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The High Energy Telescope on EXIST: Hunting High Redshift GRBs and other Exotic Transients

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The High Energy Telescope (HET) on *EXIST* is designed to locate high redshift Gamma-Ray Bursts (GRBs) and other rare transients fast (<10 sec) and accurately (< 20″) in order to allow rapid (<1–2 min) follow-up observations with onboard X-ray/optical/IR imaging and spectroscopy. The HET employs coded-aperture imaging with a 4.5 m^2 imaging CZT detector array and hybrid tungsten mask. The wide energy band coverage (5–600 keV) is optimal for capturing these transients and highly obscured AGN. The continuous scan with the wide field of view (90º × 70º at 10% coding fraction) increases the chance of capturing rare elusive events such as soft Gamma-ray repeaters and tidal disruption events of stars by dormant supermassive black holes. Sweeping nearly the entire sky every two orbits (3 hour), *EXIST* will also establish a finely-sampled long-term history of the X-ray variability of many X-ray sources, opening up a new time domain for variability studies. In light of the new *EXIST* design concept, we review the observing strategy to maximize the science return and report on our recent balloon flight test of a prototype for the CZT detectors needed for HET.

The Extreme sky: Sampling the Universe above 10 keV - extremesky2009
Otranto (Lecce) Italy
October 13-17, 2009

[1] Speaker

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1. Introduction

The Energetic X-ray Imaging Survey Telescope (*EXIST*) is newly redesigned to locate high redshift Gamma-Ray Bursts (GRBs) and other exotic transients quickly (<10 sec) and accurately (<20") in order to allow rapid (<1–2 min) followup onboard with optical/IR imaging and spectroscopy [1]. To achieve this, *EXIST* now consists of a High Energy Telescope (HET), a Soft X-ray Imager (SXI) and an Optical/infrared Telescope (IRT), all mounted on a Spacecraft (in a low inclination, low Earth orbit and with rapid slew capability, as shown in Fig. 1. Here we review the overall design of the HET and estimate the broadband sensitivity and sky coverage.

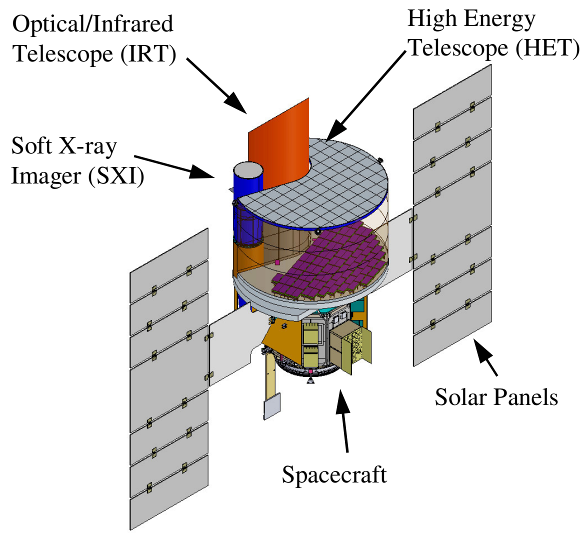

Figure 1: The *EXIST* observatory

2. High Energy Telescope

The hard X-ray band (5–600 keV) is ideal for detecting energetic GRBs, Active Galactic Nuclei (AGN), and transient sources because of the relatively low density of steady background sources and relatively high brightness of transients allowing precise localization. The HET is a wide-field hard X-ray coded-aperture imaging telescope. It will accurately locate GRBs and transients for rapid follow-up with onboard X-ray (0.1 – 10 keV) and optical-NIR (0.3 – 2.3μm) imaging and spectroscopy. Redshifts will be derived on board with sensitivity sufficient to measure within (usually) ~10min all those measured (on ground) for *Swift* GRBs. The HET employs large arrays of fine pixel (0.6mm) CZT detectors and a hybrid tungsten mask as shown in Fig. 2a. The key parameters are summarized in Table 1. Like all coded-aperture instruments,

