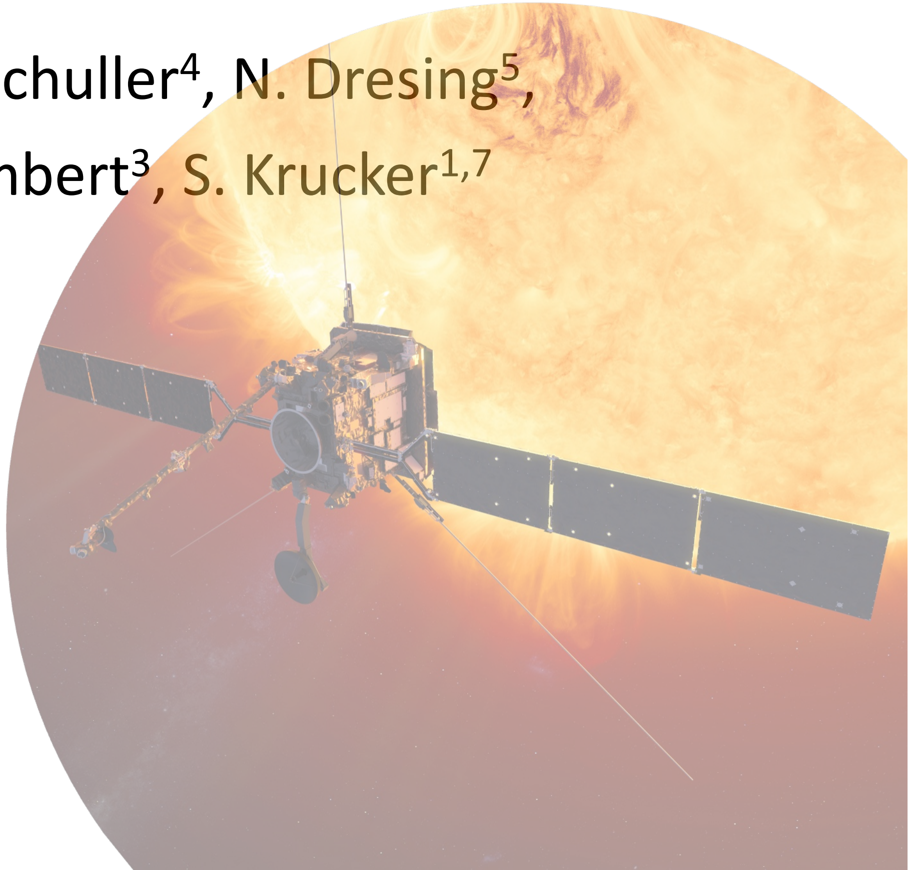
Energetic particle contamination in STIX during Solar Orbiter's passage through Earth's radiation belts and an interplanetary shock

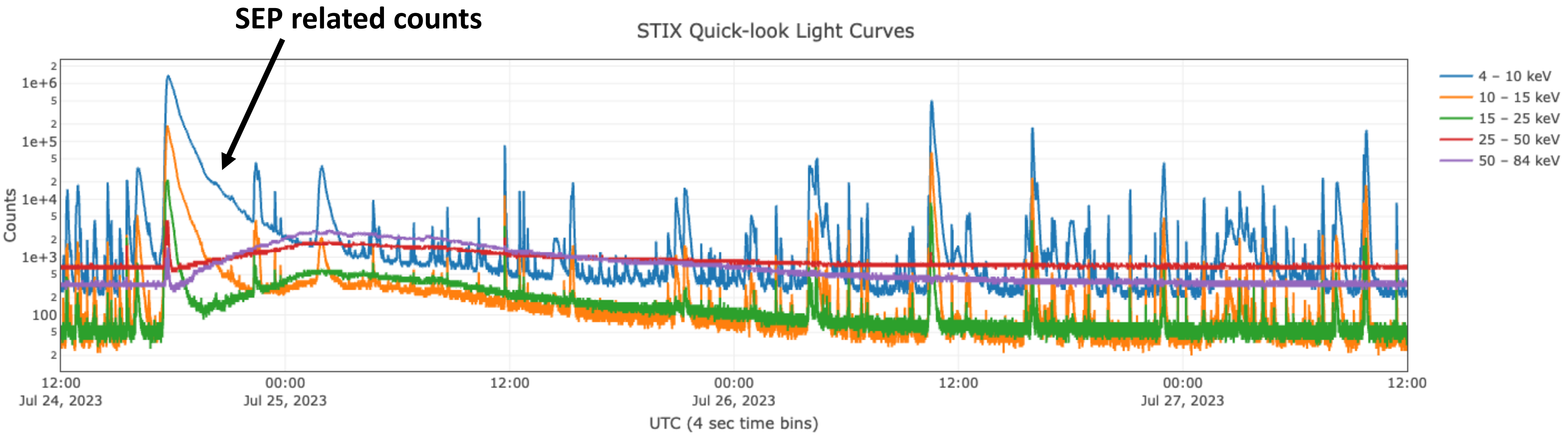
H. Collier[1,2], O. Limousin[3], H. Xiao[1], A. Claret[3], F. Schuller[4], N. Dresing[5], S. Valkila[5], F. Espinosa Lara[6], A. Fideli[5], S. Foucambert[3], S. Krucker[1,7]

[1] FHNW, Bahnhofstrasse 6, 5210 Windisch, Switzerland
[2] ETH Zürich, Rämistrasse 101, 8092 Zürich, Switzerland
[3] Université Paris-Saclay, Université Paris Cité, CEA, CNRS, AIM, France
[4] Leibniz-Institut für Astrophysik Potsdam (AIP), An der Sternwarte 16, 14482 Potsdam, Germany
[5] Department of Physics and Astronomy, University of Turku, 20014, Turku, Finland
[6] Universidad de Alcalá Space Research Group, University of Alcalá de Henarez, Spain
[7] Space Sciences Laboratory, University of California, 7 Gauss Way, 94720 Berkeley, USA



Motivation and aim of this study

- During SEP events, there are excess counts above background in STIX
- Example: July 24^{th}-27^{th} 2023, ~200 flares, at least 3 > M class



Motivation and aim of this study

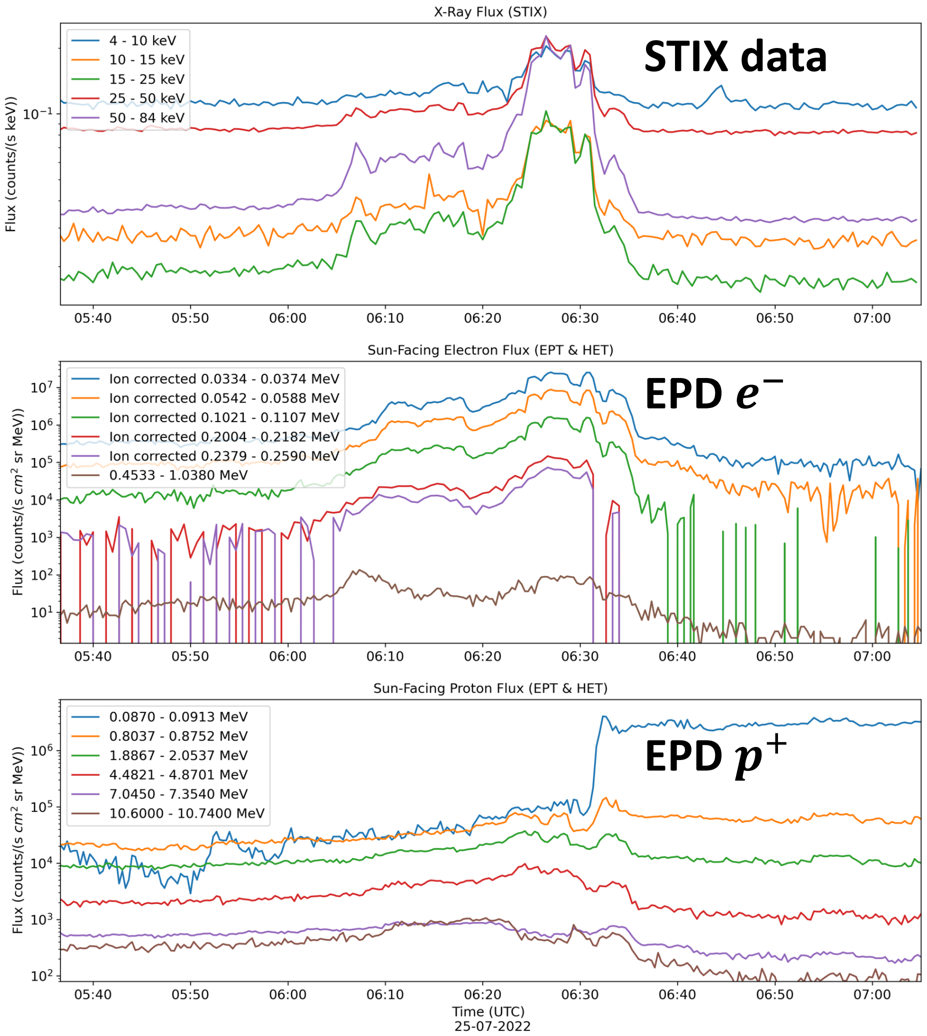
- Aim to identify the relevant particles, their energies and the mechanism(s) by which they result in contamination of the STIX X-ray spectrum during SEP events

