XRISM Resolve’s energy scale calibration and uncertainties

Megan Eckart

on behalf of the Resolve Team and XRISM In-Flight Calibration Team

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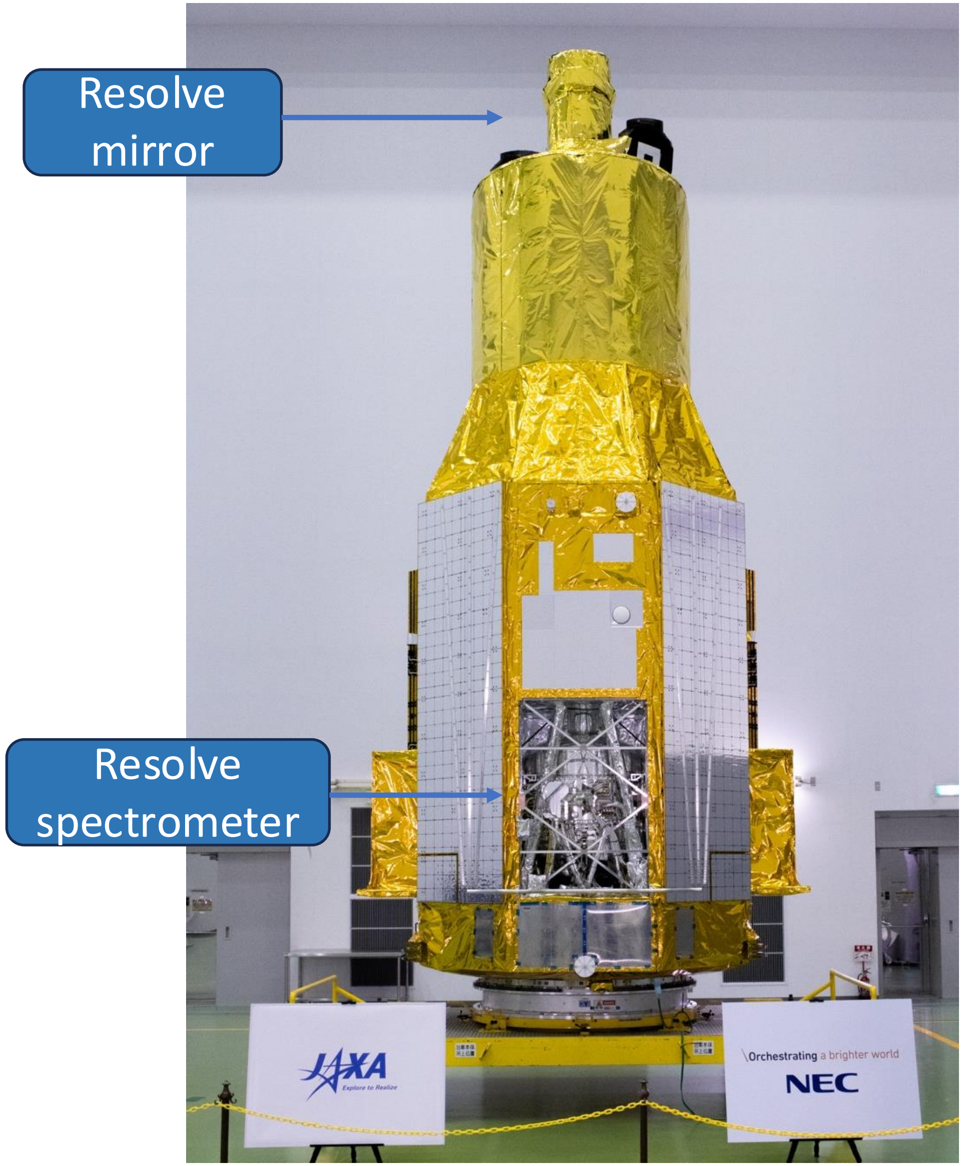
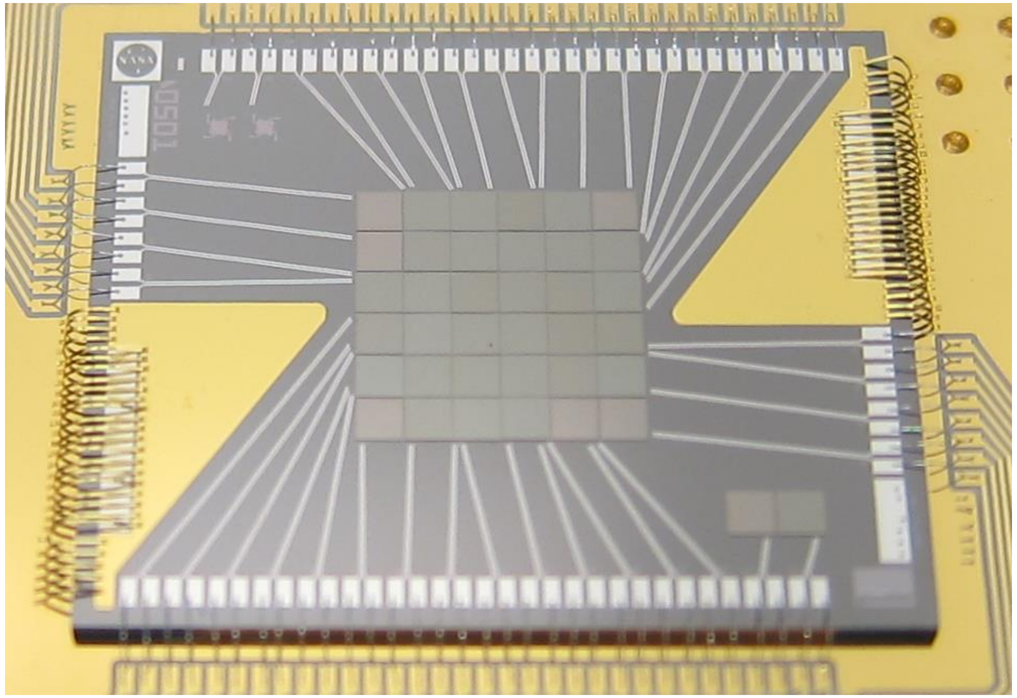
XRISM's Resolve instrument



Non-dispersive spectrometer at focus of soft x-ray grazing-incidence mirror
Photo credit: JAXA Digital Archives

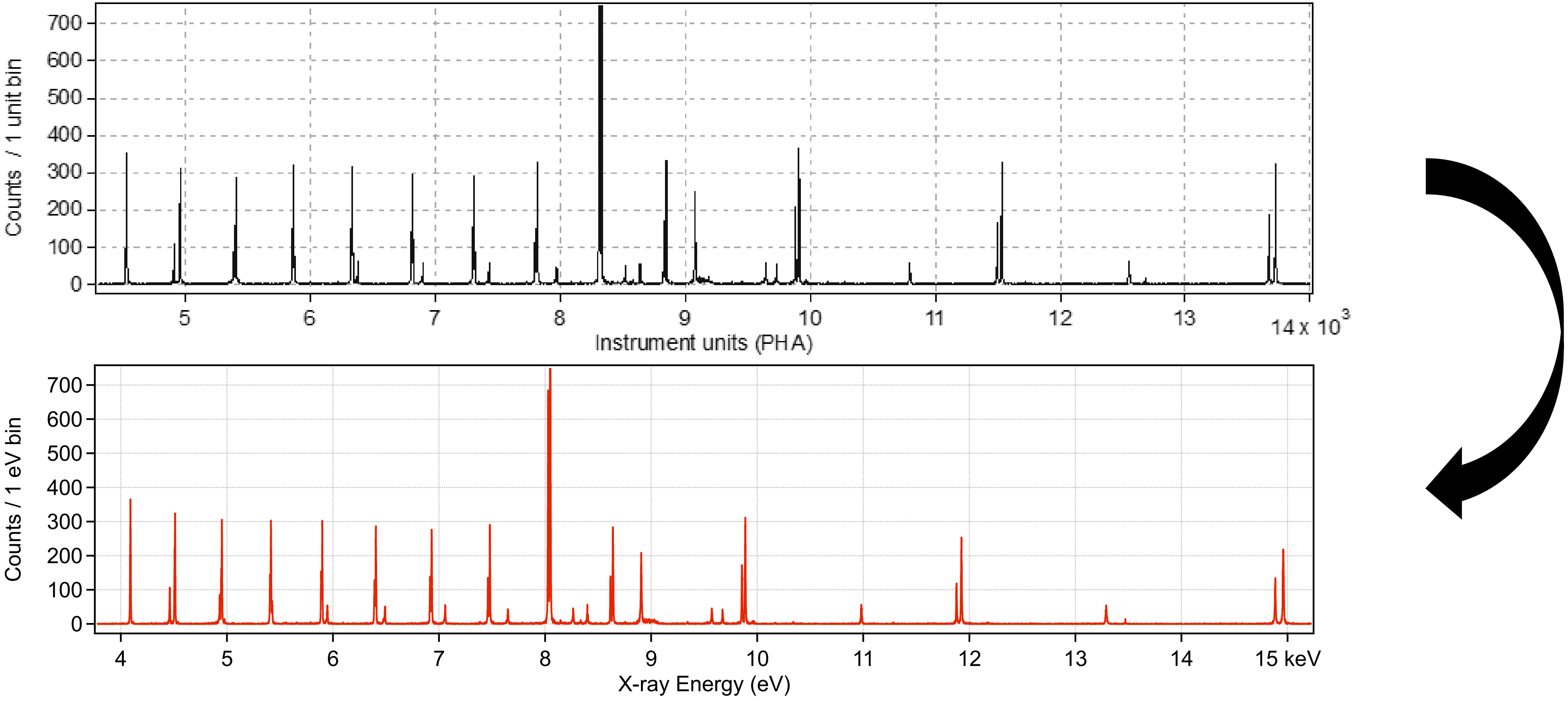


- 36-pixel detector array; each pixel provides ~5 eV FWHM resolution
- Operated at 50 mK

Energy scale transforms signal measured by Resolve instrument to calibrated photon energy

