

Refinements to Hard X-ray Spectroscopy with AstroSat CZTI

Mithun N. P. S.

Physical Research Laboratory (PRL), Ahmedabad, India

Contact: mithun@prl.res.in

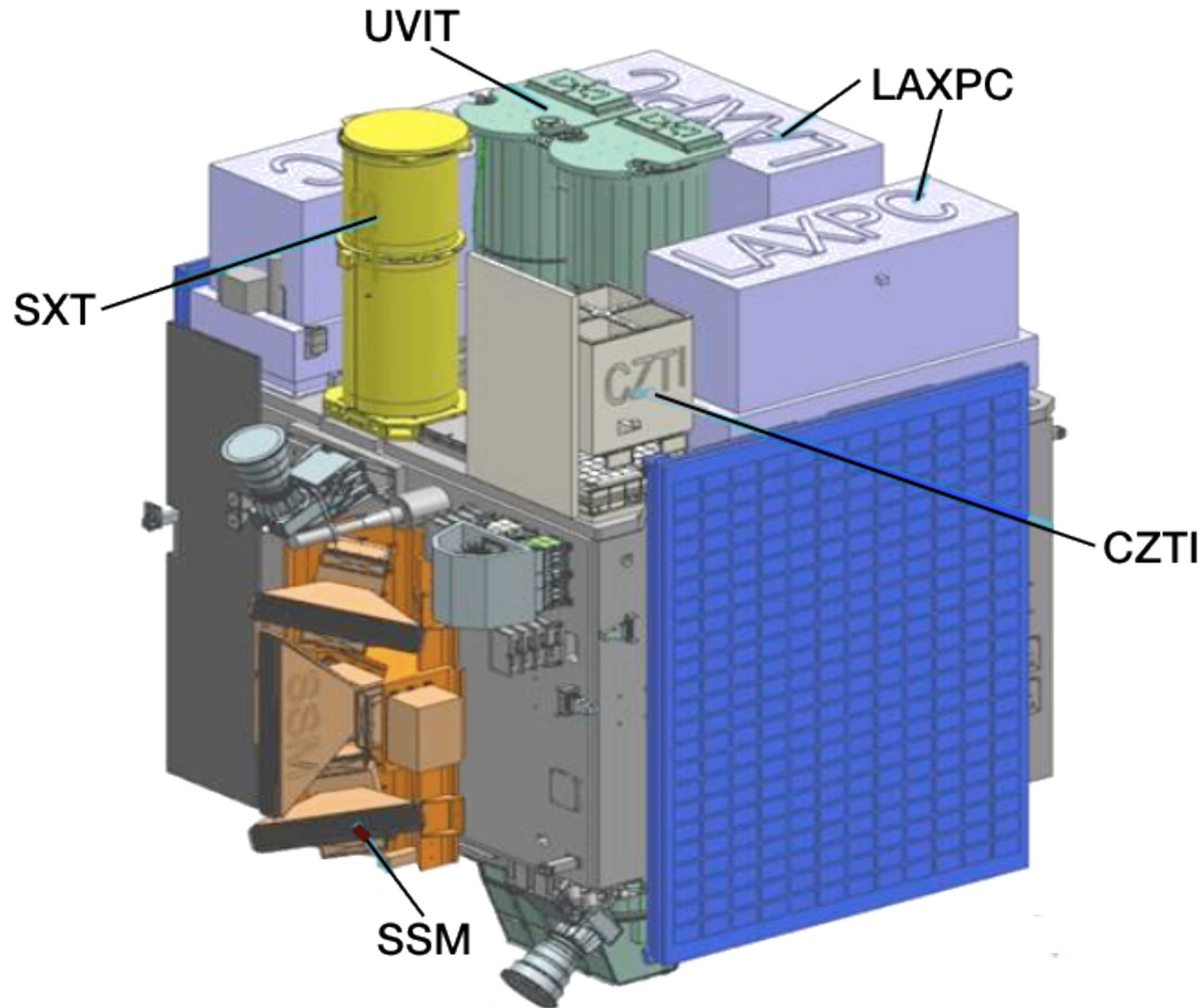
On Behalf of the AstroSat CZTI Team

18th IACHEC Meeting

Seeblick Pelham, Germany

23 April 2026

AstroSat



- UVIT: Ultraviolet Imaging Telescope (NUV, FUV, VIS)
- LAXPC: Large Area Xenon Proportional Counter (3 - 80 keV)
- SXT: Soft X-ray Telescope (0.1 - 8 keV)
- CZTI: Cadmium Zinc Telluride Imager (20 - 200 keV)
- SSM: Scanning Sky Monitor

AstroSat Mission: Current Status

- Mission operational: 10 years completed in 2025 September
- A decade of AstroSat conference in Bengaluru earlier this year
- Limited careful manoeuvres and thus less quick repointing: Resulting from failure of one Gyro - to reduce chances of further failures

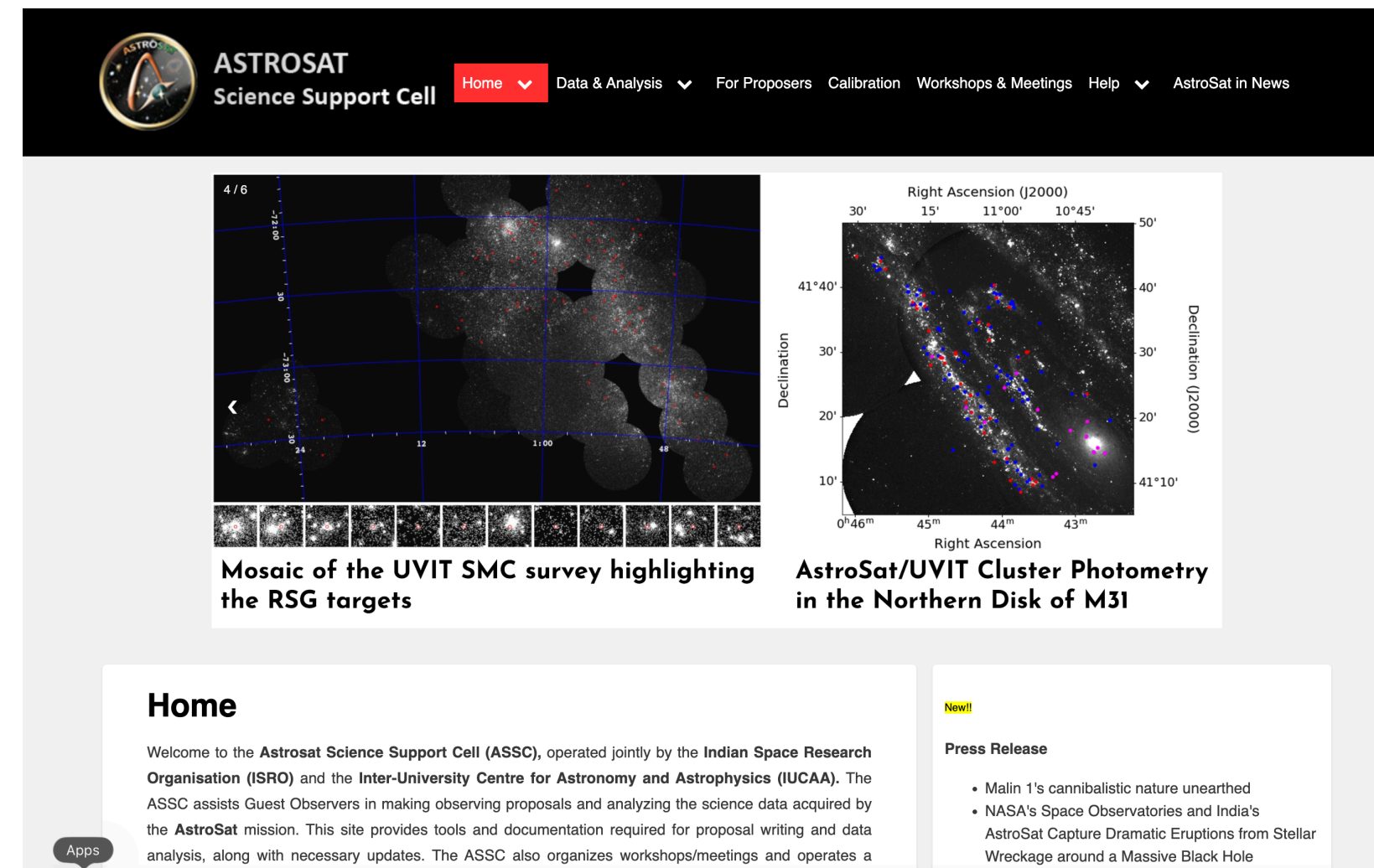
AstroSat Mission: Current Status

- Mission operational: 10 years completed in 2025 September
- A decade of AstroSat conference in Bengaluru earlier this year
- Limited careful manoeuvres and thus less quick repointing: Resulting from failure of one Gyro - to reduce chances of further failures

Instrument Status

- **UVIT:** FUV and VIS channels operational
- **LAXPC:** One unit fully operational, one operated at reduced gain
- **SXT:** Operational
- **CZTI:** Operational, more in this talk!
- **SSM:** One unit operational

AstroSat: Resources



AstroSat Science Support Cell (ASSC)

<http://astrosat-ssc.iucaa.in/>

Data Archive: AstroBrowse and PRADAN



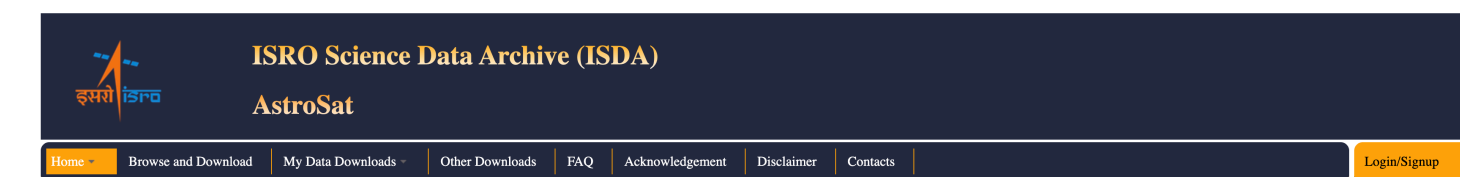
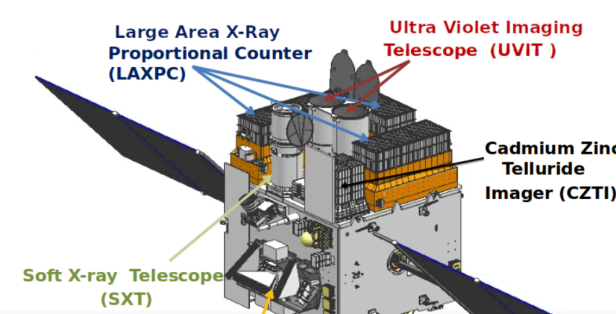
Welcome to ISRO Science Data Archive for AstroSat Mission

The science data from observations made by the instruments on board the spacecraft are available for download after the [proprietary period](#) from this portal.

ASTROSAT is India's first dedicated multi wavelength space observatory. This scientific satellite mission endeavours for a more detailed understanding of our universe. AstroSat observes universe in the optical, Ultraviolet, low and high energy X-ray regions of the electromagnetic spectrum. Multi-wavelength observations of ASTROSAT are further extended with co-ordinated observations using other spacecraft and ground based observations.

AstroSat with a lift-off mass of about 1513 kg was launched by India's Polar Satellite Launch Vehicle (PSLV) on 28th September 2015 into a 650 km circular orbit with an inclination of 6 deg. The spacecraft control centre at Mission Operations Complex (MOX) of ISRO Telemetry, Tracking and Command Network (ISTRAC) at Bangalore carries out the spacecraft health monitoring and control operations. The science data from the spacecraft is downloaded at a dedicated ground station established at Bylalu, Bengaluru and the data is made available to the users through the co-located Indian Space Science Data Centre (ISSDC). Science data processing, archival and dissemination are carried from ISSDC, the nodal point for the interface with the global scientific and user community.

AstroSat is a proposal -driven, multi -wavelength observatory operated by Indian Space Research Organization (ISRO). ISRO releases periodic calls for proposal submission. Users can submit proposals for operating the science instruments on board using the web based utility AstroSat Proposal Processing System [APPS](#) hosted at ISSDC. The science data along with the related software for processing can be downloaded from this portal.



ISRO Science Data Archive (ISDA) AstroSat

[Access Data](#)

Please register- APPS and AstroBrowse credentials are not valid here; existing PRADAN credentials from any other hosted datasets can be re-used.

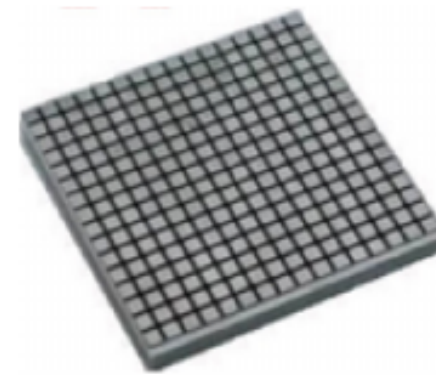
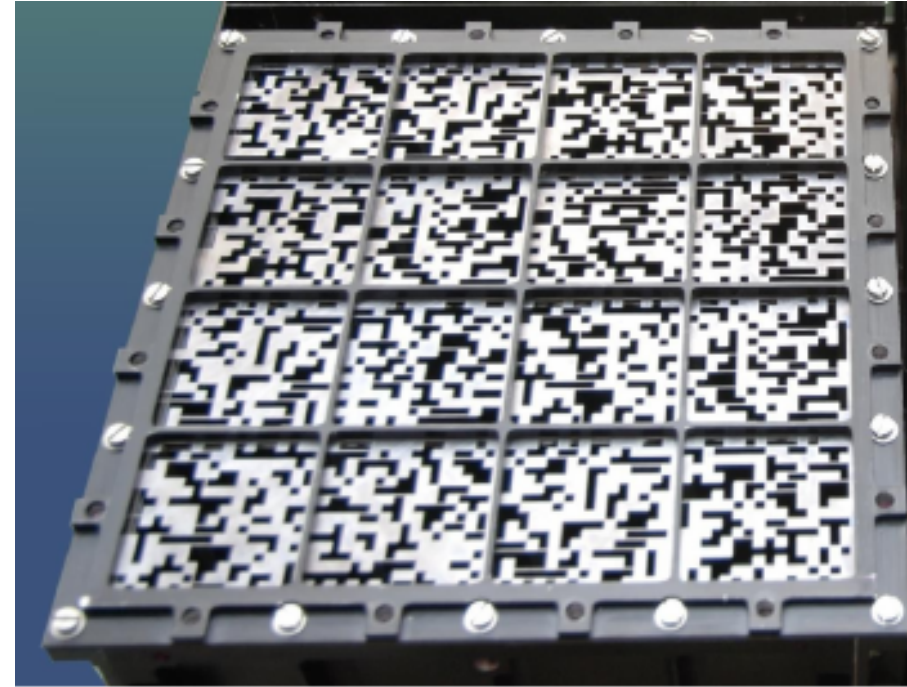
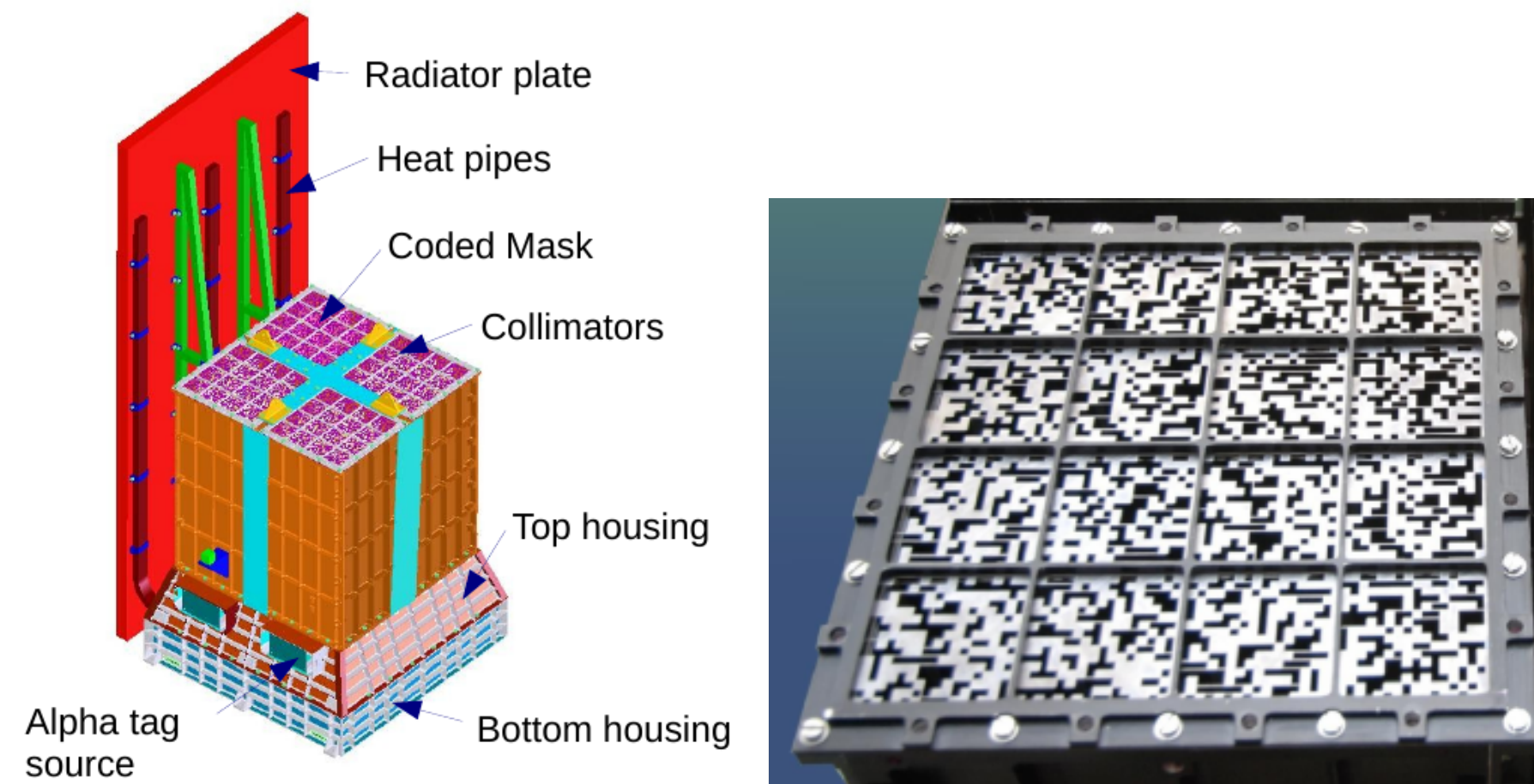
Refer [AstroBrowse](#), [AstroSat Support Cell](#) for more details.

Copyright © 2020-2025 ISTRAC. All Rights Reserved.

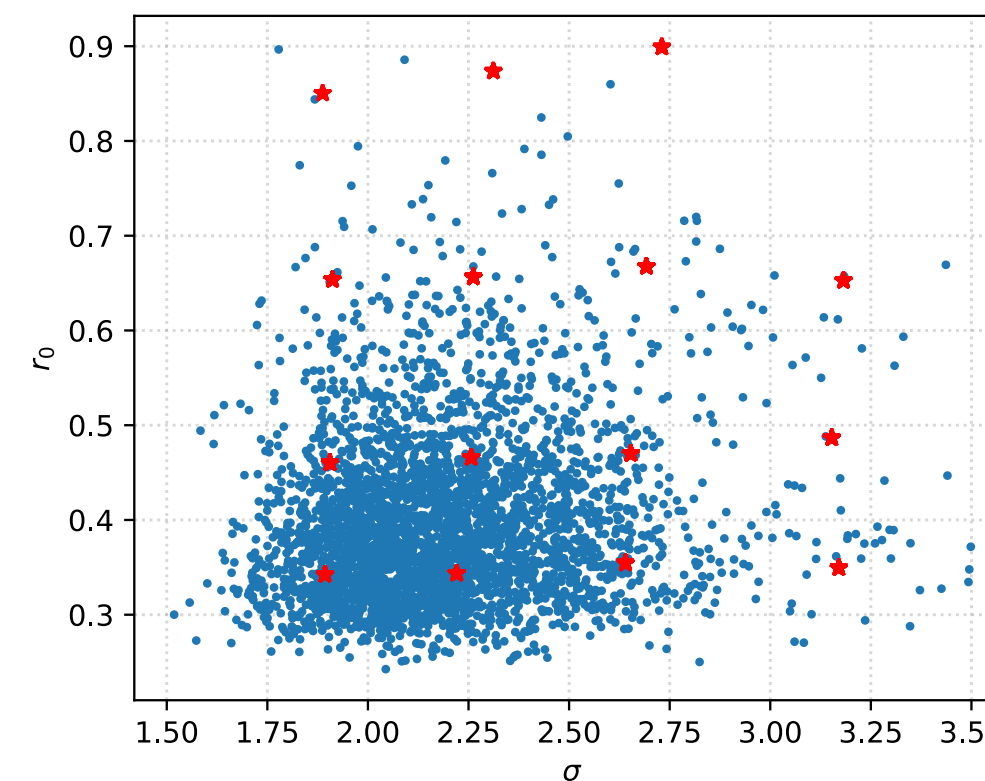
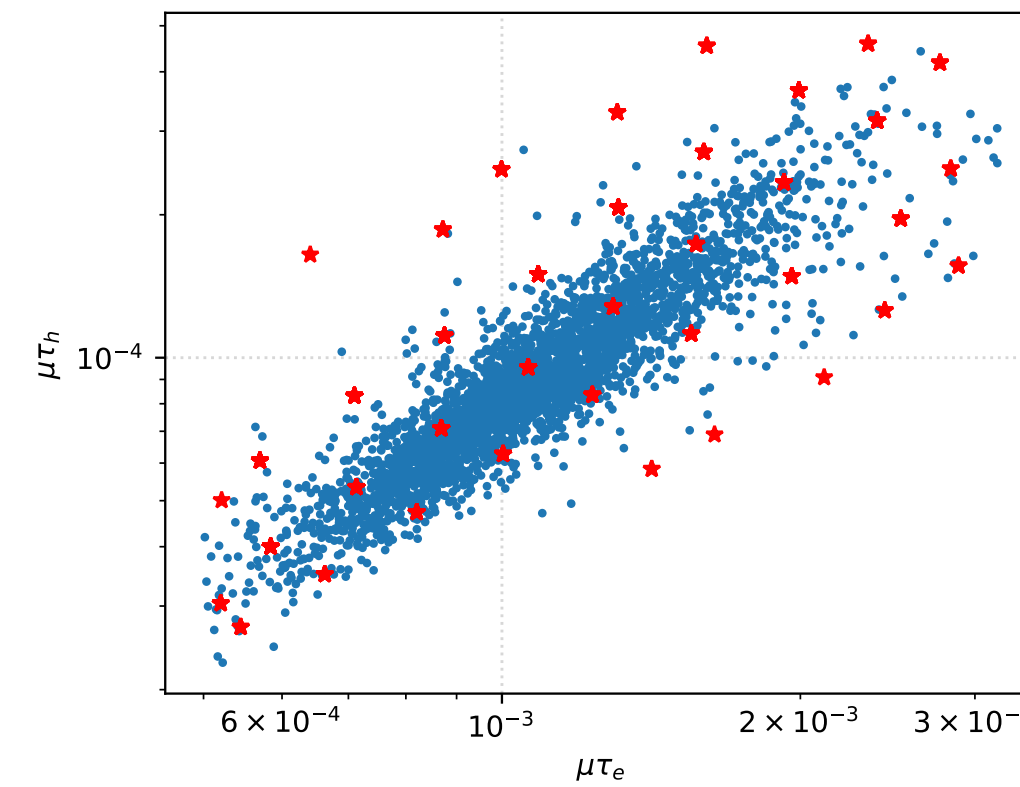
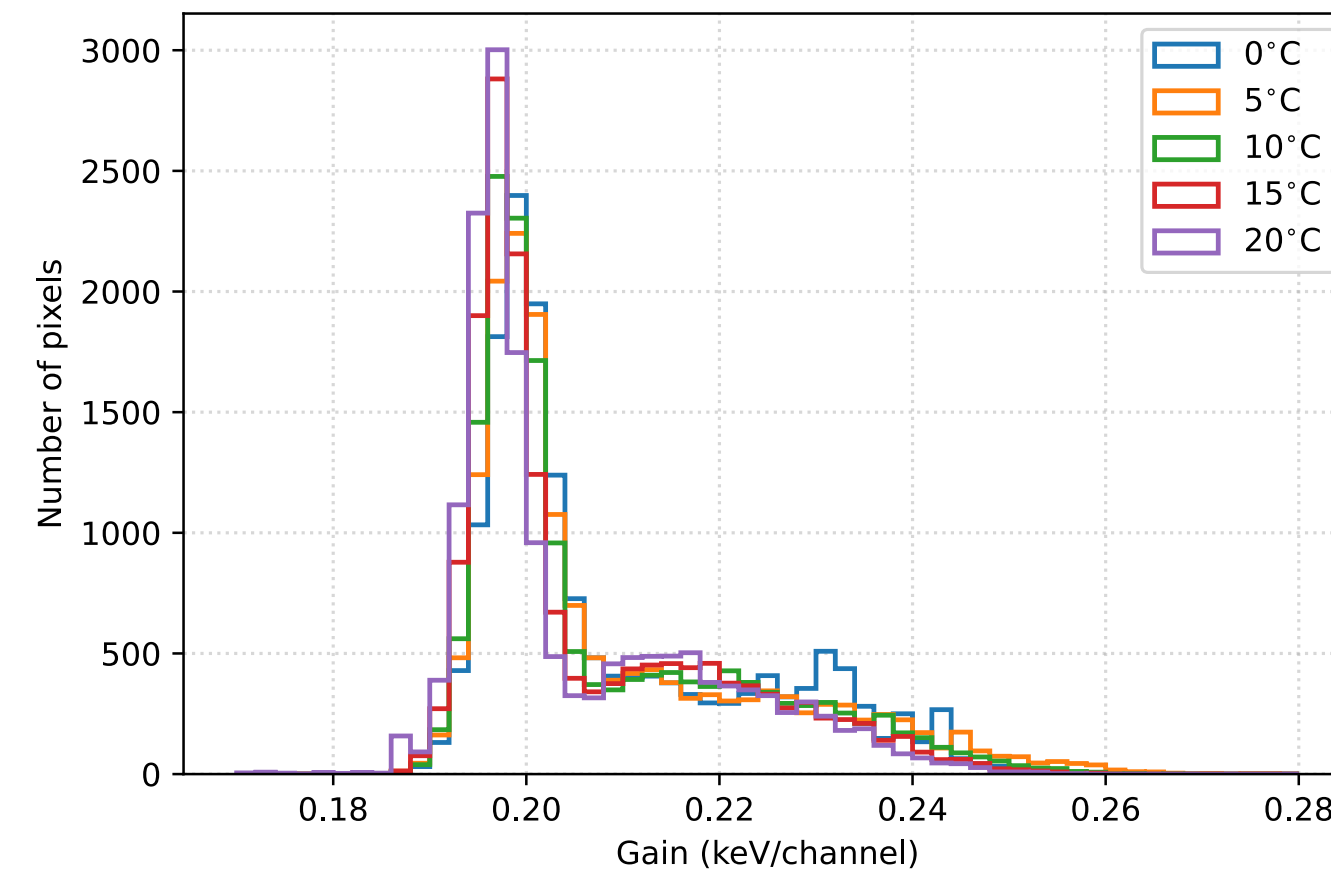
https://astrobrowse.issdc.gov.in/astro_archive/archive/Home.jsp

<https://pradan.issdc.gov.in/as1/>

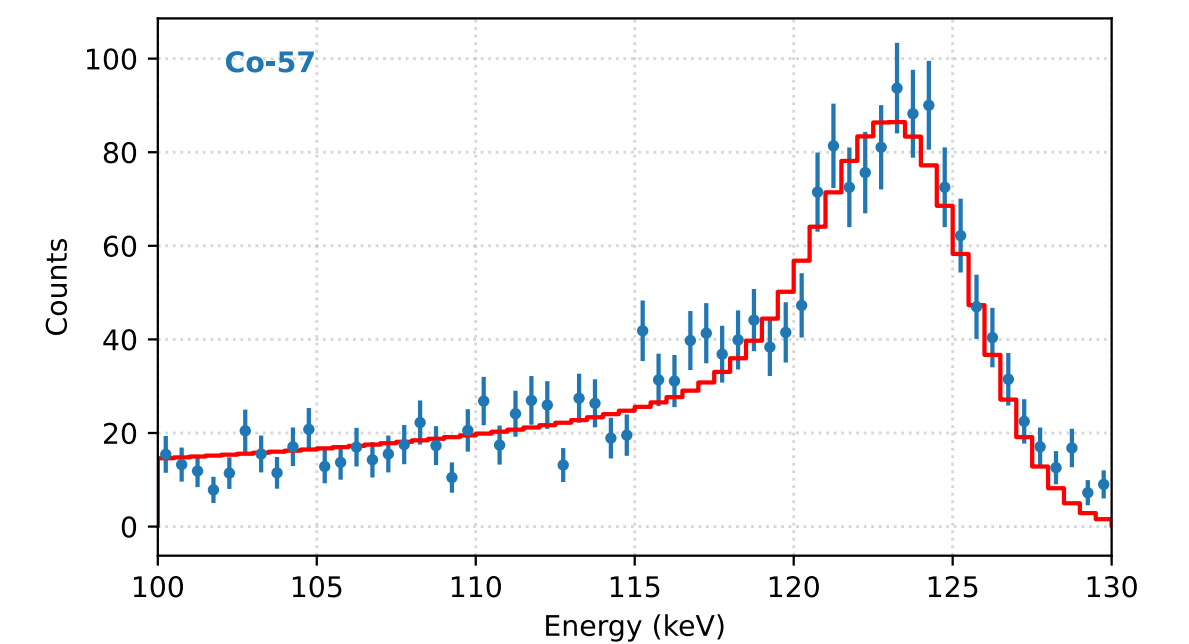
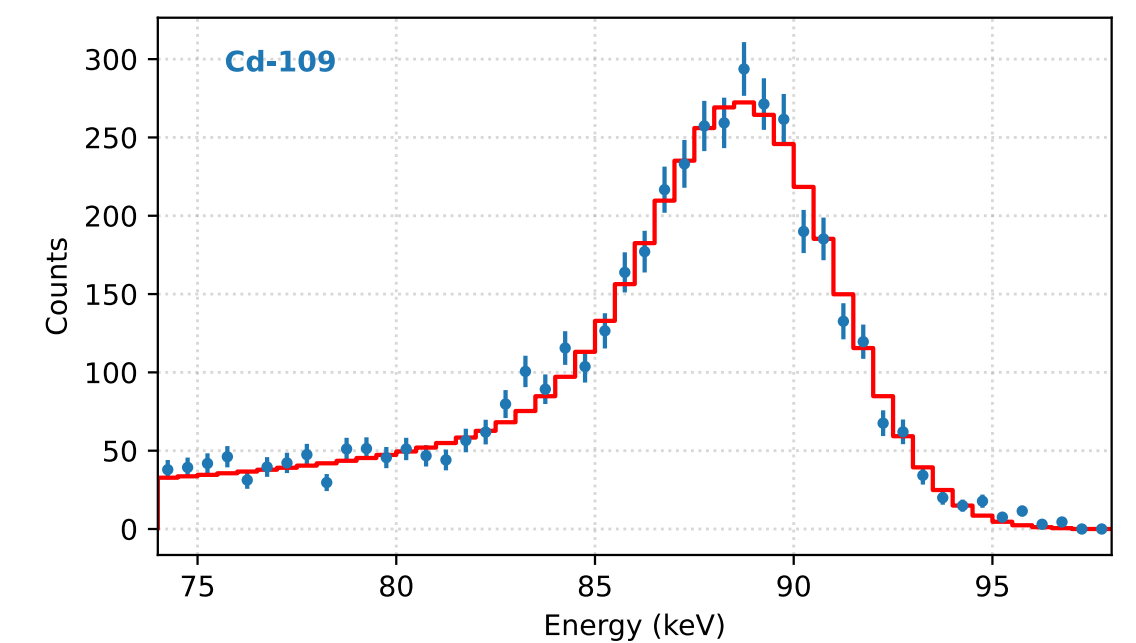
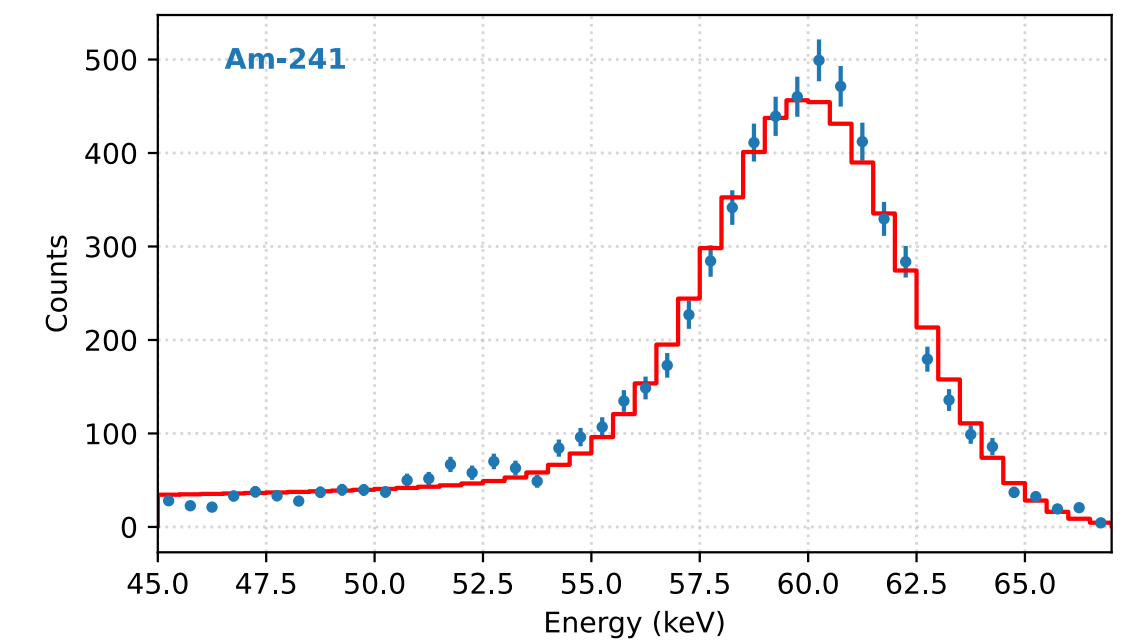
AstroSat CZT-Imager: Instrument and Ground Calibration



- Indirect Imaging and Spectroscopy in 20-200 keV
- Array of pixelated Cadmium Zinc Telluride detectors
- 16384 individual X-ray detectors



Gain and Spectral redistribution model



In-flight Surprises!