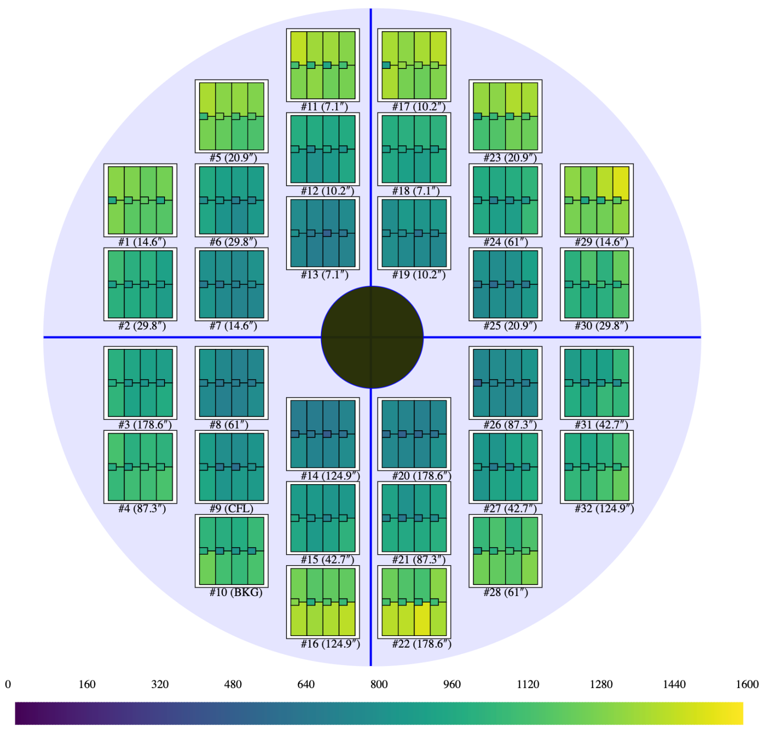
- Understand the instrument response with the intention of performing background subtraction for interesting science cases

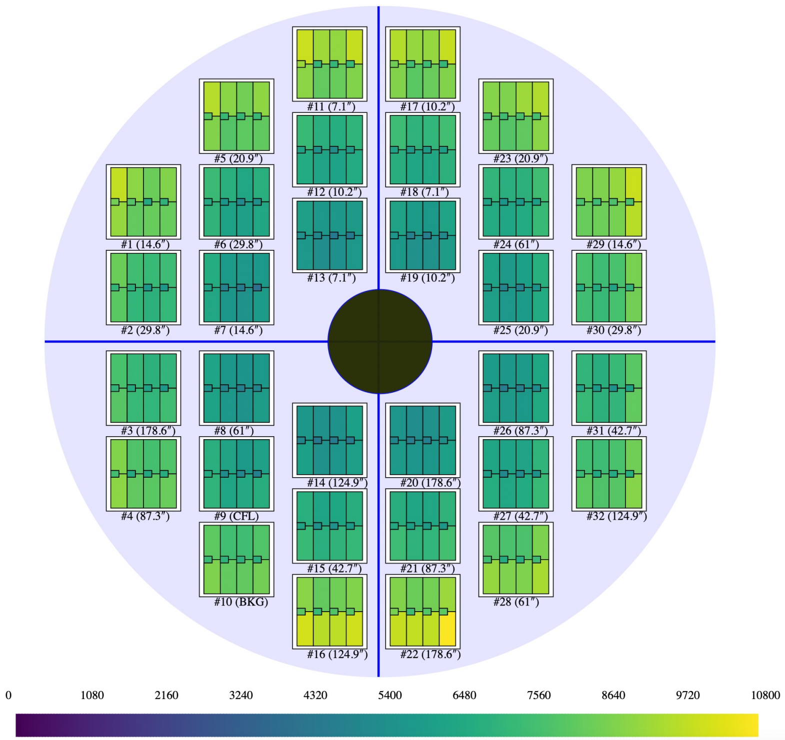
Observational Overview

Event 1: Interplanetary Shock

Event 2: EGAM







Observational Overview

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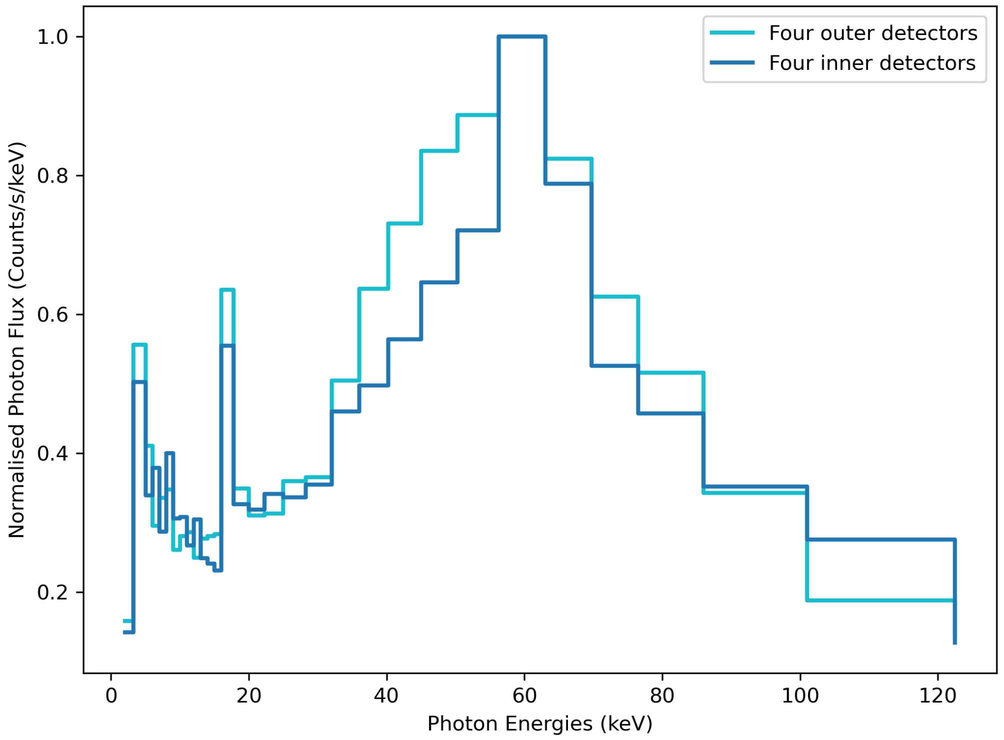
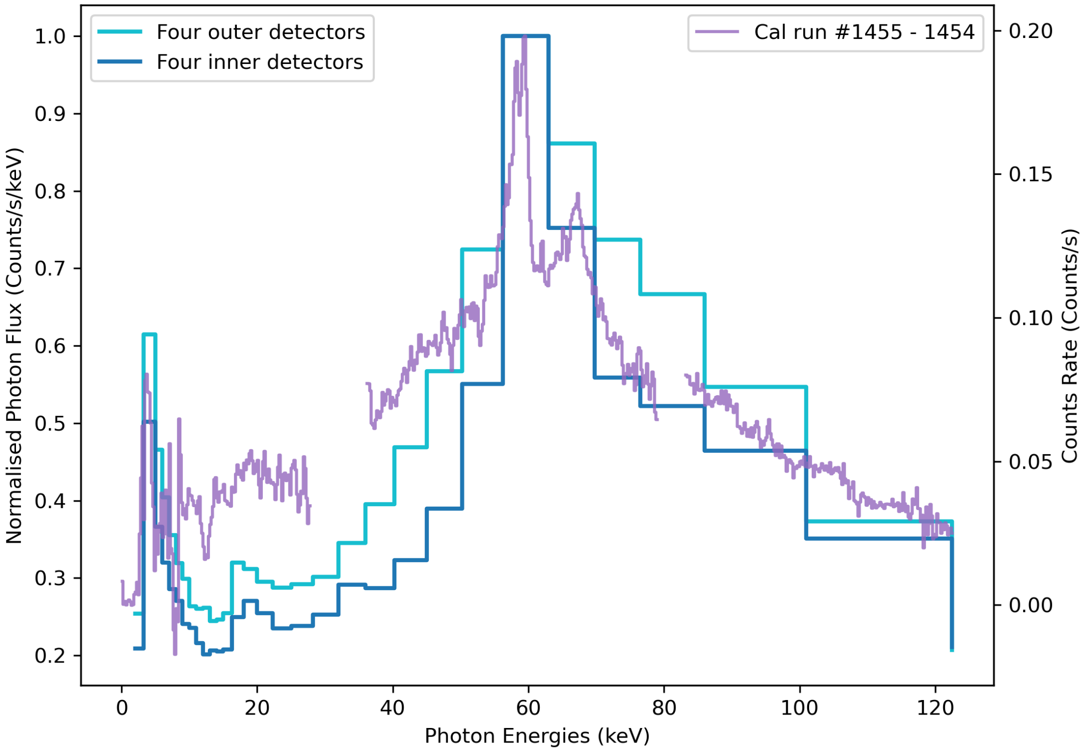


