Characterization of FOXSI sounding rocket hard X-ray detectors using Advanced Light Source at Berkeley

Jessie Duncan¹, P. S. Athiray²,¹, Juliana Vievering¹, Sophie Musset¹, Lindsay Glesener¹, Alastair MacDowell³, Lance Davis¹, Juan Camilo Buitrago-Casas⁴, Sasha Courtade⁴, Connor O’Brien¹, Tadayuki Takahashi⁵, ShinWatanabe⁶, Noriyuki Narukage⁷, Kento Furukawa⁷, Kochuici Hagino³, Steven Christe³, Daniel Ryan³, Sám Krucker³

¹University of Minnesota, ²NASA MSFC, ³Lawrence Berkeley National Lab, Berkeley, ⁴Space Sciences Laboratory, UC Berkeley, ⁵Kavli IPMU, Japan, ⁶ISAS, JAXA, Japan, ⁷NAOJ, Japan, ⁸Tokyo University, ⁹NASA GSFC

Introduction

- The Focusing Optics X-ray Solar Imager (FOXSI) sounding rocket campaigns represent the first experiment to perform direct focusing hard x-ray (HXR) imaging spectroscopy of the Sun.
- FOXSI has successfully flown three times, in 2012, 2014, and 2018.
- FOXSI sounding rocket Instrument:
  - Energy range: 4 – 20 keV
  - Focal length: 2 m
  - Optics: Wolter I type mirrors (7 modules)
  - Detectors: Double sided strip Si and CdTe
  - Pitch: 75μm (Si), 60μm (CdTe)
  - Angular resolution of the instrument is limited by the pitch of the detectors[1]

GOALS:
- Investigate the effect of charge sharing in FOXSI detectors to achieve sub-strip imaging resolution.
- Determine strip-to-strip variation in the efficiency of FOXSI detectors as a function of beam position.
- Investigate spectral response as a function of beam hit location and photon energy in FOXSI detectors.

Experimental Setup at Advanced Light Source, Berkeley

The FOXSI detector is enclosed in a metal box containing a thermo-electric cooler (TEC)

1 - 4: TEC box for controlled programmable cooling to a set steady temperature (-10°C) with power supply and water chiller
5 - 7: FOXSI electronics board for control of data acquisition, low and high voltage power supplies to power electronics and apply bias voltage across detector
8: The TEC enclosure and FOXSI electronics mounted onto a translation stage
9 - 10: Beam aperture behind controllable horizontal and vertical slits
11: Dry air purge to avoid condensation

Method

1. A fine mono-energetic x-ray beam was scanned across FOXSI detector strips at a sub-shift-pitch step size.
2. Beamline 3.3.2 at the Advanced Light Source (ALS) Synchrotron, Berkeley, provides a monochromatic x-ray beam at energies between 4-20 keV. The beam size is adjustable down to a minimum of 2μm x 2μm.
3. Scans were repeated at a variety of beam energies and locations on the detector.
4. Data was also captured with a reference Silicon Drift Detector (SDD) for absolute flux calibration for detector efficiency.

Auto-Scan Procedure

- Developed auto-scan procedure that connects detector-control and stage-control systems to perform synchronized, pre-programmed scans
- Inputs: start/end positions, step size, and integration time
- Result: Autonomous detector scan without manual intervention, efficient data collection with large area scans

Data Summary

X-direction defined parallel to cathode side strips (Y-direction defined parallel to anode side strips)

<table>
<thead>
<tr>
<th>Energies (keV)</th>
<th>Length or Area</th>
<th>Step-size</th>
<th>Beam Size</th>
<th>Integration time</th>
</tr>
</thead>
<tbody>
<tr>
<td>SDD</td>
<td>300μm (y-direction)</td>
<td>5μm (x)</td>
<td>5μm x 5μm</td>
<td>1 min</td>
</tr>
<tr>
<td>Si</td>
<td>600μm (x)</td>
<td>15μm</td>
<td>5μm x 5μm</td>
<td>1 min</td>
</tr>
<tr>
<td>Si</td>
<td>700μm (y)</td>
<td>15μm</td>
<td>5μm x 5μm</td>
<td>1 min</td>
</tr>
</tbody>
</table>

Data taken with FOXSI CdTe detector

<table>
<thead>
<tr>
<th>Energies (keV)</th>
<th>Length or Area</th>
<th>Step-size</th>
<th>Beam Size</th>
<th>Integration time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Si</td>
<td>300μm (y-direction)</td>
<td>3μm</td>
<td>3μm x 3μm</td>
<td>1 min</td>
</tr>
<tr>
<td>Si</td>
<td>300μm (x)</td>
<td>5μm</td>
<td>5μm x 5μm</td>
<td>1 min</td>
</tr>
<tr>
<td>Si</td>
<td>1200μm (x)</td>
<td>15μm</td>
<td>5μm x 5μm</td>
<td>1 min</td>
</tr>
</tbody>
</table>

Preliminary Analysis

Event selection

- Beam size : 2μm x 2μm
- Step size : 5 μm
- Energy : 6 keV
- Detector : Si
- Scan across cathode strips (y direction)

- Select events with incident energy > 4 keV
- For every beam position, find number of single, double and multi-strip events

Conclusions

- FOXSI Si detector - Scan across cathode (p-side) strips
  - Single strip: 74-99% of events (position-dependent)
  - Double strip: 1-26% of events
  - More double strip events occur with the beam in the ~20μm gap between strips.
  - This behavior is uniform among different strips
  - The observed beam intensity is also uniform among different strips
- FOXSI CdTe detector
  - The observed beam intensity shows significant variation between different strips

Ongoing and Future work

- Investigate event selection in CdTe detectors and understand charge sharing across strips
- Determine the overall efficiency of FOXSI detectors at different photon energies.
- Potential cross-calibration of FOXSI Si and CdTe HXR detectors

References