Mem. S.A.It. Suppl. Vol. 5, 166


**Memorie** della
**Supplementi**

# The HETE-2 satellite: detection of Gamma-Ray Bursts and other transient phenomena

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**Abstract.** HETE-2 (High Energy Transient Explorer) is a small scientific satellite whose main task is to detect Gamma-Ray Bursts, promptly determine their coordinates, when possible, and distribute them immediately to the scientific community. HETE-2 has detected many of the most interesting events in recent years: GRB030329, which confirmed beyond any doubt the Gamma-Ray Burst - Supernova connection; GRB021211, also connected to a SN, in this case at high redshift; and other well observed and studied bursts, for example GRB021004 and GRB030226. The prompt localization by HETE-2 of a "short" GRB allowed the first detection of an X-ray afterglow for this class of events. The energy range of the HETE-2 detectors, which starts at a few keVs, has allowed extension of the study of spectral and global properties of "classical" GRBs to the softer X Ray Flashes and X-Ray Rich events and the first redshift determination for a X-Ray Flash. HETE-2 has detected also hundreds of X-ray bursts and events from Soft Gamma-ray Repeaters; in some cases it was the first experiment to find that one of those sources had entered a new active phase.

**Key words.** gamma rays: bursts – X rays: bursts – magnetars

## 1. Introduction

The satellite HETE-2 (Ricker et al. 2003) was put in equatorial orbit on October 9, 2000, after the unsuccessful launch of HETE-1 on November 4, 1996. The second High Energy Transient Explorer, henceforth simply HETE, is mostly devoted to the detection and prompt localization of Gamma-Ray Bursts. It carries the French Gamma Telescope (FREGATE) (Atteia et al. 2004), built by CESR, in Tolouse, France, the wide field X-ray Monitor (WXM) (Kawai et al. 2003), built by the RIKEN laboratories in Japan and the soft X-ray camera (SXC) (Villasenor et al. 2003a), built by CSR at MIT in Cambridge. They are sensitive to photons in the 6 - 400 keV, 2 - 25 keV and 0.5 - 10 keV respectively. WXM, with a field of view (FOV) of 1.6 sr at FWZM, and SXC, with a FOV of 0.91 sr, can achieve localization accuracy of 10 arcminutes and 0.5 arcminutes respectively. Since January 11, 2001 to June 30, 2004 HETE has triggered on 179 GRBs and localized 60 of them. Some untriggered events are recovered by further ground analysis. FREGATE detects bursts in a FOV of 3 sr,

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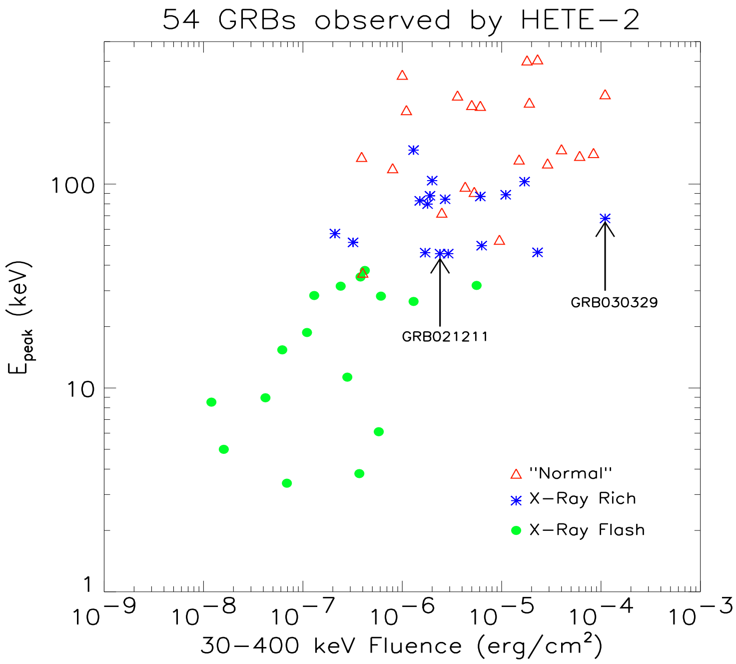