Event 2: EGAM

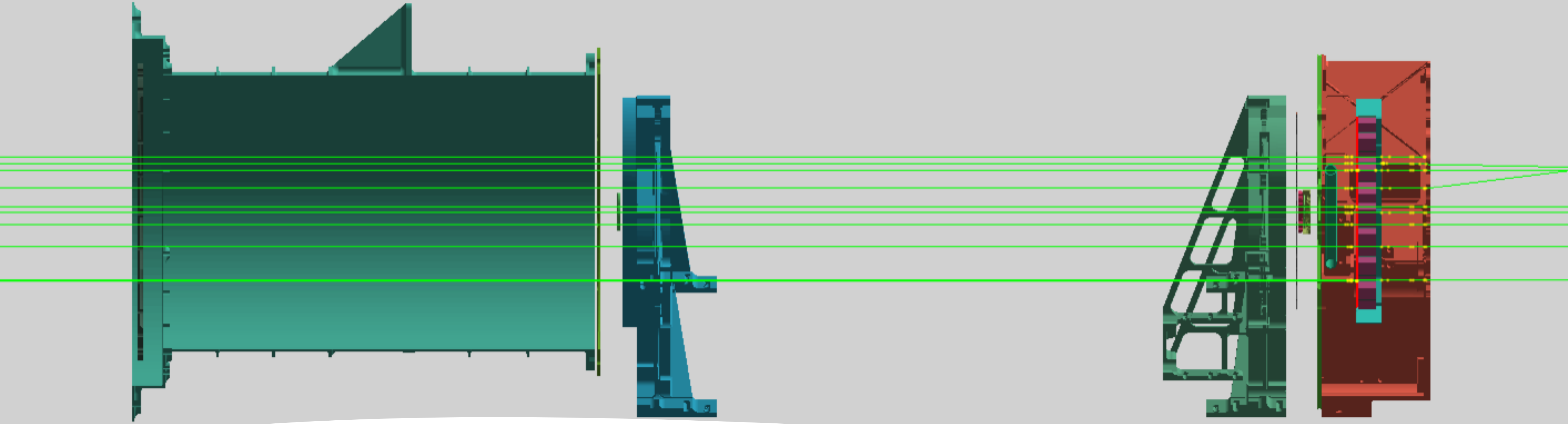


Methods

- Simulate the instrument response to energetic electrons

- Due to the lack of a spacecraft mass model we create a simplistic model of the spacecraft components and analytically compute the Bremsstrahlung and line emission

- The equivalent thicknesses and the relative contribution of these components are tuned by fitting the output to the measured spectrum during the EGAM



Geant4 simulation

- Simulate STIX response to a beam of 0.08-8 MeV e^- (no spacecraft model)
- Physical processes considered include Bremsstrahlung, compton scattering, PE effect etc
- Components included in CAD model: Be window, tungsten grids, Caliste-SO & DEM etc

GEANT4 Collaboration.
S. Agostinelli (Genoa U.) et al.
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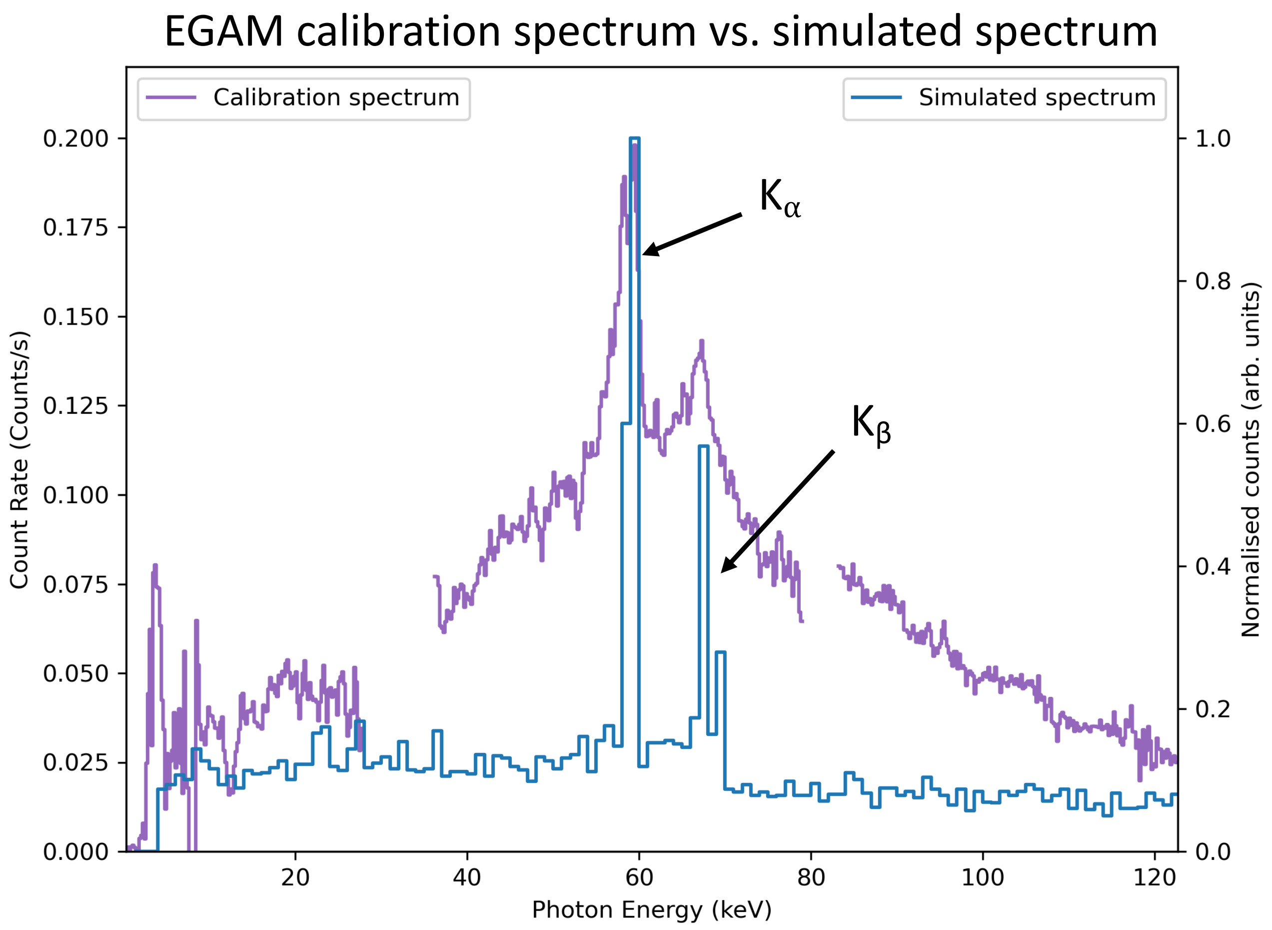
STIX Instrument Response



- Little-to-no continuum emission in the simulated spectrum
- Could it originate from other spacecraft components?

