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GABI: a compact detector for GRB prompt emission spectroscopy

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Abstract. Triggering on sky transient events can be efficiently accomplished by coded mask instruments, which can also provide positions with arcmin or sub-arcmin accuracy, but at the expense of weight and power. On the other hand good broadband spectroscopy is possible using much lighter systems, that could also provide a coarse positioning capability (∼ degrees). We present the concept of a compact, light detector based on NaI(Tl) scintillator, that can be used to complement other soft X-ray or IR/optical telescopes in detecting transients and characterizing them. The Gamma-Ray Burst Imager (GABI) will operate in the energy range 8-1000 keV that is optimal for the detection of the prompt emission of Gamma-Ray Bursts (GRB). GABI is being proposed for accomodation on board Lobster, a candidate mission of the NASA Explorer Program.

Key words. X-rays: general – Gamma-Rays: detectors – Space: instrumentation – Gamma Ray Bursts: observations

1. Introduction

The detection and localization of Gamma-Ray Bursts (GRB) is a main scientific driver for space astrophysical missions of the present and future times, especially after the discovery that they can be used as effective probes of the early Universe (Bromm & Loeb 2007). The demand for more sensitive instrumentation, capable to study in more detail the GRB characteristics, has grown considerably in the past years. A number of recent proposals for new missions rely considerably on this concept, see e.g. Grindlay et al. (2010); den Herder et al. (2011). In fact, GRB explosions carry important information on the physical conditions of the media in which they develop (their host galaxies) and propagate through (the intergalactic medium). The main challenge is to

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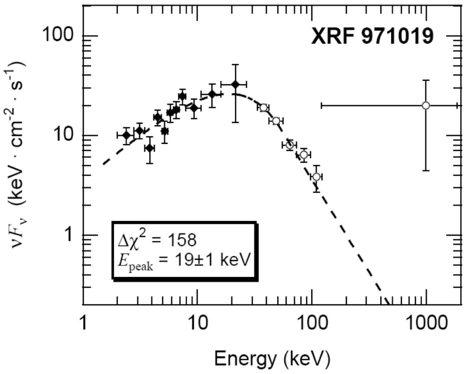

Fig. 1. The broadband spectrum of XRF971019 detected from the BeppoSAX/WFC and BATSE (Kippen et al. 2002).

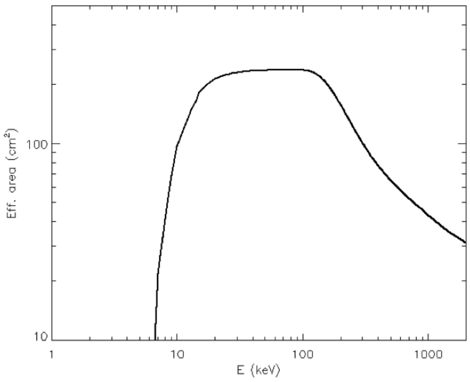

Fig. 2. Effective area for a single unit of GABI.

collect as much as possible information from these sources during the short time frame of the GRB emission. It is possible to determine the redshift of their hosts, by the observation of the afterglow emission of a GRB with an IR/optical telescope, that can detect the location of the Lyman-α break in its spectrum. The position of a GRB can be provided either by a sensitive wide field coded mask monitor, or by Lobster-eye X-ray telescopes. These devices may be limited to a rather narrow band, i.e. a few keV while it would be useful to cover the full energy range of the high energy emission of a GRB. As shown in the example of Fig. 1, even in the case of the softer class GRBs, only the broad coverage from soft X-rays to γ-rays allows to determine the spectral parameters of the bursts. The range extension is also useful to identify true GRB events from many other types of soft X-ray transients.

In the following we describe the design of a lightweight, compact detector that could extend the energy range of the GRB detection in missions dedicated to GRB studies. The instrument is based on a set of Na(Tl) scintillators with autonomous trigger capability and moderate spectroscopic performance.

2. Instrument description

2.1. GABI concept

The basic requirement is to provide broadband spectroscopy for GRBs in the range 10 keV to $\sim$ 1 MeV and the capability of autonomous triggering on transient events. The instrument is based on a combination of NaI(Tl) scintillator units that are viewing different portions of the sky through slat collimators made of high-Z material. The use of a collimator allows shielding against diffuse X-ray background while the different orientation of the units permits to cover a larger fraction of the sky, essential to increase the number of GRB detected. The best tradeoff between FOV and sensitivity indicates the optimal configuration for the instrument, see e.g. Salvaterra et al. (2008). Although each unit of GABI is designed to be independent from the others, the triggering software in its on-board electronics is required to provide the trigger signal and best positional estimate taking into account the number of units and their viewing directions.

The main parameters of GABI are listed in Table 1. The values of total mass and power have been estimated by the baseline design described in Sect. 2.2.