- Detector pixel gain: Low gain pixels - confirmed with first ~6-8 months of observations
- Background - Variability with time and detector position - while expected, understanding and modelling require long observations
- Alignment of coded mask and detectors: Images with slight offsets between quadrants - spectral extraction very sensitive to any offsets
- Crab spectral parameters - limited by background subtraction systematics and some effective area aspects

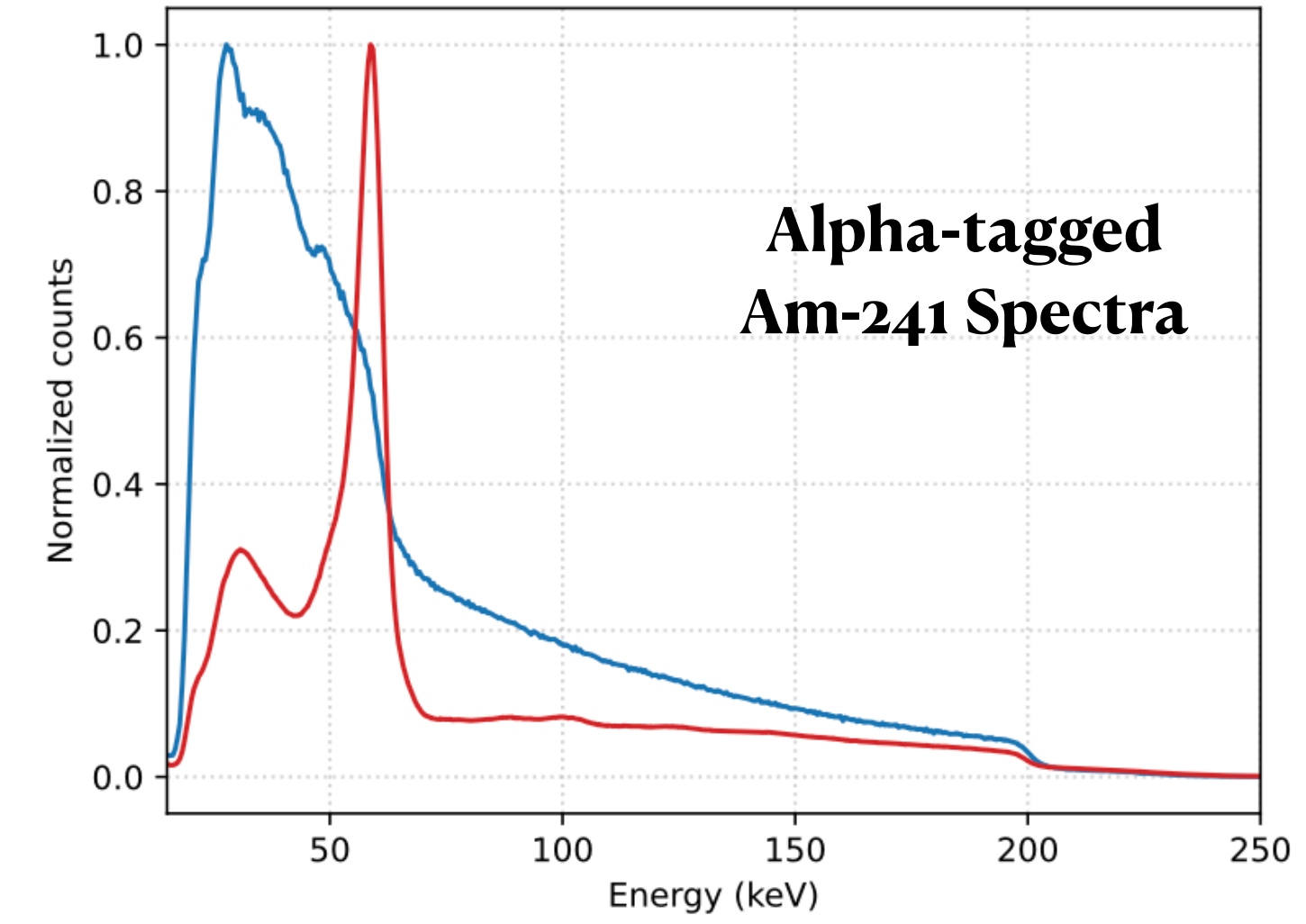
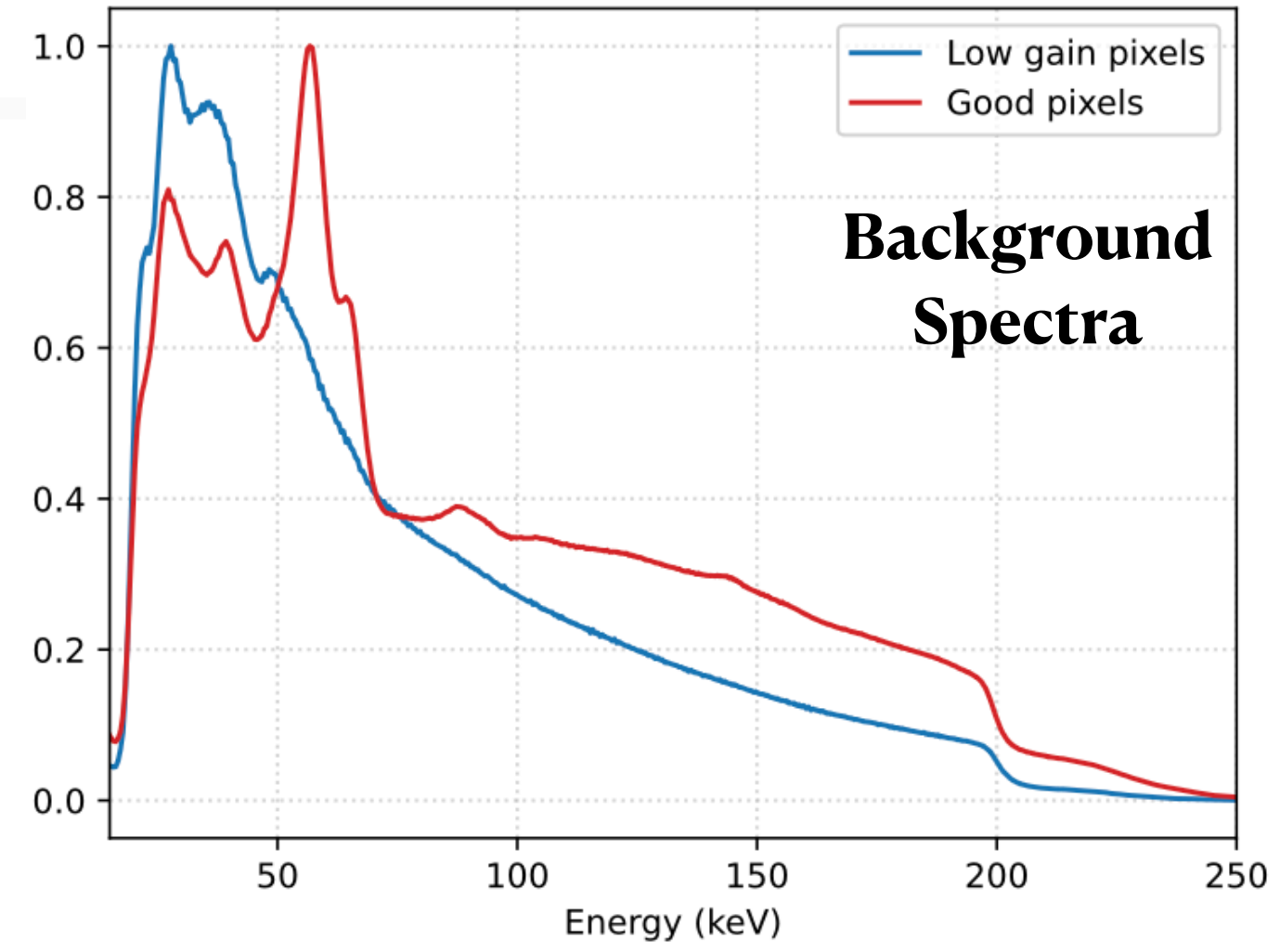
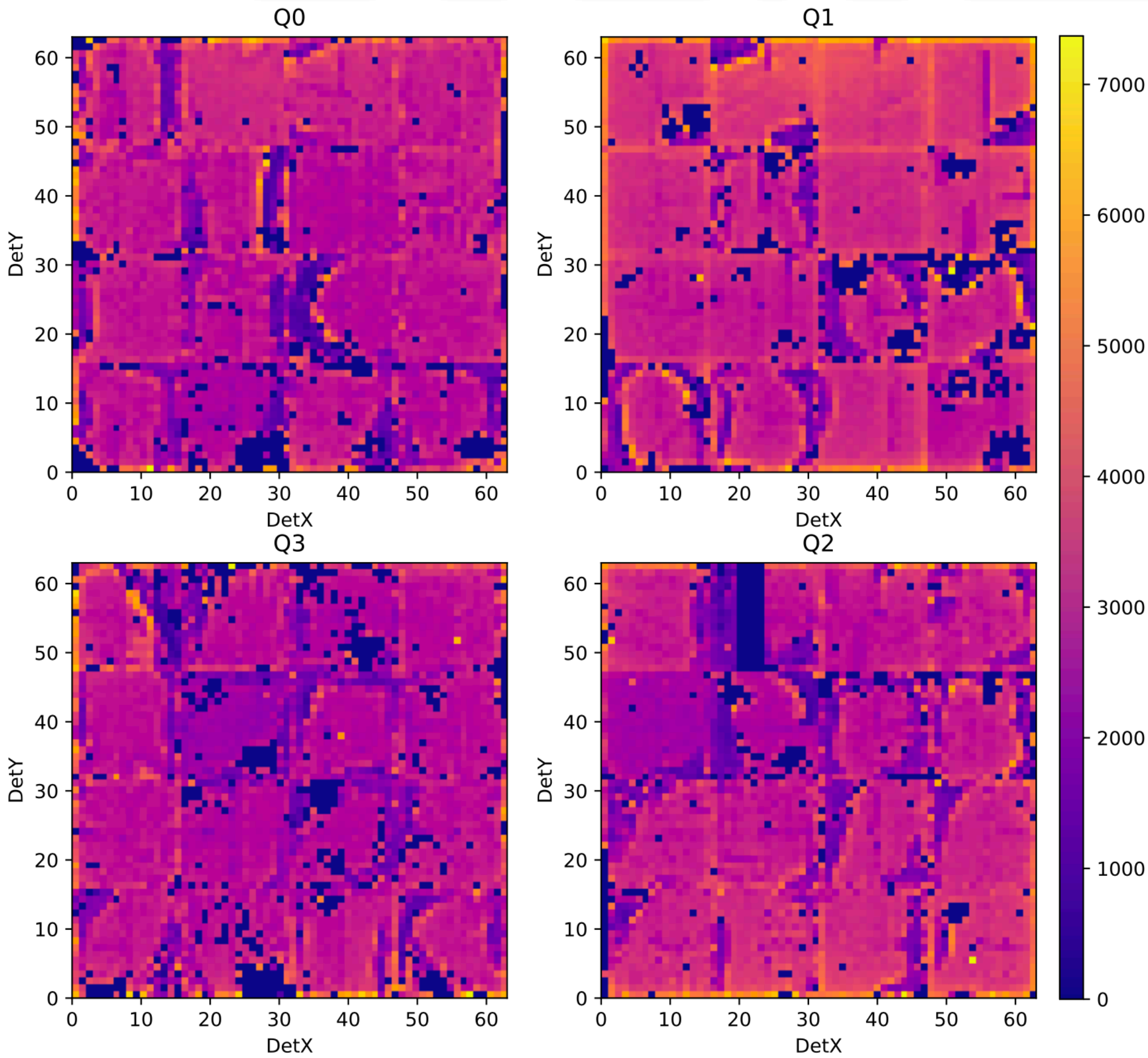
In-flight Surprises!

- Detector pixel gain: Low gain pixels - confirmed with first ~6-8 months of observations
- Background - Variability with time and detector position - while expected, understanding and modelling require long observations
- Alignment of coded mask and detectors: Images with slight offsets between quadrants - spectral extraction very sensitive to any offsets
- Crab spectral parameters - limited by background subtraction systematics and some effective area aspects

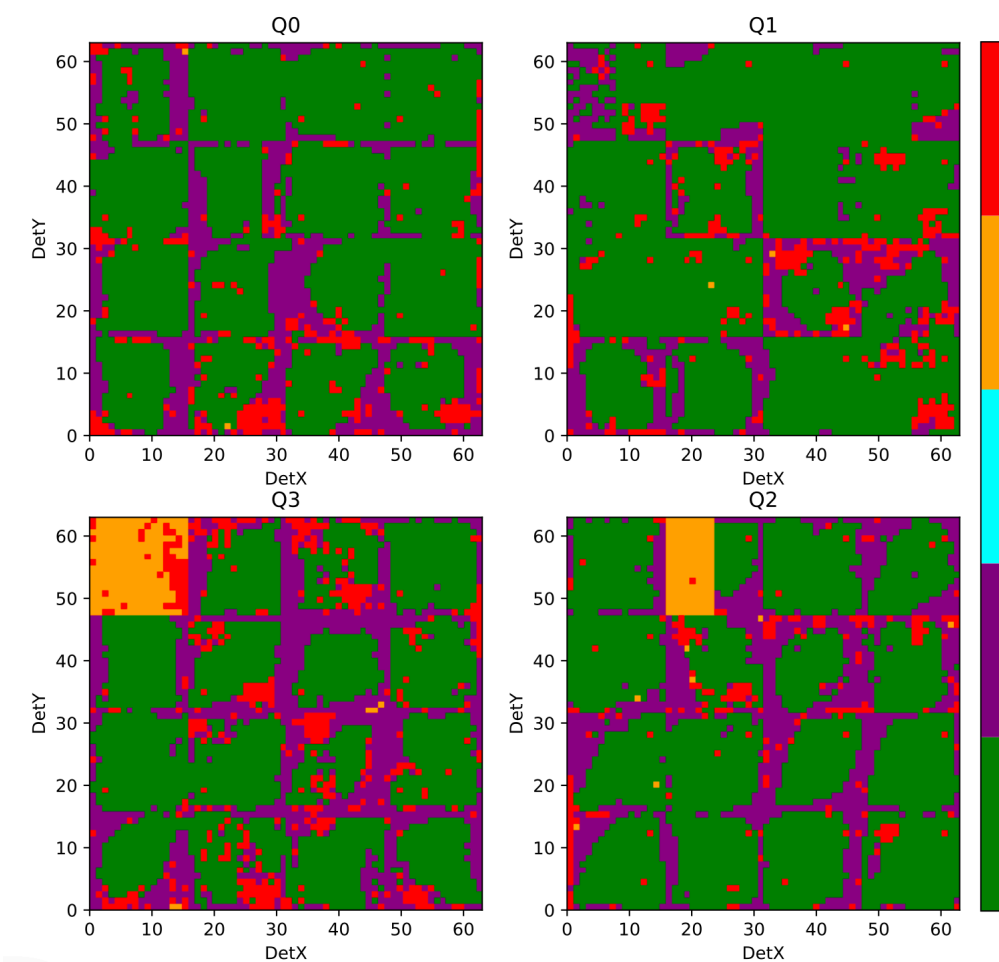
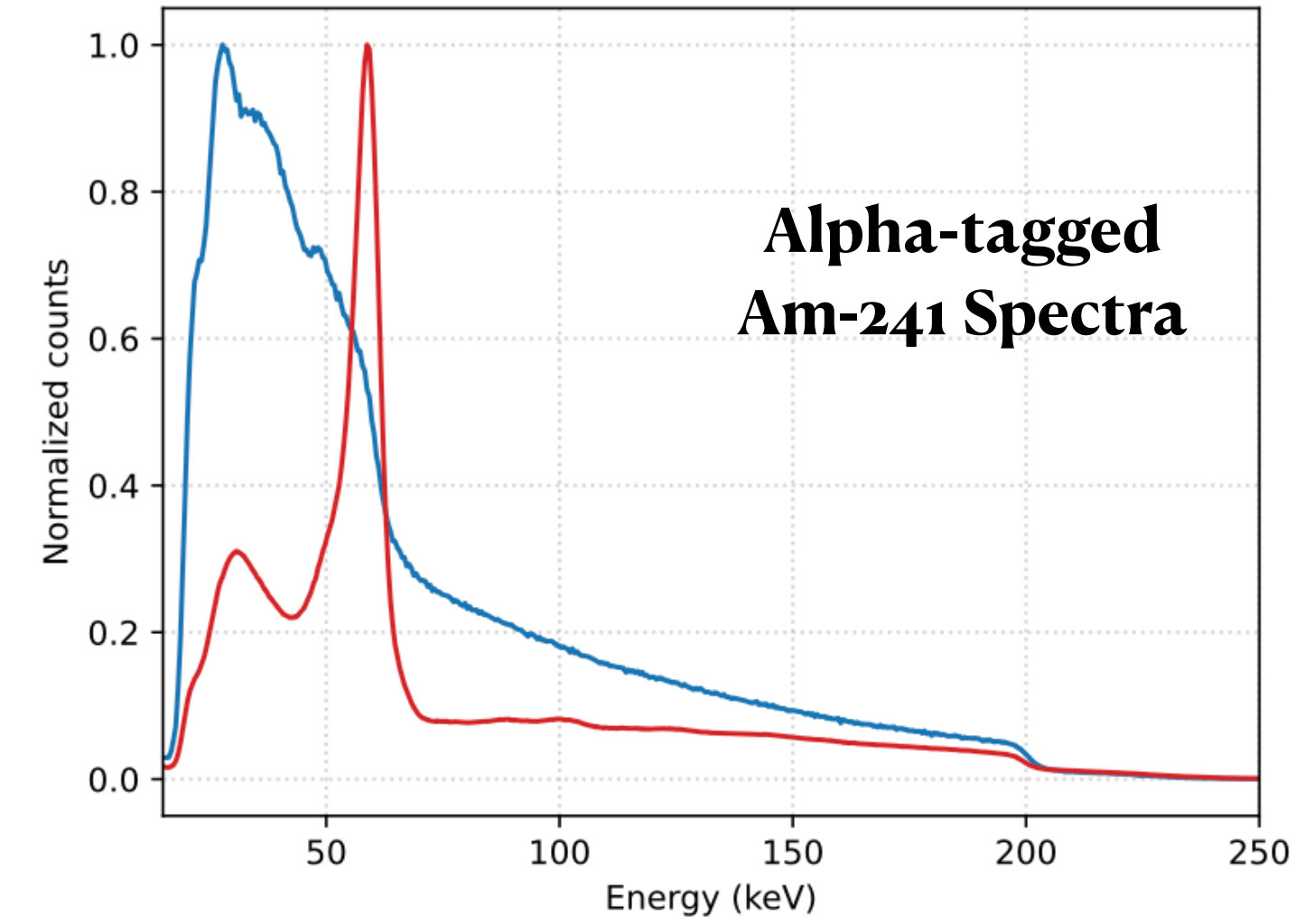
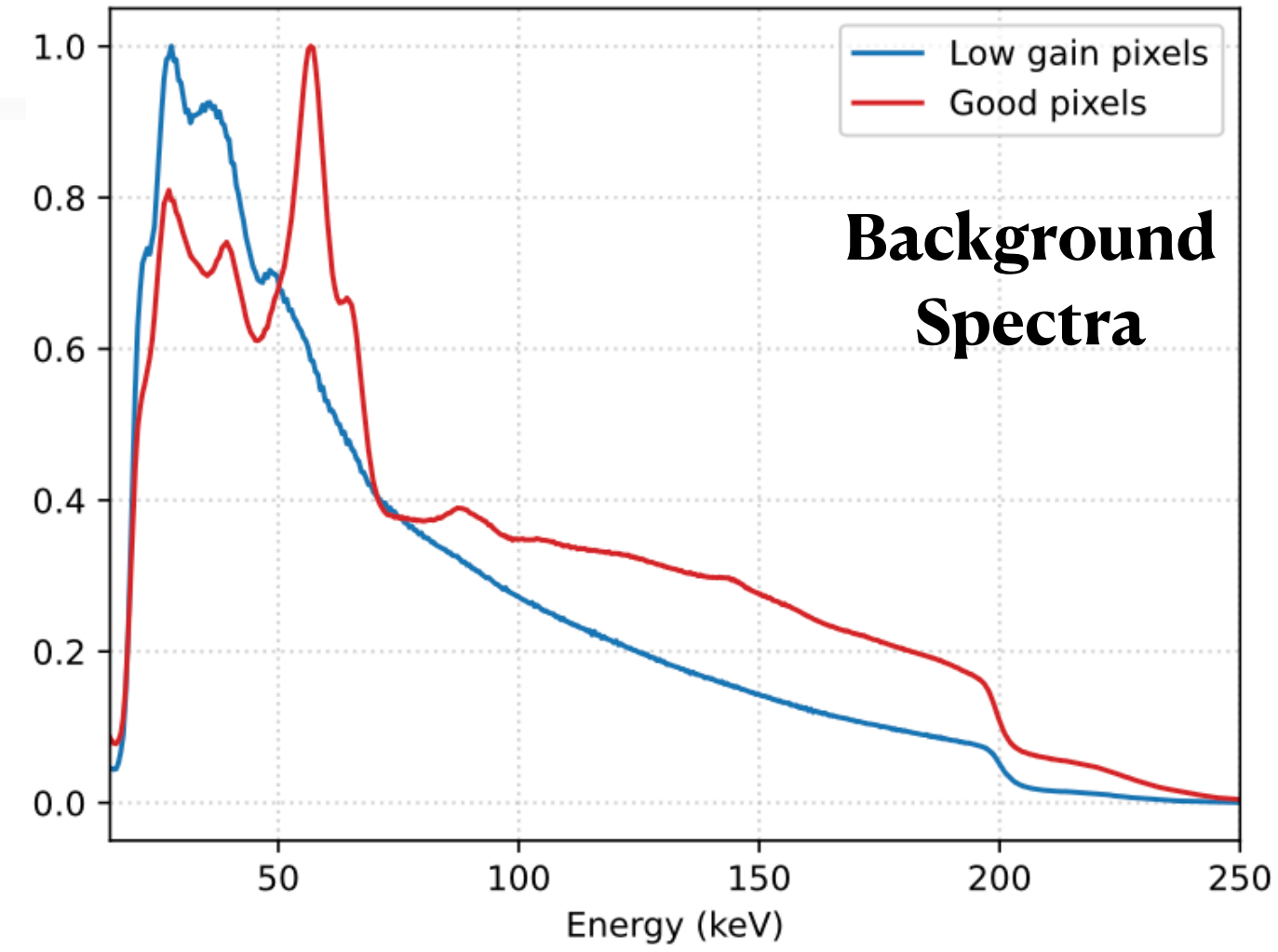
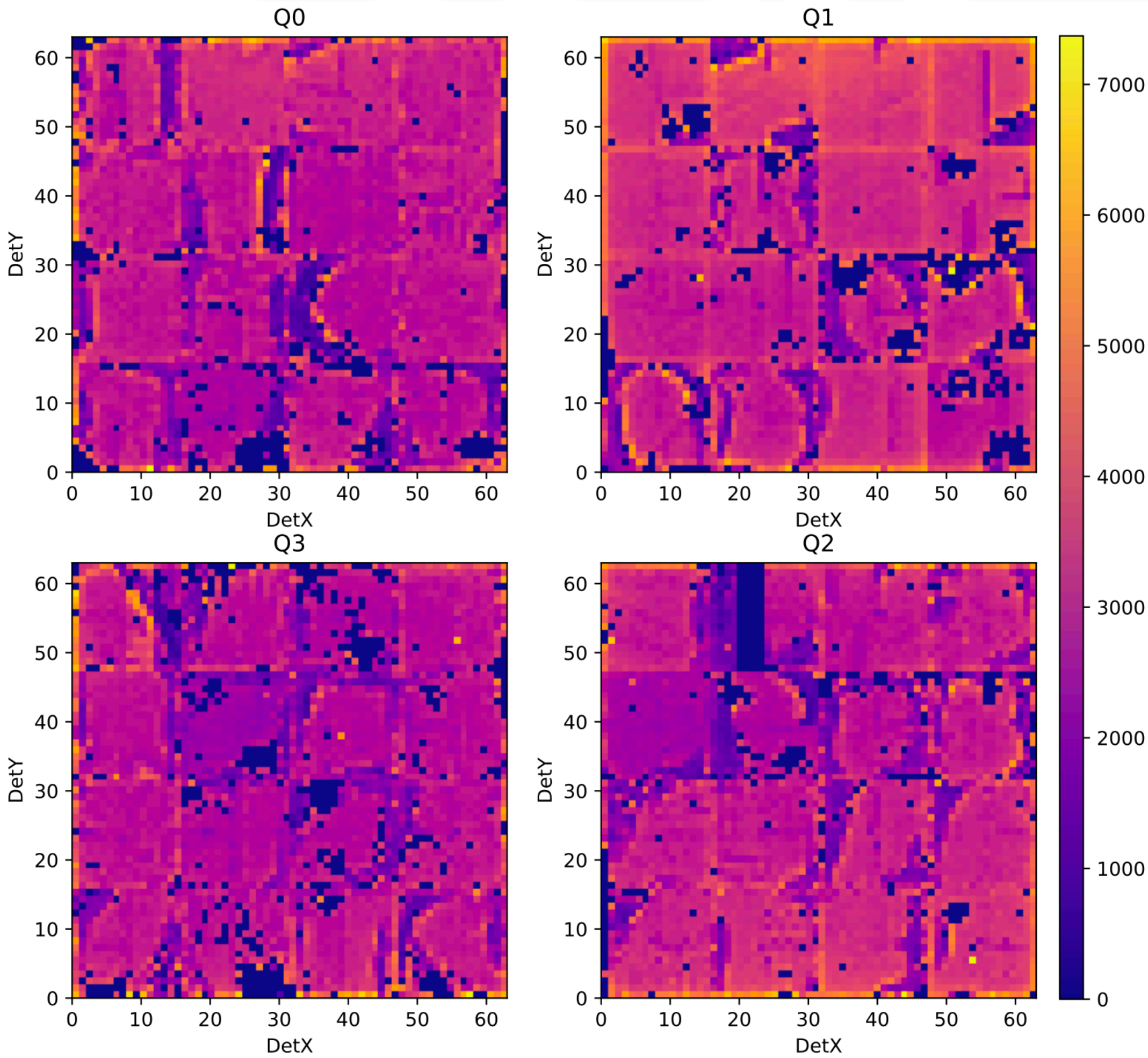
Aspects for in-flight improvements

Systematic efforts with the first 80 months of observations: Oct 2015 - May 2022

Low Gain Pixels aka “Banana Pixels” & Pixel Quality

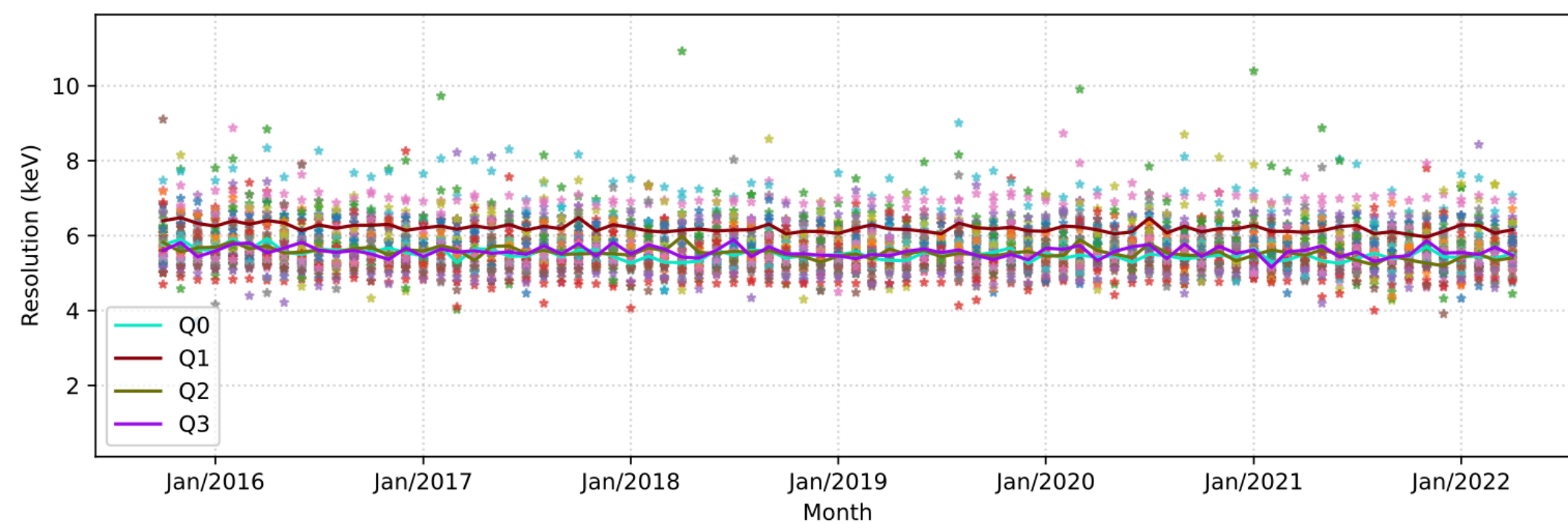
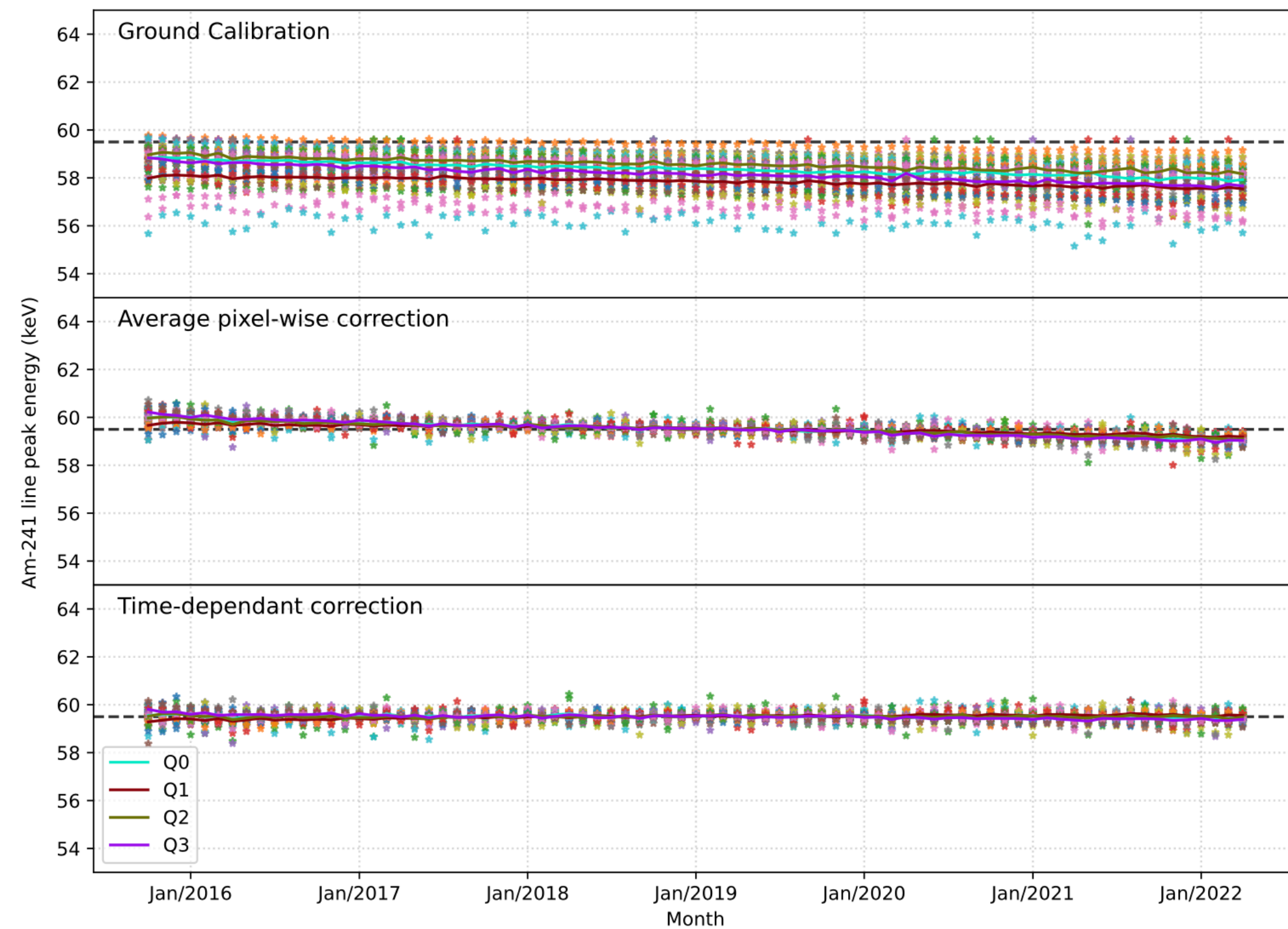


