Resolve Data Analysis – Additional Considerations

- (Somewhat) Advanced topics
- Tips, tricks, and caveats
- Things to watch out for

Michael Loewenstein for the XRISM Science Data Center (SDC)

Tahir Yaqoob, Eric Miller, Matt Holland (PDL), Bob Hill, Morgan Waddy, Mark Mekosh, Joseph Fox, Isabella Brewer, Emily Aldoretta

Efrain Perez-Solis, Trisha Doyle, Patty Hall, Efrem Braun (alumni)

Complications and caveats

So, you’ve extracted your spectra and generated response (RMF and ARF) files using standard procedures (XRISM Data Reduction Guide, previous talk). You’ve started analyzing the data and are making ground-breaking (very possibly Nobel Prize worthy) discoveries.

What could possibly go wrong???

For the first time we have a functioning X-ray Calorimeter Spectrometer aboard a major observatory conducting GO observations!

- XRISM Resolve has unique capabilities
- Analysis of XRISM Resolve data presents unique challenges

Uncertainties - Energy

XRISM X-Ray Imaging and Spectroscopy Mission

- Energy scale (gain) and resolution (line spread function)
  - Based on ground measurements of cal-sources with many strong lines
  - Were (are being) adjusted in flight – at a limited number of energies (especially since GVC)
  - Resolution accuracy is intertwined with that of the gain: pixel-to-pixel energy shift introduces a broadening in full-array spectra
- Resolve is exceeding requirements: @ 5.9 keV, FWHM ~ 4.4 eV, shift<<0.1 eV (per pixel).
- The Resolve Team's best current estimates on uncertainties are as follows:

From Scott's talk...

- Recommended energy scale uncertainties (1 sigma):
  - 5.4-9.0 keV: 0.3 eV
    - Add cal pixel reconstruction error for each observation in quadrature
  - < 5.4 keV: 1 eV, constrained by Si Ka instrumental line
  - Above 9.0 keV: 2 eV, conservatively

E (keV)	Sigma_ FWHM (eV)
2	0.052
4	0.075
6	0.13
7	0.17
8	0.21
10	0.29
12	0.39
17	0.63

Extrapolated >12 keV

include these in your error budget

Eckart et al.
Leutenneger et al.
2025, JATIS, in press

Uncertainties - Throughput

$$C(I) = \int f(E) R(I, E) dE + C(I)^{*}$$

observed **source** **calibrated** **non-source**

To infer source characteristics from observed spectra, one needs to know

1. The effective area (one component of the response R)
2. The fraction of real source X-rays discarded for reasons of quality
3. The fraction of non-source X-rays that sneak past the screening

The goal of screening is to keep high-quality source events, discard non-source events, and keep track of the source events that are discarded for quality reasons. We are still fine-tuning procedures to minimize and track 'imposters'.

Resolve events are filtered both for non-source events (e.g., antico-coincidence), events with compromised quality (e.g., pixel 27), and for good time intervals (e.g., SAA passages, ADR recycles (previous talk).

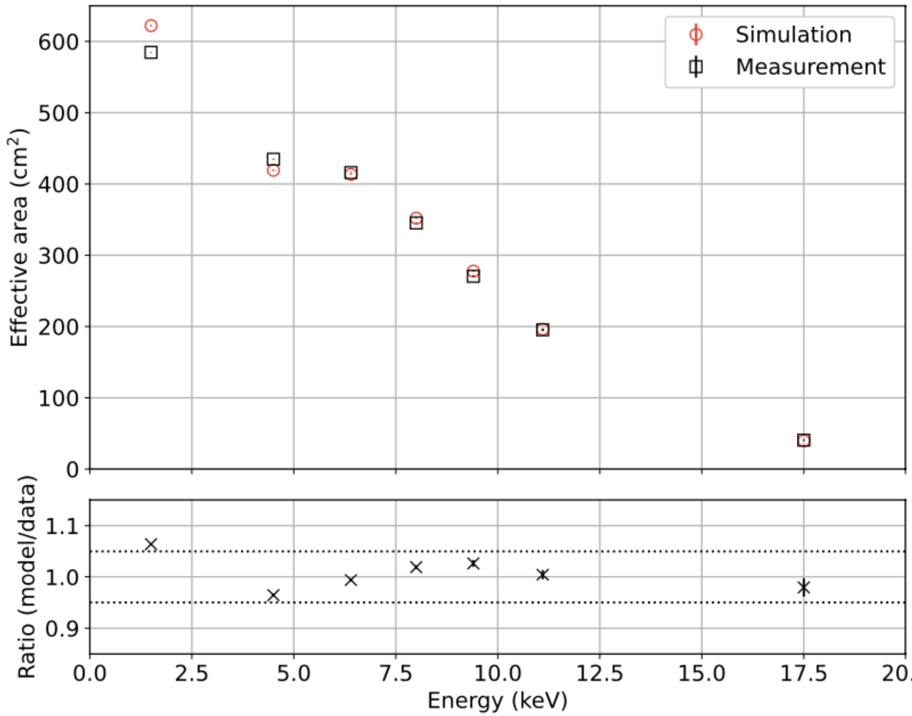
*Handbook of X-ray Astronomy, Arnaud et al.

Uncertainties - Throughput

XRiSM X-Ray Imaging and Spectroscopy Mission

Effective area uncertainties – and uncertainties in the uncertainties

1. The relative on-axis effective area precision is <6% in the nominal bandpass based on ground calibration (SPIE proceedings, https://doi.org/10.1117/12.3020154).
2. Ground calibration covered a limited number of energies and off-axis angles and is not as accurate for individual pixels (subarrays).



