Feasibility of Using 3D CZT Drift Strip Detectors for Small Compton Camera Space Missions

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Motivation

The MeV domain remains largely unexplored compared to the remaining electromagnetic spectrum:
• Sensitivity of existing observatories are orders of magnitude worse compared to neighbouring bands

Difficulties of observing in this domain are due to:
• Three energy-loss processes.
• Low interaction cross sections.
• Inherent difficulty of imaging.
• High instrumental and atmospheric background.

To improve sensitivity, new state-of-the-art detector technology is required.

Simulation setup

Simulation software: MEGAlib
www.megalibtoolkit.com

Geometry

• Simplified geometry with 8 detectors.
• 2mm W shield, 2 detectors per layer, total of 4 layers.
• 1 cm layer distance.

Sources

1 MeV source: Point at zenith (on-axis).
• Monochromatic (100 keV - 2000 keV).
• Crab nebula (far field point source) 50 keV - 10 MeV.
• Background source (same as NuSTAR in LEO).

Event selection

We consider Compton events which pass the criteria:
• Trigger threshold: 20 keV.
• 3e ARM cut (source extraction region).
• 2-7 Compton interactions.
• Compton scatter angles: 0° - 180°.
• Minimum distance (MD) between any interaction: 0.8 mm / 1.6 mm.
• Energy-cut:
  - Narrow line: ±2σ of photo-peak.
  - Continuum: E = σ E.

Telescope efficiency

• Telescope efficiency is comparable to that of COMPTEL in the high energy range.
• The efficiency of the telescope peaks around 300 keV.

Narrow-line sensitivity

• The narrow-line sensitivity of the telescope is:
  - One order of magnitude worse than that of SPI (INTEGRAL), after 1 s observation time.
  - ~5 times worse compared to COMPTEL in the high energy range.

Minimum detectable polarization

• MDP of a Crab-like source after an observation time of 10 s.
• MDP below 8% for the energy range 150 - 450 keV.
• MDP below 17% for the energy range 300 - 900 keV.

Observing the Crab

• Reconstructed image of the Crab after 1.33ks (~1.5 days) in orbit observation time in the energy range 150 - 450 keV.

Conclusions: This feasibility study shows that a small, simple Compton camera consisting of eight 3D CZT drift strip detectors and sparse shielding can result in astronomical observations, for further increasing technology readiness level of the detector. The telescope can achieve an efficiency comparable to that of COMPTEL, and even higher at lower energies. The narrow line sensitivity of the telescope is worse than that of SPI and COMPTEL, which is expected due to small geometrical area (hence small effective area) together with high background due to sparse shielding. Long observations of a Crab-like source can allow polarization measurements with MDP below 8% for the energy range 150 - 450 keV. Observing the Crab in the same energy range can result in a 3σ observation after ~1.5 days of effective observation time with the source positioned at zenith.

The 3D CZT Drift Strip Detector

Detector properties:
• Semiconductor detector (CdZnTe).
• Electron only device.
• Room temperature operation.
• Size: 20 mm x 20 mm x 5 mm / 40 mm x 40 mm x 5 mm.
• Energy resolution: ~1% @ 661.6 keV.
• Angular Resolution Measure.

Sensitivity

• Narrow-line sensitivity.
• Continuum sensitivity (Crab).
• Background only.

In orbit simulations

• Minimum detectable polarization (Crab-like source).
• 3σ observation of the Crab.
• Source input:
  - Background:
    - Continuum source (Crab).

Basic telescope performance parameters

• Energy resolution.
• Angular Resolution Measure.
• Effective area and efficiency.

Source input:
• Far field point sources:
  - Monochromatic: 100 - 2000 keV.

Material uniformity analysis

S. H. Owe, I. Kuvvetli, C. Budtz-Jørgensen, and A. Zoglauer
Carrier Lifetime and Mobility Characterization using the DTU 3D CZT Drift Strip Detector.
Energy resolution: ~1% @ 661.6 keV.

Medical

S. R. H. Owe, I. Kuvvetli, A. Cherlin et al.
Evaluation of CZT drift strip detectors for use in 3D molecular imaging.
1.7 keV resolution in resolution and Phantom Medical Science.

Compton camera

S. R. H. Owe, I. Kuvvetli, A. Cherlin et al.
Evaluation of the 3D CZT Drift Strip Detectors.