Low Gain Pixels aka “Banana Pixels” & Pixel Quality



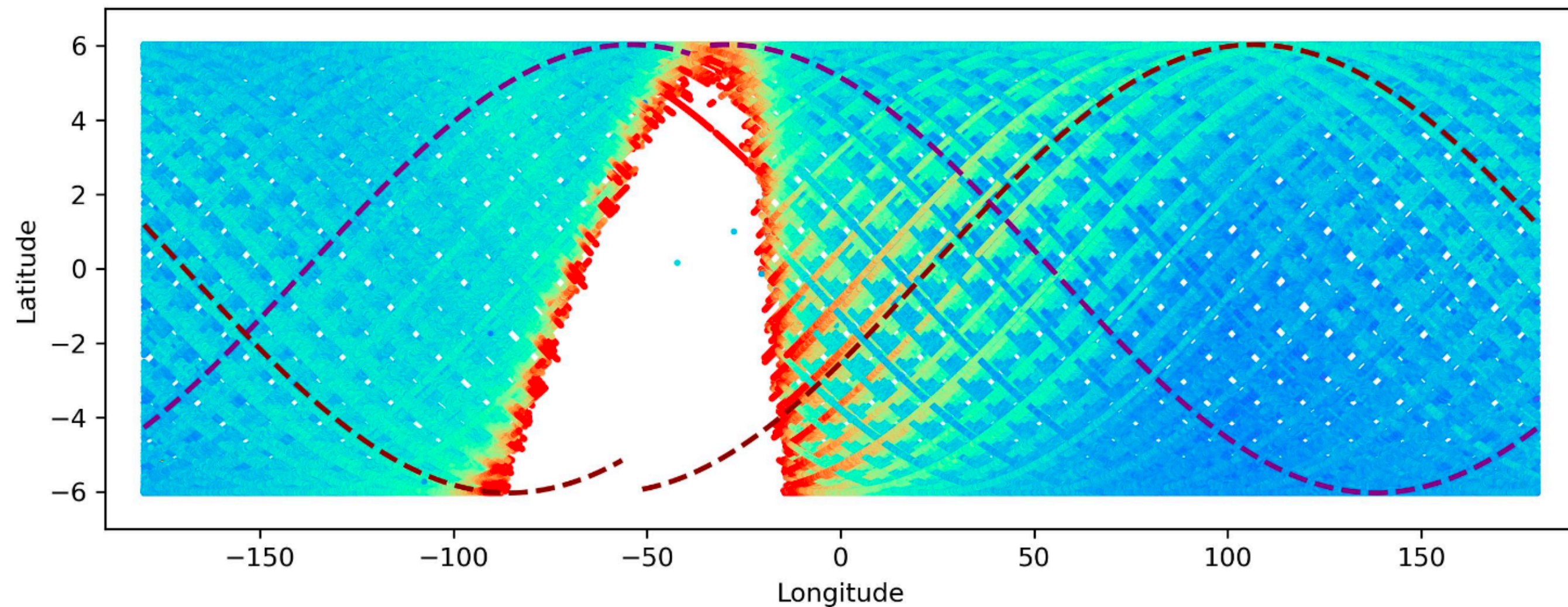
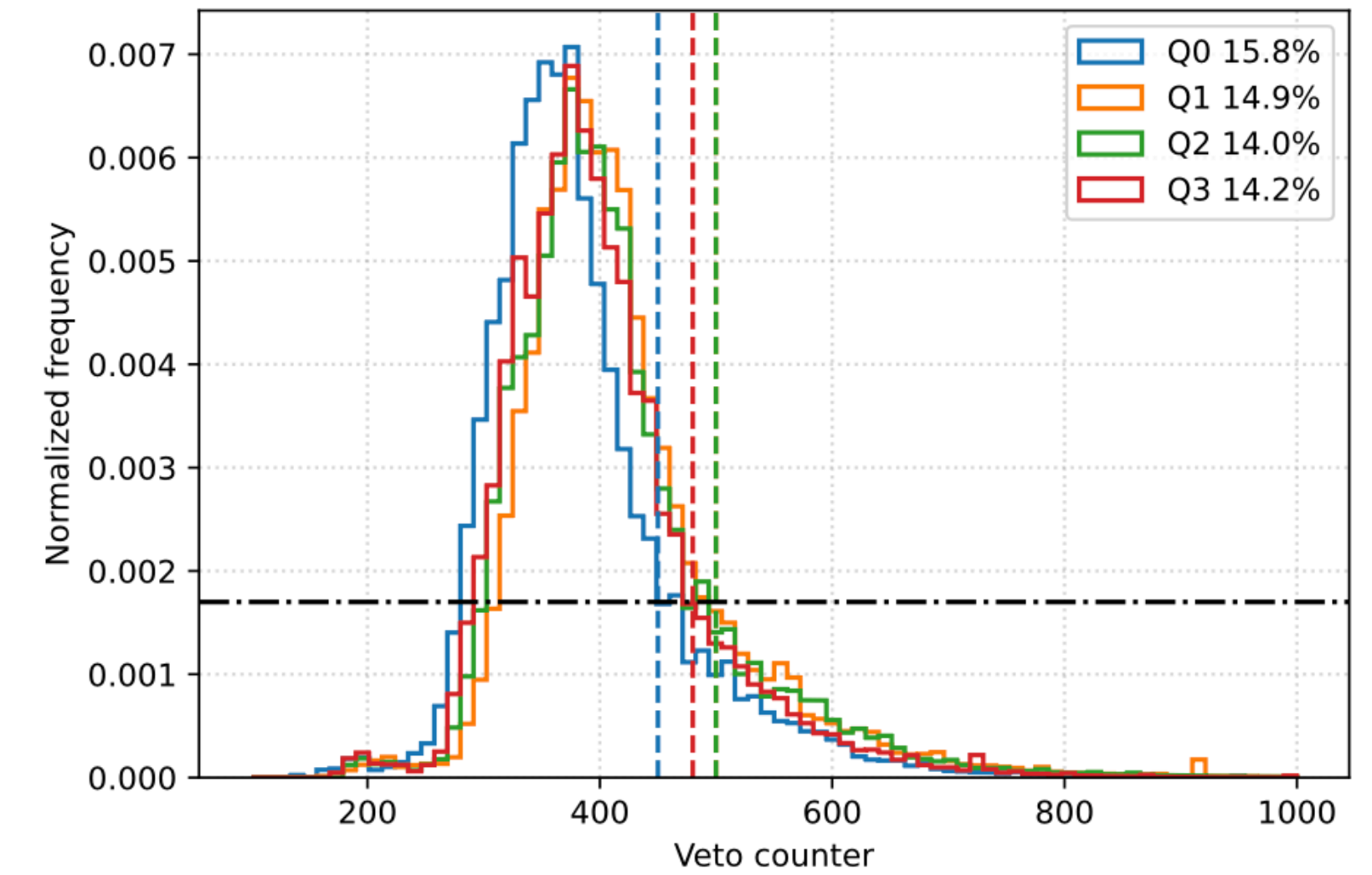
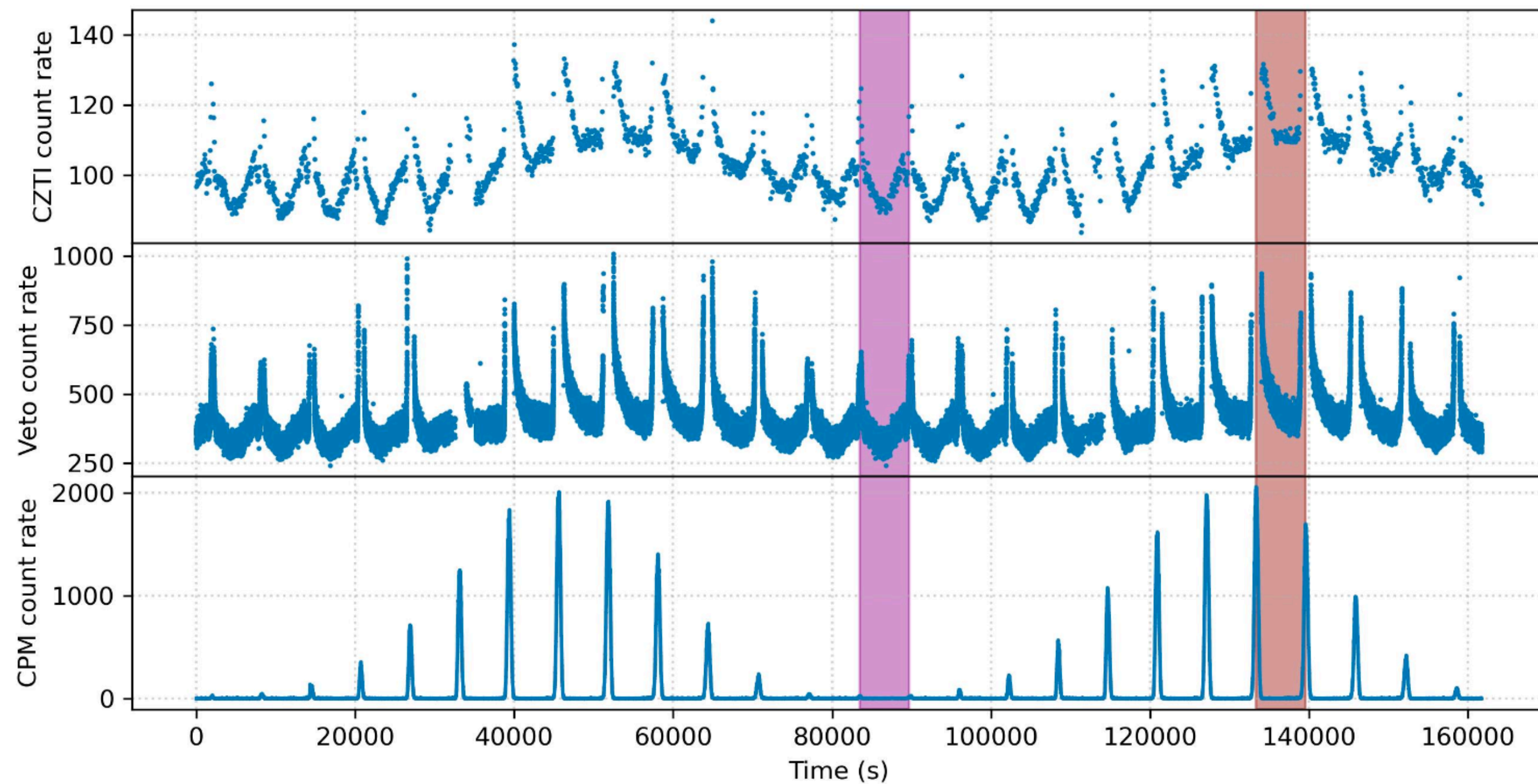
Quadrant	Good	Low gain	Noisy	Disabled
A	2981	816	2	297
B	3103	650	3	340
C	2781	970	134	211
D	2375	1075	211	435
Total	11240	3511	350	1283
Total (%)	68.6	21.43	2.14	7.83

Detector Gain over the years: With Corrections



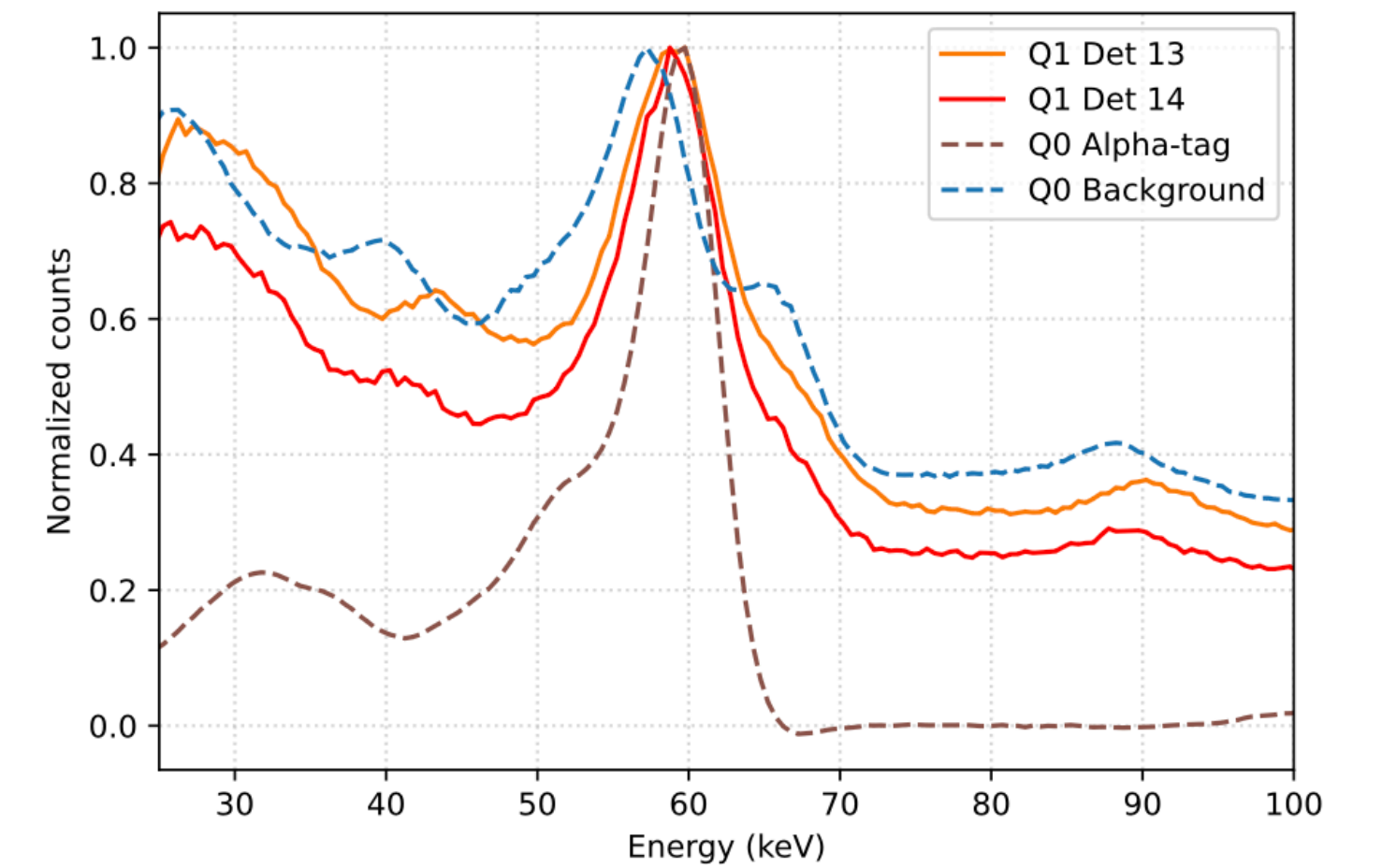
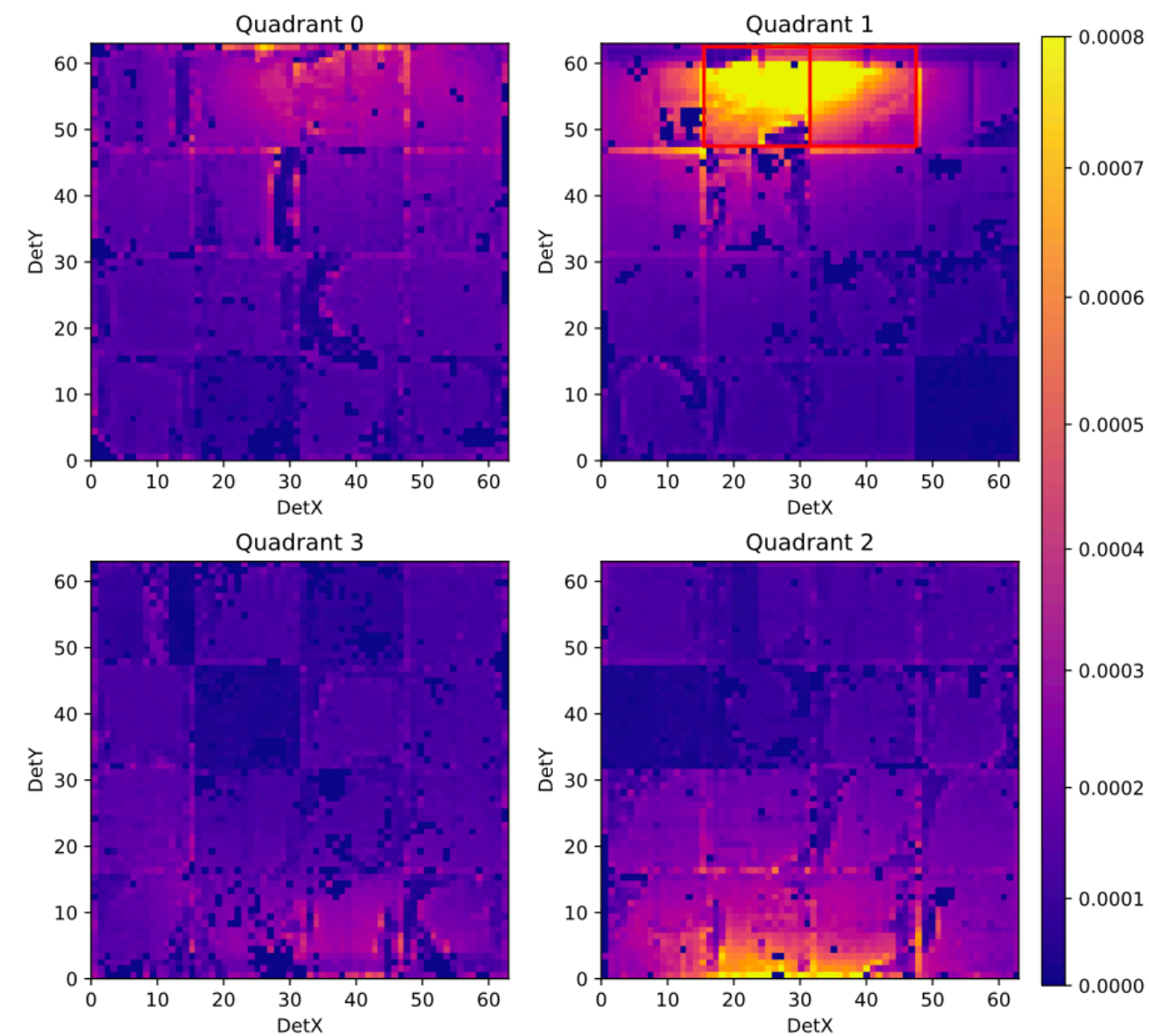
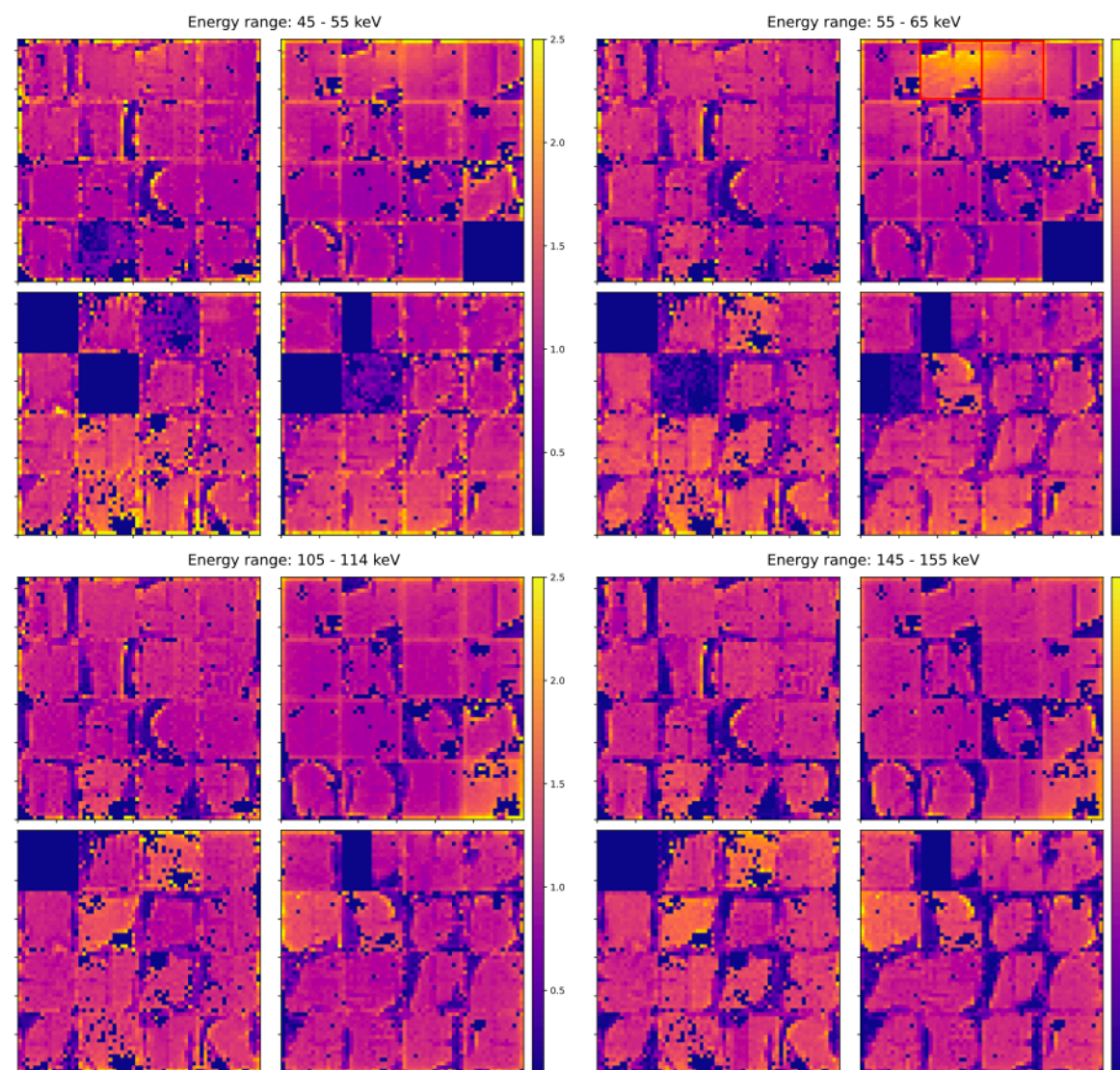
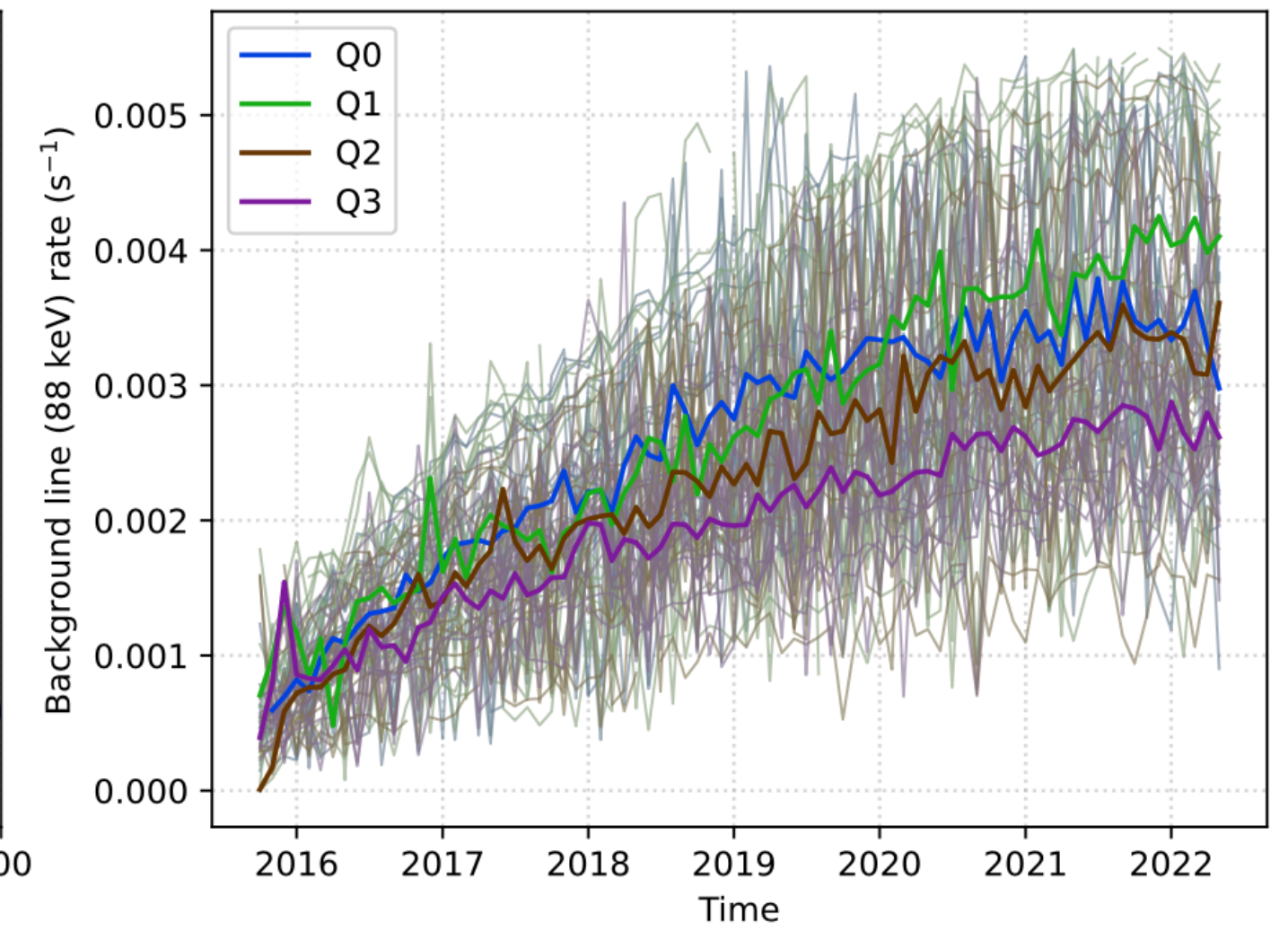
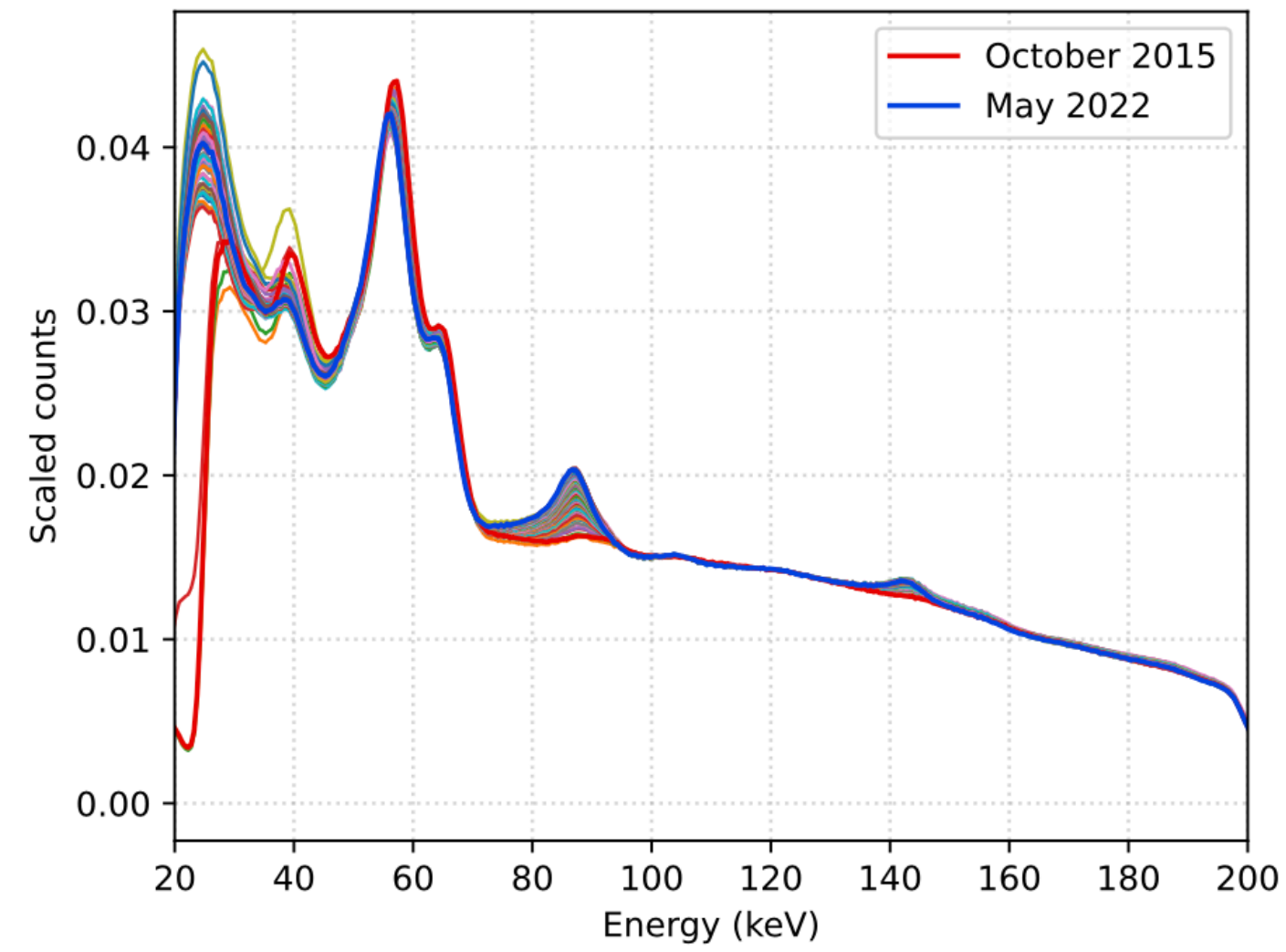
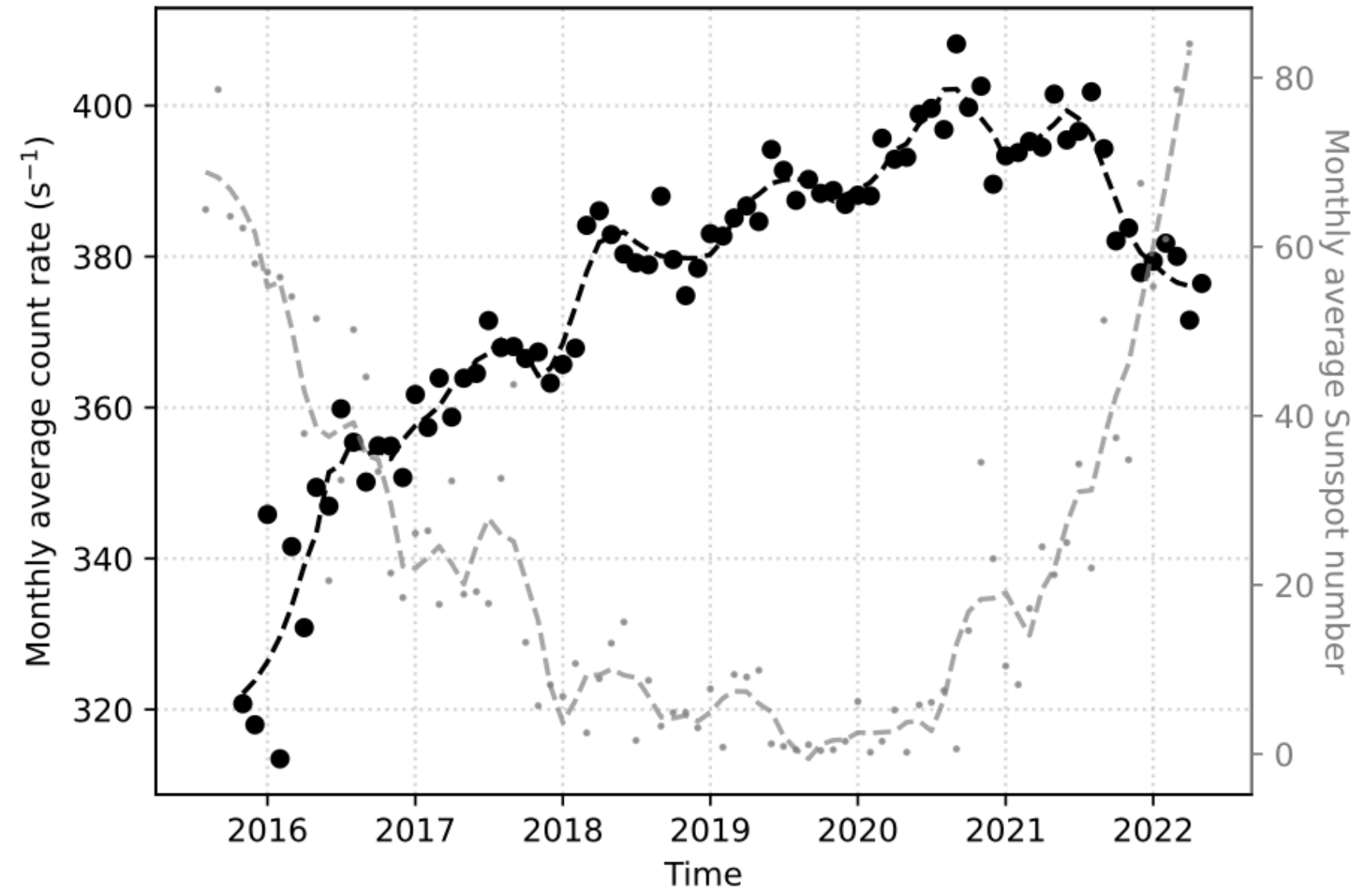
- Spectroscopically good pixels: Gain similar to ground - but not exactly
- Pixel-wise gain difference from ground calibration and a slow temporal evolution
- 80 months of data (Oct 2015 - May 2022) used to determine the pixel-wise correction and time-dependant correction
- Corrected energy scale - correct within ± 0.5 keV
- Resolution - no systematic variation with time - spectral redistribution kept same as ground calibration