2.2. Design and operations

GABI is designed for the study of the broadband (8-1000 keV) emission of GRB in the

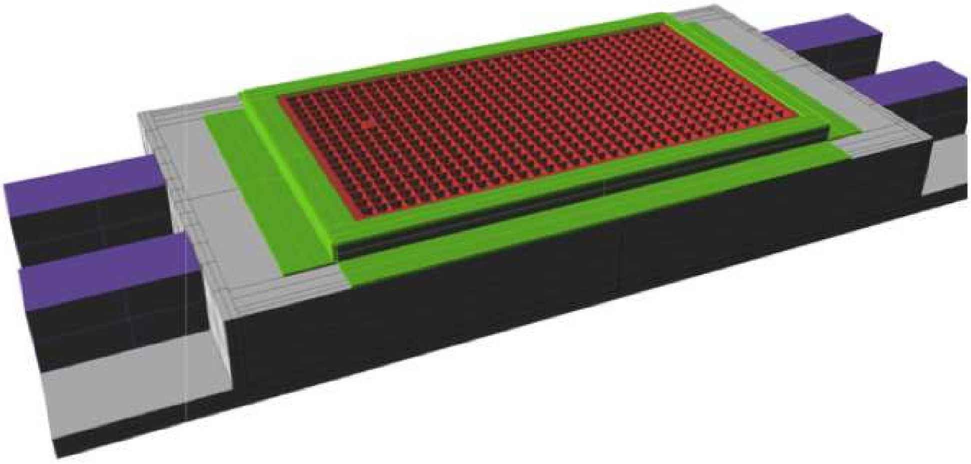

Fig. 3. Design of the single scintillator assembly. The slat collimator is visible on the top (red/green). The grey structure is the Carbon Fiber Reinforced Plastic (CFRP) support enclosing the NaI crystal and the light guides.

Table 1. GABI main performances assuming 3 scintillation units. Mass and power estimates are including a 20% contingency.

Energy Range	8 − 1000 keV
Field of View	~ 1 sr
Effective Area	> 200 cm^2 within 0.5 sr
Energy Resolution	13% (FWHM at 100 keV)
5σ Sensitivity	~ 10^{-9} erg cm^{-2} s^{-1}
Total Mass	16.5 kg
Power	10W

prompt phase. It is composed by three or four units of NaI scintillation crystals, each having a detection area of 240 cm^2. Each crystal is 1 cm thick and with a slat collimator on top of its window, in order to improve the sensitivity below ~ 150 keV. The height of the collimator can be tuned to the desired value of FOV. For the present baseline the collimator aperture is 30.4 square degrees, that could be suitable to complement the detection by wide-field (~ 10 − 20 deg aperture) soft X-ray imagers. This would match the characteristics of a mission such as Lobster (Gehrels 2011), see Sect. 3. Fig. 2 shows the effective area of a single unit.

A view of the single unit assembly is shown in Fig. 3. A single 12×20 cm^2 NaI crystal is enclosed in aluminum housing, with a thin Al window on the entrance side. This is viewed on each lateral side by 2 photomultiplier tubes (PMT). PMTs are connected to the crystal by means of light guides. The current baseline is to use Hamamatsu R8900U-100 phototubes, with a 5.5 cm^2 entrance window. The crystal, PMTs and light guides are enclosed in a CFRP support structure, having an internal mechanical grid to support the crystal. The overall lenght of the unit is 39.2 cm.

The background rate of a single module is estimated of the order of ~ 600 c/s in Low Earth Orbit. A bright source like the Crab Nebula will provide ~ 140 c/s. Since the design is based on multiple units (typically 3-4) a digital electronics unit, the GABI Control Box

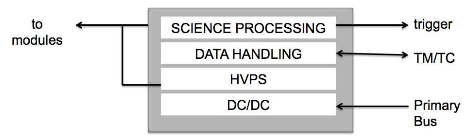

Fig. 4. Functional diagram of the GABI control box.

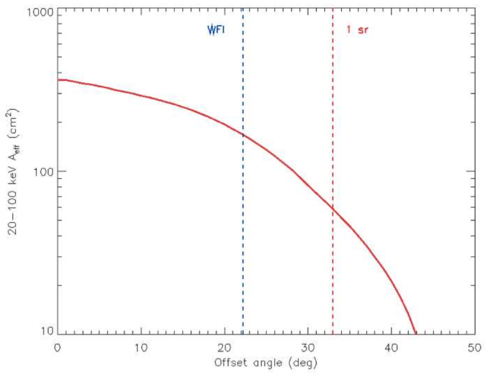

Fig. 5. Effective area of GABI as a function of the angle offset from the spacecraft main axis.

(GCB) will be devoted to command and receive analog signals from the modules PMTs, to distribute the power to the units and perform digital HV adjustment and gain control (see Fig. 4). The GCB will also contain the Science Processing Unit (SPU) based on FPGA that will generate trigger signals for the spacecraft control unit. The data in normal (i.e., non trigger) operations is organized in low rate science telemetry as integrated spectra/timing information.

3. A study for the Lobster mission

We study a possible configuration of GABI for accomodation on board the Lobster mission. This is a proposed NASA Explorer mission based on a powerful combination of Lobster-eye telescopes and an IR telescope (Gehrels 2011). GABI could complement the Lobster payload by provide wider sky coverage and spectroscopy for the GRB prompt emission.

A minimal configuration with three tilted units can provide a coverage of > 200 cm^2 (see Fig. 5). In this case the units are designed to cover the FOV of four Lobster-eye X-ray telescopes and are tilted respect to the spacecraft pointing axis by 15 deg, each with a different azimuthal orientation. GABI can be very effective for the detection of GRB events in the FoV of the Lobster Wide Field Imagers (WFI) and up to $\sim$ 1 sr. It will measure GRB broadband spectra and help minimize the false triggers. In this case, GRB with prompt fluence greater than a few 10^{-7} erg/cm^2 will be amenable to study in combination with the WFI.

4. Conclusions

GABI is proposed as a small, consolidated technology payload for improving the scientific performance of GRB missions. Although the mass and power resources required by the instrument are very limited, its return in terms of additional triggering capability, broadband spectroscopy and wider FOV coverage is remarkable. A pre-phase A study is being conducted for possible implementation with the Lobster mission and a prototype is being developed in Italy. The study is supported by simulations of the background and scintillator response, including light transport in the crystal and optical devices.

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