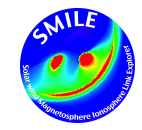# The SMILE Soft X-ray Imager tools to model and tackle its radiation damage effects

Claudio Pagani, University of Leicester
(for the SMILE-SXI ground processing team)
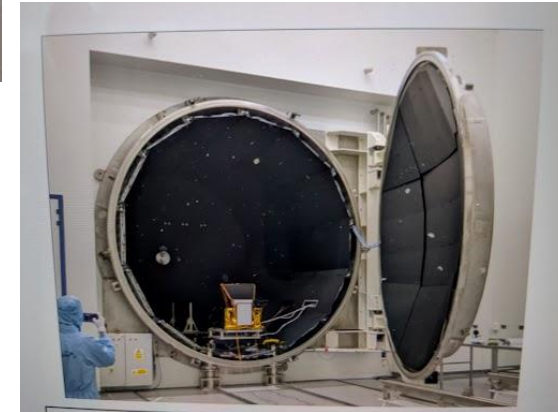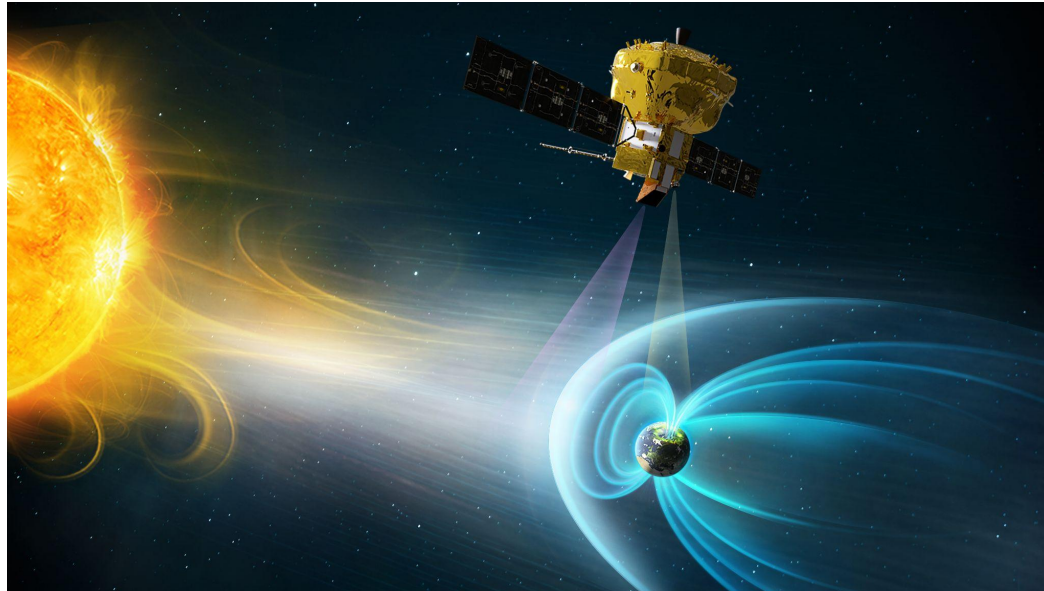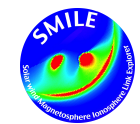
IACHEC 16 - Parador de La Granja, 13th May 2024

