SMILE SXI Pre-launch Testing

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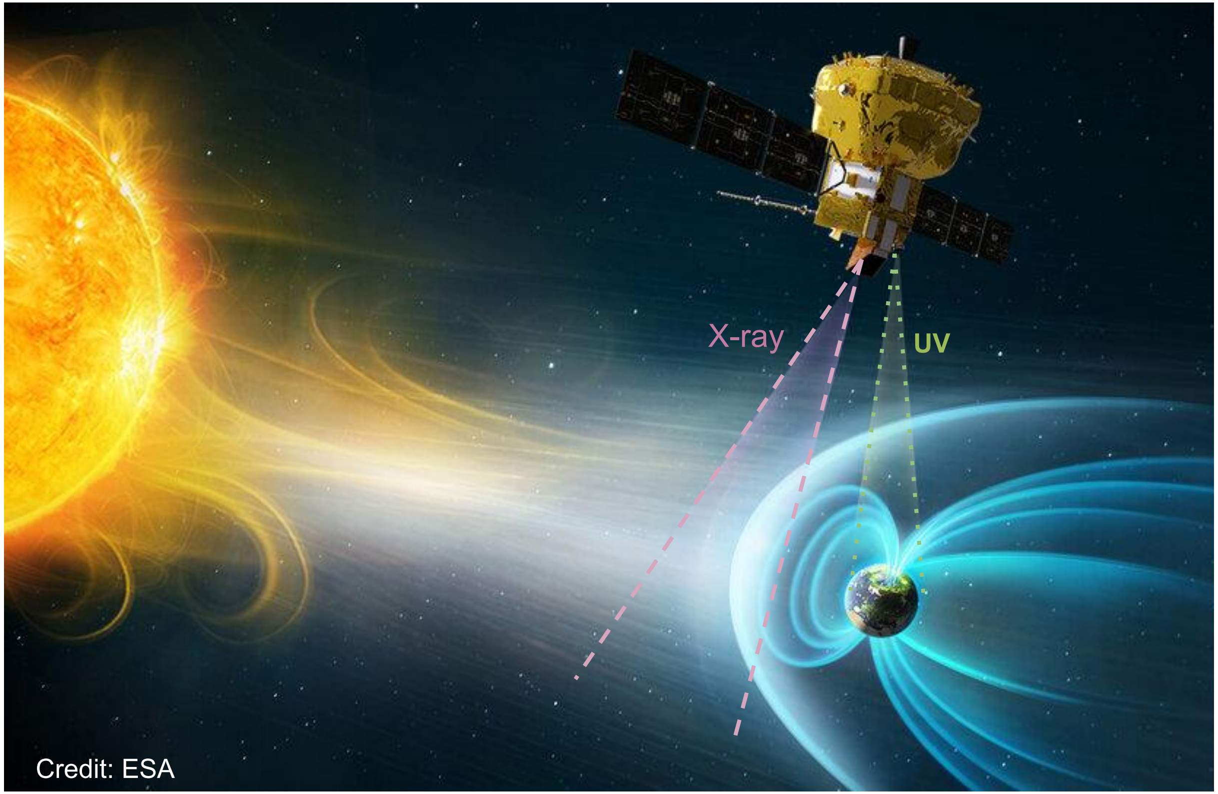
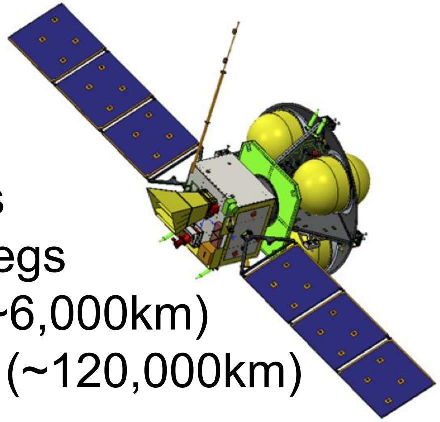
+
SXI Team

IACHEC (2024-May-15)

SMILE





Orbit:

Period ~51 hours
Inclination ~70 degs
Perigee ~ 1RE (~6,000km)
Apogee ~ 19 RE (~120,000km)

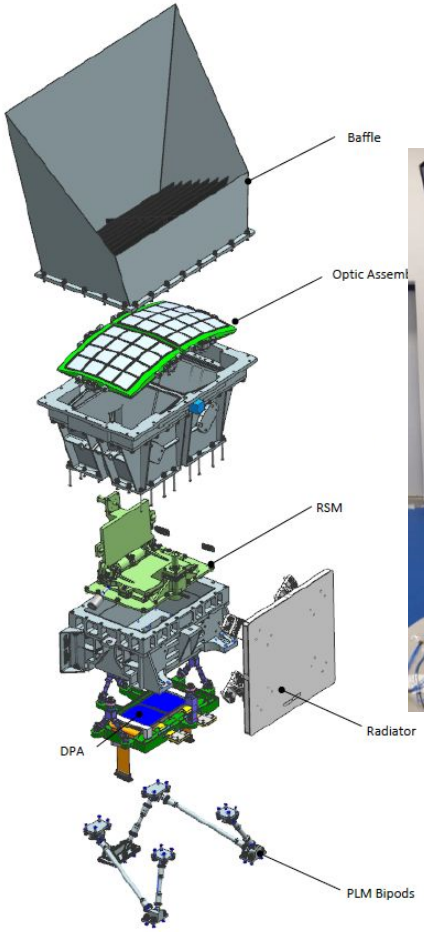
Available science time ~ 40 hours

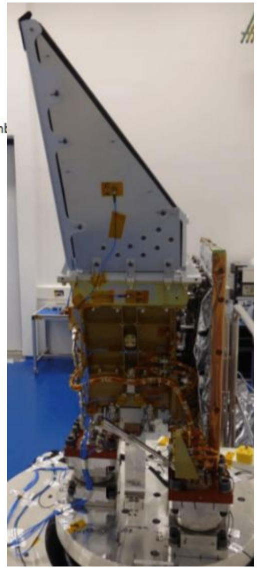
Mission Duration:

Nominal: 3 years
Maximum ~ 7 years

Launch: End 2025 (Vega-C)