**Fig. 1.** The $E_{peak} - (30-400keV)$ Fluence scatter diagram for 54 GRBs localized by HETE-2 and listed in the HETE burst page at `http://space.mit.edu/HETE/Bursts/Data/`; we use the definition of Lamb et al. (2004), that is the ratio $S_X(2-30keV)/S_\gamma(30-400keV)$ is $> 1./\sqrt{10}$ and $\leq 1.$ for X-Ray Rich bursts and $> 1.$ for X Ray Flashes, where S is the fluence in that energy range.

but does not localize them. In some cases the events were inside the FOV of the two position sensitive instruments but not enough photons were collected.

A detailed description of the whole experiment, burst list and data archives are available at HETE's web page: `http://space.mit.edu/HETE/`.

## 2. Global properties of GRBs observed by HETE-2

The fact that HETE's energy range starts at 6 keV for FREGATE, 2 keV for the WXM and 0.5 keV for the SXC, lower than most GRB detectors, makes it particularly sensitive to softer events, called X-Ray Flashes (XRF) and X-Ray Rich (XRR) bursts. Figure 1 gives the definition of XRF and XRF and shows the distribution of the HETE localized events for which it was possible to obtain this classification. Redshift measurements are available for 12 of those events. For them it is possible to check that they follow both the $E_{peak} - E_{iso}$ Amati et al. (2002) relationship, extending it to decades lower in $E_{iso}$, (Lamb et al. 2004) and the more recent one by Ghirlanda, Ghisellini & Lazzati (2004) and showing that in this respect XRFs and XRRs do not differ from "classical" GRBs. This property might be very important for the Supernova-GRB connection: we recall that the four GRBs which, until now, have been certainly found to coincide with a Supernova (Galama et al 1998; Stanek et al. 2003; Hjorth et al. 2003; Della Valle et al. 2003) were all XRFs.

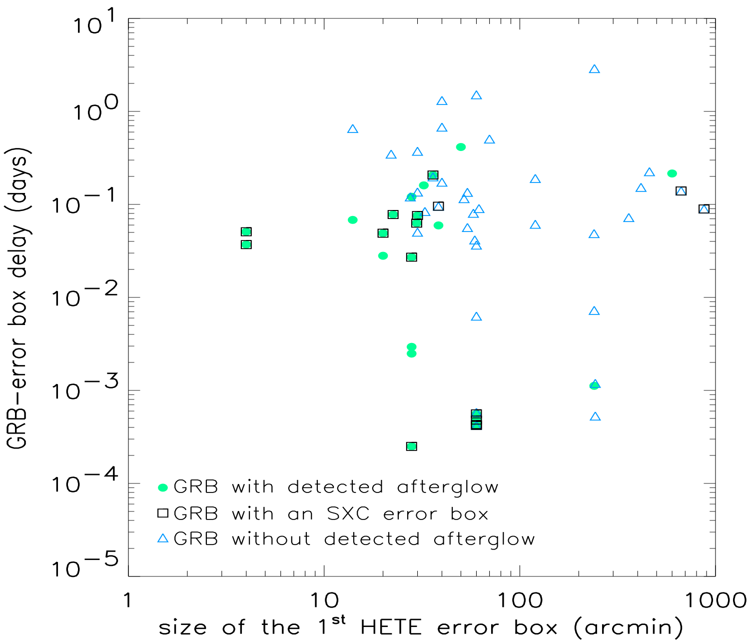


**Fig. 2.** The delay in days of the first optical observation versus the size of the first HETE GRB error box.

## 3. The importance of prompt and precise GRB localizations

HETE can determine very small GRB error boxes in very short times. For GRB021211 the initial error box was 28 arcmin in diameter, which is not the smallest possible size for an HETE localization of a GRB, but it was released only 22 seconds after the event. The initial error box for a GRB detected by HETE has been as small as 4 arcmin., with a delay of 53 minutes. That was the case for GRB030328. Error boxes are later refined, either on-board or later by ground computations: the size has been as small as 1.73 arcmin., again for GRB030328.