SMILE and the SXI

SMILE: **S**olar wind **M**agnetosphere **I**onosphere **L**ink **E**xplorer, a joint mission between the European Space Agency (ESA) and the Chinese Academy of Sciences (CAS).
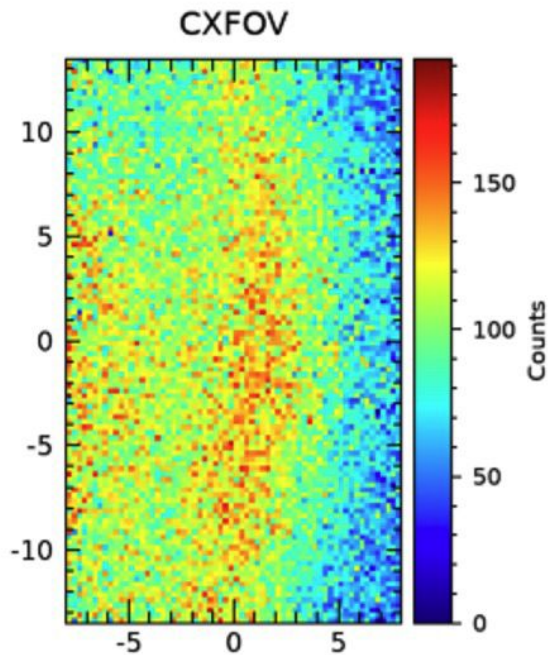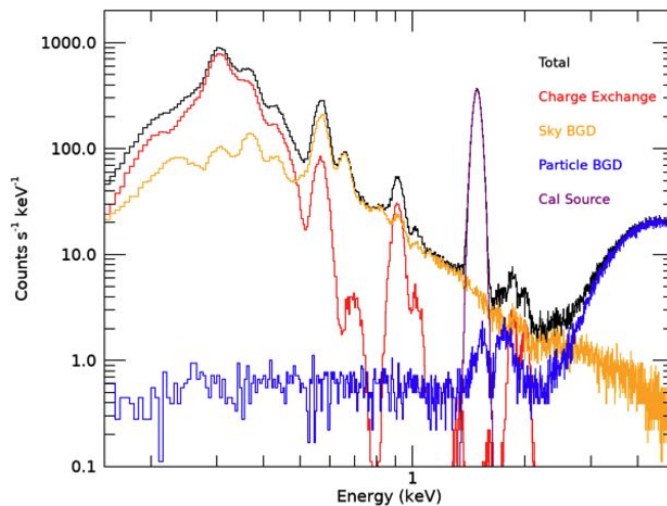
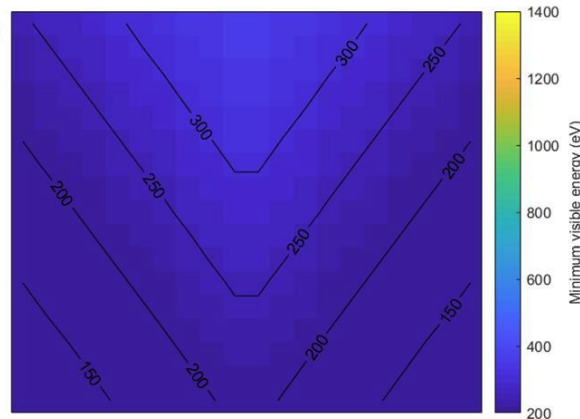# SXI science and the CTI impact

CXFOV

Charge exchange foreground emission
(Simulations credit: Steve S, Andy R)
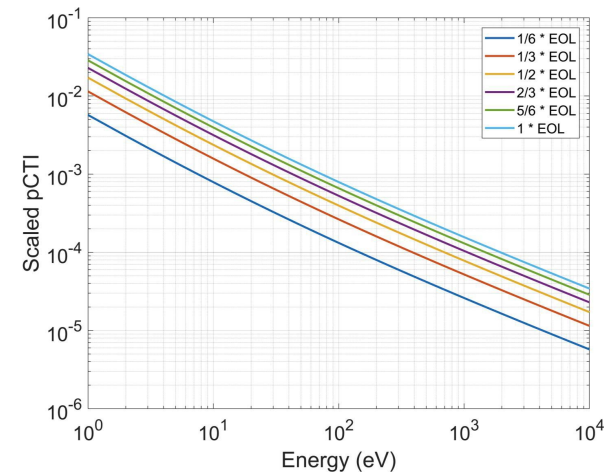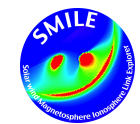