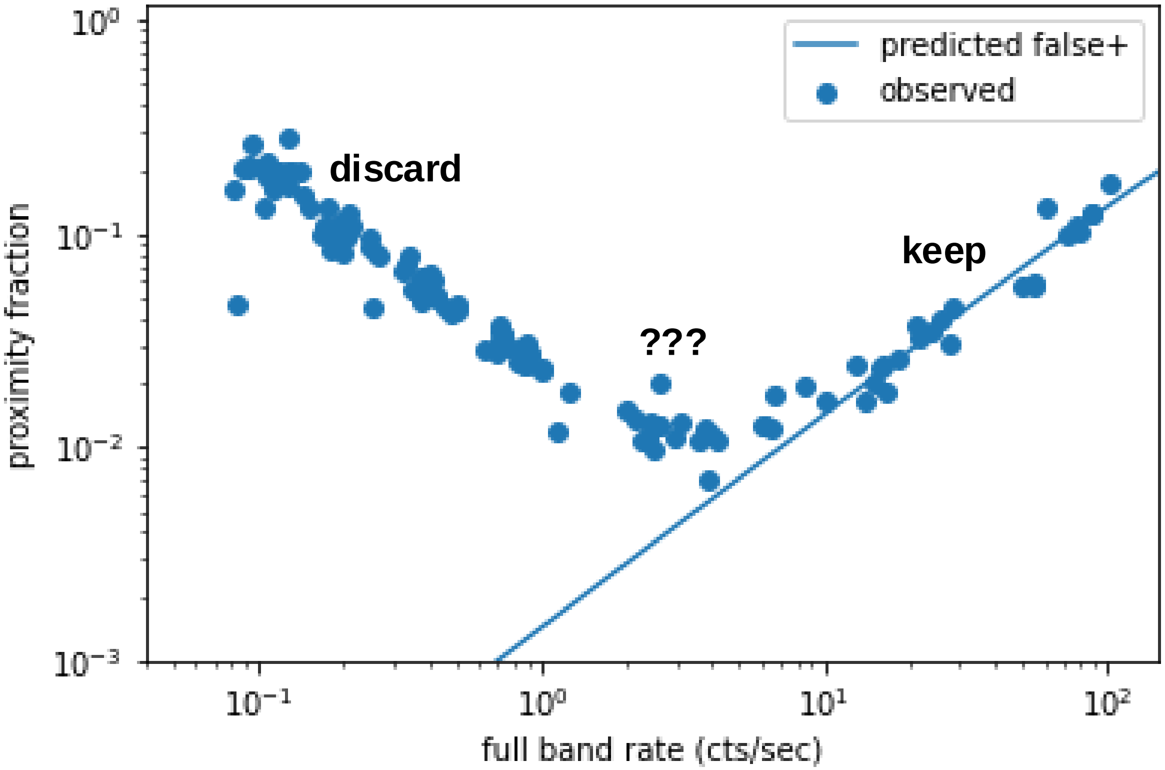
Boissay-Malaquin et al. 2024
https://doi.org/10.1117/12.3020154

Uncertainties - Throughput

3. Statistical errors are also larger when generating per-pixel and subarray ARFs.
4. In-flight calibration is a work in progress and involves a better understanding of the uncertainties with (2) and (3) above.
5. Systematics (and limitations in their estimation) between the XMA model and inflight data will persist at some level.
6. Strategies and new tools that enable users to address these are under development, though some of the infrastructure (auxiliary transmission option) already exists.
7. The XMA is not calibrated above 17.5 keV. This is also the energy above which there are no ground calibration line sources, and events may saturate in pulse height (clipped events) above ~20 keV.

Uncertainties - Throughput

- Additional screening for crosstalk (PI+DERIV_MAX/RISE_TIME) and frame events (previous talk) is generally recommended. However, the latter removes progressively more true source events as the count rate increases.



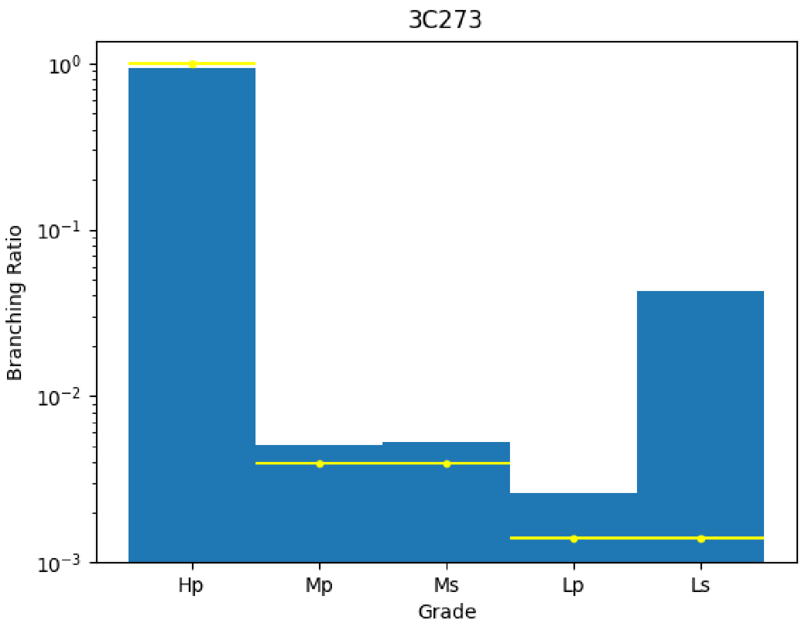
In the gray area, compare results with and without STATUS[4] filtering

The fraction of STATUS[4] (‘proximity’-flagged events) is dominated by false positives above ~10 ct/sec, and by frame (and other false) events below ~ 1 ct/sec

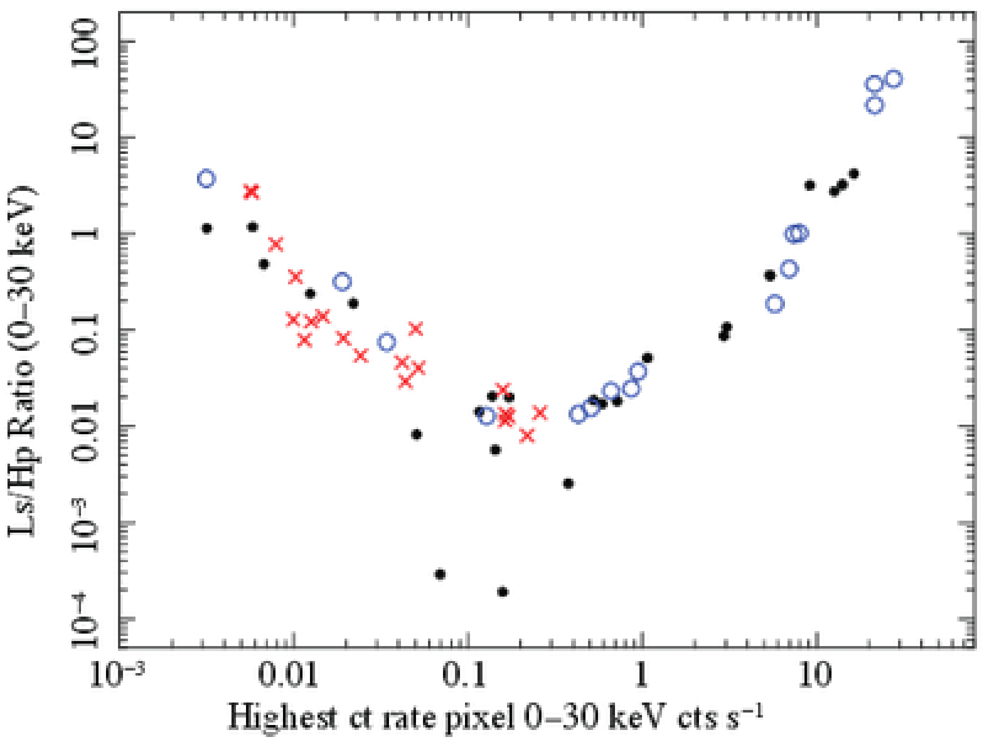
Anomalous Ls Events

XRISM X-Ray Imaging and Spectroscopy Mission

- Excess fractions of Ls events are seen at all count rates – in amounts that vary with pixel and energy (generally more at low energy), distorting the measured branching ratios.

