XRISM
Resolve - High Resolution Soft X-Ray Spectrometer

XRISM/Resolve performance
(and helpful-to-know instrumental effects)

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For the Resolve Instrument Team

thanks especially to Scott Porter for providing many of these figures

12 February 2024

Summary up front:
Resolve is performing very well!

XRISM
Resolve - High Resolution Soft X-Ray Spectrometer

- After energy-scale reconstruction, at 6 keV:
  - Array composite energy resolution = 4.5 eV (H grade), 4.8 eV (Mp grade)
  - Energy scale error ~ 0.05 eV
  - No new outlier pixels.
    - Worst pixels are same two that were the worst on the ground.
  - Si K spectral-redistribution line has FWHM <4.0 eV and scale error ~ 1.3 eV presently.
    - Calibration still in ongoing.
- Anti-co is working, and it appears background will be similar to that seen on Hitomi/SXS.
  - But without the Mn K line (scattered photons from collimated cal source)
- Cooling system is performing better than requirements.
  - LHe lifetime projected to be ~ 4 years. Cryo-free operation thereafter.
  - Operational efficiency at 50 mK is ~98%.

Thermal detectors don't discriminate!

→ implications for energy scale, resolution, and background

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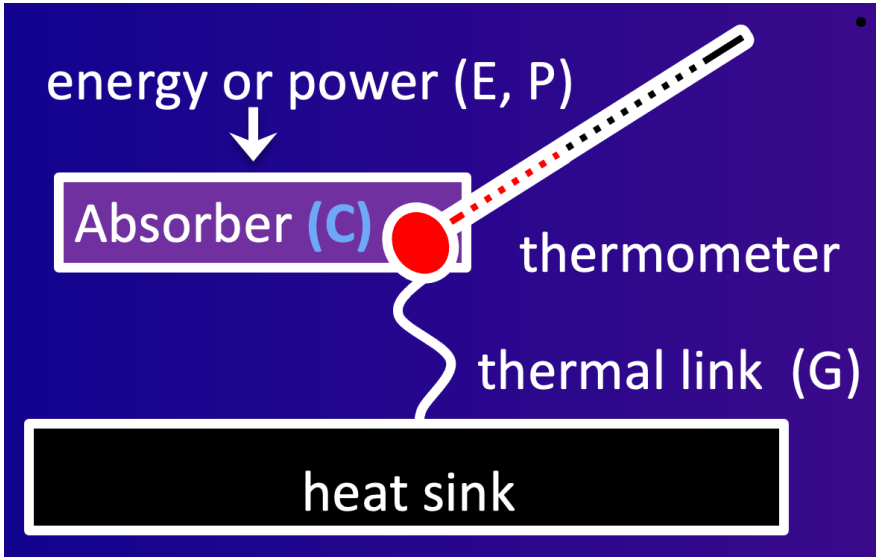


Microcalorimeters sense energy and power as heat, without regard to origin

- Pulses
  - Triggered → signal and background
  - Untriggered:→ noise
- Power load
  - Changes quiescent temperature and thus the response to temperature pulses
    - Any change to operating temperature changes the energy scale!
      - Loading control thermometer
      - Change in detector bias voltage
        - Additional effects from this

Without feedback

$$\tau = \frac{C}{G}$$

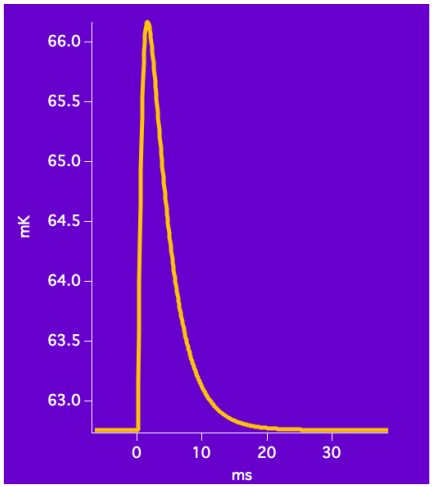
Impulse response

Time domain

$$\propto \frac{E}{C} e^{-t/\tau}$$

Frequency domain

$$\propto \frac{E}{C} \sqrt{\frac{1}{1+(\omega\tau)^2}}$$



Power response

(both into absorber and across thermal link)

To constant power $\propto \frac{P}{G}$

Frequency response $\propto \frac{P}{G}\frac{1}{(1+i\omega\tau)}$ (complex); $\propto \frac{P}{G}\sqrt{\frac{1}{1+(\omega\tau)^2}}$ (magnitude)

Resolve detector system

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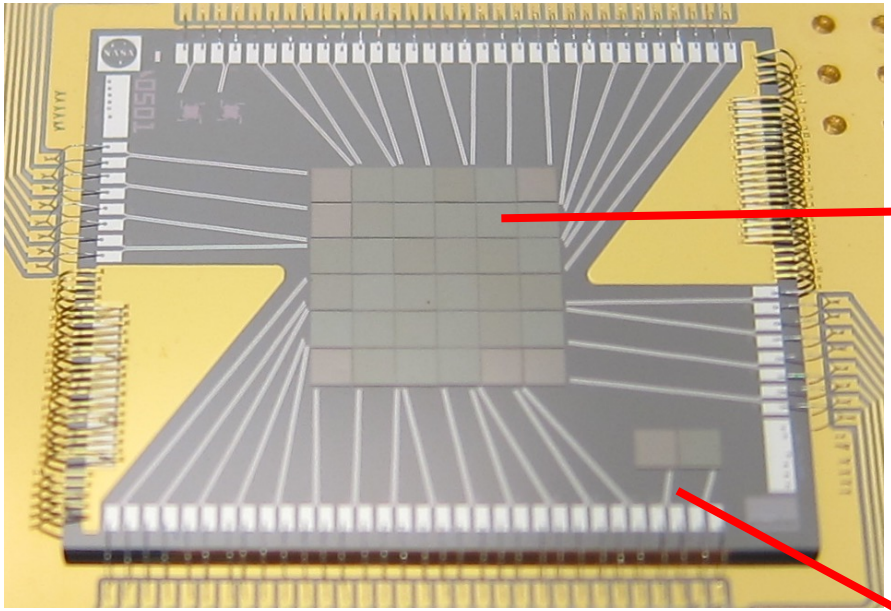
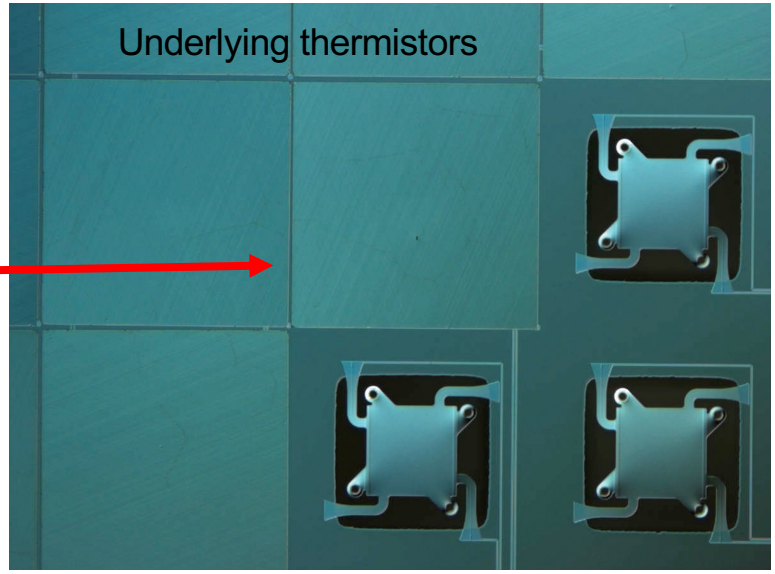
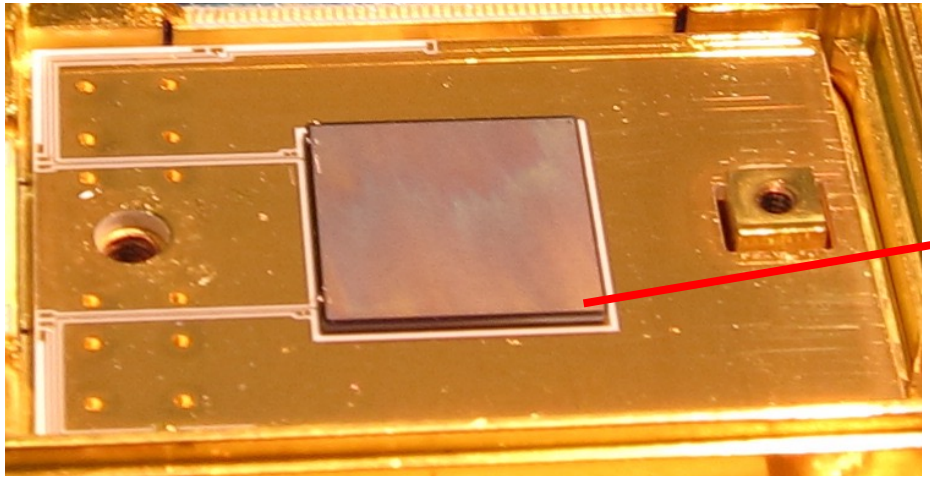
Microcalorimeter Array