Summed CTI Smear

88% of device detects 300 eV

Open University irradiation estimates:
Total non-ionising dose 1.3e9 10 MeV p/cm2
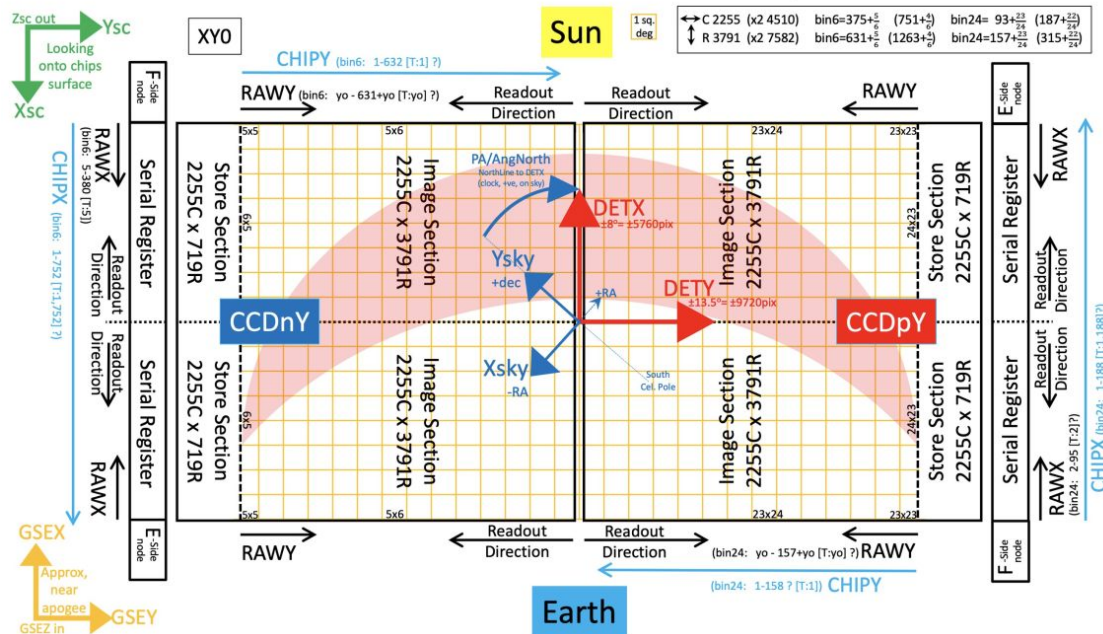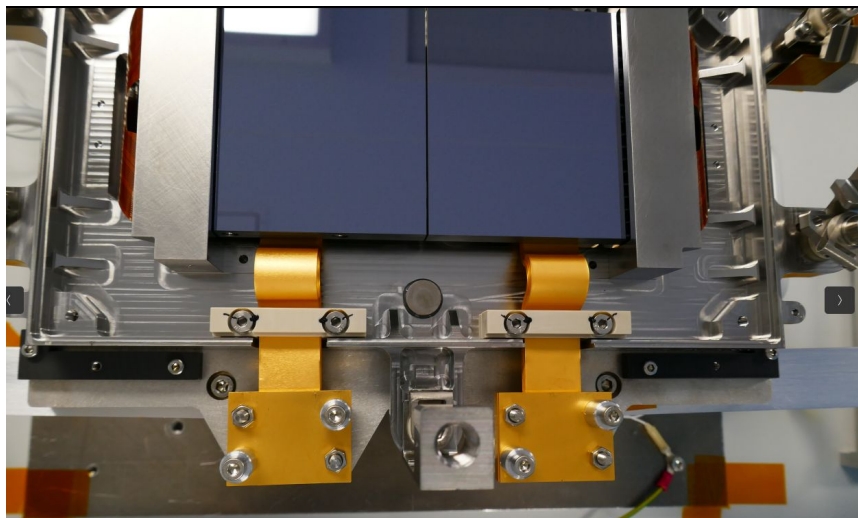
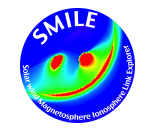# The SXI CCDs

SXI equipped with two large area
(4510x4510 pixels) e2V CCDs

- Supplementary buried channel
- 2-nodes readout
- Charge Injection mechanism at the top of the CCDs
- Frame Transfer, 6x6 binning, event detection mode
- Special trap-pumping operational mode to monitor the density evolution of the trap species
- Fe55 radioactive source (CTI monitoring/calibration)

The SXI Charge Distortion Model

SXI_CMD: Physically motivated, pixel based implementation to model the expected SXI radiation damage