Soft X-ray Imager (SXI)



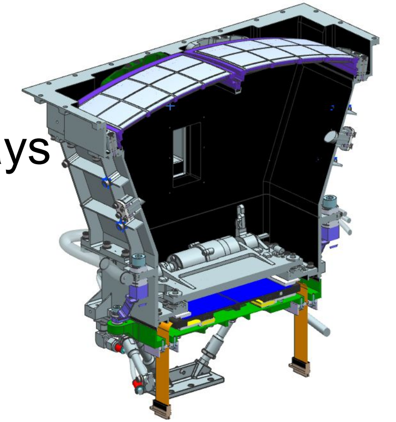


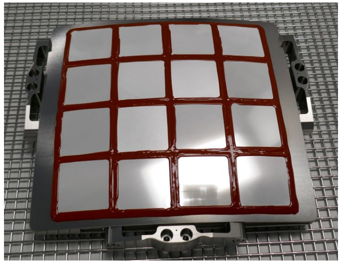
Optics

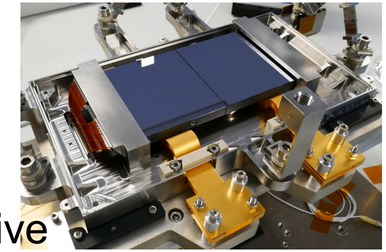
- 32 MPOs (Photonis) arranged in two 4x4 arrays
  - MPOs are 4 cm x 4 cm, 1.2 mm thick
  - 40 micron channels, 12 micron walls
  - Iridium coated channels
  - 100nm Al optical blocking filter on top
  - Slumped to give nominal focal length 300mm
  - FOV = 26°.5 x 15°.5

Detectors

- Two Te2V CCD370 devices
  - Plato CCD270 heritage, with additional supplemental buried channel (to improve CTI)
  - Back illuminated, 18 micron depletion depth
  - 4510 x 4510 18 micron native pixels
    - 3791 image, 719 store (shielded)
  - Two readout nodes per CCD
  - Nominal science mode uses 6 x 6 binning to give 632 x 376 binned pixels per node (Frame Transfer [FT] mode)

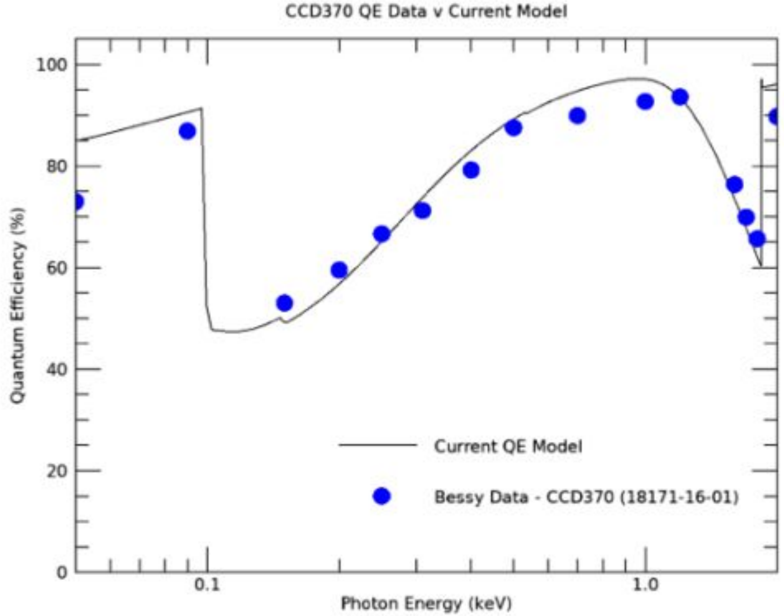


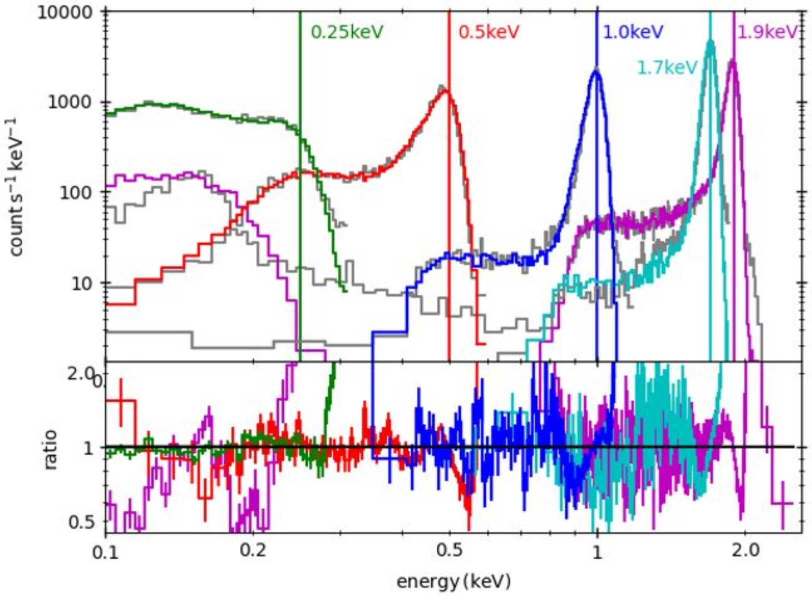




CCD QE and RMF

- QE and redistribution measured on a CCD370 device at the Bessy synchrotron beamline by colleagues at the Open University

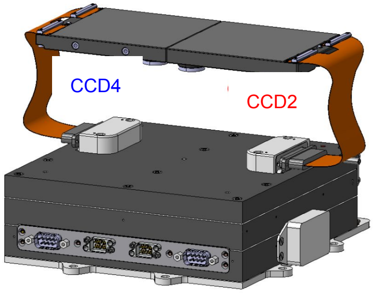




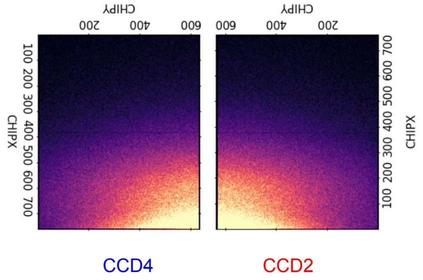
- QE as expected for a BI device with 18 micron depletion depth + 0.03 micron Si dead layer
- XRT CCD simulator modified for BI device and Charge Collection Efficiency function updated

Front-End Electronics (FEE) Testing

- The FEE drives the CCDs, performing FT 6x6 binning and event detection. Designed around FPGA at colleagues from MSSL.
- 3 FEES: BB, EQM, FM



- TVAC campaign at RAL in Dec 2023.
  - Using EQM FEE and EBOX
- Fe-55 radioactive source positioned between CCDs, below focal plane, meant Mn-Ka and Al-Ka X-rays would be detected from the underside of the closed door (by scattering and fluorescence).
- Frame Transfer (FT) and event detection (ED) data were taken after thermal balance (> 8hrs) during which the CCD was read out continuously - so all residual charge was drained.



