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

Selina R. H. Owe [1], Irfan Kuvvetli [1], Andreas Zoglauer [2], and Carl Budtz-Jørgensen [1]

[1] DTU Space, Technical University of Denmark, Elektrovej building 327, 2800 Kgs. Lyngby, Denmark
[2] University of California, Berkeley, Space Sciences Laboratory, 7 Gauss Way, Berkeley, CA 94720, USA

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

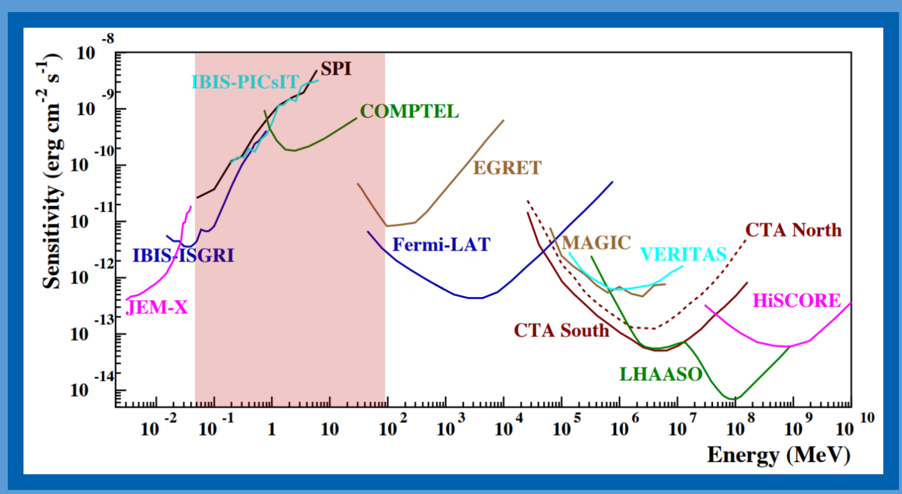

Figure 1: Sensitivity of instruments observing in the MeV-GeV energy range.
Credit: D. Thompson and J. McEnery, GammaSIG Meeting, AAS-Washington, Jan. 2018.

Difficulties of observing in this domain is 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.