Background: Short Term Variability and Data Selection

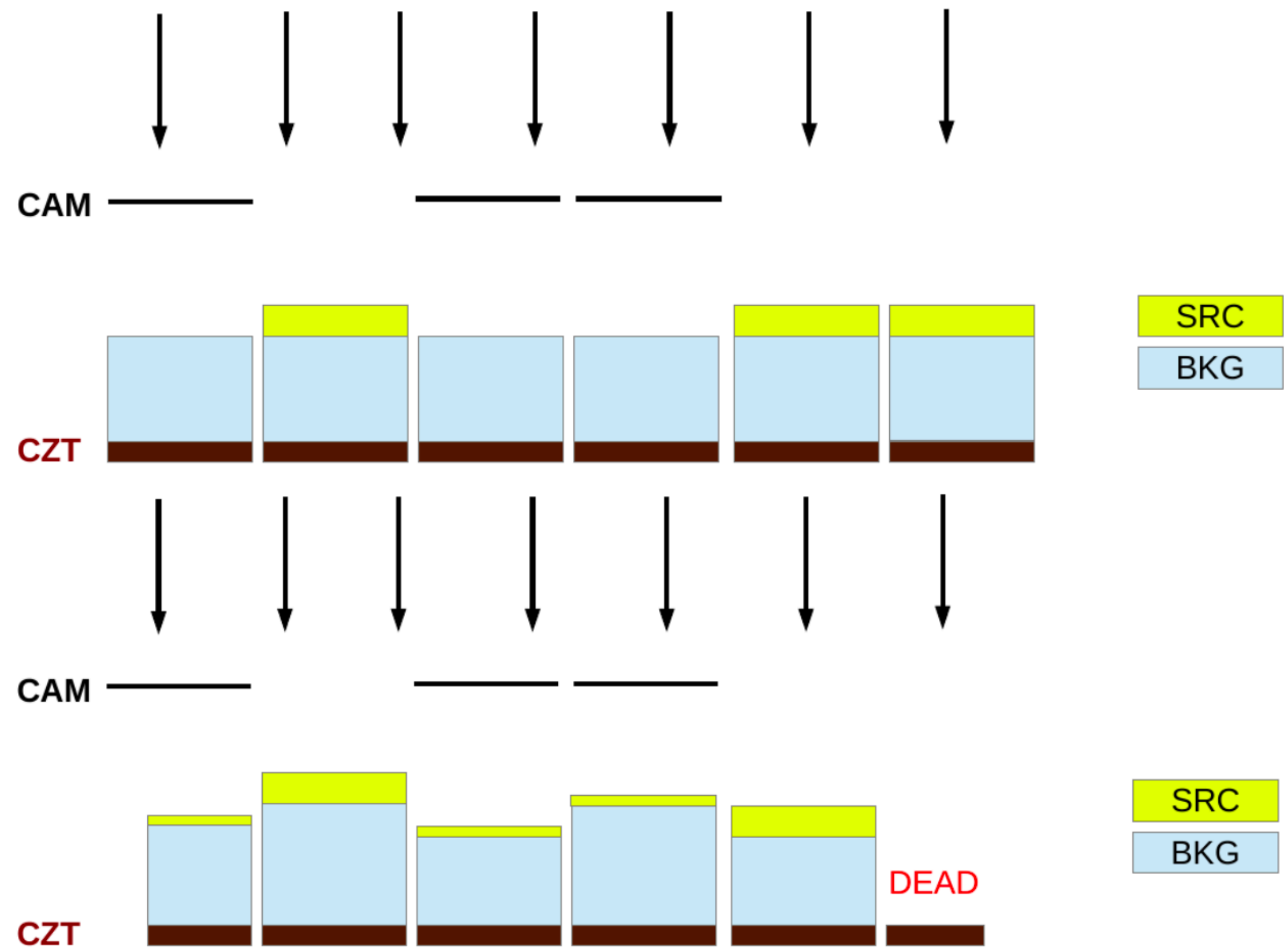


- Near SAA & 'SAA tentacle' background - different from the rest
- Veto counters - good proxy for increased background in CZT detectors
- Cutoff based on Veto: 15% exposure lost - much less variability in background

Background: Long Term, Spectral, and Spatial Variability



Spectral Extraction by Mask-weighting: Algorithm



Initial mask-weight

$$w_i' = 2 f_i - 1$$

Mask open Fraction

Re-normalization

$$D(I) = \frac{\sum_i w_i' B_i(I)}{\sum_i B_i(I)}$$

Background Non-uniformity Model

Final mask-weight

$$w_i(I) = w_i' - D$$

Background subtracted counts

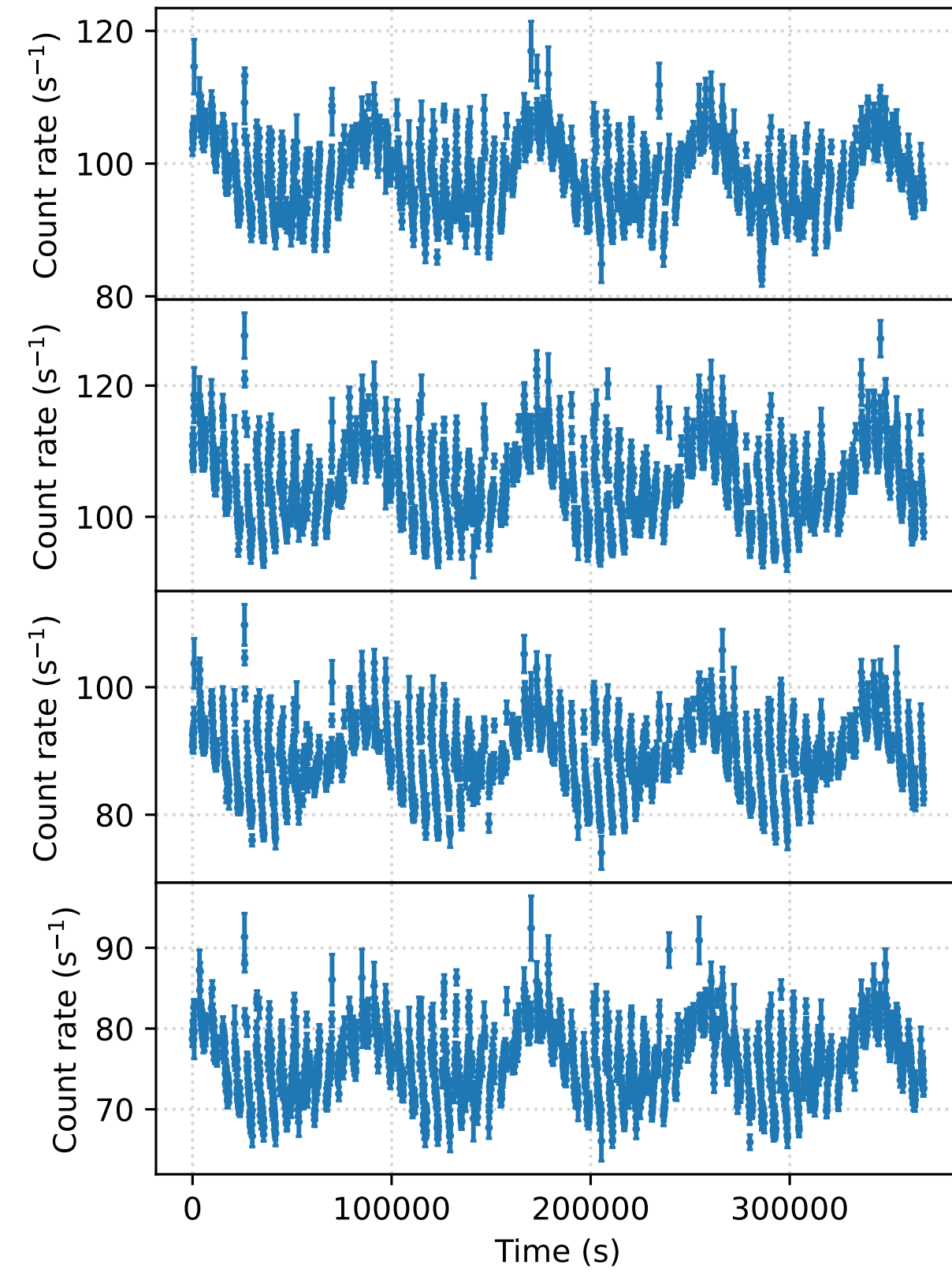
$$S(I) = \sum_i w_i(I) * C_i(I)$$

Observed Raw counts

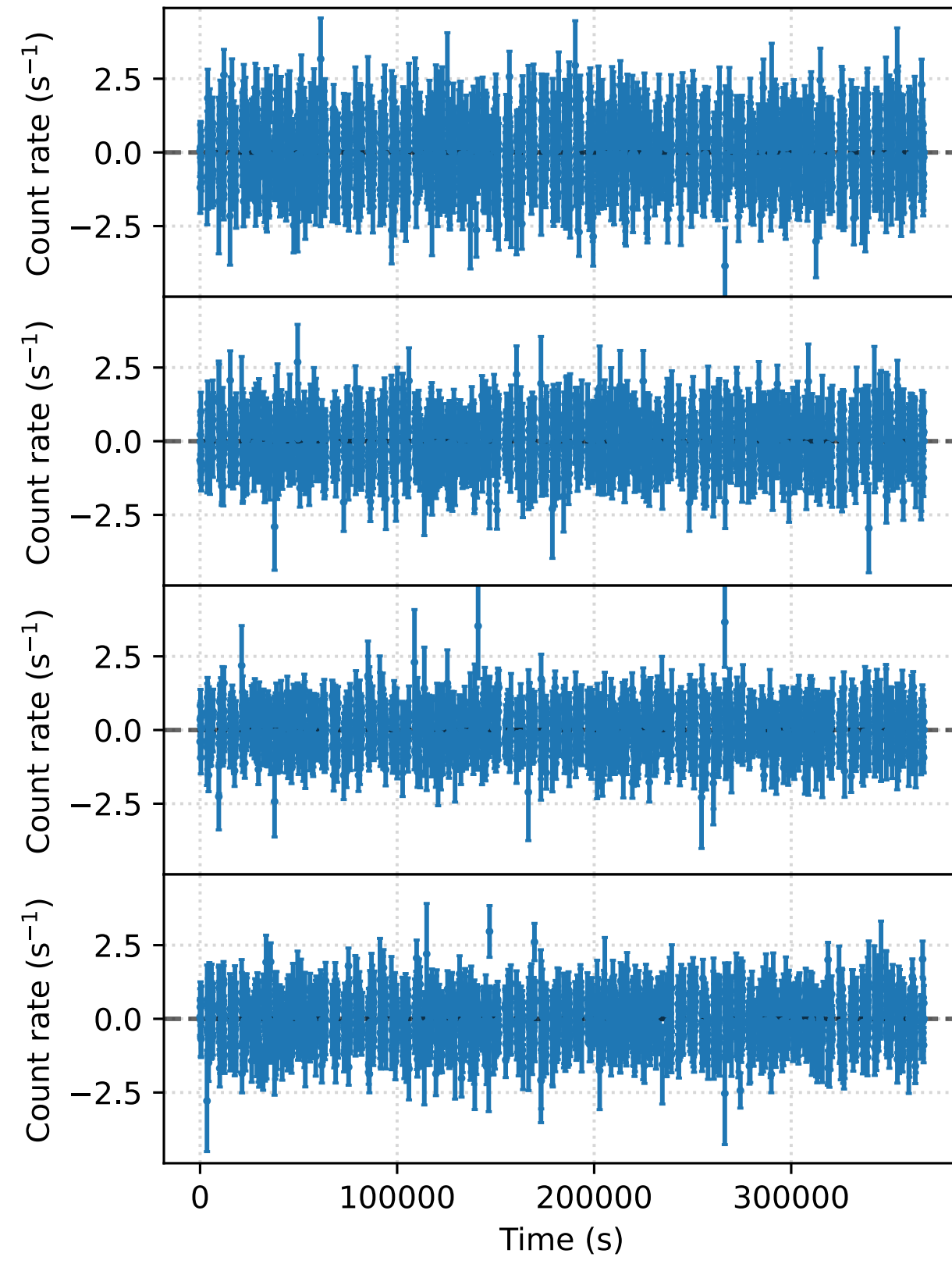
Error

$$\sigma_S(I) = \sqrt{\sum_i w_i(I)^2 * C_i(I)}$$

Spectral Extraction by Mask-weighting: Efficacy

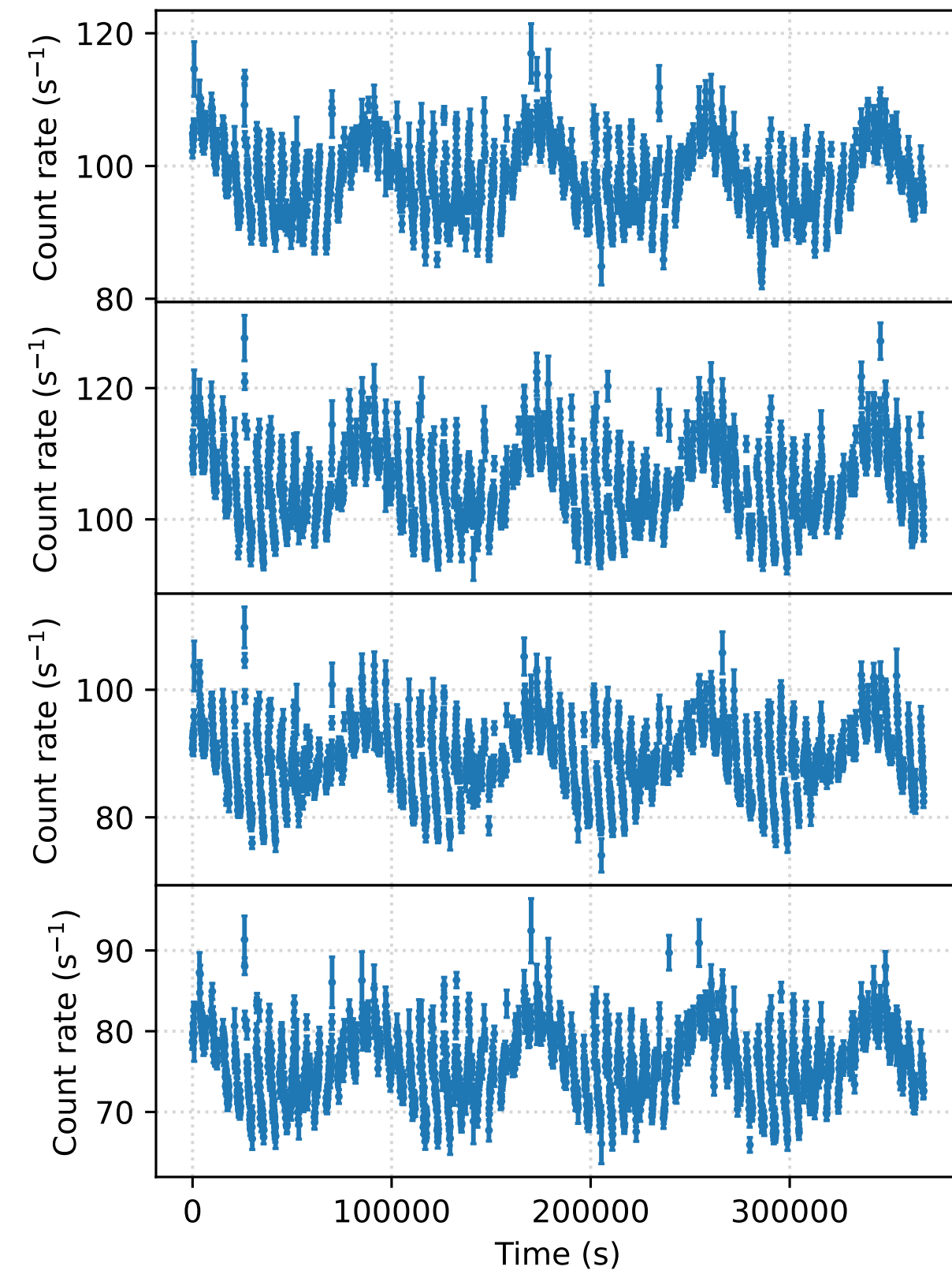


Total light curve

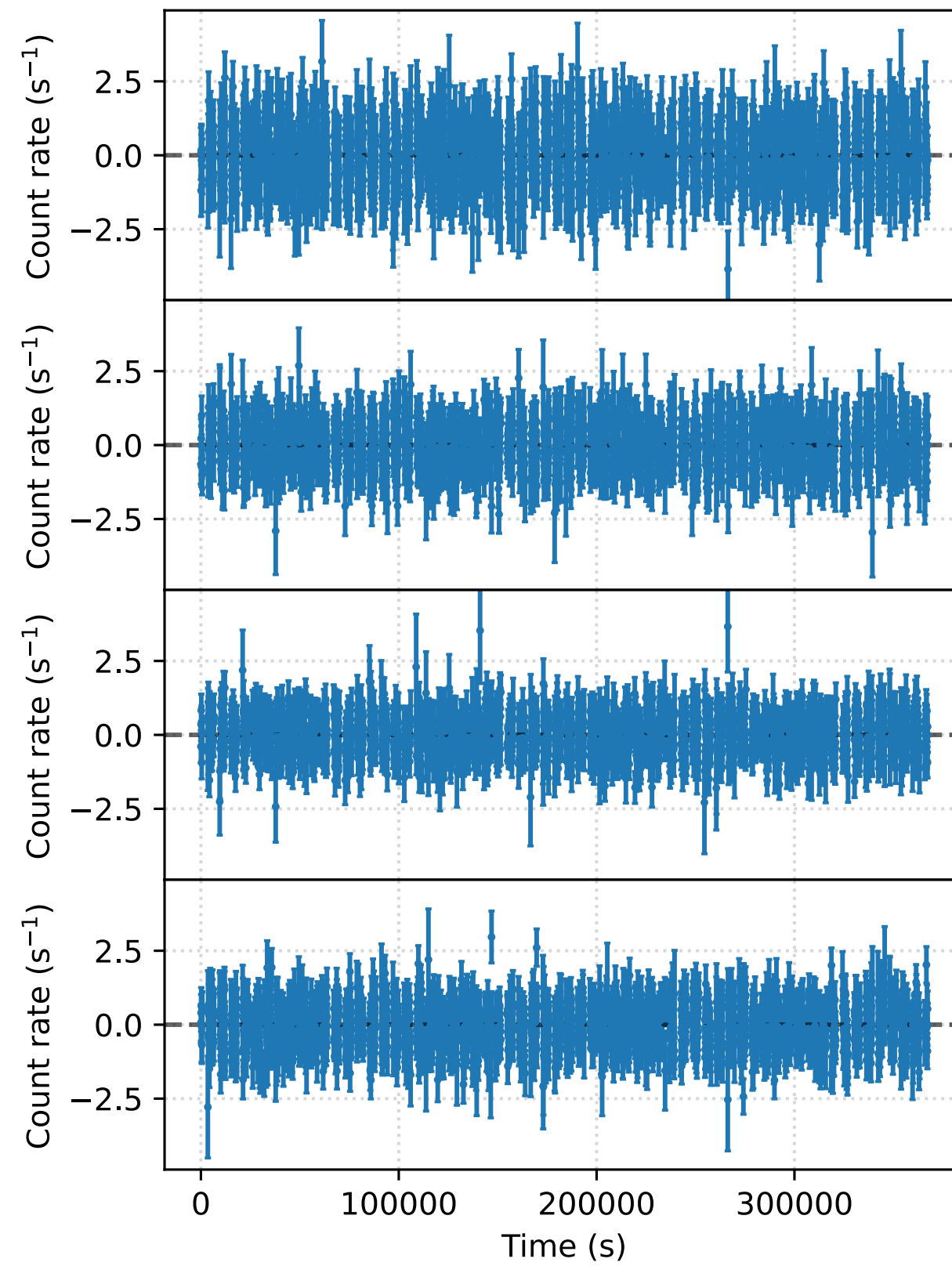


Background-subtracted

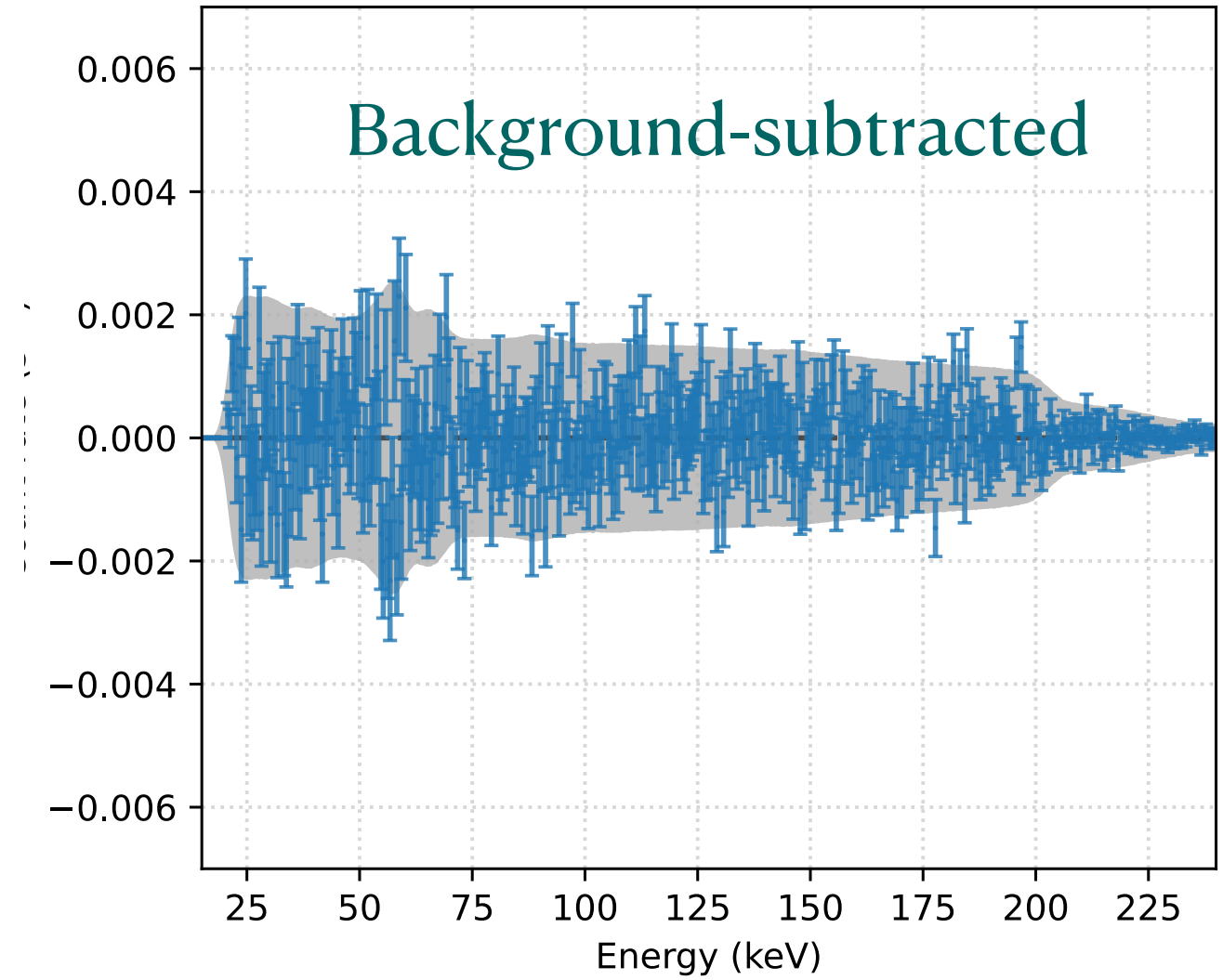
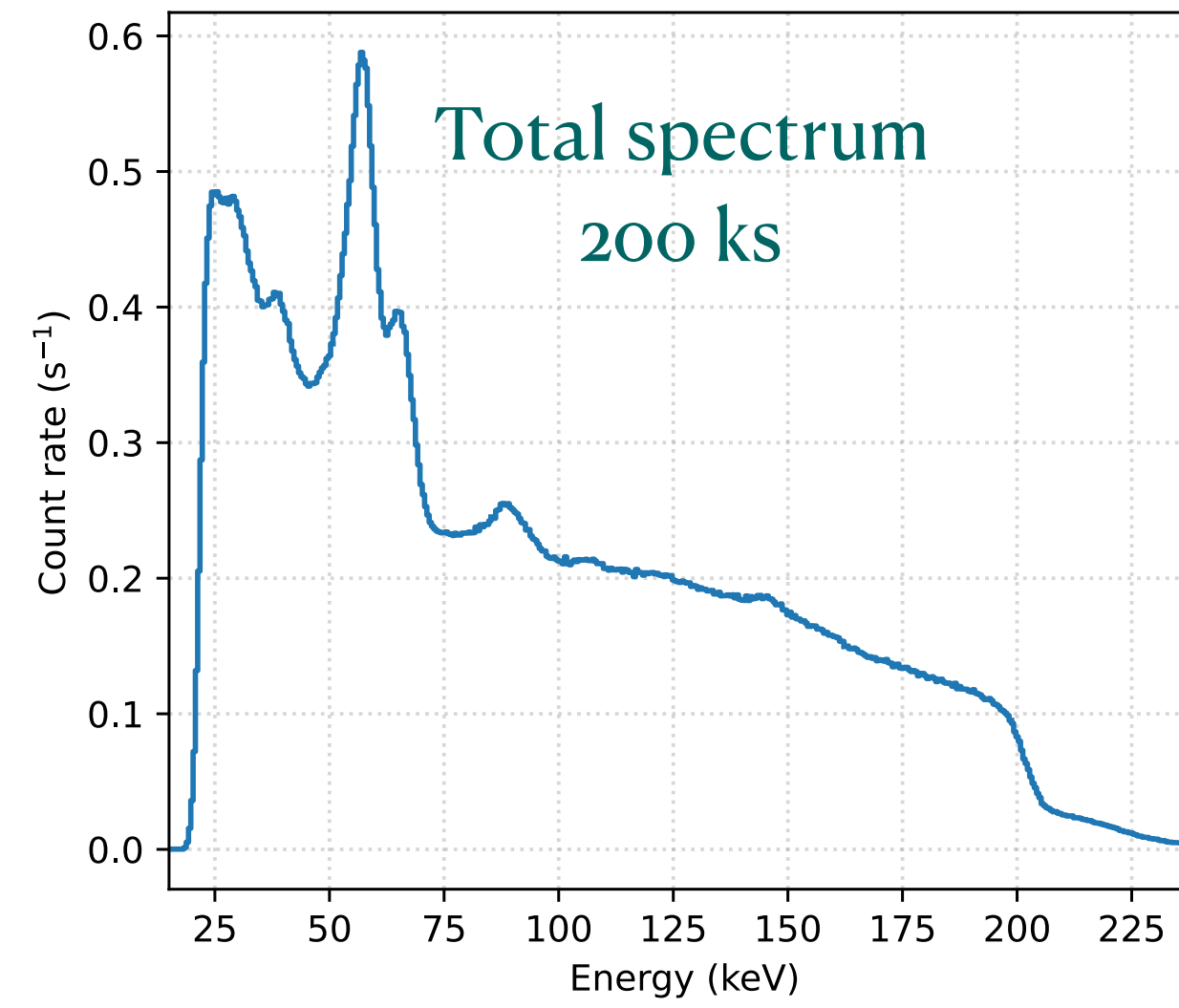
Spectral Extraction by Mask-weighting: Efficacy



