HX-POL – A Balloon-Borne Hard X-ray Polarimeter

K. Lee[a], A.B. Garson III[a], Q. Li[a], J. Martin[a], M. Beilicke[a], P. Dowkontt[a], E. Wulf[b], G. De Geronimo[c], M.G. Baring[d], H. Krawczynski[a]

[a]Washington University in St. Louis and McDonnell Center for the Space Sciences, St. Louis, MO 63130, USA
[b]High Energy Space Environment Branch, Naval Research Laboratory, Washington, DC, USA
[c]Instrumentation Division, Brookhaven National Laboratory, Upton, NY, USA
[d]Department of Physics & Astronomy, Rice University, Houston, TX, USA

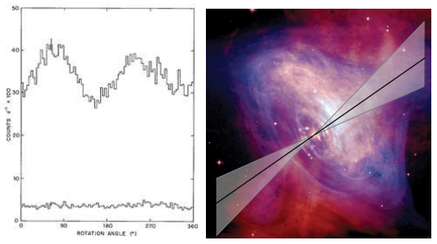
Abstract Summary

We report on the design and estimated performance of a balloon-borne hard X-ray polarimeter called HX-POL. The experiment uses a combination of Si and Cadmium Zinc Telluride (CZT) detectors to measure the polarization of 50-500 keV X-rays from cosmic sources.

Abstract

We report on the design and estimated performance of a balloon-borne hard X-ray polarimeter called HX-POL (Krawczynski et al. 2008). The experiment uses a combination of Si and Cadmium Zinc Telluride (CZT) detectors to measure the polarization of 50-500 keV X-rays from cosmic sources through the dependence of the angular distribution of Compton scattered photons on the polarization direction. On a one-day balloon flight, HX-POL would allow us to measure the polarization of bright Crab-like sources for polarization degrees well below 10%. On a longer (15-30 day) flight from Australia or Antarctica, HX-POL would be able to measure the polarization of bright sources down to polarization degrees of a few percent. Hard X-ray polarization measurements provide unique venues for the study of particle acceleration processes by compact objects and relativistic outflows. In this contribution, we discuss the overall instrument design and performance. Furthermore, we present results from laboratory tests of the Si and CZT detectors.

X-Ray Polarization: Crab Nebula



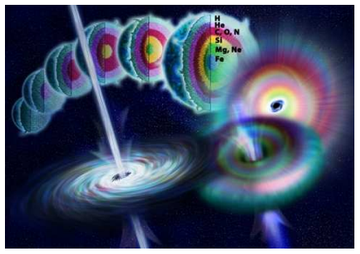
OSO-8

- Polarization of 2.6 keV and 5.2 keV emission: 20%.
- A polarization angle aligned around 30 degrees oblique the the X-ray jet. (Weisskopf et al. 1978)

INTEGRAL

- 0.1 - 1 MeV interpulse emission polarized to 46%±10%.
- A polarization direction aligned with the orientation of the X-ray jet. (Dean et al. 2008)

X-Ray Polarization: Probing Relativistic Outflows



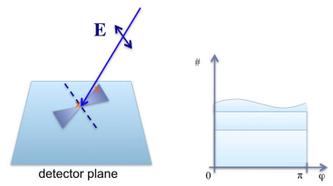
Magnetically-dominated outflows will produce highly polarized emmission. The polarization of reflected X-rays from Gamma-ray bursts and AGNs can give insight into the surrounding environment (Tueller et al. 2009). Measurements of these short transients most likely requires large, space-borne detectors.
Very sensitive measurement will be done by GEMS, a recently selected NASA Small Mission Explorer that will probe polarization degrees in the soft X-ray band in the year ∼2013 (http://heasarc.gsfc.nasa.gov/docs/gems/).

Acknowledgements

This work is supported under NASA grant NNX07AH37G.

kuenlee@wustl.edu

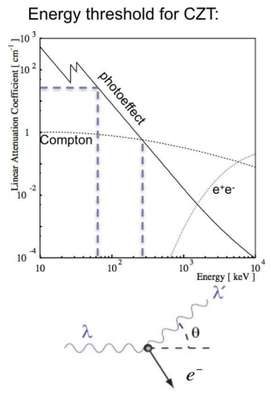
Hard X-Rays: Compton Polarimetry



Hard X-rays are preferentially scattered perpendicular to their electric field vector in Compton interactions. Polarization characteristics will appear in as an asymetry in the distribution of scattering angles for a collection of events.