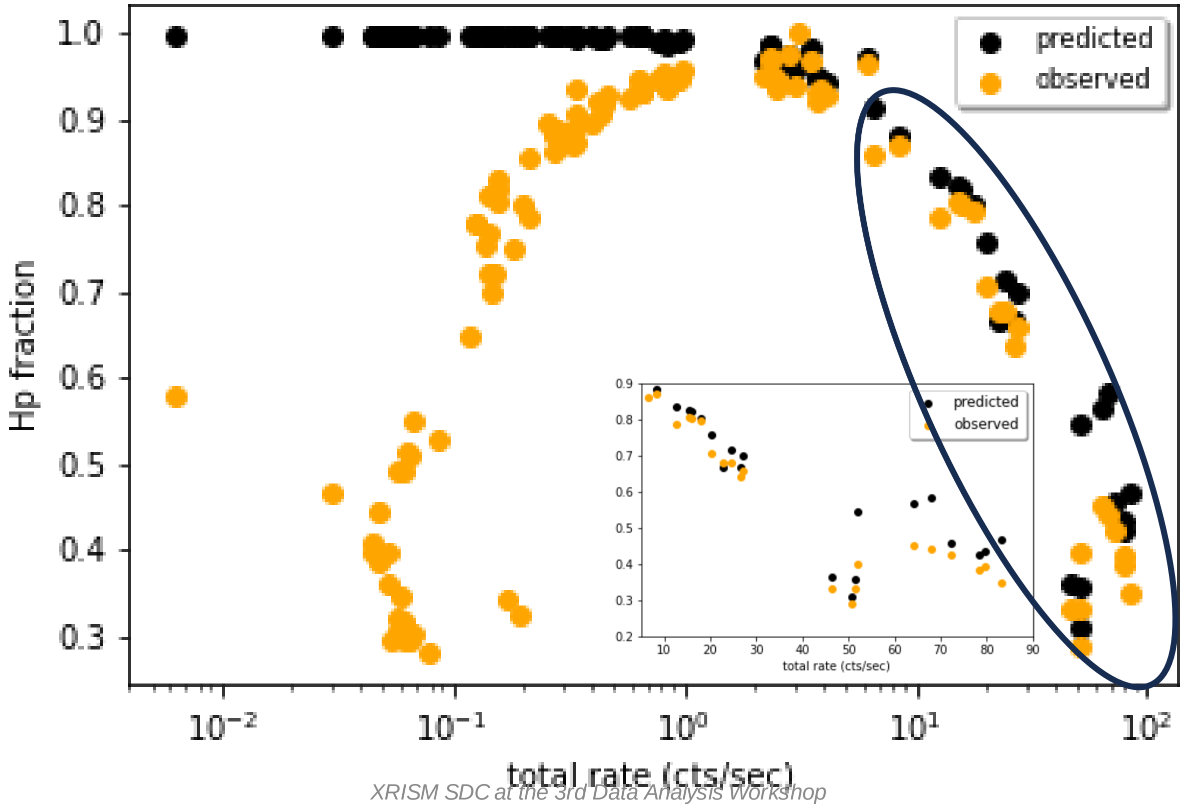


histogram:observered, errorbars: predicted



Anomalous Ls Events

- Associated with particle events but not picked up in on-board pulse processing or in the pipeline by antico flagging, or distinguishable using simple (e.g., rise-time) cuts.
- Since Ls events are not useful for spectroscopy we can discard them all – *but when*? To get a correct normalization when generating the RMF we need to know how many are real and how many are not.

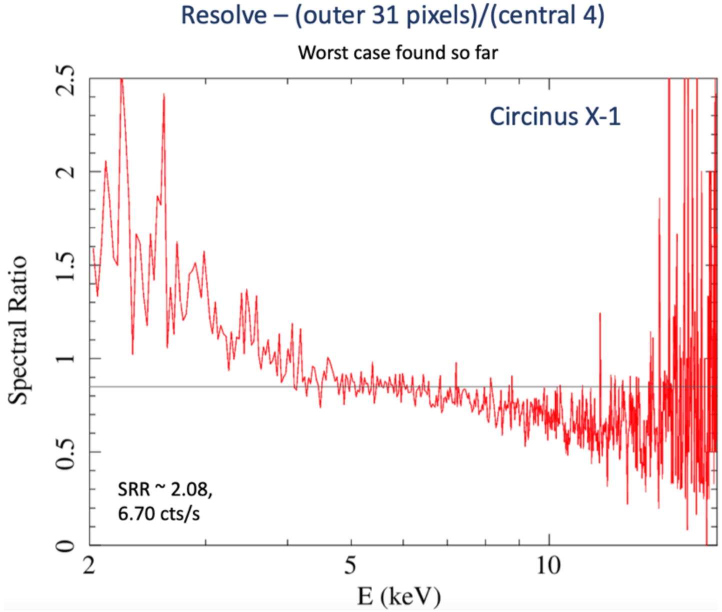


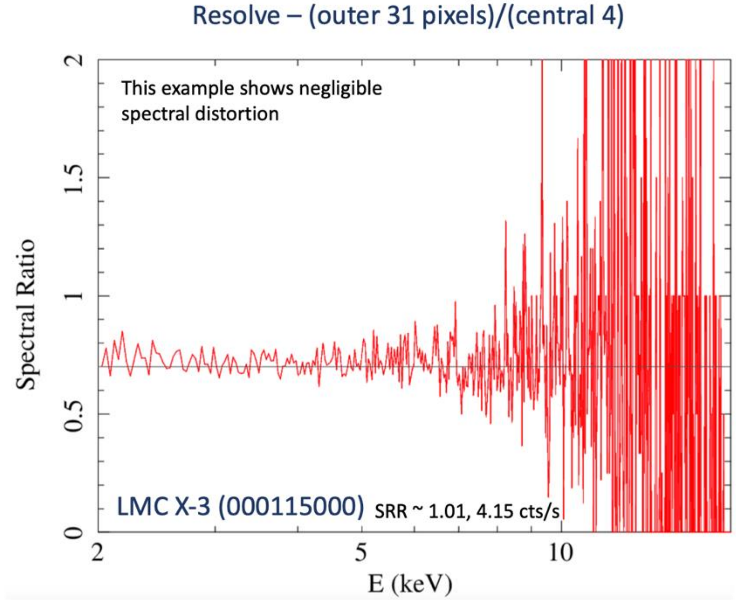
Anomalous Ls mitigation

- As usual, extract spectrum for Hp events only, but be wary of fitting above 12 keV
- Customize the event files used for RMF generation (which, ideally, should have all source – and only source – events)
  - Choose bandpass to correspond best to constant branching ratios
  - All sources
    - Event file for RMF(1): 3-10 keV Ls events - 6000<PI<20000&&ITYPE<4
    - Use RMF(1) for fitting
  - Intermediate and bright (maximum count/sec/pix >~ 0.4) sources
    - Event file for RMF(2): 5-8 keV Ls events - 10000<PI<16000&& ITYPE<5
    - *Also* use RMF(2) for fitting – this represents an effective area upper limit, while RMF(1) represents an effective area lower limit

Spectral Distortion

- Differences are seen in spectra extracted from different Resolve pixels (or subarrays).





