Cross-Calibration of Solar X-ray Spectrometers with Chandrayaan-2 XSM

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On behalf of CH-2 XSM Team and Collaborators

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Coordinated X-ray Observations for Cross-Calibration

- Cross calibration of high energy missions: Coordinated observations of Crab, other IACHEC standards
- A few opportunities for coordinated observations - strictly simultaneous or quasi - simultaneous

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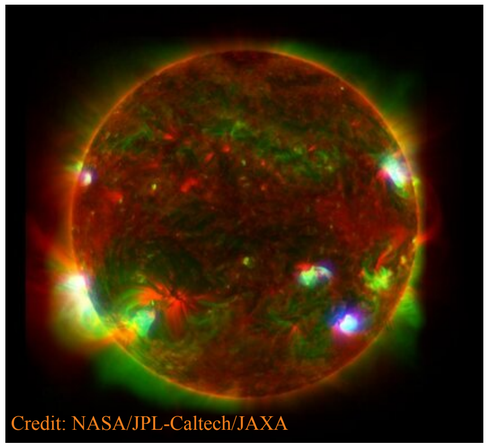

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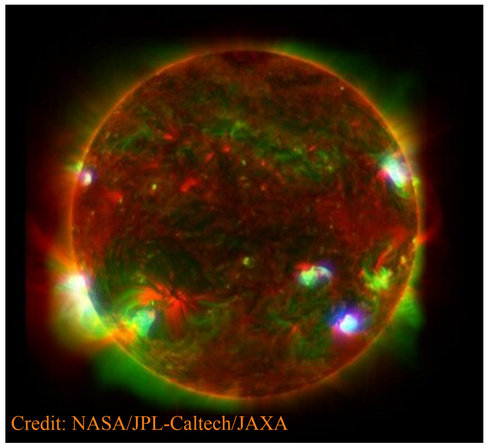
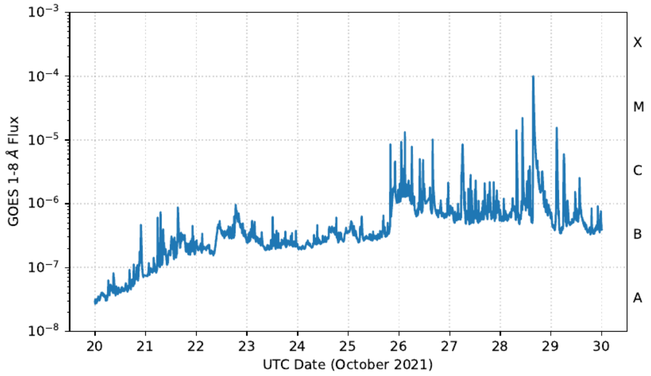




Better chances of cross calibration

But need to be strictly simultaneous - Highly Variable!!

X-ray Spectroscopy of the Sun: Past, Present, and (near) future

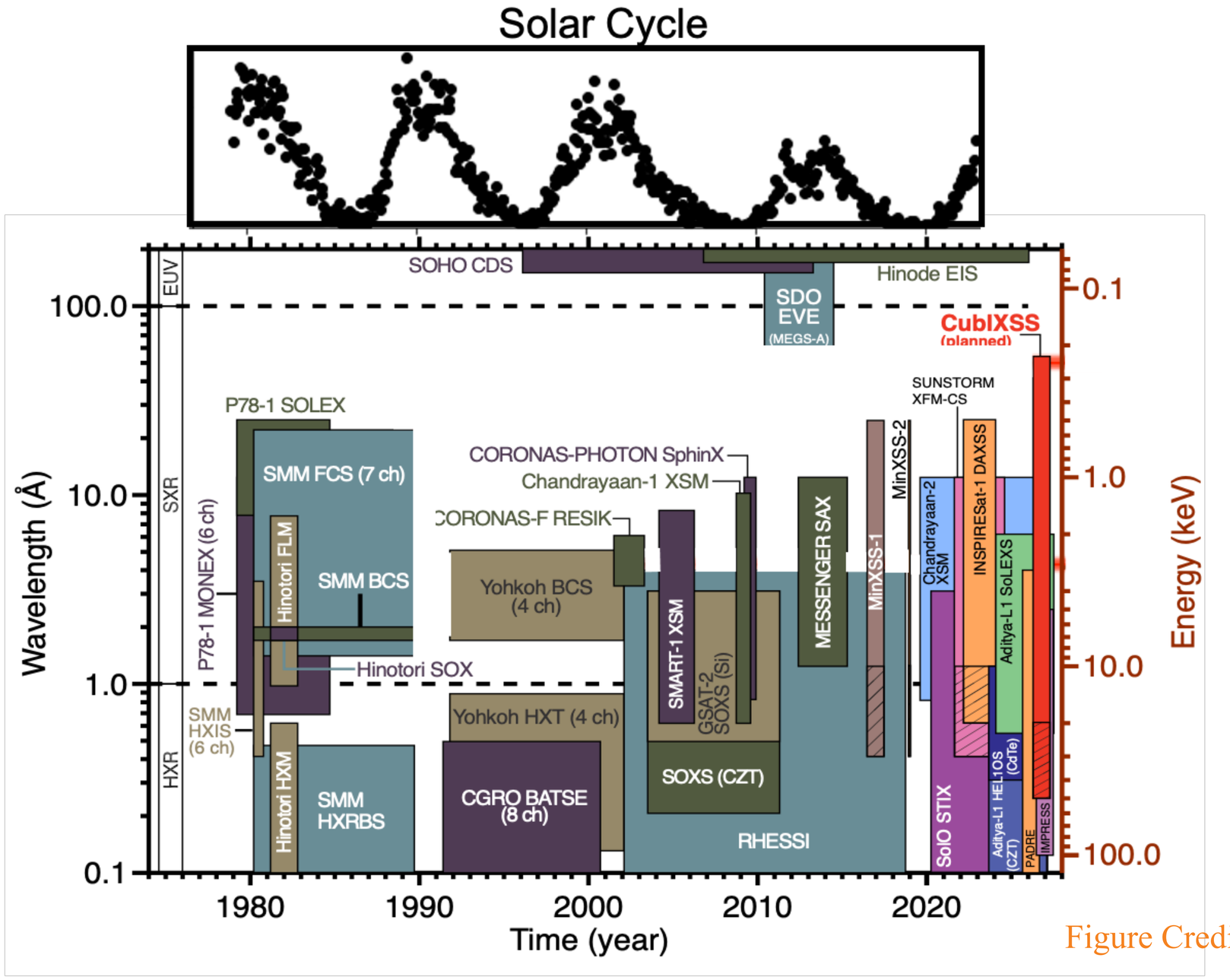
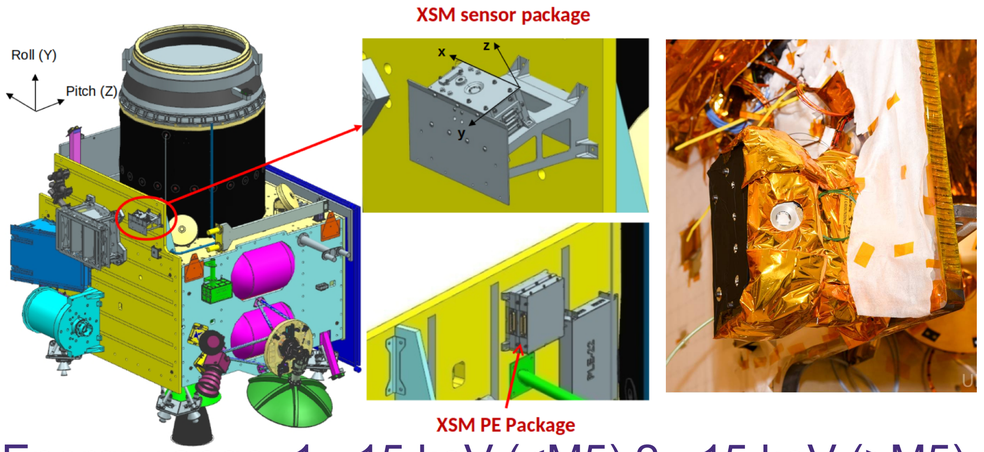


Figure Credit: Amir Caspi, SwRI

X-ray Spectroscopy of the Sun: Present Instruments

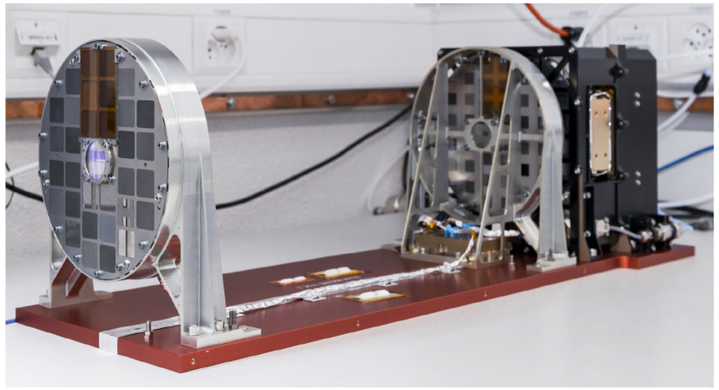
Chandrayaan-2 XSM: Sep 2019 -



Energy range: 1 - 15 keV (<M5) 2 - 15 keV (>M5)

Shanmugam et al (2020), Mithun et al (2020)

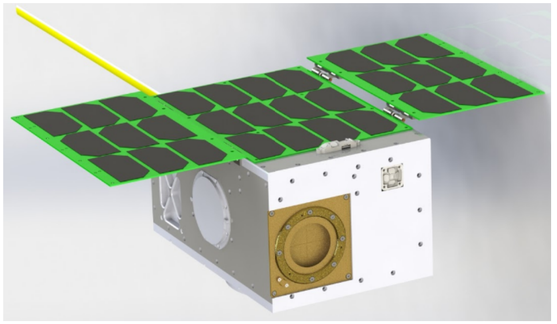
Solar Orbiter STIX: Feb 2020 -



Energy range: 4 - 150 keV

Krucker et al (2020)

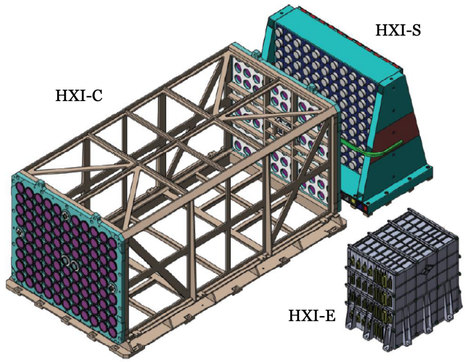
Inspiresat-1 DAXSS: Feb 2022 - Oct 2023



Energy range: 0.8 - 15 keV

Schwab et al (2020), Woods et al (2023)

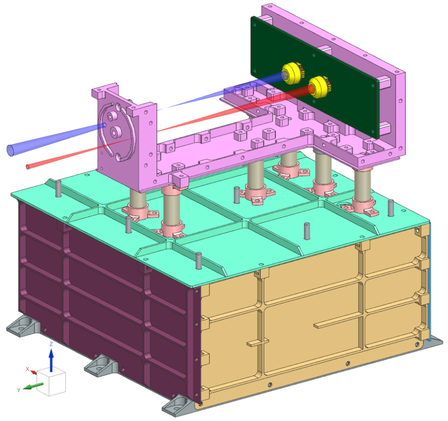
ASO-S HXI: Apr 2023 -



Energy range: 10 - 300 keV

Zhang et al (2019)

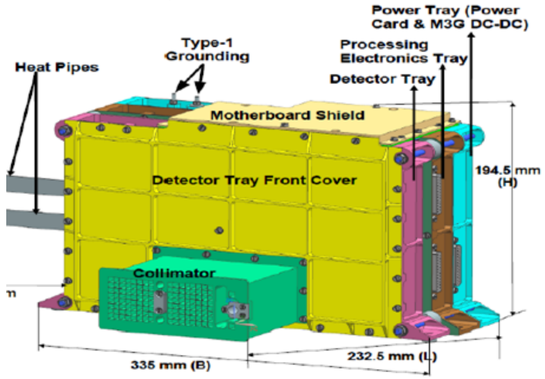
Aditya-L1 SoLEXS: Jan 2024 -



Energy range: 2 - 22 keV

Sankarasubramaniam et al (2025), Sarwade et al (2025)

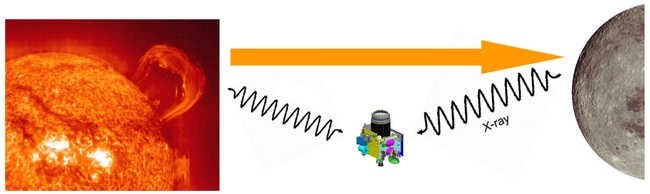
Aditya-L1 HEL1OS: Jan 2024 -



Energy range: 8 - 150 keV

Nandi et al (2025)

Chandrayaan-2 Solar X-ray Monitor (XSM)

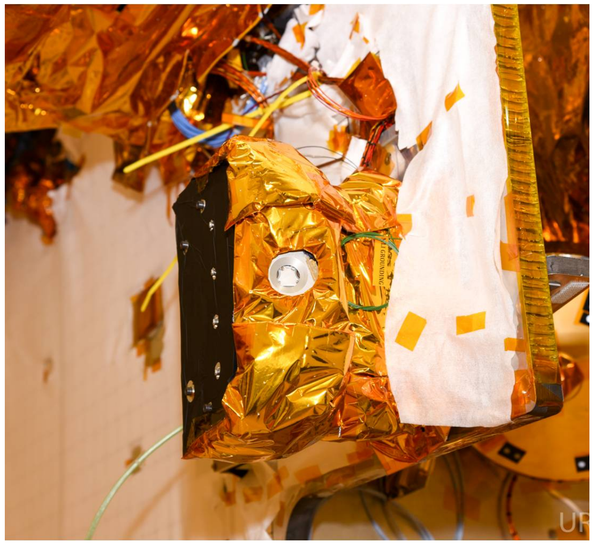


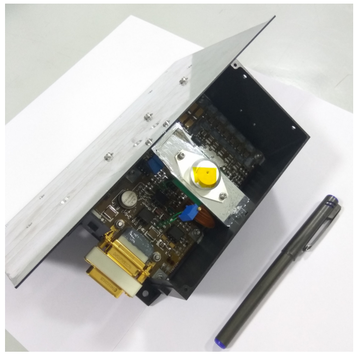
Remote X-ray fluorescence spectroscopy experiment on **"Lunar Mission"**

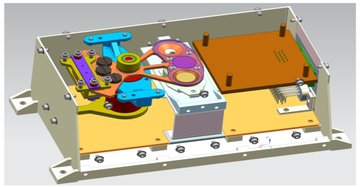
CLASS: Large area spectrometer for X-ray fluorescence spectrum from the Moon