Constraints (Kinematics & Cross Section)

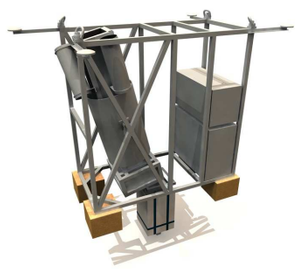
Energy threshold for CZT:



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

For $E_{threshold} = 5$ keV and $\theta = 90°$, $E_\gamma \geq 53$ keV

Concept Study of Balloon-Borne Experiment

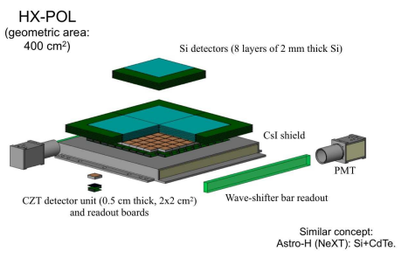


Conceptual drawing of the HX-POL gondola, instruments, and hardware.

Possible balloon flights:

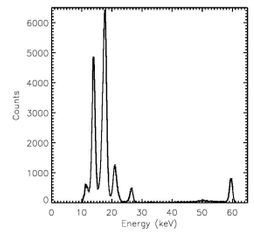
- Fort Sumner (NM) or Palestine (TX): 6-12 hrs
- Antarctica: ∼20 days

HX-POL: Detectors



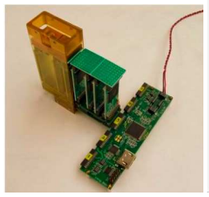
HX-POL will use eight layers of 2mm-thick Si strip detectors as a low-Z scatterer. Below the Si detectors will be 5mm-thick CZT detector units. The readout electronics will be packaged underneath the CZT allowing for mosaic tiling of the detectors. An CsI active shield will be used to veto background events.

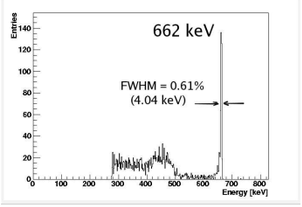
Si Detectors for HX-POL



(*left*)The 2mm-thick 10 x 10 cm^2 Silicon strip detectors for HX-POL have crossed anode and cathode strips with a strip pitch of 1.4mm. Eight layers of these Si detectors absorb ∼50% of vertically incident 50 - 100 keV X-rays. The detectors will be tiled for a total detection area of 400 cm^2. (*right*) The NCI-ASIC and a Si strip detector (17 x 1.4 x 0.5 mm^3) were used to acquire this ^{241}Am spectrum. The FWHM energy resolution at 59 keV is 1.4 keV (Wulf et al. 2008)

CZT Detectors for HX-POL

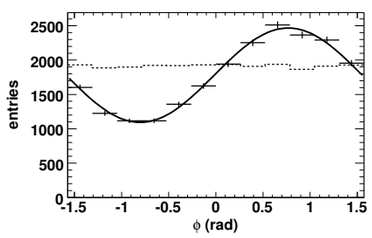


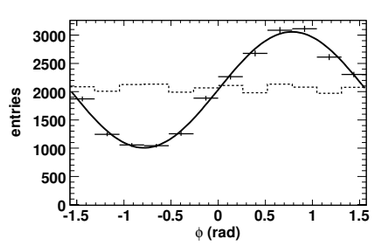


The left panel shows a photograph of the "Mosaic CZT system". The HX-POL prototype will use this system to read out an array of 25 CZT detectors. Pairs of CZT detectors (not shown here) are mounted on one interface board that connects to five ASIC boards. Four ASICs are used to readout the 128 pixels of the detectors. One ASIC is used to read the cathode of the detectors. The ASIC boards connect to a digitizer board and pairs of detectors can be connected to a "detector line". The harvester board (shown in the lower right of the image) can read out five lines of detectors. The NCI-ASIC was used with a 1 x 2 x 2 cm^3 CZT detector to measure a ^{137}Cs spectrum (*right*). The FWHM energy resolution is 0.61% for the best pixel and 0.79% averaged over the entire detector (Li et al. 2007).

