

# Using the EXIST Active Shields for Earth Occultation Observations of X-ray Sources

Colleen A. Wilson, G.J. Fishman

*XD 12, NASA/MSFC, Huntsville, AL 35812*

J.-S. Hong, J.E. Grindlay

*Harvard Smithsonian Center for Astrophysics, Cambridge, MA 02138*

H. Krawczynski

*Washington University in St. Louis, St. Louis, MO 63130*

The EXIST active shields, planned for the main detectors of the coded aperture telescope, will have approximately 15 times the area of the BATSE detectors, and they will have a good geometry on the spacecraft for viewing both the leading and trailing Earth's limb for occultation observations. These occultation observations will complement the imaging observations of EXIST and can extend them to higher energies. Earth occultation observations of the hard X-ray sky with BATSE on the Compton Gamma Ray Observatory developed and demonstrated the capabilities of large, flat, uncollimated detectors for applying this observation method. With BATSE, a catalog of 179 X-ray sources was monitored twice every spacecraft orbit for 9 years at energies above about 25 keV, resulting in 83 definite detections and 36 possible detections with  $5\sigma$  detection sensitivities of 3.5-20 mcrab (20-430 keV) depending on the sky location. This catalog included four transients discovered with this technique and many variable objects (galactic and extragalactic.) This poster describes the Earth occultation technique, summarizes the BATSE occultation observations, and compares the basic observational parameters of the occultation detector elements of BATSE and EXIST.

## 1. Introduction

### 1.1. Earth Occultation Technique

The Earth Occultation technique is simply measuring the change in total count rate in a non-imaging detector when an X-ray source rises above or sets below the Earth's horizon, due to the spacecraft orbital motion. This produces a step-like feature in the data, illustrated in Figure 1. This technique, described in detail in Harmon et al. (2002)[1], was used very successfully with the Burst and Transient Source Experiment (BATSE) on the Compton Gamma Ray Observatory to monitor a catalog of 179 sources, of which 83 were definitely detected. This catalog included 32 stellar mass black hole systems of which 23 were definitely detected, including 3 newly discovered systems, and 12 AGN sources of which 6 were definitely detected. Details of the BATSE catalog can be found in Harmon et al. (2004)[2], including data on the web at <http://gammaray.msfc.nasa.gov/batse/occultation>.

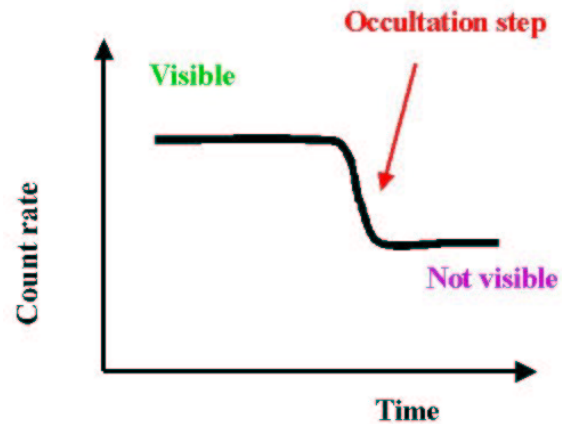


Figure 1: Illustration of an Earth Occultation step in count rate data.

### 1.2. EXIST

The Energetic X-ray Imaging Survey Telescope (EXIST) is a mission concept for the Beyond Einstein Black Hole finder probe [3]. The current design concept is shown in Figure 2. Its primary mission will be to study obscured active galactic nuclei and gamma ray bursts. The main instrument, the high energy instrument, is a coded mask telescope with  $\sim 6 \text{ m}^2$  of cadmium-zinc telluride (CZT) detectors in the focal plane. It will be sensitive to photons in the 10-300 keV range. In this poster we propose using the CsI

side shields as Earth occultation detectors to supplement the energy range and time coverage of the main instrument. The high energy instrument on EXIST will consist of a  $6 \times 3$  array of sub-telescopes, one of which is shown in Figure 3. Honeycomb side panels and both active and passive shields will be shared by adjacent sub-telescopes. The thicknesses and areas of these active and passive shields will be optimized to meet the mission constraints. See Figure 4 for an exploded view of the current configuration. Table I lists various parameters for the current EXIST concept and BATSE for comparison.