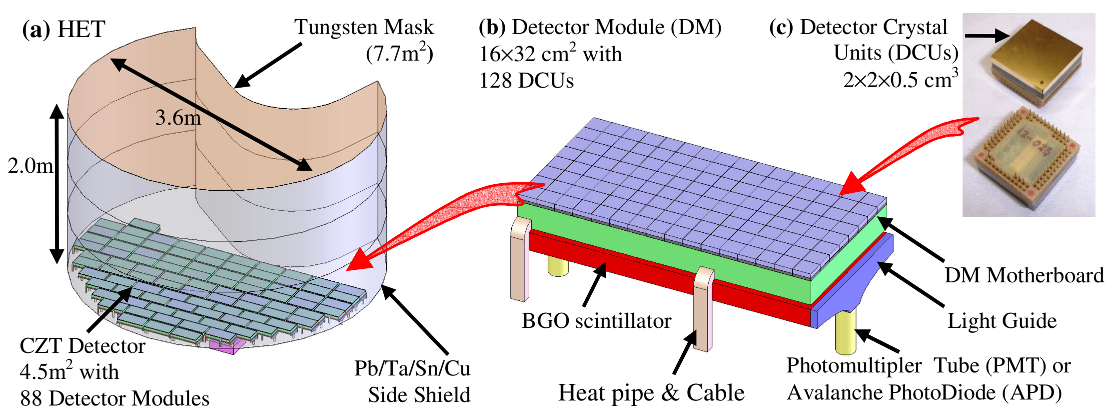

Figure 2: (a) The HET design overview and the CZT detector plane consisting of **(b)** Detector Modules (DMs), which in turn consist of **(c)** Detector Crystal Units (DCUs).

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the design is very tolerant to losses of detector pixels or modules. The HET design enjoys a long heritage of successful missions such as *Swift* and *INTEGRAL* [2,3].

Table 1: The HET parameters.

Parameters	Values
Telescope (coded-aperture)	4.5 m^2 CZT (0.6 mm pix, 11.5Mpix) 7.7 m^2 tungsten mask
Energy Range	5 – 600 keV (imaging CZT) 200 – 2000 keV (BGO for GRBs)
Sensitivity (5σ) (~1y survey)	0.08–0.4 mCrab (<150keV) 0.5–1.5 mCrab (>200keV)
(10s on-axis)	~24 mCrab (<150keV)
Field of View	$90^o \times 70^o$ (out to 10% coding)
Angular Res. Centroiding	2.4′ resolution <20″ for >5σ source (90% conf. rad.)
Sky Coverage	Full sky every two orbits
Spectral Res.	3 keV (3% at 60 keV, 0.5% at 511 keV)
Time Res.	10 μsec
Heritage	*Swift*/BAT, *INTEGRAL*/IBIS (and *Fermi*/LAT for orbital operation)

CZT is the optimal choice for the detectors because of its combination of: (a) high-Z for gamma-ray detection efficiency, (b) good position resolution with the pixilated detectors, (c) low cost, (d) Adequate energy resolution at room temperature, and (e) good *Swift* experience. The CZT detector plane of the HET is hierarchically modular both in mechanical packaging and in the data concentration and processing. Based on the architecture implemented on *Swift*/BAT, the CZT detector allows both redundancy and fast imaging but with resolution improved by factors of ~10 (spatial; angular) and ~3 (energy).