XSM: Small area spectrometer for incident solar X-ray spectrum

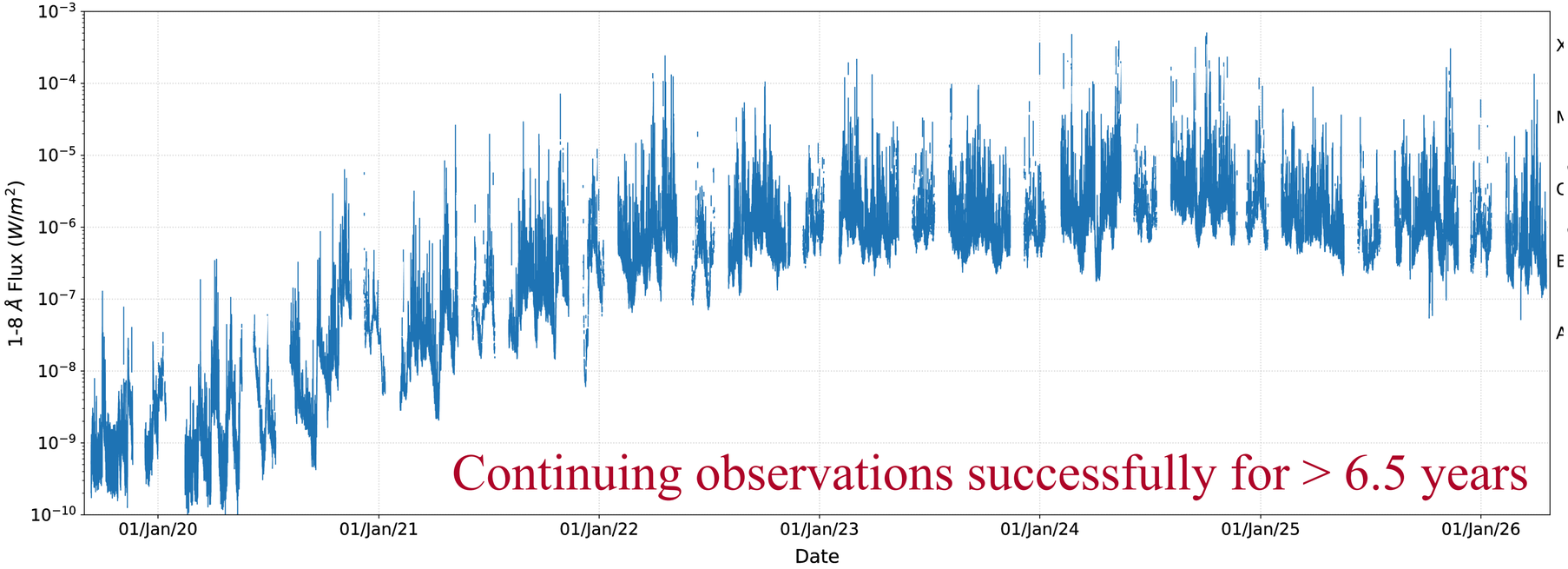
- Energy range: 1-15 keV (up to M5) 2-15 keV(>M5)
- Energy resolution: 175 eV @ 5.9 keV
- Time cadence: 1 second
- Dynamic range: sub-A to X9 class
- Collimated SDD - with some clever designs



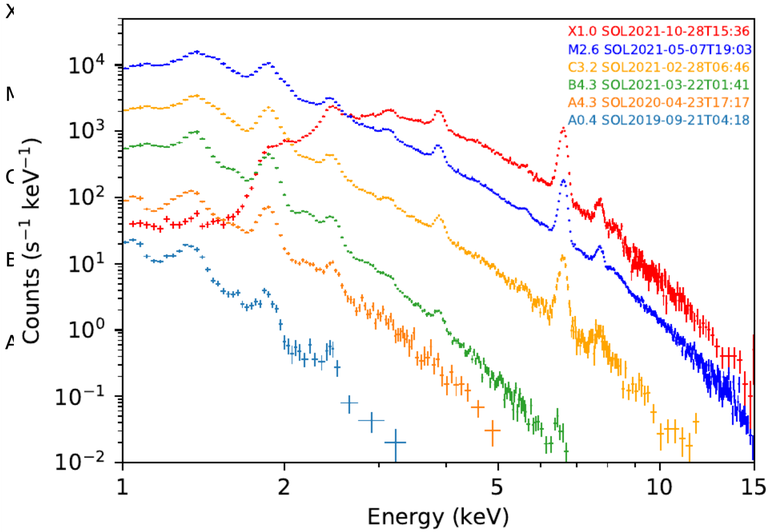




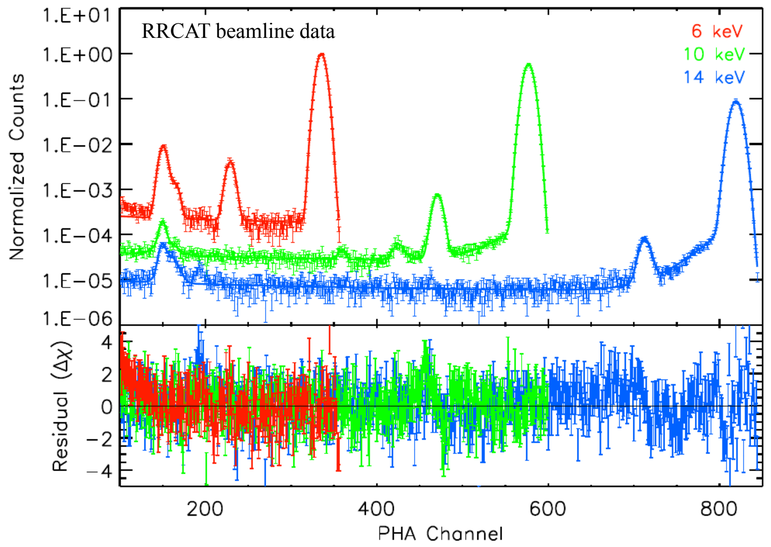
Shanmugam et al (2020), Mithun et al (2020)

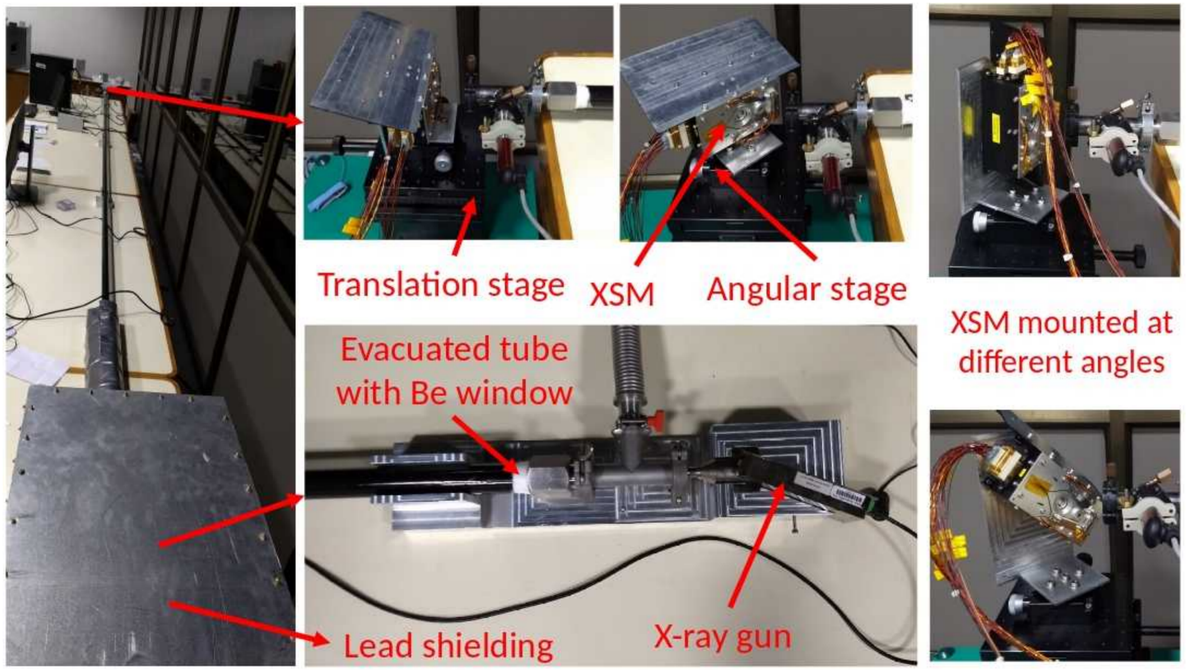


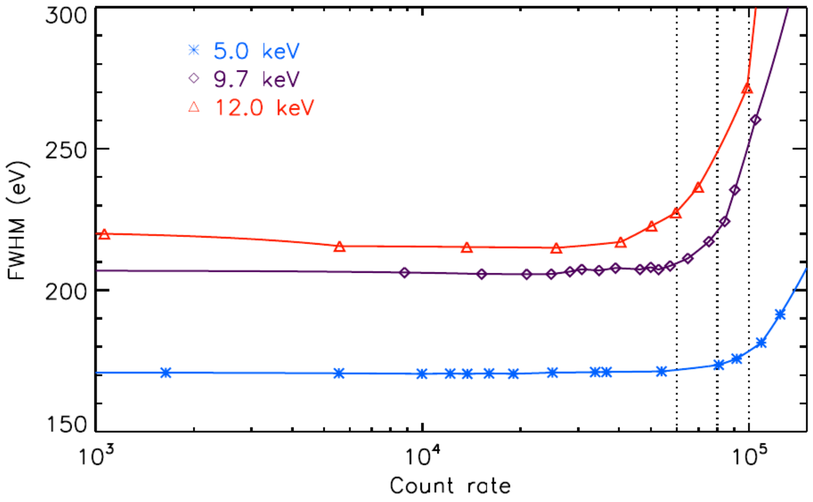
Continuing observations successfully for > 6.5 years