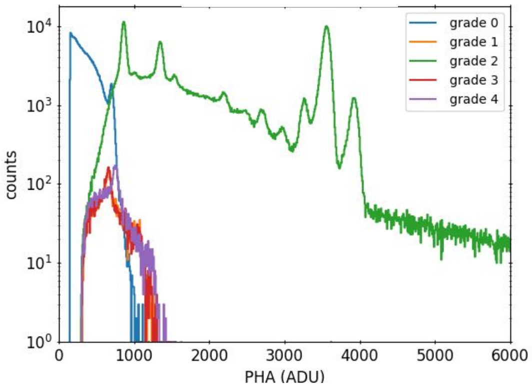
UNIVERSITY OF LEICESTER

TVAC FT Event Detection Data

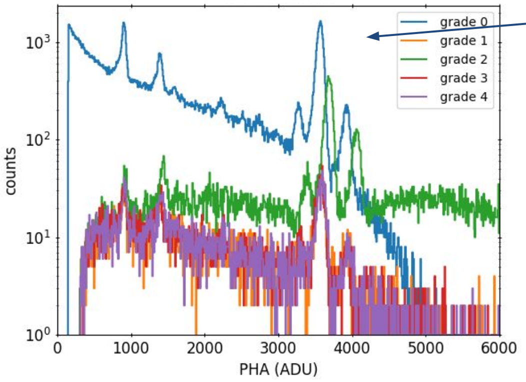
- Expectation: single pixel (grade 0) events dominate at all energies (>80%)
- However, high fraction of horizontally split events were found