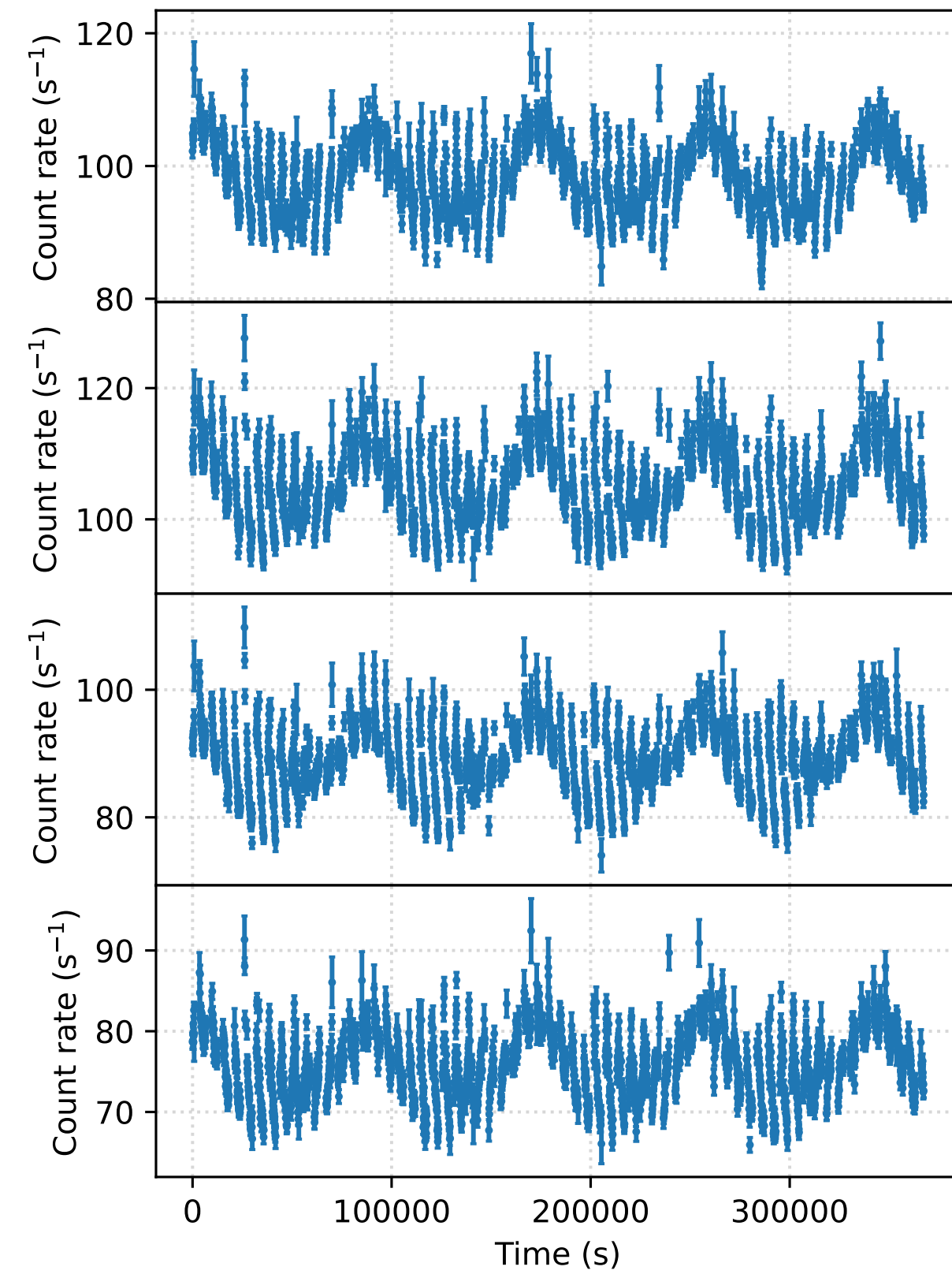
Total light curve



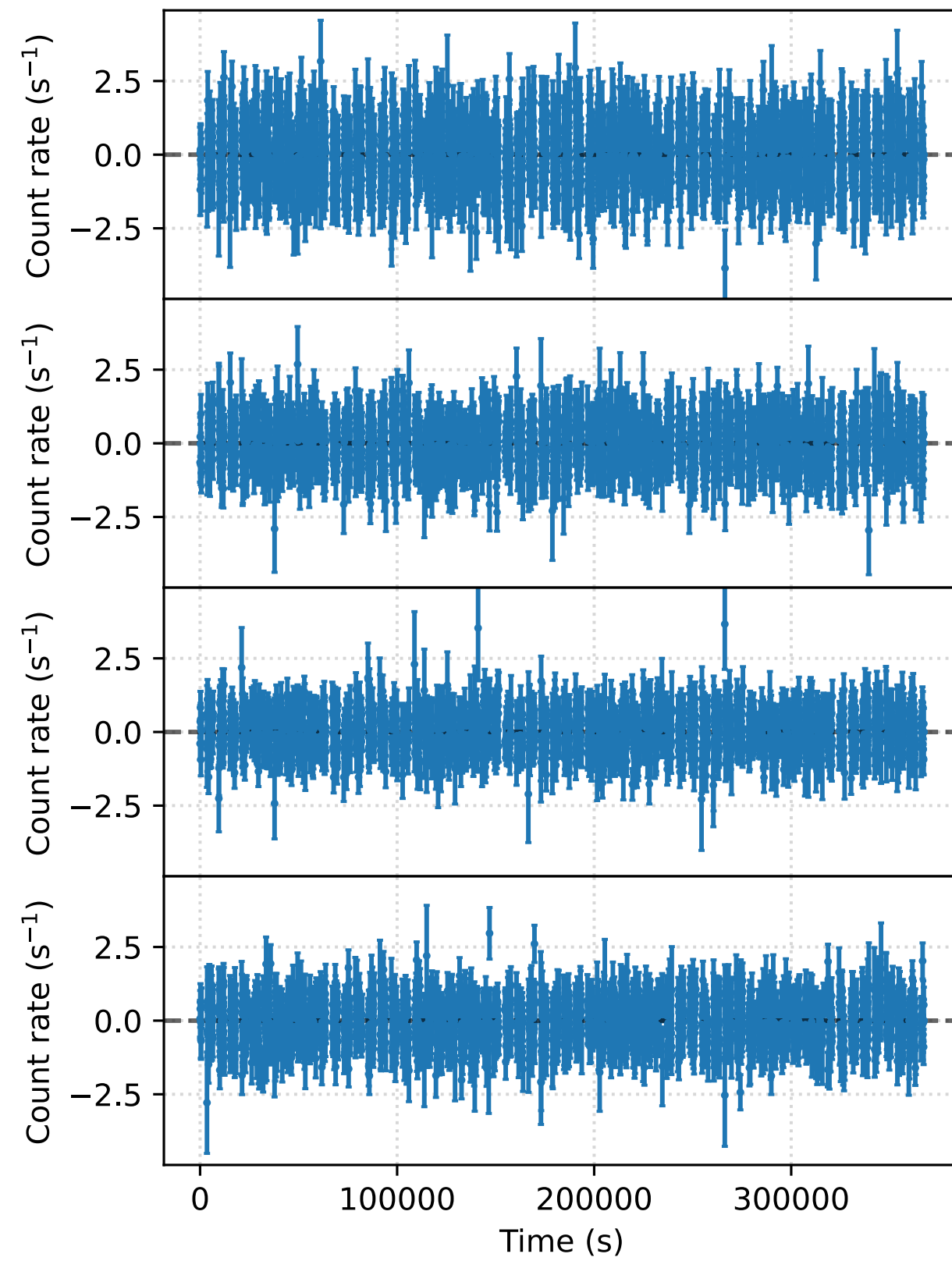
Background-subtracted



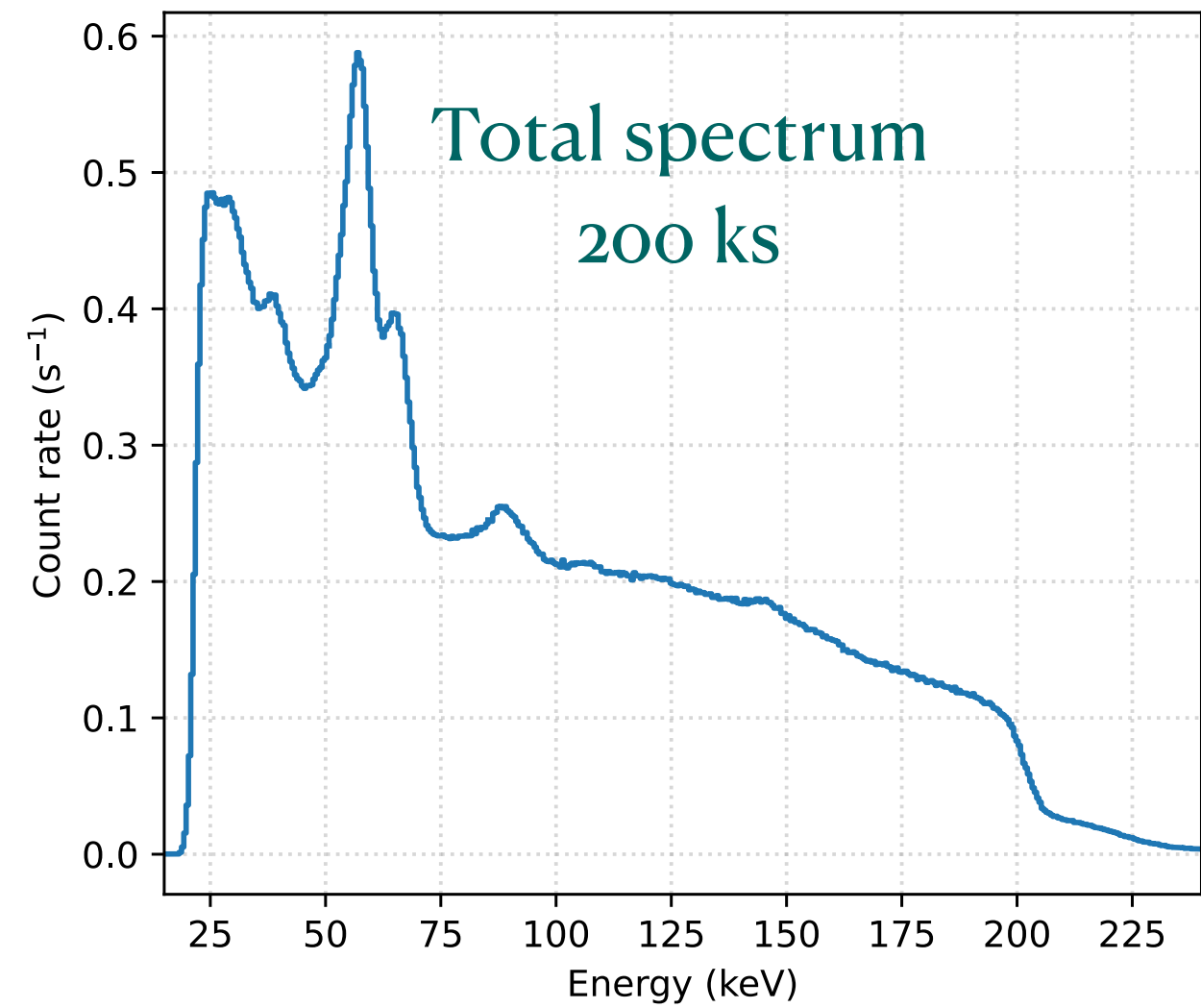
Spectral Extraction by Mask-weighting: Efficacy



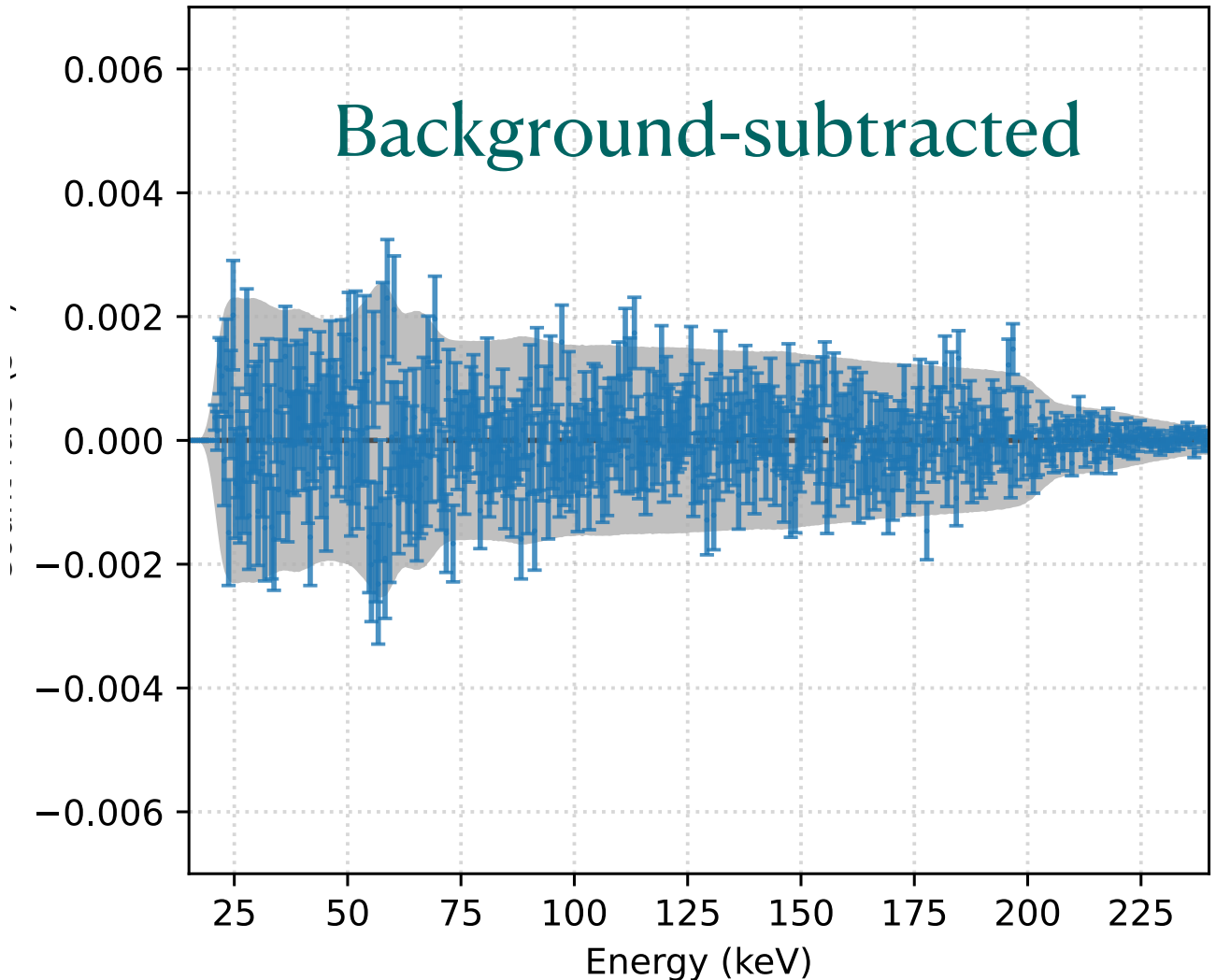
Total light curve



Background-subtracted

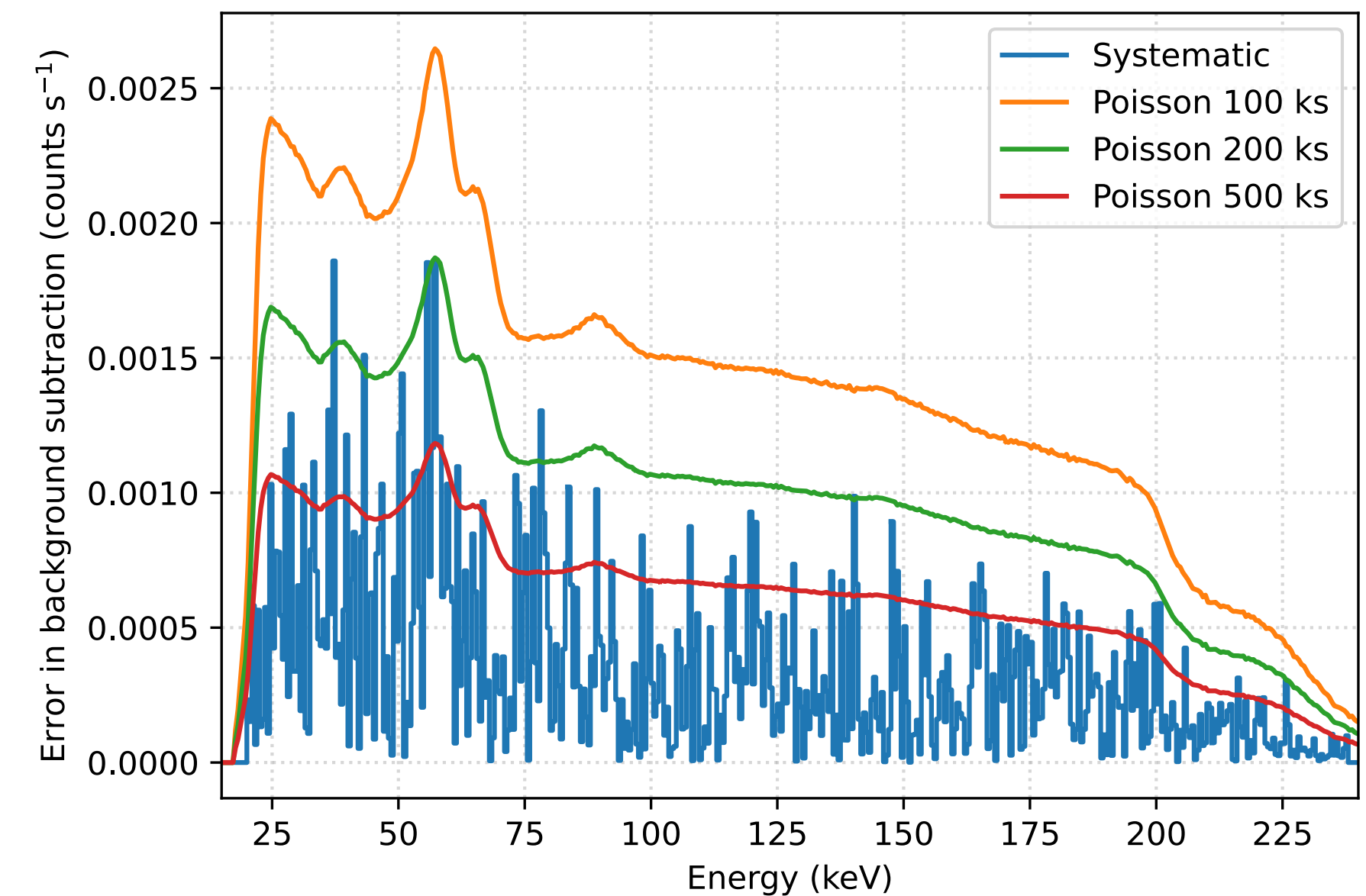


Total spectrum
200 ks

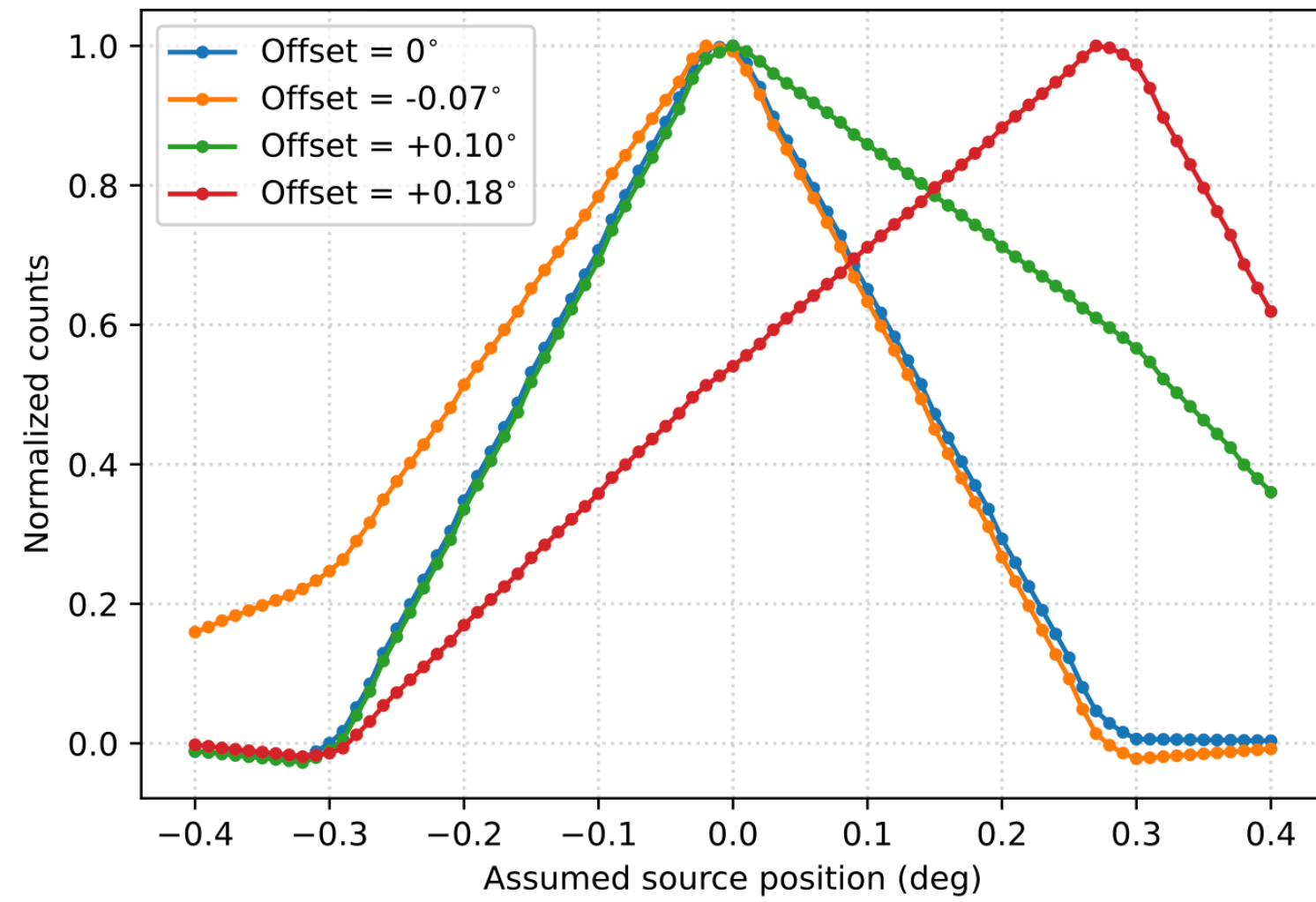


Background-subtracted

Background subtraction
limited only by statistics up to ~200 ks

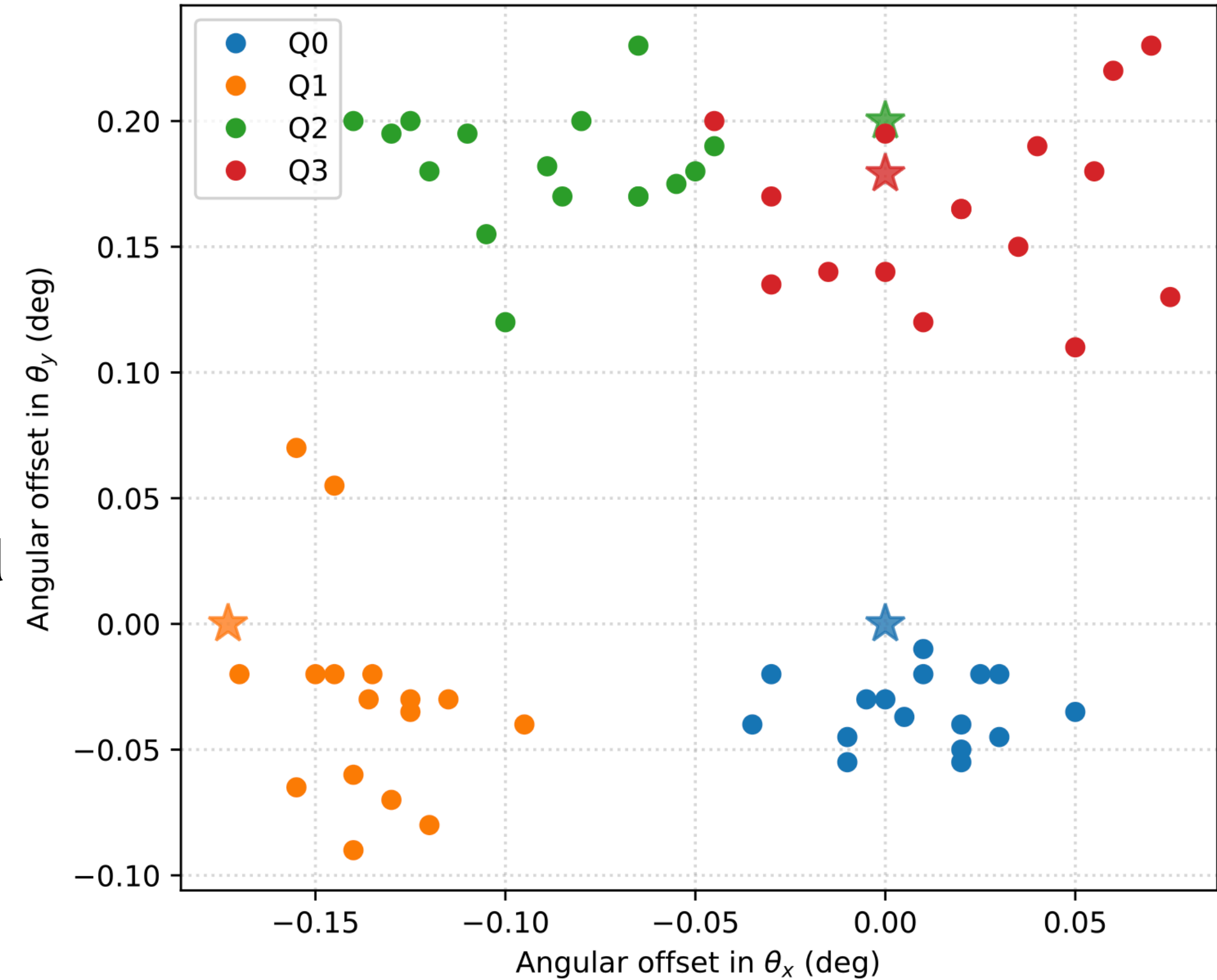
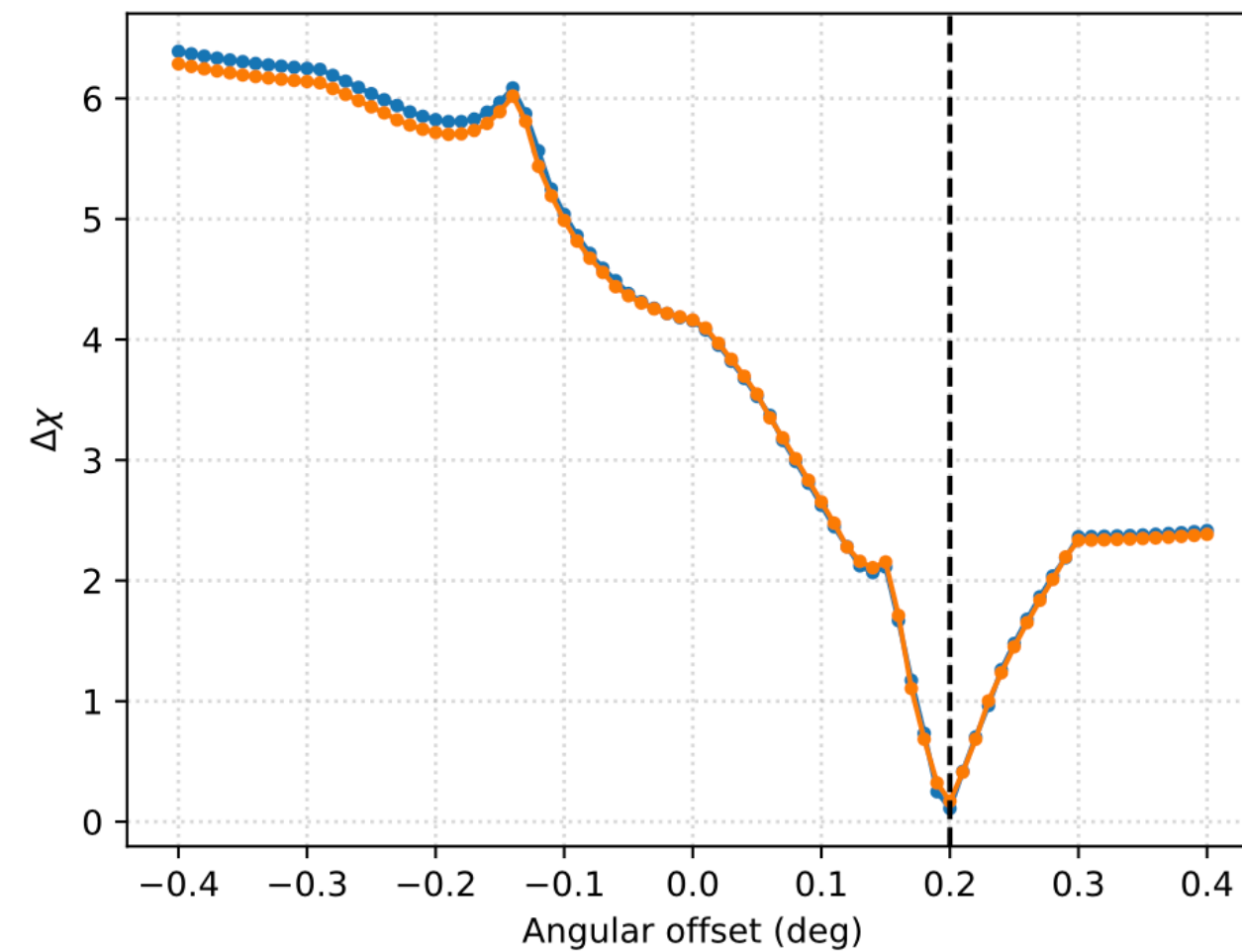
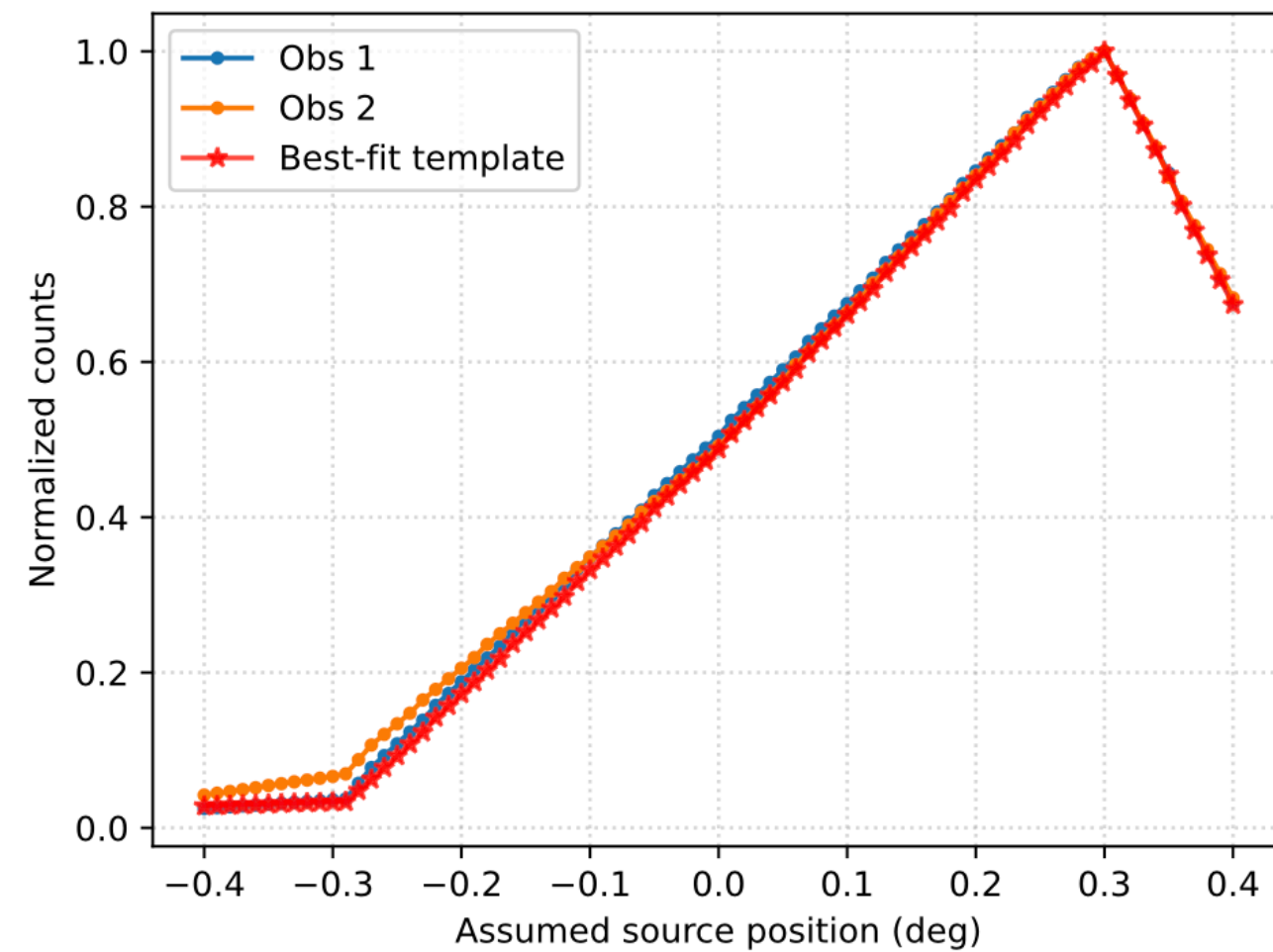