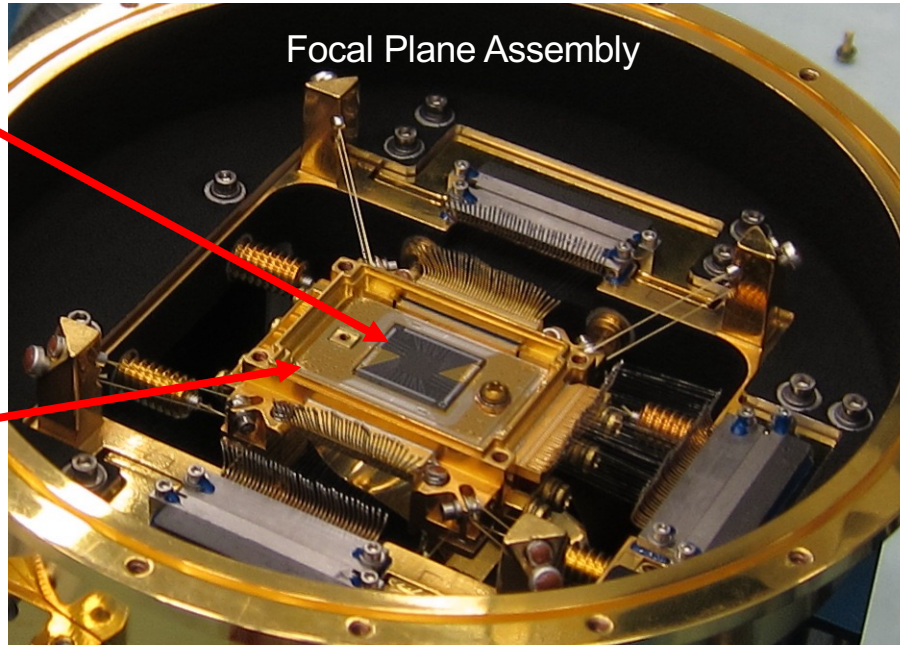
Underlying thermistors



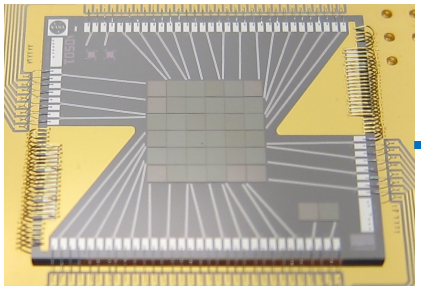
Anti-coincidence detector

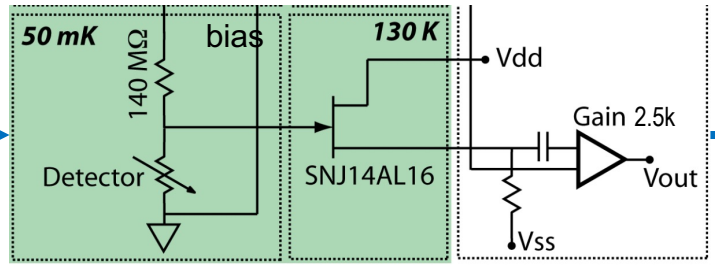


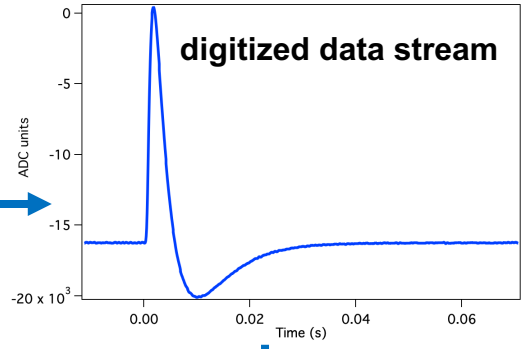
Focal Plane Assembly



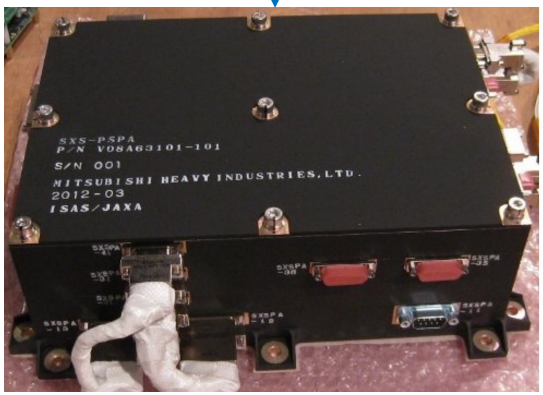
Signal route







8 Mb/s



Event list:
- **PH (det units)**
- **Event time**
- **Risetime**
- **Grading**
- **Pile-up**
- **Other flags**

20 kb/s

Ground station

Pre-pipeline (fff)

Quick look

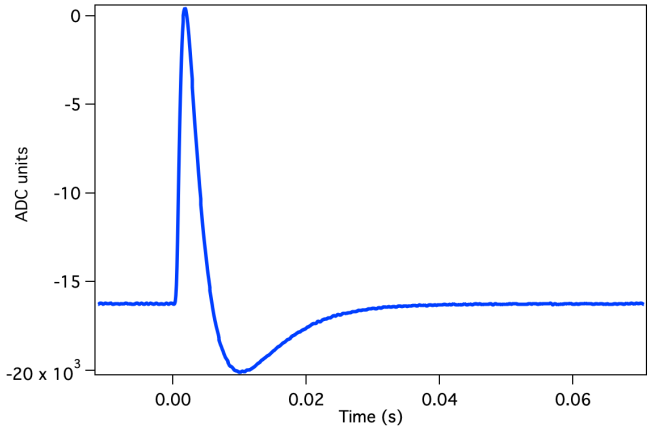
Pipeline

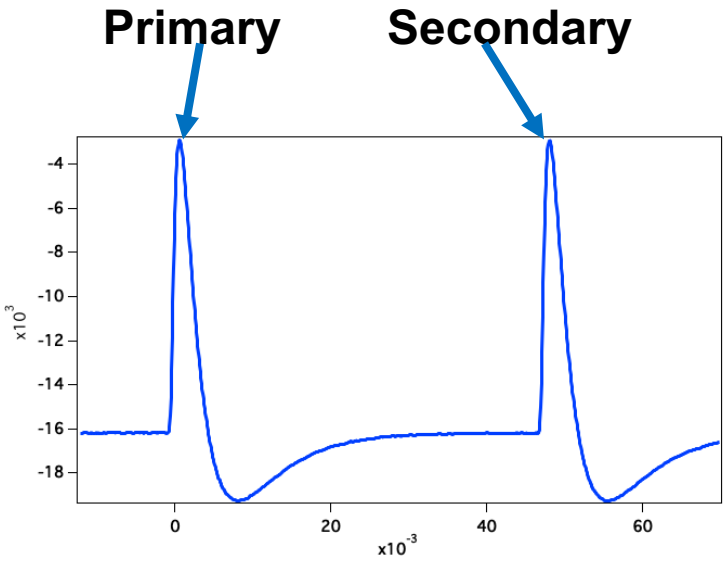
Observer data

Pulse Shape Processor

Applies unique digital filter to each channel.
Ground calibration based on using these filters.

Event processing and grading





Want to measure x-ray energy

- Use all available information
  - Optimal estimator
    - Signal/(noise)^2 in all freq bins
      - For Resolve, we zeroed out the filter above 366 Hz to provide immunity to changes in high-frequency noise.
    - Longer records allow this calculation to be done using smaller frequency bins
- What do you do with pile-up?

Two kinds of pileup

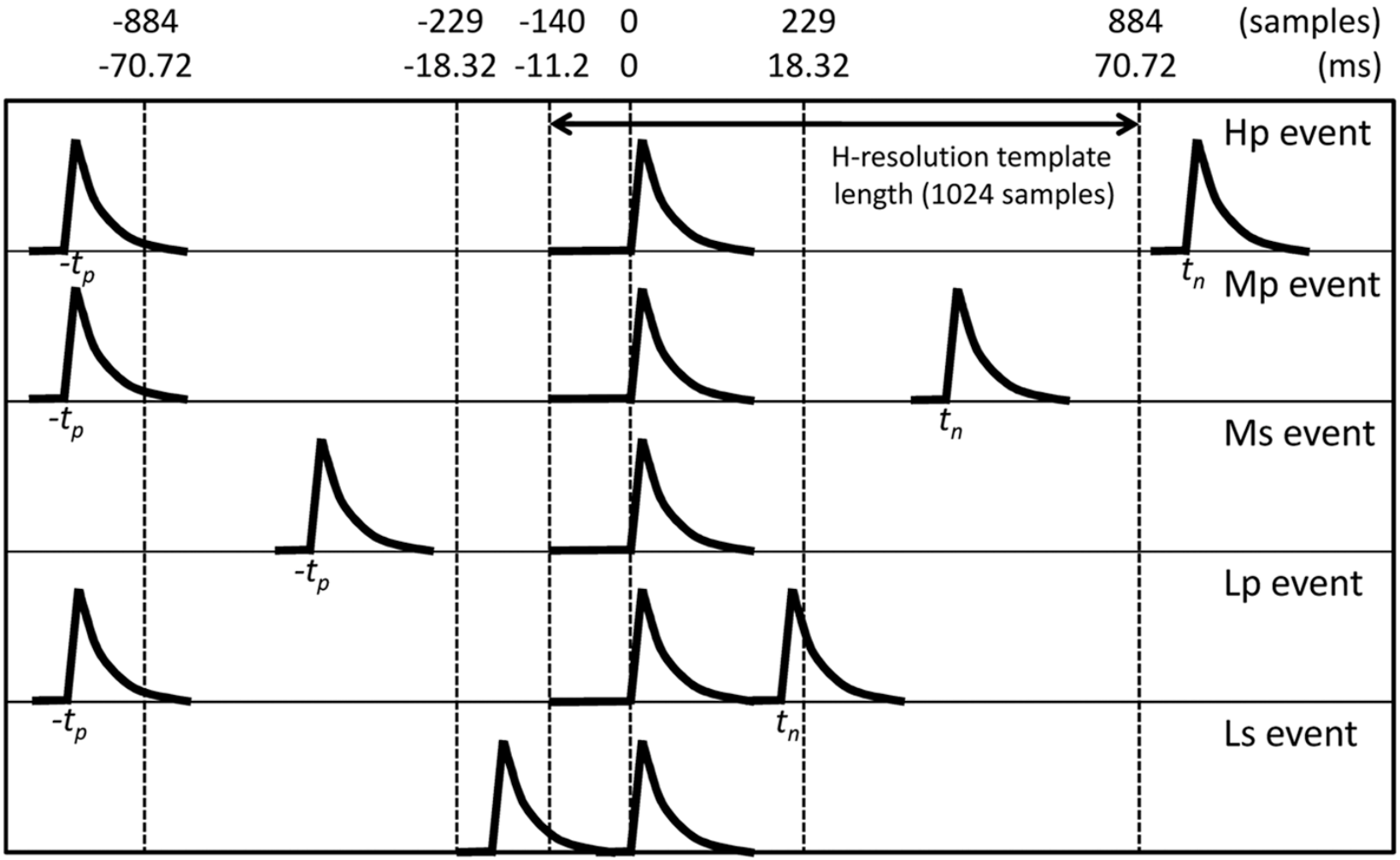
- Only affects the pulse processing
- Affects the pulse thermally