grade 0 : 24.65
grade 1 : 0.43
grade 2 : 68.56
grade 3 : 0.44
grade 4 : 0.55

CCD2, F-side



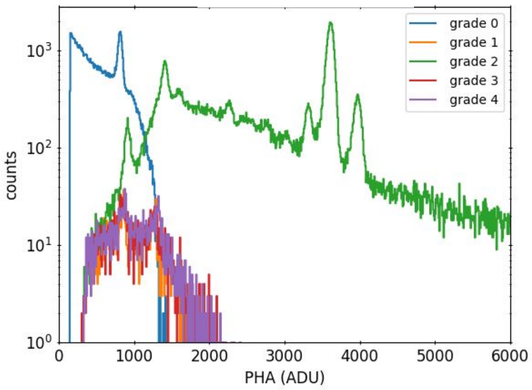
CCD2, E-side



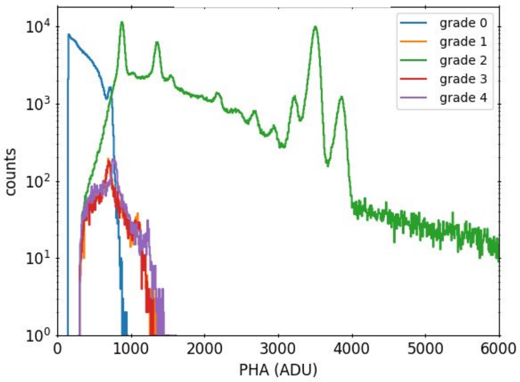
“Best” Amp

grade 0 : 78.20
grade 1 : 2.06
grade 2 : 13.27
grade 3 : 2.14
grade 4 : 2.10

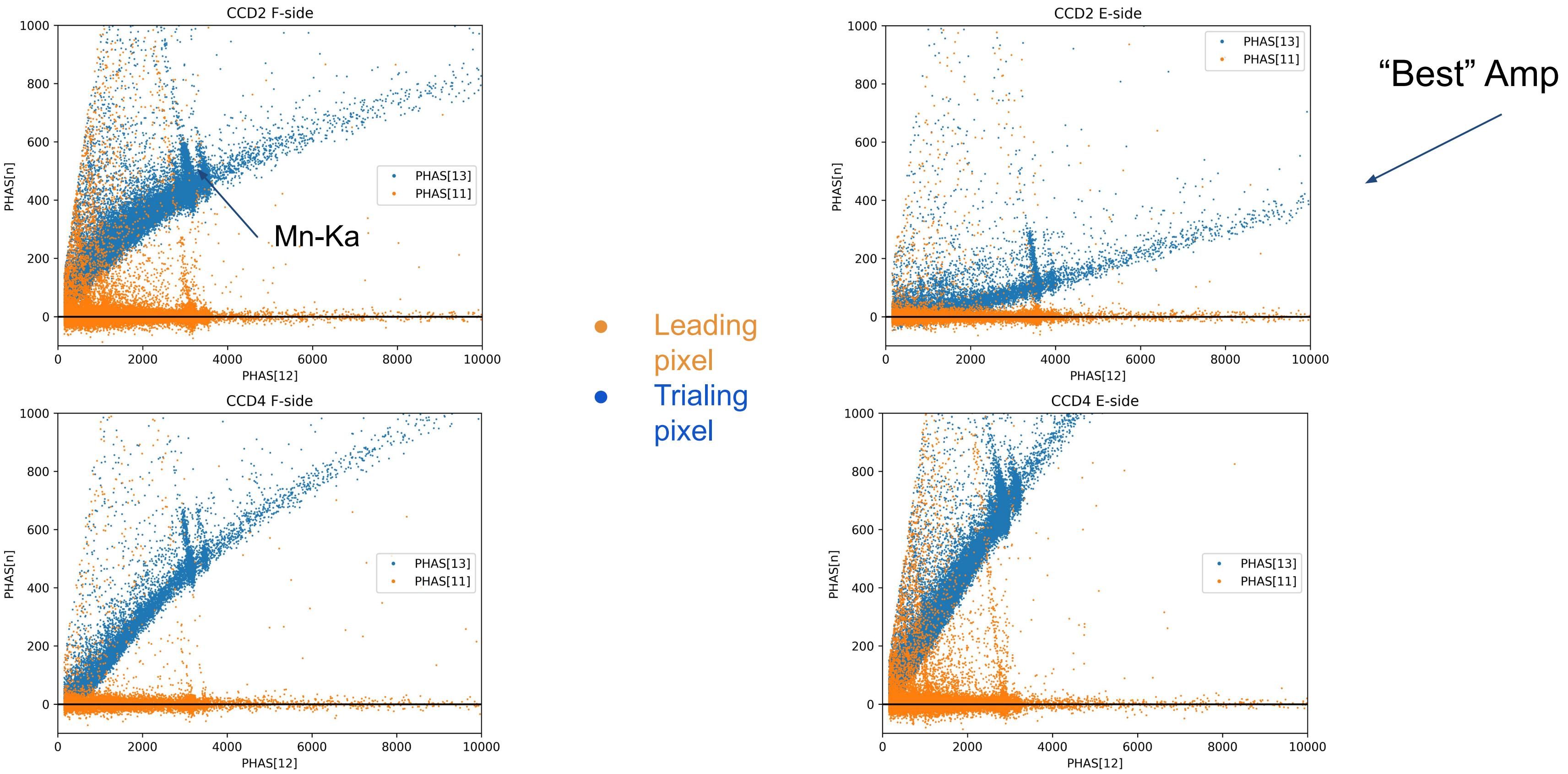
CCD4, F-side



CCD4, E-side



TVAC FT Data - Trailing Charge



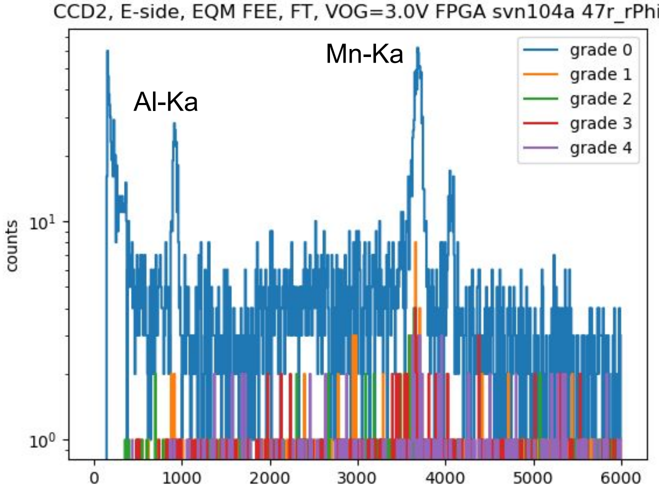
- Conclusion: Trailing serial charge causing event migration (not CTI)
- CCD2, E-side better as effect less severe from this readout node

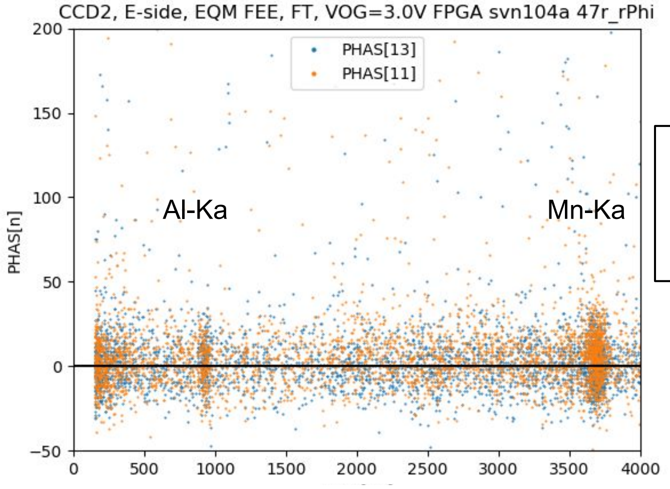
FEE Testing (cont'd)

- Further FEE testing continued at MSSL using a spare CCD370 illuminated with a Fe-55 source
  - Single FEE port at a time
  - 40 datasets taken covering different FEEs, FPGA code versions, output gate voltage settings and hardware modifications
- Trailing charge effect removed by
  - Changing output gate voltage from 2 to 3V helps reduce the level of trailing charge seen (maximum allowed 4.5V)
  - Adding extra resistance to the summing well (SW) and register (rPhi) clocks modified the waveforms sufficiently to reduce the trailing charge effect to negligible levels in both Frame Transfer and Full Frame modes, resulting in good X-ray spectra and performance
- Changes now made permanently to the EQM and FM FEE hardware