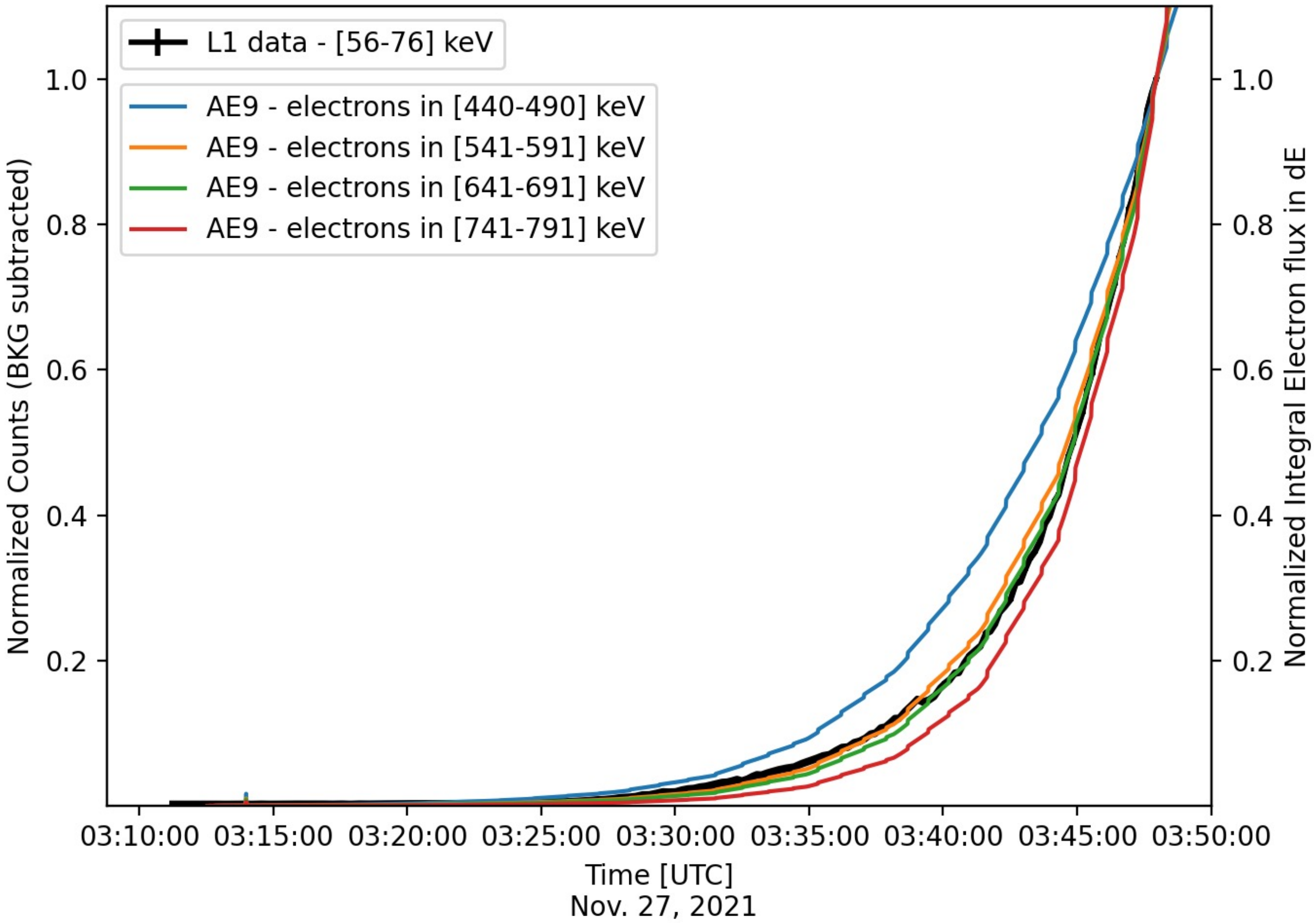
Model spacecraft components and compare to the data

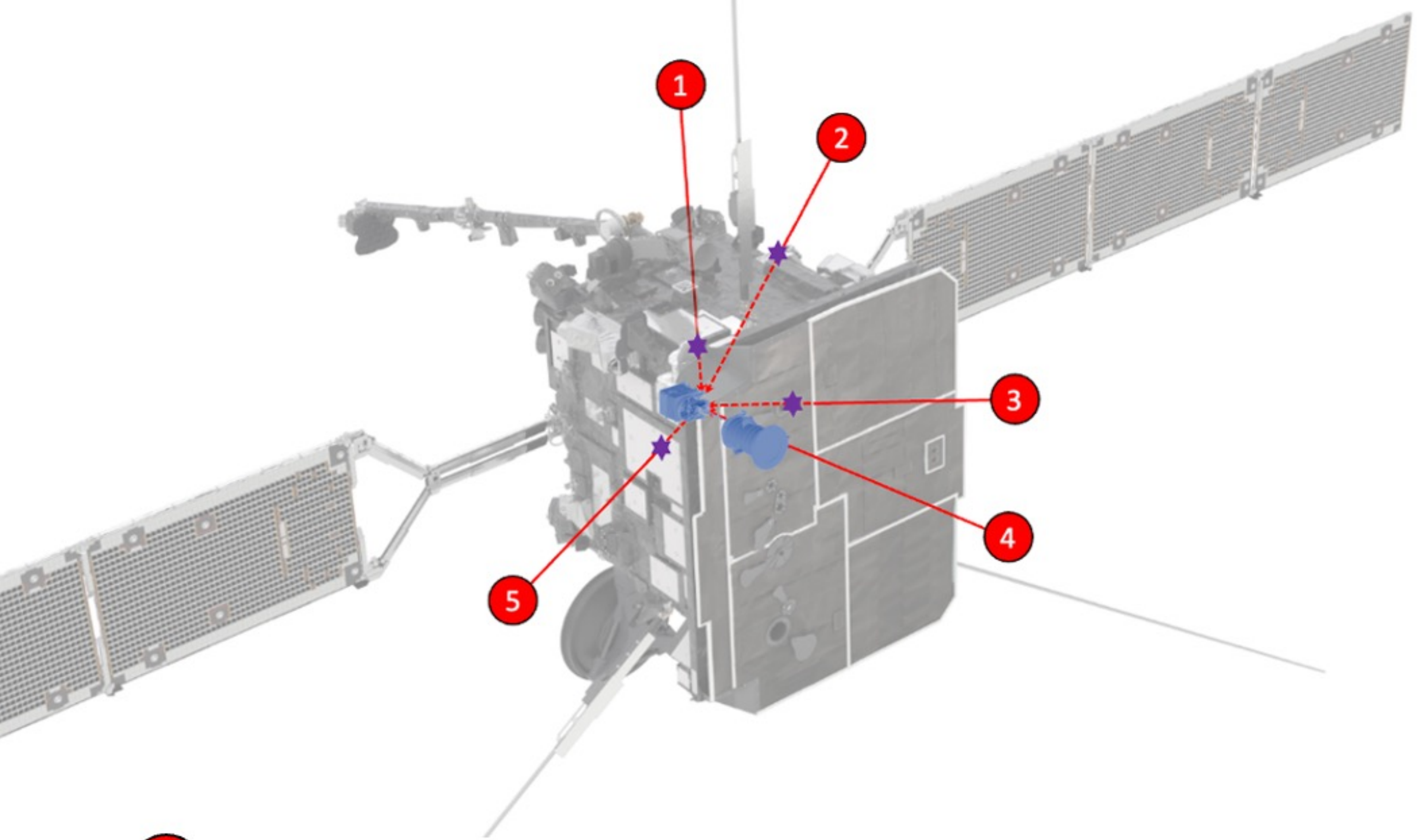
Steps involved:

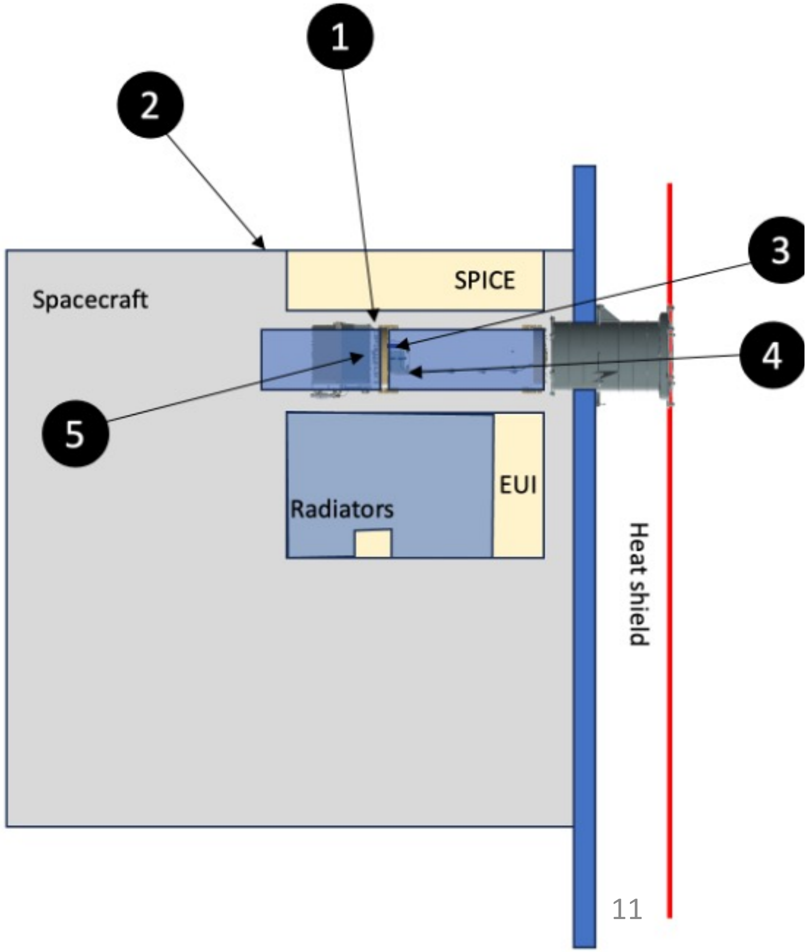
1. Predict electron spectrum along orbit
2. Initial guess spacecraft components (no mass model available)
3. Analytically compute the Bremsstrahlung radiation and line emission from those materials + absorption
4. Convolve output with detector efficiency and energy resolution
5. Fit output to measured spectrum by varying the free parameters (equivalent thicknesses and relative contribution of spacecraft materials)