Events from instrument

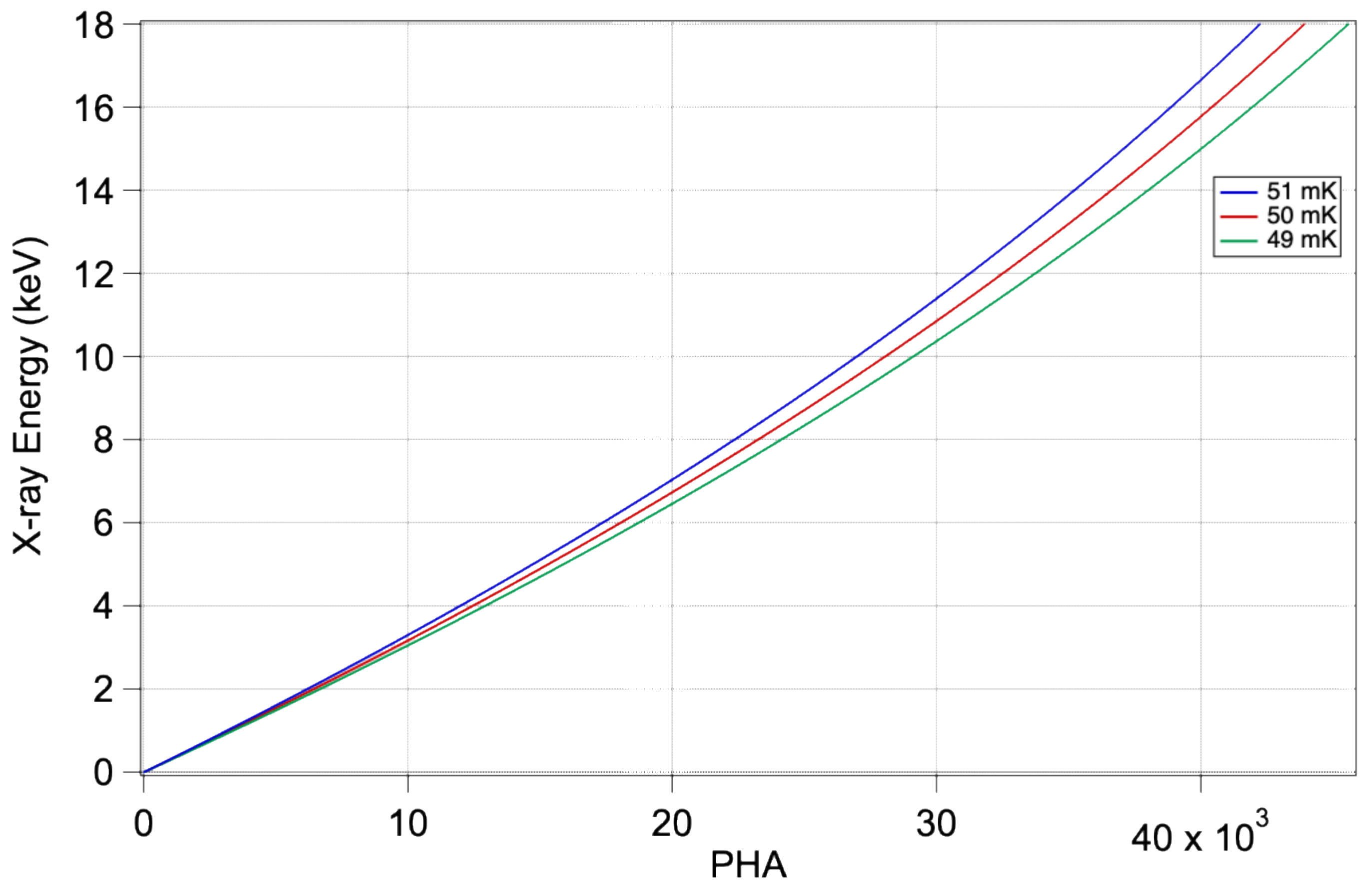
Calibrated events



Energy gain scale curve determined empirically by fitting PHA vs energy of known emission lines using ~6th order polynomial.

Measured at instrument operating temperature of 50 mK and at nearby temperatures (±1 mK).

Gain curves at 49, 50, 51 mK



Example from a single pixel – CalDB contains curves for each pixel

Accuracy of energy scale is a top-level instrument requirement and has been met on orbit

Requirement:

Knowledge of absolute energy gain scale to ±2 eV

Approach:

Measure and parameterize gain on ground for each pixel using fluorescent sources

Use these parameters to calibrate flight data, informed by Mn Kα monitoring onboard

Verify calibration using onboard sources and celestial sources

Outline

- Ground measurements
- In-flight calibration exposures & uncertainties
- Mid-res secondary gain

Ground measurements

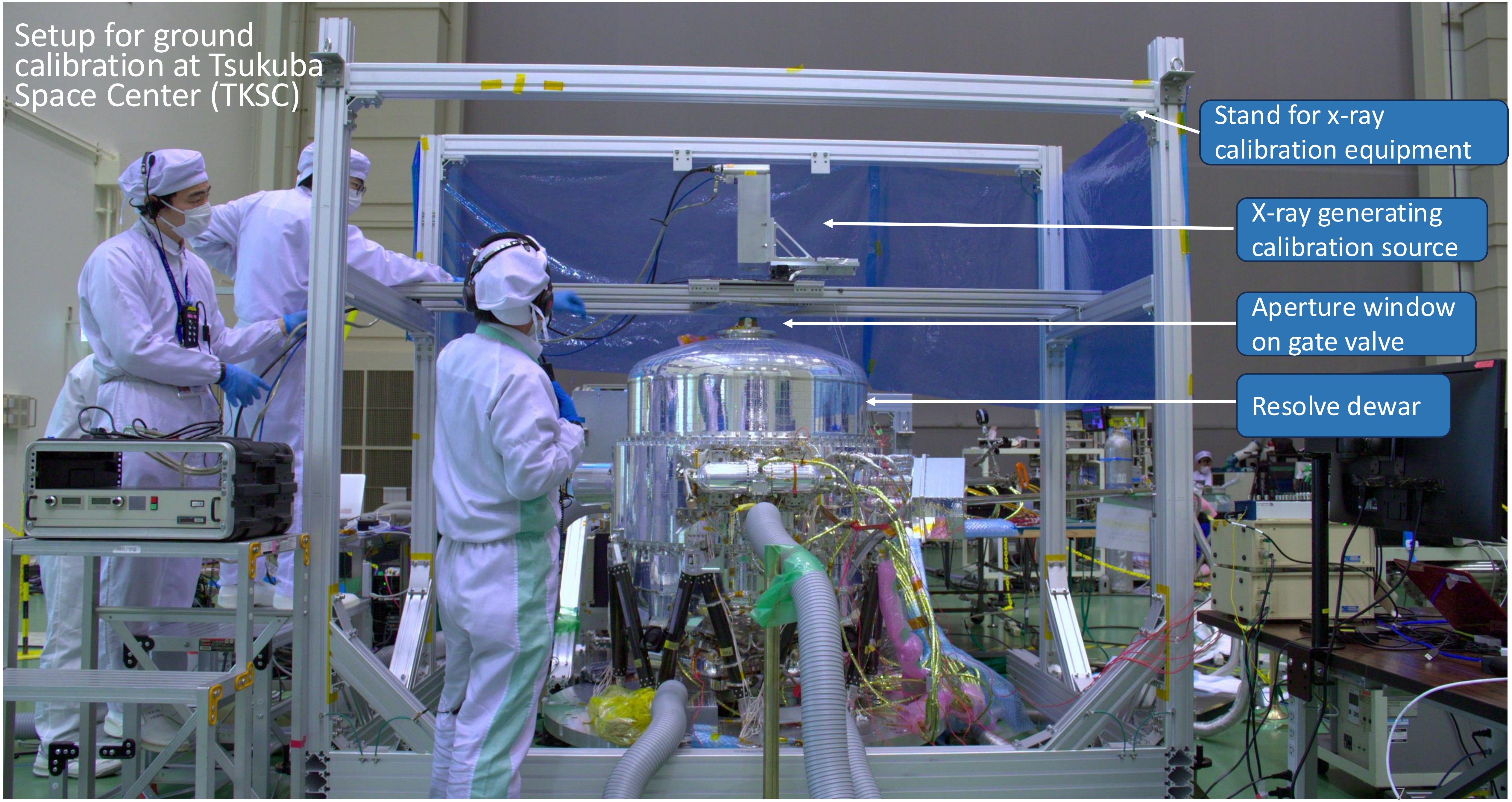


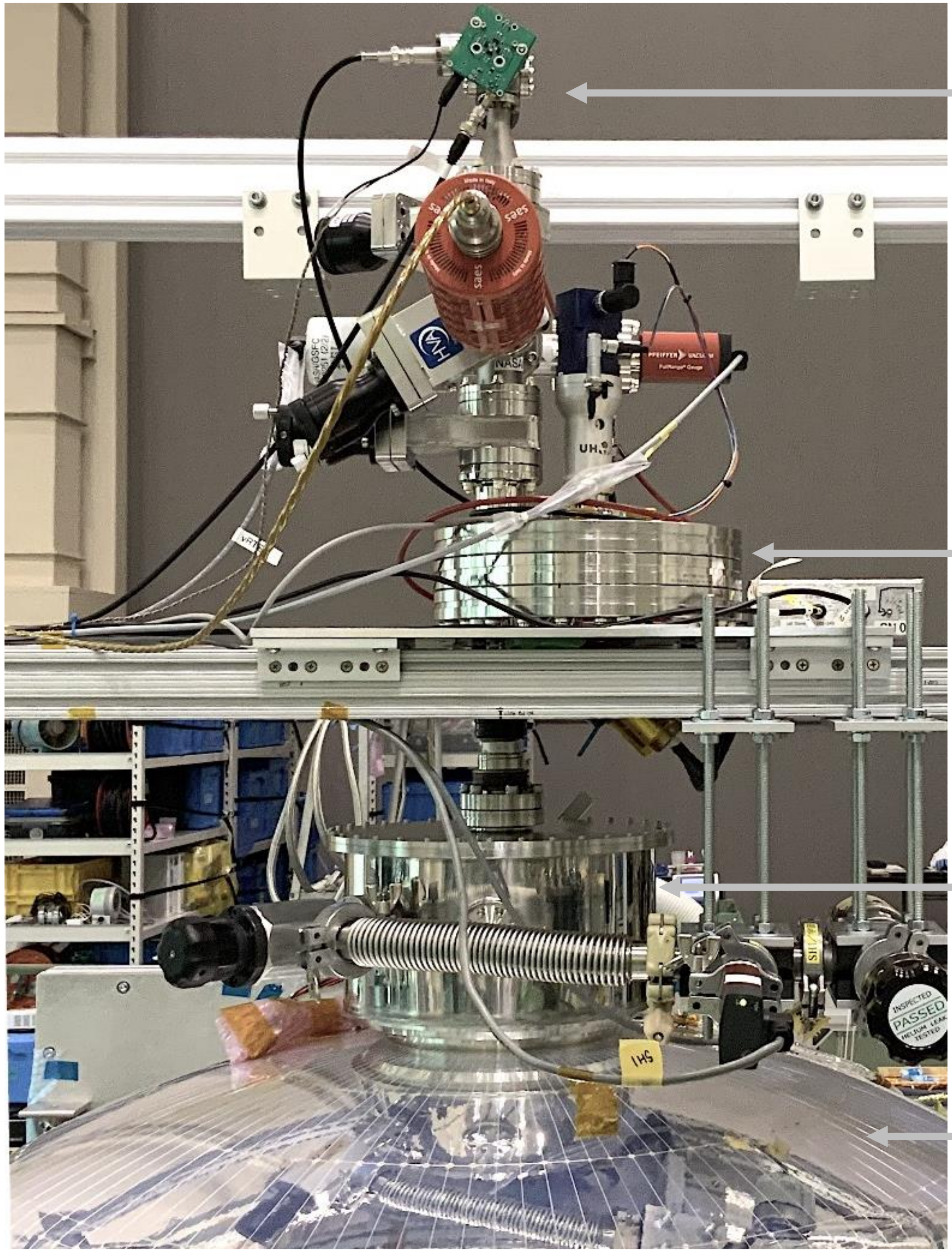
Photo credit: JAXA Digital Archives

Setup to measure low-energy gain scale with gate valve open at TKSC

250 µm Be window removed from from optical path by opening gate valve

MXS photons shine through open position on rotating target wheel

Natural line shapes of MXS's oxygen K and fluorine K complexes measured with spare detector, using EBIT emission lines for precise gain reference.