EQM FEE, FT - VOG 3V + SW & rPhi resistors, SVN104A

CCD2 E-side

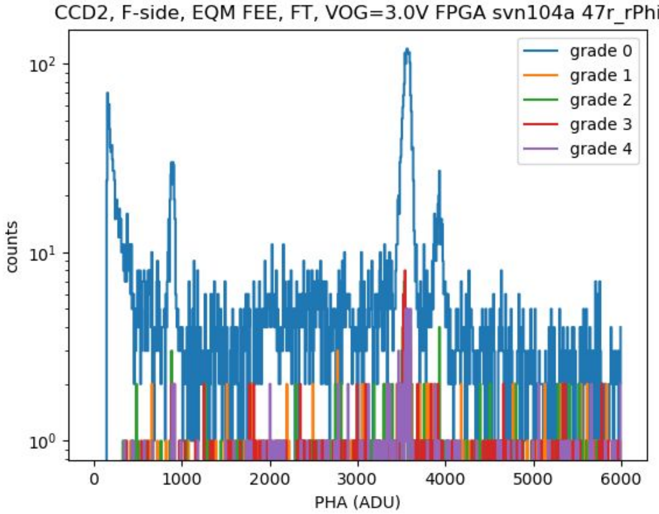


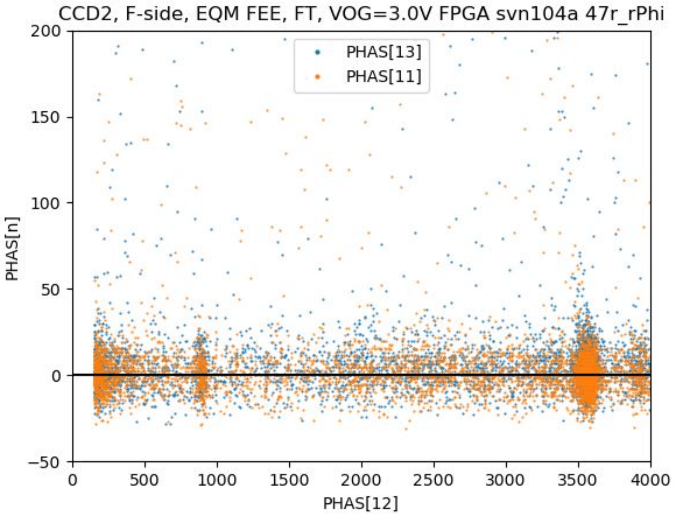


Frame Transfer Mode

No trailing charge

CCD2 F-side

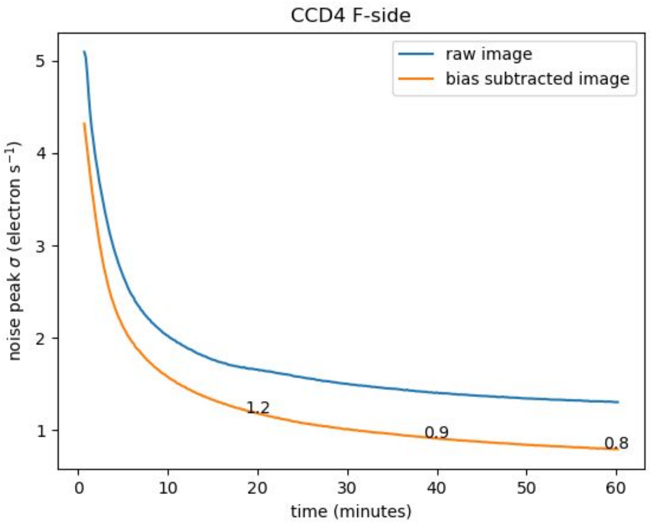


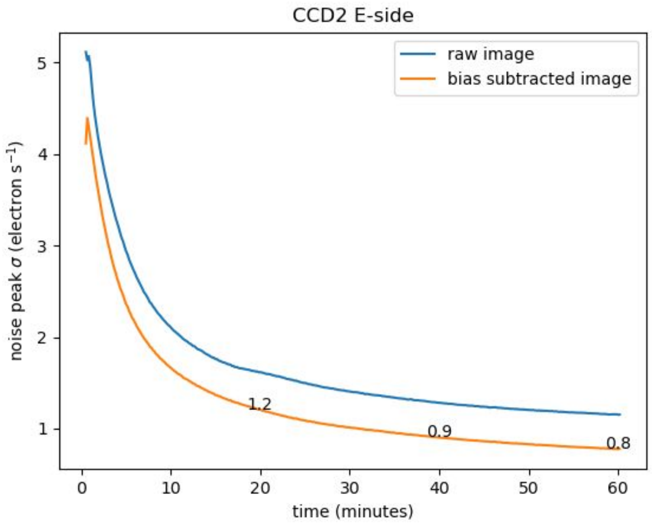


Residual Charge

- Due to SMILE's highly elliptical orbit and the radiation environment, SXI will close its door at 50000km then switch off at 32000km (~2 hour window)
- However, after each switch on, time has to be allowed for the build up of residual charge to decay.
- TVAC data

Residual charge decay

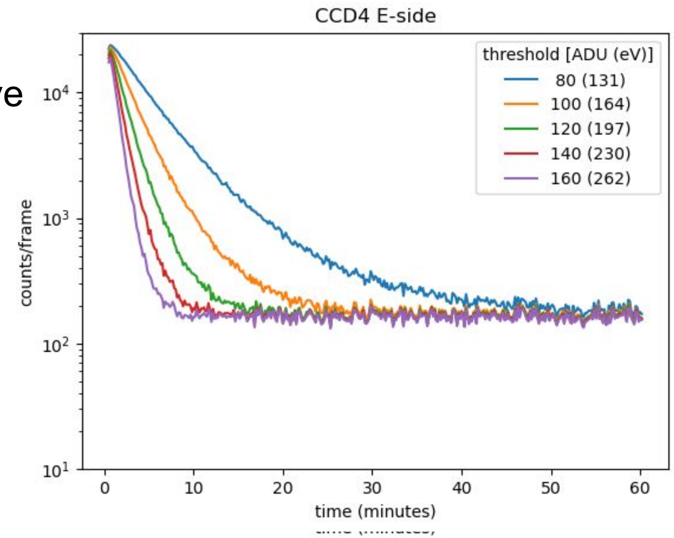


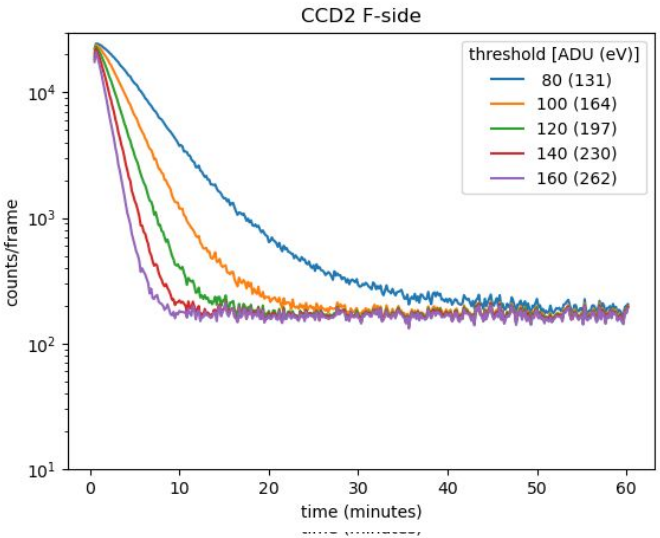


Residual Charge

- Due to SMILE's highly elliptical orbit and the radiation environment, SXI will close its door at 50000km then switch off at 32000km (~2 hour window)
- However, after each switch on, time has to be allowed for the build up of residual charge to decay.
- TVAC data suggest the noise peak and rate above 200 eV threshold will have decayed sufficiently 30 mins after switch on.