HX-POL: Simulated Crab Observations

Polarization Direction





Results from the HX-POL simulation for 100% polarized (solid lines) and unpolarized X-ray beams (dashed lines). The upper panel shows the distribution of azimuthal scattering angles for "Si-CZT" events where one Si detector records a hit and one CZT detector pixel records a hit. The lower panel shows the same for "Si-Si" events with hits in two or more Si detectors. The absolute number of events correspond to a 3 hr ON-observation of a source with the flux and spectrum of that of the Crab Nebula (Tueller et al. 2009).

HX-POL: Simulated Crab Observations

Modulation factor

The modulation factor is defined as

$$\mu = \frac{C_{\max} - C_{\min}}{C_{\max} + C_{\min}} \qquad (2)$$

where $C_{\max}$ and $C_{\min}$ are the maximum and minimum counts detected for different azimuthal scattering angles. For the Si-CZT and the Si-Si events the modulation factors are $\mu_{\text{Si-CZT}} = 0.4$, and $\mu_{\text{Si-Si}} = 0.5$, respectively.

Minimum Detectable Polarizations (MDP)

The simulations can be used to determine the MDP. We compute the 99% confidence level MDP with a modified version of the Equation (10) in Weisskopf et al. (2009) that accounts for the statistical errors of the OFF-data:

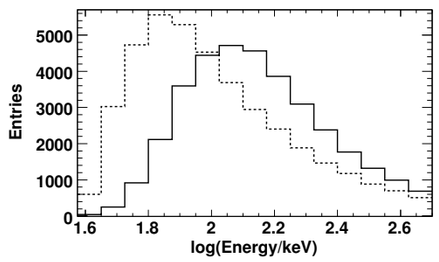
$$\text{MDP} = \frac{4.29}{\mu R_{\text{src}}}\sqrt{\frac{R_{\text{src}} + 2R_{\text{bg}}}{T}} \qquad (3)$$

where R_{src} is the total source counting rate, R_{bg} is the total background counting rate and T is the ON integration time (assumed to equal the OFF integration time).

HX-POL Minimum Detectable Polarizations

Events	μ	R_{src} [Hz]	R_{bg} [Hz]	MDP [%]
Si-CZT	0.40	2.0	0.13	7.7
Si-Si	0.50	2.3	0.14	5.8
All	0.46	4.3	0.27	4.7

Energy Distribution



The panel shows the energy distribution of Si-CZT events (solid line) and the Si-Si events (dashed line). Most Si-CZT events have energies between 60 keV to 400 keV. Most Si-Si events have energies between 50 keV and 300 keV.

Summary

- HX-POL will use Si scatterers and CZT absorbers to measure the polarization angle and degree of X-rays in the energy range of 50 keV - 500 keV.
- HX-POL combines a high detection efficiency with high modulation factors: $\mu = 0.4$ for Si-CZT events and $\mu = 0.5$ for Si-Si events.
- HX-POL will measure Crab Nebula emission polarization in several energy ranges for a one day balloon flight.
- Excellent Si/CZT energy resolution makes it possible to measure energy dependence of polarization properties. HX-POL's energy resolution will be about 6% in the 100 keV-150 keV energy region.
- Proof of principle measurements are in progress.

References

- Dean, A.J. et al. 2008, Science, 321, 5893, 1183-1185.
- Krawczynski, H,. et al. 2008, Procs. IEEE,[arXiv:0812.1809].
- Li, Q. et al. 2007, Procs. NSS/MIC conference, [arXiv:0712.1178].
- Tueller, J. et al. 2009, submitted to the ApJS [arXiv:0903.3037].
- Weisskopf, M.C. et al. 1978, ApJL, 220, 117-121.
- Weisskopf, M.C. et al. 2009, in press [arXiv:astro-ph/0611483].
- Wulf, E.A. et al. 2008, NIMA, 579, 371-374.