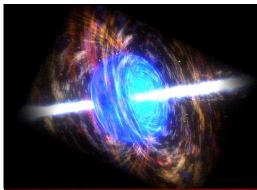
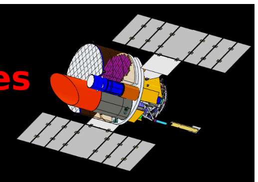


EXIST: Surveying the birth and evolution of Black Holes

The Hard X-ray Polarization Sensitivity of *EXIST*



H. Krawczynski[1], A. Garson III[1], J. Martin[1], M. Beilicke[1], J. Hong[2], J. Grindlay[2], G. K. Skinner[3], S. Sturner[3] for the EXIST Team

[1]Physics Department and McDonnell Center for the Space Sciences, Washington University in St. Louis, 1 Brookings Drive, CB 1105, St. Louis, MO 63130

[2]Harvard-Smithsonian Center for Astrophysics, 60 Garden St., MS 06, Cambridge, MA 02138,

[3]Astrophysics Science Division, NASA/GSFC, Code 661, GSFC, Greenbelt, MD 20771.

What is *EXIST*? (1)

- EXIST [1,2] is a proposed Medium Class infrared/X-ray observatory to conduct the most sensitive full-sky survey for Black Holes on all scales (stellar to supermassive).
- A leading candidate to be the Black Hole Finder Probe (BHFP) as one of the 3 Einstein Probe missions [3] (launch hopefully in 2017, next after the Joint Dark Energy Mission).
- A mission currently under study for the Advanced Mission Concept Study (AMCS) program, in preparation for review by the next Astronomy/Astrophysics Decadal Survey (2009-2010).

EXIST Components:

- The High Energy Telescope (HET) operates in the hard X-ray band (5 keV to 600 keV) and has a 2 sr wide field of view.
- The Infrared Telescope (IRT) has a 1.1 m primary mirror, operates over the 0.3-2. 2μm wavelength band, and has imaging, low-resolution (~10) and high-resolution (~1000) spectroscopy capabilities.
- The soft X-ray imager (SRI) is an optional pointed X-ray telescope that operates from 0.3 keV to 8 keV, contributed by Italy.

Hard X-ray Polarization - Scientific Motivation I (2)

- The *EXIST* High Energy Telescope uses finely pixilated Cadmium Zinc Telluride (CZT) detectors and has inherent polarimetry capabilities in the energy range from 80 keV to 250 keV.

Observations of Binary Black Holes:

- Owing to its all-sky coverage, *EXIST* will observe sources in different emission states without missing major flaring events. *EXIST*'s large energy bandpass from 5 keV to 600 keV and excellent timing capabilities are ideally suited to constrain the emission states and to track the evolution of the emission components.
- At >80 keV energies, the *EXIST* hard X-ray polarimetry observations will shed light on the origin of the non-thermal emission, and they will make it possible to test hypotheses about the origin of the hard X-ray emission as emission from the jet and/or from a disk corona.

Observations of Neutron Stars, Young Pulsars, and Magnetars:

- The emission mechanism and the propagation of the X-rays through the highly magnetized plasma surrounding neutron stars might lead to polarization degrees of several 10% [4,5]. At high energies, photon-splitting (a higher order QED effect) is expected to produce strong polarization leading up to a high-energy cut-off in high-magnetic-field pulsars and magnetars [6,7]. This effect cannot be observed in terrestrial laboratories and would provide a test of QED in extreme conditions.

Hard X-ray Polarization - Scientific Motivation II (3)

Observations of Gamma-Ray Bursts (GRBs):

The measurement of the polarization may reveal the inner structure of the jets from GRBs [8-10]. For high polarization fractions, the observations could establish the magnetically dominated character of the jet flow, and would constrain the process of jet formation as well as the central engine.

Observations of Active Galactic Nuclei (AGN):

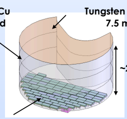
EXIST can shed light on the origin of the non-thermal emission from AGN. Of particular interest are blazars (mass-accreting supermassive black holes with highly relativistic outflows (jets) pointing at the observer), which are strong emitters of continuum emission. The *EXIST* polarimetry observations can reveal key information about the structure of the jets in the ``blazar zone'' less than 1 pc away from the black hole. If jets have a strong helical magnetic fields, it might be possible to detect a swing of the direction of the polarization on time scales of ~10 MBH/(10^8 $M_\odot$) days.