The detector plane consists of 88 identical detector modules (Fig. 2b), each with 128 Detector Crystal Units (DCUs). Each DCU is made of a 2×2×0.5 cm^3 CZT crystal (32×32 pixels, 0.6 mm pixel) bonded to an *EXIST*-specific ASIC (EX-ASIC), with a matching 2-D array of 32×32 channels. The EX-ASIC is essentially the direct bonded (DB)-ASIC developed for the CZT detectors in *NuSTAR* [4]; but with a modification for lower power and close tiled packaging of DCUs and DMs. The power consumption of the current DB-ASIC is already relatively low (~80μW/pixel with ~1 keV FWHM resolution and 0.3 keV FWHM electronics noise), but is four times higher than required. Because of the inverse relation between power and noise and the ~2 keV vs. <~0.5 keV electronics noise (FWHM) requirements for *EXIST* vs. *NuSTAR*, the modification for lower power is straightforward. To

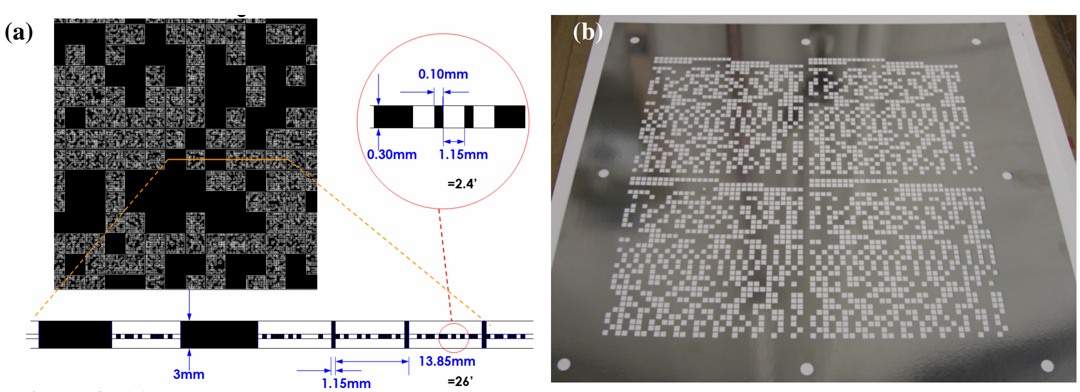

Figure 3: (a) A segment of the HET hybrid mask with cross sectional view: coarse (15 mm pitch, 3mm thick) and fine (1.25 mm pitch, 0.3 mm thick). **(b)** A prototype Tungsten mask for *ProtoEXIST1* experiment (32×32 cm^2). The open holes are chemically etched out from a thin sheet (0.3 mm). This mask is a 2×2 URA: full *EXIST* mask would be random.

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reduce background, the detectors are surrounded by graded-Z passive side shields (Pb/Ta/Sn/Cu) and Bismuth Germanate (BGO) rear anti-coincidence shields as shown in Fig. 2. The latter also extends GRB spectral measurement up to a few MeV.

The hybrid mask, as originally proposed by Skinner and Grindlay (1993) [5], has two scales of pixel elements and thicknesses (Fig. 3), overcoming the difficulty in conventional coded-aperture masks of achieving simultaneously: (1) fine angular resolution, (2) wide energy band and wide field coverage, with minimal auto-collimation, and (3) rapid source localization. The 3mm thick coarse elements (15 mm pixel, 50% open fraction) are effective over the whole 5–600 keV energy band, allowing for the wide field imaging by minimizing off-axis losses due to vignetting (auto-collimation). They also allow rapid FFT calculation of images that can be searched for GRBs and transients. The fine elements (1.25mm pixels, 0.3 mm thick) are effective below ~100 keV. They are superimposed on the coarse mask, giving 25% overall open fraction below ~100 keV and ~50% above ~200 keV. The fine mask allows the precise location of events found in the rapid initial-onboard analysis. Onboard fine-resolution imaging of small regions around candidate locations is then conducted for rapid determination of <20″ (90% confidence) source locations. Despite the slightly reduced sensitivity of the coarse-mode analysis, the overall detection threshold is not impaired.