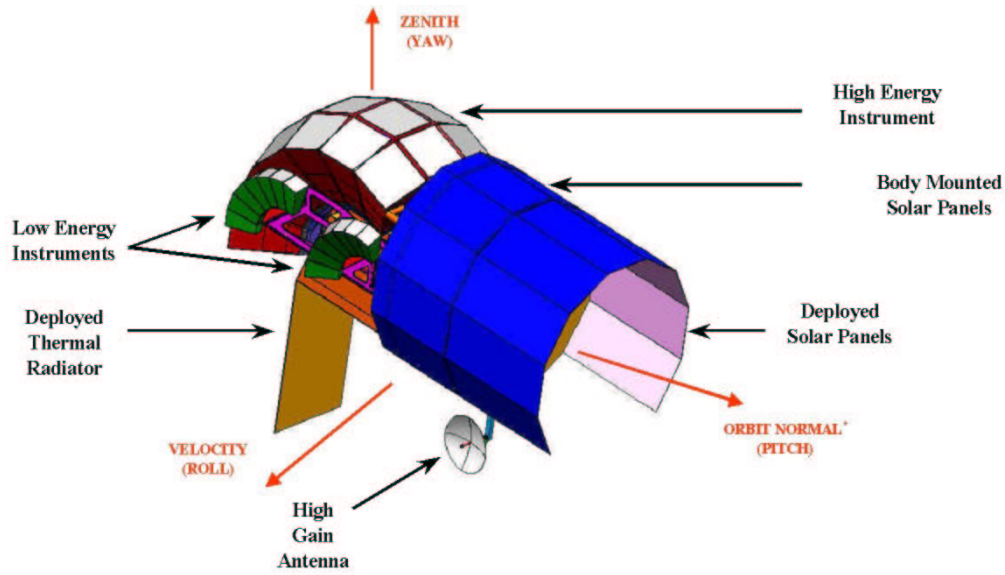


Figure 2: Current design concept for the EXIST satellite.