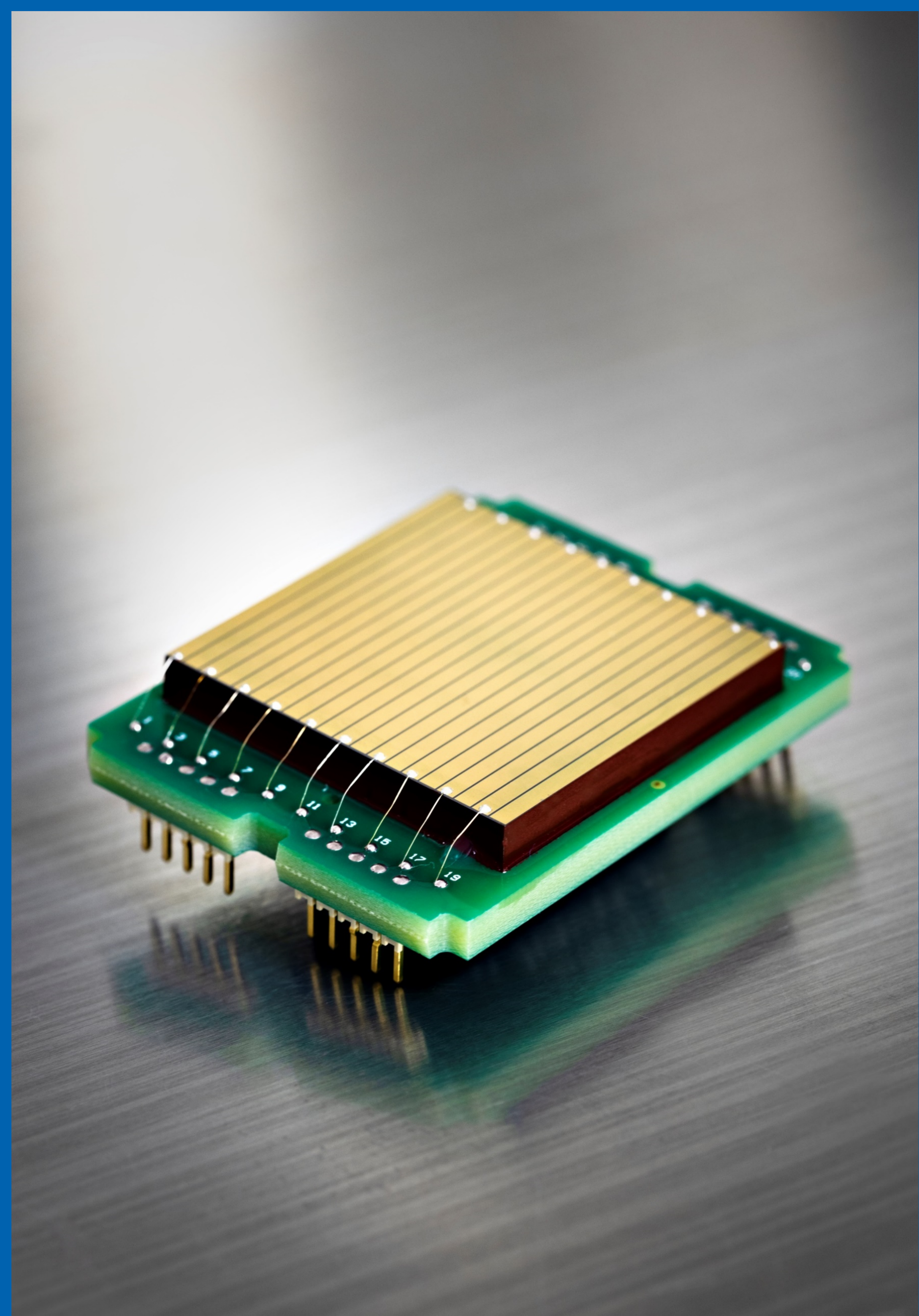

Figure 2: The 3D CZT drift strip detector (4cm x 4cm x 0.5cm).

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**.
- 3D position capability: **0.4 mm in 3D @ 661.6 keV**.

Application examples

Material uniformity analysis
S. H. Owe, I. Kuvvetli, C. Budtz-Jørgensen
Carrier Lifetime and Mobility Characterization using the DTU 3D CZT Drift Strip Detector.
In: IEEE Transactions on Nuclear Science. 2021 ; Vol. 68, No. 9. pp. 2440-2446.

Medical
S. R. H. Owe, I. Kuvvetli, A. Cherlin et al.
Evaluation of CZT Drift Strip Detectors for use in 3D Molecular Breast Imaging.
In: IEEE Transactions on Radiation and Plasma Medical Sciences. 2023 ; Vol. 7, No. 2. pp. 113 - 123.

Compton camera
S. H. Owe, I. Kuvvetli, C. Budtz-Jørgensen, and A. Zoglauer
Evaluation of a Compton Camera Concept using the 3D CdZnTe Drift Strip Detectors.
In: Journal of Instrumentation. 2019 ; Vol. 14, No. 1.

Next step:
To fly several 3D CZT Drift Strip Detectors on a small payload operating as a Compton Camera, to increase technology readiness level of the detector.