Event grades:

- High Resolution → full record
- Mid Resolution → ¼ record
- Low Resolution → Simple PH
- Secondaries (only mid and low)

Event grades

Full event grading matrix for Resolve

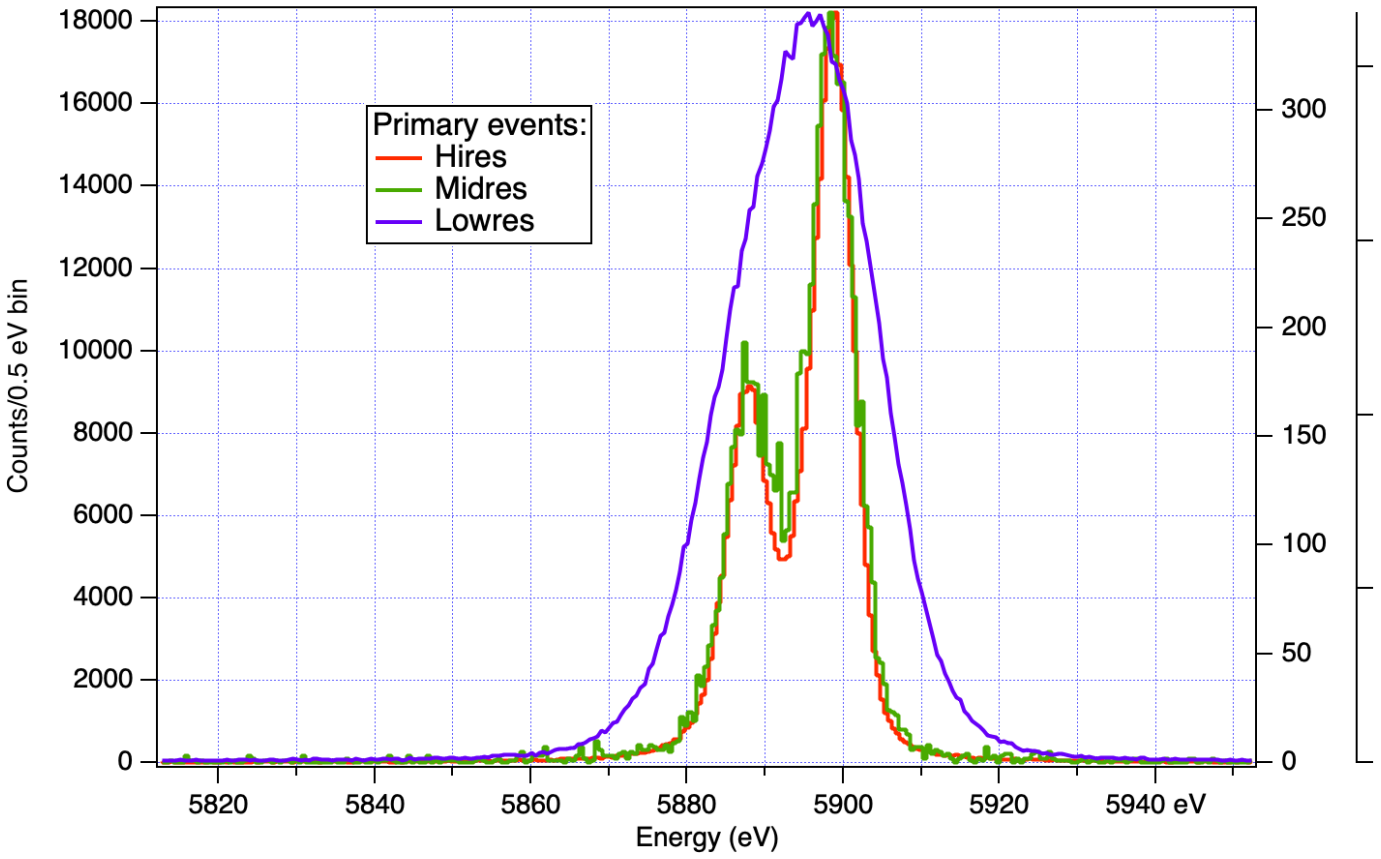


Ishisaki et al. (2018)

Resolution of the different grades

- Energy resolution requirement of 7 eV applies to both H and Mp
- Low res and secondaries are degraded

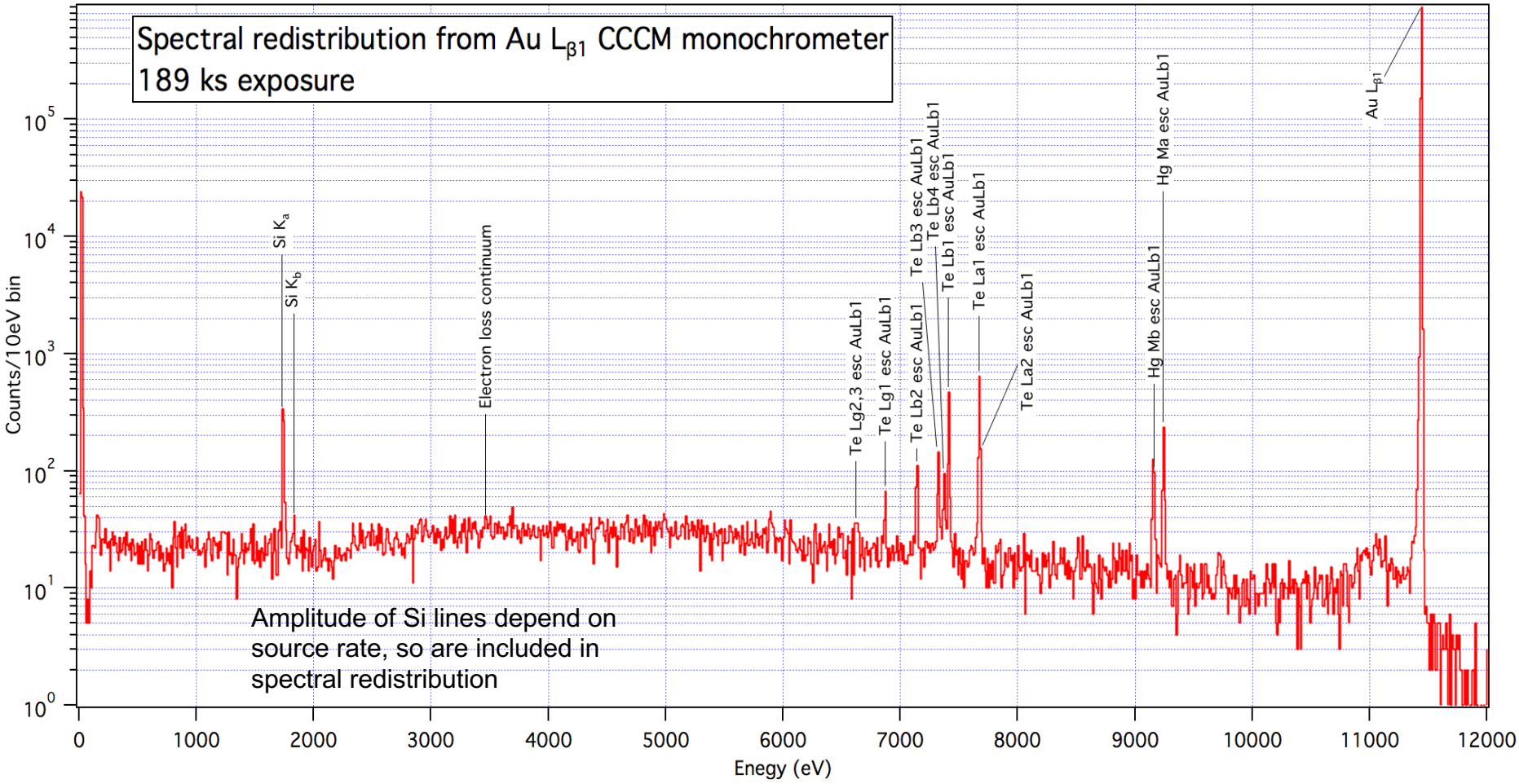
Example from in-flight data:



At 6 keV:
Hires: 4.5 eV
Midres: 4.8 eV
Lowres: 15.8 eV

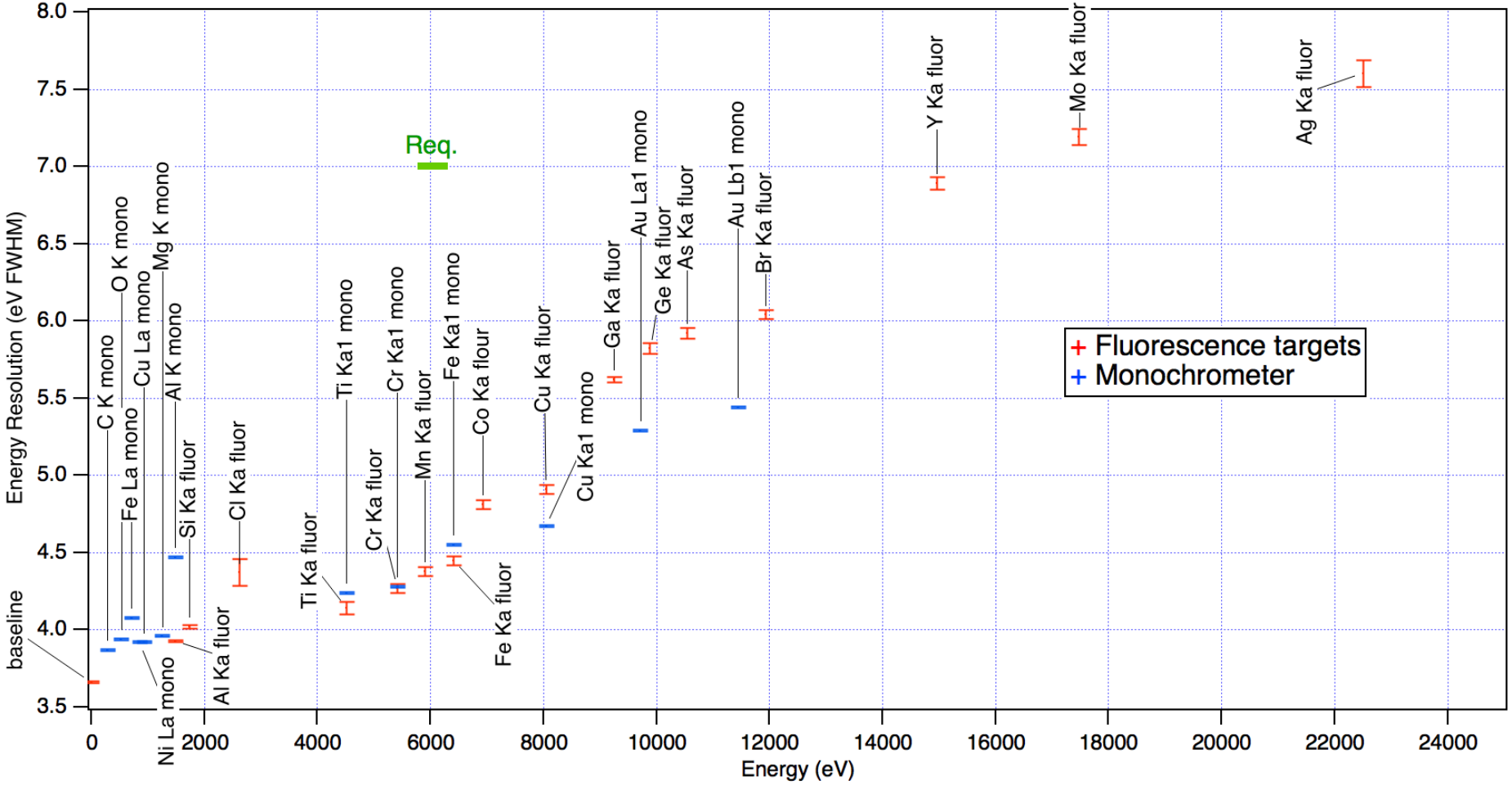
Spectral redistribution

- Core line shape: dominated by detector intrinsic noise and system noise
- Broadband redistribution: dominated by detector material properties.
- Used to measure: Monochromators, modeled fluorescent lines, EBIT measurements



Core line shape across the band pass

- Energy resolution tends to get worse at higher energy
  - Thermalization variation and non-linearity
- There are some systematic differences between monochromator and fluorescence measurements from incomplete line-shape knowledge



Energy-scale measurement

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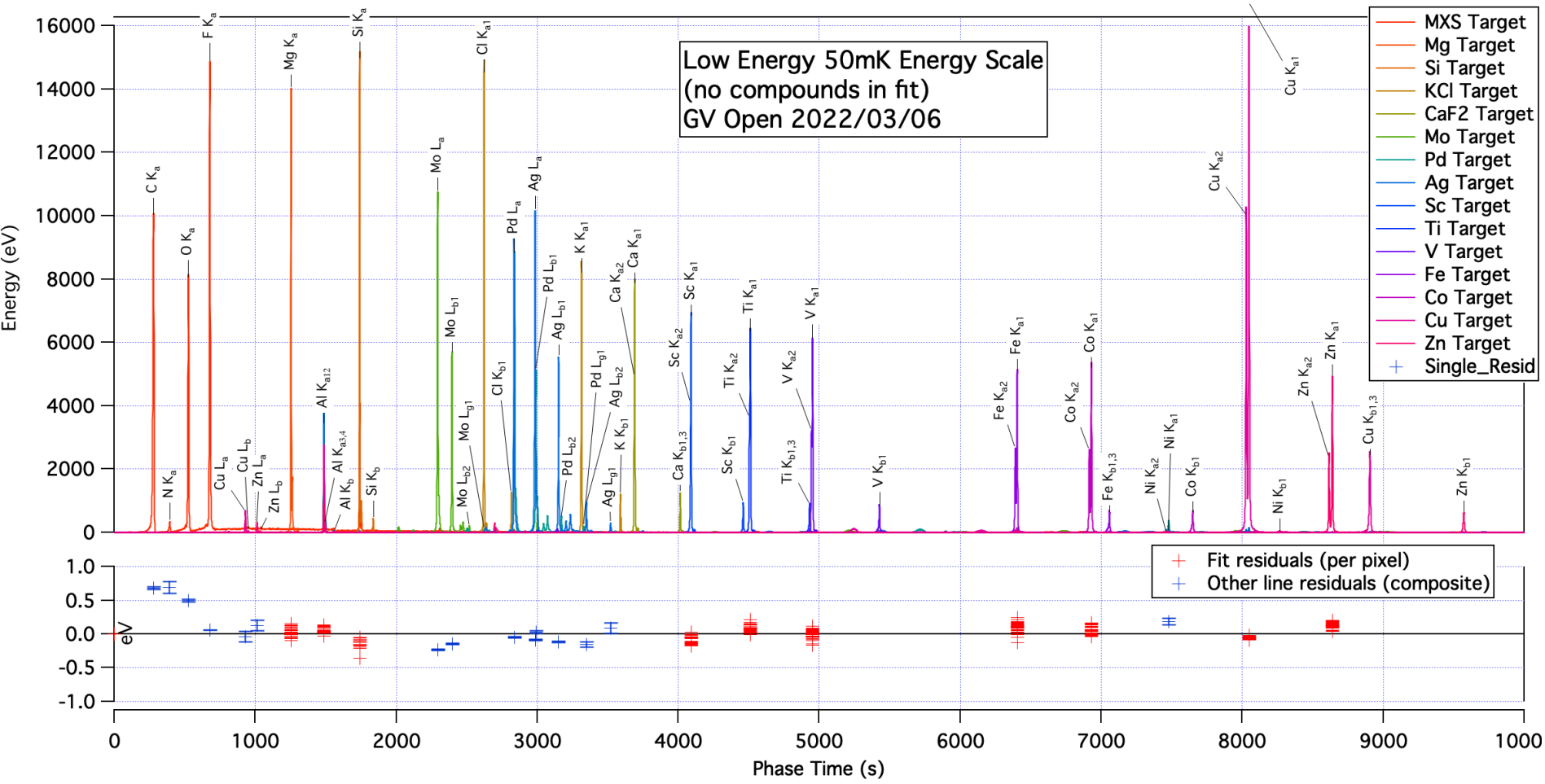
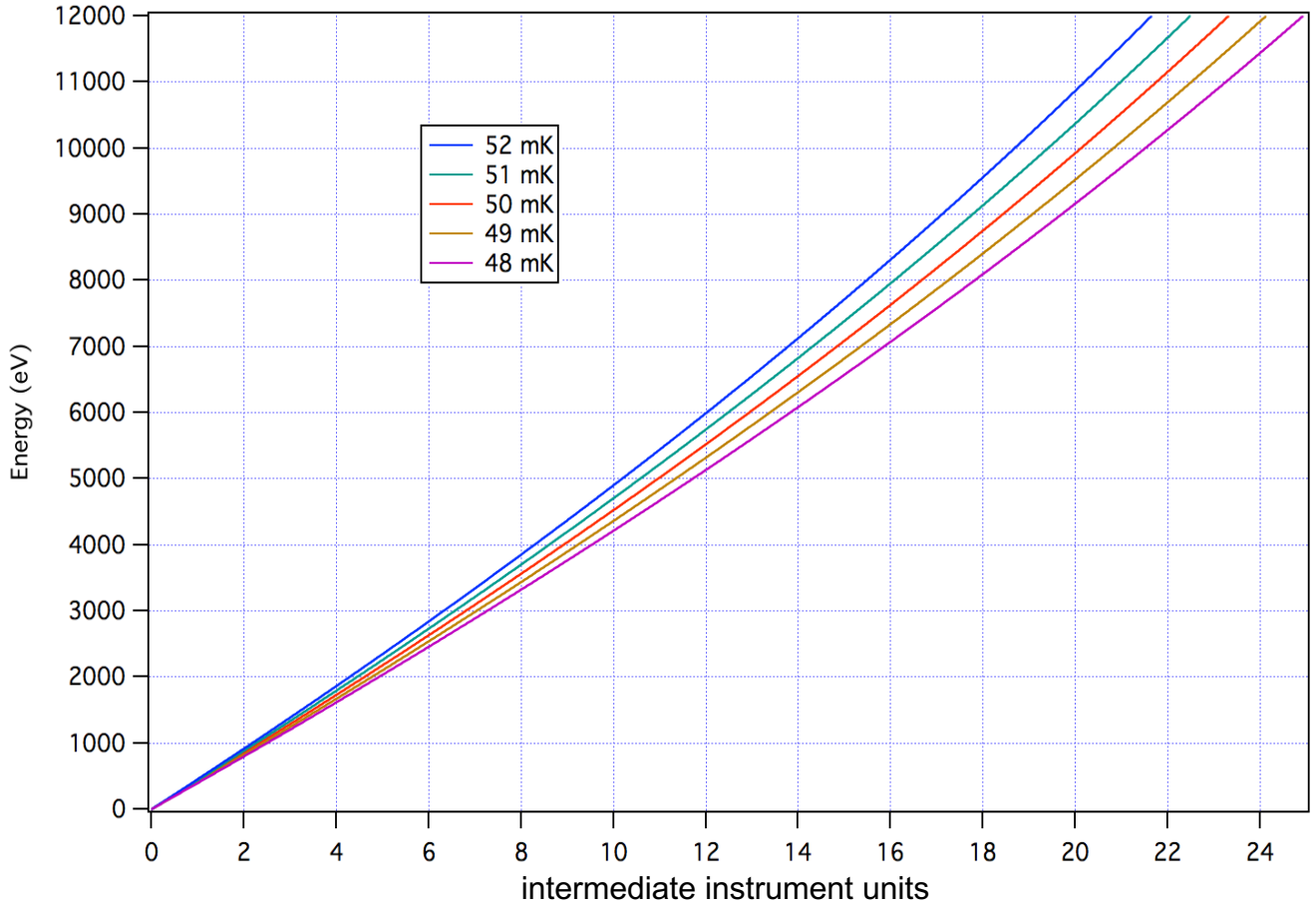
- One of 3 sets of measurements to span bandpass
- Precision dominated by fluorescent line models