Figure 2 shows that, although it is not impossible to detect an afterglow, optical or otherwise, for events with large error boxes, or at least with a large first error box, most GRBs with a detected afterglow concentrate preferably, as could be easily expected, in the small error box - small delay region.

In Figure 3 we now consider the magnitude of the OT at the first optical observation, or the limiting magnitude of the first observation, when the OT was not detected, and the size of the error box at the time of that observation, which is not necessarily still the first error box determined by HETE, because in the meantime it might have been updated.

Here the connection between the two quantities is less evident, because the limiting magnitude depends on many more factors, for example the telescope used, the weather at the observation site, the moon and choice of filter, but, again as we could easily guess, the size of the HETE error box clearly makes a difference: none of the events without a detected OT have an error box size smaller than 10 arcmin., while 7 out of 19 events with detected OT are in that region.

A very important HETE result, which is certainly connected to the size of the error box and its prompt release is the fact that for 15 of the 18 bursts localized by the SXC an af-

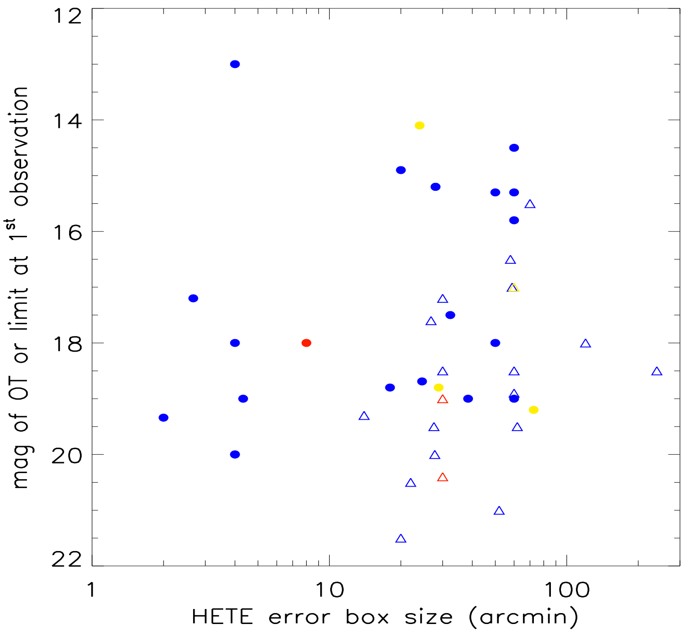


**Fig. 3.** Magnitude limit of the first optical observation of the error box, or of the Optical Transient at the first observation, versus size of the first HETE GRB error box. Dots: GRBs with detected afterglow; triangles: afterglow was not detected; orange for unfiltered observations, blue for Johnson Rc and red for Johnson Ic filters. All data derived from the GRB Coordinates Network at `http://gcn.gsfc.nasa.gov/`.

terglow, either optical, or radio or X-ray was detected: of the remaining three, there is however a detection of a likely host galaxy for XRF030823 by Fynbo et al (2003); the other two events, XRR040319 (Sato et al. 2004) and GRB040423 (**?**), were localized by the SXC only in one direction, thus they had narrow, but long error boxes, 2.6 arcmin by 8.3 degrees for XRR040319 and 3 arcmin by 11 degrees for GRB040423, in which the search for an afterglow was much less likely to be successful.