Low-energy Modulated X-ray Source (MXS) 0.3–1.5 keV

Vacuum Rotating Target Source (RTS) 1.2–10 keV

Vacuum bell jar around dewar aperture with mechanism to manually open dewar gate valve

Top of dewar dome

Illustration of ground data for 50 mK gain scale

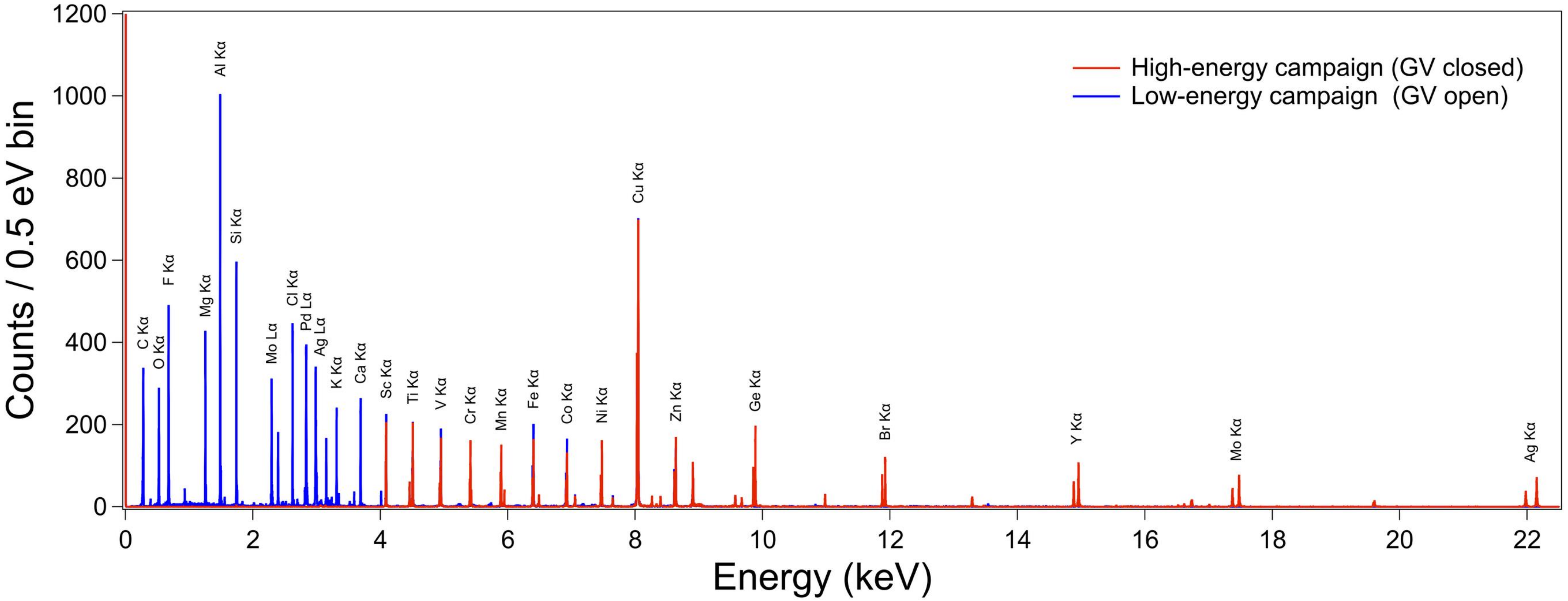
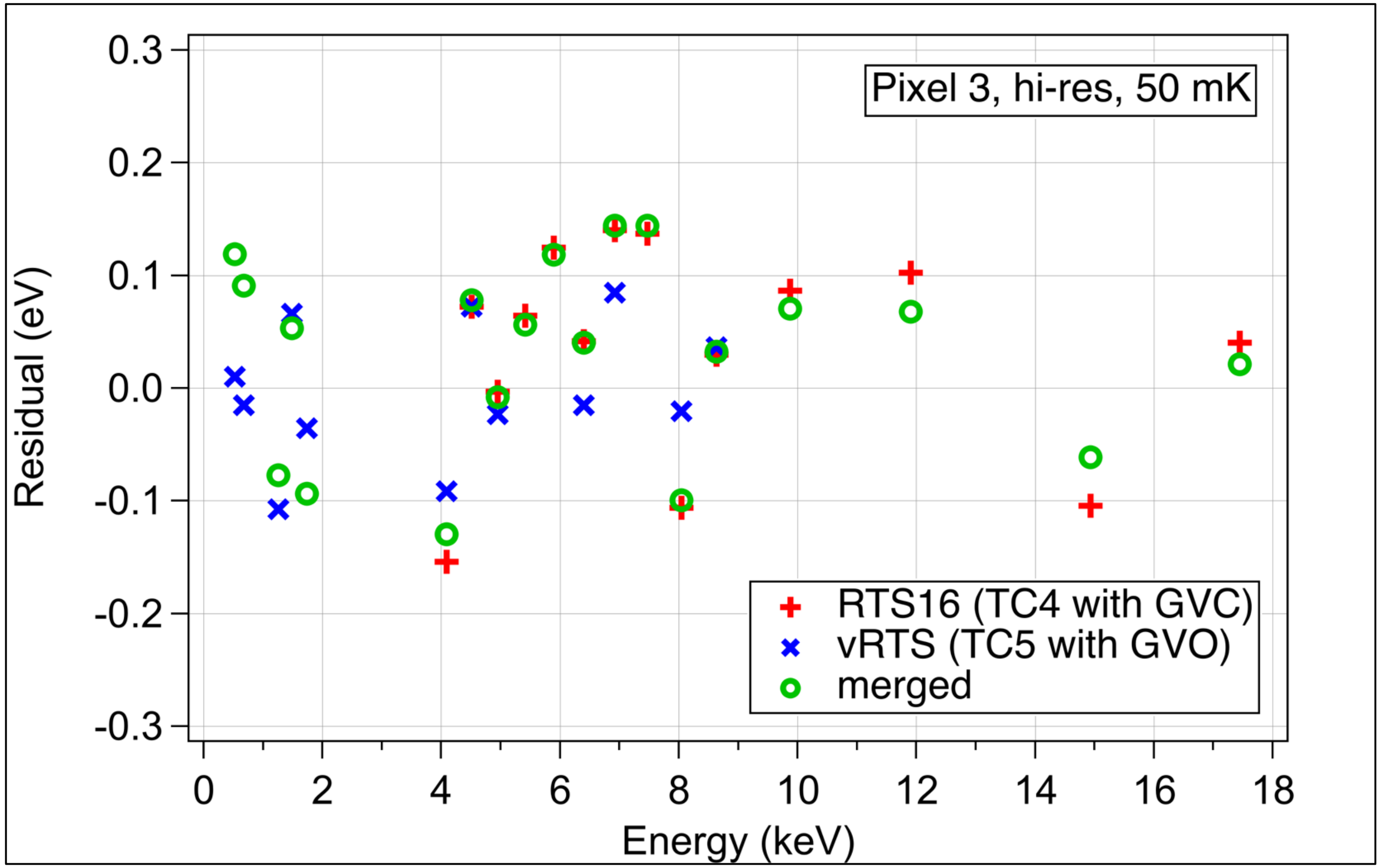
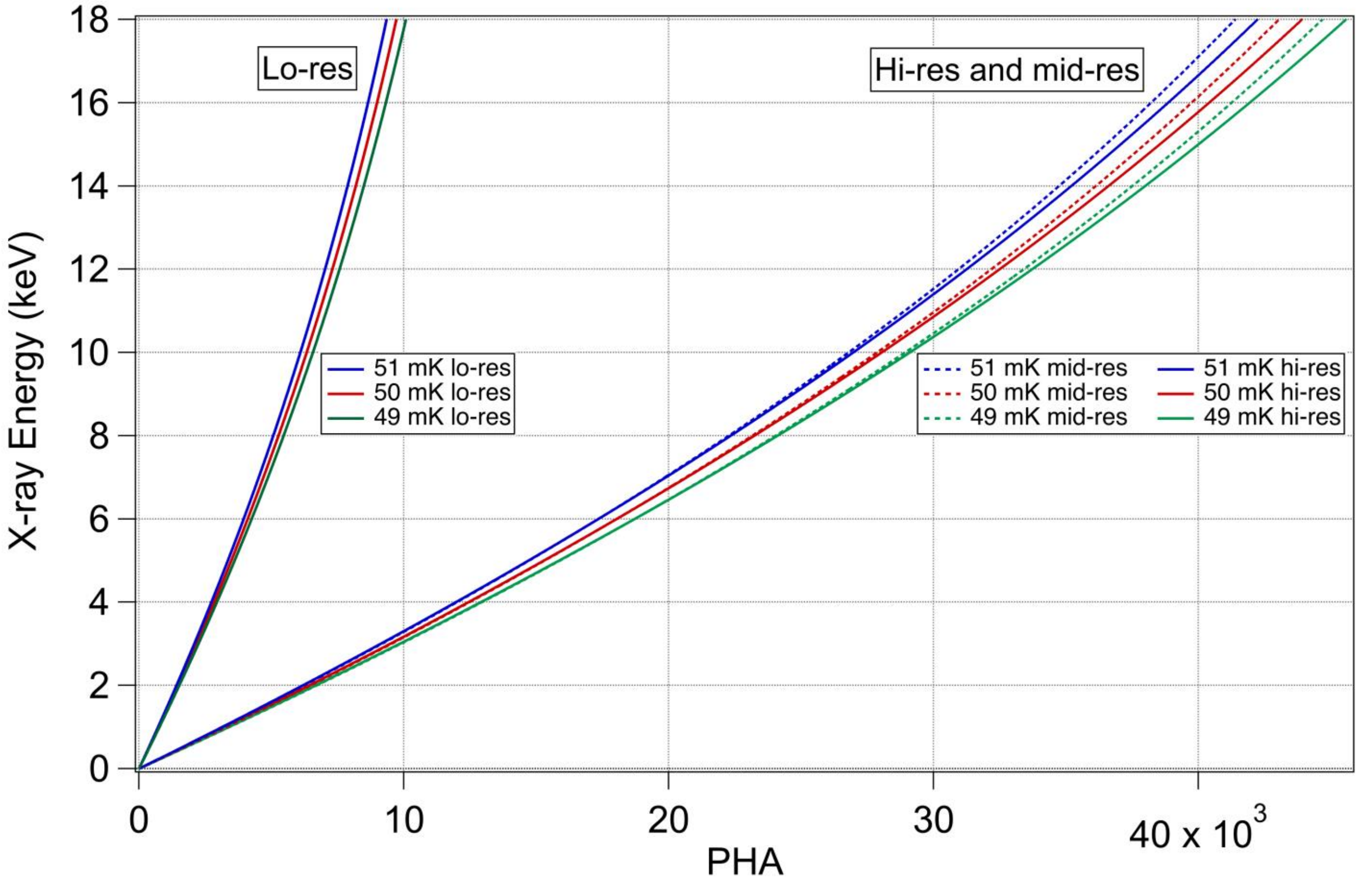


Illustration of ground data for 50 mK gain scale – fit residuals show gain scale accuracy of ~0.2 eV