Energy scales in orbit

- Energy scale is non-linear and varies with temperature
- Need to reconstruct as function of time on-orbit using a fiducial
  - Interpret gain changes in fiducial line as change in “effective heat-sink temperature” of each pixel

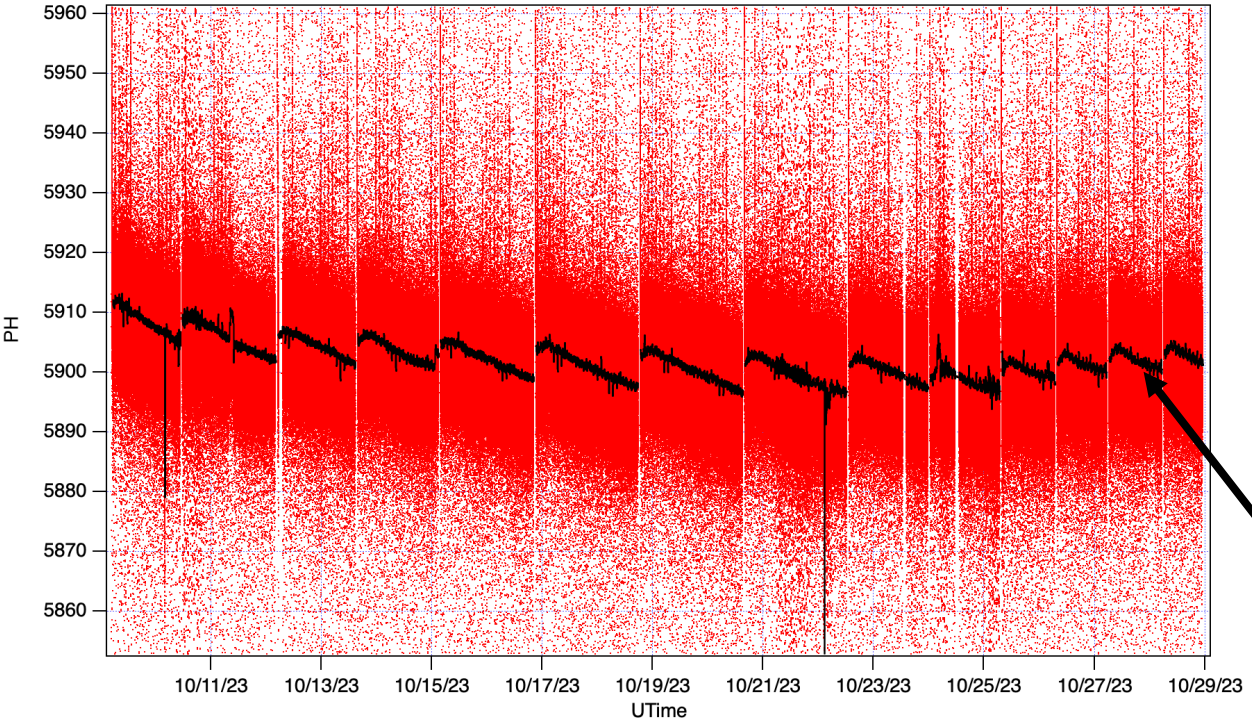


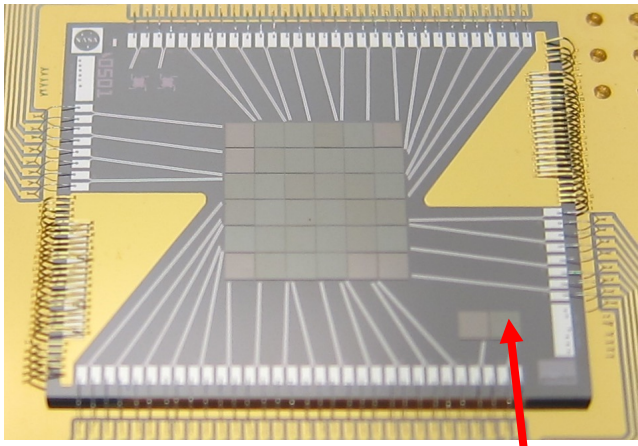
Energy scale reconstruction

Resolve has three fiducials to track detector gain vs time:

- Calibration pixel with collimated internal ^{55}Fe source (5.9 keV), always on
- Modulated x-ray source: flood source for all pixels, but well defined time
- ^{55}Fe source on the filter wheel that can be rotated into the FOV