Based on the stochastic theory of charge trapping and release formulated by **Shockley-Read-Hall**

**SXI_CDM** models a number of trap species with specific charge capture probabilities and characteristic charge emission timescales

Implements all the 'unique' SXI CCDs features (binning, Charge Injection, 2-node readout)
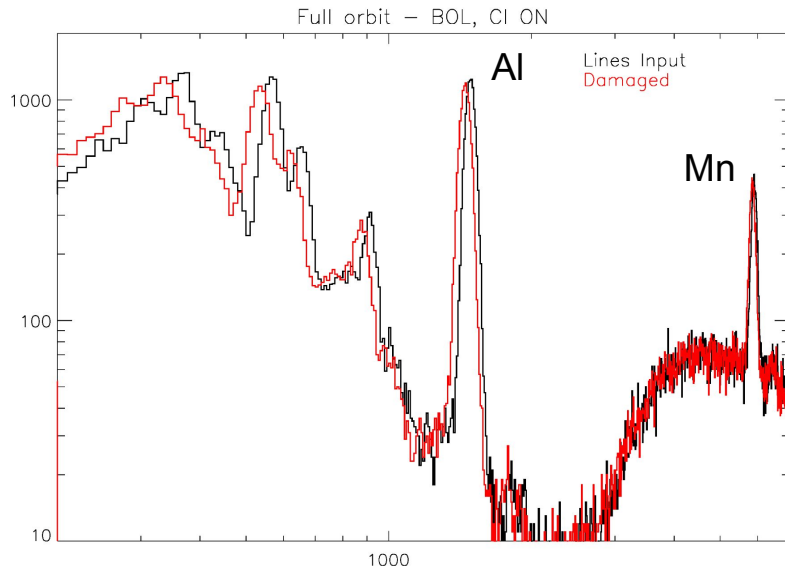
The CDM allowed the investigation of CTI effects such as:

- Temperature dependence
- Time evolution
- Charge Injection mitigation effect
- Sacrificial charge effect
  - Diffuse background
- Charge trails
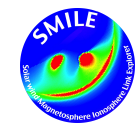
The SXI calcpi pipeline task

calcpi: pipeline task to calculate the energy scale and the CTI corrections for the SXI data

The pixel based **SXI_CDM** is computationally too onerous and overkill at the start of the mission (Beginning of Life, BoL), when we'll (hopefully) see little charge losses due to CTI

The current implementation of the energy corrections in *calcpi* maintains physically motivated parameters and a simple, 2-steps derivation of the charge losses:

1 - Capture Probability

$$P_c = 1 - e^{-cti_\alpha * E^{1-\beta}}$$

2 - Charge Losses

$$L = P_c \rho N_{transfers}, \rho \text{ is the trap density/pixel}$$

The *calcpi* task uses a forward modelling, iterative approach to estimate the observed energy of the X-ray events:

$$Oi \xrightarrow{\text{CTI}} Di, \text{ until } |D_i - M| < \epsilon$$
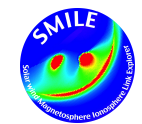
The calcpi/gain file in orbit calibration

- Fe55 radioactive source, uniform illumination of the focal plane, Al, Mn K-alpha lines

- Supernova remnants (Puppis A, N132D, etc) transiting the detector in all sort of directions while the SXI is observing the soft X-rays of the solar wind charge exchange

- Trap pumping mode

Puppis A (Dubner et al. 2013). Mosaic of XMM/Chandra images
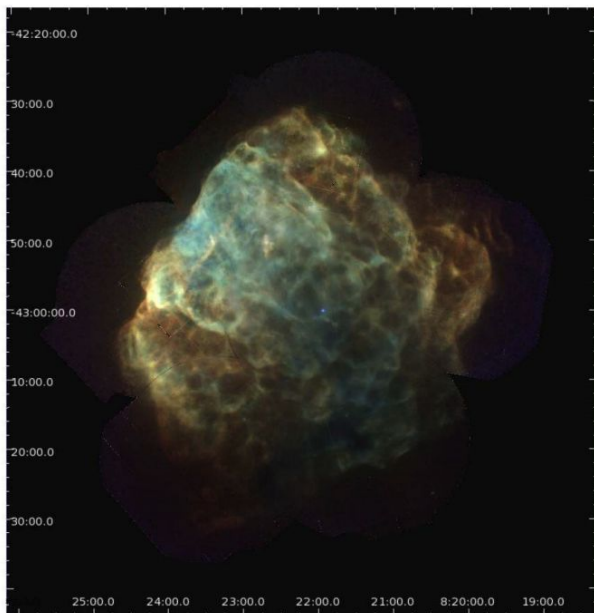
N132D, simulated, CTI-damaged SXI spectrum