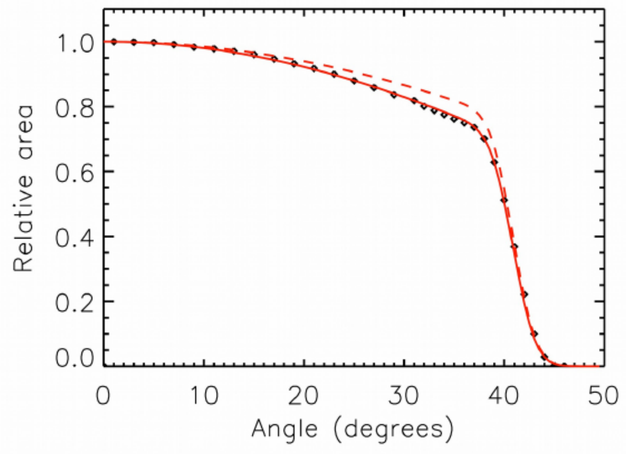


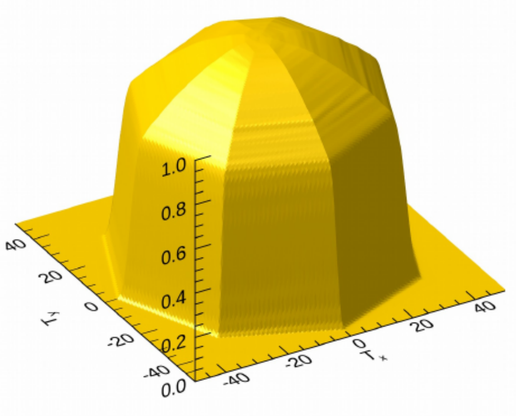
A Summary of Ground Calibration of XSM





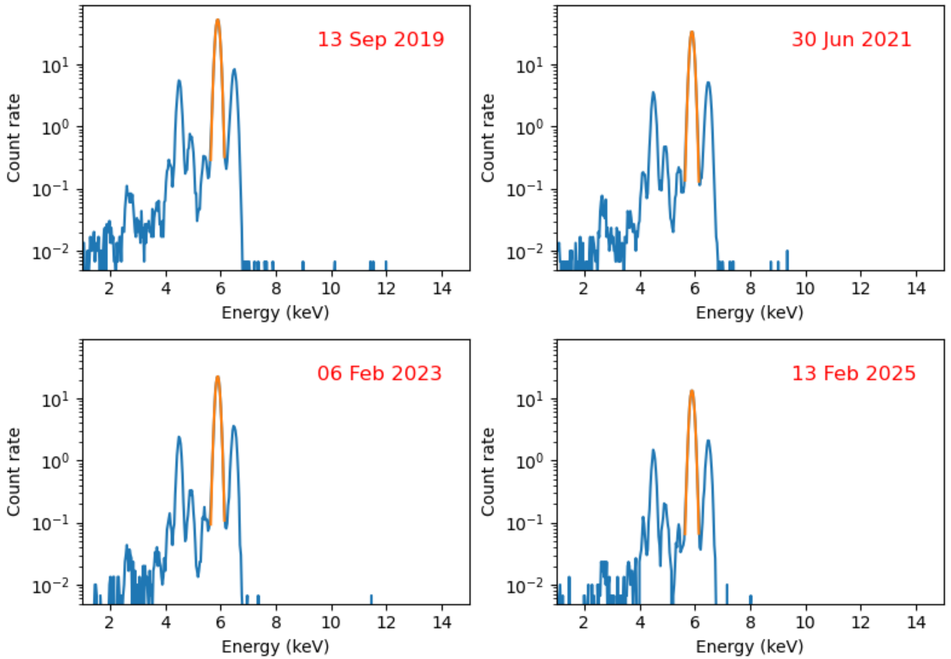


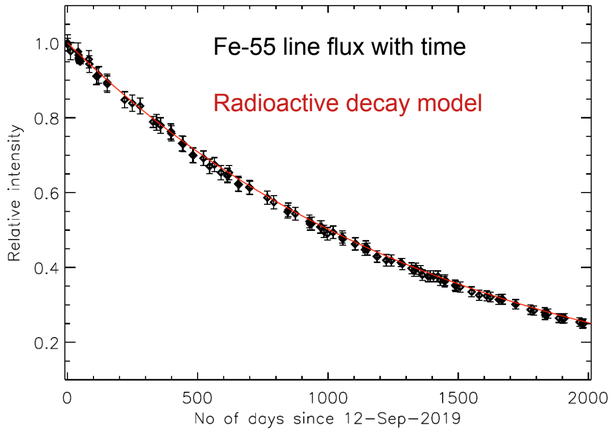


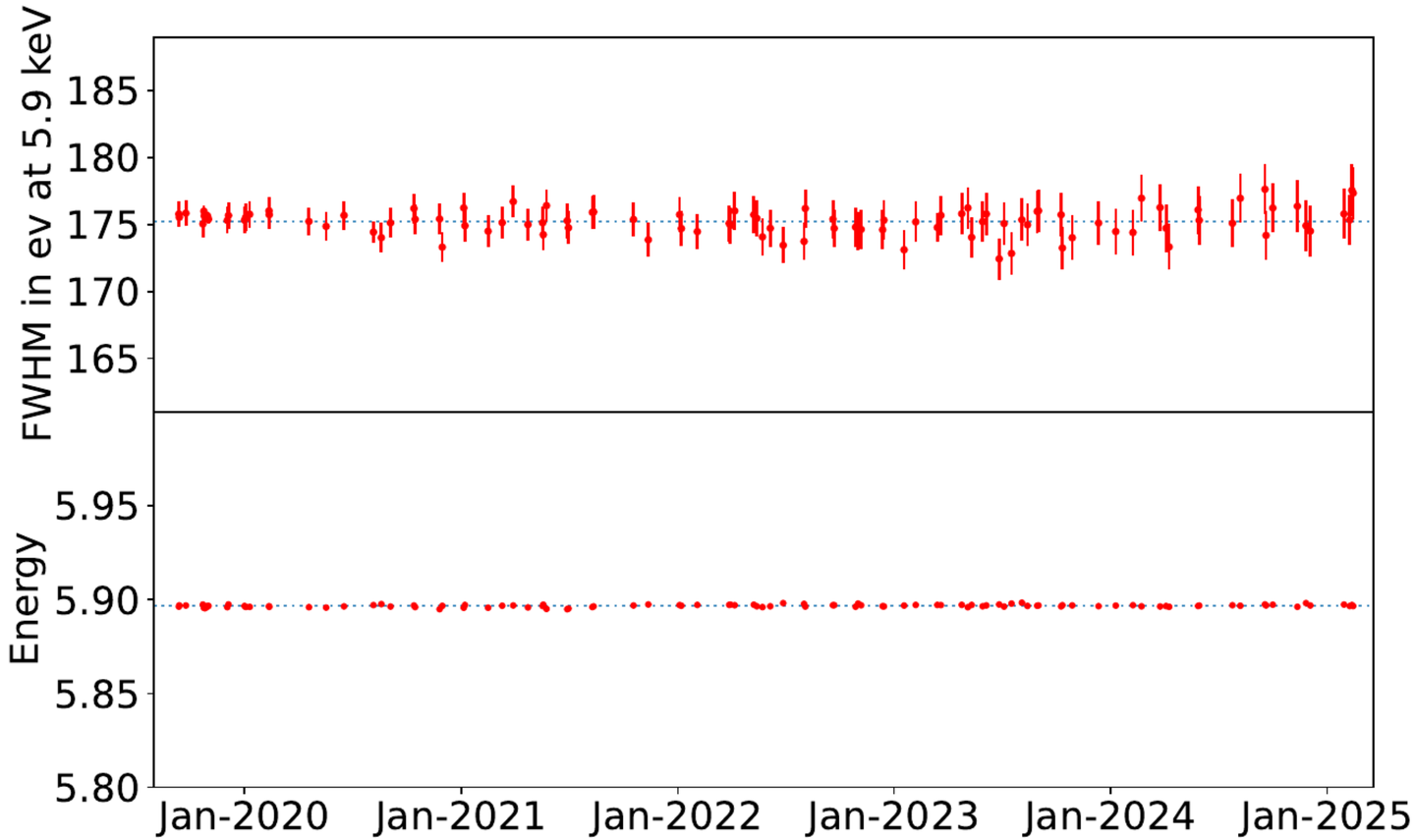


Mithun et al (2021, *Exp. Astr.*)

On-board calibration of XSM



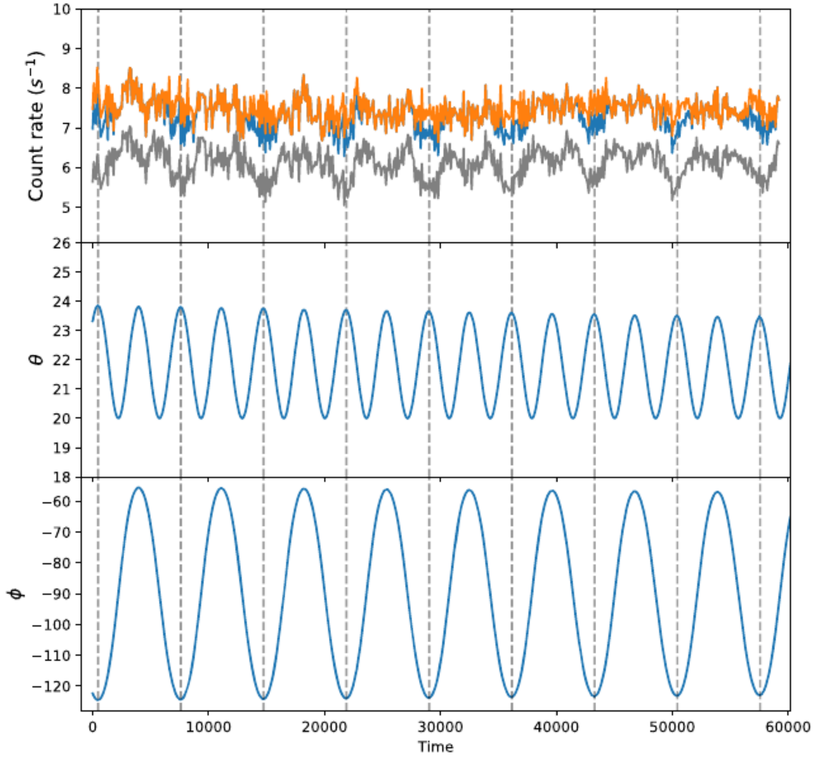




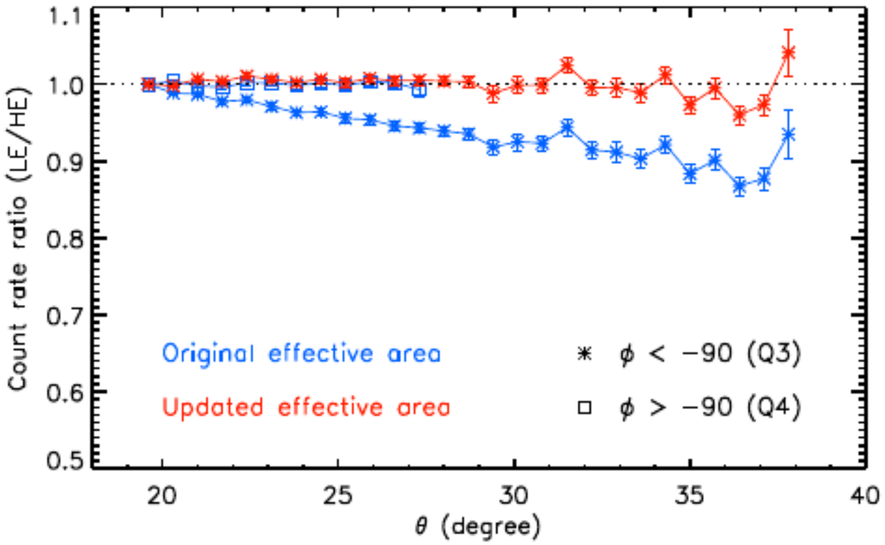
Instrument performance has remained unaffected

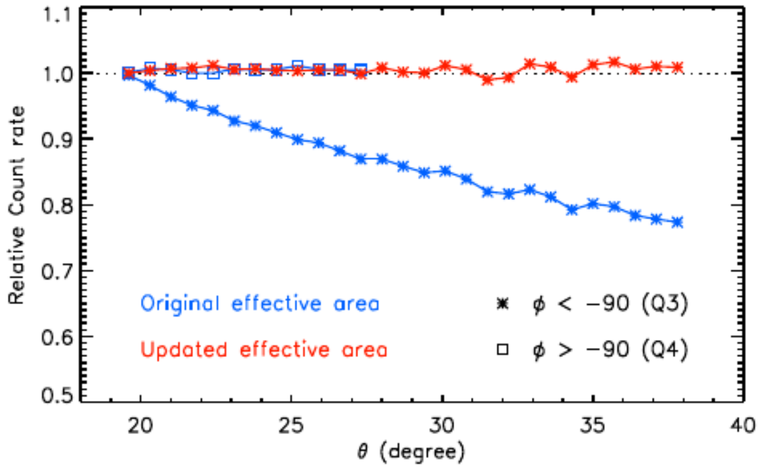
No change in spectral resolution or gain with time

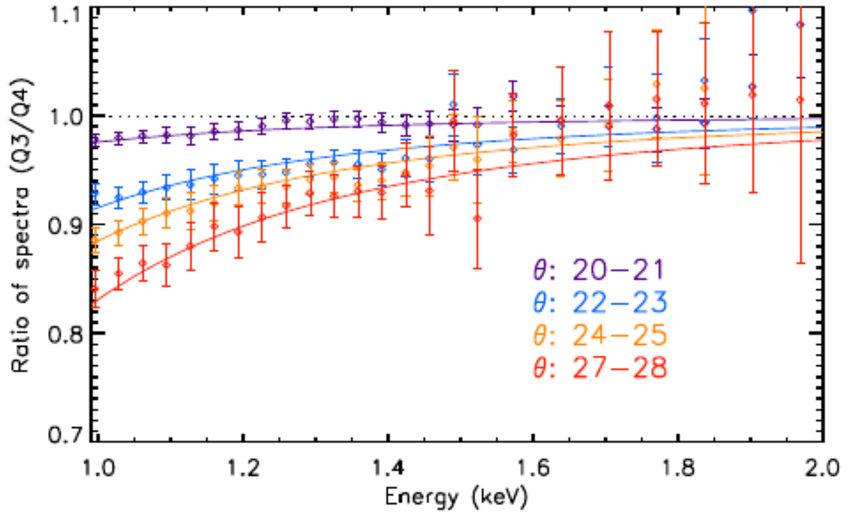
In-flight Calibration: Be window thickness non-uniformity



- Quiet Sun observations at different angle: Showing sinusoidal behaviour after effective area correction
- Non-uniformity in Be window thickness inferred; was included in the XSM response
- Relative changes in thickness of the order 4 um
- However, absolute value of Be thickness could not be measured in this manner
- Issues with < 1.3 keV response: **Spectral fitting for 1.3 keV onwards**

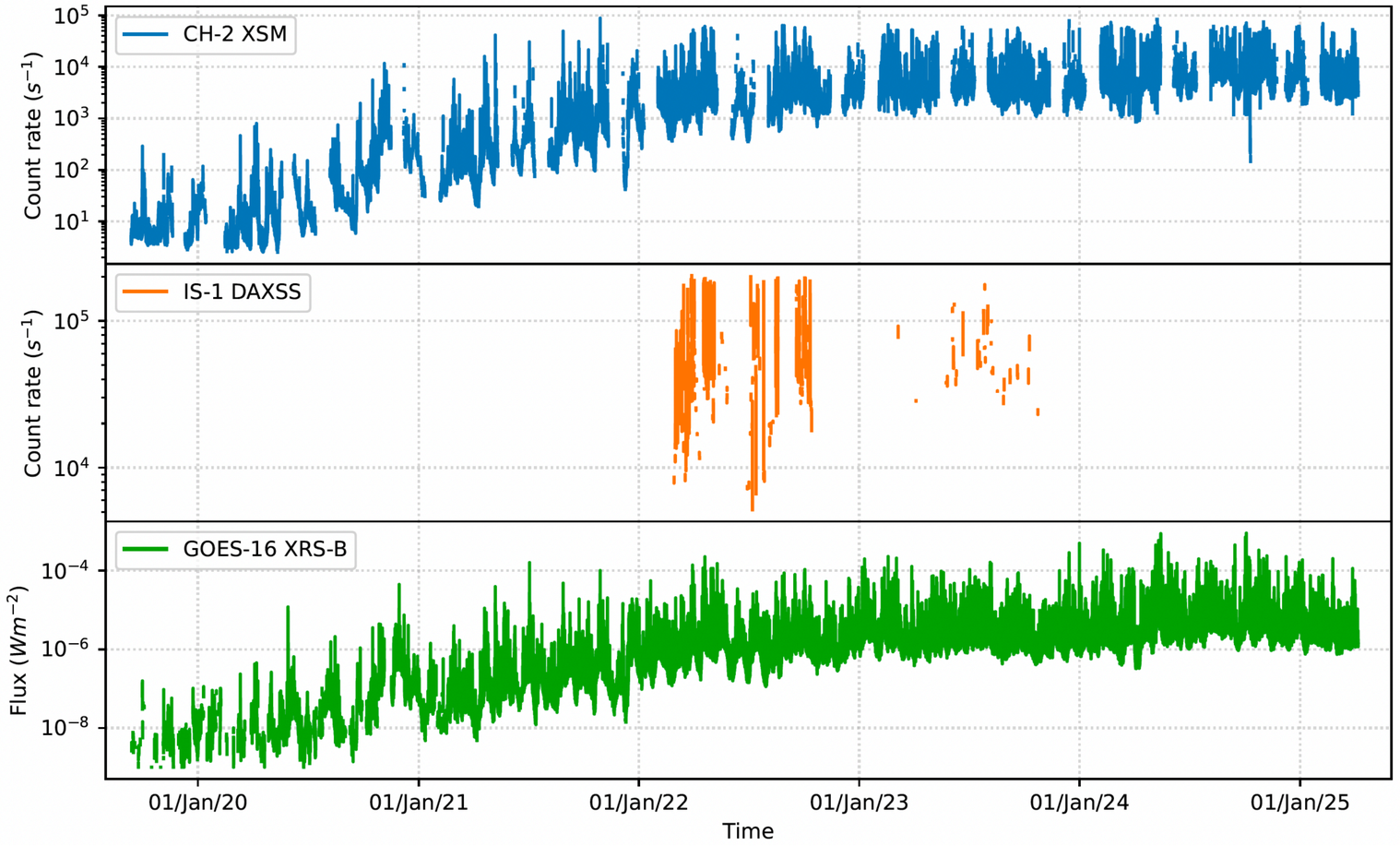






Mithun et al (2020, *Sol. Phys.*)

