE-2* is XRF 020903 – its spectrum has an observed peak energy of 3 keV with no photons above $\sim$10 keV. The burst is shorter at higher energies, which is similar to the behavior of long GRBs. XRF 020903 lies also on the hard/soft fluence correlation for the other GRBs and X-ray rich GRBs and appears to extend by a decade the hardness-intensity correlation (Sakamoto et al. 2004). These results provide a strong evidence that XRFs, X-ray rich GRBs and ordinary GRBs form a continuum and a single phenomenon.

Recently *HETE-2* made an alert of a localization for XRF 030723 (Prigozhin et al. 2003). Then a faint fading optical transient was discovered in an error circle of *HETE-2* alert by Fox et al. (2003c). However, its redshift value has not been determined because of no spectral structure. The optical transient re-brightened two weeks later, possibly due to associated supernova (Fynbo et al. 2003).

4. SUMMARY

HETE-2 is the first transient explorer with a prompt GRB alert system to distribute GRB position data to observers over the world in times as low as 10 s. Consequently *HETE-2* has been making a great contribution to afterglow science of GRBs. It has revealed various varieties of GRB afterglows. There are more than one kind of "dark bursts": (1) the quick fading cases (e.g., GRB 021211), (2) the bursts absorbed locally in the host galaxy (e.g., GRB 030115) and (3) high z bursts(?). Supernova connection of some of the long GRBs accompanying bright optical transients has been established. X-ray rich GRBs, or XRFs, have the properties that are distributed in sequence with the classical GRBs.

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