Gamma-Ray Burst Studies With the Energetic X-ray Imaging Survey Telescope (*EXIST*)

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The Energetic X-ray Imaging Survey Telescope (*EXIST*) is a sensitive, wide field of view hard X-ray (10 – 600 keV) coded-aperture telescope. This paper describes the capabilities and characteristics of *EXIST* as proposed to NASA's Medium - Class Explorer (MIDEX) program. A larger version of *EXIST* is being studied as a NASA New Mission Concept. In addition to its primary science objective, which is to carry out the first high-sensitivity (0.5 mCrab) hard X-ray imaging survey (14′ resolution) of the entire sky, *EXIST* has a number of important Gamma-Ray burst (GRB) objectives which include: 1) A sensitive observation toward M31 to search for an extended burst halo to confirm or eliminate models in which isotropically emitting burst sources are distributed in an extended ($\sim$ 200 – 400 kpc) Galactic halo. 2) Sensitive wide FOV monitoring to probe the GRB log$N$-log$P$ distribution an order of magnitude fainter than BATSE 3) Rapid dissemination of accurate (30″) burst positions for ground-based followup. 4) High time-resolution (100μsec) burst observations. 5) High quality (ΔE = 4.4 keV FWHM @ 60 keV) measurements of GRB spectra.

INTRODUCTION

The Energetic X-ray Imaging Survey Telescope (*EXIST*) is a sensitive, wide field of view hard X-ray (10 – 600 keV) coded-aperture telescope. This paper describes the capabilities and characteristics of the *EXIST* experiment as proposed to NASA's Medium - Class Explorer (MIDEX) program. A larger version of *EXIST* is being studied as a NASA New Mission Concept (3). *EXIST* 's primary science objective is to carry out the first high-sensitivity (0.5 mCrab) hard X-ray imaging survey (14′ resolution) of the entire sky. In addition, *EXIST* has a number of important Gamma-Ray Burst (GRB) objectives, described in the following section. In this paper, we also provide a technical overview of the instrument, and point out its principal characteristics.

TABLE 1. Number of excess bursts detectable in 3 months towards M31 vs. a control field as a function of $R_{\rm BATSE}$.

Model: Galactic Corona			
$R_{\rm BATSE}$	# excess bursts	$R_{\rm BATSE}$	# excess bursts
150	36	300	105
250	76	400	98
Model: Cosmological		# excess: 0	
Control Field (3.5×80°)		<10	

GAMMA RAY BURST SCIENCE OBJECTIVES

One of the primary GRB objectives of *EXIST* is to perform a long, sensitive observation to search for an extended burst halo around the galaxy M31. If burst sources radiate isotropically, and are distributed in an extended halo of size $\gtrsim$ 150 kpc around our Galaxy, *EXIST* will be able to detect an excess of bursts in the direction of M31, and thus test extended halo models consistent with the BATSE data where burst sources radiate isotropically. The required instrument sensitivity is a factor $\sim (D_{\rm M31}/R_{\rm BATSE})^2 = (670kpc/150kpc)^2 = 20$ lower than the BATSE threshold, where $R_{\rm BATSE}$ is the characteristic distance to BATSE's weakest bursts, and $D_{\rm M31}$ is the distance to M31. The range of acceptable halo sizes (150 – 400 kpc) implies that M31's corona will subtend 20° – 60° on the sky, and thus a large FOV must be observed to detect bursts from M31.

EXIST has a detection threshold over the central portion of its FOV which is a factor 25 – 30 lower than the BATSE threshold. Coupled with a large FOV, *EXIST* is ideally suited to observe a burst halo surrounding M31. To illustrate expected detection rates, we have calculated the number of excess bursts expected in a three month observation towards M31 assuming a radial distribution for the burst corona appropriate for a dark matter halo (4), and standard candle GRB luminosities (in peak flux as measured over the BATSE band). Under these assumptions BATSE detects all bursts up to a sharp cutoff at distance $R_{\rm BATSE}$. Table 1 shows the number of excess bursts detectable by *EXIST* from M31 in 3 months as a function of $R_{\rm BATSE}$ in the central $3.5 \times 80°$ FOV (where the burst detection sensitivity is highest). An upper limit to the number of bursts expected in three months in a control field (away from M31) of the same size (taken from survey data) is 10, calculated by extrapolating the BATSE $\log N - \log S$ directly to the *EXIST* threshold. The dark matter distribution is somewhat arbitrary, and only chosen for illustration. Similar sensitivity requirements for isotropic bursts are found by considering distributions derived from a detailed model where burst sources are born in the disks of the Milky Way and M31 and move in a realistic Galactic potential (2).

In addition to the M31 objective, *EXIST* observations will provide fast, accurate burst localizations, high time-resolution, and high signal to noise observations of burst spectra. The primary GRB science capabilities are sum-

TABLE 2. Burst Science Capabilities Summary

detection threshold (10 – 600 keV)	5×10^{-9} erg cm^{-2}
positioning	$30'' - 5'$ [a]
time resolution	100 μsec
spectral resolution	4.4 keV @ 60 keV

[a]limits indicate strong source(systematic) – weak source

marized in Table 2. Accurate burst positions of $30''$ – $5'$ will be derived for 150 – 300 bursts (dependent on the shape of the log$N$-log$P$ distribution below the BATSE threshold). This number of accurate burst locations will provide tighter constraints on burst repetition. Using a limited portion of the detector area, ~40 of these will be reconstructed immediately and sent to the ground within 60 seconds for followup observations. In addition, *EXIST* has spectral coverage to low energy, and good energy resolution with large collecting area. Each photon is individually time tagged with 100 μsec resolution and sent to the ground, enabling high time-resolution studies of burst profiles.