First 14 ADR cycles in orbit





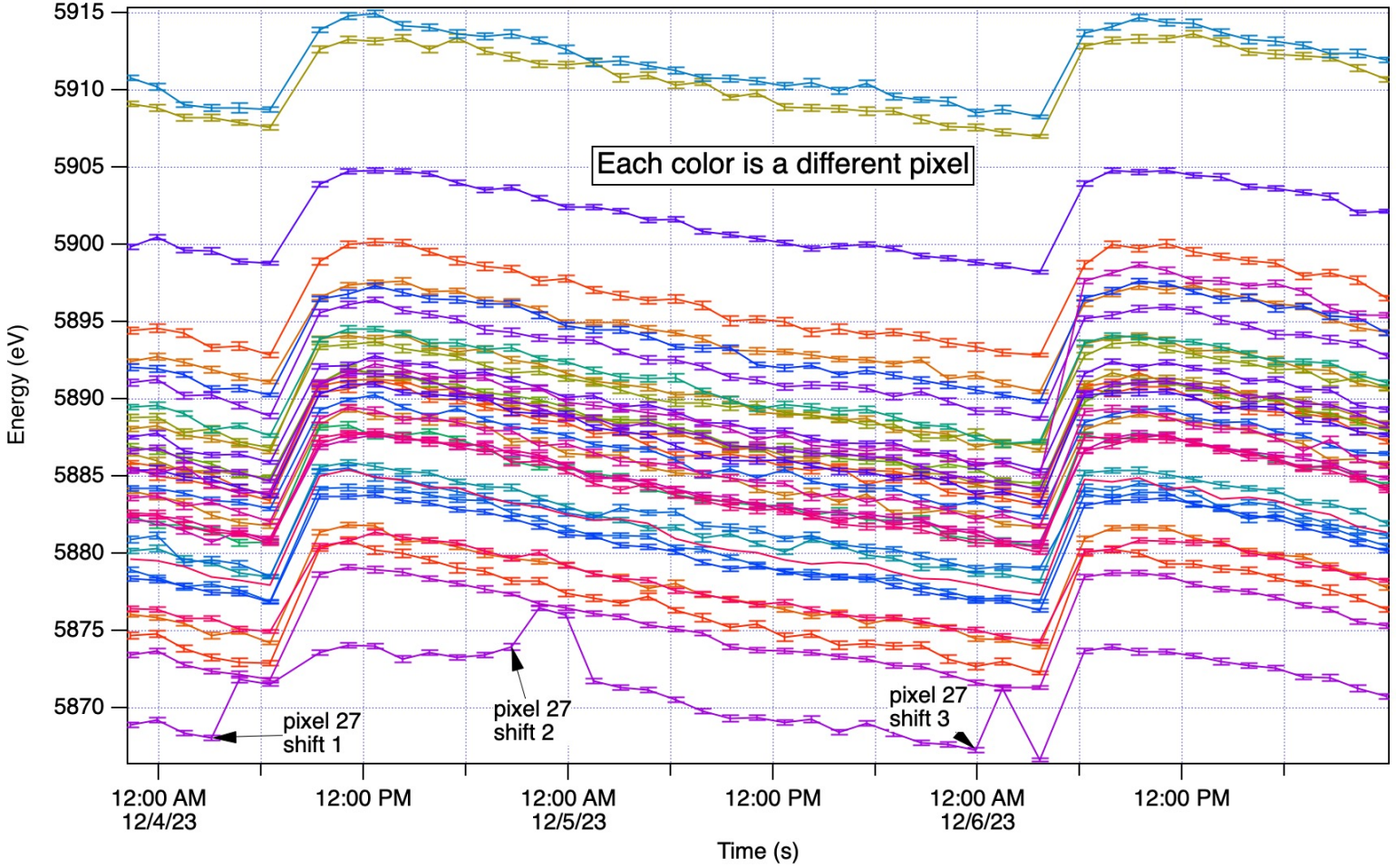
Cal pixel

Gain tracking function

Gate valve closed → FW ^{55}Fe

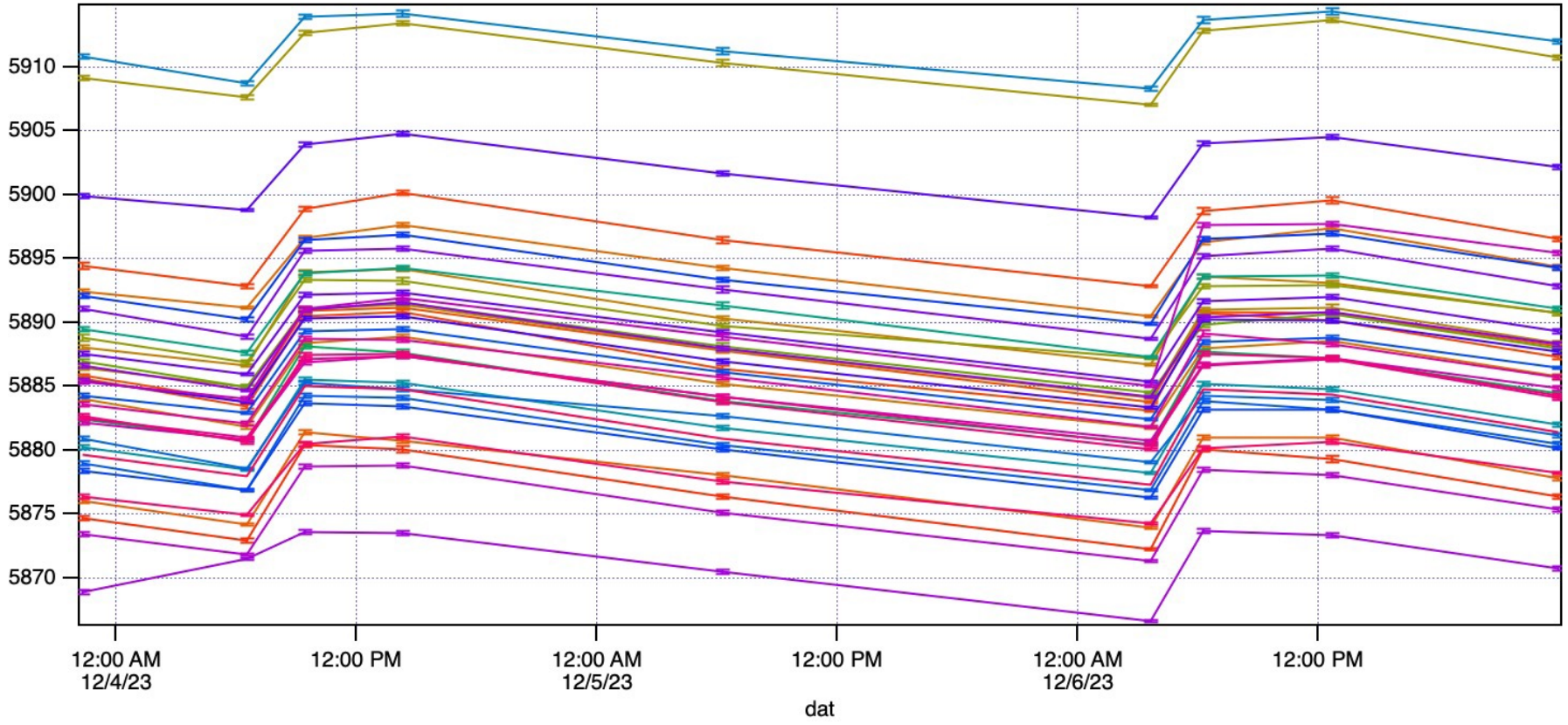
With the Gate Valve closed, each modulated x-ray source only illuminates half the array, and the rate across the illuminated half is highly non-uniform → gain tracking using the FW ^{55}Fe source during eclipse

Trial gain tracking during observation of the N132D (every eclipse)



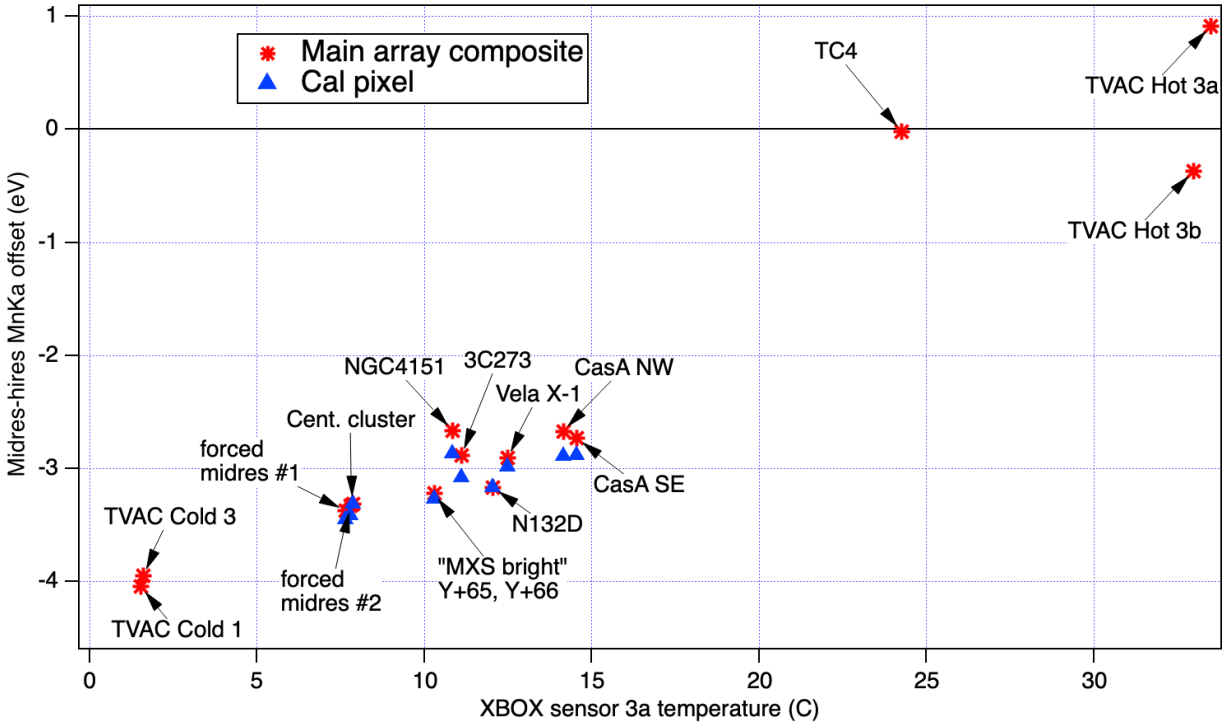
Routine gain fiducials - current plan

High-cadence gain fiducials revealed the minimum set needed to characterize the ADR cycles with negligible LSF broadening (except from pixel 27, which experiences gain steps not yet correlated with any telemetered parameter).



XBOX temperature and energy scale

- Gain also depends on XBOX temperature (which depends on attitude and orbital position)
- This is also well corrected for H events by treating as an effective temperature; however, there is an offset between H and Mp that depends on XBOX temperature and pixel ID.
- Hypothesis that effect due to subtle pulse-shape changes resulting from changes in detector bias that interact differently with the high-res and mid-res digital filter was verified in lab tests of similar detectors.
- Scott Porter's results of in-flight calibration work so far indicate that the offset can removed through linear correction based on XBOX temperature.