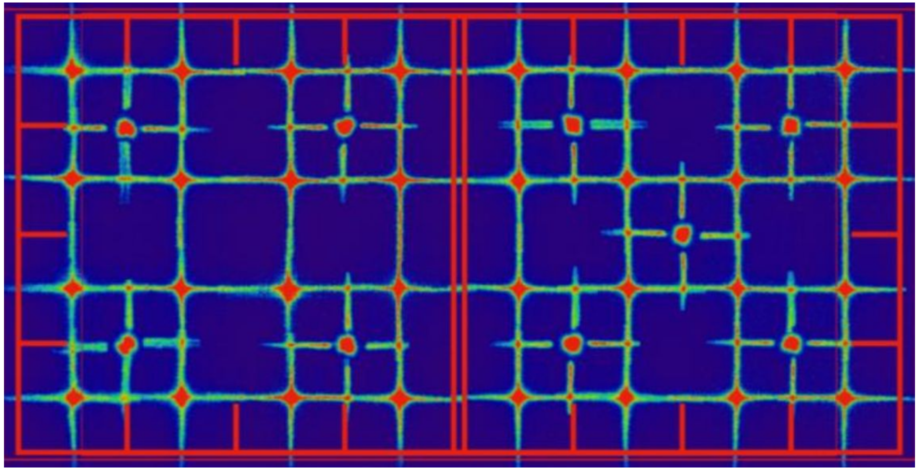
Rate above threshold decay



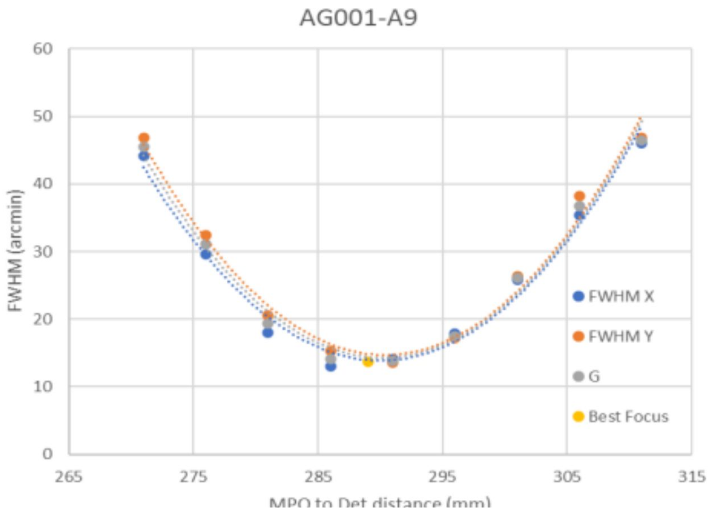


MPO testing overview

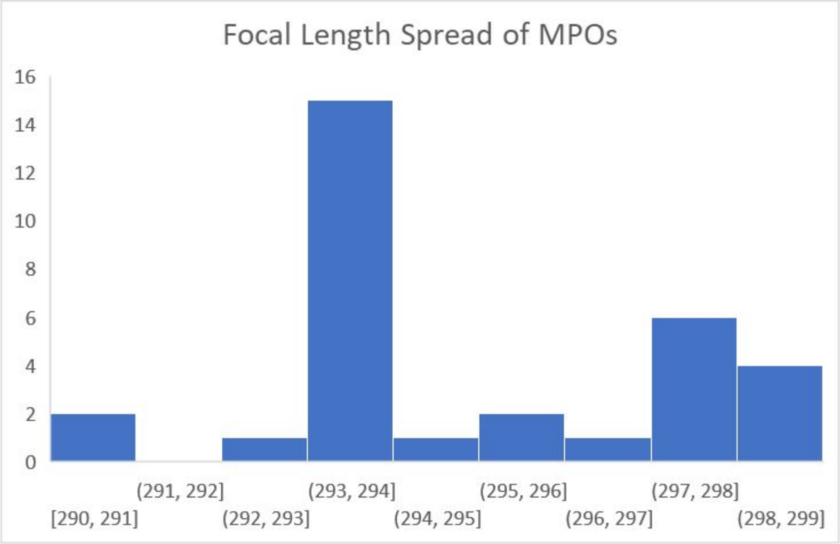
- Optical performance quantified using the 27.5m beamline test facility at the University of Leicester
- Testing performed primarily at Cu-L (930eV); some data at C-K (277 eV)
- 4 MPOs tested at a time in 4 quadrants of the optical assembly - other quadrants blocked
- Data taken in 5mm steps to determine the focal length
- PSF FWHM determined by 2D Lorentzian fitting