Causes of spectral distortion:

- Known factors (do not fully explain the magnitude and trends)
  - Pixel-to-pixel differences in the effective area shape, and in the NXB/source ratio
  - Branching ratios effects for bright, variable, sources – especially at high column density
- Astrophysics (e.g., sources that are not simple, isolated constant point sources)
- Unknown instrument and mirror effects (many of these already ruled out)

Mitigation

- check to see whether your results depend on choice of pixels (e.g. in 'radial' groups) - for point sources
- check to see whether your results show non-physical jumps in adjacent pixels/subarray-regions - for extended sources

Coming Attractions

Resolve Branching Ratio Diagnostics (rslbratios)

- Provides detailed branching ratio diagnostics to assess whether the observation has “issues” and how severely affected the data are.
- Identifies pixels where count rates are sufficiently low that the Hp fraction ought to be ~unity.
- Identifies “like” groups of pixels that may be combined for (spectral) analysis.
- Makes plots and tables of branching ratios in selected energy band vs. time, and time-averaged branching ratios as a function of energy for individual pixels or specified groups of pixels.
- Compares observed and predicted branching ratios.
- Assists in mitigating false Ls events effect for getting the optimal RMF normalization.
- **Included in next release.**

Also in the works... (not exhaustive)

- Mp correction tool (and accompanying CalDB updates) – reduces relative Hp/Mp relative gain offset from ~ 3 eV to <0.5 eV - **included in next release**
- Celestial coordinate traceback tool for extended sources (xmatraceback; next sub-talk) - **included in next release**
- Resolve PSF Systematic Errors Utility Tool (rslpsfutil)
- Resolve Sub-Array Effective Area Systematic Errors (rslseaset)
- Other product extraction and response generation shortcut and visualization tools (multiple pixels/subarrays)
- Raytracing Utilities
- Updates to flagging (e.g., anomalous Ls removal)
- RSP generation and robust procedures for subarray analysis
- *Your suggestion here*

Takeaways

- The Resolve detector is really 35 individual detectors.
- Resolve has a small FOV that is comparable to the XMA angular resolution.
- Be mindful of systematics and account for them.
- Be careful and skeptical if extending your analysis beyond the nominal (<12 keV) bandpass.
- Apply consistency and sanity checks.
- Effects discussed here are count-rate and spectrum dependent (e.g., for time-varying bright sources the grade fractions vary differentially across the array) - generate separate responses for each time- or phase-resolved spectrum.
- Look at the energy scale reports for your observation (next sub-talk).
- Watch out for updates to the XRISM Data Analysis website!

Extra Slides

New Tool: xmatraceback

A tool designed to facilitate
extended source analysis

Objective

- Using real data, it is impossible to precisely trace back photons that hit the detector plane to their origin at the source
- However, using simulations, it is possible to see exactly where photons originated in the sky and where on the detector plane the photon lands
- Can determine fractional contribution to a detector region from outside of the region - useful for spatial-spectral mixing (SSM) estimates

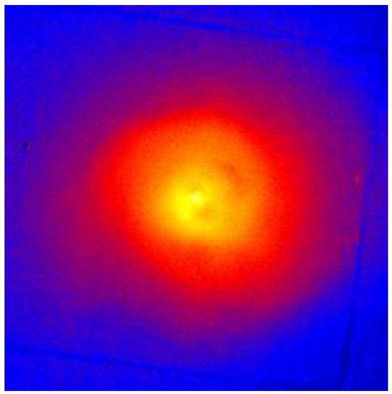
Identify image/data from other X-ray mission with better spatial resolution (e.g. Chandra/XMM)→ run through aharfgen/xaarfgen → use raytracing and heasim event files to run xmatraceback

Using the Tool

- Inputs:
  - Raytracing event file (from ah/xaarfgen)
  - Heasim event file (should be created with the same instance of aharfgen/xaarfgen)
  - xcen, ycen: where on the detector to align the origin of raytracing coordinates (default is 3.5, 3.5, the center of the detector)
  - Energy range of interest
  - Mission and instrument name
    - Currently only available for Hitomi SXS and XRISM Resolve
- Outputs:
  - 37 traceback images containing only photons that hit the detector plane (one for each pixel and one for the full array)
  - 37 x2 region files (in DET and RA/DEC)