XSM - DAXSS - GOES XRS Comparisons



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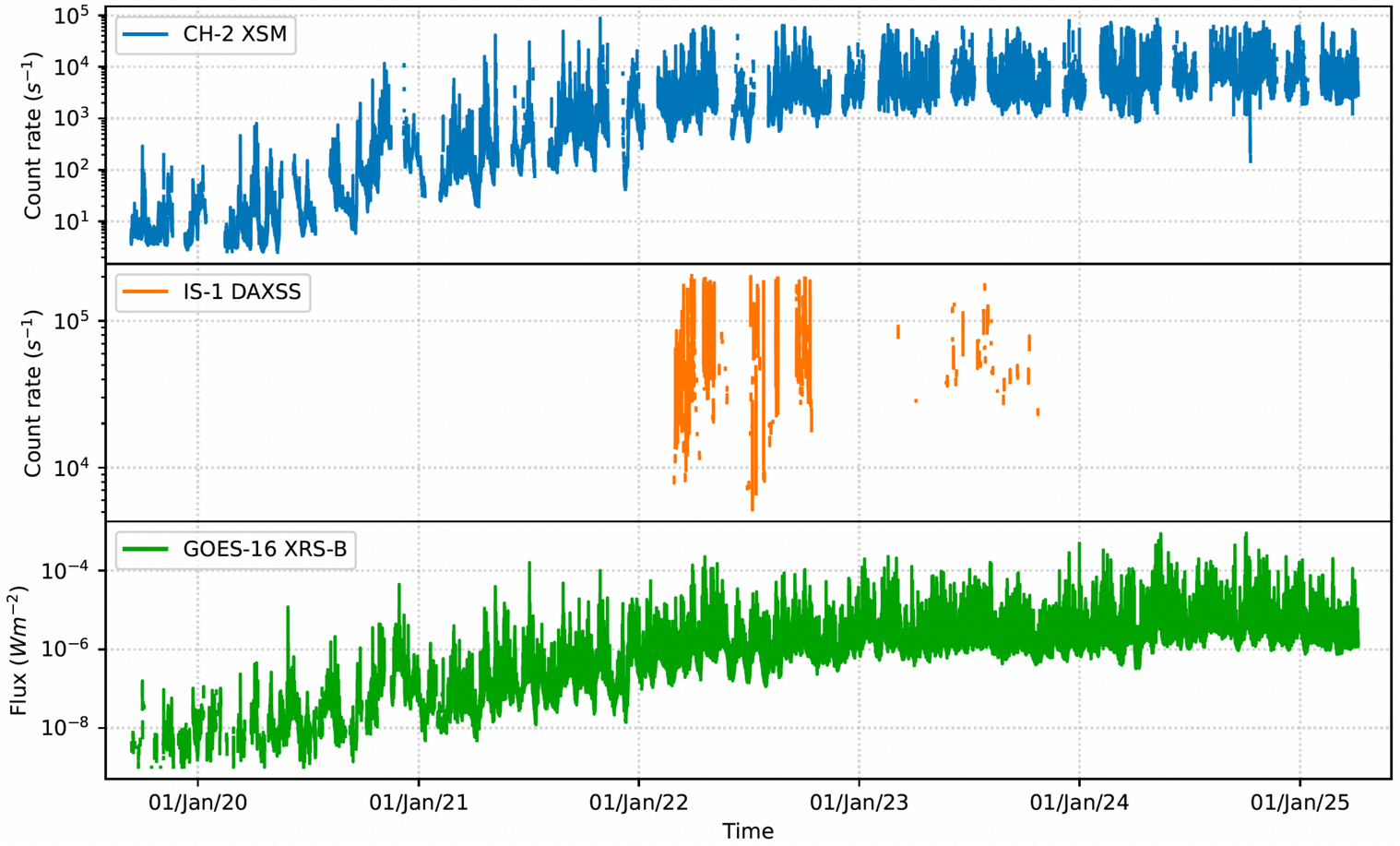
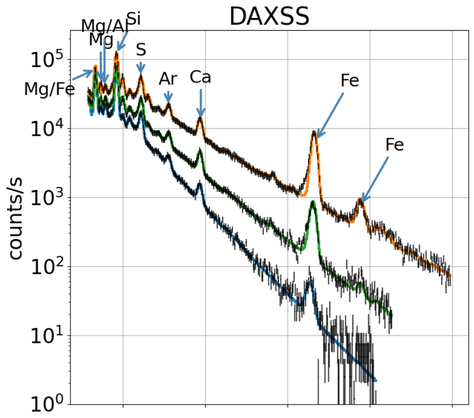
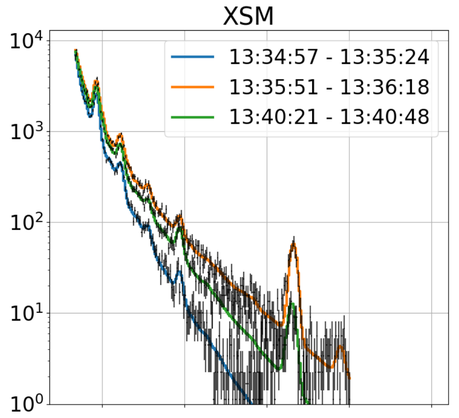
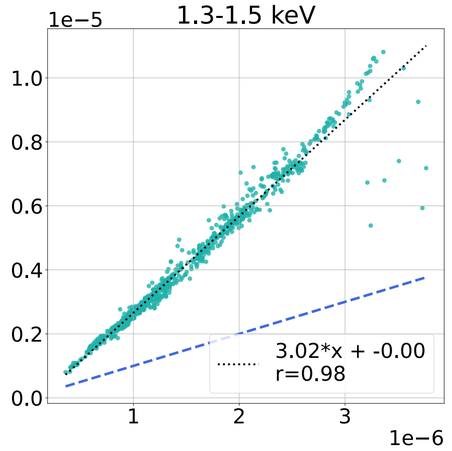
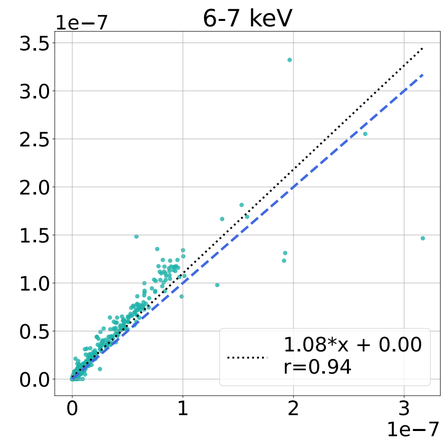


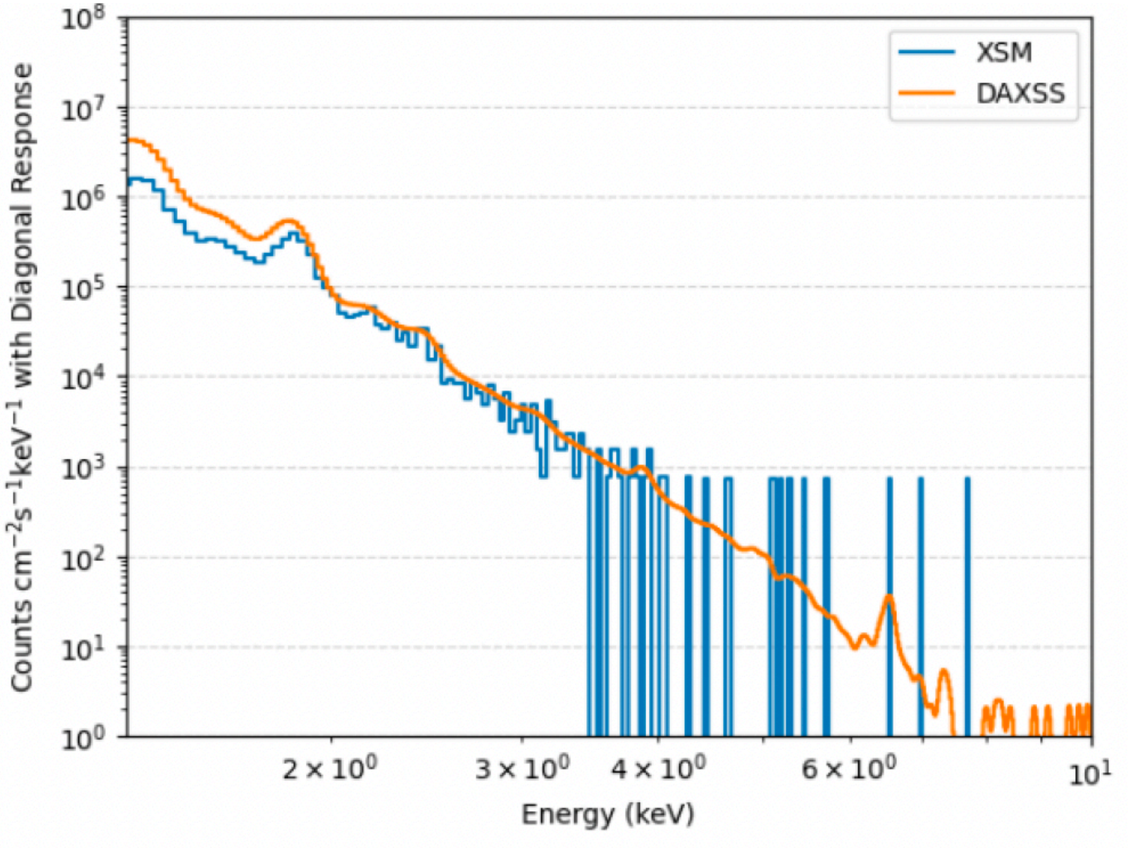






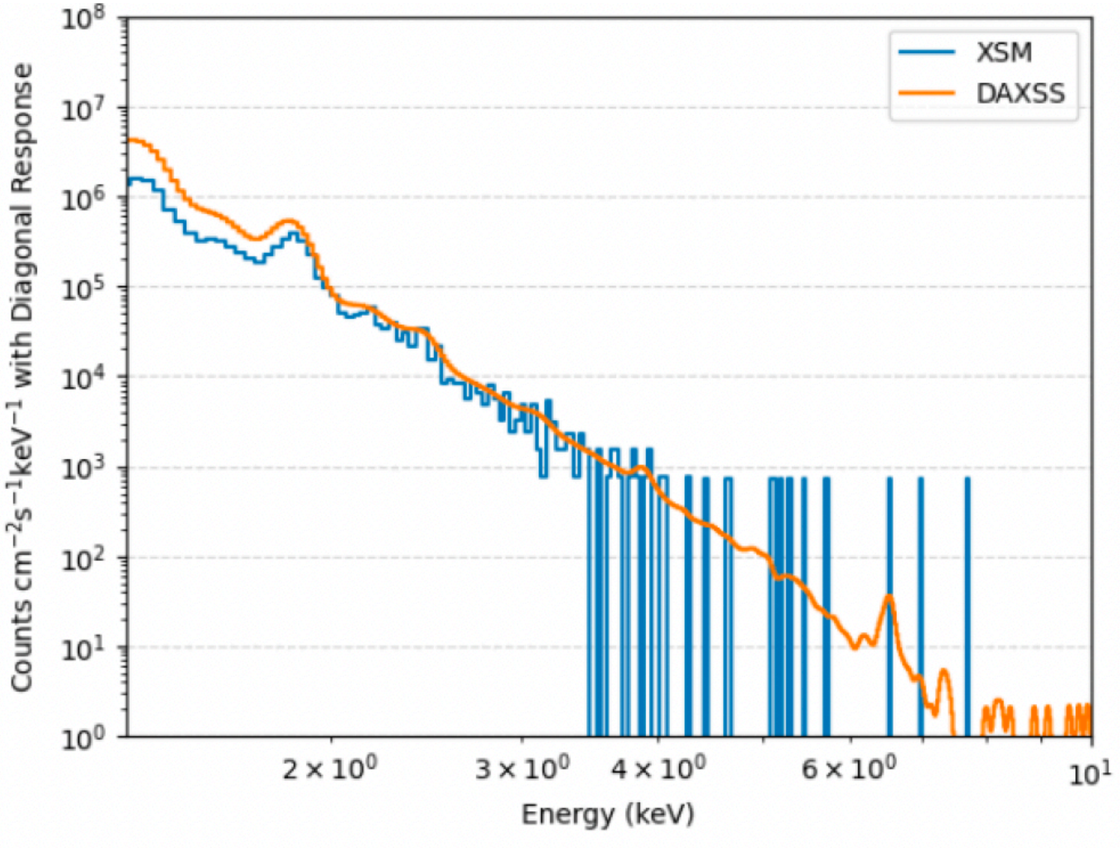


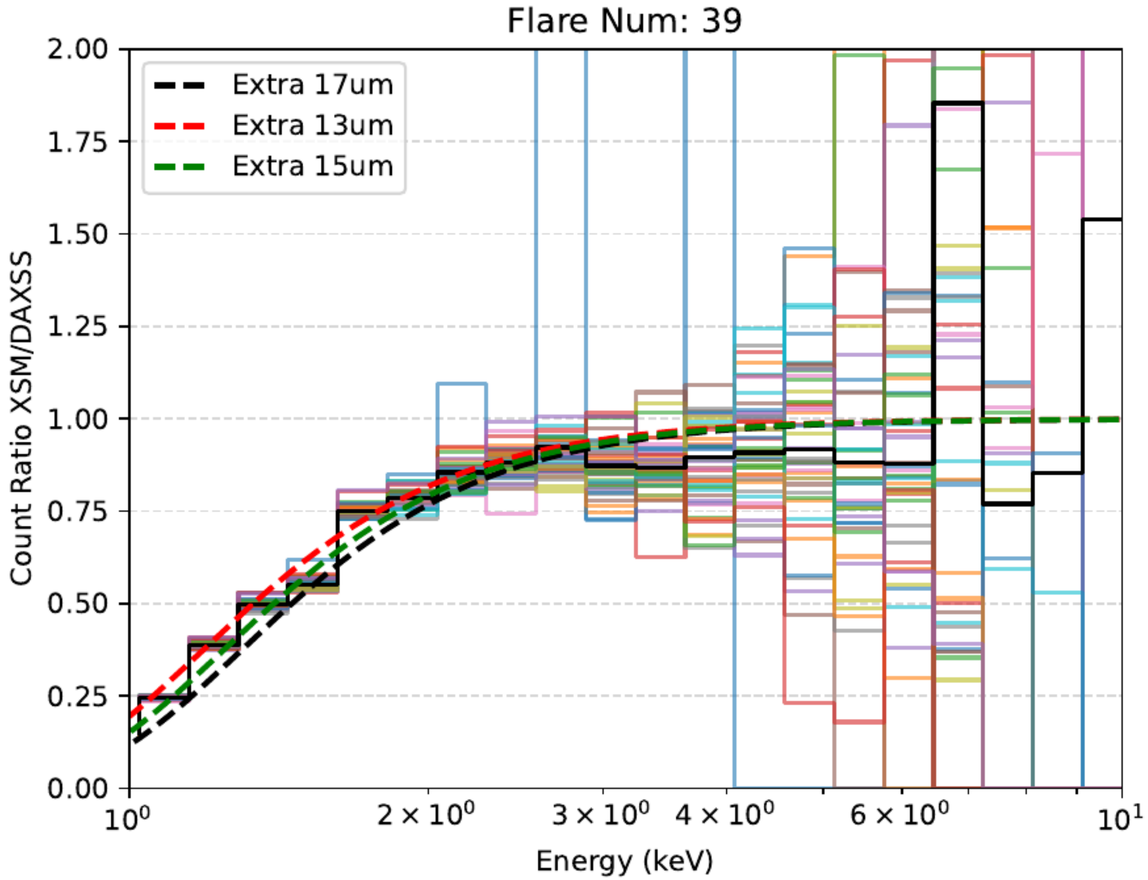
XSM-DAXSS Comparisons



Mithun et al (in prep)