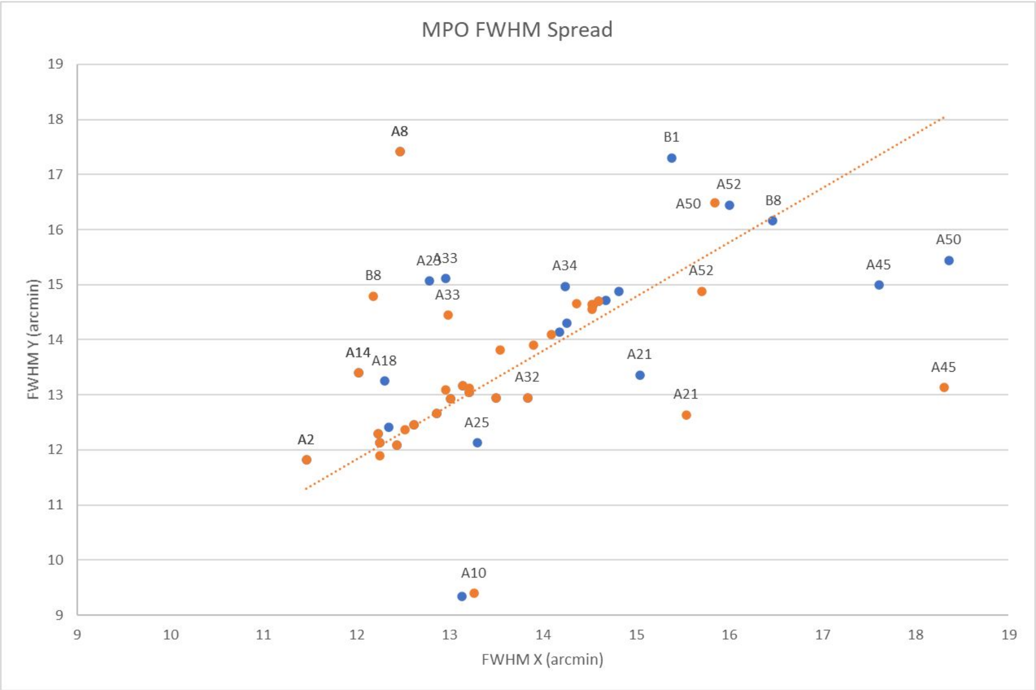
Composite image



MPO Focal Length and FWHM



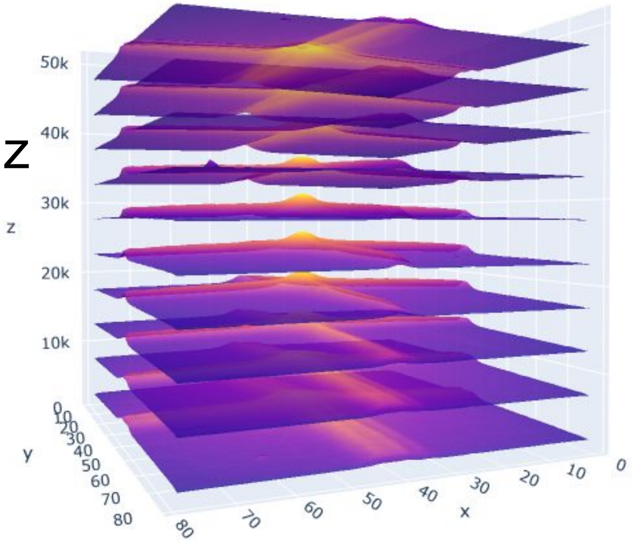
Focal length (mm)

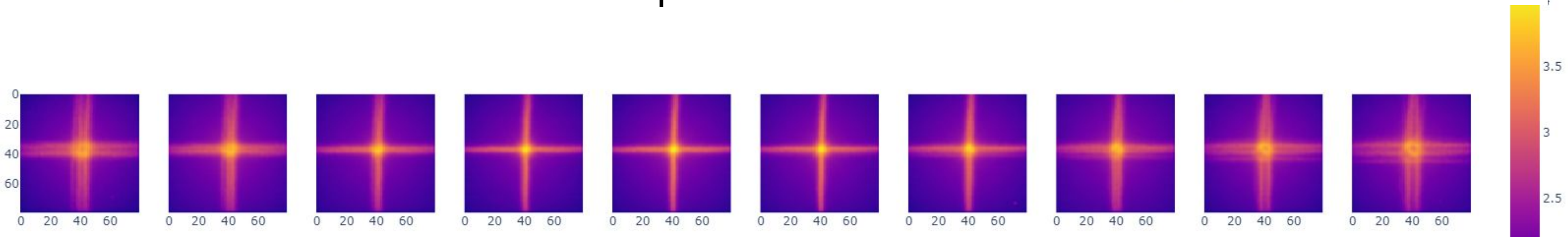


- Cu-L (930eV)
- C-K (277keV)

Interpolated 3D PSF

- Cu-L (930 eV) source
- 10 planes captured around focus in 5mm steps in z
- Resolution 2048x2048 pixels at 13.5 micron/pixel
  - Downsampled to 80x80 pixels ~4 arcmin/pixel
- Interpolated to 40 planes with 1.25mm separation
- Allows estimation of empirical PSF at different off-axis angles where detector and focal planes intersect at difference focal depths