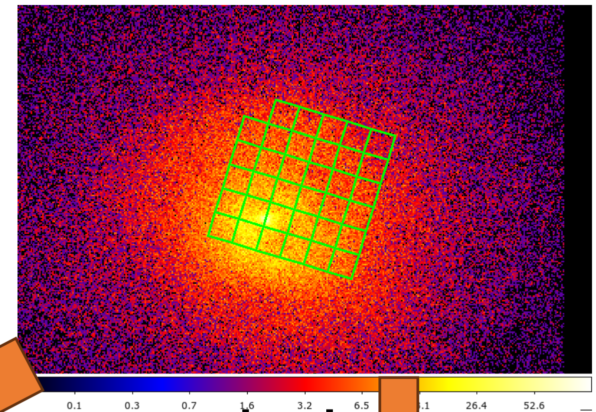
Example: Perseus Cluster

Data:
XMM Observation of the Perseus Cluster

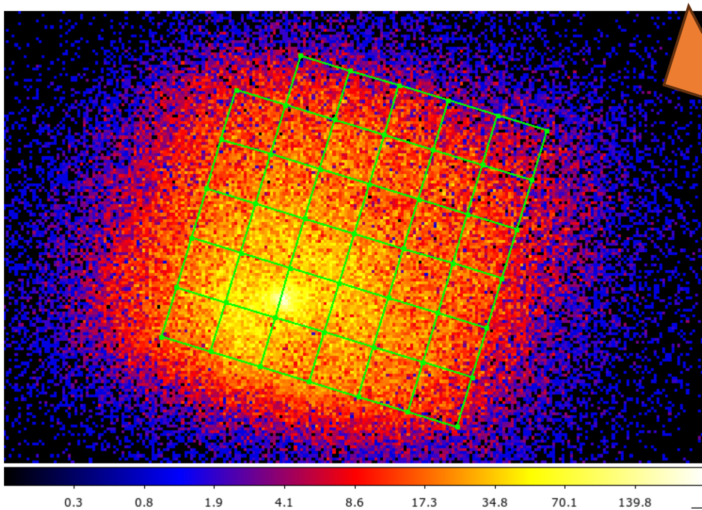


aharfgen/xaarfgen

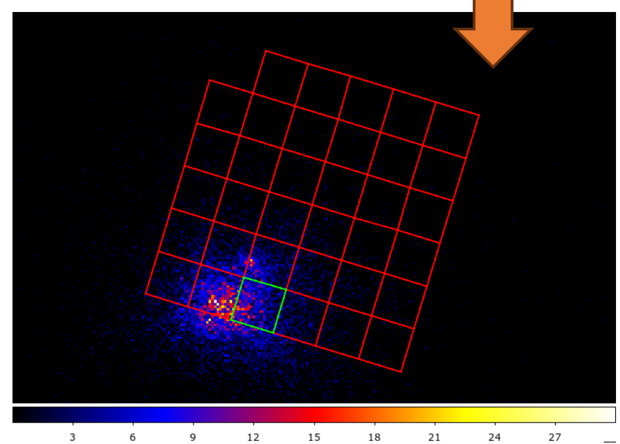
Heasim events



xmatraceback



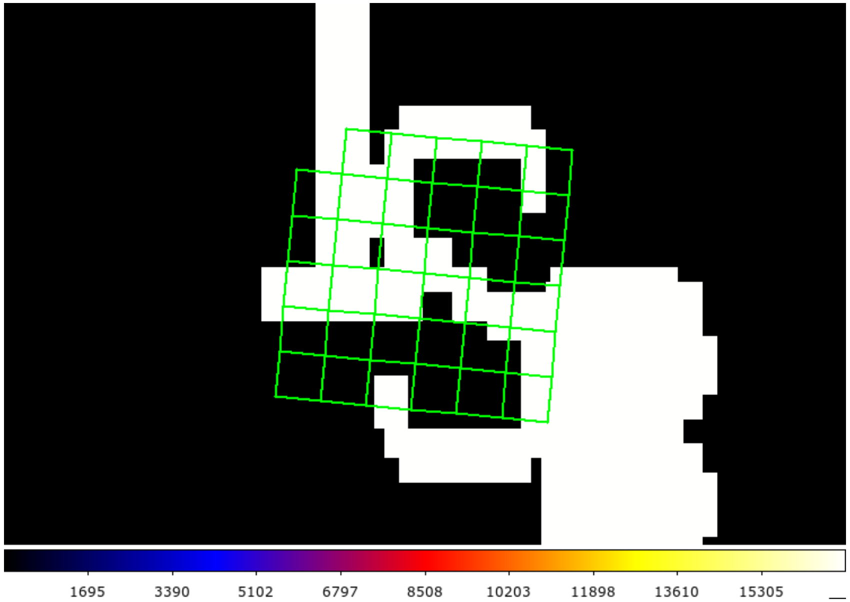
Full array traceback image



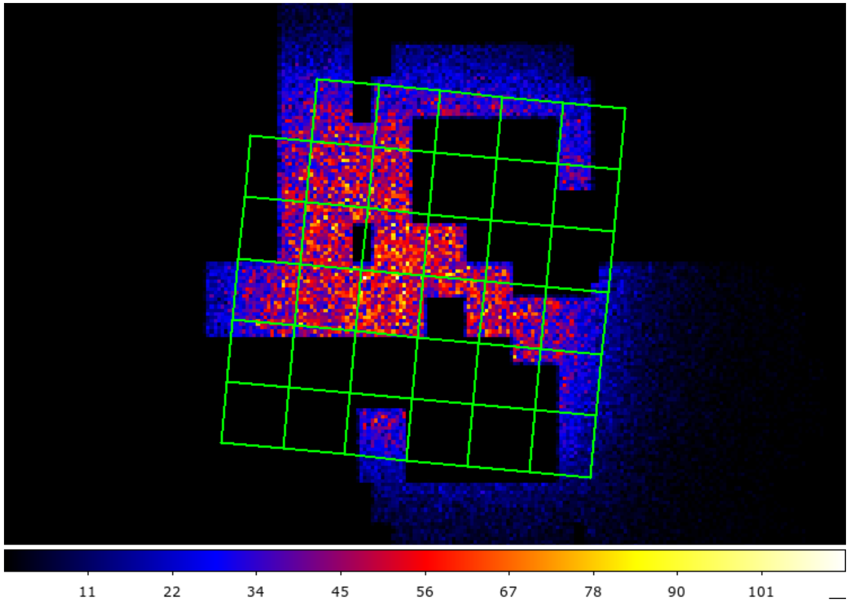
Individual pixel traceback image (pixel 1)

Example: Custom Source

Custom Image With Distinct Orientation/Shape



Full-Array Traceback Image



Summary and Next Steps

- Main purpose of xmatraceback is to facilitate analysis for extended sources: we want to know which parts of the source contribute to which parts of the detector.
- The tool will also be useful for proposals.
- xmatraceback will be available in the next software release
- A corresponding tool for the Hitomi SXI and XRISM Xtend instruments may be developed at a later time

Resolve Energy Scale Reports

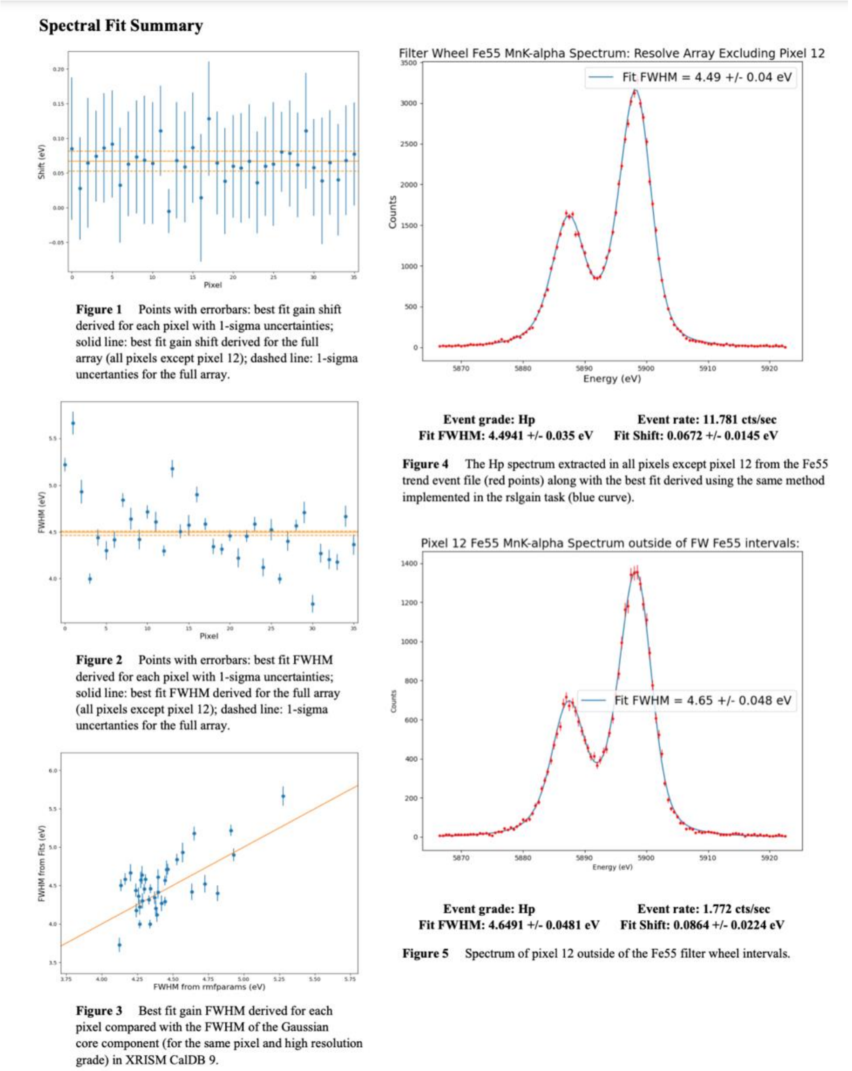
Providing the users with a first look at the energy scaling and resolution for each observation