N132D fit, CTI distorted spectrum, 2 gau + lin, file = cti_sxi_n132d_bg_30ks_988_dety1
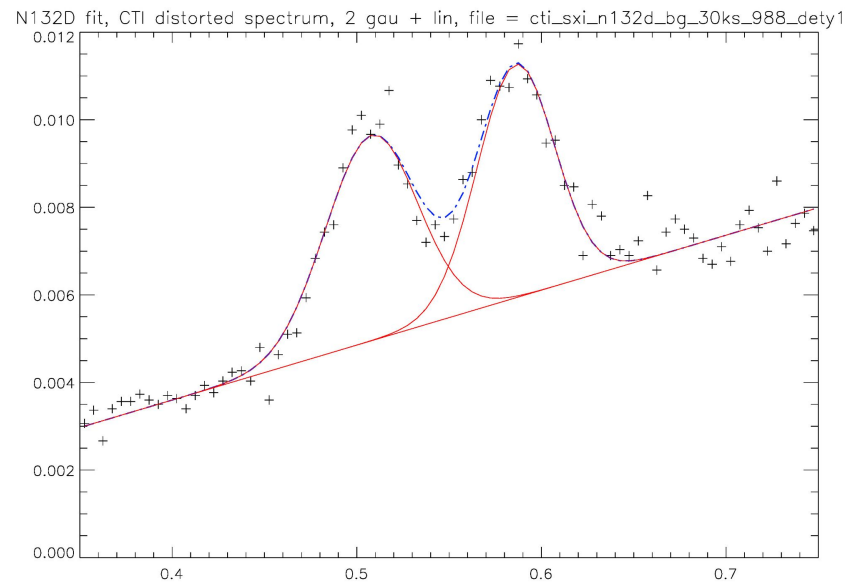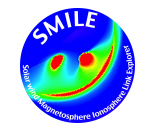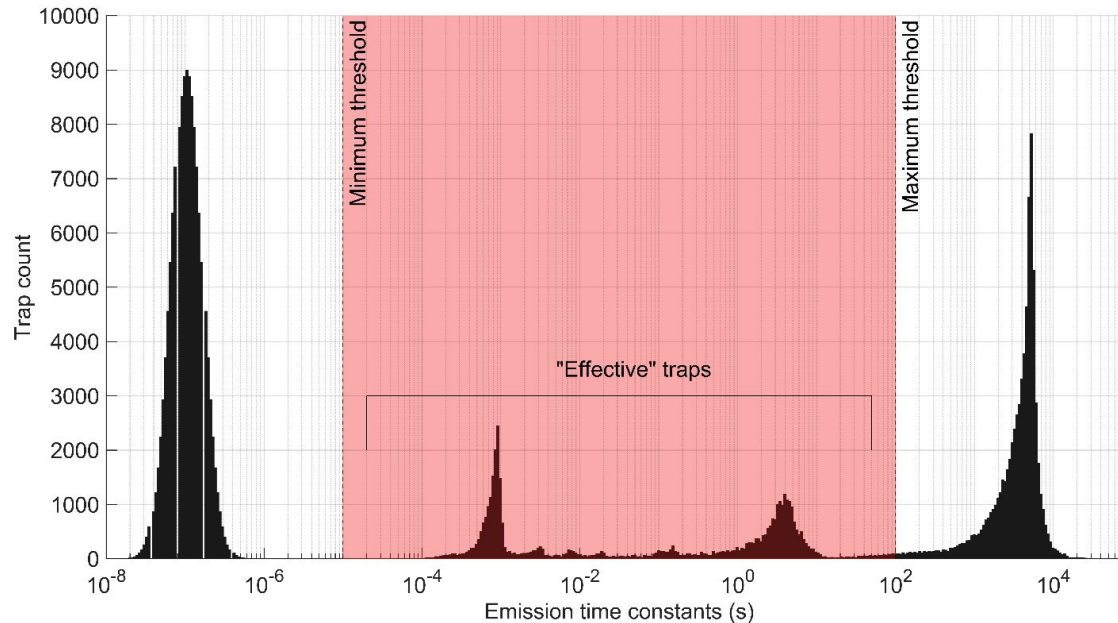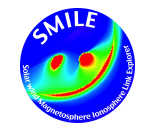
Trap pumping mode