XSM-DAXSS Comparisons

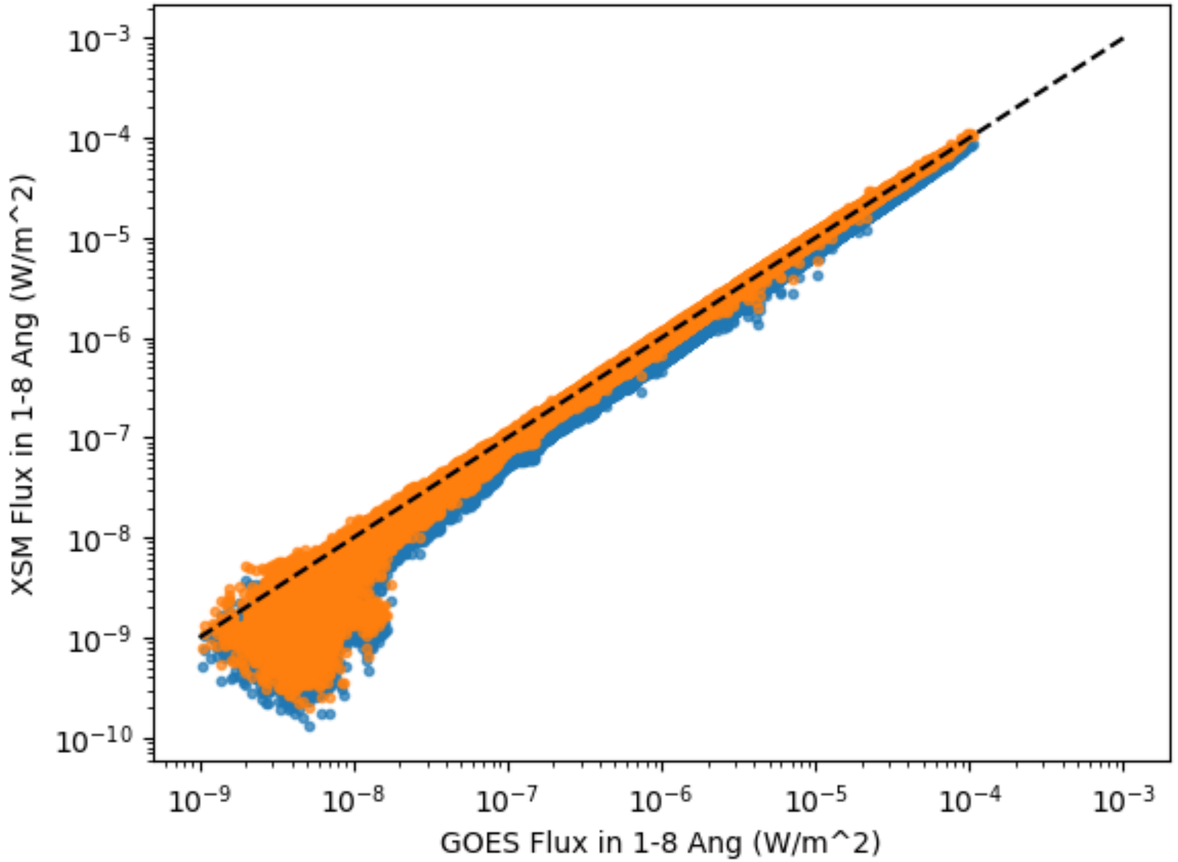


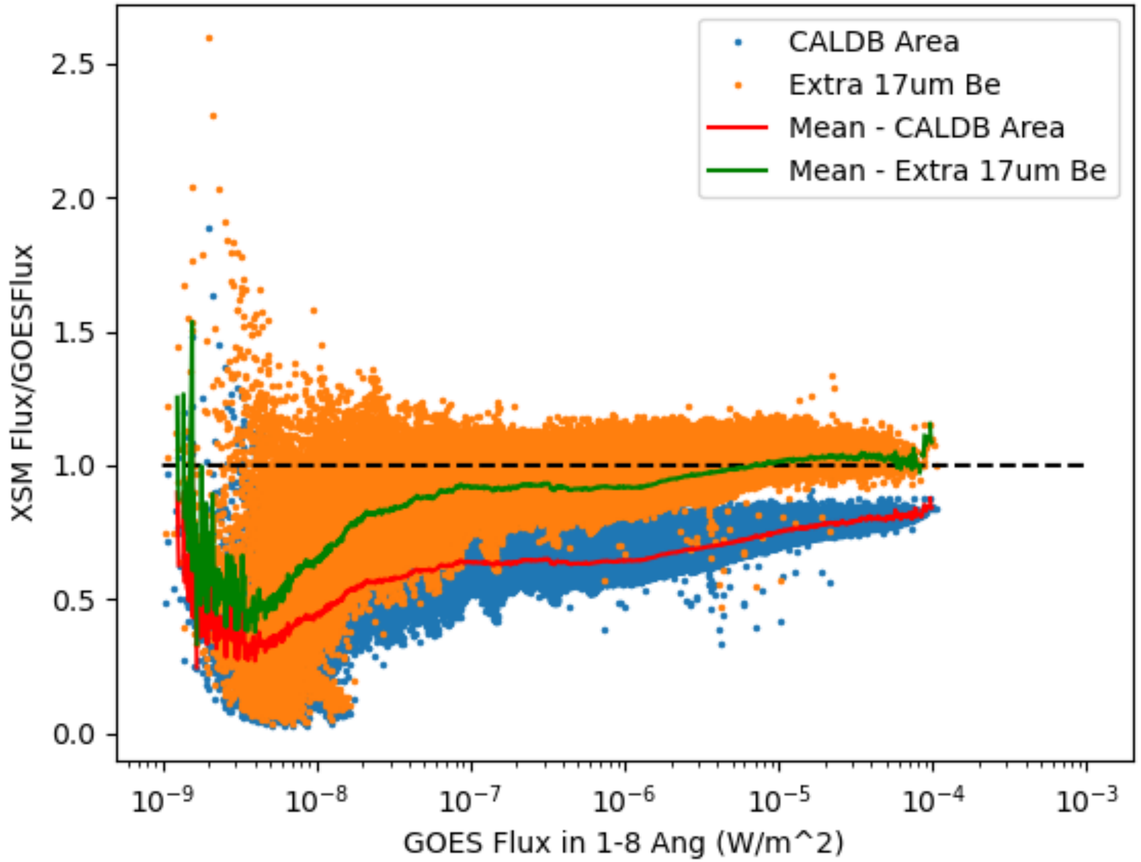


Spectral ratio consistent with additional 17 um Be: Thickness is 25 um instead of 8 um

Mithun et al (in prep)

XSM-GOES XRS Flux



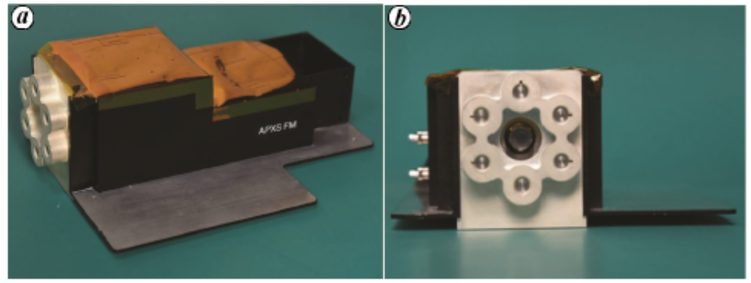


Better agreement with GOES XRS flux in 1 - 8 Angstrom (1.55 - 12.4 keV)

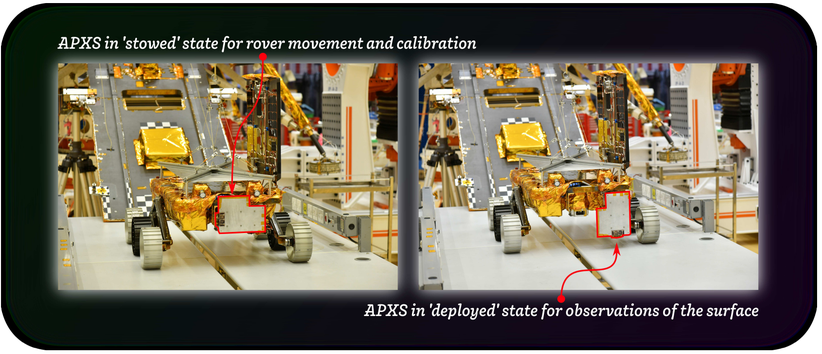
Not expected to match exactly - GOES XRS flux is approximation

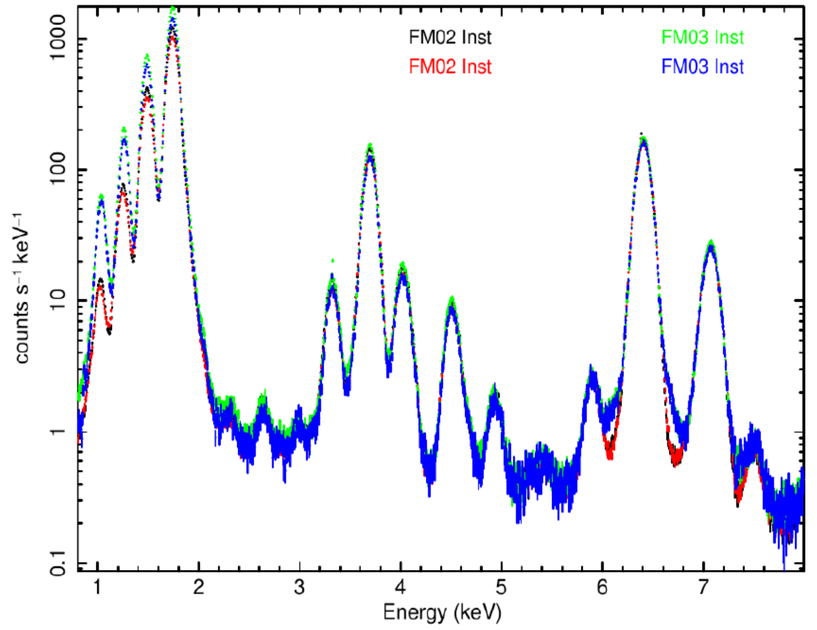
Mithun et al (in prep)

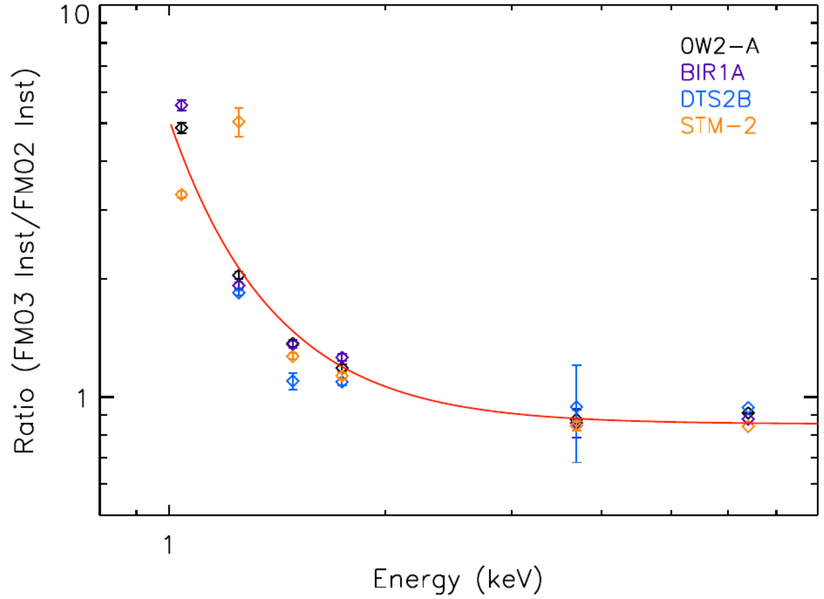
Further Evidence : Ground Data from Chandrayaan-3 APXS



- Additional evidence for Be window thickness variations in SDD - ground data of spare instrument of APXS
- XSM & APXS - detectors from the same batch
- Difference in Be window thickness between two models of APXS - 17 um!!