Purpose

- Provide users with a summary of the Resolve energy scale performance by providing summary plots and text as quick assessment of the non-propriety trend data
- Allows the instrument team to make an assessment and pass that assessment to the SDC → allows SDC to give PIs a heads-up with regards to their data
- Are there any pixels that should be ignored? Any suspicious calibration spectra?
  - We are looking for failed gain solutions, outlier FWHM/shift fit values, outlier pixels in the gain history curves

What is in a Report?

- A summary of what is in the report and text for context
- Summary plots of individual pixel performance and the full-array spectrum with fit values
- Individual pixel calibration spectra
- Also contains gain history plots, any failed pixel solutions, highlights pixel 12 outside the Fe55 filter wheel intervals
- Pixel 12 outside of Fe55 FW intervals shows detector functionality outside of this calibration



Spectral Fit Summary

Figure 1 Points with errorbars: best fit gain shift derived for each pixel with 1-sigma uncertainties; solid line: best fit gain shift derived for the full array (all pixels except pixel 12); dashed line: 1-sigma uncertanties for the full array.

Figure 2 Points with errorbars: best fit FWHM derived for each pixel with 1-sigma uncertainties; solid line: best fit FWHM derived for the full array (all pixels except pixel 12); dashed line: 1-sigma uncertanties for the full array.

Figure 3 Best fit gain FWHM derived for each pixel compared with the FWHM of the Gaussian core component (for the same pixel and high resolution grade) in XRISM CalDB 9.

Event grade: Hp **Event rate: 11.781 cts/sec**
Fit FWHM: 4.4941 +/- 0.035 eV **Fit Shift: 0.0672 +/- 0.0145 eV**

Figure 4 The Hp spectrum extracted in all pixels except pixel 12 from the Fe55 trend event file (red points) along with the best fit derived using the same method implemented in the rslgain task (blue curve).

Event grade: Hp **Event rate: 1.772 cts/sec**
Fit FWHM: 4.6491 +/- 0.0481 eV **Fit Shift: 0.0864 +/- 0.0224 eV**

Figure 5 Spectrum of pixel 12 outside of the Fe55 filter wheel intervals.

Where Can I Find The Reports?

XRISM X-Ray Imaging and Spectroscopy Mission

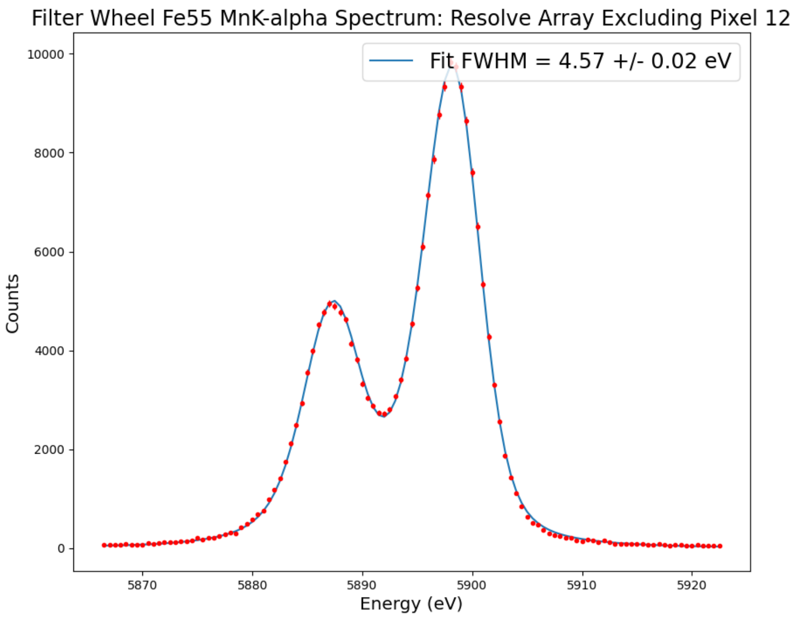
- https://heasarc.gsfc.nasa.gov/FTP/xrism/postlaunch/gainreports/
- https://heasarc.gsfc.nasa.gov/docs/xrism/analysis/index.html

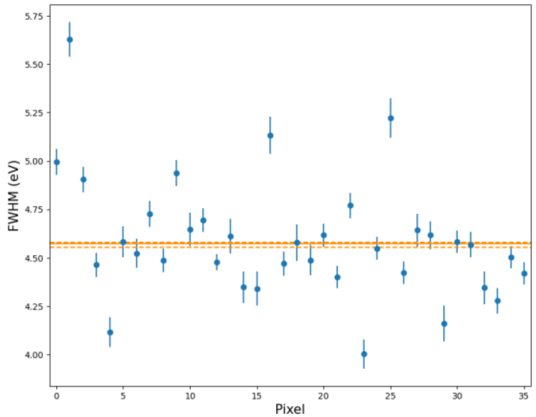
Index of /FTP/xrism/postlaunch/gainreports

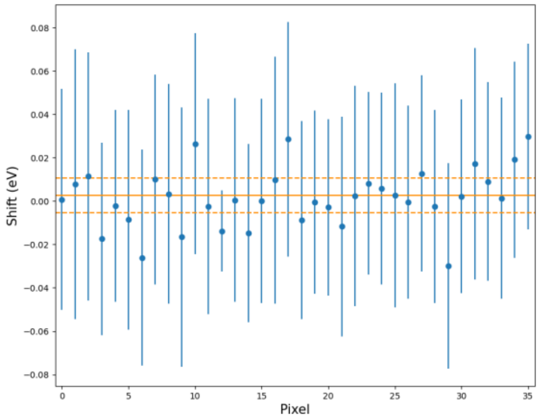
Name	Last modified	Size	Description
Parent Directory		-	
0/	21-Aug-2024 11:05	-	
1/	16-Jan-2025 17:49	-	
2/	28-Jan-2025 10:56	-	
3/	24-Dec-2024 15:51	-	
4/	19-Aug-2024 15:16	-	
5/	19-Aug-2024 15:16	-	
6/	19-Aug-2024 15:16	-	
7/	19-Aug-2024 15:16	-	
8/	19-Aug-2024 15:16	-	
9/	04-Oct-2024 16:10	-	