Gain curves – all primary grades



Example from a single pixel – CalDB contains curves for each pixel

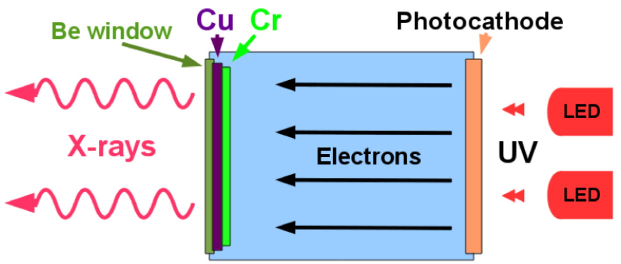
In-flight calibration exposures & uncertainties

In-flight energy scale calibration monitoring

Approximately every six months, use onboard sources (^{55}Fe, MXS1, MXS3) to check energy gain scale and pixel behavior

- To-date: October 2024, April 2025, October 2025, April 2026

These exposures take place when Xtend is looking at a soft source

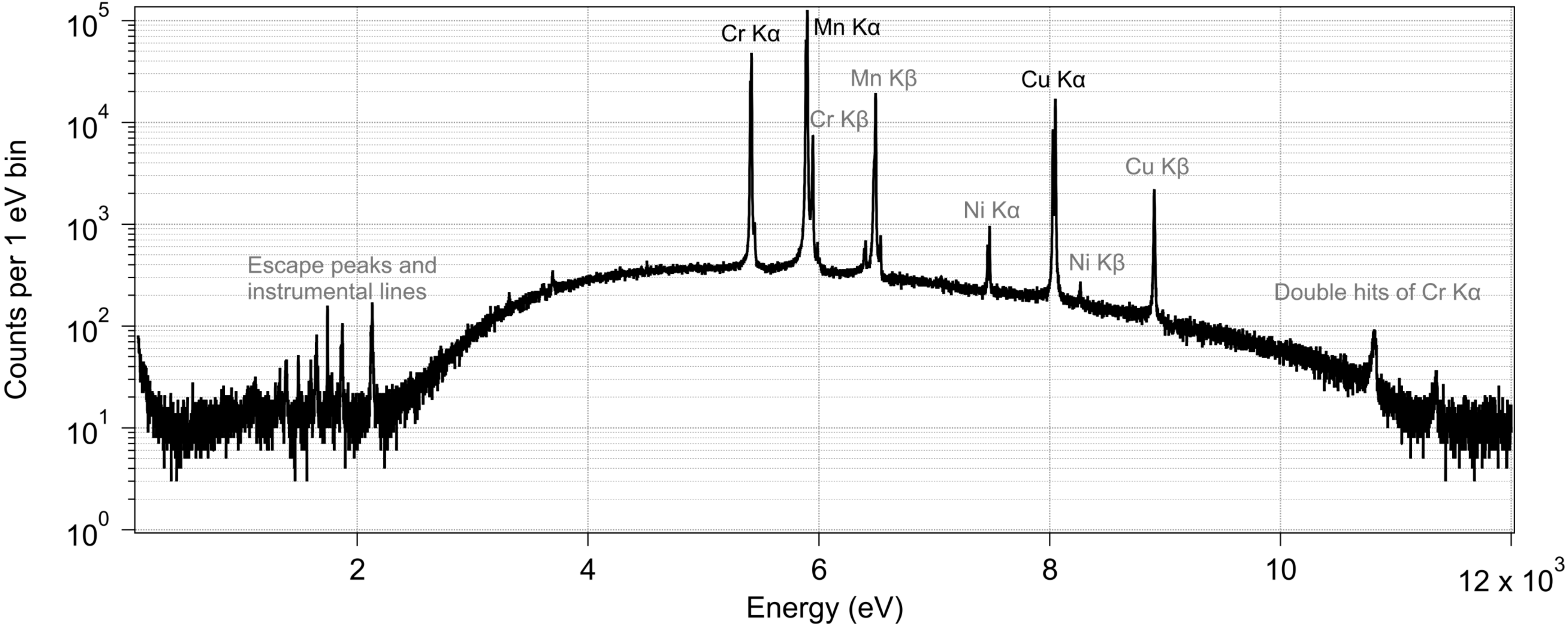


Modulated X-ray Source (MXS)

Complications:

- MXSs can induce gain shifts! This makes our gain assessment away from 6 keV very challenging
- MXSs are operated at extremes of allowed pulse parameter space (e.g., low LED current, short pulse period)
  - This part of phase space was not well explored on ground
  - Some of the calibration time in 2025 was used to determine optimized parameters to provide calibration assessments of gain uncertainties (avoiding MXS-induced gain offsets)
  - Spring 2026 exposures: long exposures with MXS1 (April) and MXS3 (May) to assess per-pixel gain uncertainties

Spectrum from calibration monitoring observation



Recommendations – hi-res gain uncertainties

PSF-weighted or flat-weighted systematic energy scale uncertainty from 5.4-9.0 keV: ±0.3 eV

This should be added to the cal pixel Mn Kα line offset during each observation *(more in Scott's talk)*

Outside of 5.4-9.0 keV:

- Below 5.4 keV: ~ ±1eV (constrained by Si Ka instrumental line)
- Above 9.0 keV: < ±2 eV through 17.5 keV

Developing guidance for mid-res events (primaries and secondaries) and lo-res primaries

Eckart, et al., *JATIS,* 2025

Low-energy gain systematics

Below 5.4 keV, pixel-level calibration has not been possible due to reduced soft-band effective area with the gate valve closed.

- Onboard low-energy MXSs create lines at E<1.5 keV (Mg, Al) but are blocked by Be window on gate valve

Current guidance includes a conservative ±1 eV uncertainty, based on a +1 eV offset of a Si instrumental line in stacked data *(backup slides)*

Similar positive offsets occur in Al and Si lines from the NXB database and atmospheric Ar line during solar flares, but these lines are unsuitable for absolute calibration to better than 1 eV. *(Caroline)*

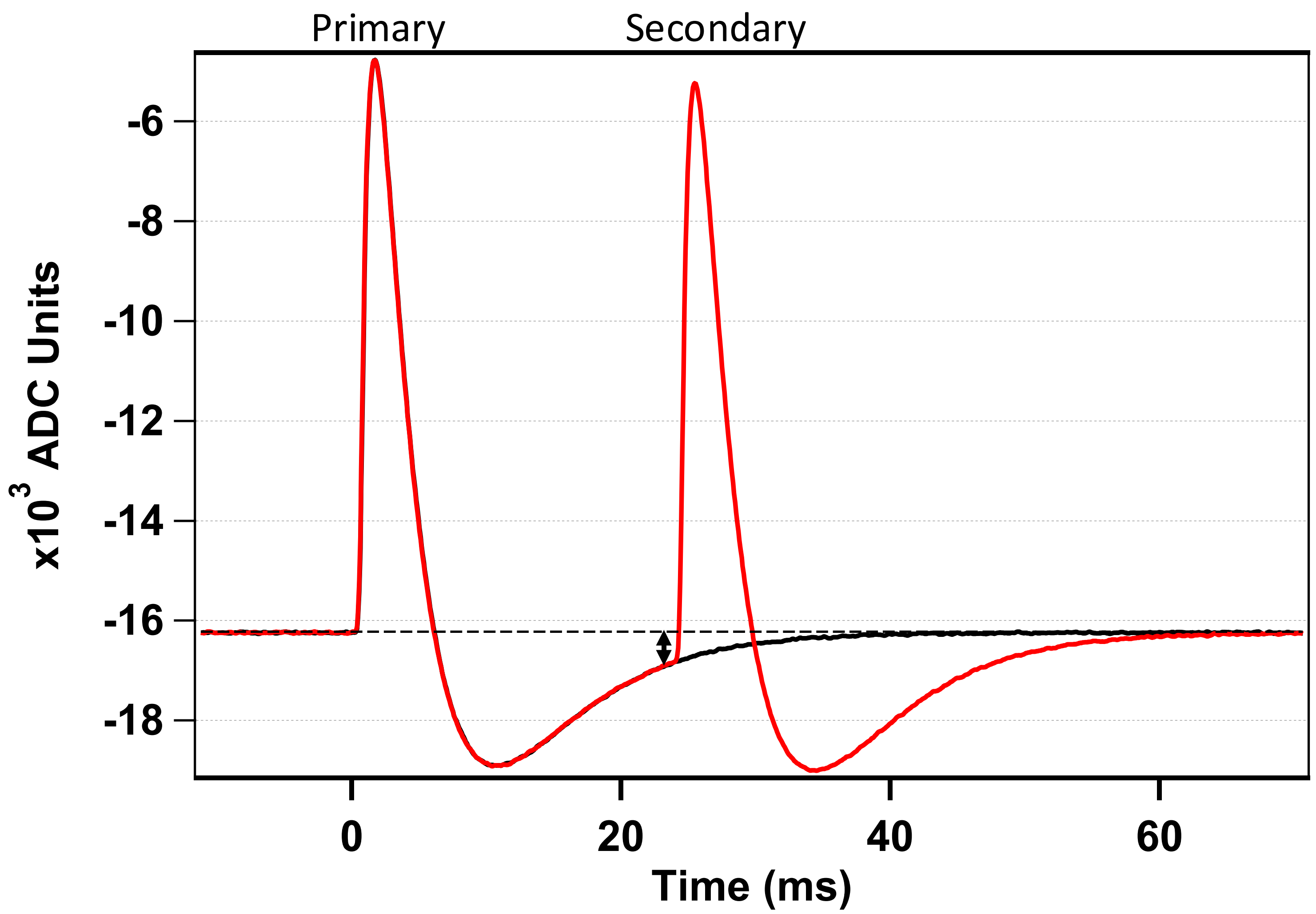
- Attempted to use line broadening to constrain energy-scale uncertainty → also consistent with 1 eV

We would like to revisit a strategy using celestial sources

- Attempts in March 2023 using HR1099 were unsuccessful in constraining gain to-date
- Is there a suitable source for simultaneous XRISM and Chandra cross-calibration observations?