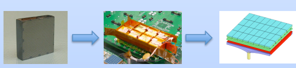
Astroparticle Physics:

Observations of the polarized X-ray emission from GRBs and AGNs can be used to constrain fundamental physics beyond the standard model, e.g. quantum gravity theories [11]. The *EXIST* observations can improve on the current best limit [12] on the linear energy dependent modification of the speed of light by 9 orders of magnitude.

The High Energy Telescope (HET) (4)

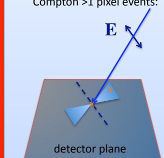
- Coded mask imaging with hybrid Tungsten mask: angular resolutions of 1.4 arcmin and 20 arcsec.
- 4.5 m^2 of 0.5 cm thick CZT detectors.
- Each CZT detector: 1024 pixels at a pitch of 0.6 mm.
- Readout with NuStar ASIC [13]: energy thresh.: 4-5 keV, readout noise: 0.9 keV.



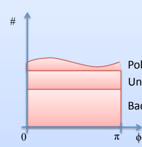


Polarization Measurements with *EXIST* (5)

Measurements based on Compton >1 pixel events:



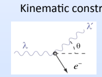
Distribution of azimuthal scattering angles:



- Photons scatter preferably perpendicular to the photons' electric field vector.
- The distribution of azimuthal Compton scattering angles can be used to measure the X-ray polarization.
- The *EXIST* Polarization measurements use ≥2 pixel events; for each event, the azimuthal angle is determined from the position of the two pixels with the maximum signal.

Energy Range for Polarization Measurements (6)

Kinematic constraints:



$$\Delta\lambda = \frac{h}{m_e c}(1-\cos\theta)$$

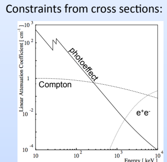
$$E_{thr} = 5\text{ keV} \;\rightarrow\; E_\gamma > 53\text{ keV } (\theta = 90°)$$

High-confidence identification of first interaction up to energies of 255.5 keV:

$$E_\gamma < \frac{m_e c^2}{2} = 255.5\text{ keV} \;\rightarrow\; E_e < \frac{E_\gamma}{2}$$

at higher energies, only a subset of the events can be used.

Constraints from cross sections:



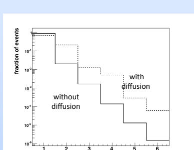
The requirement of a substantial fraction of Compton interactions and photon mean free paths comparable to the pixel pitch result in a low-energy threshold of ~80 keV.

⇨ Energy threshold for *EXIST* polarization measurements: 80 keV.

Detector Simulations and Impact of Charge Sharing (7)

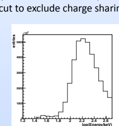
- Simulation with GEANT-4 [14] and GLECS [15] assuming a Crab energy spectrum, and >100 keV background level of 0.03 cm^{-2} s^{-1}.
- Detector simulation accounts for electron diffusion in CZT with diffusion constant $D_e = k_B\,\mu_e\,T / e \approx 25\ cm^{-2}\ s^{-1}$.
- Electron diffusion ("charge sharing") leads to ≥2 pixel events, even when a photon looses all its energy in a single photoeffect interaction (see Figure on the right).
- Excluding events with the maximum signal in two horizontally or vertically adjacent pixels suppresses most of these charge sharing events.

Multiplicity of triggered pixels before and after accounting for charge carrier diffusion:

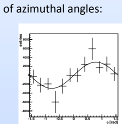


Sensitivity Estimates (8)

Energy distribution of ≥2 pixel events (after cut to exclude charge sharing events):



Modification of distribution of azimuthal angles:



(100 mCrab signal polarized to 6%, 5 day pointed integration)

Preliminary Sensitivity Estimates (5σ detection):

- 100 mCrab source, 5 days pointed observations: 6% polarization fraction.
- 100 mCrab source, 2 year all sky survey: 1.5% polarization fraction.

Systematic Uncertainties & References (9)

HET properties leading to relatively small systematic uncertainties:

Large number of independent detector elements (11 million pixels) with a small distance between adjacent pixels (600 microns) compared to the size of the instrument.

→ If there are large scale background non-uniformities, they will have little impact on the polarization measurements, as the latter use only pixels that are rather close to each other. Gain variations of pixels on individual CZT detectors can be determined and corrected for with high precision making use of the background data acquired during the mission.

However: sufficiently rapid spinning of EXIST observatory to cancel systematics is not foreseen.

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