The acquisition of calibration datasets in Trap Pumping mode will be carried out periodically in orbit.

Trap pumping data will be analysed with a dedicated task developed by the Open University, it can inform on:

- Number of trap species
- Specific trap densities
- Trap parameters (time emission timescales, charge trails)
- Damage evolution

The CCD370 irradiation campaign

The CCD370 has been irradiated with a series of proton doses (4.0E+9 10 MeV protons at End of Life), to predict and analyse the CCD performance, energy resolution, trap energy losses, temperature dependence and charge injection CTI mitigation at different phases of the mission.
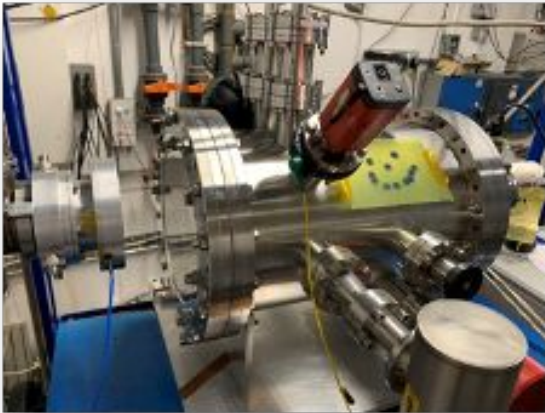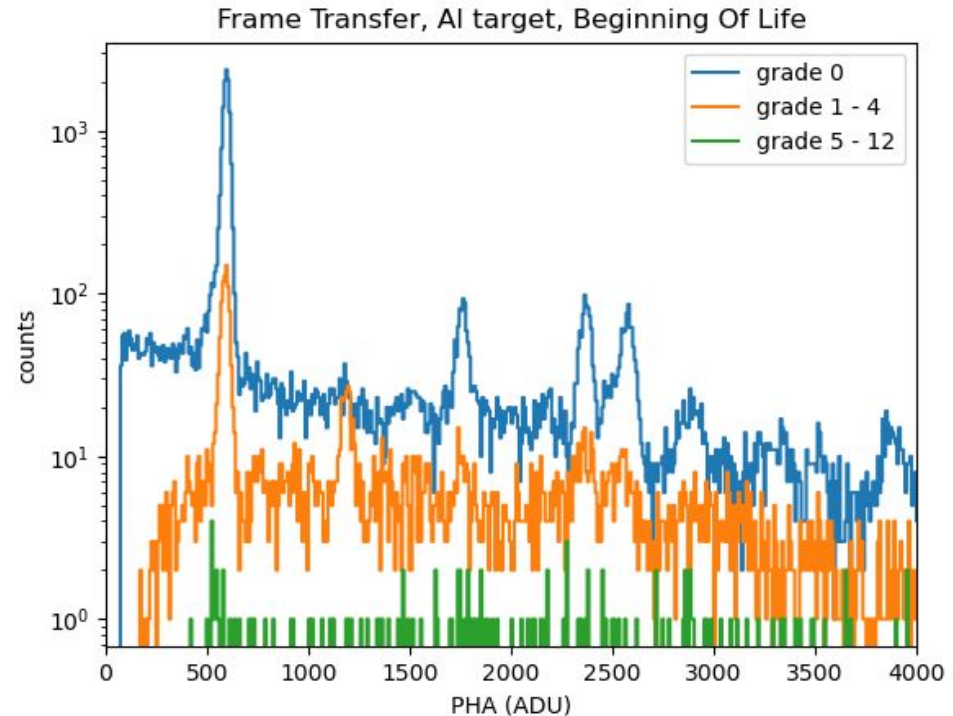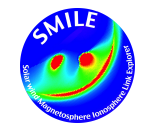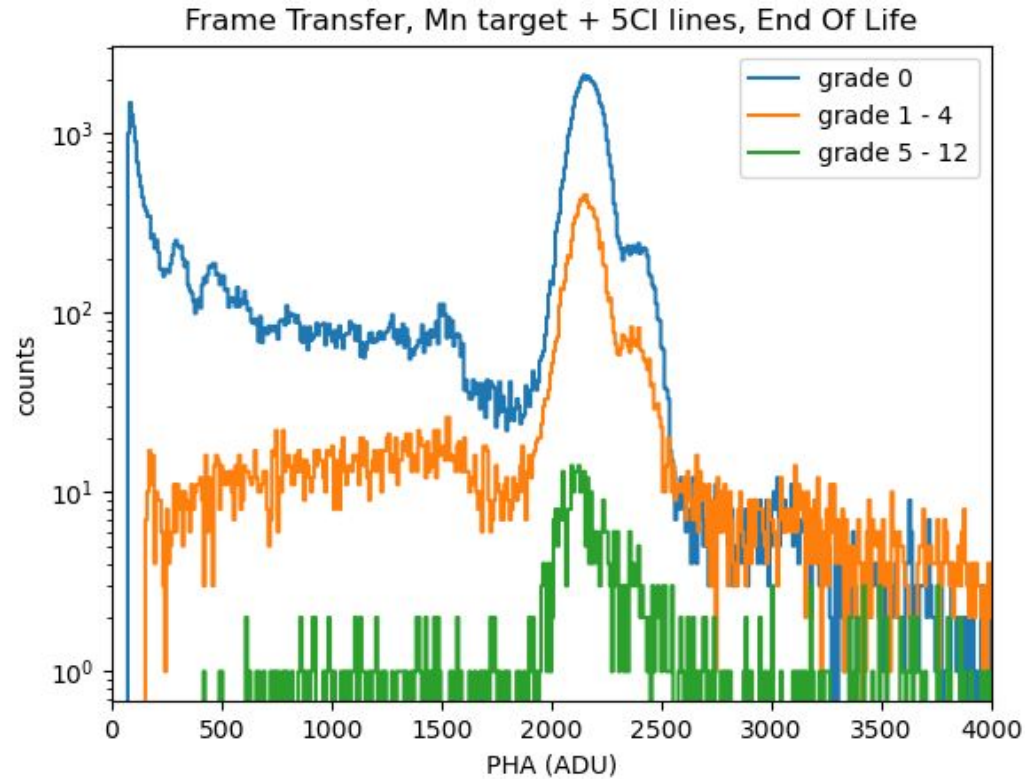
CCD370 irradiation setup

Photo courtesy of the Open University

The irradiation campaign (Mn, T=-120C)

Frame Transfer, Mn target + 5Cl lines, End Of Life
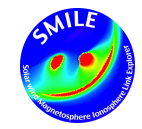
calcpi calibration task

The *calibrate_calcpi* procedure involves

- Gaussian fits of spectral lines of CTI-damaged datasets
- CStat minimisation to derive gain file best fit parameters using the *calcpi* algorithm

Attempt the correction of the damaged spectra using the *calcpi* task and the newly derived gain file

What data to test the procedure on?

