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

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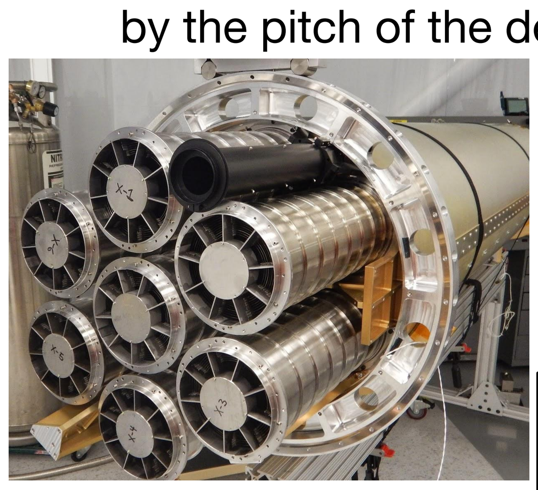
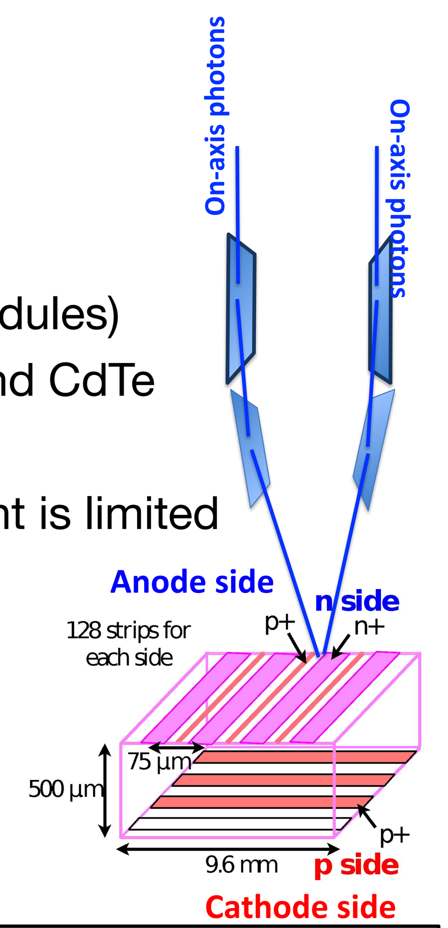
Introduction

- The **F**ocusing **O**ptics **X**-ray **S**olar **I**mager (*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]





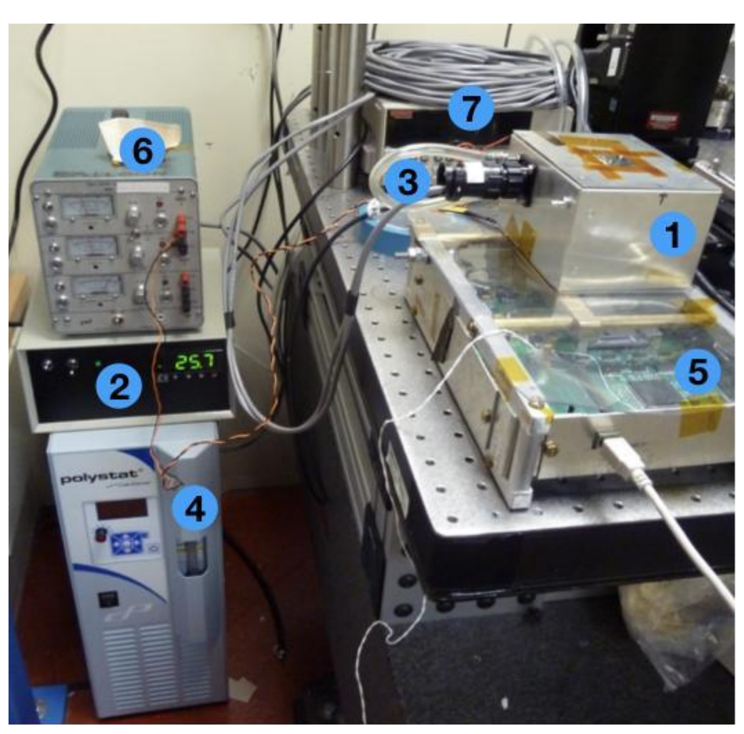
(Left) FOXSI optics modules assembled for flight.
(Top) Diagram of optics + FOXSI Si detector.

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 .