Anti-coincidence detector energy scale

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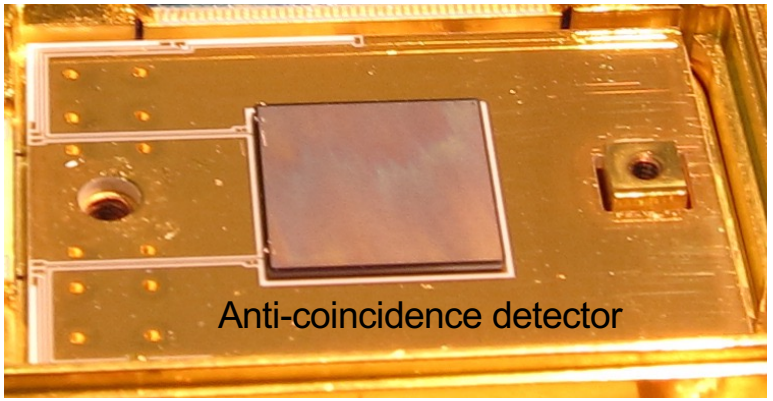
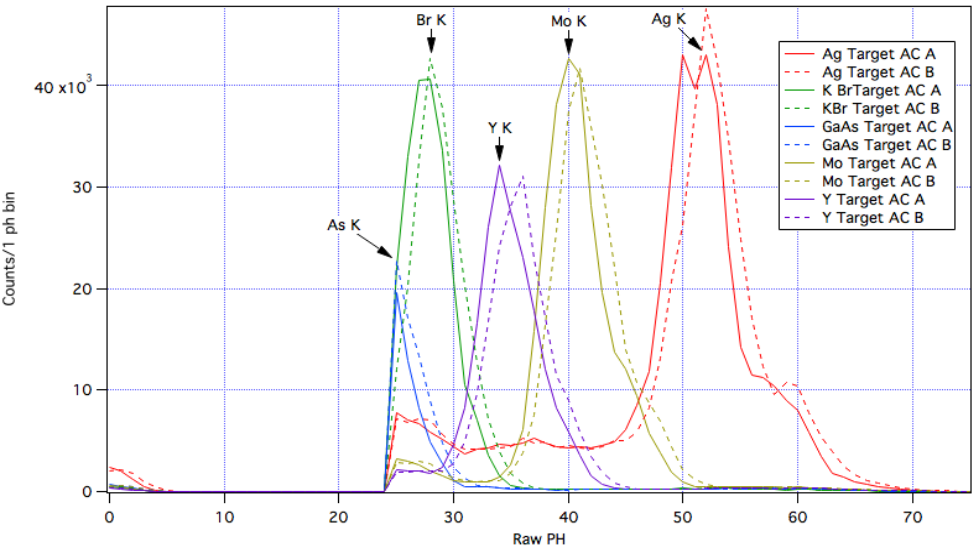
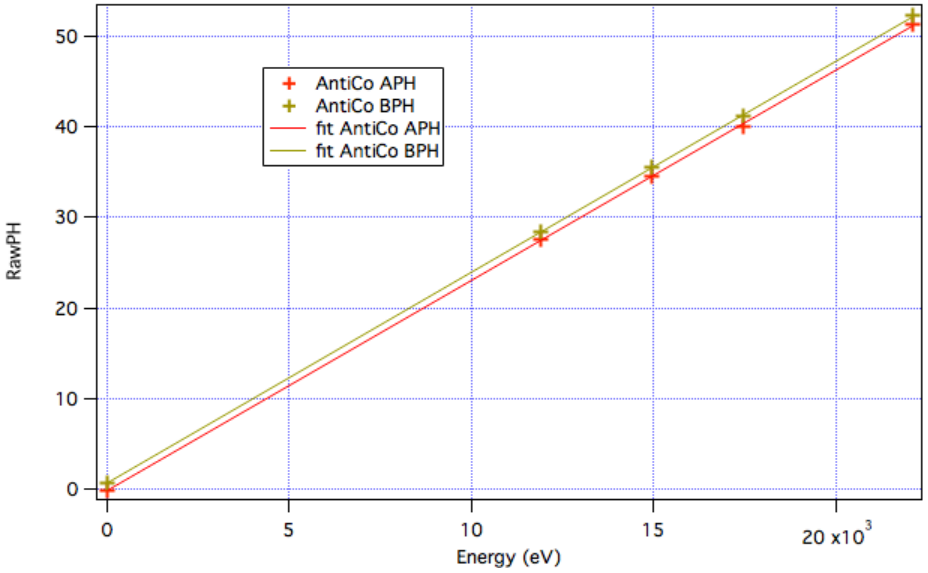
- Low voltage ionization detector behind the main detector array
- Dual independent readouts for redundancy
- Energy scale is linear and independent of temperature over Resolve operating range





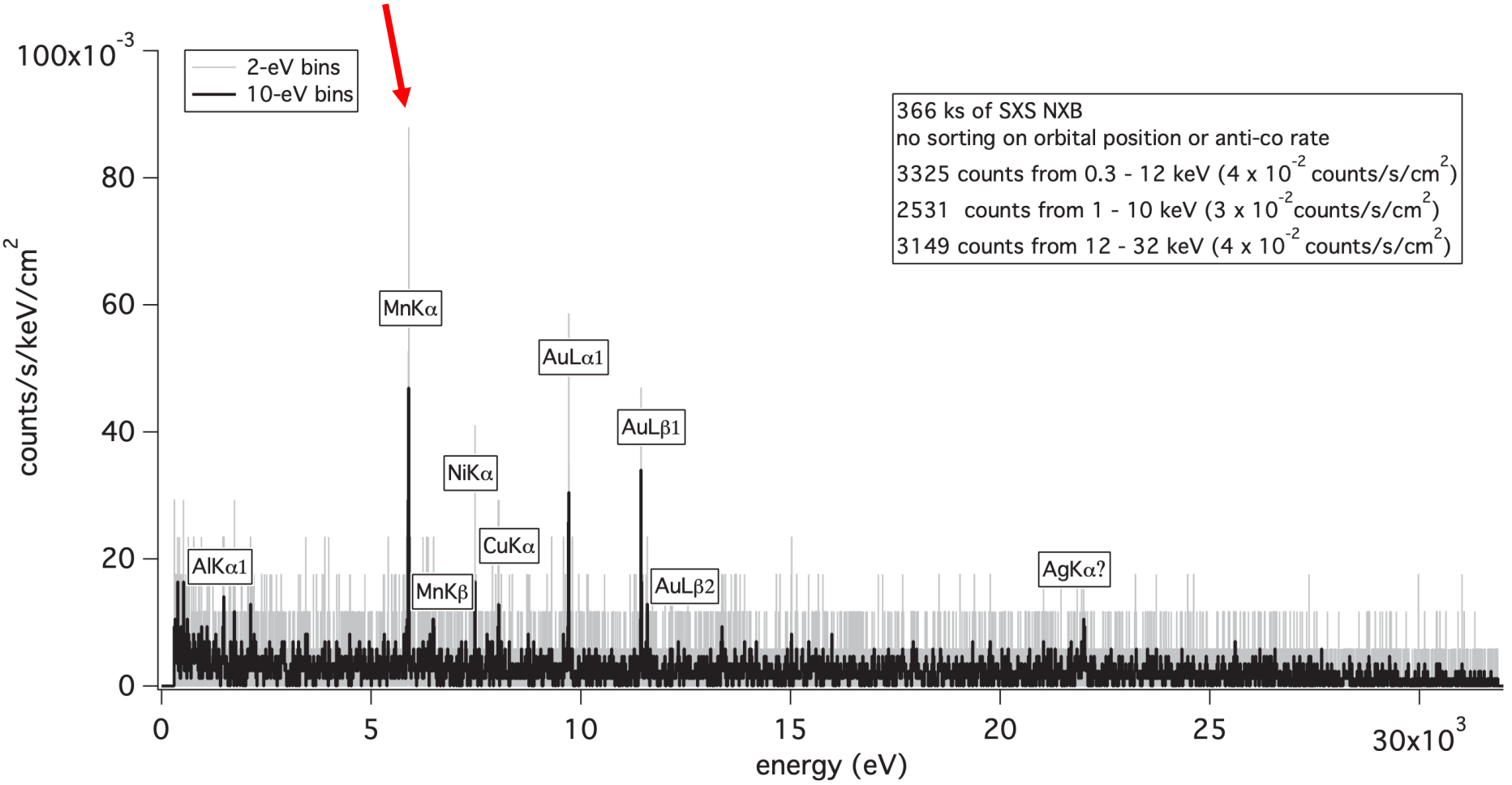


Resolve event screening

- Most background is removed via the particle veto, but there are other important event-screening steps
  - Pulses produced on multiple pixels when particle deposits energy in array frame
    - Effectively cut via combined risetime and pixel-pixel coincidence cut
  - Electron lost from one pixel detected by another
    - Only a concern in cases of high contrast (mainly from cal pixel to field with low surface brightness)
  - Crosstalk
    - Very few crosstalk events are large enough to be triggered
  - GTI
    - SAA borders
    - COR
- Definitions still being refined
- Where user discretion may be applied, it will be important to screen the NXB determined from the data base in the same manner as the observation.
- Currently, the pipeline DOES NOT screen on risetime or pixel-pixel coincidence (other than the tightly constrained pixel-calpix test).

Resolve NXB

Measured background from Hitomi/SXS. Early indications are that XRISM/Resolve is very similar, but Mn K line is not detected.



Kilbourne, et al., PASJ, 2018

Summary

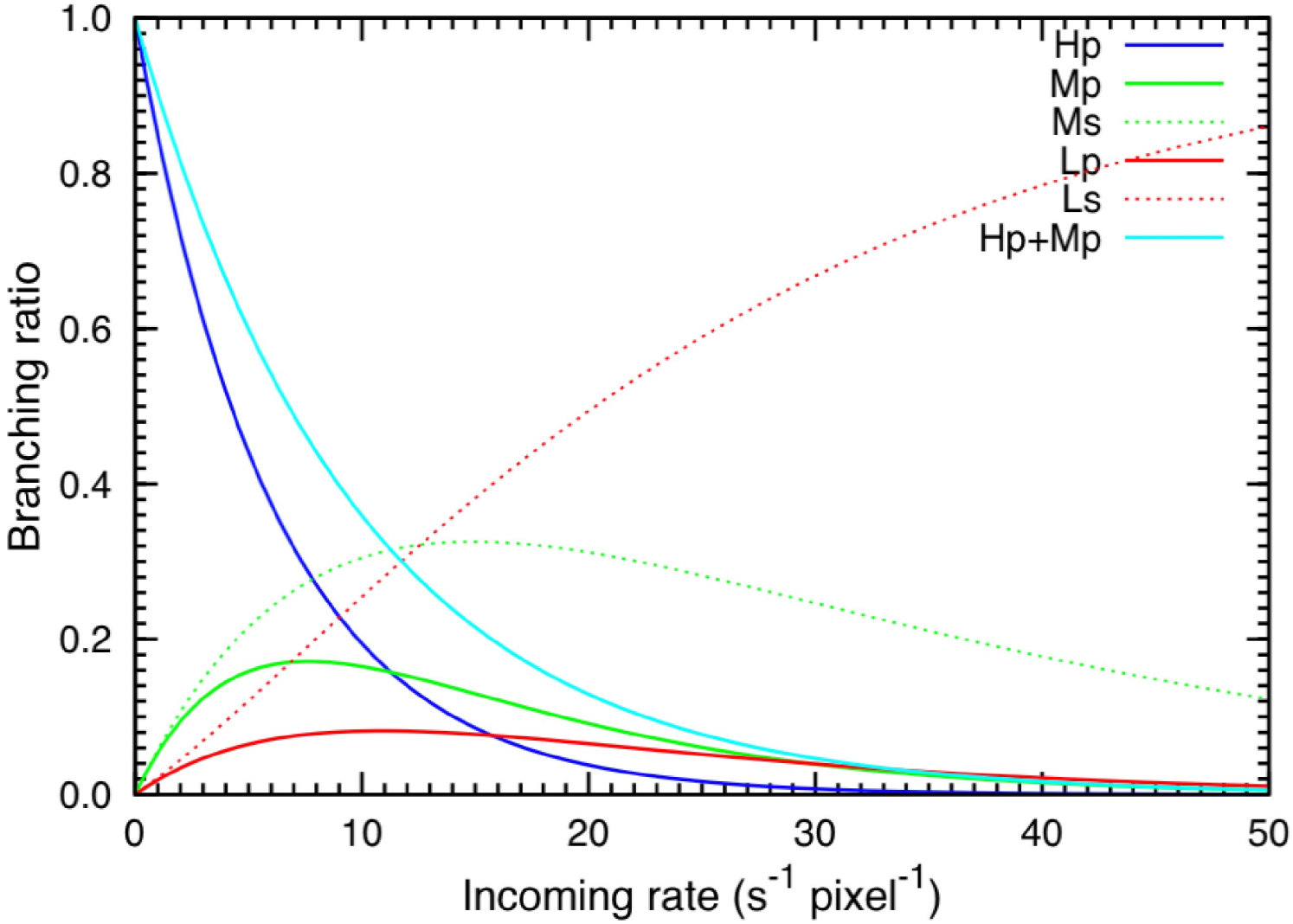
- Resolve relies on thermal detectors, and you have to keep that in mind when working with this instrument.
- Each pixel is an independent spectrometer.
- Requires extensive ground calibration and in-flight verification.
- Inflight calibration/verification is currently on-going.
- Finalizing of initial recommended screening parameters is also currently on-going.
- Resolve is working very well!
  - (except for the fact that the GV is not yet open)