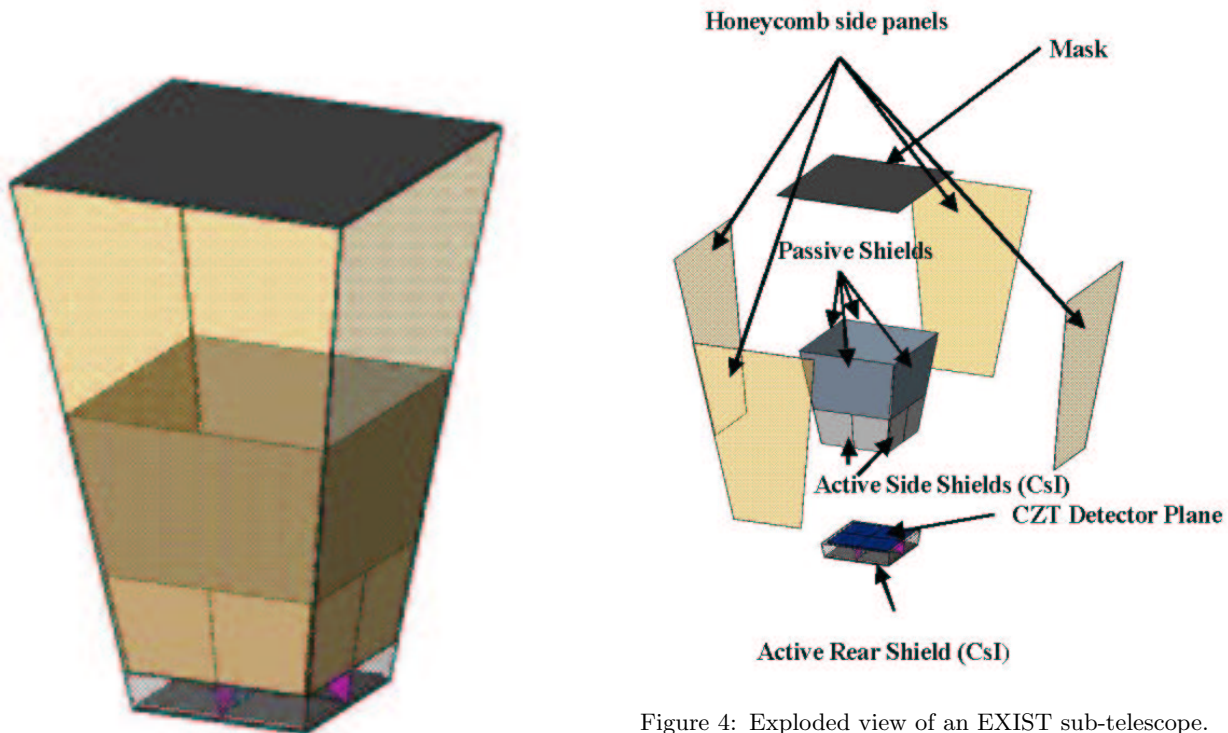


Figure 3: One of 18 sub-telescopes in the EXIST high-energy instrument.

## 2. Estimating the Earth Occultation Sensitivity of the EXIST Side Shields

To estimate the sensitivity of the EXIST CsI side shields for Earth Occultation measurements, we scaled the BATSE large area detector (LAD) count rates

from a typical interval outside of South Atlantic Anomaly (SAA) passage by the ratio of the CsI side shield area ( $2.31 \text{ m}^2$ ) to the area of 1 BATSE LAD ( $0.2025 \text{ m}^2$ ). Next we generated a time series of random background rates, using the 16 BATSE energy channels.

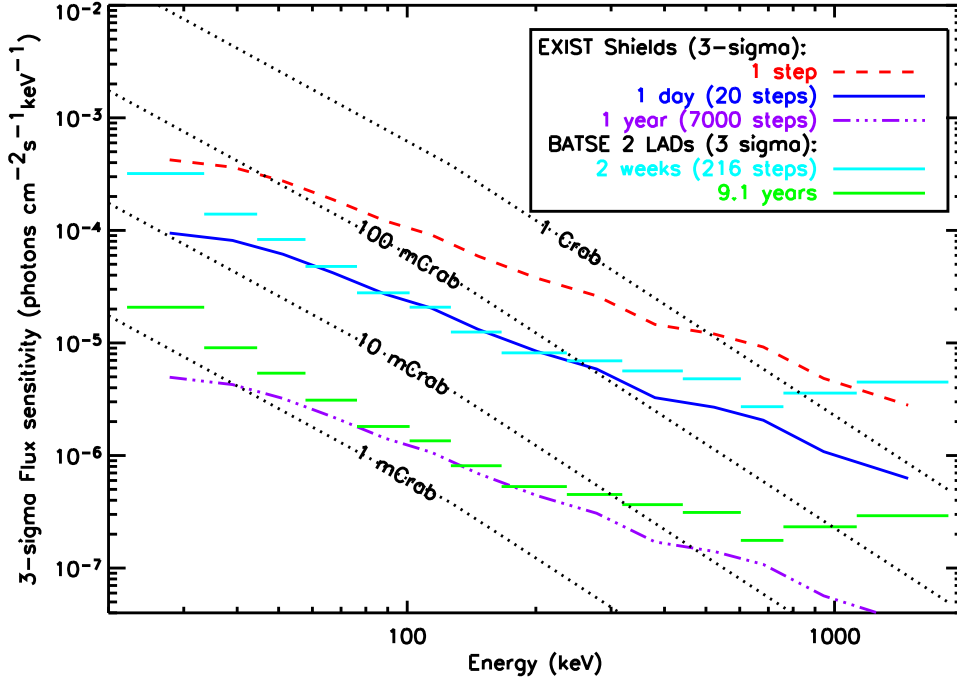


Figure 5: Comparison of estimated sensitivity of the EXIST CsI side shields to the BATSE Large Area detectors for Earth Occultation measurements. Dashed, solid, and dash-dot curves show EXIST CsI sensitivities for 1 step, 1 day, and 1 year, respectively. Horizontal bars denote BATSE sensitivity for 2 LADs for 2 weeks and for the full 9.1 year mission