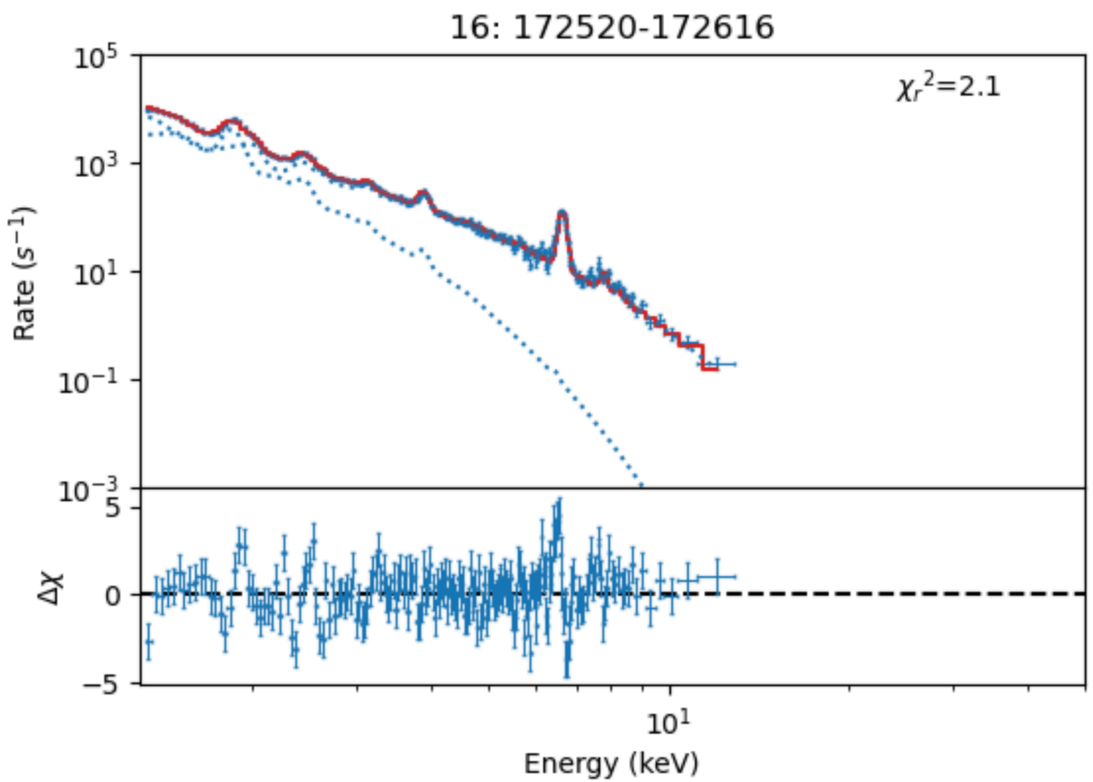




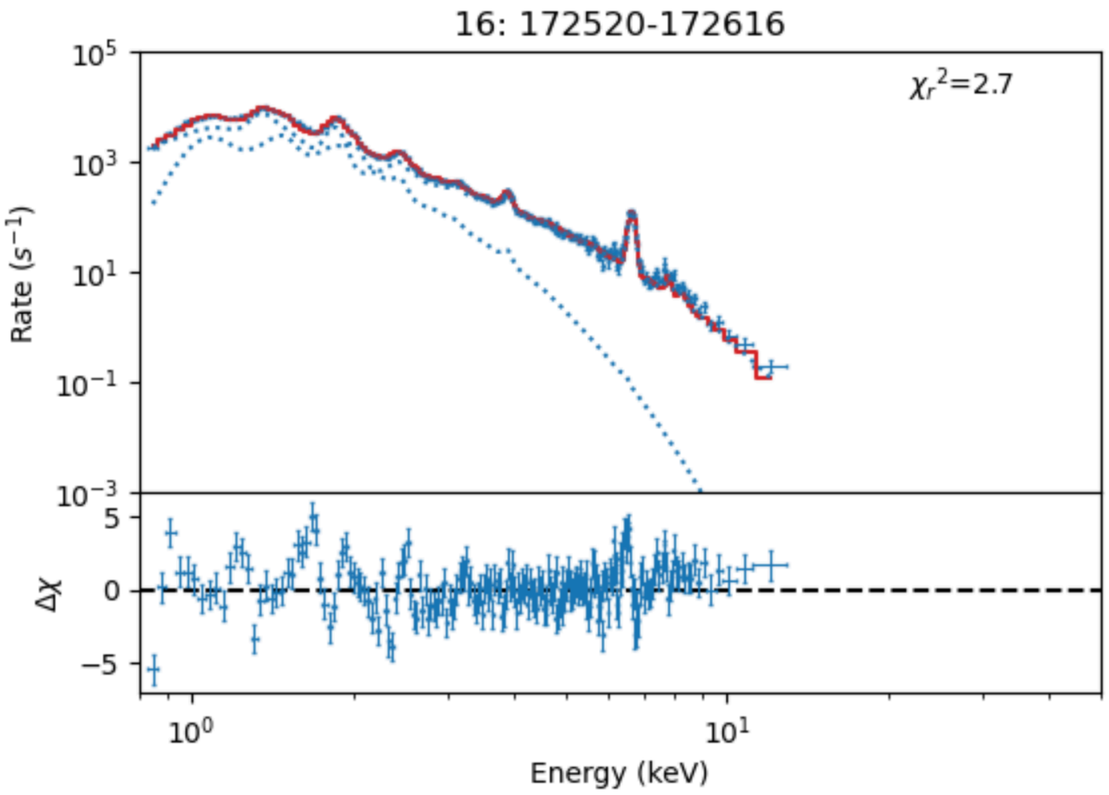


XSM Spectral fits with updated response

Current calibration

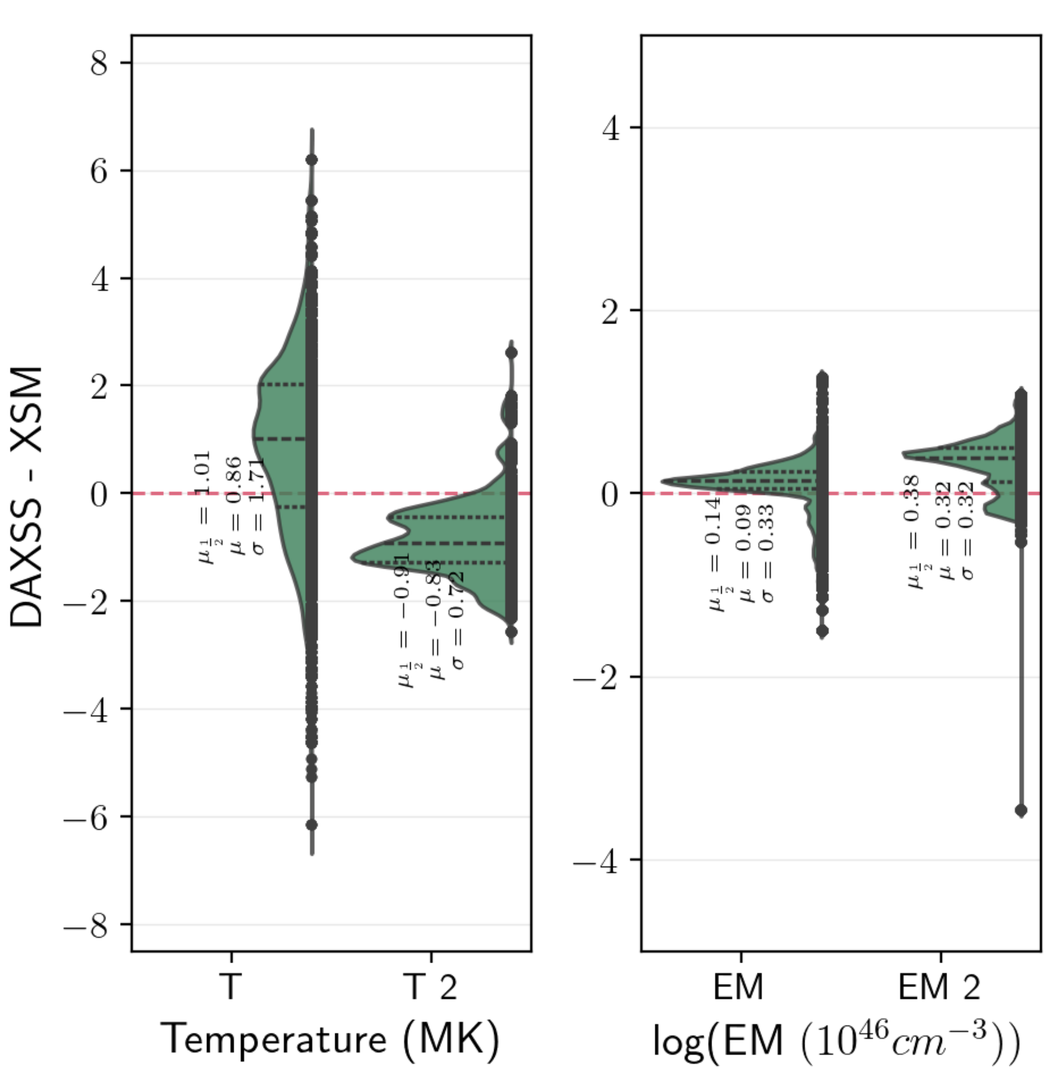


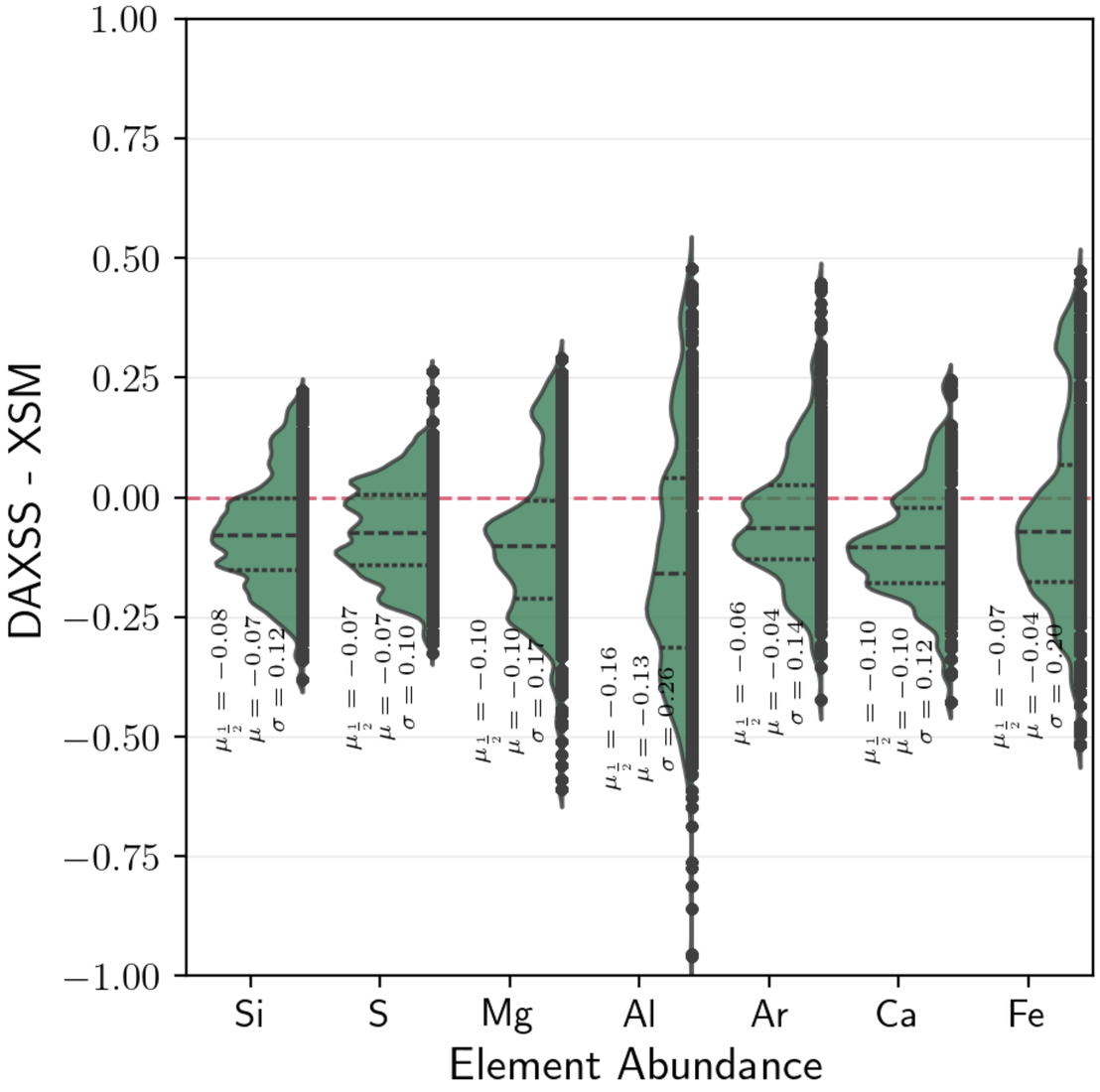
25 um Be window



Consistent spectral model fitting from 0.8 keV onwards instead of 1.3 keV

XSM and DAXSS Spectral parameters for 12 flares

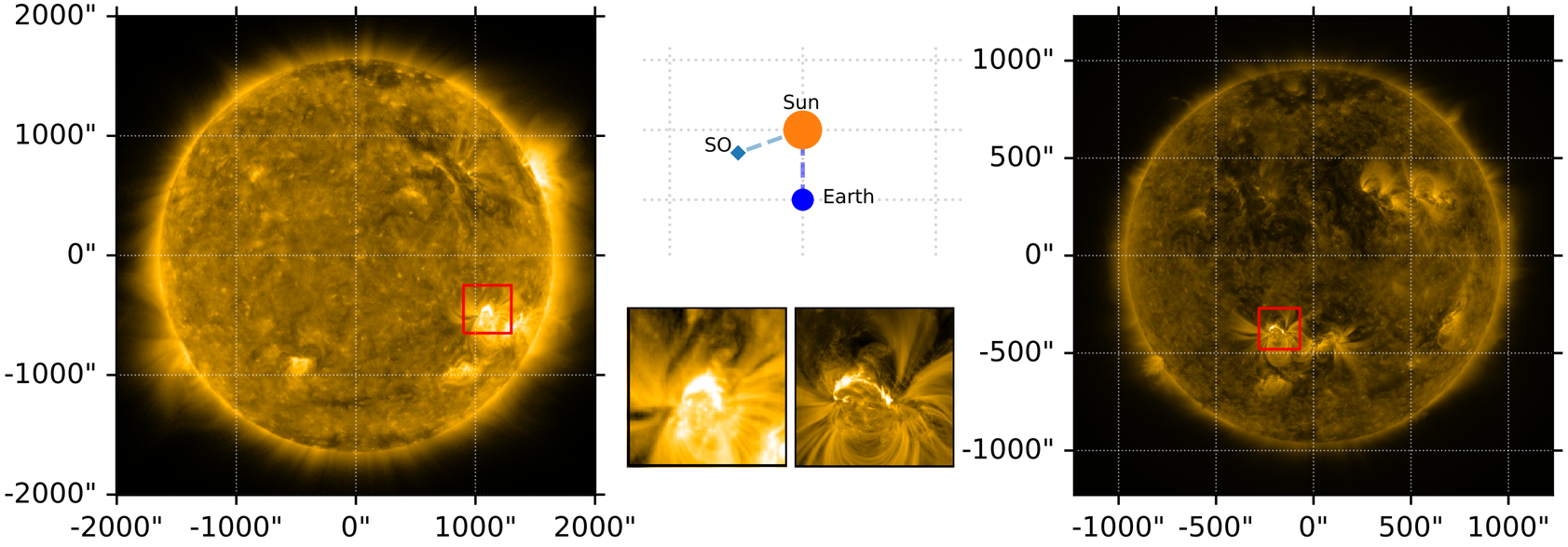


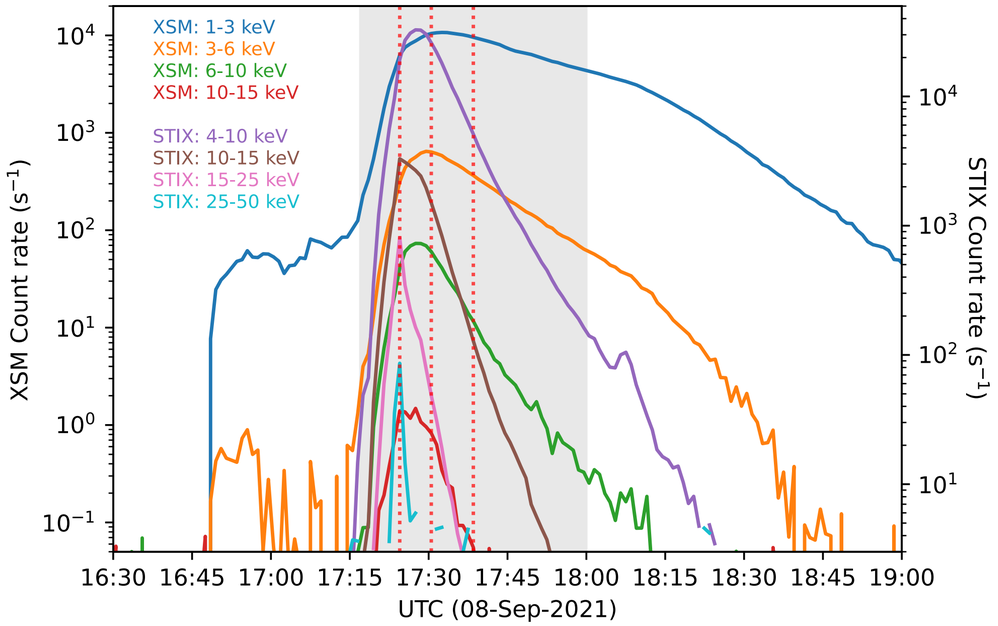


Work in progress: Asif M et al (in prep)