AE9 Model of Earth's Radiation Belt

- No particle data (e.g. EPD)
- Predict the electron population along Solar Orbiter's trajectory using AE9 model
- Static model, mean level of solar activity

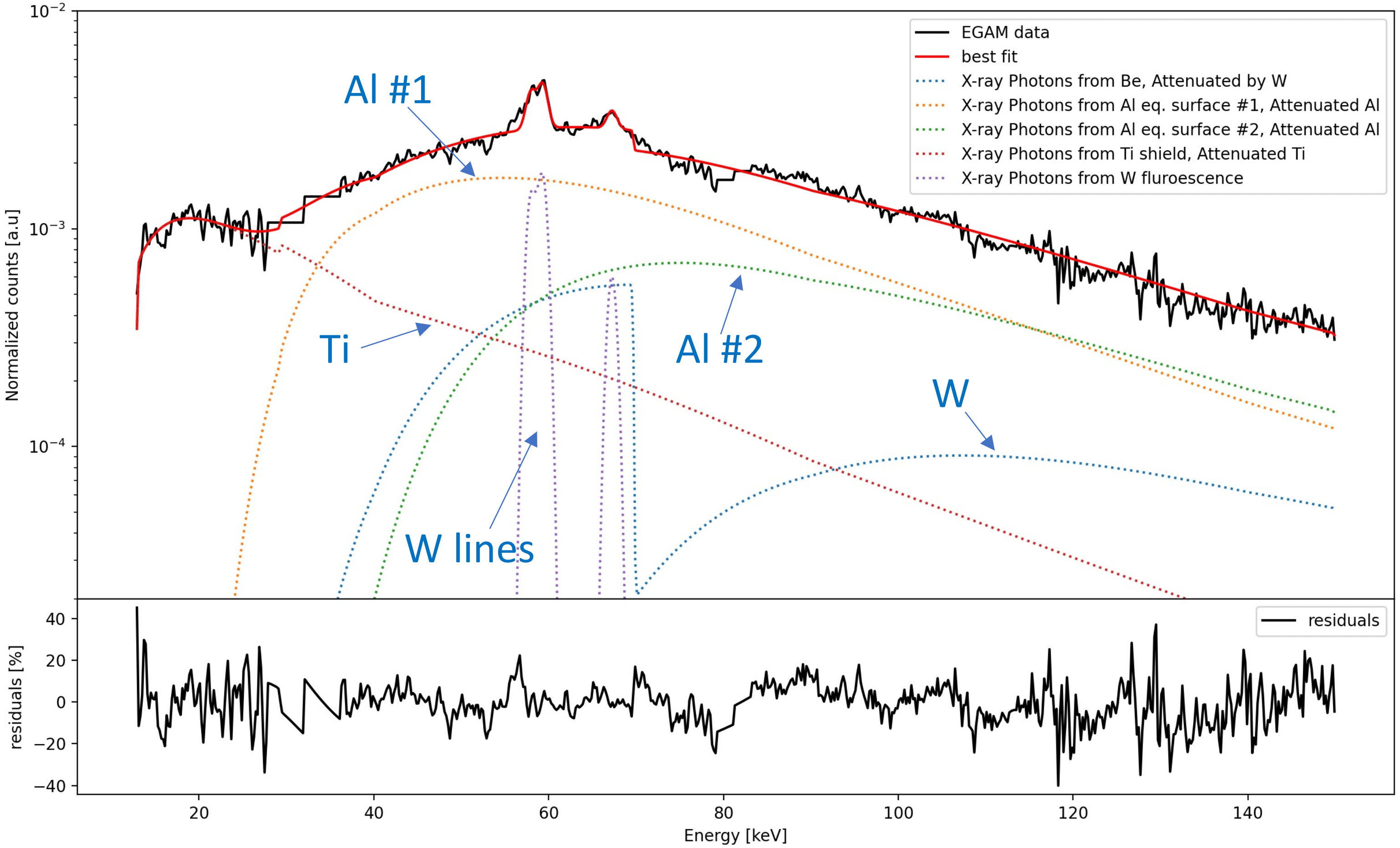






1. Electrons enter through SPICE instrument and produce Bremsstrahlung
2. Electrons enter through the back of the spacecraft, most are absorbed
3. Electrons bypass the entrance window and interact with the thermal shield
4. Electrons enter through the Be window and produce Bremsstrahlung
5. Electrons enter from the side of the spacecraft, through the radiators on top of STIX

Fit Measured Spectrum with an Analytical Model

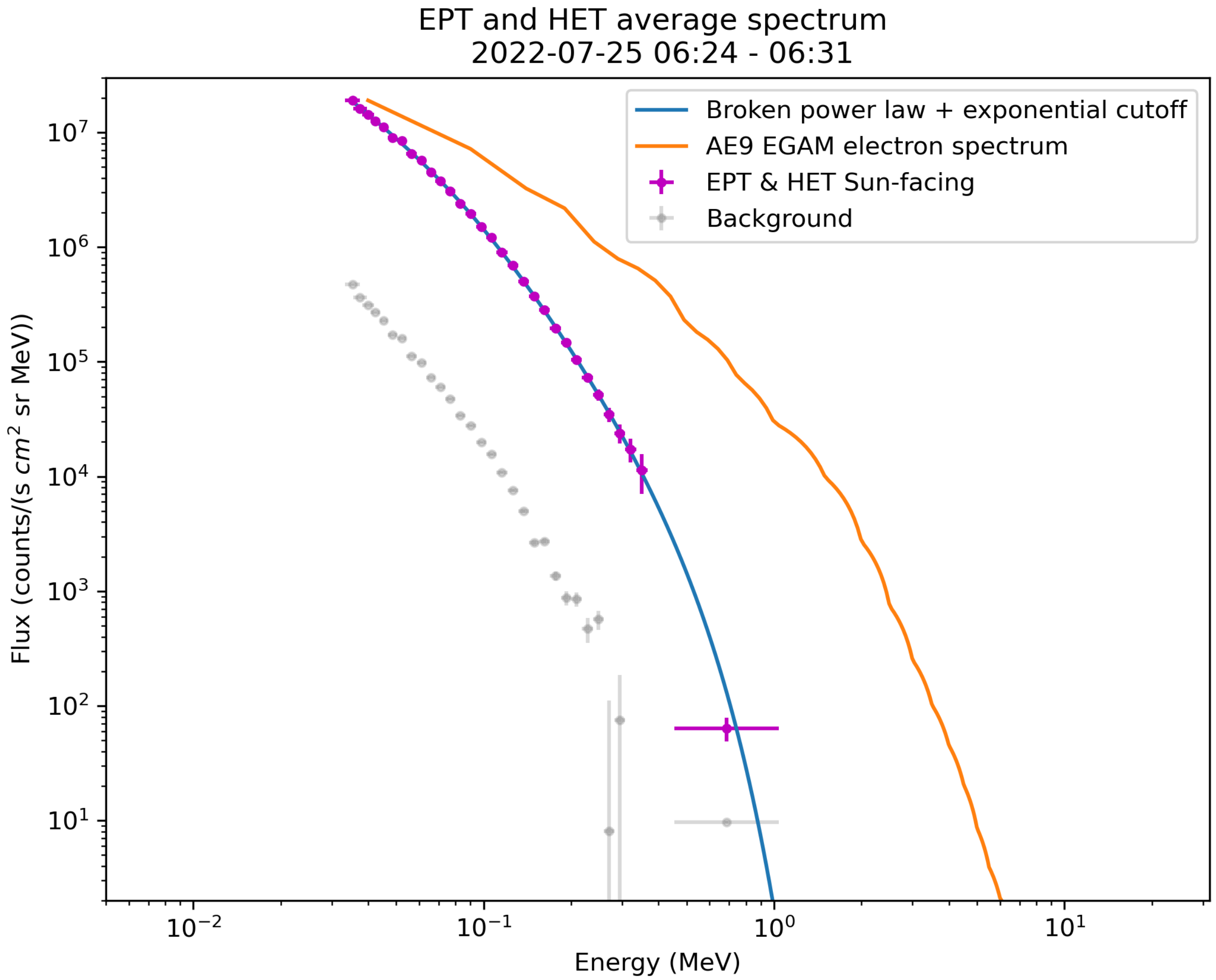


The components included are:

- Be entrance window with attenuation by W grids with equivalent thickness of 200±35 µm
- Al thick and thin component with equivalent thicknesses of 4.92 ± 0.43 cm and 1.25 ± 0.07 cm respectively
- A Ti component of equivalent thickness 62 ± 4µm
- W X-ray fluorescence

Event spectra comparison

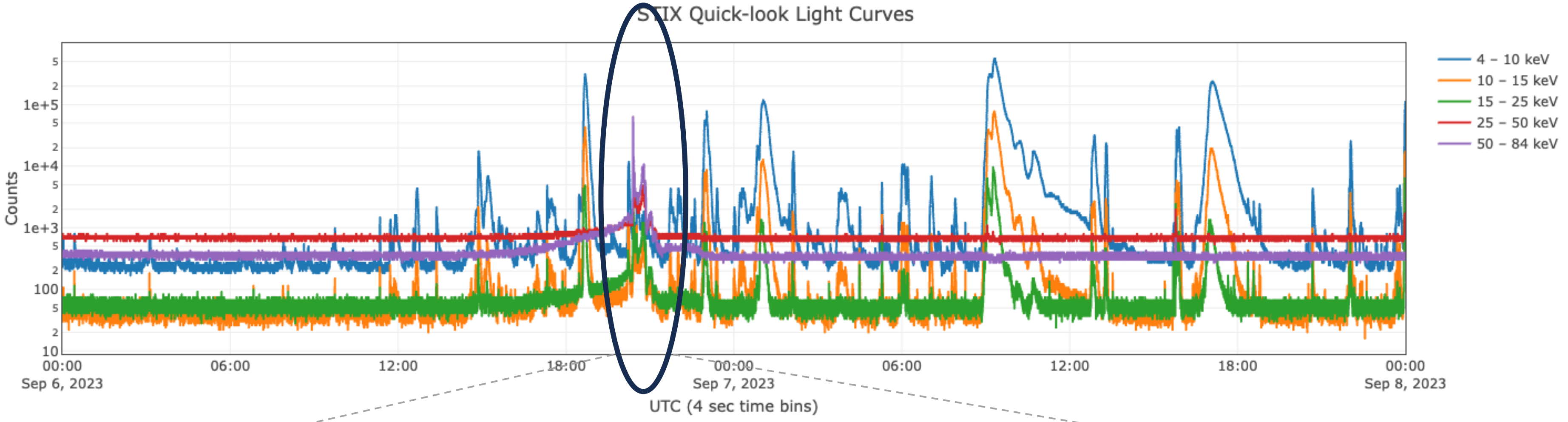
- EGAM ~2-3 times stronger than the shock @ 0.5 - 1 MeV
- Leads to a stronger signal in STIX

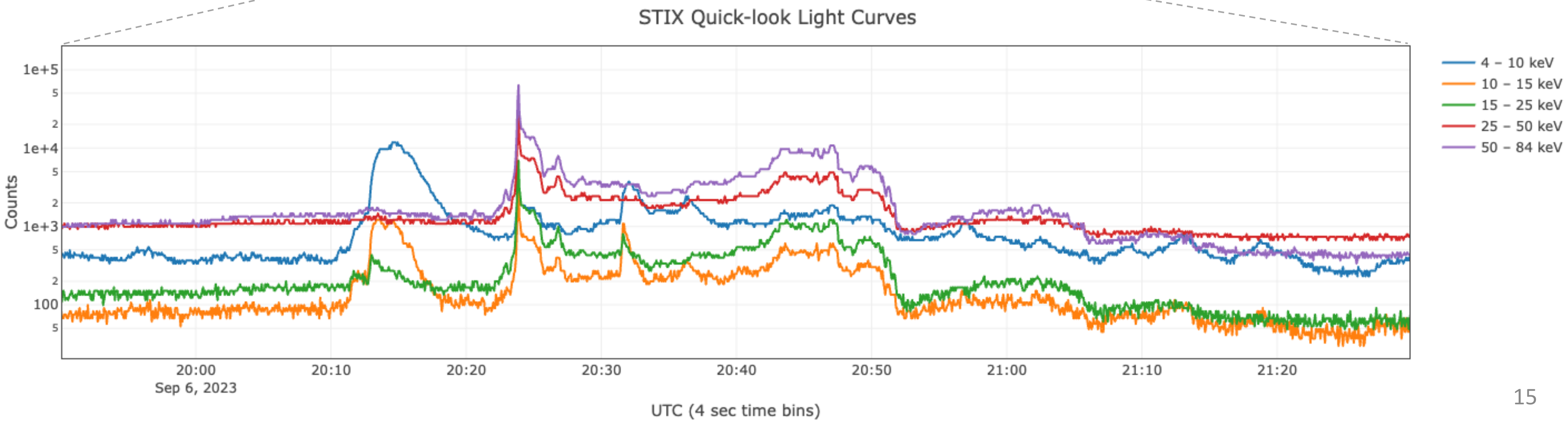


Conclusions from this study

- Electrons with energies $> \sim$ **0.5 MeV are significant** contributors to the contamination in STIX during SEP events
  - Presence of W in grids produces X-ray fluorescence lines
  - We demonstrate that bremsstrahlung emission arises from interaction of particle with materials surrounding the instrument, however, **a spacecraft mass model is required** to fully understand the response.
- Caliste-SO are robust to SEP events

Interesting event for future analysis: 06th Sep 2023 shock





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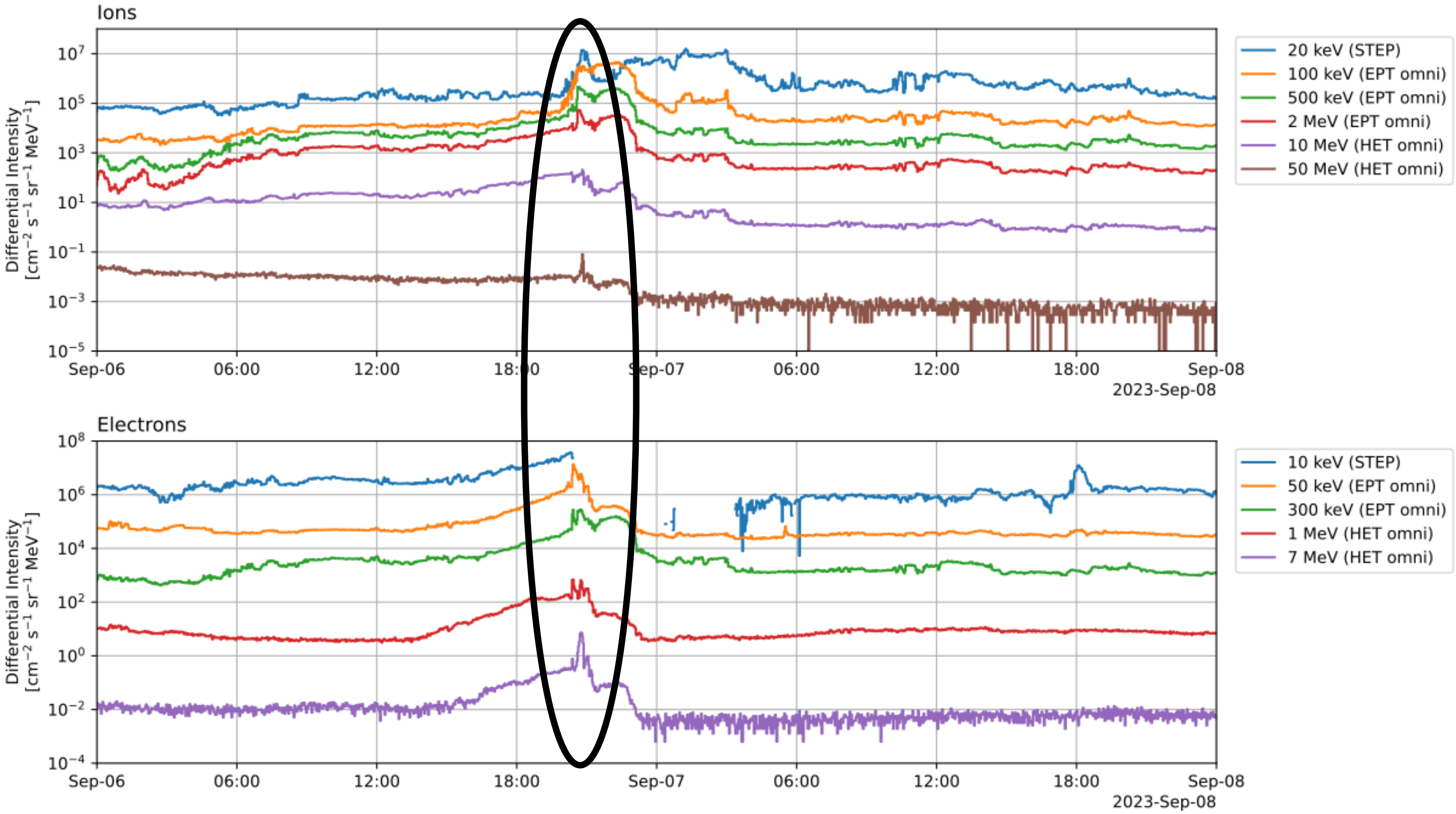