Alignment of mask and detector



Profile of Mask-weighted counts with source with different assumed source position - very sensitive to actual alignment

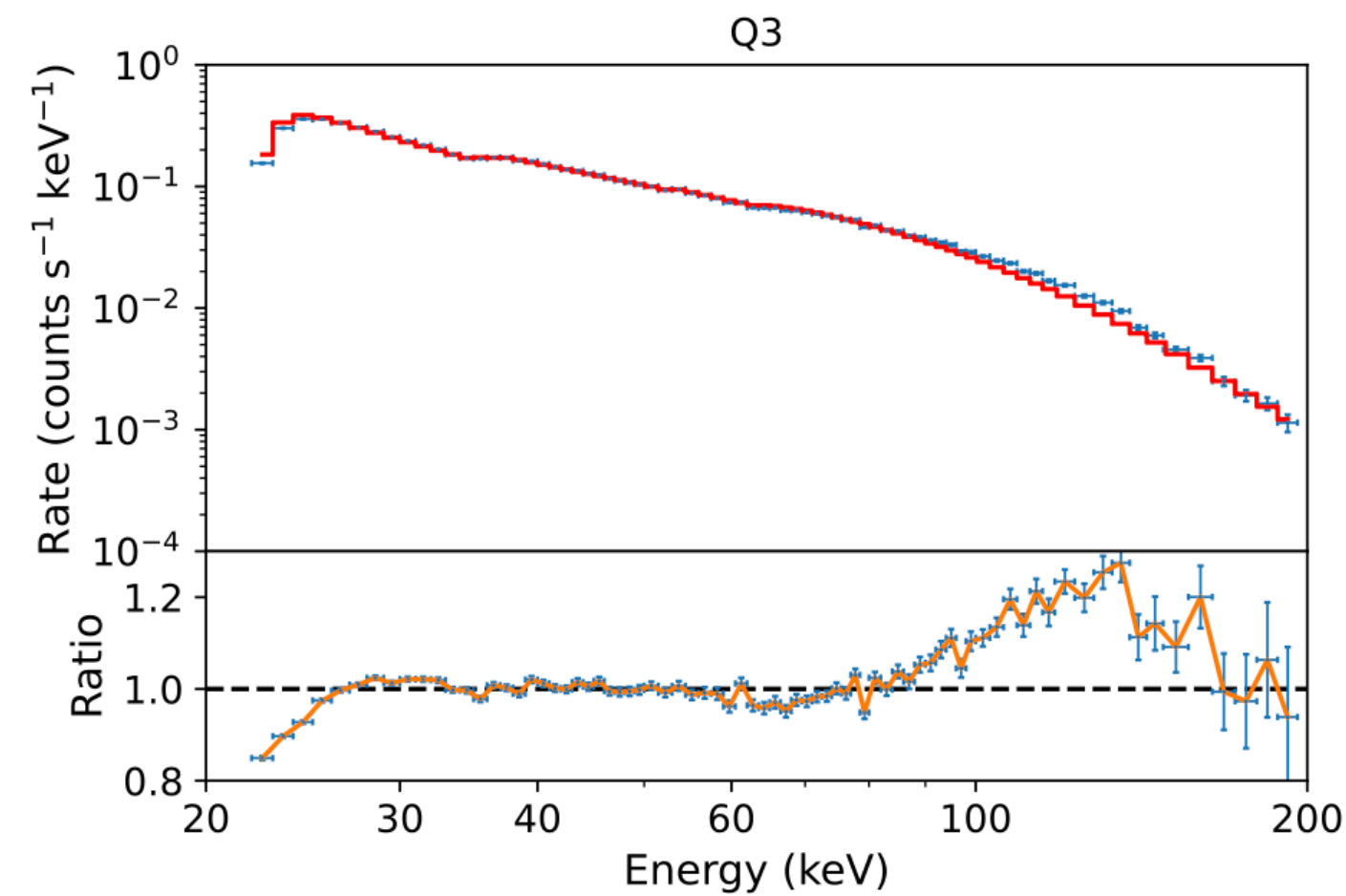
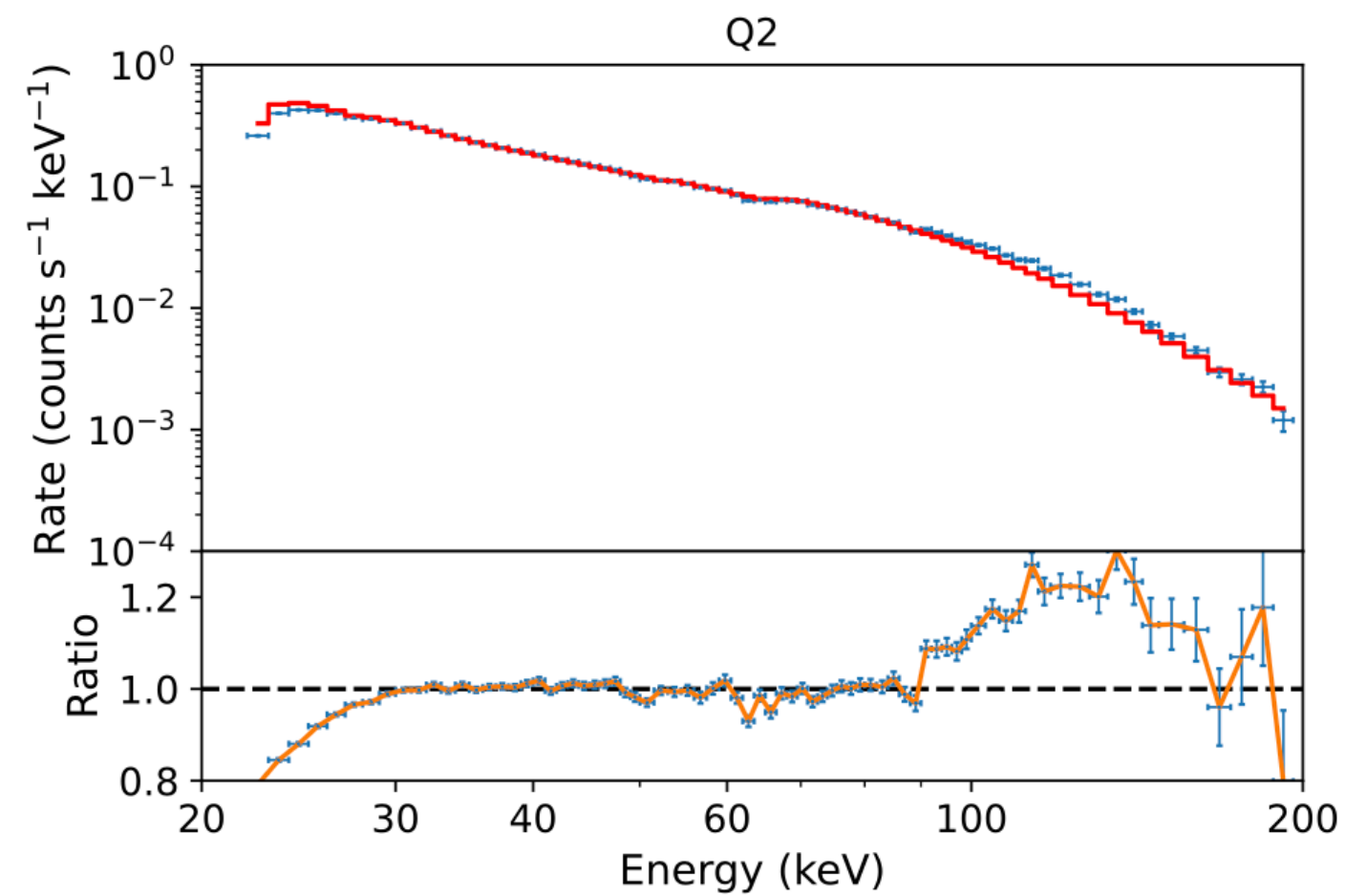
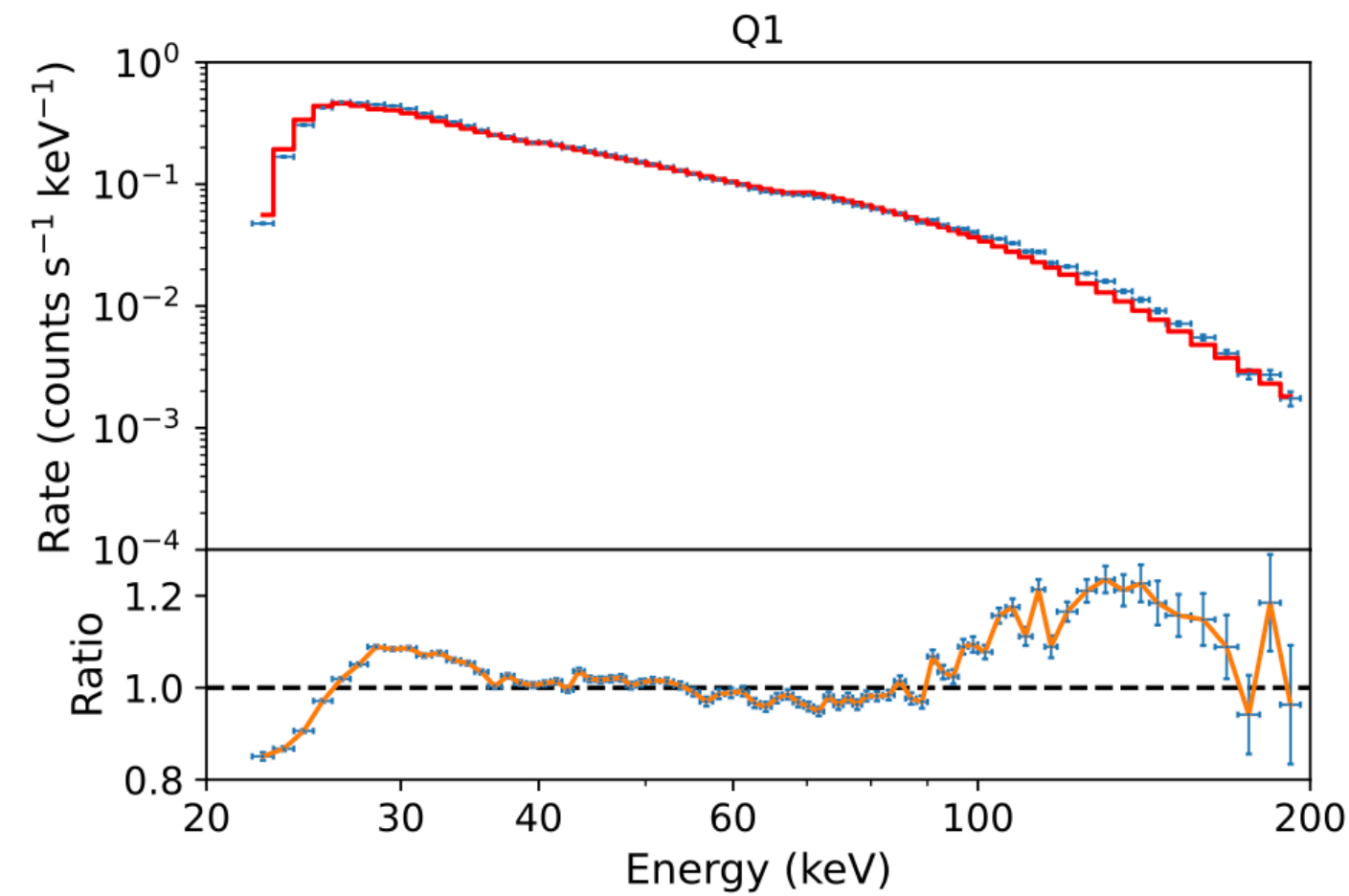
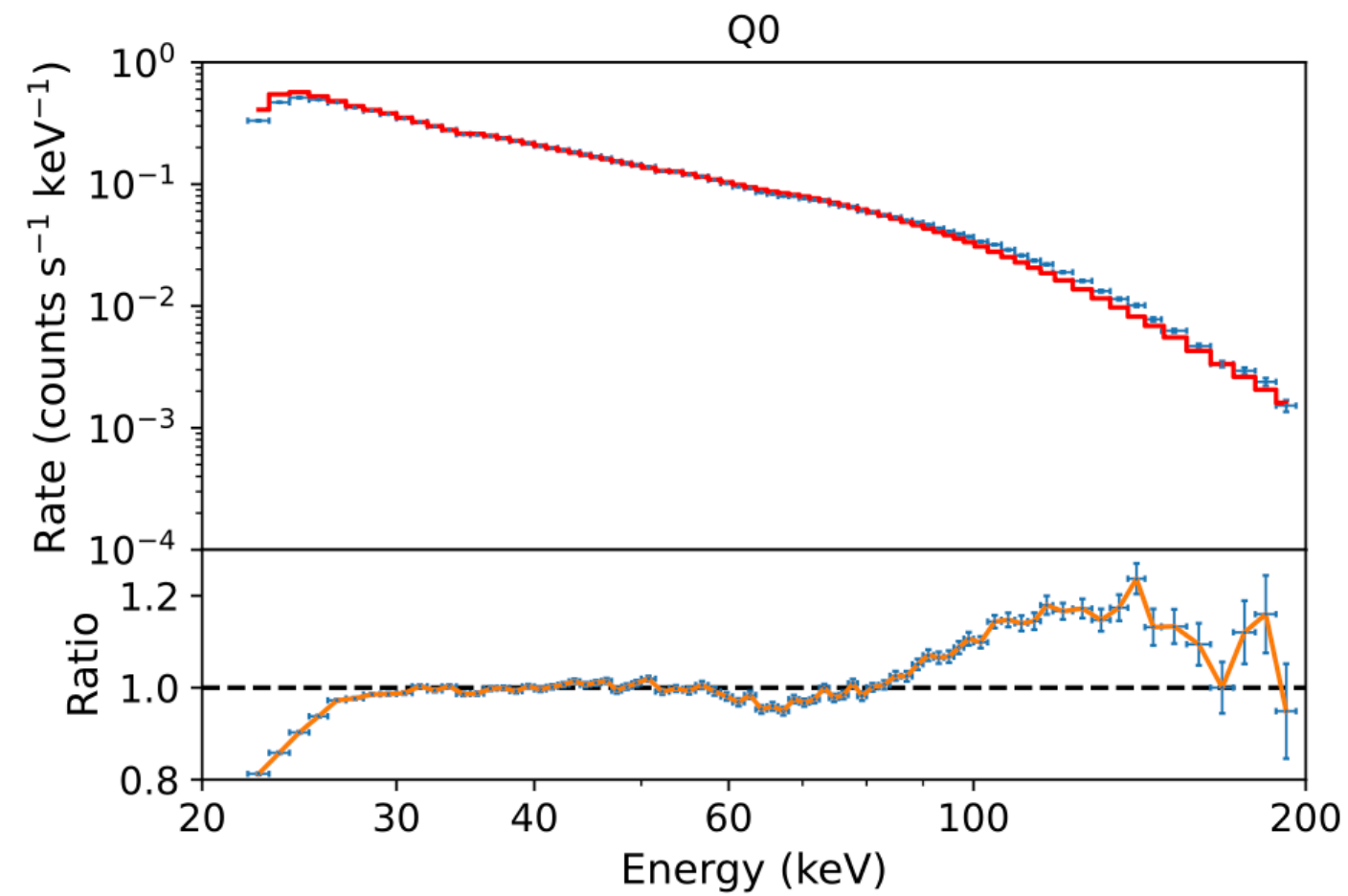
Systematic shifts between detector and mask measured



Filled circles : Individual detector module-mask offset

Star: Average Quadrant level offset from imaging

Crab observations: How well the spectra match the model?



With all improvements so far implemented, how does the Crab spectra compare with the canonical model?

➔ More or less consistent behaviour across all quadrants and detectors !!

➔ ~ 30-80 keV band: Consistent with the model

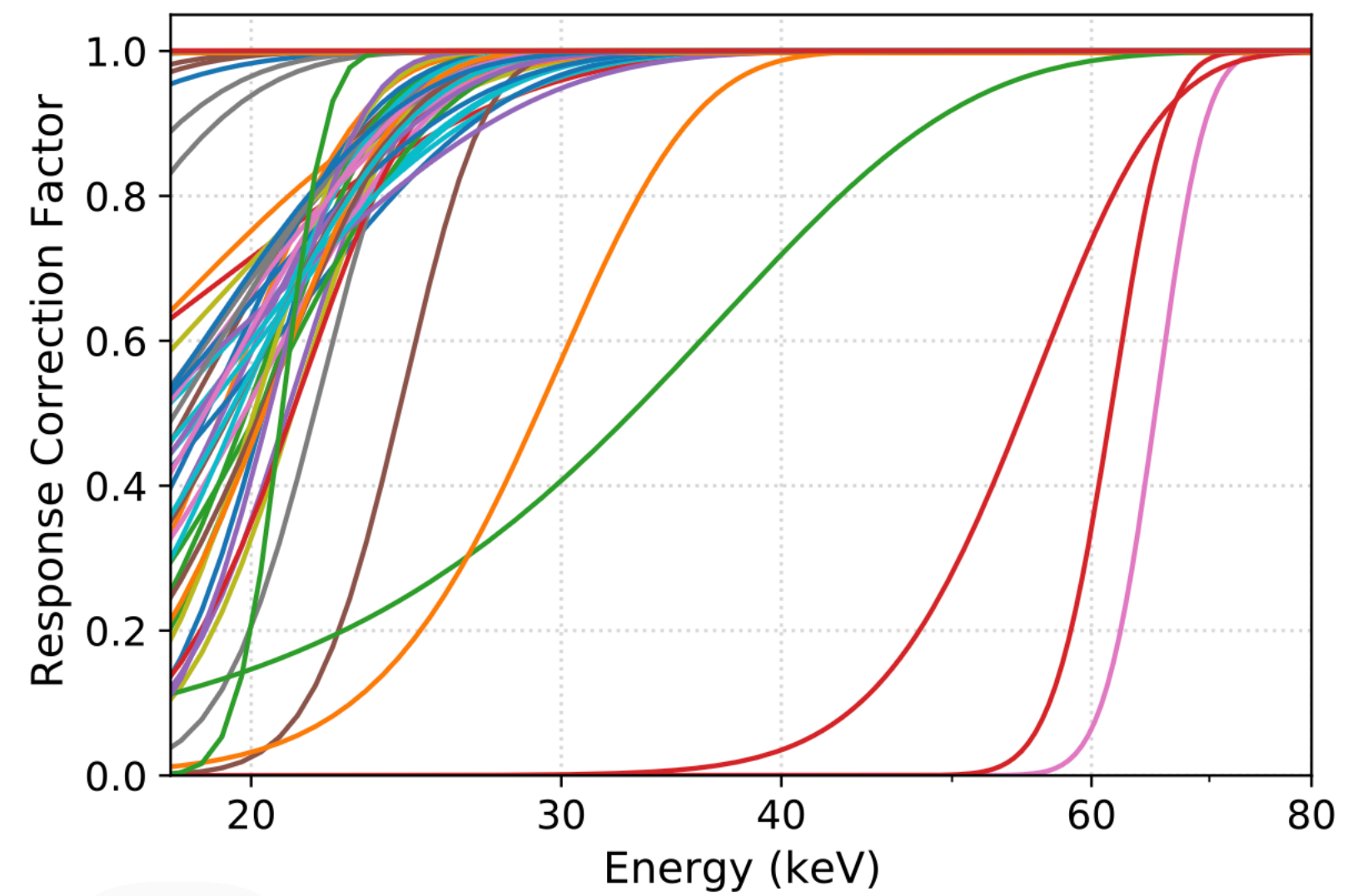
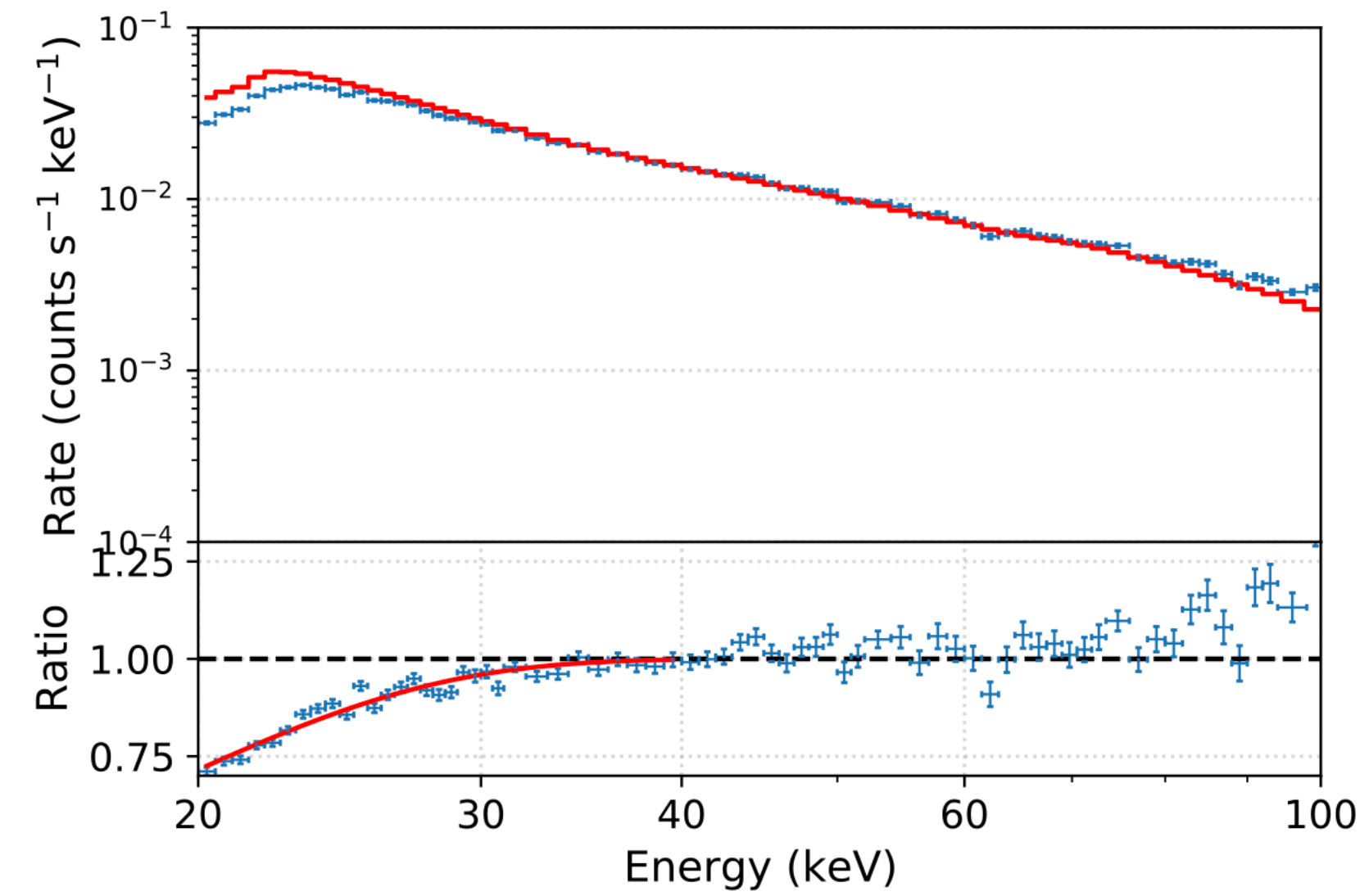
➔ Lower and higher energies - systematic departure

➔ Lower energy: Event triggering efficiency close to LLD - empirical model

➔ Higher energy: Several attempts to identify physical origin - did not find any - empirical model