3. Development Roadmap for the HET: *ProtoEXIST1*, 2 & 3

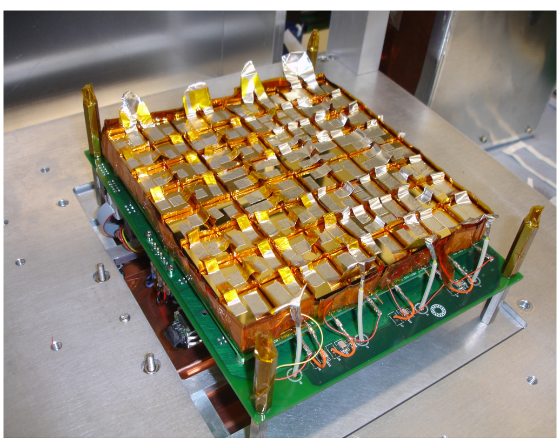

Figure 4: Initial integration of the full 16×16 cm^2 CZT detector plane for *ProtoEXIST1* on test-stand in lab. HV bias (–600V) lines (white) connect to 4 arrays of 2 x 4 DCUs on each side.

A series of the balloon-borne experiments are underway to bring the ASIC and electronics packaging for large-array CZT detectors to the point of space qualification for the HET. The first *EXIST* prototype, *ProtoEXIST1,* consisting of a 256 cm^2 CZT detector with 2.5 mm pixels (Fig. 4) and 1024 cm^2 Tungsten mask (15º×15º at ~50% coding fraction), had a successful balloon flight from Ft. Sumner, New Mexico, USA on Oct 9, 2009 [6,7]. During the 7.5 hr flight at 39.9km altitude, the detector system performed near flawlessly, and a ~65 min observation of Cygnus X-1 with coarse pointing for all but the final ~8min produced a 7σ detection of the source as expected, despite a few malfunctions in the pointing and aspect system that resulted in about 6º offset from the target (and thus ~70% coding fraction). The detector module in *ProtoEXIST1* demonstrates our

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modularization concept to build a very large area CZT detector. The success of the flight is very encouraging for the future development of, next, *ProtoEXIST2* with full imaging resolution.

In *ProtoEXIST2*, we will use the *NuSTAR* DB-ASIC with its 0.6 mm pixel resolution CZT but with the tiled DCU modularization concept as in *ProtoEXIST1*. Then, in *ProtoEXIST3*, we will employ the EX-ASIC – a lower power version of DB-ASIC. Thus the detector module for *ProtoEXIST3* will be identical to that proposed for the HET but will be half the size (256 cm^2 for the *ProtoEXIST3* vs. 88 × 512 cm^2 for the full HET).