Mid-res event grade gains – secondary correction

Correcting energy assignment of secondaries: events that begin on tail of previous event



- Correct secondary pulse height estimate using
  - Time between events
  - Pulse height of primary event
  - Lookup tables calculated using average pulse shapes & offset params derived by analysis
  - Uses 16 lookup tables per pixel, split by energy of primary
- Focus on mid-res secondaries, where thermal effects are smaller

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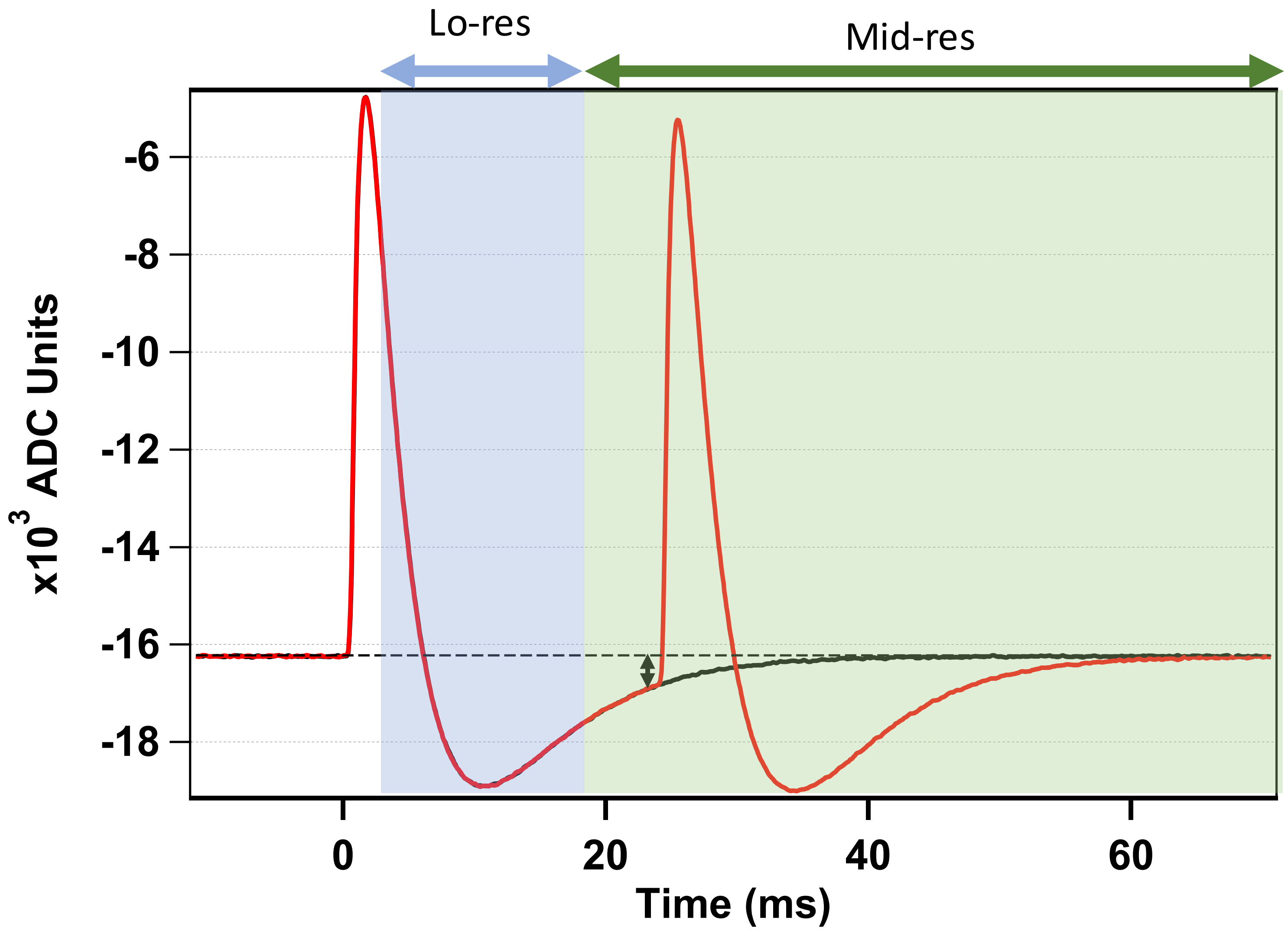

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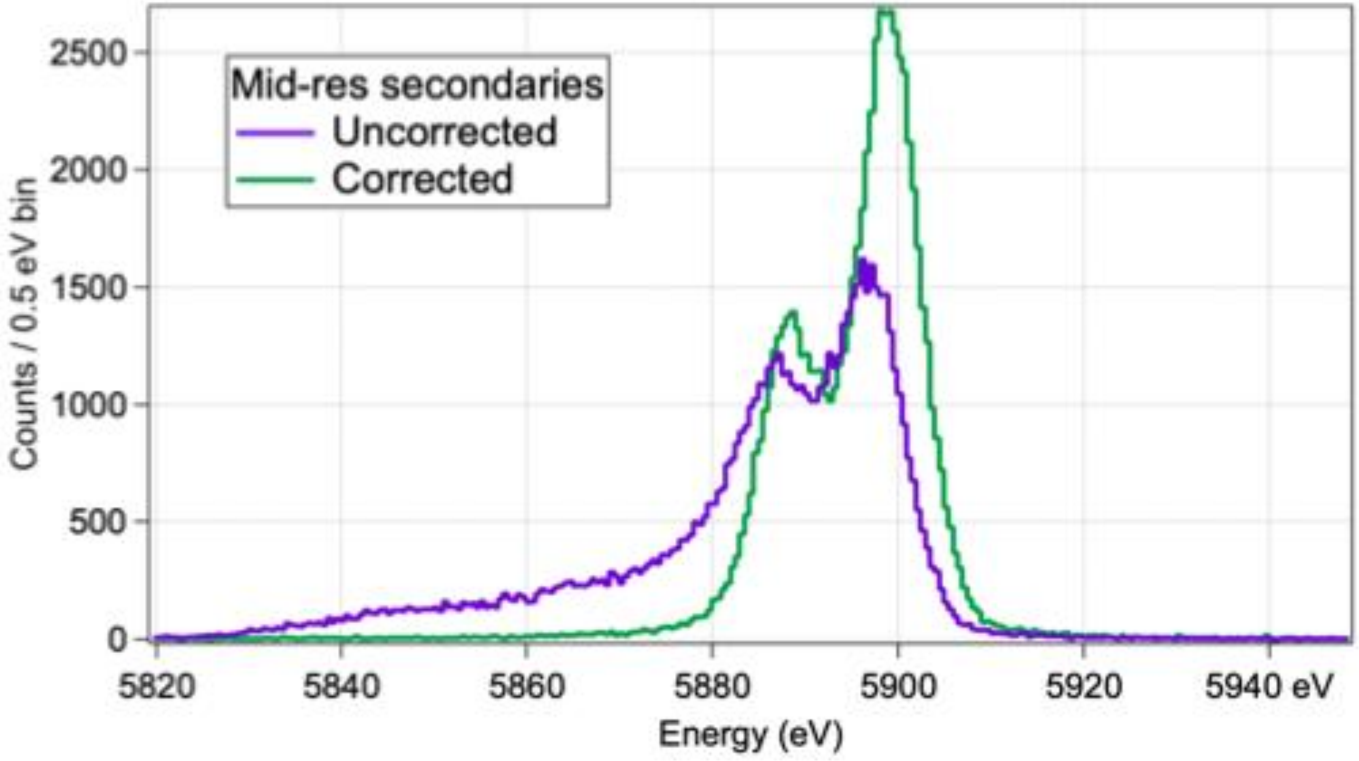
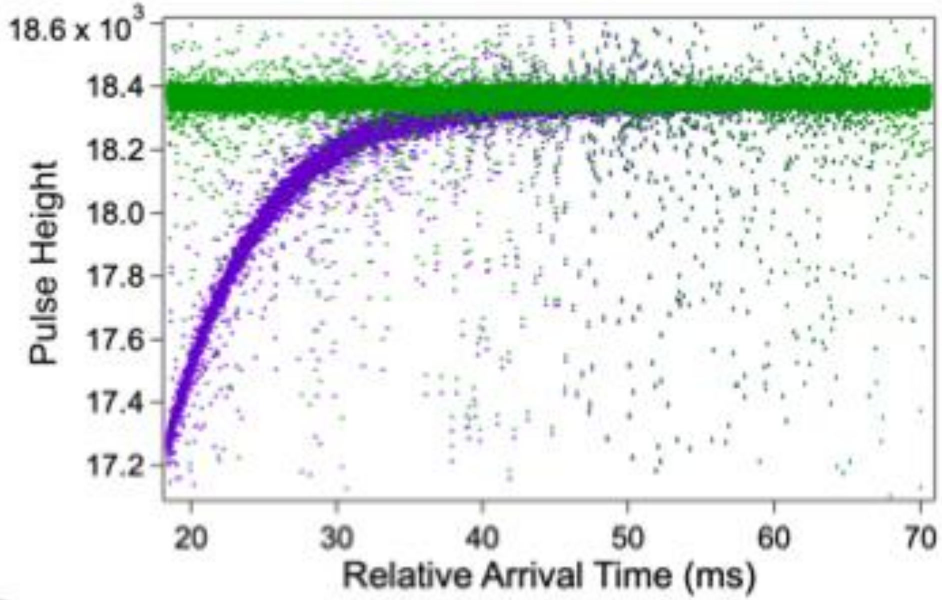
Mid-res secondary correction derived using ground data from 1.25 – 17.5 keV



Example at 6 keV



Plot shows PH vs Δt correction

From 1.25-10 keV: FWHM of secondaries only degraded by ~0.1-0.5 eV compared to primaries (Δt=30-70ms) on ground. E_{shift} within ± 0.5 eV.

Summary

Energy scales derived using ground calibration data (0.7-17.5 keV) are being used to process XRISM Resolve data

In-flight uncertainties are assessed using on-board calibration sources

Accuracy meets the ± 2 eV requirement

Challenges in assessing gain

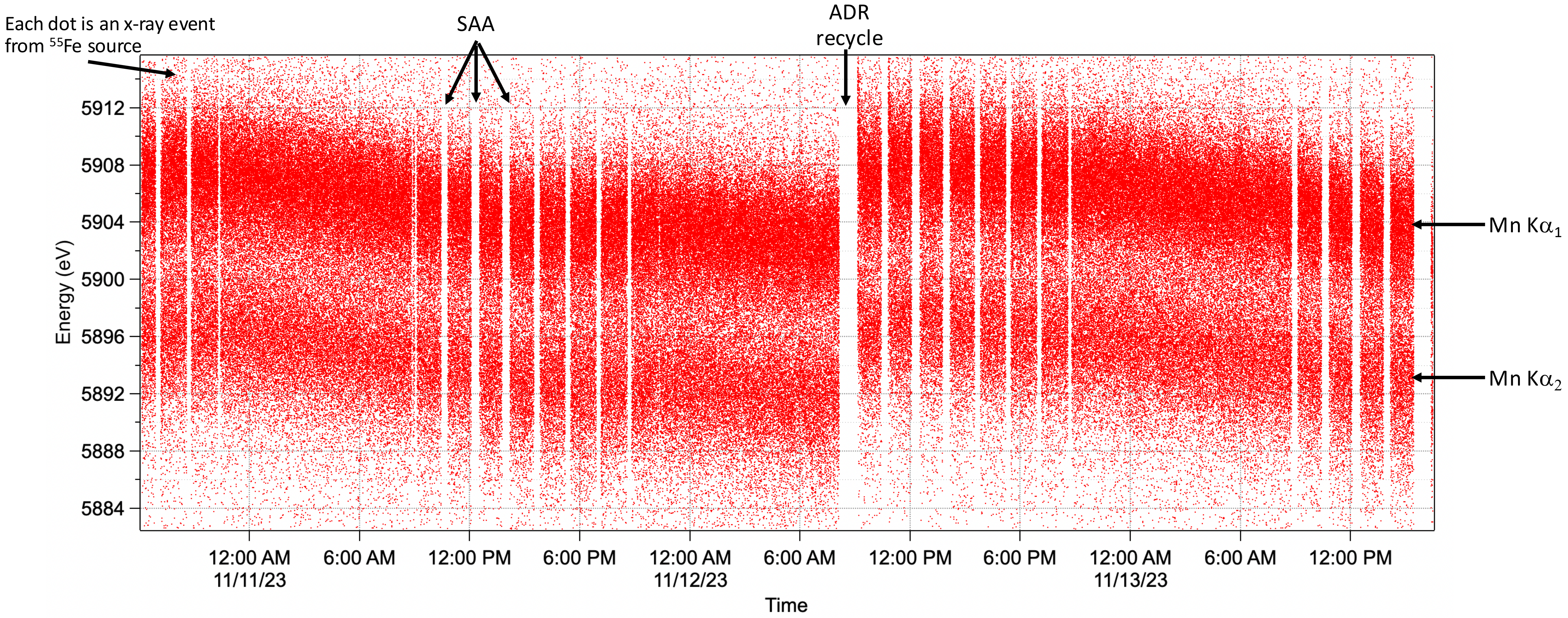
MXS-induced gain shifts

Lack of good calibrator below 5.4 keV given gate valve configuration

Work underway to estimate in-flight uncertainties for mid-res primary and mid-res secondary event grades