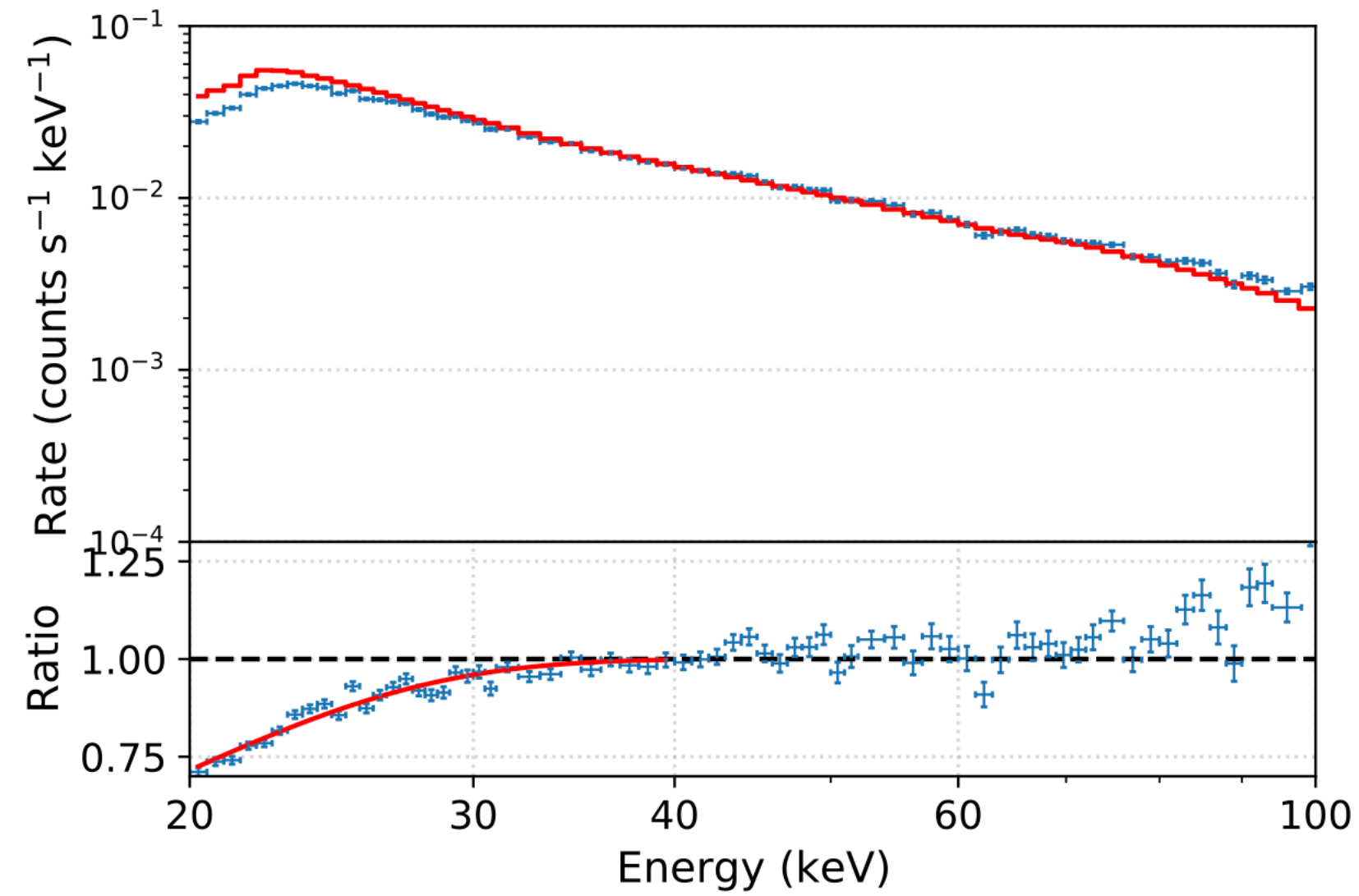
Effective Area Calibration with Crab

Low Energy

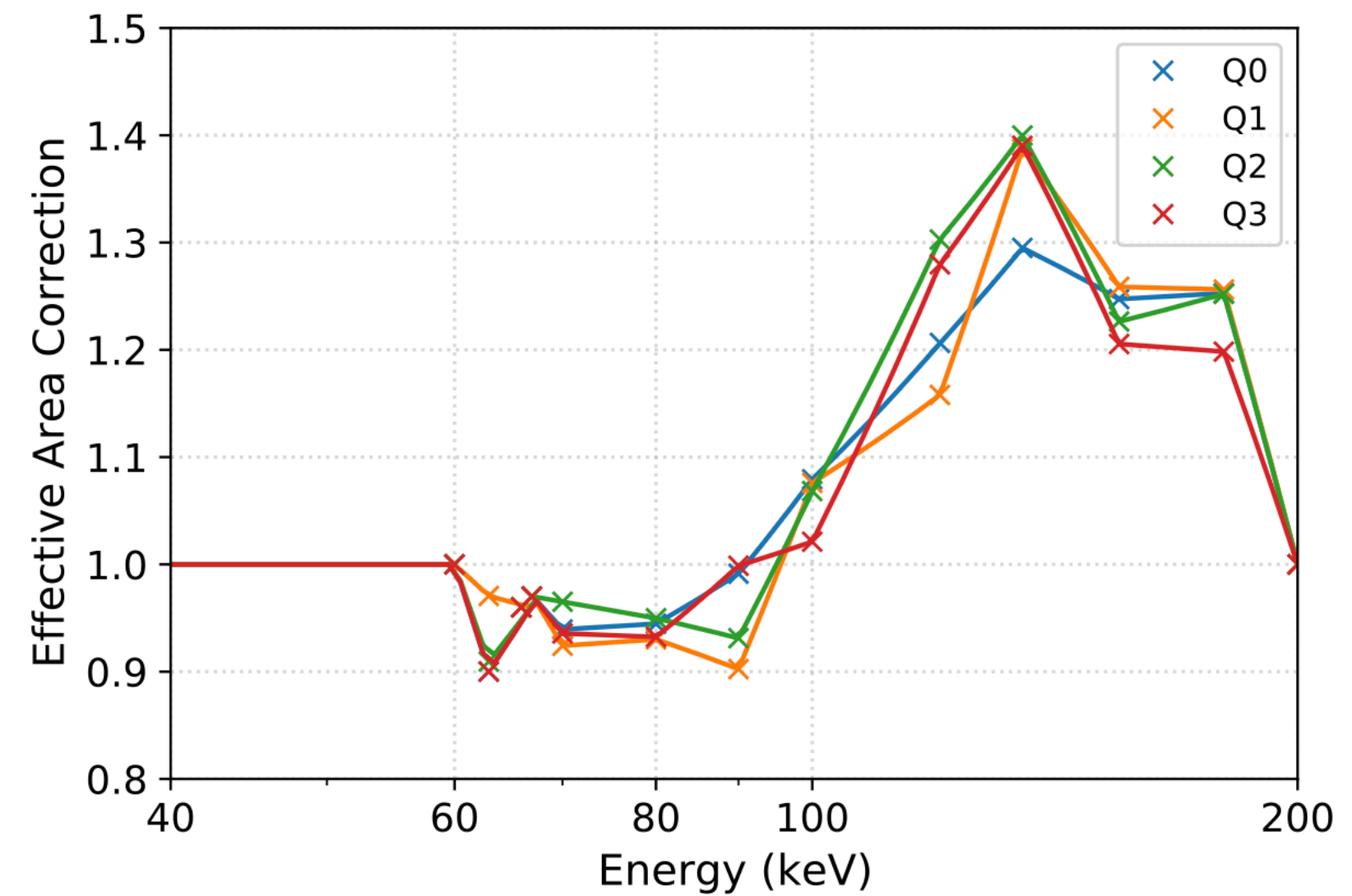
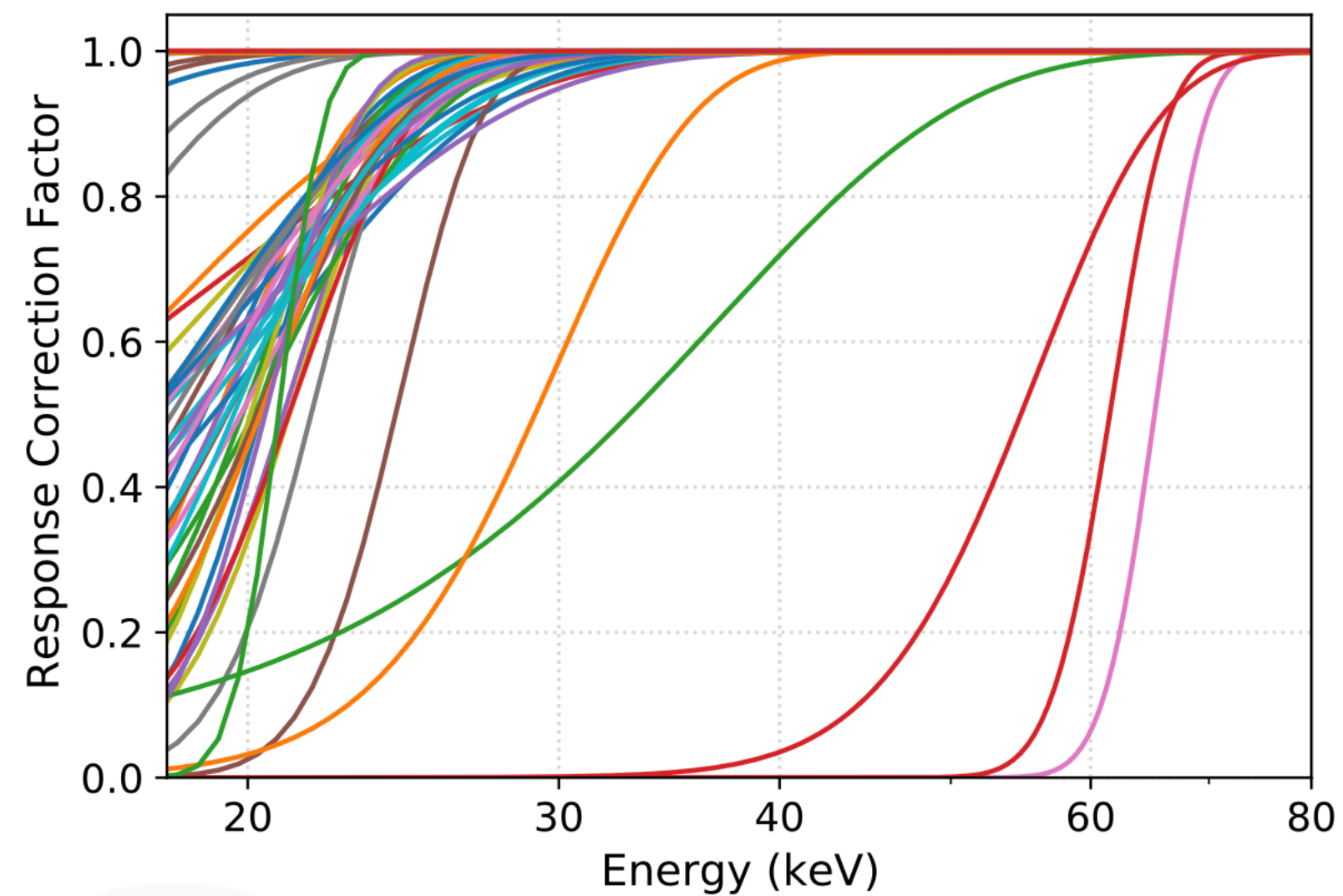
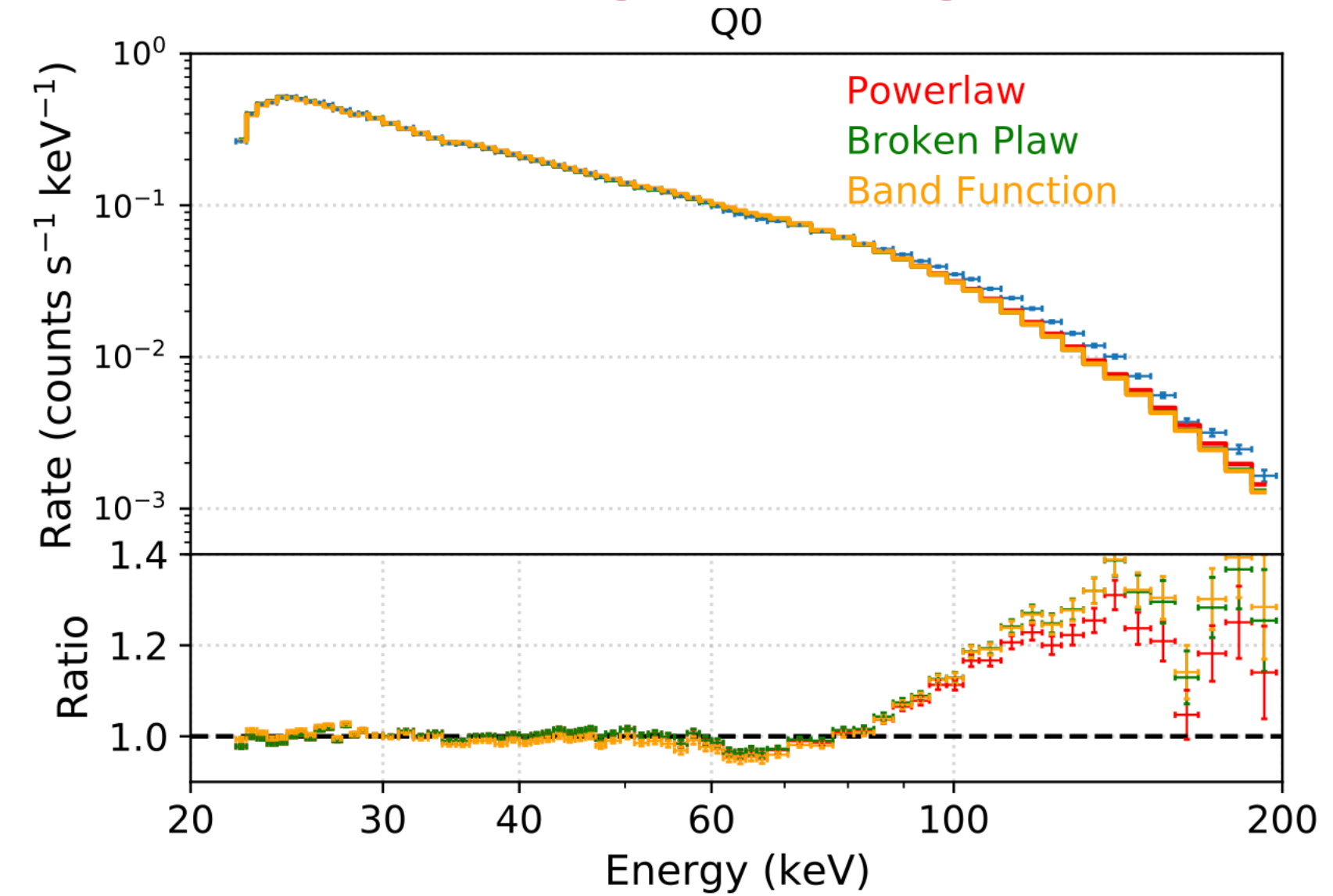


Effective Area Calibration with Crab

Low Energy

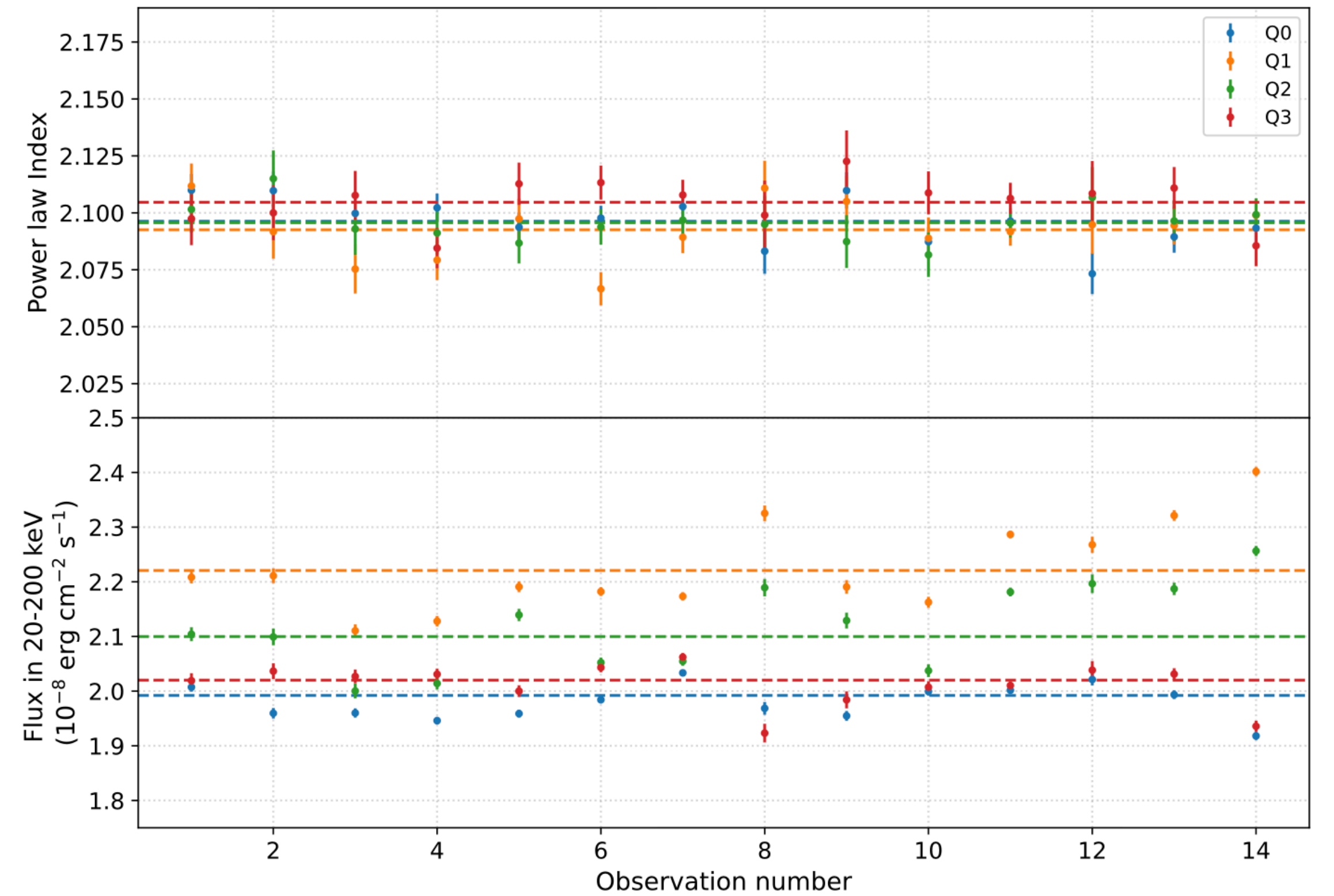
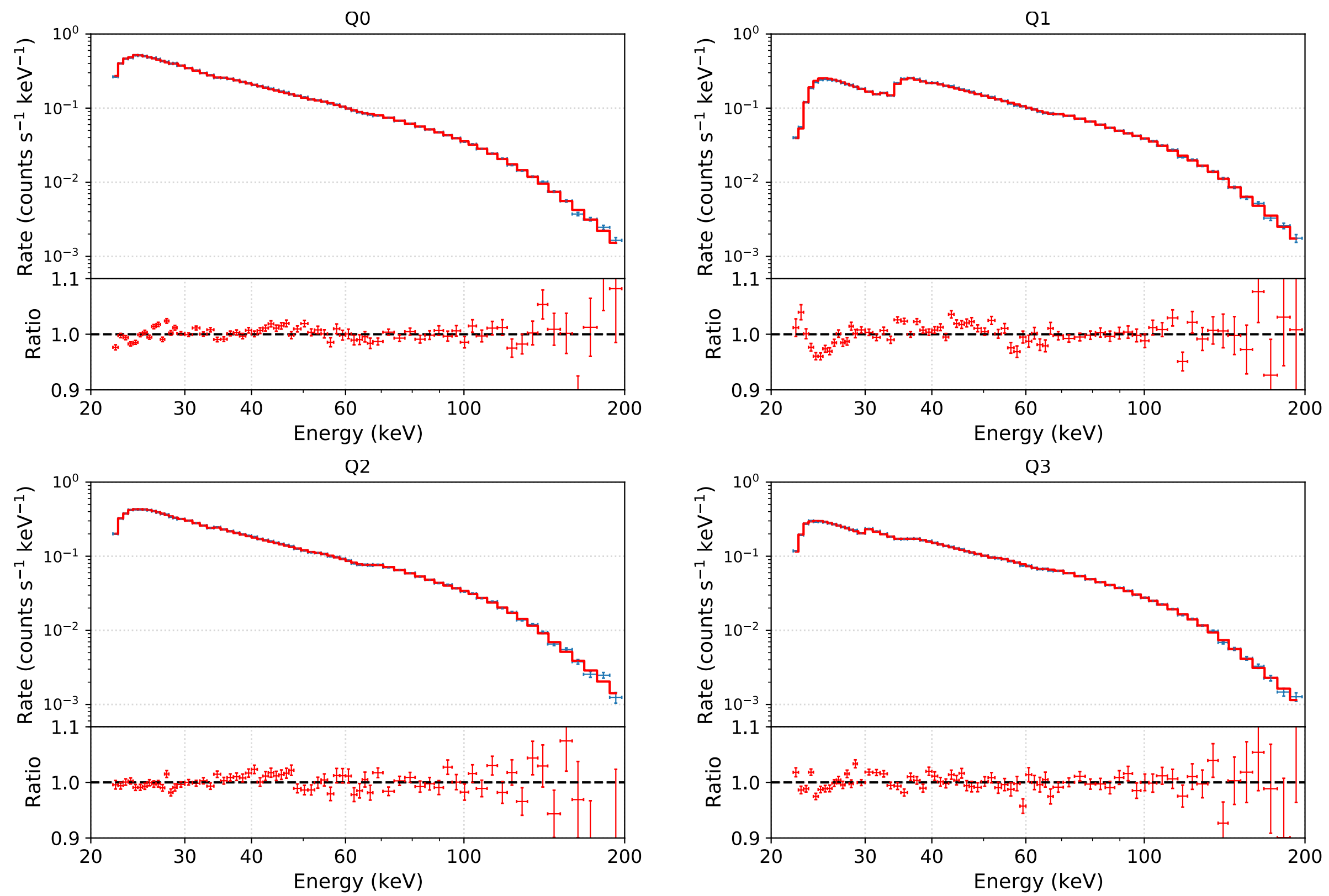


High Energy



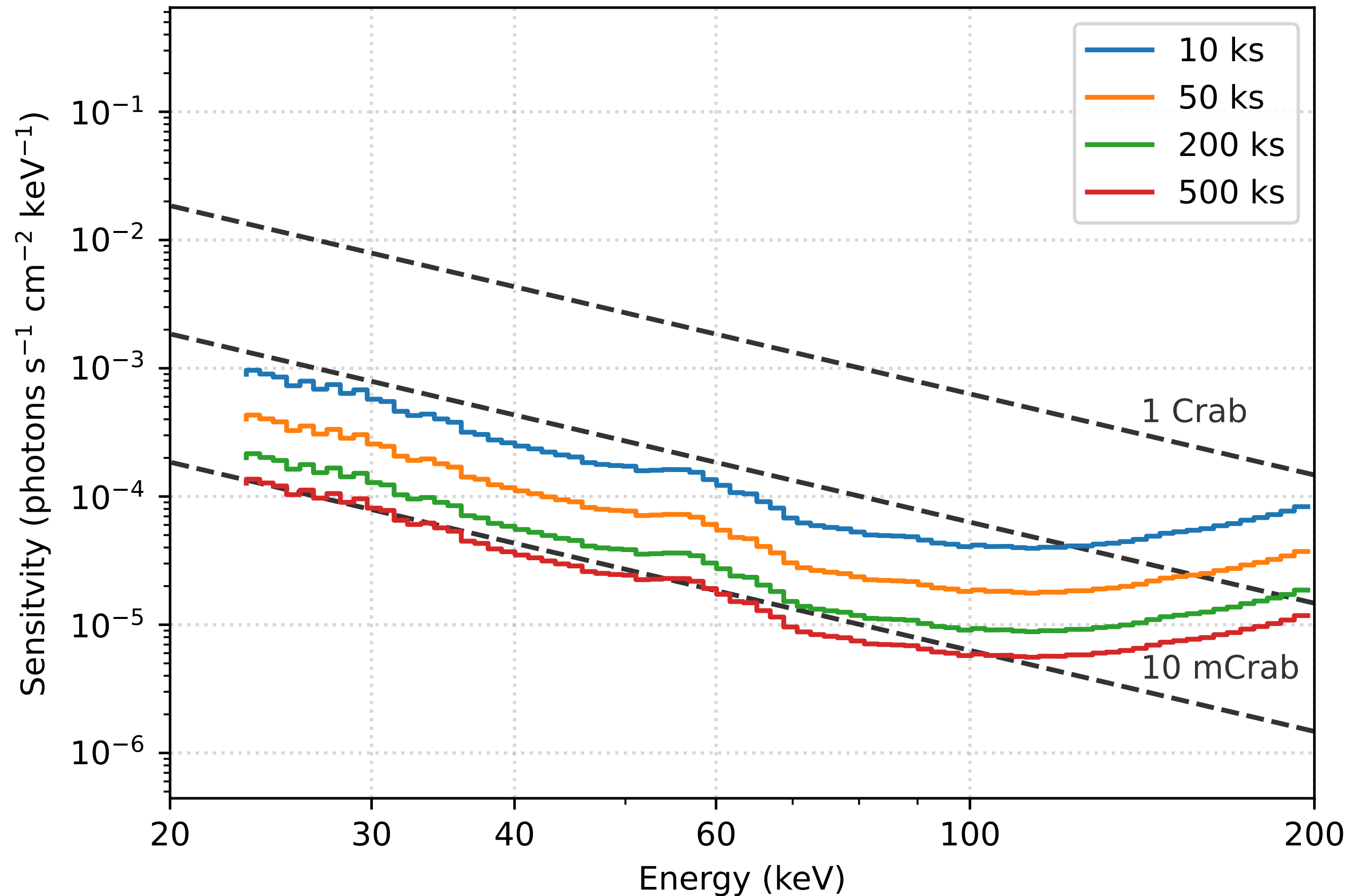
Updated CZTI Spectra of Crab

Crab Spectra with all improvements in response



Consistent spectral index across observations

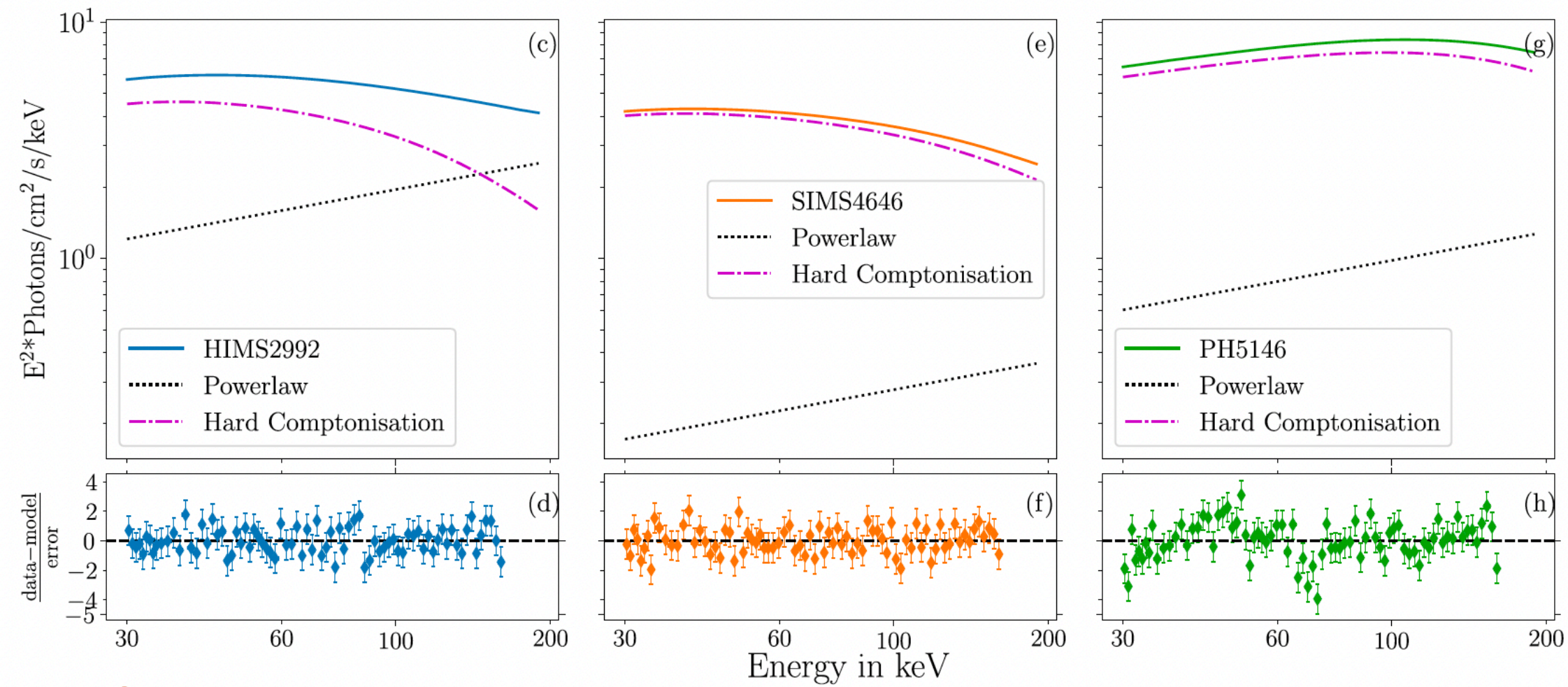
Spectroscopic Sensitivity and Current Calibration Status



- Sensitivity: 50 mCrab sources in 50 ks
- Energy scale: Within $\sim \pm 0.5$ keV (work in progress to verify this for recent data)
- Background subtraction systematics: Negligible for exposures up to ~ 200 ks
- Systematics well below statistical uncertainties (for typical exposures) - spectroscopy limited by statistics alone
- Absolute flux (norm) uncertainties - within 5-8% between quadrants: Norm not fixed with Crab
- All these updates includes in Version 3 of CZTI Pipeline and associated CALDB: Released in December 2022 with minor updates later on

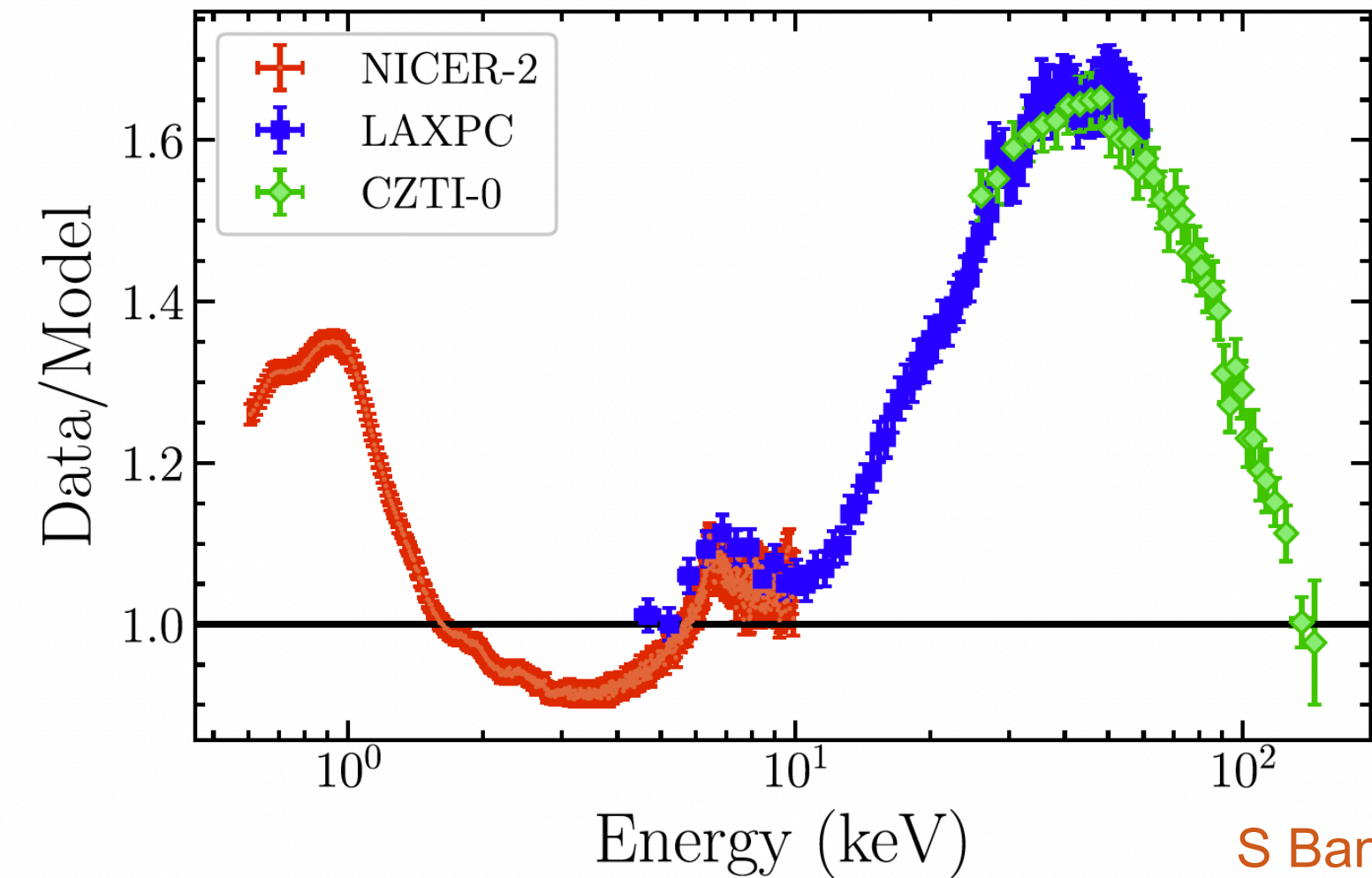
Refined CZTI Spectroscopy: Some Examples