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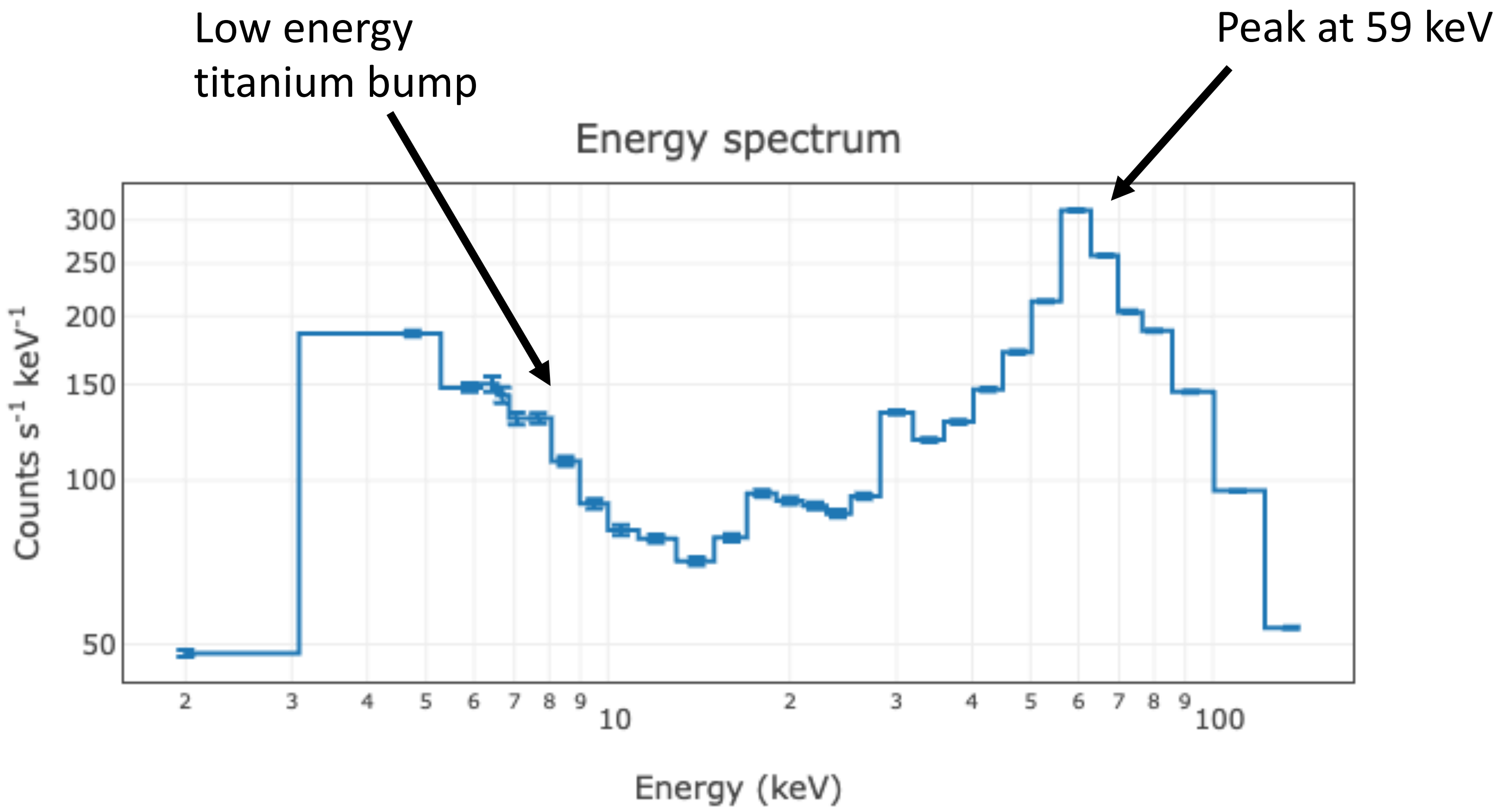
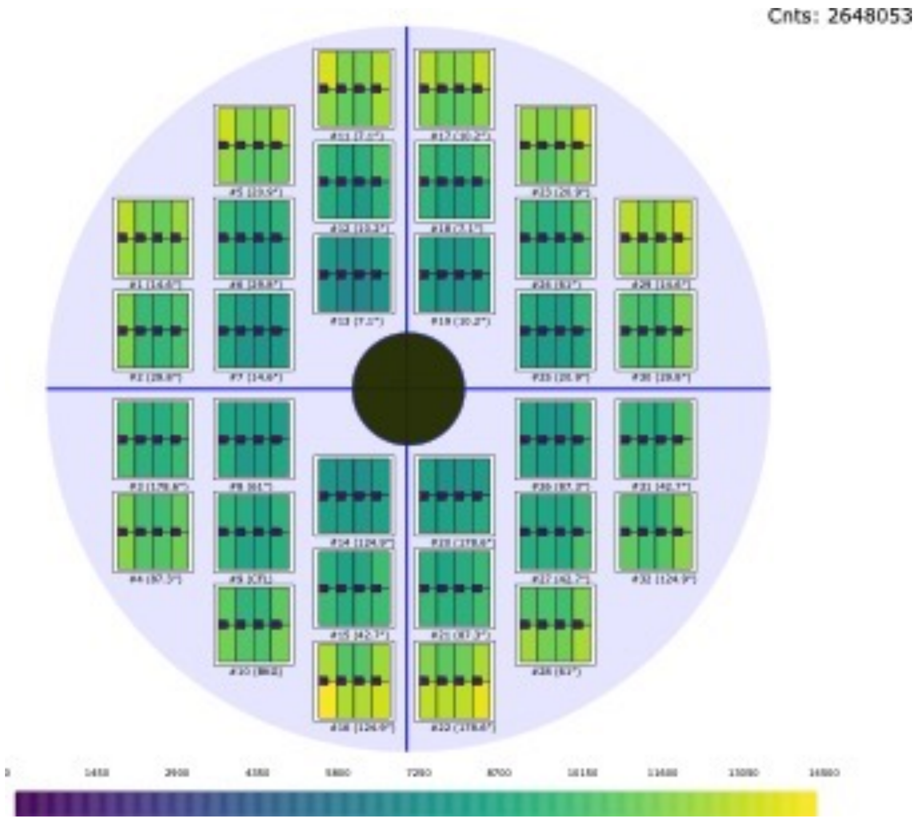