Backup

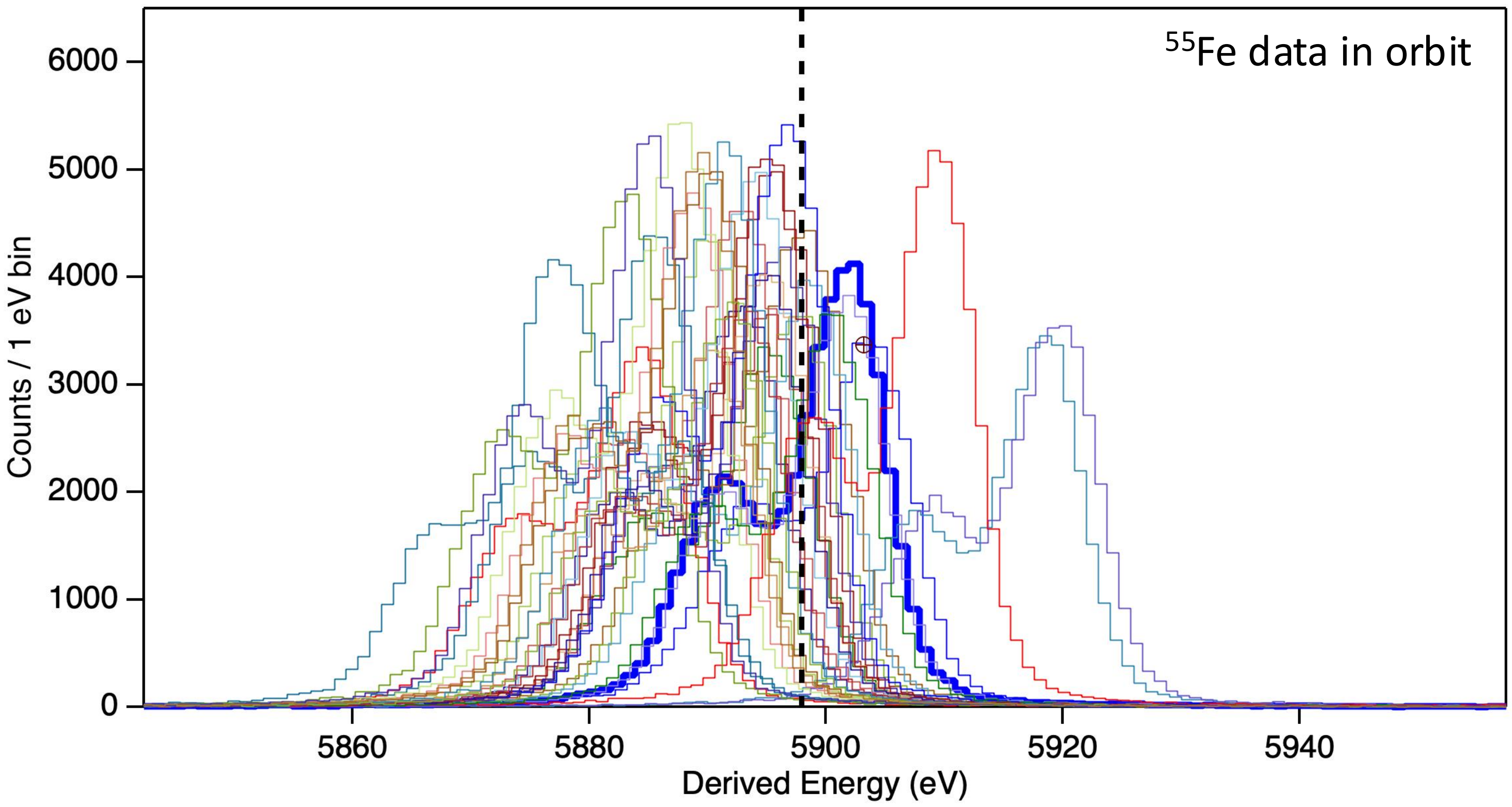
Time-dependent changes in instrument operating conditions cause small drift within observations



- Affected by electronics box temperatures, ADR recycles, dewar temperatures

Tracking changes in energy scale: use an x-ray emission line to monitor and correct gain

- In-flight data with CalDB gains applied (no drift correction)
- Change in instrument operating conditions in flight compared to on ground cause error in energy assignment (~40 eV spread)
- Gain correction must be recalculated using measured line centroids and coefficients in CalDB



Monitor gain curves and nature of pixel jumps using long exposures with onboard sources

Aim #1:

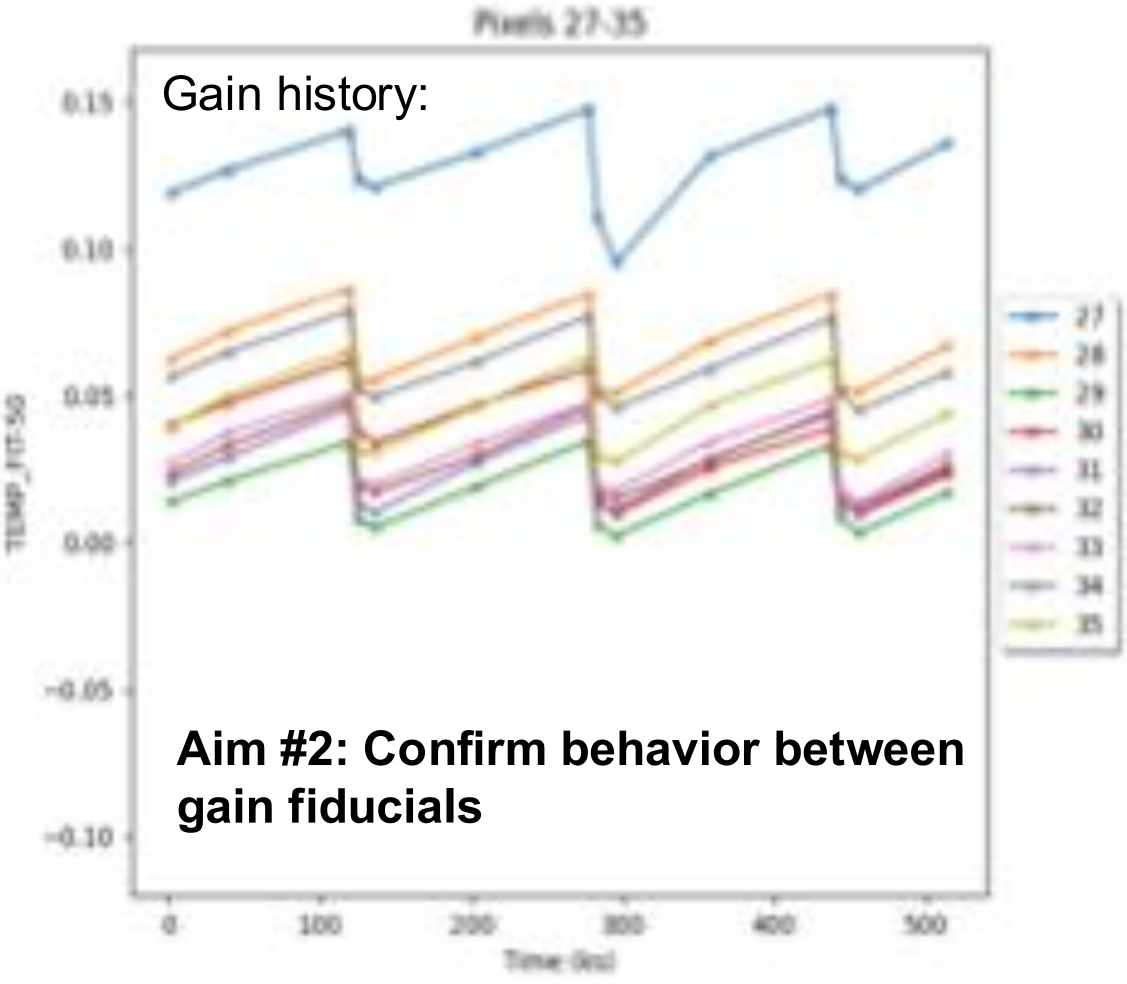
Check whether shape of gain has changed using lines at multiple energies.

- Possible action: update CalDB gain file or gain uncertainties estimates

Aim #2:

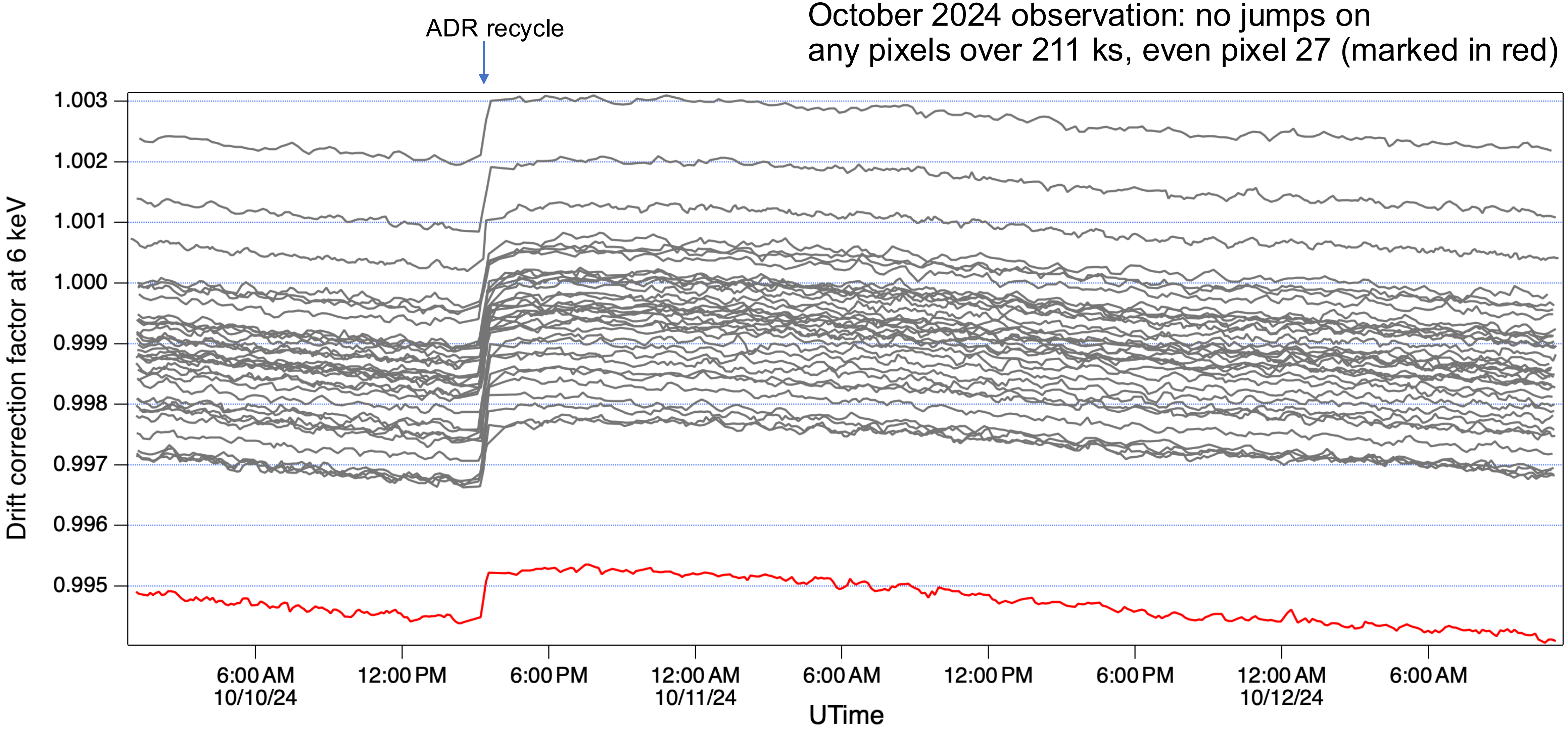
Monitor nature of pixel jumps by tracking gain over 1–2 ADR cycles continuously.