## 4. An abridged results list

We give here a very brief list of some of the most noticeable GRBs detected and localized by HETE: it includes GRB010921 (Ricker et al. 2002), the first HETE burst for which optical afterglow and host galaxy were detected; GRB020531 (Lamb et al. 2002, 2003a), the only ??? instance of a promptly localized short, hard burst and the only one for which an X-ray afterglow and a candidate host galaxy have been found (Butler et al. 2002; Fox, Kulkarni & Weissman 2002; Kulkarni et al. 2002): and very stringent limits were put on the existence of an OT (Klotz, Boer & Atteia 2003); GRBs 020813, 020903 (Sakamoto et al. 2004), 021004 (Doty et al. 2002), 030226 (Suzuki et al. 2003), 030328 (Villasenor et al. 2003b) and 030723 ( Prigozhin et al. 2003), events whose afterglows were very well followed by many observers. Even for the most recent one, GRB040511 (Dullighan et al 2004), the OT (Fox et al. 2004) has been identified. The best known event detected by HETE is by far GRB030329 (Vanderspek et al. 2004), whose coincidence in time and space with SN2003dh (Stanek et al. 2003; Hjorth et al. 2003), earned it the definition of "Rosetta Stone" of the GRB-

SN connection, since it provided unambiguous proof for it for the very first time. More proof of the GRB-SN connection was later detected by Della Valle et al. (2003) for HETE burst GRB021211 (Crew et al. 2003) and SN 2002lt at redshift = 1.006 (Vreeswijk et al. 2003), the highest one as yet measured for a SN coincident with a GRB.

We point out that the early optical afterglow of GRB021211 was similar in time behaviour to those of many other events, but its magnitude was constantly higher by about 3 units, not surprisingly so, because of the redshift much higher than those of GRB Supernovae: 1998bw, z = 0.0085 (Galama et al 1998), 2003dh, z = 0.1685 (Greiner et al. 2003) and 2003lw, z = 0.1055 ( Prochaska et al. 2003, 2004).

Here we stress the fact that without the promptness of HETE, which released the first error box, with a 28 arcmin diameter, 22s after the event and a 4 arcmin error box after 2h 11m, the afterglow might very likely have been missed. The HETE grb information can be retrieved at `http://gcn.gsfc.nasa.gov/hete_grbs.html` , maintained by Scott Barthelmy.

## 5. Other HETE-2 observations

The energy range of the instruments on HETE-2 is very well appropriate to detect events from Soft Gamma Repeaters and from X-ray bursters. As can be be seen by inspecting the publicy available burst catalog at `http://space.mit.edu/HETE/Bursts/summaries.html`, HETE-2, in about 3.5 years, has detected hundreds of X-ray bursts and SGR events: of them, 419 and 134 respectively triggered FREGATE from January 11, 2001 to June 30, 2004. For them prompt alerts are not released via GCN messages, which are released only for GRBs, in order to allow follow-up observations. However, since SGR sources can be inactive for long time intervals and produce many events when they become active again, GCN messages can be released when HETE observations show new activity. This is the case, for example, with Ricker et al. (2001) and Golenetskii et al. (2002) The wide HETE field of view allows it to monitor for new SGR sources: a possible one, SGR1808-20 was found (Lamb et al. 2003b).

## 6. Conclusions

HETE has detected some of the most interesting GRBs in recent years, in particular the famous GRB030329, which definitely confirmed the SN-GRB connection and one of the other three SN connected GRBs, plus many SGR events and X-ray flashes. After 3.5 years in orbit the HETE instruments, FREGATE, SXC and three of the counters of the WXM instruments are operating normally. The Yb counter of the WXM is no longer operating since Jan. 11, 2003, probably because of impact with a micrometeorite, with a reduction of 25% of the total effectve area and of 20% of the solid angle in which a two dimensional localization can be obtained by the WXM. However, since that date HETE has localized some of its most famous events, such as GRB030226, GRB030329 and GRB030723. A part from possible accidents like the one above mentioned, the HETE instruments are expected to be able to continue their performances for several years yet.

*Acknowledgements.* This research has made use of data obtained from the HETE science team via the web site `http://space.mit.edu/HETE/Bursts/Data` Part of this work was supported by the Italian Space Agency (ASI).

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