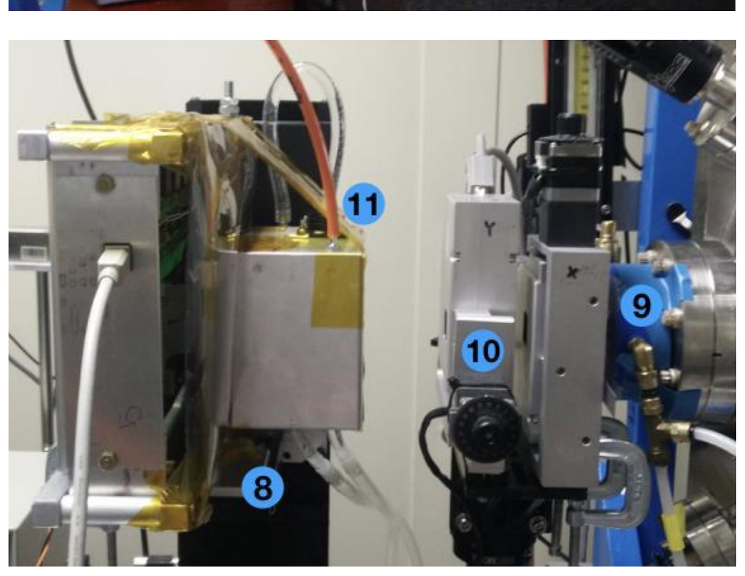
Experimental Setup at **A**dvanced **L**ight **S**ource, Berkeley

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 (-10ºC) 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-strip-pitch step size.
2. Beamline 3.3.2 at the **A**dvanced **L**ight **S**ource (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)

Data taken with FOXSI Si detector

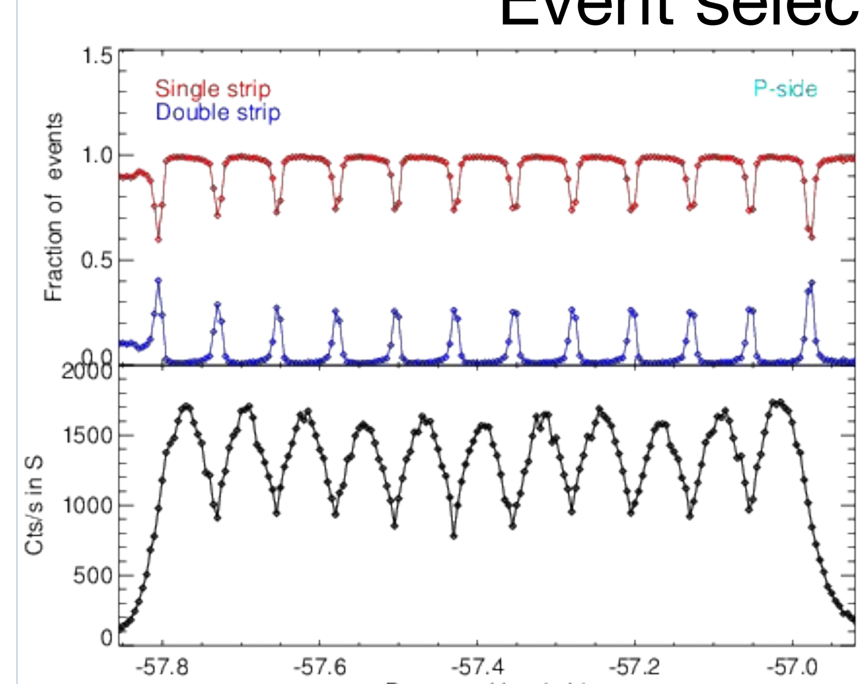
Energies (keV)	Length or Area	Step-size	Beam Size	Integration time
6	300µm (y-direction scans at 4 different x positions)	25 µm (y) 500 µm (x)	5µm x 5µm	1 min
5.5 & 7 (each 1 scan)	700 µm (y-direction)	15 µm	5µm x 5µm	1 min
6,8 (2 scans each-different x)	700 µm (y-direction)	15 µm	5µm x 5µm	1 min
6	1200 µm (y-direction)	5 µm	2µm x 2µm	3 min

Data taken with FOXSI CdTe detector

Energies (keV)	Length or Area	Step size	Beam Size	Integration time
5.5,6,7,8,10,11,12 (2 scans, different x)	300 µm (y-direction)	12 or 20 µm	5µm x 5µm	4 min (5.5 keV) 2 min (others)
6, 9	300 µm (x-direction)	12 µm	5µm x 5µm	2 min
6	300 µm	4 µm	2µm x 2µm	2 min
7	540µm (x), 540µm (y) (L-shape scan)	3 µm	2µm x 2µm	2 min
6,7	300µm x 300µm (square scans)	15 µm (x,y)	5µm x 5µm	2 min