- Possible action: update guidance on pixels to watch/exclude or change cadence of gain fiducials during observations

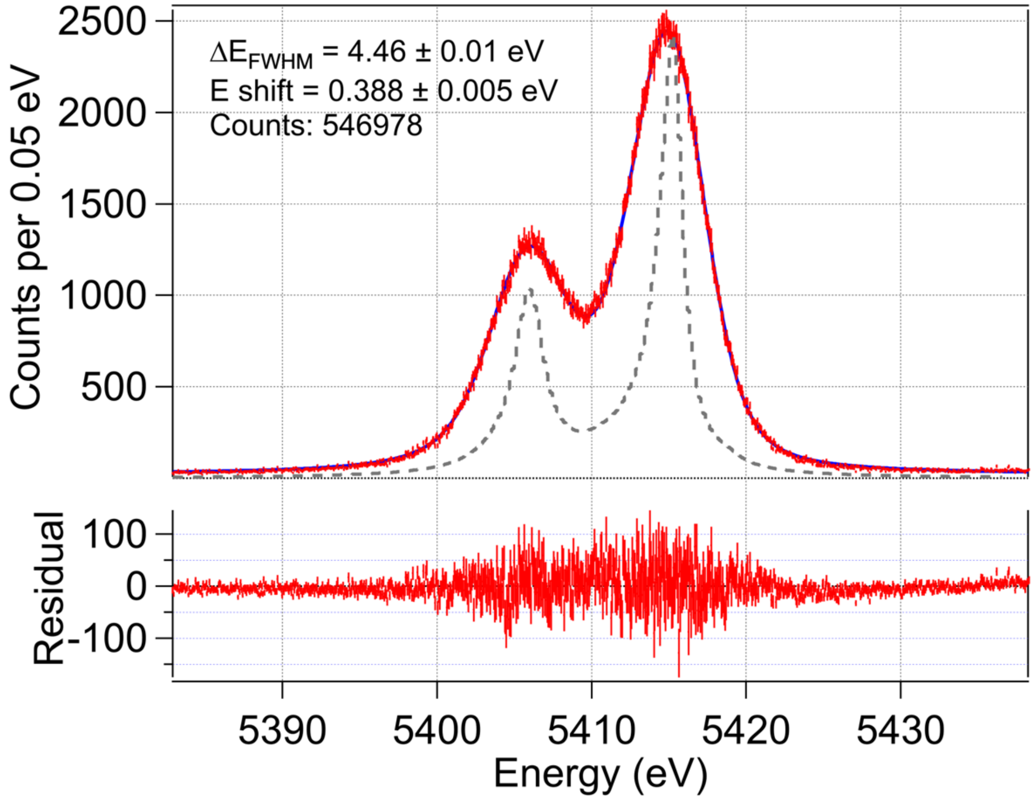


No gain jumps on any pixels during monitoring observations to-date

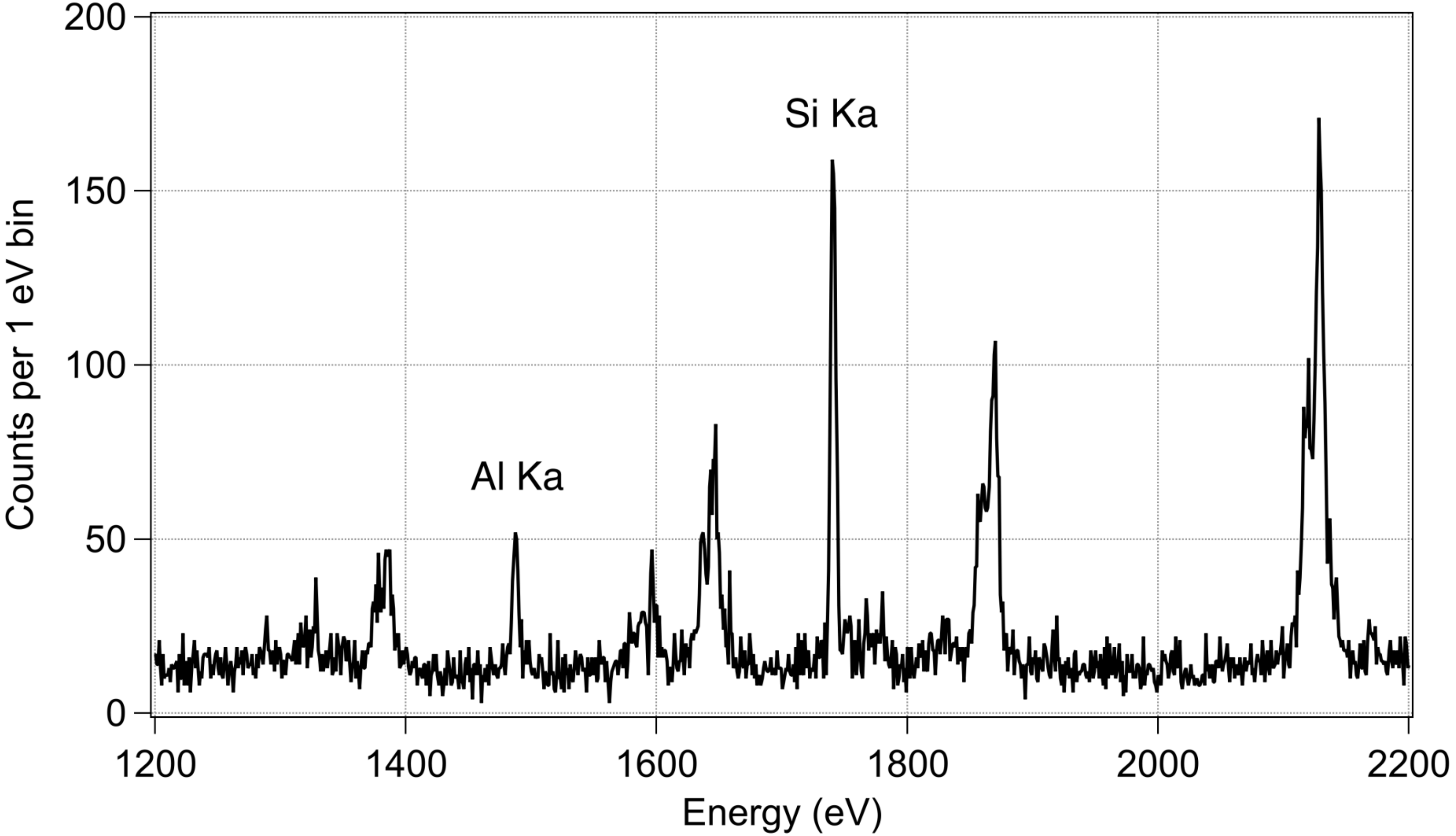
October 2024 observation: no jumps on any pixels over 211 ks, even pixel 27 (marked in red)



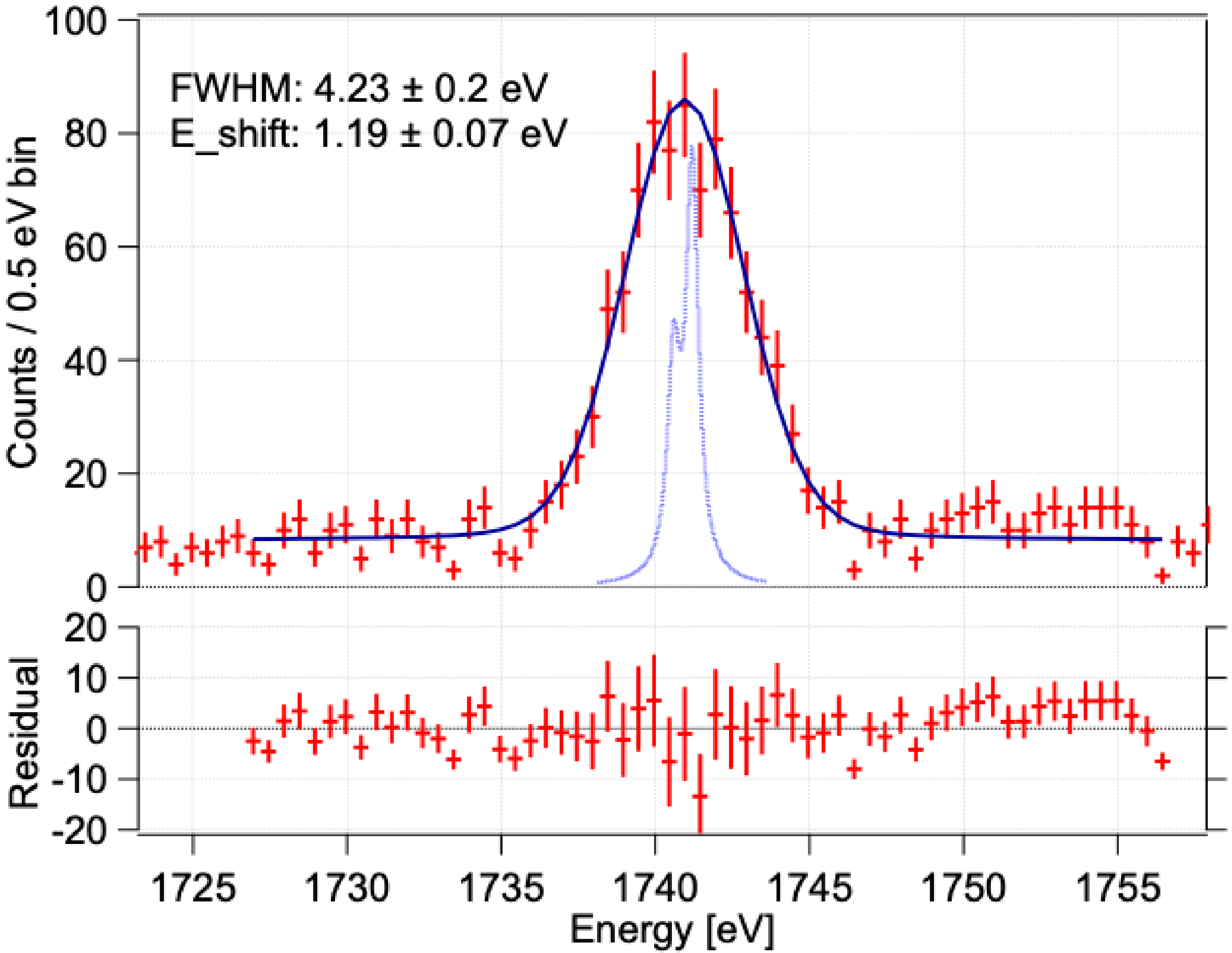
Spectrum from calibration monitoring observation – showing small MXS induced shift at 5.4 keV