XSM-STIX Joint Observations

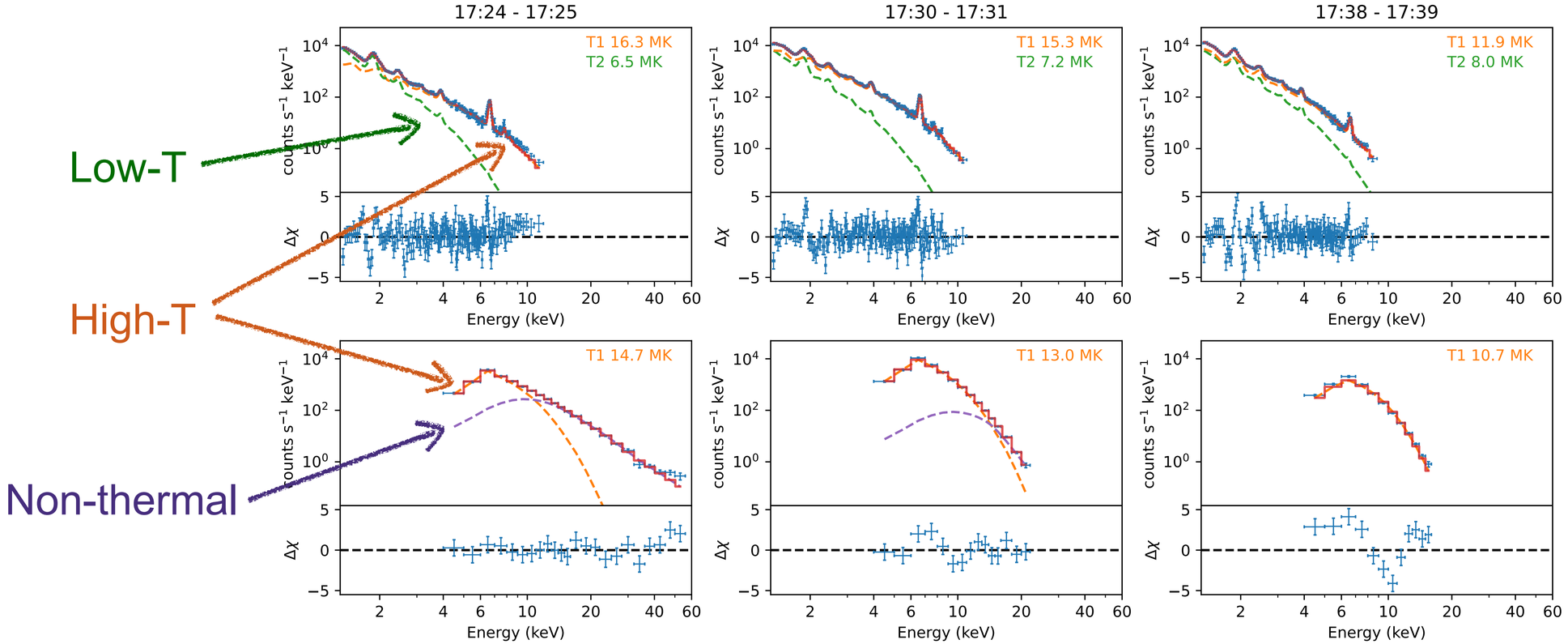
Flare observed simultaneously with Chandrayaan-2 XSM & Solar Orbiter STIX





Mithun et al (in prep)

XSM-STIX Joint Fitting Results



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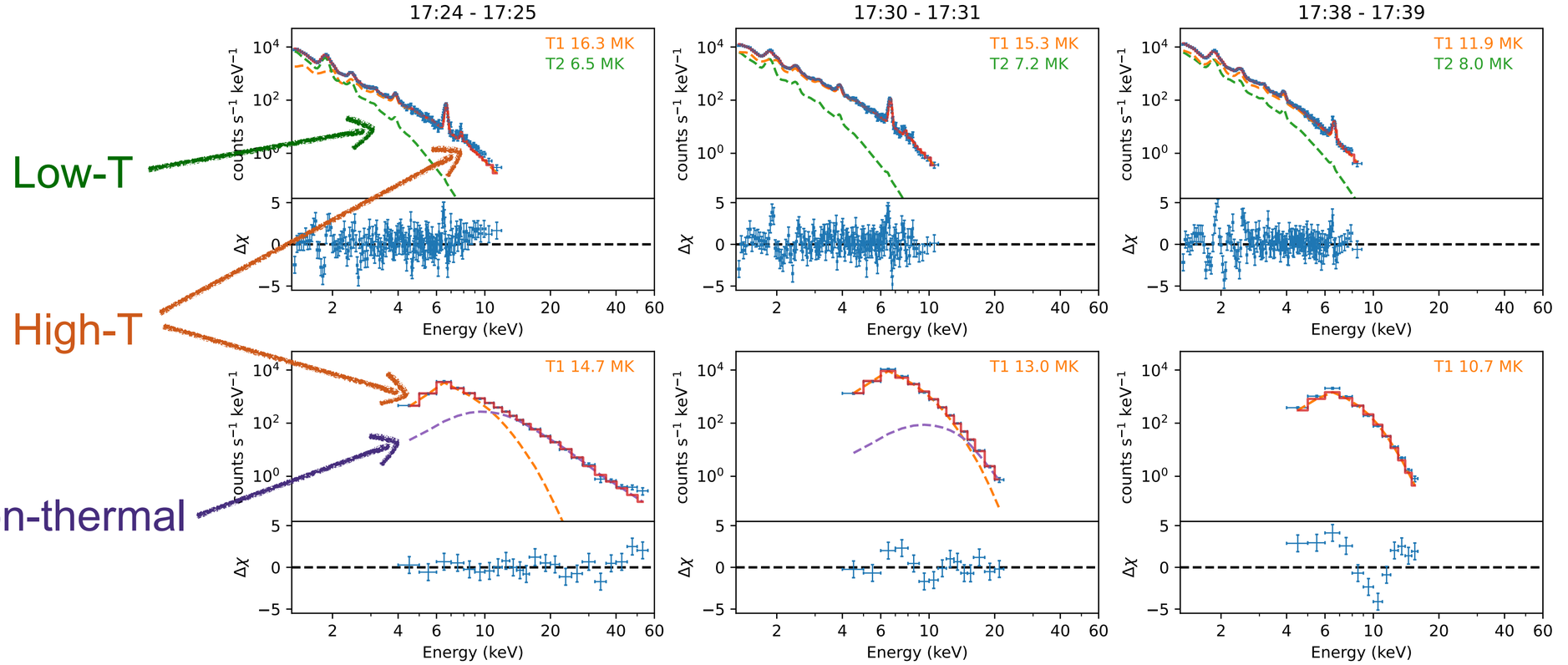
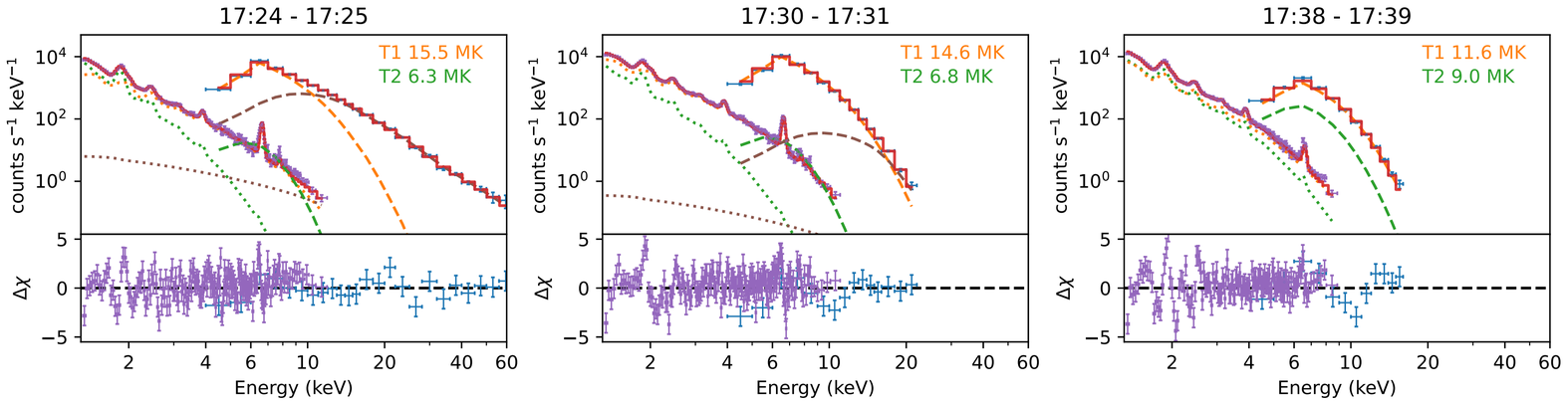


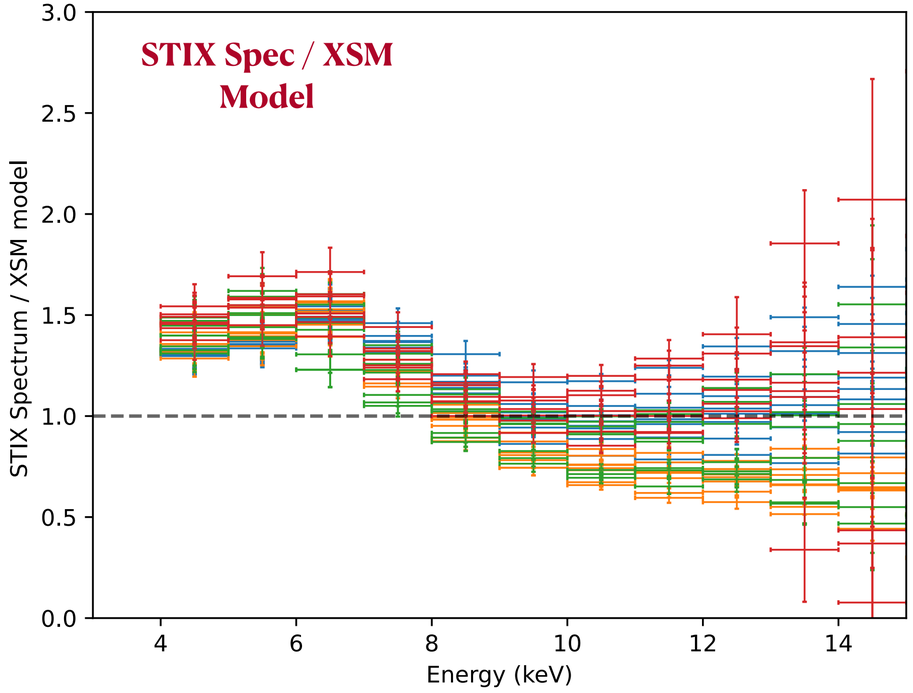
Same model consistent with both spectra

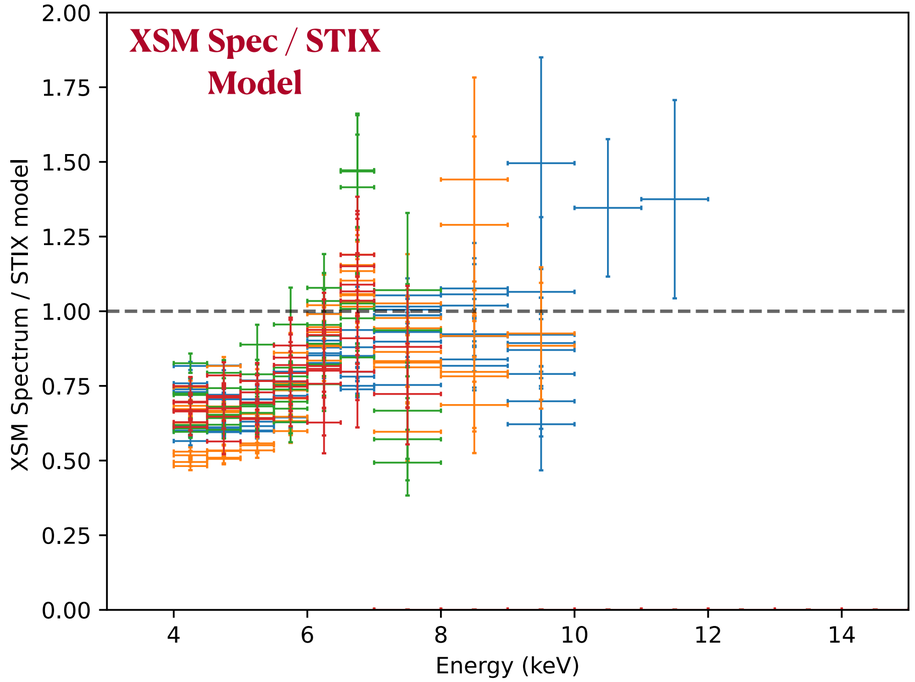
With systematic Uncertainties

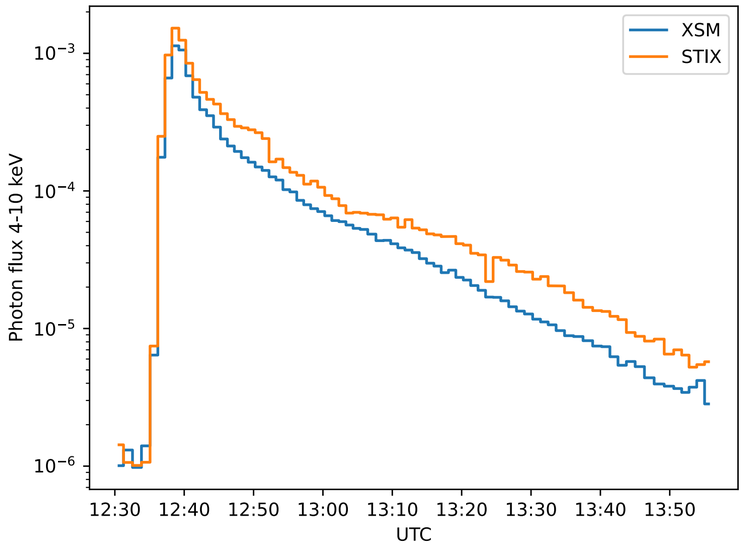


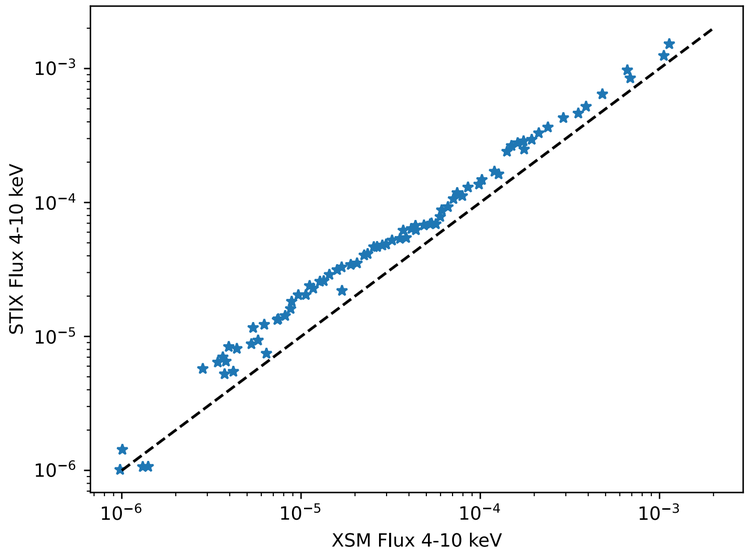
Mithun et al (in prep)