Preliminary Analysis

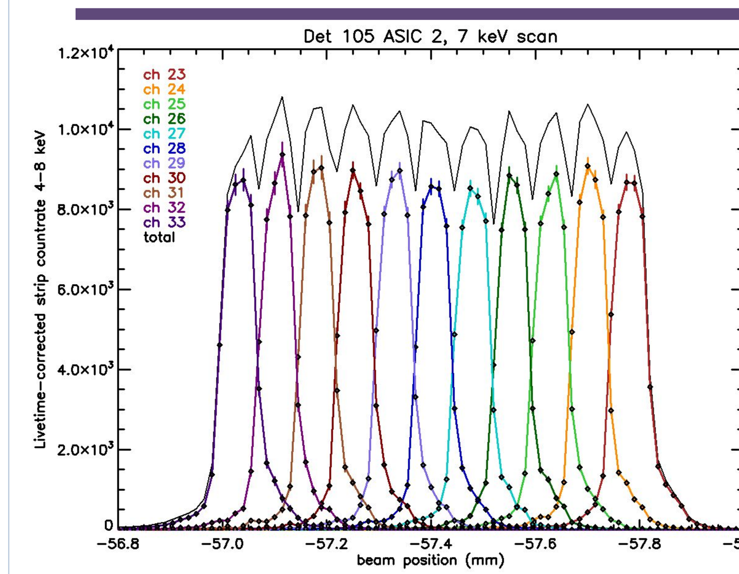
Event selection



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

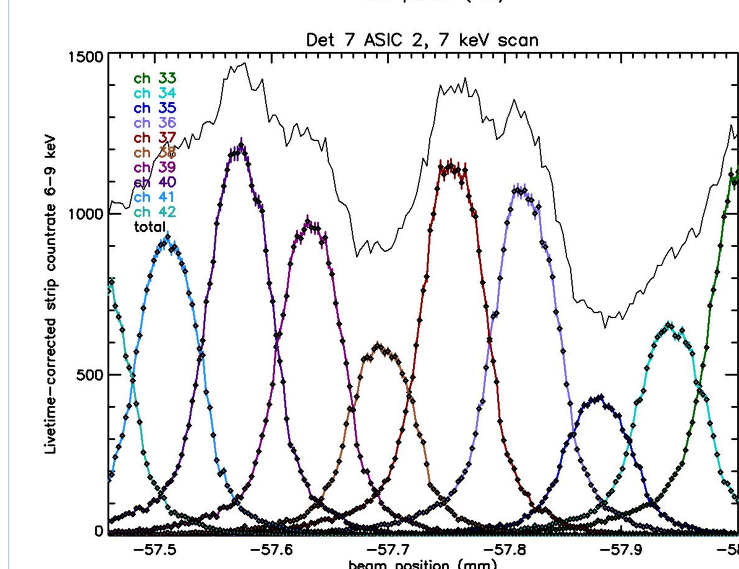
- Select events with incident energy > 4 keV
- For every beam position, find number of single, double and multi-strip events

Strip-to-Strip Intensity variations



- Beam size : 5µm x 5µm
- Step size : 15 µm
- Energy : 7 keV
- Detector : Si
- Scan across cathode strips

Si detector measures uniform beam intensity across different strips

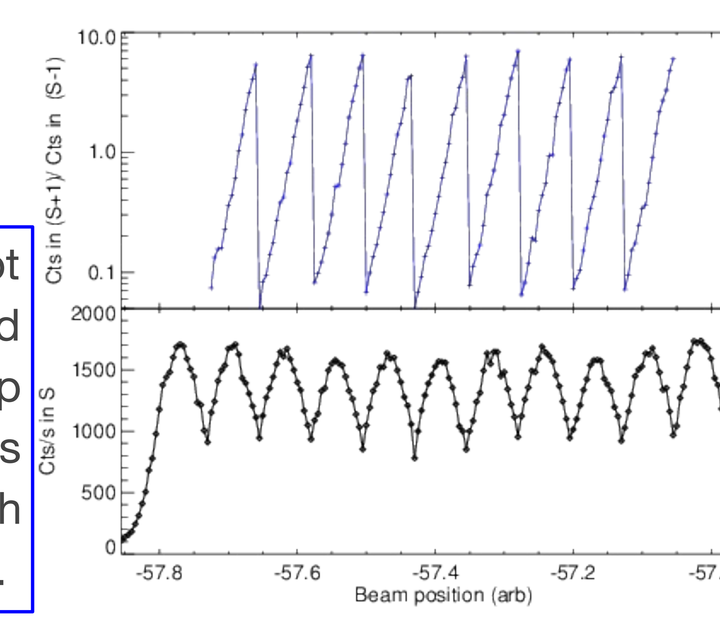


- Beam size : 2µm x 2µm
- Step size : 3 µm
- Energy : 7 keV
- Detector : CdTe
- Scan across cathode strips

CdTe detector shows significant variation in beam intensity between different strips

Identify beam hit location

- Beam size : 2µm x 2µm
- Step size : 5 µm
- Energy : 6 keV
- Detector : Si



For beam in strip S, upper plot shows ratio of events collected in strip (S+1) to those in strip (S-1). Lower plot gives counts in the highest count strip (both as functions of beam position).

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

1. Furukawa et al., "Development of 60 µm pitch CdTe double-sided strip detectors for the FOXSI-3 sounding rocket experiment", NIMPR Section A, 2018.

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