Observations of Gamma-Ray Bursts by HETE-2

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Abstract

The High Energy Transient Explorer 2 (HETE-2), launched in October 2000, is currently localizing gamma-ray bursts (GRBs) at a rate of $\sim$20 yr^{-1}, many in real time. As of April 2003, HETE-2 had localized 39 GRBs; 16 localizations had led to the detection of an X-ray, optical, or radio afterglow. In the last four months (January–April 2003), HETE-2 had localized 8 GRBs, among which 7 had afterglows. The prompt position notification of HETE-2 enabled probing the nature of so-called "dark bursts" for which no optical afterglows were found despite of accurate localizations. In some cases, the optical afterglow was

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found to be intrinsically faint, and its flux declined rapidly. In another case, the optical emission was likely to be extinguished by the dust in the vicinity of the GRB source. The bright afterglows of GRB021004 and GRB030329 were observed in unprecedented details by telescopes around the world. Strong evidence for the association of long GRBs with the core-collapse supernovae was found. HETE-2 has localized almost as many X-ray rich GRBs as classical GRBs. The nature of the X-ray rich GRBs and X-ray flashes have been studied systematically with HETE-2, and they are found to have many properties in common with the classical GRBs, suggesting that they are a single phenomenon.

1. Mission overview

The primary goals of the HETE mission are the multiwavelength observation of GRBs and the prompt distribution of precise GRB coordinates to the astronomical community for immediate follow-up observations [16]. To achieve these goals, HETE-2 is equipped with one gamma-ray (French Gamma Telescope; FREGATE [1]) and two X-ray detectors (Wide-Field X-ray Monitor; WXM [9] and Soft X-ray Camera; SXC [21]), which share a common field of view of $\sim$1.5 steradians, and, together, are sensitive to photons in the energy range of 2 keV to over 400 keV. The two X-ray detectors are coded-aperture imagers. Sophisticated on-board processing software allows the location to be calculated on board in real time, and ground post-burst analyses will provide refined localizations. The typical accuracy (90% error radius) is 30 arcmin (WXM real-time flight localization), 10 arcmin (WXM ground analysis), and 2 arcmin (SXC ground analysis) [20].

2. Optically Dark GRBs

Optical afterglows had not been found for more than half of the well-localized GRBs despite early and deep follow-up observation, while X-ray observations to date are consistent with all long GRBs having X-ray afterglows. HETE-2 is solving the mystery of these "optically dark" GRBs.

In some cases, the optical afterglows are found to be intrinsically dim. Near-real time optical followup observations [4],[15],[13],[22] of an X-ray rich gamma-ray burst GRB021211, which was localized by HETE-2 in real time [3], showed that its afterglow was bright at R$\approx$14 at $t \approx 100$ seconds after the GRB, but quickly faded and was very much fainter at $t > 60$ minutes than that have been observed previously. Without the prompt localization of HETE-2, the optical transient would not have been discovered, and this GRB would have been categorized as a dark GRB. Upper limits or measurements of the optical afterglows of the HETE-2 localized bursts GRB011130, GRB020903, and GRB021211, which are all "X-ray Rich" GRBs or X-ray Flashes [17], suggest that such GRBs have optical afterglows that are very faint.

Rapid follow-up observations of the HETE-2 localized burst GRB030115 [10] revealed an infrared afterglow [12],[8], while the optical afterglow was very dim. In this case, the optical afterglow is likely to be extinguished by dust in the vicinity of the GRB or in the star-forming region in which the GRB occurs, supporting the core-collapse origin of the GRBs.

Another possible reason for the optically dark GRBs is that the optical afterglow is absorbed by neutral hydrogen in the host galaxy and in the intergalactic medium due to very high redshift. No such case has been identified yet.

3. Detailed light curve study

The early discoveries of optical transients also enabled the study of their light curves in details, which were not possible before. In the light curve of the optical afterglow of GRB021211 from 104 seconds after the start of the burst to $\approx$ 170 minutes after the burst [13], the transition from the reverse shock component [18] to the forward shock component is clearly visible. Comparison with light curves with other GRBs shows that the light curve of the afterglow of GRB021211 tracks that of the afterglow of GRB990123 but is three magnitudes fainter. GRB021004 and GRB030329 were observed by tens of telescopes around the world thanks to the very early discovery of bright optical afterglows. Deviations from the simple power-law description of the decay are common. Continuous energy injection is discussed to account for the plateau in the very early light curve of the afterglow of GRB021004 [5]. Repeated breaks, flattenings, and rebrightenings has been found in the light curve of GRB030329 afterglow, which can be caused by the additional repeated injections of explosion energy, and/or variation in the circumstellar density. Evidence for the supernova components was found to emerge in the optical spectrum of the GRB030329 afterglow [6], establishing the association of (at least some of) the long GRBs with the core-collapse type supernovae.

4. Classical GRBs, X-ray Rich GRBs, and X-ray Flashes

Besides classical GRBs, HETE-2 is detecting X-ray flashes (XRFs), which have large fluence in the 2–30 keV X-ray band [7]. Other than their spectral energy distribution, their properties such as time profile [19], spectral evolution, and sky distribution, are similar to those of classical GRBs. Unlike previous missions (Ginga, BATSE, and BeppoSAX), HETE-2 has the ability to trigger on and localize XRFs, and can carry out detailed studies of their spectral properties, using FREGATE and the WXM. The softest event HETE-2 detected is XRF020903: the spectrum has an observed peak energy $E_{\rm peak}^{\rm obs} \sim 3$ keV and no photons were detected above ~ 10 keV [17]. The burst is shorter at higher energies, which is similar to the behavior of long GRBs. We find that the spectral properties of

“X-ray rich” GRBs form a continuum with those of ordinary GRBs and suggest that XRFs may represent a further extension of this continuum. XRF 020903 lies 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 [14]. These results provide strong evidence that XRFs, X-ray-rich GRBs, and GRBs are a single phenomenon.

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