Routine monitoring: zoom at low energy



Si Ka instrumental line – assess gain at low-E



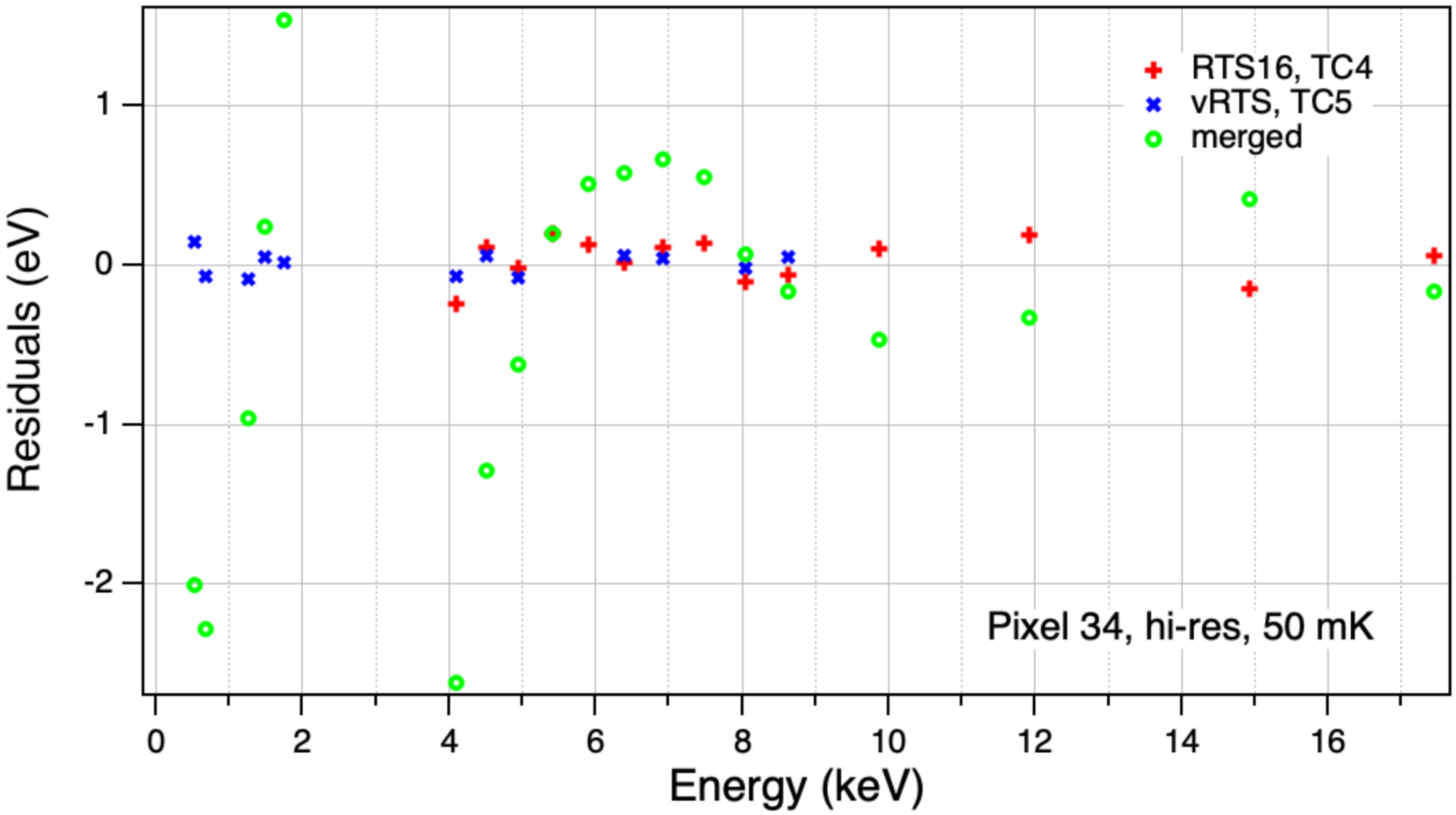
Set of ground energy scale measurements at instrument level are in use calibrating science data

	Low-E / High-E bands	Heat sink temperature (49, 50, 51 mK)	Grade (hi-res / mid-res / lo-res)	Pixels	Total
Simultaneous data acquisition			✓	✓	6 exposures each 24–36h
Analyzed separately	✓	✓	✓	✓	18 x 36 curves
Merged after initial analysis	✓*				9 x 36 curves in XRISM CalDB

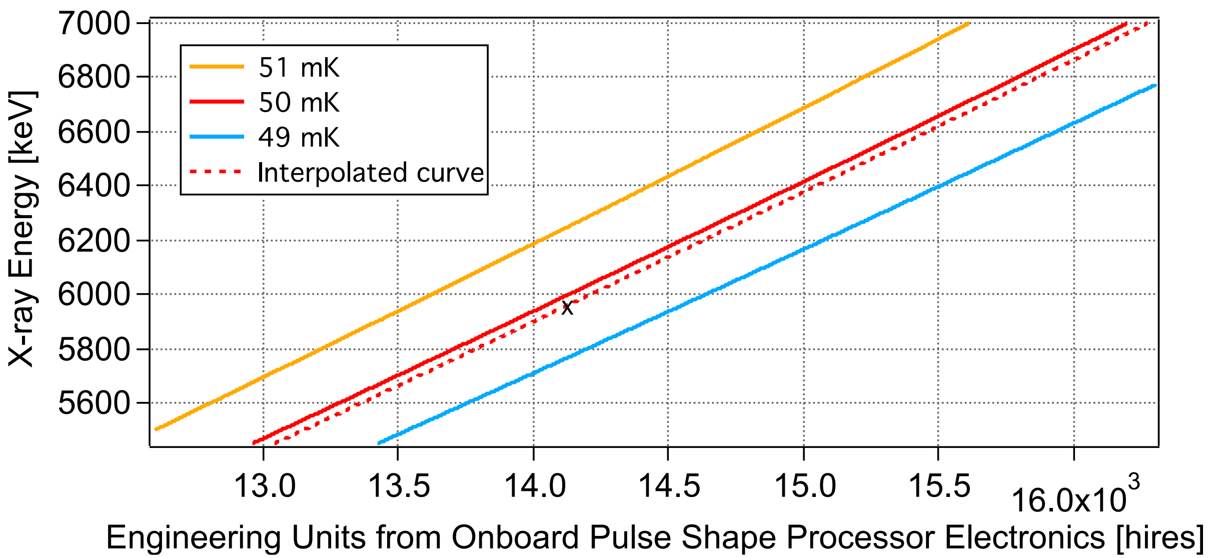
* Could not combine curves on a few pixels

Also acquired similar datasets in cryogen free mode (high-E only)

Pixel 34 gain is different between TC4 and TC5



Hi-res to mid-res gain normalization changing with XBOX temperature

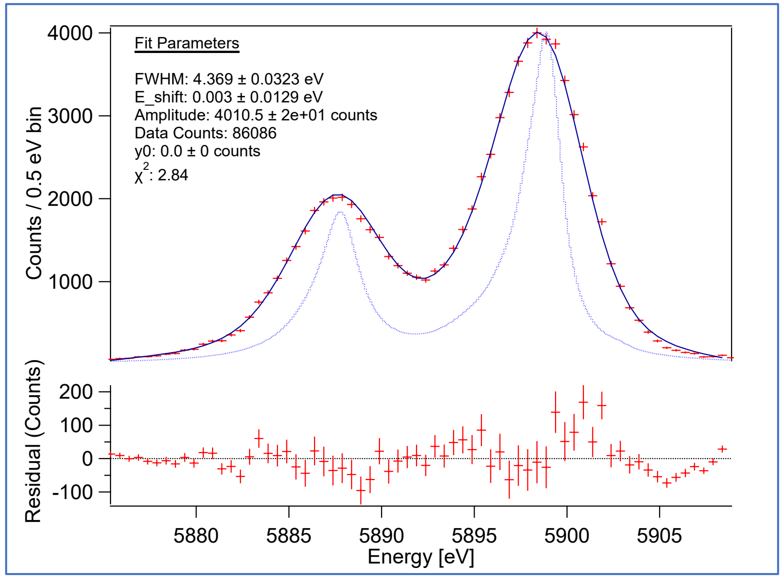


Example of calculating interpolated gain curve using measured PHA from MnKa calibration line ('X').

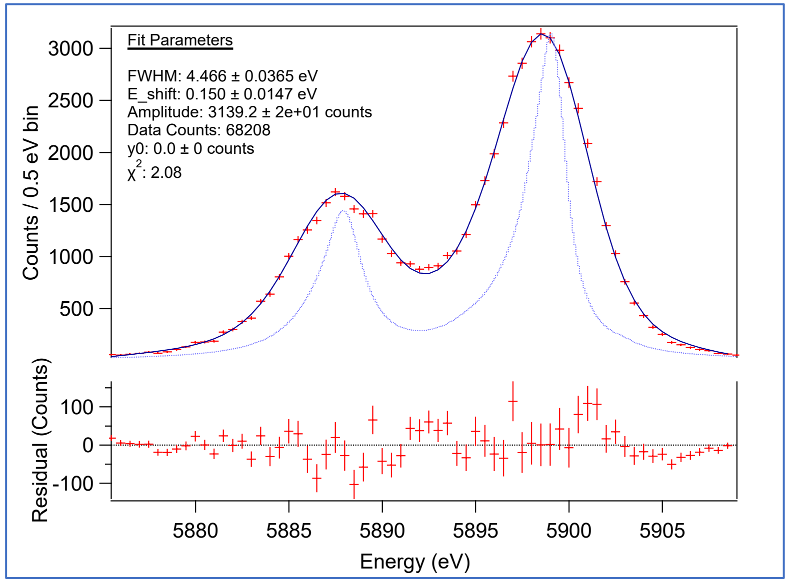
Effective temperature is 49.9 mK in this example.

- Took great care to make sure gain curves for different event grades were normalized properly
- By doing so, effective temperature derived using hi-res data will properly drift correct mid-res data
- During TVAC and on-orbit, when XBOX changes temperature from calibration conditions (room temp), **the calculated detector effective temperature differs between hi-res and mid-res**
  - Drift correcting using hi-res data then no longer works for midres (of order 1 eV error)
  - Likely due to small change in detector bias, and corresponding change in pulse shape
- On-orbit calibration performed using forced mid-res mode to characterize offset with XBOX temp – adds small linear correction using HK

Mid-res secondary correction derived using ground data works well across bandpass



Mid-res primaries
ΔE = 4.37 eV FHWM, E_{shift}=0.003 eV



Mid-res secondaries, Δt = 30-70 ms
ΔE = 4.47 eV FHWM, E_{shift}=0.150 eV

Example at 6 keV

Derived using ground data from 1.25–17.5 keV.

Across waveband:

FWHM of secondaries ~0.1-0.5 eV worse than primaries (Δt=30-70ms).

E_{shift} within ± 0.5 eV.