Table I Comparison of EXIST and BATSE

Parameter	EXIST	BATSE
Area	23100 cm <sup>2</sup> (array of 6 shields)	2025 cm <sup>2</sup> (1 BATSE LAD)
Material	CsI	NaI
Thickness	0.8 cm per layer (up to 4 layers)	1.27 cm
Density	4.51 g cm <sup>-3</sup>	3.67 g cm <sup>-3</sup>
Orbit Altitude	500 km	400-600 km
Orbit Inclination	7°	28.5°

We then fit these rates with the following model:

$$R(t) = FA\varepsilon T(t)\cos(\theta) + \sum_{i=0}^2 c_i(t-t_0)^i, \quad (1)$$

where  $F$  is the source flux in photons cm<sup>-2</sup> s<sup>-1</sup>;  $\theta$  is the angle to the source;  $A$  is the geometric detector area;  $\varepsilon$  is the detector efficiency;  $T(t)$  is the atmospheric transmission function;  $c_i$  are coefficients of a simple quadratic fitted to the background rate; and  $t_0$  is the occultation time of the source. The atmospheric transmission function,  $T(t)$ , depends on the mass attenuation of gamma rays in air, and the air mass along

the line of sight at a given altitude, which in turn depends upon the precise position of the spacecraft. For EXIST we simply used an atmospheric transmission function from BATSE.

The assumed EXIST CsI shield detector efficiency was given by

$$\varepsilon = (1 - e^{-\mu_{\text{CsI}}(E)\rho_{\text{CsI}}h_{\text{CsI}}})e^{-\mu_{\text{H}}(E)\rho_{\text{H}}h_{\text{H}}} \quad (2)$$

where  $\mu_{\text{CsI}}(E)$  and  $\mu_{\text{H}}(E)$  are the energy dependent mass attenuation coefficients for CsI and the honeycomb panels,  $\rho_{\text{CsI}}$  and  $\rho_{\text{H}}$  are the densities of CsI and the honeycomb panels, and  $h_{\text{CsI}}$  and  $h_{\text{H}}$  are the thickness of CsI and honeycomb panels. We used 1 CsI layer ( $h_{\text{CsI}} = 0.8$  cm) and 1 honeycomb panel ( $h_{\text{H}} = 0.8$  cm) for energies up to about 200 keV. Above 200 keV, we assumed all 4 CsI layers were used ( $h_{\text{CsI}} = 3.2$  cm) and that the photons passed through 7 honeycomb layers ( $h_{\text{H}} = 5.6$  cm).

The sensitivity is then given by  $N\sigma_F$ , where  $\sigma_F$  is the computed error on the source flux  $F$ . In our case we chose  $N=3$  to obtain 3  $\sigma$  sensitivity estimates, shown in Figure 5.

### 3. Conclusions

Our estimates show that we should reach flux levels in about a day with EXIST that took an entire 2

week pointing with BATSE and similarly, in about 1 year we should reach levels comparable or better than those obtained over the entire BATSE mission. We used a very rough approximation for the background in the EXIST CsI side shields, obtained by simply scaling the average background in a BATSE LAD by area, to estimate the Earth Occultation sensitivity for EXIST. One should keep in mind that our estimates especially at the low and high ends will be affected by materials in close proximity to the detector. At low energies, we have assumed an 8 mm thick honeycomb panel with a density of  $0.5 \text{ g cm}^{-3}$  sandwiching each shield. At high energies, we simply scaled the BATSE rates, assuming that the spacecraft materials are similar for BATSE and EXIST. The background levels at high energies are due to cosmic rays interacting in materials near the detectors. More detailed background estimates are needed to better determine Earth Occultation sensitivity for EXIST.

The CZT coded mask imaging system on EXIST

will provide more sensitive measurements of sources especially at energies below 300 keV. Our Earth Occultation measurements will complement these measurements, providing additional time coverage when sources are outside the field of view of the main instrument. This may prove important especially for rapid or short lived events, such as the rise of a transient stellar mass black hole outburst. In addition this technique will complement the energy range of the CZT detectors, providing coverage at energies where the CZT detectors have low efficiency.

## References

- [1] Harmon, B.A. et al. 2002, ApJS, 138, 149
- [2] Harmon, B.A. et al. 2004, ApJS, 154, 585
- [3] Grindlay, J.E. et al. 2003, Proc. SPIE, 4851, 331