- Simulated datasets damaged with *calcpi* task (sanity check)
- Irradiated CCD370 datasets
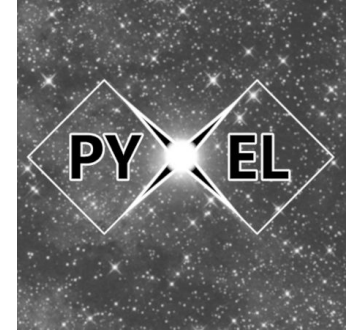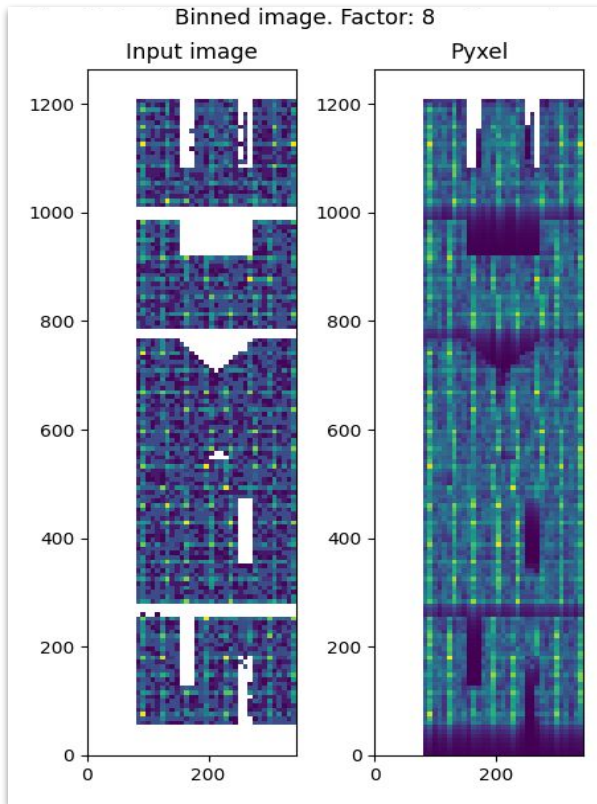- Pyxel - Python based detector simulator
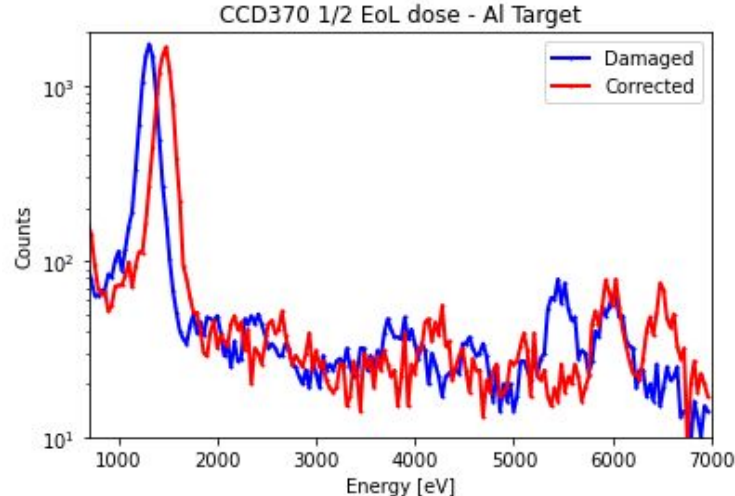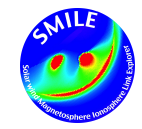
Pyxel modelling tool
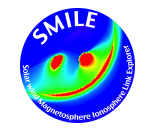
Pyxel - "A novel and multi-purpose Python-based framework for imaging detector simulation", SPIE Proceedings Volume 10709, High Energy, Optical, and Infrared Detectors for Astronomy VIII; 107091A (2018), https://doi.org/10.1117/12.2314047

GitLab repository: https://gitlab.com/esa/pyxel

- Modelling, analysis of radiation damage
- Test of *calibrate_calcpi* procedure

Summary

The SXI radiation damage is a critical aspect of the SMILE project, as at the end of the mission if could prevent the detection of the soft X-rays from the solar wind charge exchange emission.

The SXI ground software team has been working on the tools to simulate, monitor, analyse, and correct the effects of radiation damage on SXI spectra. The preparation work includes:

- The Charge Distortion Model, developed to analyse a number of CTI effects and dependencies

- CCD370 irradiation campaign and lab test datasets to predict the performance of the CCD in orbit

- The initial versions of the *calcpi* sxipipeline task and the *calibrate_calcpi* gain/cti calibration procedure