Backup Slides

- Backup Slides

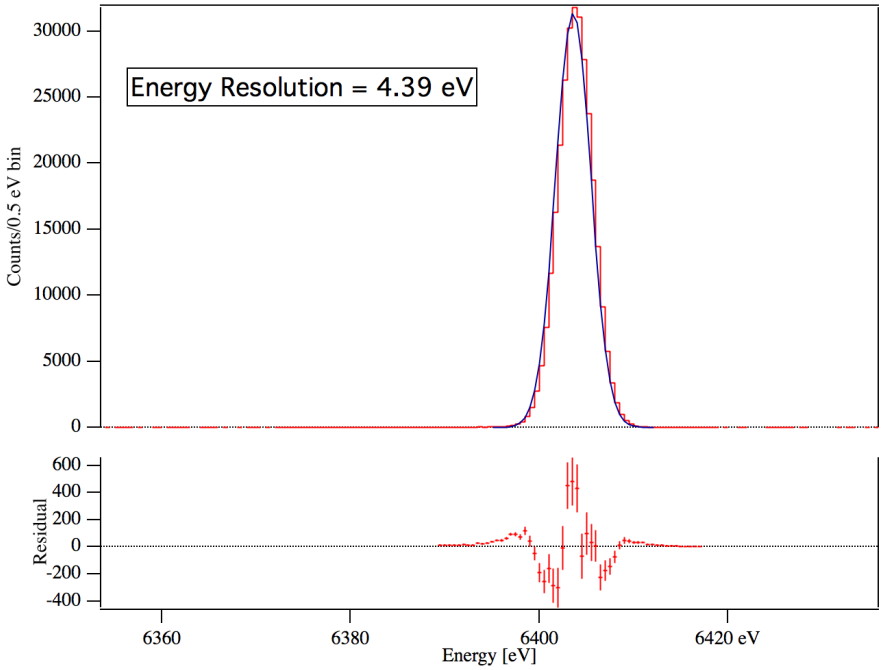
Branching ratio

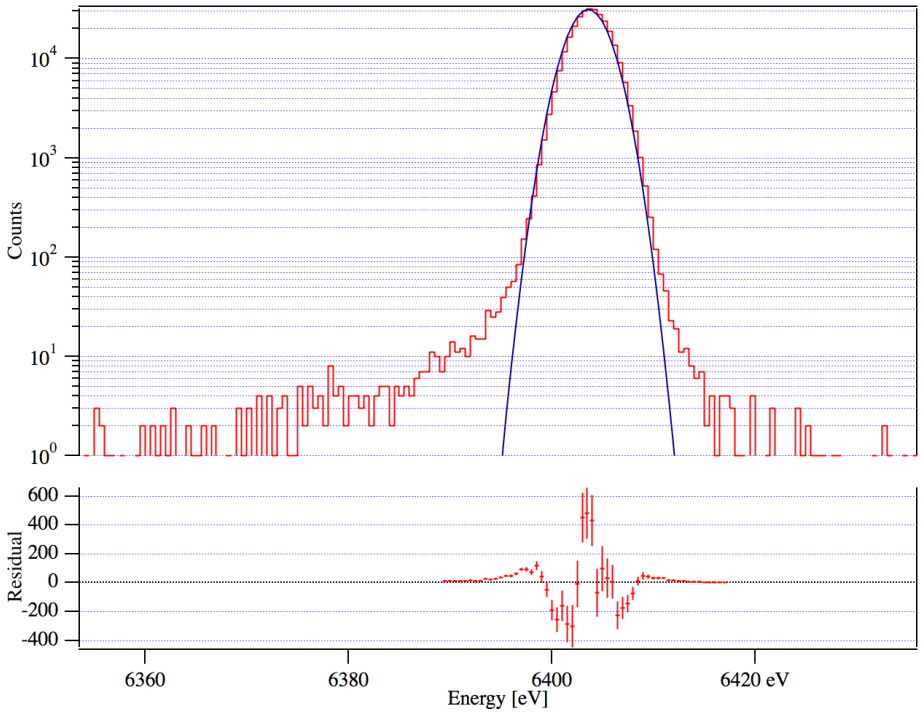
Note: Most celestial source rates are < 1 cps/pixel



Core line shape

Deviates from a gaussian instrumental function at the 1% level, shape depends on energy





Low energy measurements with EBIT

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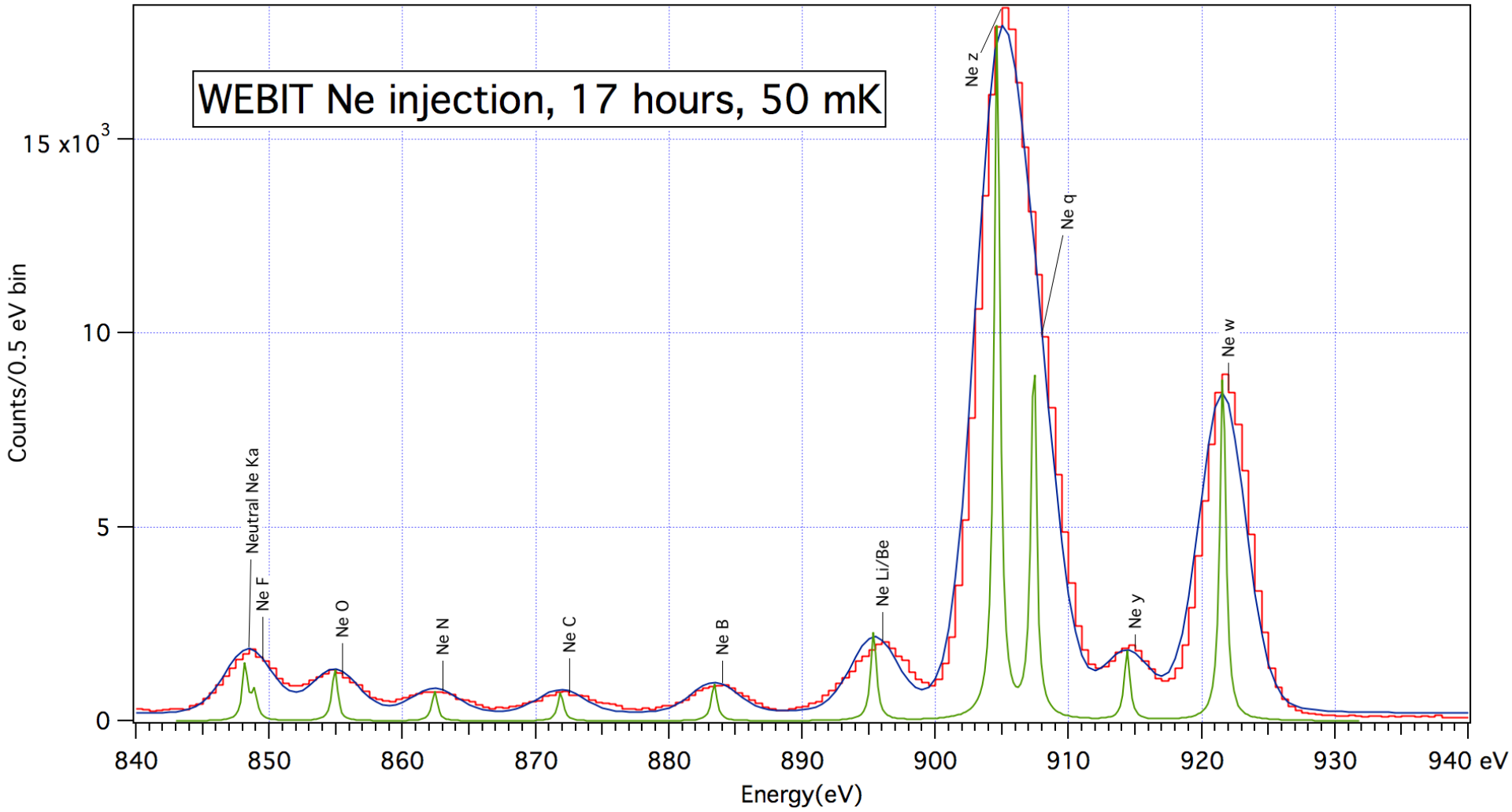
EBIT results for Neon

Energy scale error = +0.41 eV, Energy resolution = 3.83 eV (composite 35 pixels)



Per-pixel results during evaluation of fiducial scenarios