Spectroscopic Context for polarimetry: Cyg X1



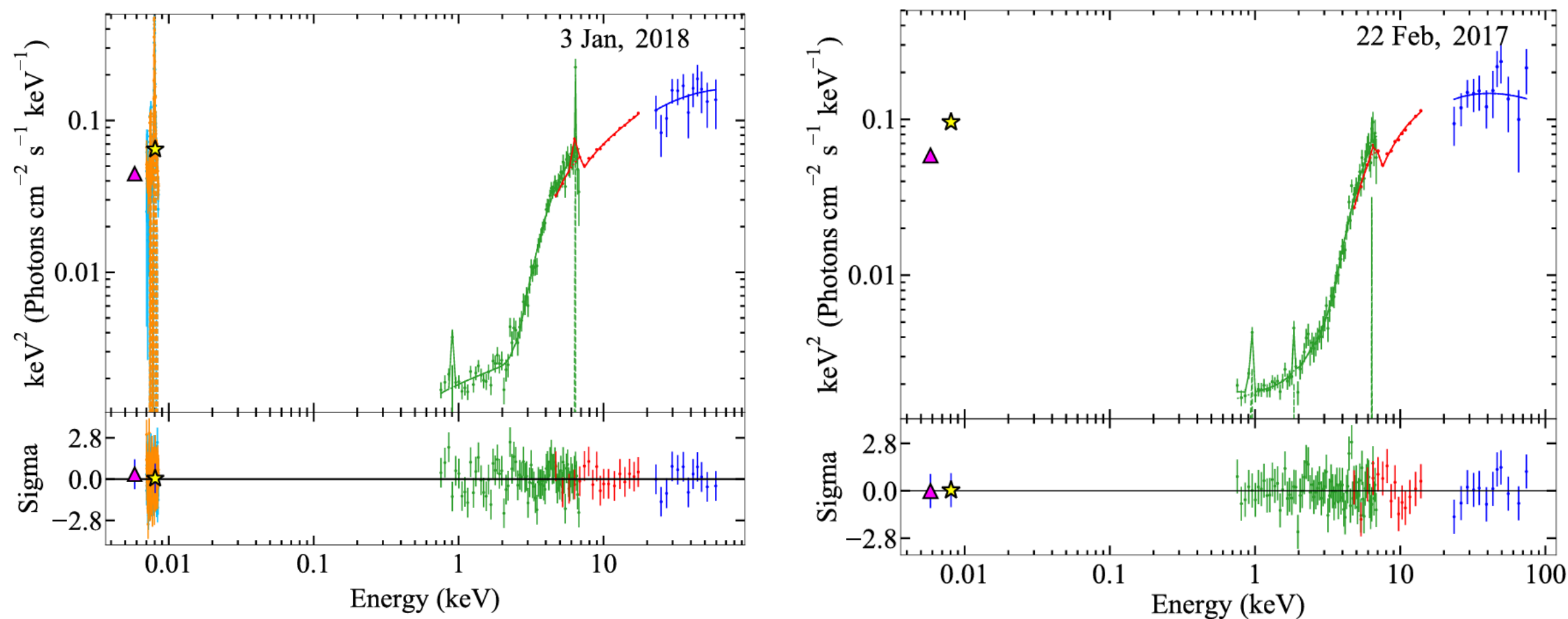
T Chattopadhyay et al, 2024

Reflection component in BHB: MAXI J1820+070



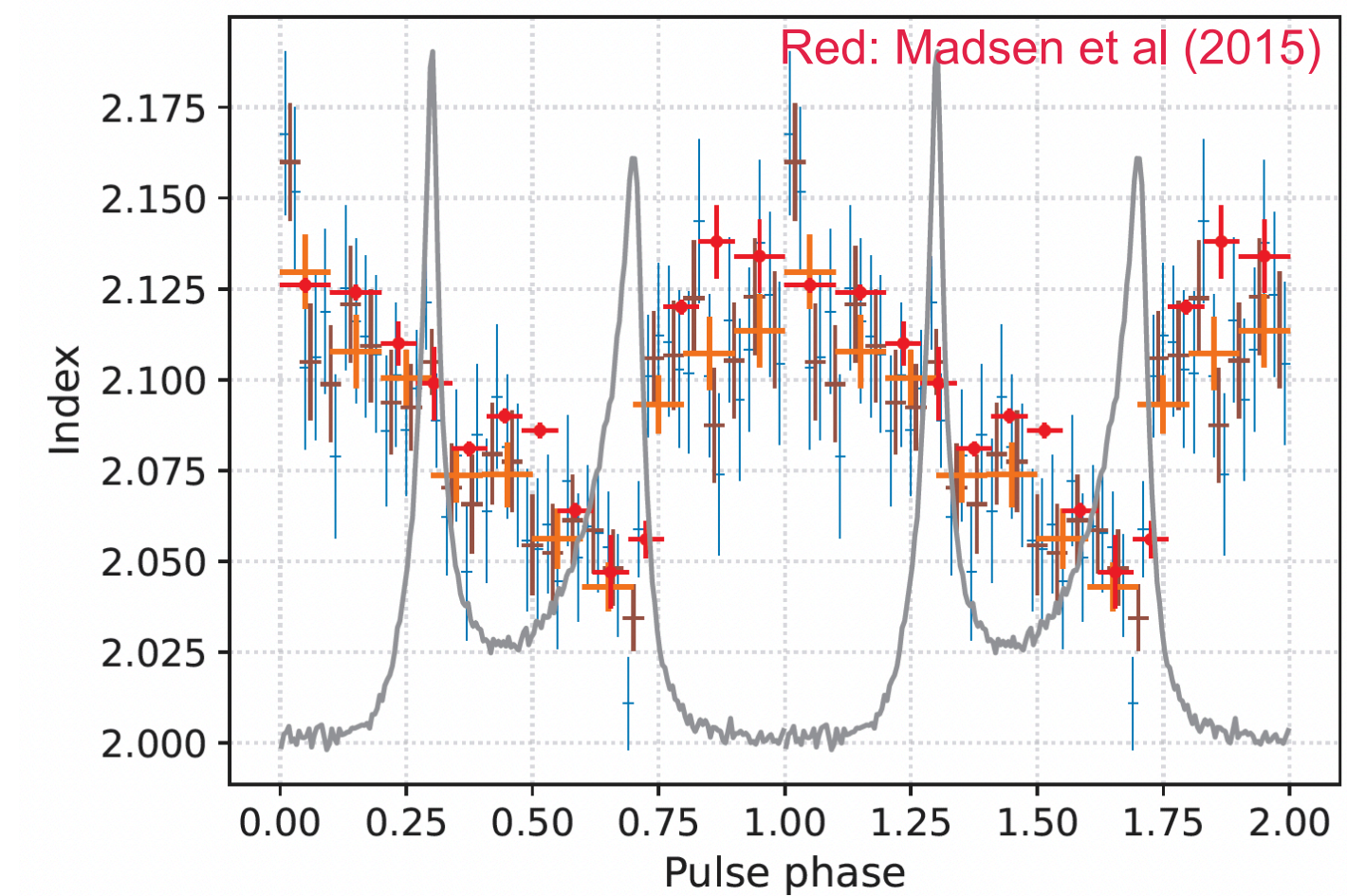
S Banerjee et al, 2024

Wide band spectral modelling: NGC 4151



S Kumar et al, 2024

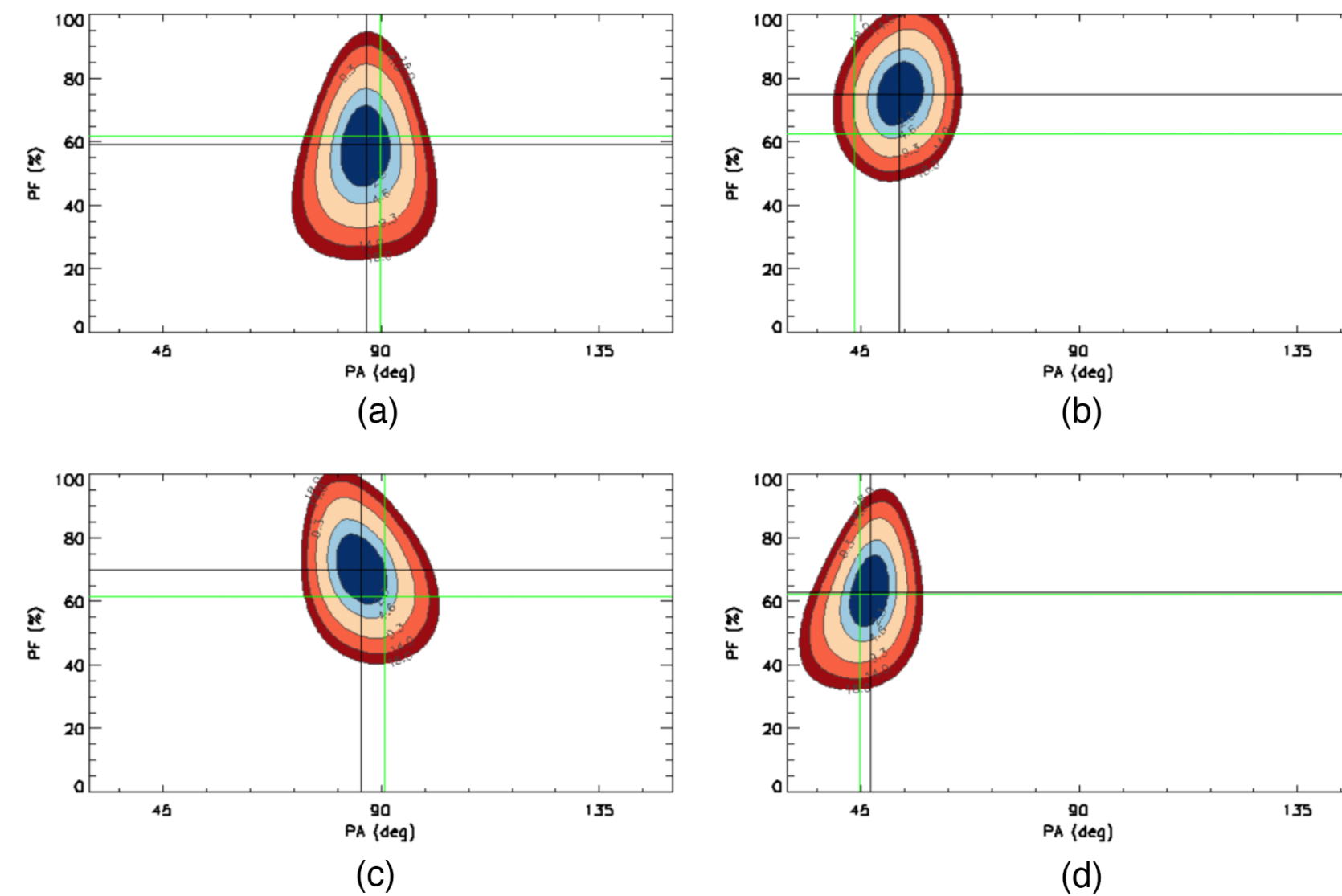
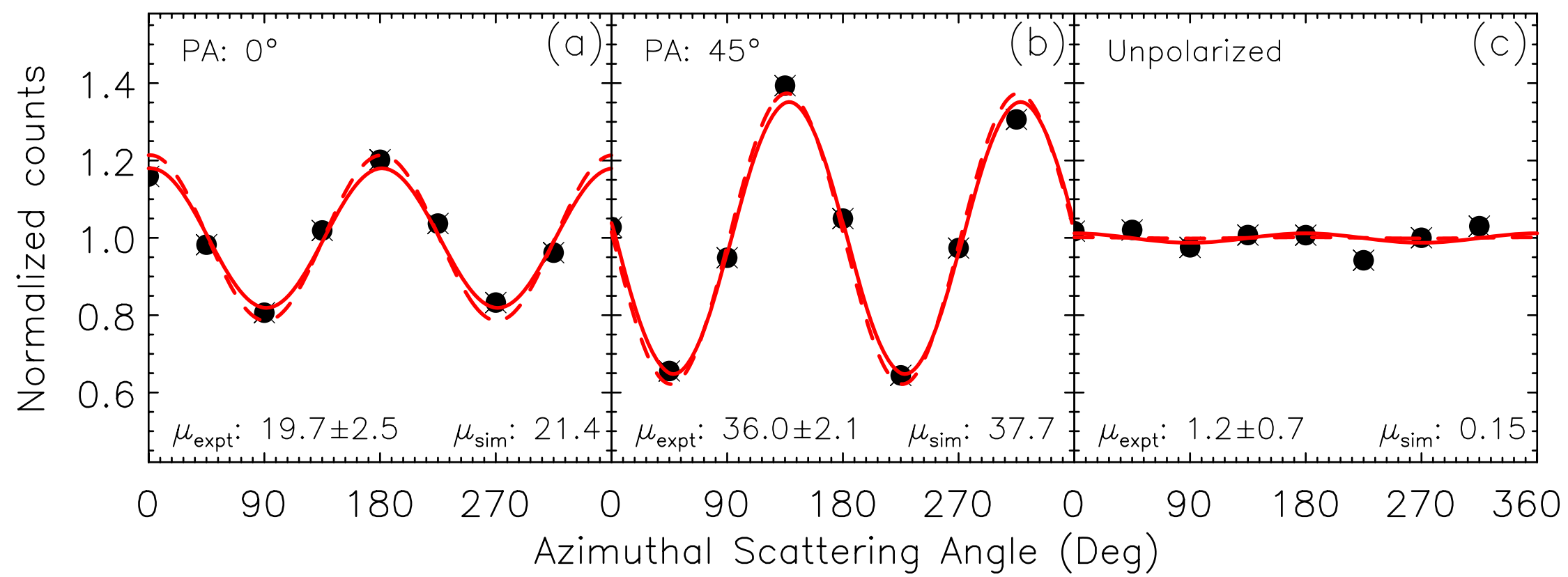
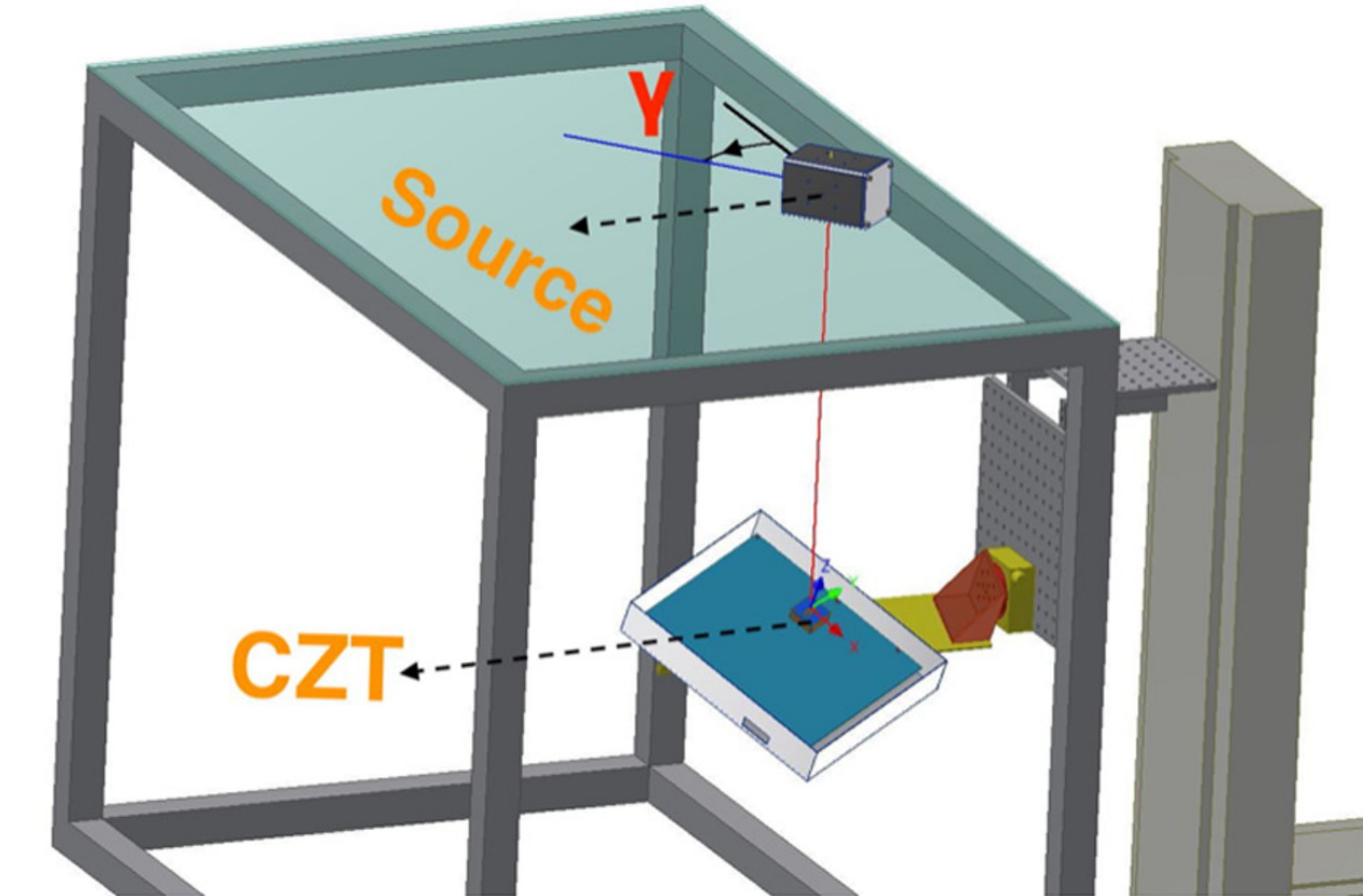
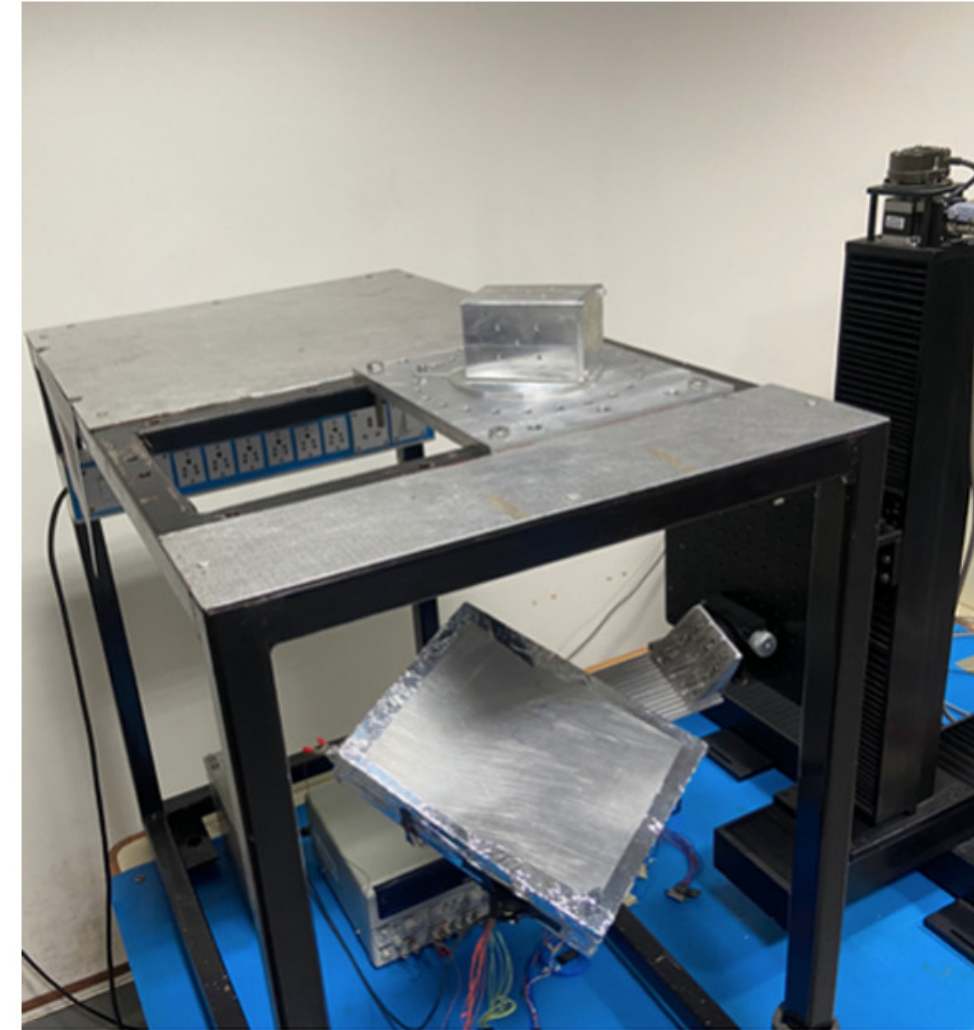
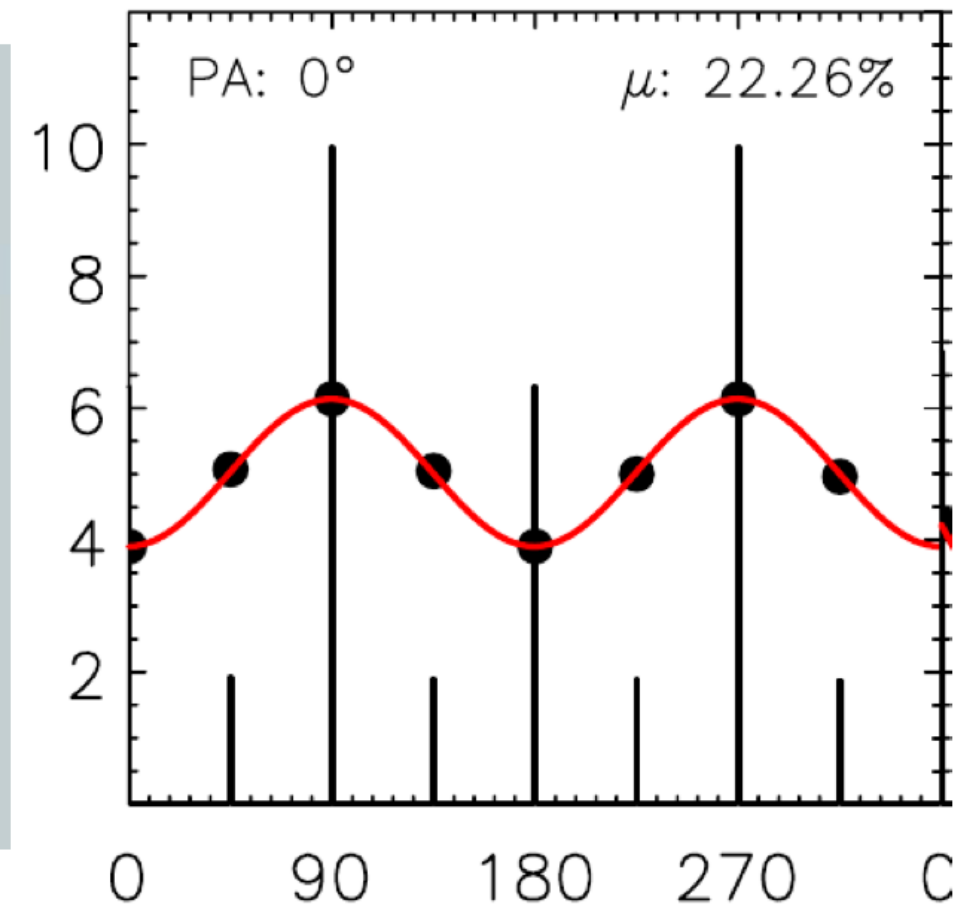
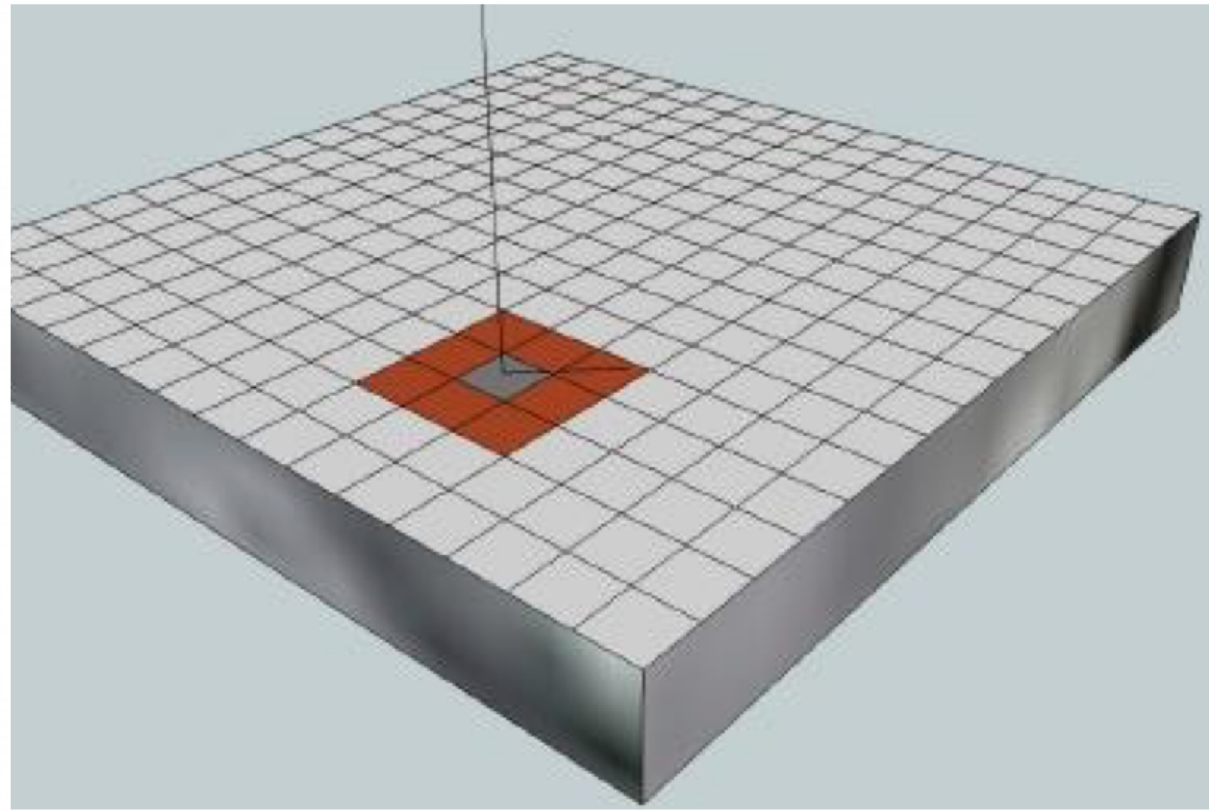
Phase-resolved Spectroscopy: Crab



Work in progress

X-ray Polarimetry with CZTI

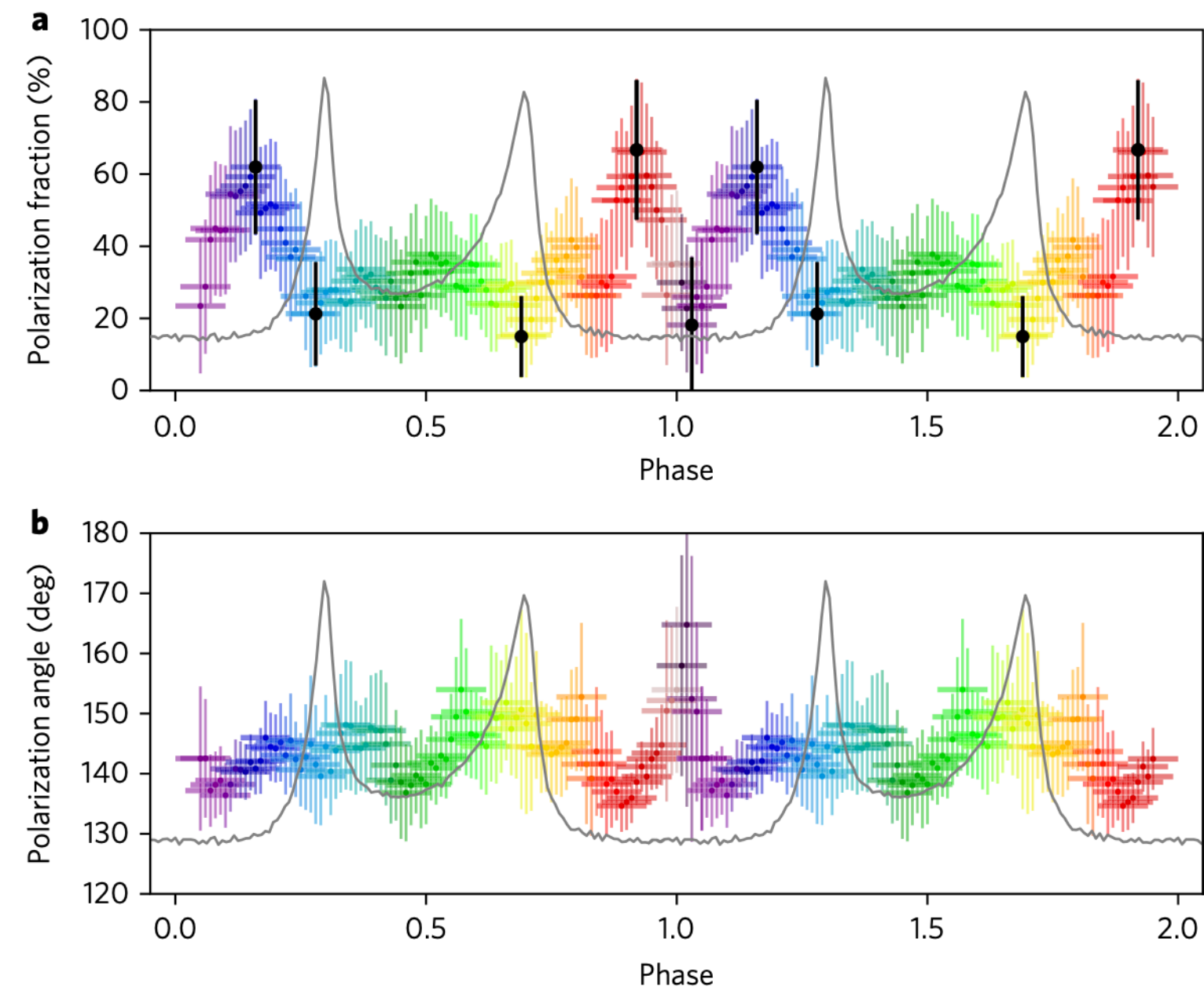
Demonstration of technique on ground



Validation of
off-axis
polarimetry

X-ray Polarimetry with CZTI: Results

Crab Pulsar and Nebula



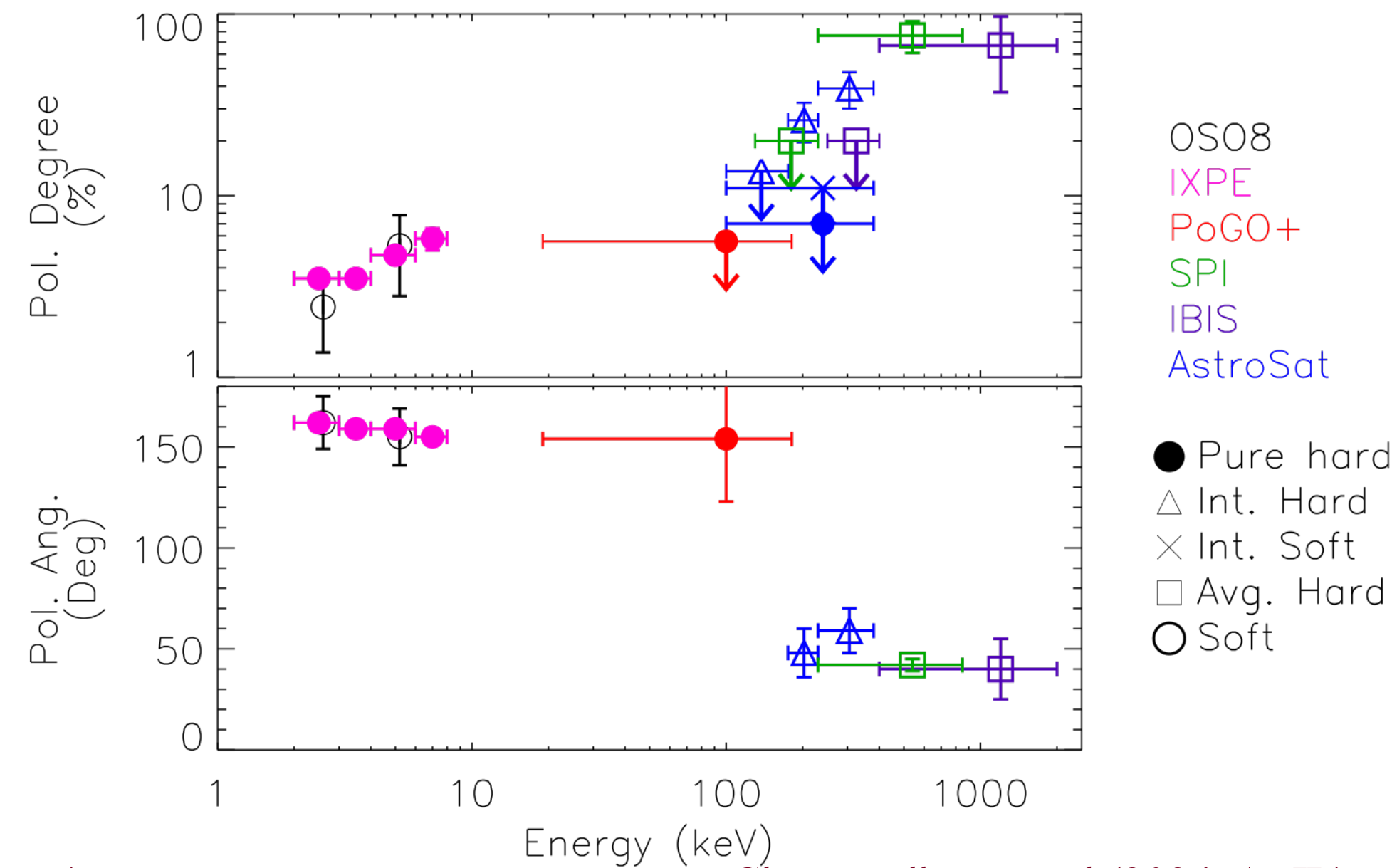
Vadawale et al (2018, Nat. Astr.)

Precise measurements of X-ray polarisation
this hard X-ray band

Swings in polarisation fractions: Rules out
models such as polar cap

Intriguing observation: Polarisation variations
in off pulse period - Not explained by current
models

Cygnus X-1



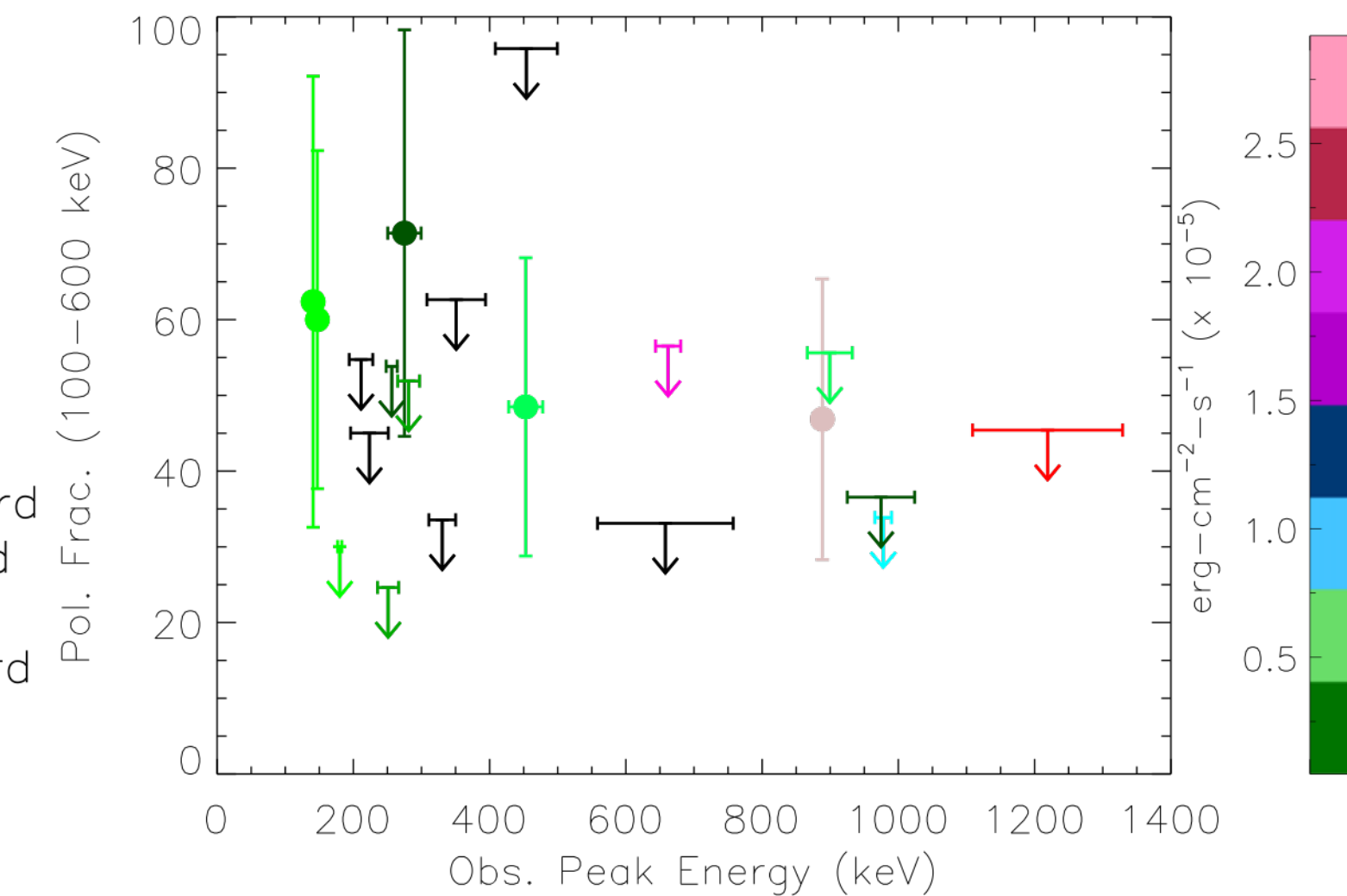
Chattopadhyay et al (2024, ApJL)

State-dependant polarisation of black hole
binary Cygnus X-1

Polarisation only in Intermediate hard state - no
detection in intermediate soft and pure hard
states

Contribution of jet in hard X-rays

Gamma Ray Bursts



Chattopadhyay et al (2022, ApJ)

Largest sample (20) of GRB polarisation
measurements

Only five GRBs show detection of
polarisation : Rest unpolarised when
integrated over the entire GRB duration

Suggesting synchrotron in ordered
magnetic field

Future Work

- Gain: Some changes in recent data - may revisit the time-dependant correction
- Crab Norm: Scatter across quadrants, consistency for more recent observations
- Cross-calibration using observations of other sources with NuSTAR etc.

Future Work

- Gain: Some changes in recent data - may revisit the time-dependant correction
- Crab Norm: Scatter across quadrants, consistency for more recent observations
- Cross-calibration using observations of other sources with NuSTAR etc.

Thank you