Simulation setup

Simulation software: MEGAlib
www.megalibtoolkit.com

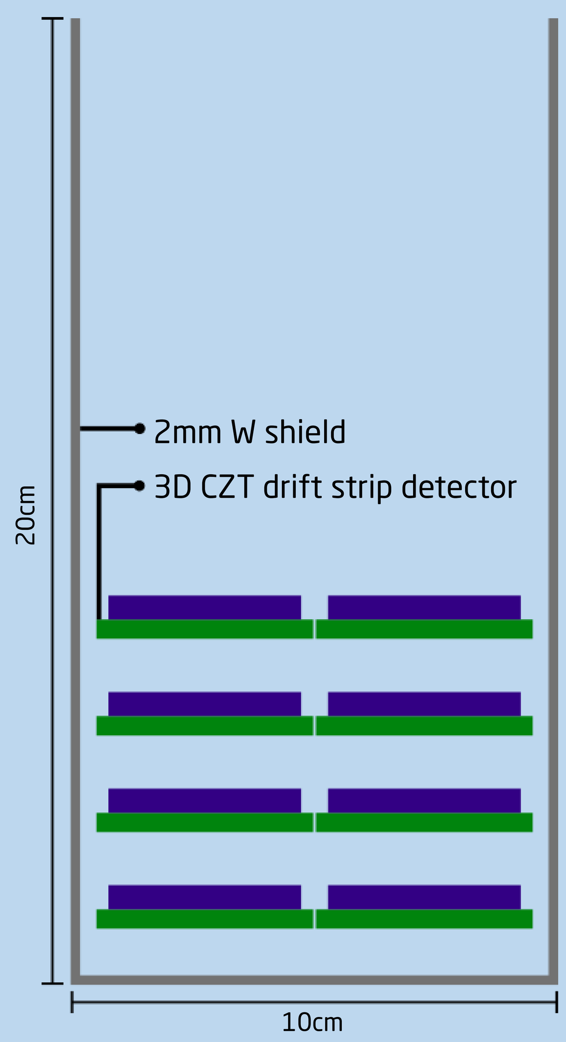

Figure 3: 3D CZT drift strip detector Compton Camera geometry.

Geometry

- Simplified geometry with 8 detectors.
- 2mm Wolfram shielding.
- 2 detectors per layer, total of 4 layers.
- 1cm layer distance.

Sources

All sources fixed 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.
- 3σ ARM cut (source extraction region).
- 2-7 Compton interactions.
- Compton scatter angles: 0° -180°.
- Minimum distance (MD) between any interaction: 0.8mm / 1.6mm.
- Energy-cut:
  - Narrow line: ±2σ of photo-peak.
  - Continuum: $E = \Delta E$.

Simulation pipeline

Basic telescope performance parameters

- Energy resolution.
- ARM (Angular Resolution Measure).
- Effective area and efficiency.

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

Sensitivity

- Narrow-line sensitivity.
- Continuum sensitivity (Crab).

Source input:
- Monochromatic: 100-2000 keV.
- Background only.
- Continuum source (Crab).

In orbit simulations

- Minimum detectable polarization (Crab-like source).
- 3σ observation of the Crab.

Source input:
- Background.
- Continuum source (Crab).