INSTRUMENT DESCRIPTION

The *EXIST* experiment consists of two large-area, wide FOV coded aperture telescopes with $14'$ angular resolution. Gamma rays incident on each telescope cast a shadow of the mask onto a 2300 cm^2 position-sensitive solid state detector array which operates in the 10–600 keV band. Subsequent post-processing of the shadow pattern yields an image of the sky. The pointing axes of the two telescopes are offset by 40° in one direction, yielding a combined field-of-view of 80° × 20° FWHM above 80 keV. At lower energies the count rate due to cosmic diffuse flux is reduced to acceptable levels and the sensitivity is maximized by a dual collimator which cuts the FOV to 3.5°× 40° FWHM for each telescope (with a combined FOV of 3.5°× 80°) below 40 keV. To decrease the detector background, a 2-cm thick active BGO shield covers the rear and sides of the detector array. The primary instrument characteristics are summarized in Table 3.

EXIST is designed to have a count rate dominated by diffuse aperture flux for energies less than 200 keV. This is accomplished through the use of an active shield and energy-dependent collimation. Since the effective aperture of each telescope is more than a factor 280 smaller than for an individual LAD at 40 keV, and a factor $\gtrsim$50 smaller at 100 keV, the instrumental background relative to BATSE is greatly reduced. *EXIST* has comparable geometric area to a LAD, minimal grammage of material in the aperture (and thus high detector quantum efficiency), and thus high detection sensitivity over the energy range 10 – 200 keV. Since the *EXIST* energy band optimal for burst detection (10 – 150 keV) is different from that of BATSE, the burst detection threshold relative to BATSE was determined by folding the sample of bright

TABLE 3. Instrument Characteristics and Telescope Configuration

Instrument Characteristics	
Energy Range	10-600 keV
Angular Resolution	14 arcmin
Field-of-View	$80° \times 3.5°$ ($\leq$ 40 keV); $80° \times 20°$ ($\geq$ 80 keV)
Orbit	Low Earth Orbit (nominal 30° inclination)
Survey	~60% sky coverage each orbit Full-sky each two months Survey sensitivity: < 1 mCrab (10-200 keV)
Survey Scan Motion	Optimized; pointing axis always < 15° from zenith
Baseline Telescope Configuration	
Number of Telescopes	2 - pointing axes offset by 40°
Detectors Detector Area Energy Resolution Detector Array	CdZnTe (5 mm thick) 2300 cm^2 per telescope 3.7 keV FWHM @ 10 keV, 4.9 keV FWHM @ 100 keV 160×160 pixels each telescope, 3 mm in size
Shield	Bismuth Germanate (2 cm thick)
Collimator	Titanium and Tantalum/Tin Slats
Mask Mask Size Mask-Detector Spacing	URA Coded-Aperture (Tantalum/Tin/Copper) 1.59 m $\times$ 1.03 m 1.5 m

BATSE Spectroscopy detector GRB spectra characterized by Band *et al.* 1993 through the LAD response (assuming an optimal angle for burst detection midway between two detectors) and through the *EXIST* instrument. For similar trigger timescales *EXIST* has an average burst detection threshold a factor 15 lower than BATSE.

Further sensitivity improvement is realized by *EXIST*'s ability to search for bursts on longer timescales than the maximum 1 second BATSE trigger. The longer burst search intervals possible for *EXIST* are made feasible by two important characteristics; 1) each photon is individually time tagged and telemetered to the ground, making search intervals adjustable, and 2) simulataneous signal and background monitoring resulting from the imaging nature of the experiment, allowing time-varying backgrounds to be properly subtracted. By allowing search intervals exponentially spaced up to ten seconds, an additional factor of two in sensitivity is gained for the average burst. The overall sensitivity threshold of *EXIST* for burst detection is a factor 25 – 30 lower than BATSE. It should be noted that this factor applies only over the central ($3.5° \times 80°$) portion of the FOV.

EXIST's good spectral resolution relative to alkali halide scintillator experiments is due to the use of newly-developed room-temperature solid state Cadmium Zinc Telluride pixel detectors. These detectors allow good spectral and spatial resolution to be achieved in a light weight, compact design.

Burst positions can be unambiguously reconstructed over the full $80° \times 20°$ FOV of the *EXIST* coded aperture telescopes. Weak bursts are positioned with $5'$ accuracy, several times better than the $14'$ telescope resolution. The position accuracy of 30″ for strong bursts is limited by the accuracy with which the spacecraft attitude can be reconstructed. For strong bursts, the central 100 cm^2 of the detector area will be used to derive immediate (within 60 seconds) burst positions. These positions, along with rudimentary information on the burst time history and spectrum will be transmitted to the ground and made immediately available.

The *EXIST* spacecraft will be placed into a nominal 30° inclination low earth orbit, and the MIDEX mission has a planned two-year lifetime. The first year of the mission will be devoted to the all-sky survey, and the second year will be devoted to several large key projects, including the M31 burst observation. Prompt burst localization will be operative throughout the entire two year mission. There will be no proprietary data for any phase of the mission, and raw and processed data products will be made available to the community immediately.

CONCLUSION

As a next-generation imaging hard X-ray experiment, *EXIST* will provide a number of important observational advances in burst astronomy. Principal among these is *EXIST*'s high sensitivity for burst detection. *EXIST* will perform an long (several month), high-sensitivity observation toward M31 to search for an extended burst halo to confirm or eliminate models in which isotropically emitting burst sources are distributed in an extended ($\sim$ 200 – 400 kpc) Galactic halo. In addition, *EXIST* will probe the shape of the GRB $\log N$-$\log P$ distribution an order of magnitude below the BATSE threshold, provide high-quality burst spectra and 30″ burst positions which will be available promply (within 60 seconds) for ground-based followup.

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