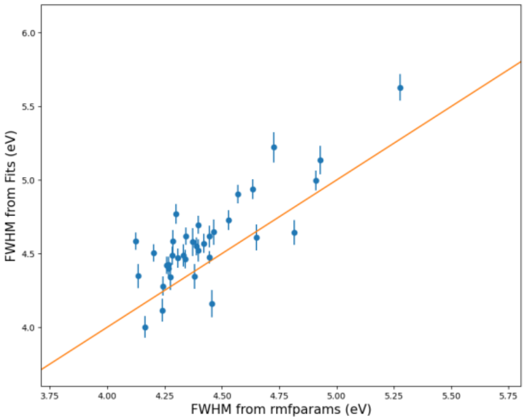
Example Contents

- From OBSID 201089010 (ABELL 2199)



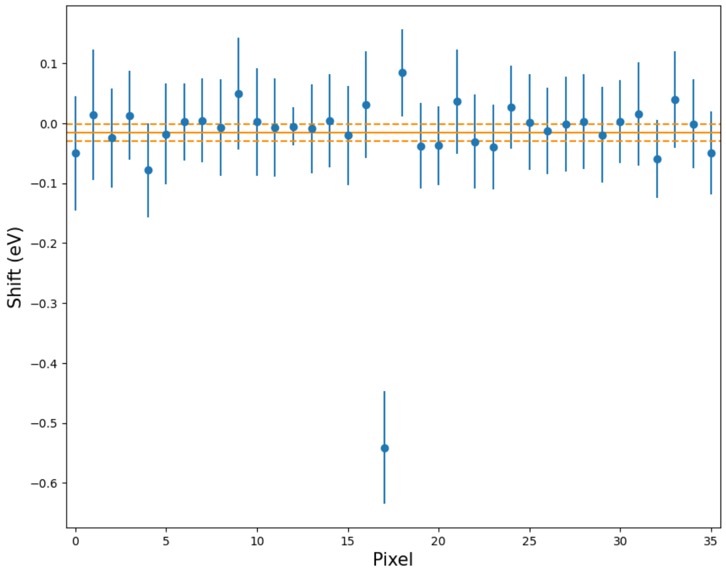


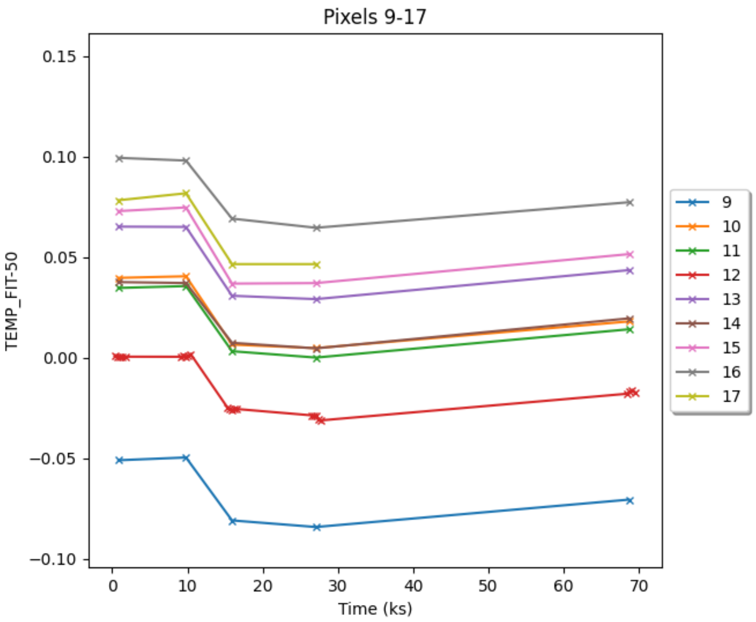




"Bad Report"

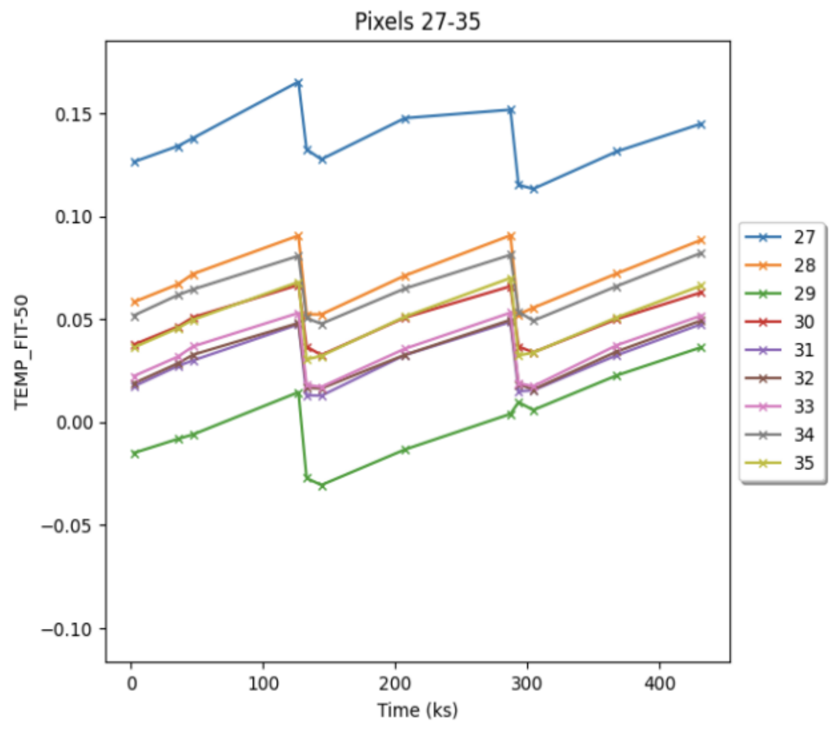
- What do some red flags look like?
- From OBSID 201003010 (GAMMA CASSIOPEIAE):





"Bad Report"

- Gain history plot of showing pixel 27 from latest report (OBSID 201087010, ABELL1795 CENTER)