A closer look at XSM and STIX spectra





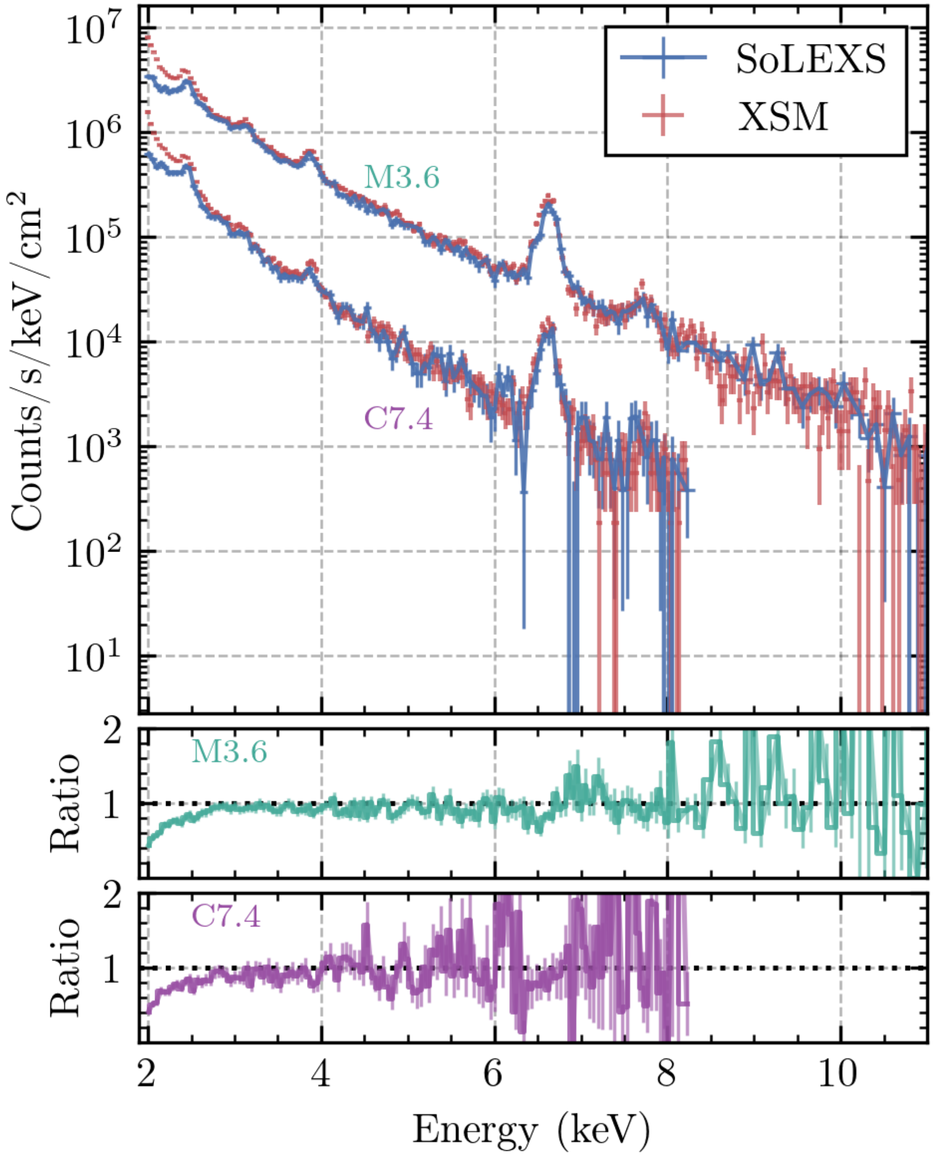


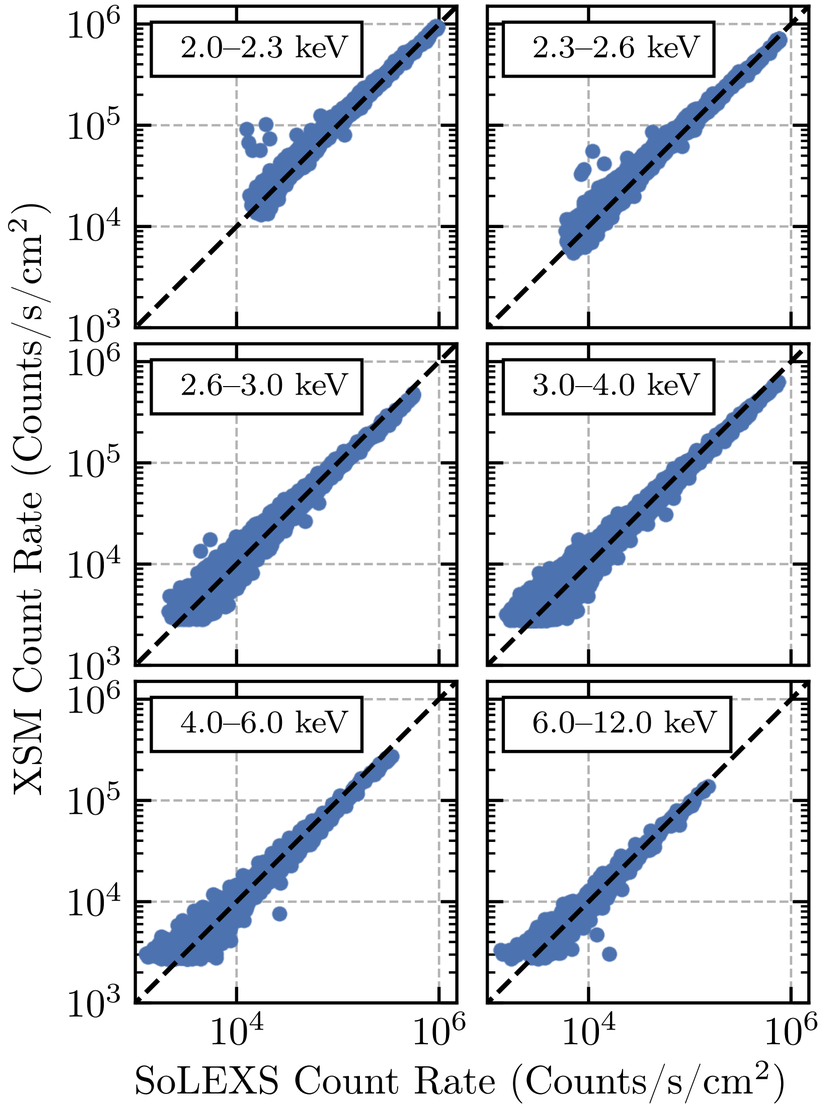


Low energy transmission in STIX response to be likely culprit:

Work in progress to understand this better

XSM - SoLXES Comparison

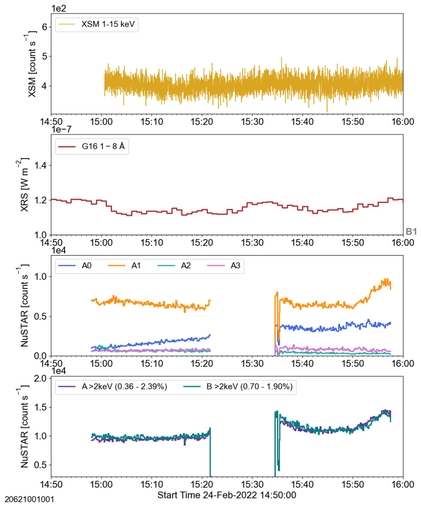


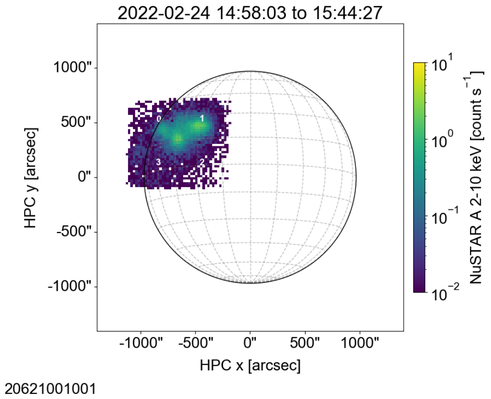


Credit: Abhilash Sarwade (URSC/ISRO)

XSM and NuStar Observations of the Sun

XSM+ NuSTAR catalogue



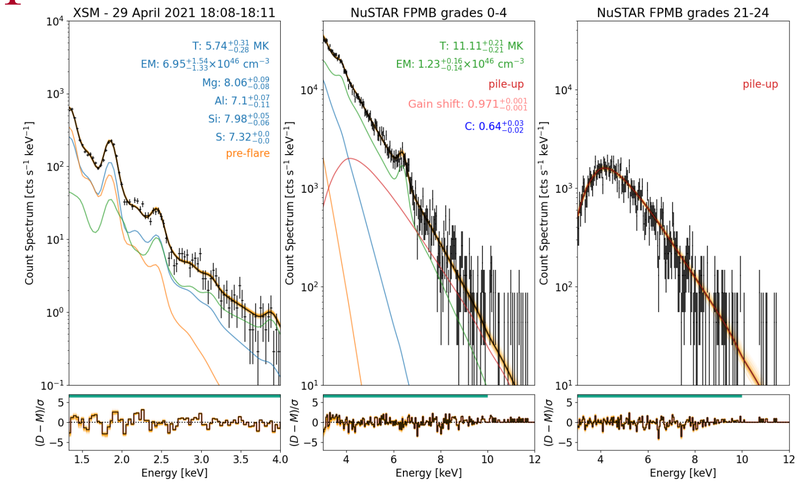


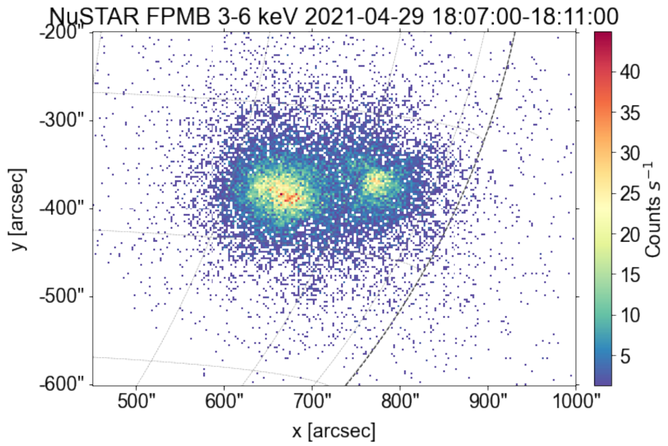
https://ianan.github.io/nsx_summ/xsm_figs/index.html

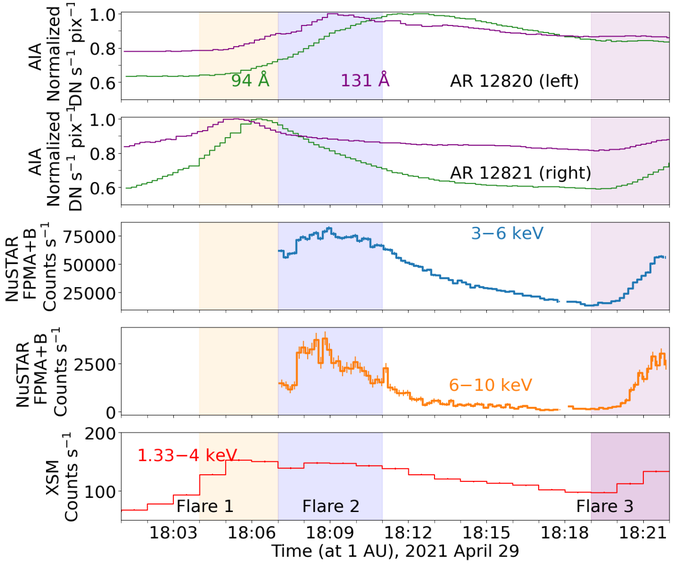
Joint-fitting (in Sun-kit-Spex) of flare events on 29 Apr 2021

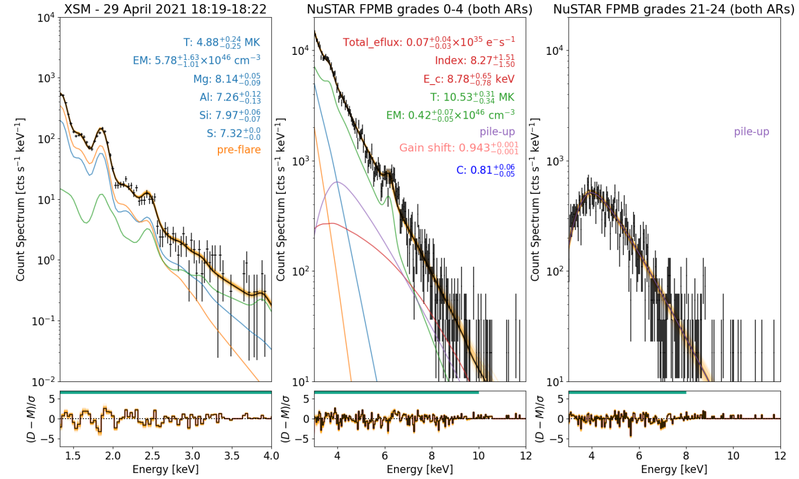
Multiple flaring regions - difficult to handle: Additional complexity of chip-gap loss in NuSTAR

Still, reasonably good match: Some improvements expected with new XSM calibration









Credit: Natalia Bajnokova (University of Glasgow)

Summary

- **Several X-ray spectrometers for Sun, many having similar energy ranges: Cross calibration very pertinent**
  - Advantage: Better chances of getting simultaneous observations
  - Disadvantage: No standard model like IACHEC models for astrophysical sources
  - Methods:
    - Empirical models that best fit the spectra: Compare them
    - Spectral ratios in count space - correcting for effective area assuming diagonal response
    - Spectral parameter comparisons - complicated by requirement of several parameters especially in soft X-rays
  - IACHEC community feedback

- **Lessons learnt (or re-learnt as we knew them already!!)**
  - Low energy transmission - major factor
  - Specifically the window transmission of detector modules that are integral part of the detector. Other components can be characterised relatively easily

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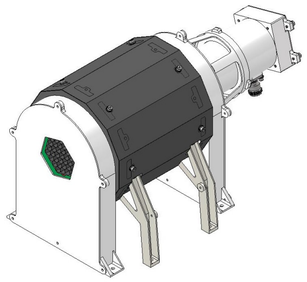
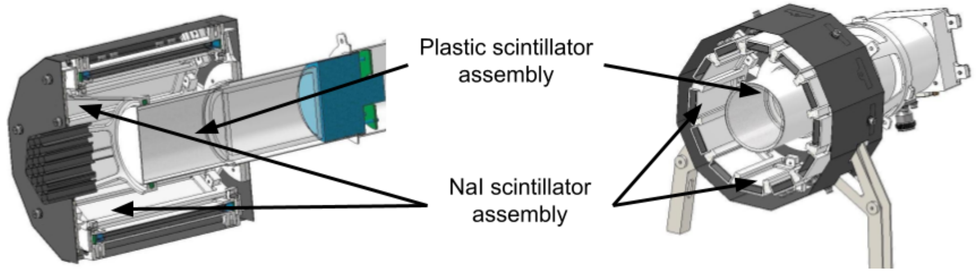
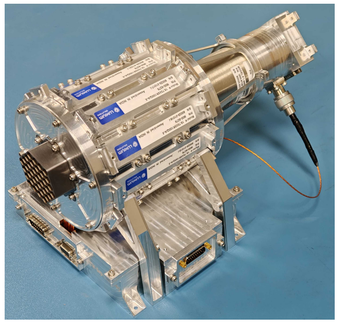
- **Next in pipeline: Solar Hard X-ray Polarimeter on small satellite platform**







Thank you

Questions? Comments?

Useful Links

XSM website: https://www.prl.res.in/ch2xsm/

Spectral analysis demo with PyXSPEC: https://github.com/xastprl/xsm-analysis

Chandrayaan-2 (XSM) & Aditya L1-1 Data archive: https://pradan.issdc.gov.in/pradan/