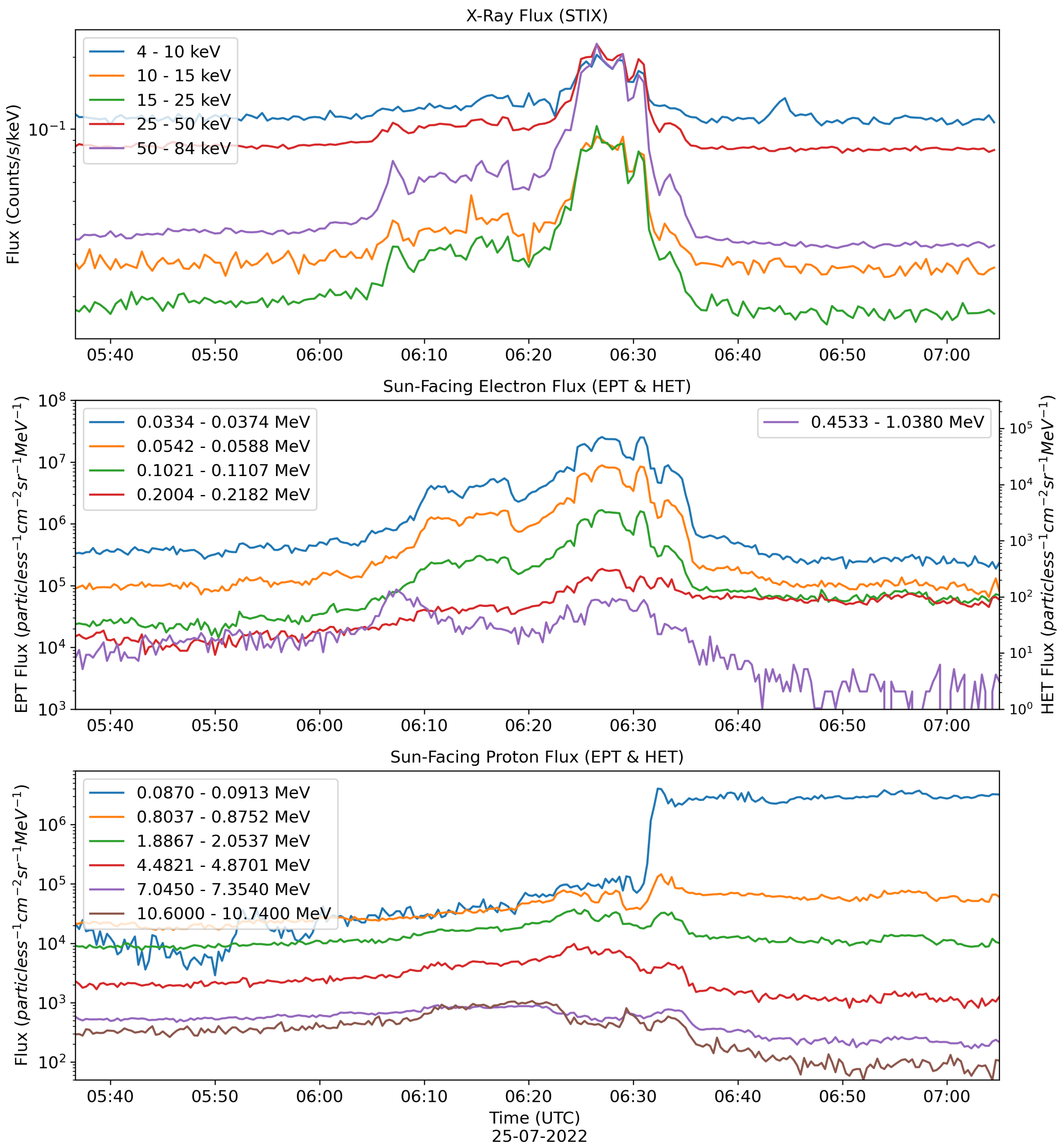
Outlook and future work

- Many energetic particle contamination events from flare associated SEPs, IP shocks & EGAMs to study
- Future work to analyse the effect of energetic ions
- Compare the effect of ion rich vs electron rich events
- Consider particle anisotropy further
- Search further for a detailed spacecraft model!

solar orbiter

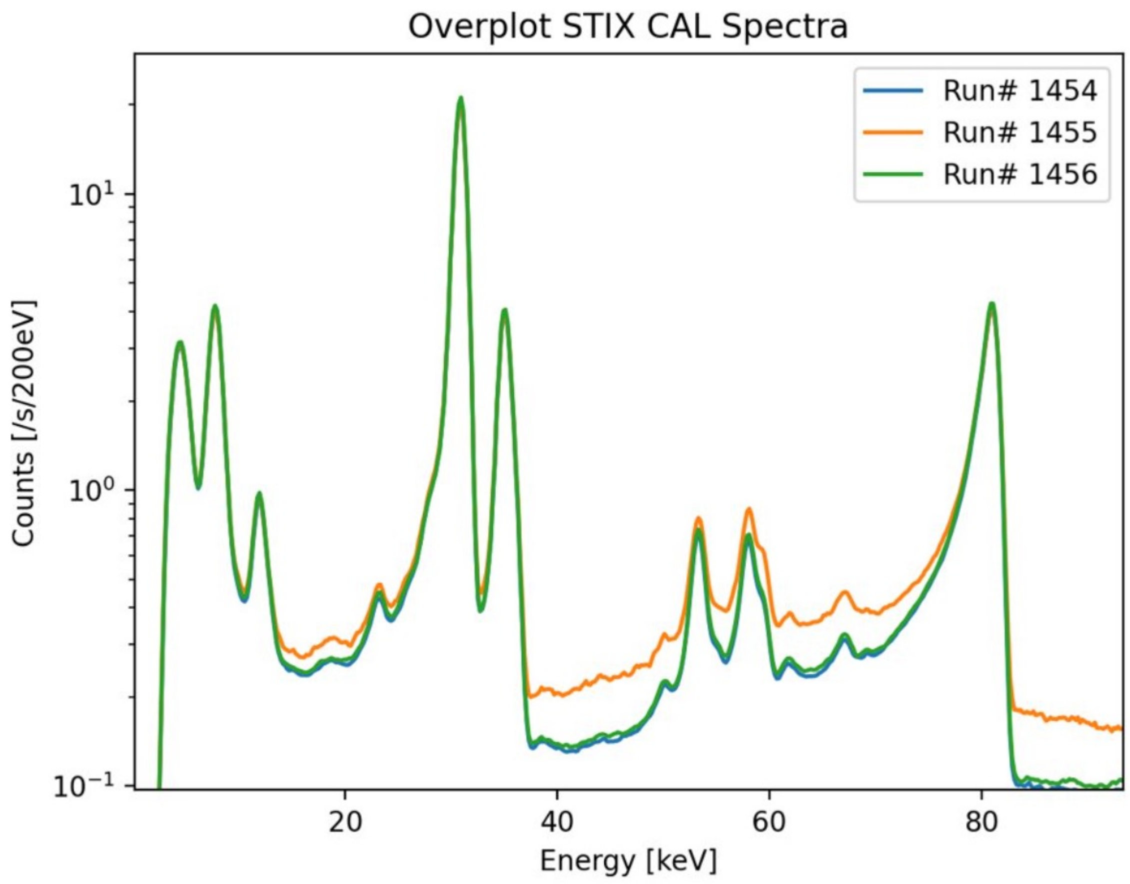
Thank you for your attention!

Additional Slides


X-Ray Flux (STIX)
4 - 10 keV
10 - 15 keV
15 - 25 keV
25 - 50 keV
50 - 84 keV
Flux (Counts/s/keV)
Sun-Facing Electron Flux (EPT & HET)
0.0334 - 0.0374 MeV
0.0542 - 0.0588 MeV
0.1021 - 0.1107 MeV
0.2004 - 0.2182 MeV
0.4533 - 1.0380 MeV
EPT Flux ($particles^{-1}cm^{-2}sr^{-1}MeV^{-1}$)
HET Flux ($particles^{-1}cm^{-2}sr^{-1}MeV^{-1}$)
Sun-Facing Proton Flux (EPT & HET)
0.0870 - 0.0913 MeV
0.8037 - 0.8752 MeV
1.8867 - 2.0537 MeV
4.4821 - 4.8701 MeV
7.0450 - 7.3540 MeV
10.6000 - 10.7400 MeV
Flux ($particles^{-1}cm^{-2}sr^{-1}MeV^{-1}$)
05:40 05:50 06:00 06:10 06:20 06:30 06:40 06:50 07:00
Time (UTC)
25-07-2022

Caliste-SO Detector Recovery

- Calibration spectrum recovers well after SEP events



Fit the Calibration Spectrum with Analytical Models

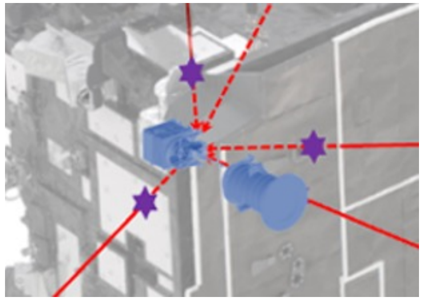
Electron spectrum and orbital data

- Solar Orbiter trajectory
- OMERE
- AE9 electron belt model

Physical data and constants

xraylib

Geometry 'first guess'



Analytical Model

$$f = \sum_{i=1}^{4}(w_i.\tilde{B}_i) + \propto \cdot XRF_{tungsten}$$

$\tilde{B}_i$ are Bremsstrahlung radiation components and depend on:

- Kramer's bremsstrahlung profile
- Z_{target_i}, $Z_{attenuator_i}$, $d_{attenuator_i}$, $t_{attenuator_i}$
- Electron spectrum along orbit
- Radiation yield
- Detector efficiency
- Energy resolution dE

Free parameters: w_i, $\propto$, $t_{attenuator_i}$

$i \in [2, 7]$ is minimized

Calibration data

$$\tilde{S}_i = \frac{S_{i(EGAM)} - S_{i(before\ EGAM)}}{\sum_j (S_{j(EGAM)} - S_{j(before\ EGAM)})}$$

Fit the data