Summary and Next Steps

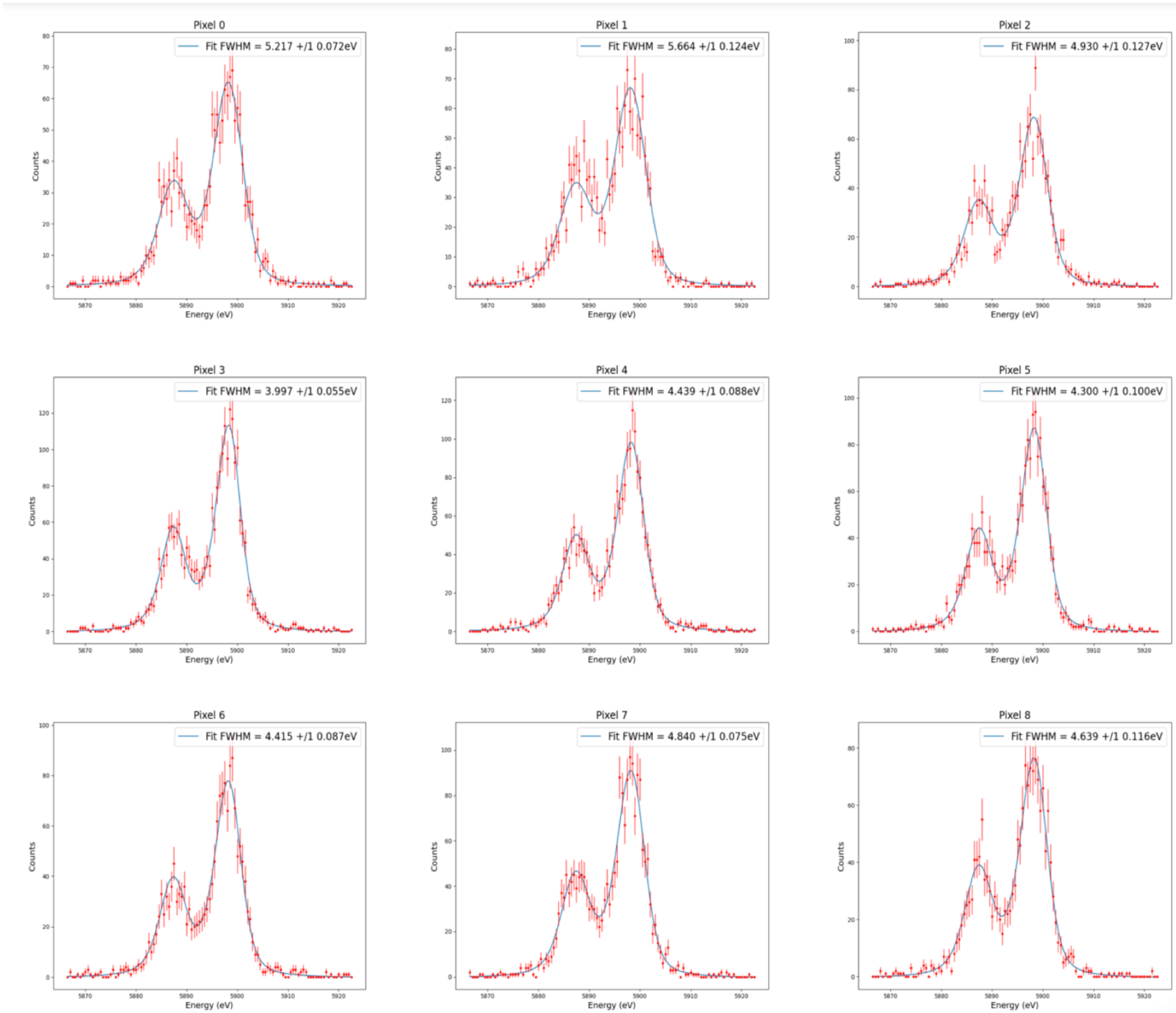
- In addition to full array and individual pixel spectra, gain history plots, and pixel summary tables, there are also tables summarizing the SAA and ADR GTI.

- Currently only sent to PIs of released GO observer data, but technically available to anyone online at https://heasarc.gsfc.nasa.gov/FTP/xrism/postlaunch/gainreports/.

- The plan is to integrate the energy scale report generator into the pipeline.

Extra Slides

Example Contents



Example Contents

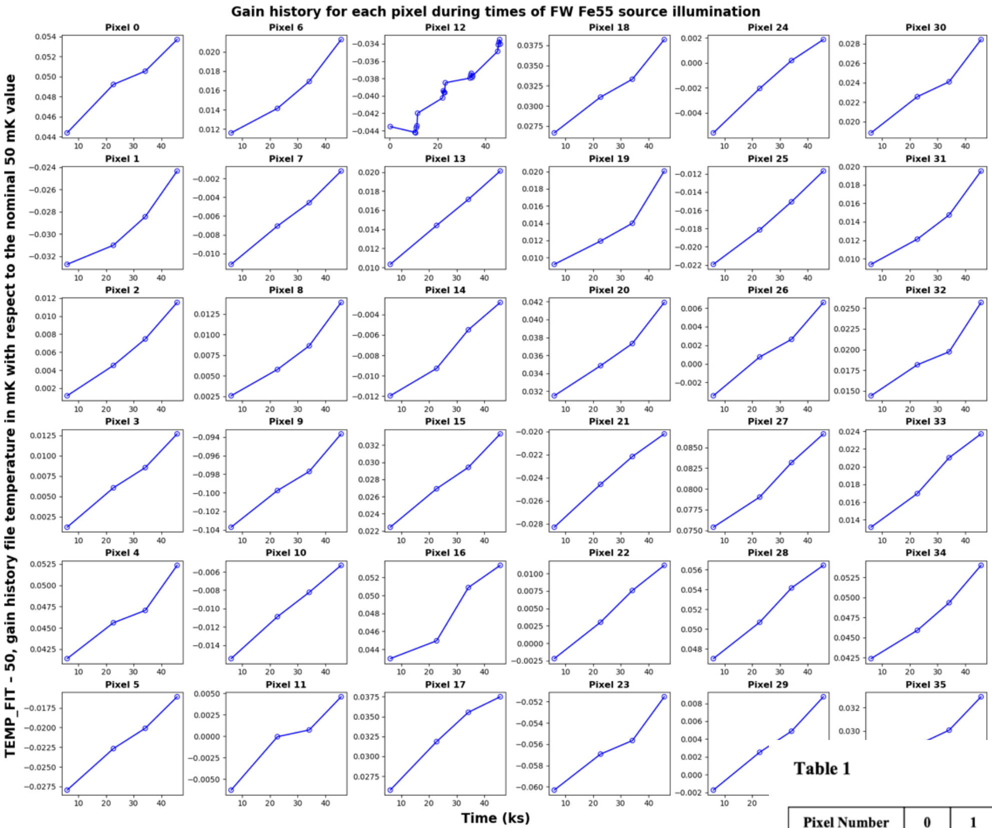


Table 1

Pixel Number	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Gain Solutions	4	4	4	4	4	4	4	4	4	4	4	4	21	4	4	4	4	4
Failed Solutions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Pixel Number	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Gain Solutions	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
Failed Solutions	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0