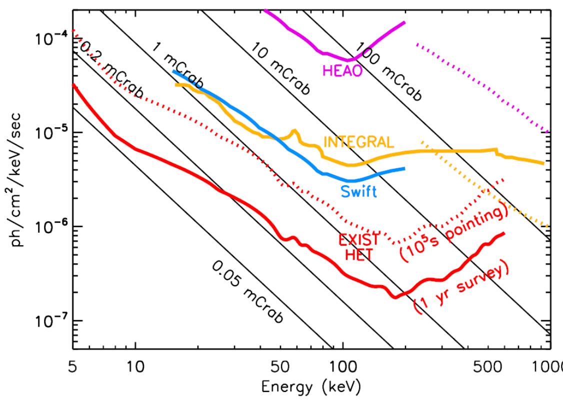

Figure 5: 1-yr survey sensitivity of *EXIST*/HET and other instruments

4. Sensitivity and Sky Coverage

The 1-year full-sky survey sensitivity of the HET is expected to be ~0.1–0.2 mCrab, depending on the energy range (Fig. 5). The full mission sensitivity, with 2y scanning and 3y sky coverage from pointings, will be ~0.04-0.1 mCrab. The continuous scan with the wide field of view (~90º x 70º at 10% coding fraction) increases the chance of capturing rare elusive events such as soft Gamma-ray repeaters and tidal disruption events of stars by dormant supermassive black holes. Sweeping nearly the entire sky every two orbits (3 hours, Fig. 6) will also establish a finely-sampled long-term history of the X-ray variability of many X-ray sources, enabling new variability studies of AGN which can constrain SMBH masses. The first 2y of continuous scanning is also desirable for optimal imaging performance by averaging out ever-present systematic noise. After the initial 2 years of the full sky survey in scanning mode, *EXIST* will be primarily in pointing mode for followup studies (X-ray and optical-near-IR spectra, source IDs and redshifts) of selected samples of the ~40,000 AGNs in the survey. GRB detections and afterglow followups will continue throughout the mission lifetime (>5 years).

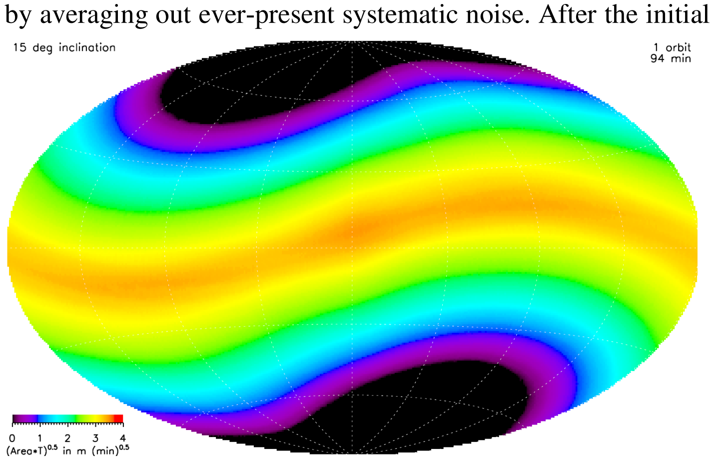

Figure 6: 1-orbit sky coverage of *EXIST*/HET. The HET will scan nearly full sky every two orbits (3 hr), which is obtained by alternatively scanning above/below the orbital plane by ±25º.

5. Summary

The HET on *EXIST* will scan nearly the full sky every two orbits (~3hr) for capturing GRBs/transients and exploring new variability. Its broadband coverage (5–600 keV) with CZT detectors (<2–3 keV resolution, FWHM) is ideal for unveiling distant, obscured sources. The HET will localize GRBs with <20″ accuracy (5σ) and the rapid slew (<100 sec) allows for immediate onboard Optical/IR imaging and spectroscopy of GRB afterglows and prompt redshifts – which enable powerful diagnostics of the early Universe. The advanced CZT imaging detectors required for the HET have been developed through a series of balloon-borne experiments. The 1st generation of the advanced CZT imager with 256 cm^2 active area and 2.5 mm pixel (*ProtoEXIST1*) had a successful flight on 2009 Oct, 9. In the 2nd generation (*ProtoEXIST2*) we will employ 0.6 mm pixel CZT imager with the *NuSTAR* DB-ASICs. In the 3rd generation (*ProtoEXIST3*) we will use a low power version of the DB-ASIC to meet all the requirements for the CZT imagers in *EXIST*/HET.

References

[1] Grindlay, J. et al., AIP Conf.Proc.1133:18-24, 2009 (astro-ph/0904.2210). See http://exist.gsfc.nasa.gov for more information about *EXIST*.

[2] Gehrels, N. et al., Astrophysical Journal, 611, 1005, 2004

[3] Parmar, A. N. Et al., Proc. SPIE 4851, 1104, 2003

[4] Harrison, F. and NuSTAR Team, BAAS Vol. 41, p.347, 2009

[5] Skinner, G. and Grindlay, J., Astron. & Astrophys., 276, 673, 1993.

[6] Hong, J. et al., Nuc. Instr. & Meth. in Phys. Res. Sec. A, Vol 605, 364, 2009.

[7] Hong et al, 2010, in preparation