Telescope efficiency

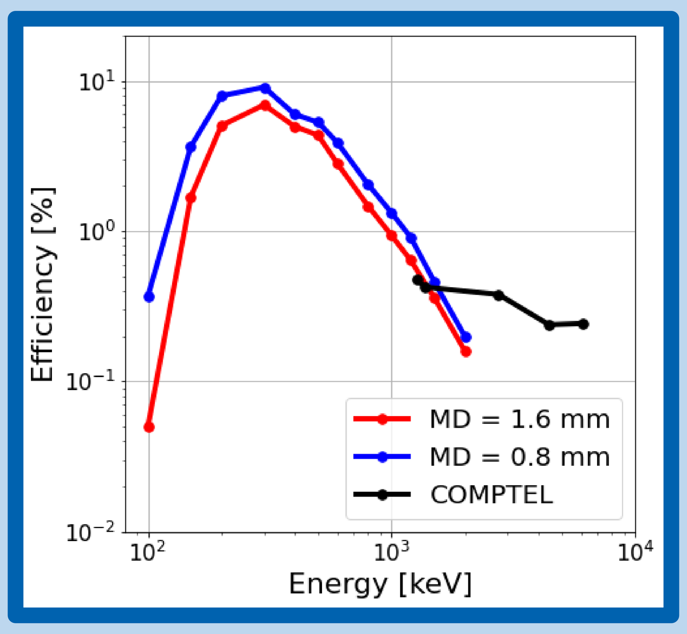

Figure 4: Simulated efficiency verses input energy, *preliminary results.*

- 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

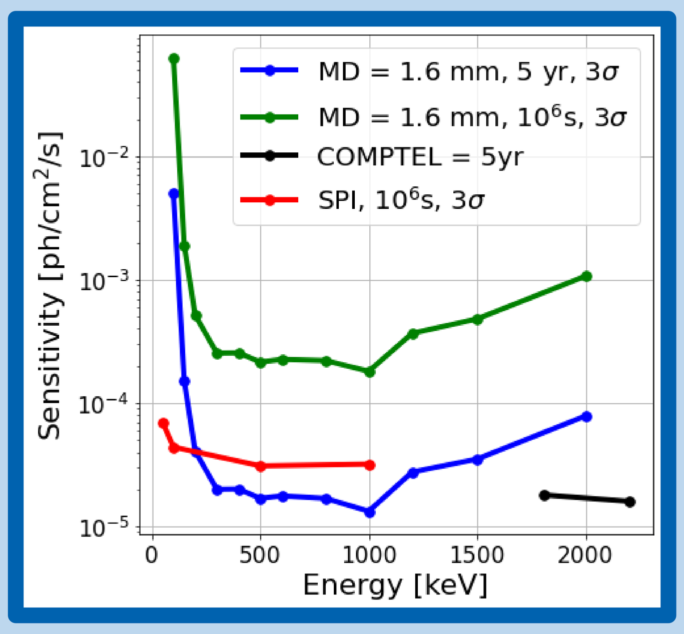

Figure 5: Simulated narrow-line sensitivity compared to existing Space missions, *preliminary results.*

- The narrow-line sensitivity of the telescope is:
  - One order of magnitude worse than that of SPI (INTEGRAL), after 10^6 s observation time.
  - ~5 times worse compared to COMPTEL in the high energy range.

Minimum detectable polarization

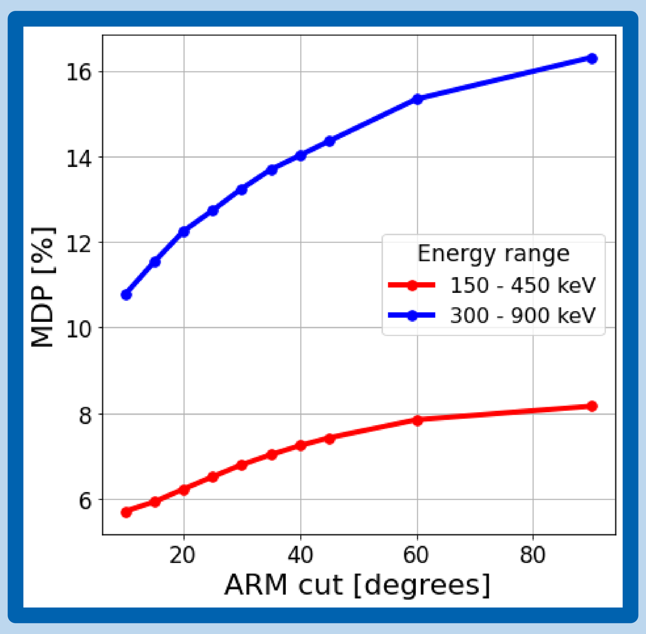

Figure 6: Minimum detectable polarization of a Crab-like source with an observation time of 10^7s, *preliminary result.*

- MDP of a Crab-like source after an observation time of 10^7 seconds.
- MDP below 8% for the energy range 150 - 450 keV.
- MDP below 17% for the energy range 300 - 900 keV.

Observing the Crab

Energy [keV]	100	300	511	600	800	1000
T_{eff} (3σ)	4.8	1.5	8.1	17.5	77.3	257.9

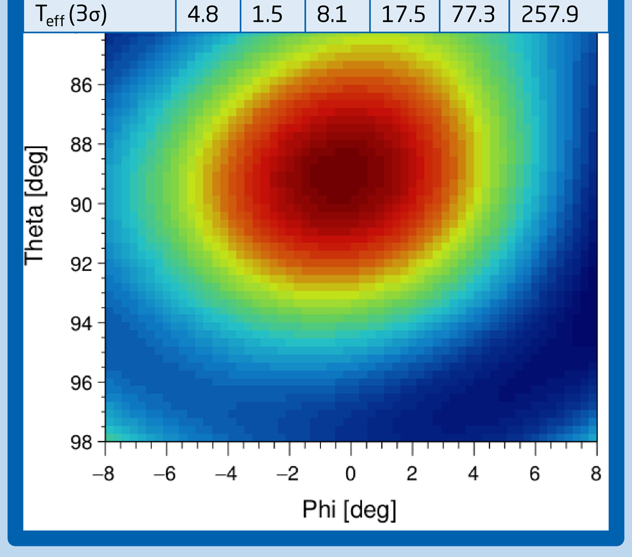

Figure 7: A 133ks observation of the Crab. The table summarizes the required observation times to achieve a 3σ observation at different energies, *preliminary result.*

- Reconstructed image of the Crab after 133ks (~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 compared 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.

DTU Space
Technical University of Denmark

Selina Ringsborg Howalt Owe
shoowe@space.dtu.dk
www.linkedin.com/in/selinaowe/