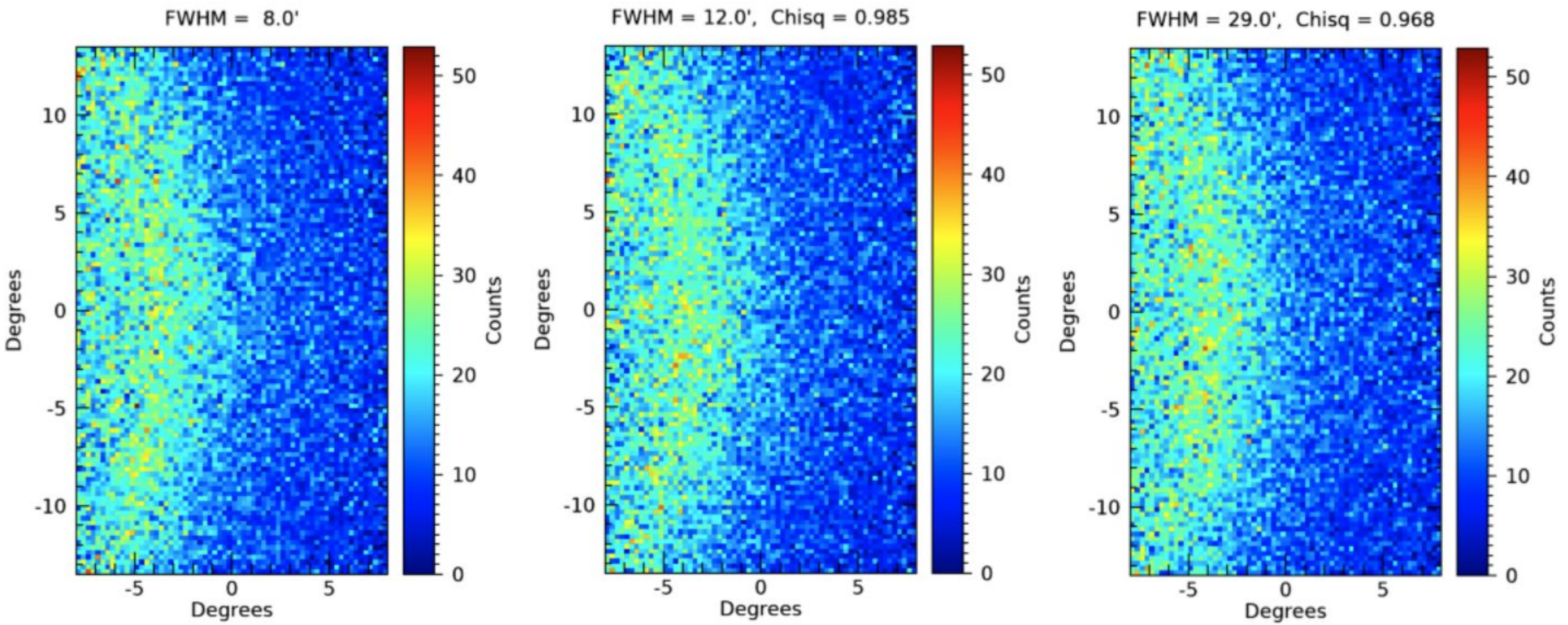




Empirical PSF Cross-Sections (log10) from 0..50mm in z

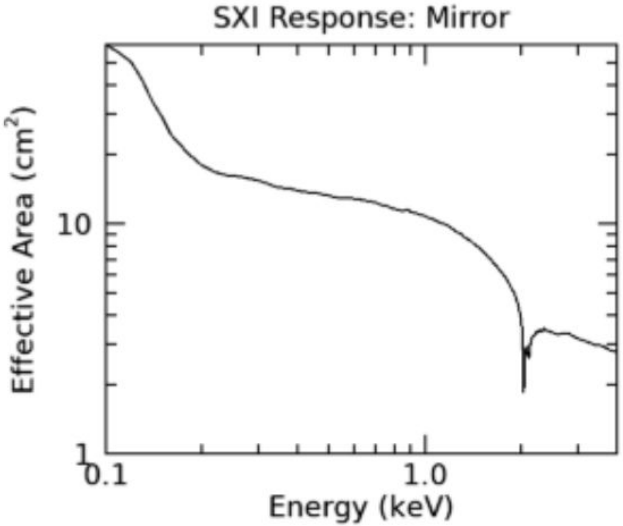
SXI Scientific Requirement

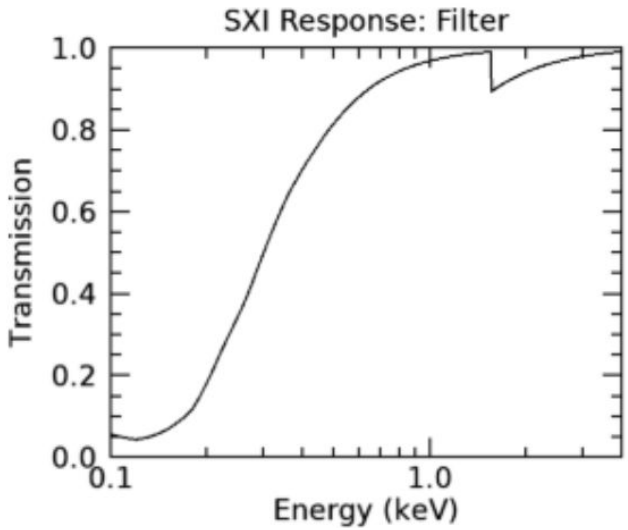
- For a medium solar wind strength, determine the magnetopause boundary to 0.5Re accuracy for a 5 minute integration
    - Met even when FWHM performance degraded by > factor 2



Effective Area

- Effective area = Optic Area * Filter Transmission
  - presently being tested on flight spare MPOs at the University of Leicester Vertical Test Facility
- Simulated area and filter transmission:





- High expectation that simulated area will be accurate based on SVOM MXT calibration experience at Leicester

SXI Scientific Requirement

- For a medium solar wind strength, determine the magnetopause boundary to 0.5Re accuracy for a 5 minute integration
  - Met even when effective area reduced by a worse case expectation of 23% at EOL

Table 8: Comparison of the estimated subsolar magnetopause position error as a function of solar wind flux at BOL and EOL with reduced effective area and CTI.

Beginning of life

End of life with conservative 23 % area reduction

SW Flux	No. of SIms	Mean $R0_{MP}$	STDDEV($R0_{MP}$)	Mean $\delta R0_{MP}$	Mean SNR
BOL, 5 minute integration					
3.0×10^8 cm^{-2} s^{-1}	18	9.27	0.74	0.90	28.8
4.9×10^8 cm^{-2} s^{-1}	21	8.50	0.23	0.28	48.0
8.0×10^8 cm^{-2} s^{-1}	20	7.71	0.10	0.18	81.2
1.4×10^9 cm^{-2} s^{-1}	12	6.91	0.10	0.13	129.7
EOL, 5 minute integration					
3.0×10^8 cm^{-2} s^{-1}	18	9.20	0.64	1.05	22.5
4.9×10^8 cm^{-2} s^{-1}	21	8.49	0.30	0.39	38.1
8.0×10^8 cm^{-2} s^{-1}	20	7.71	0.14	0.27	64.0
1.4×10^9 cm^{-2} s^{-1}	12	6.95	0.13	0.16	102.9

Summary

- No end-to-end ground calibration of the complete SXI instrument was possible because door mechanism had to be locked in the closed position for launch
- Good QE and response calibration on a representative qualification model CCD
- CCD residual charge can be managed by in orbit operations
- Good irradiation data on representative CCD which provides confidence in our in-orbit CTI predictions for EOL
  - Charge injection available to improve CTI
- Some scheduling issues meant MPO calibration is more limited in scope than originally planned
  - Current data show we are consistent with our science requirements
- SXI will use serendipitous observations of the diffuse X-ray background and numerous astrophysical point sources to inform the in-flight calibration (E0102 [SMC], N132D [LMC], Vela, AB Dor - concentrated around southern sky)
- UL plan to rig-up a ground test system using spare FEE and CCD370 to test the Instrument Application Software and operating modes while collecting X-ray data