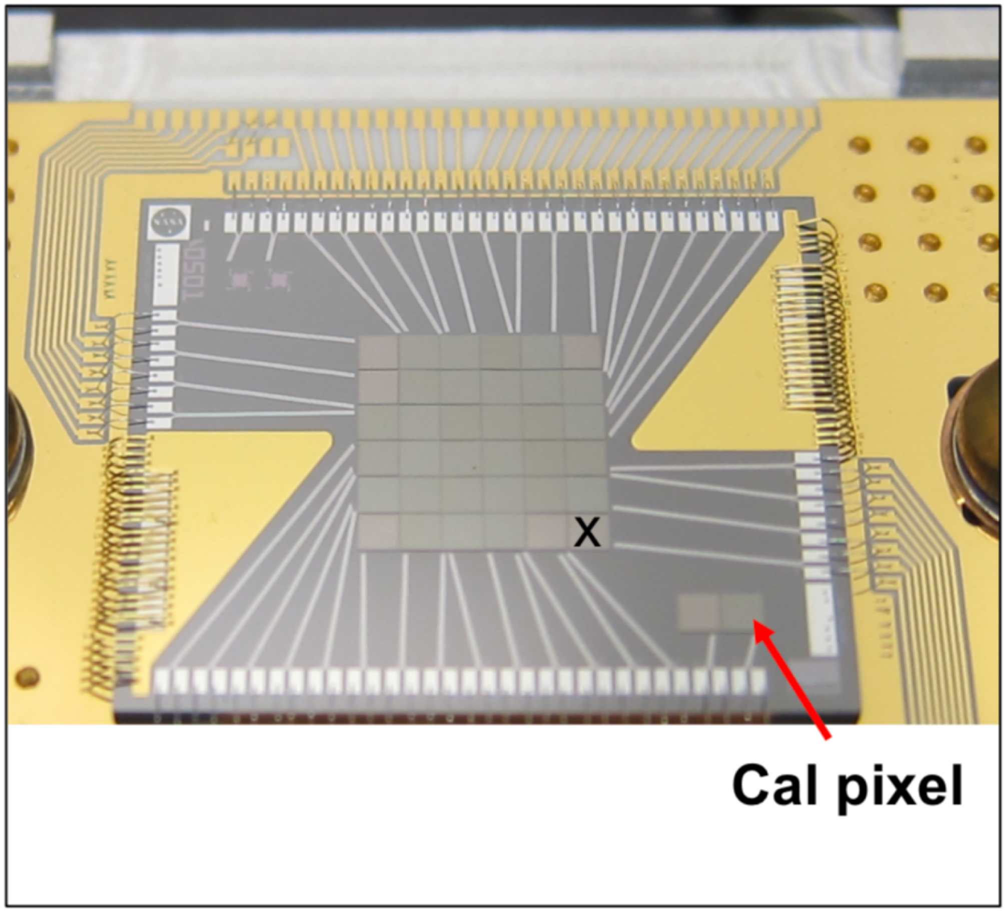
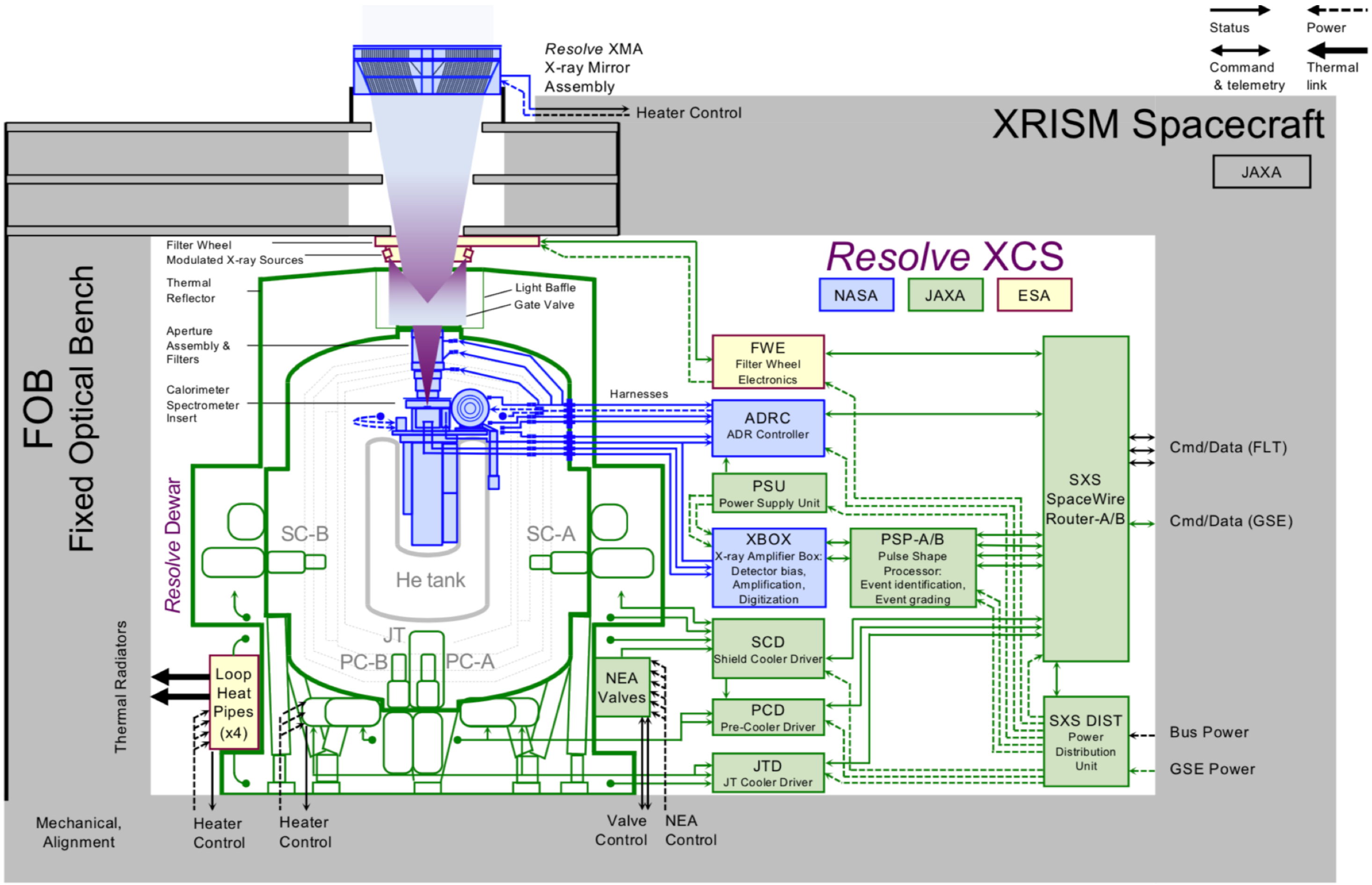
Calibration of the XRISM/Resolve instrument

Maurice Leutenegger for the Resolve calibration team

Resolve detector



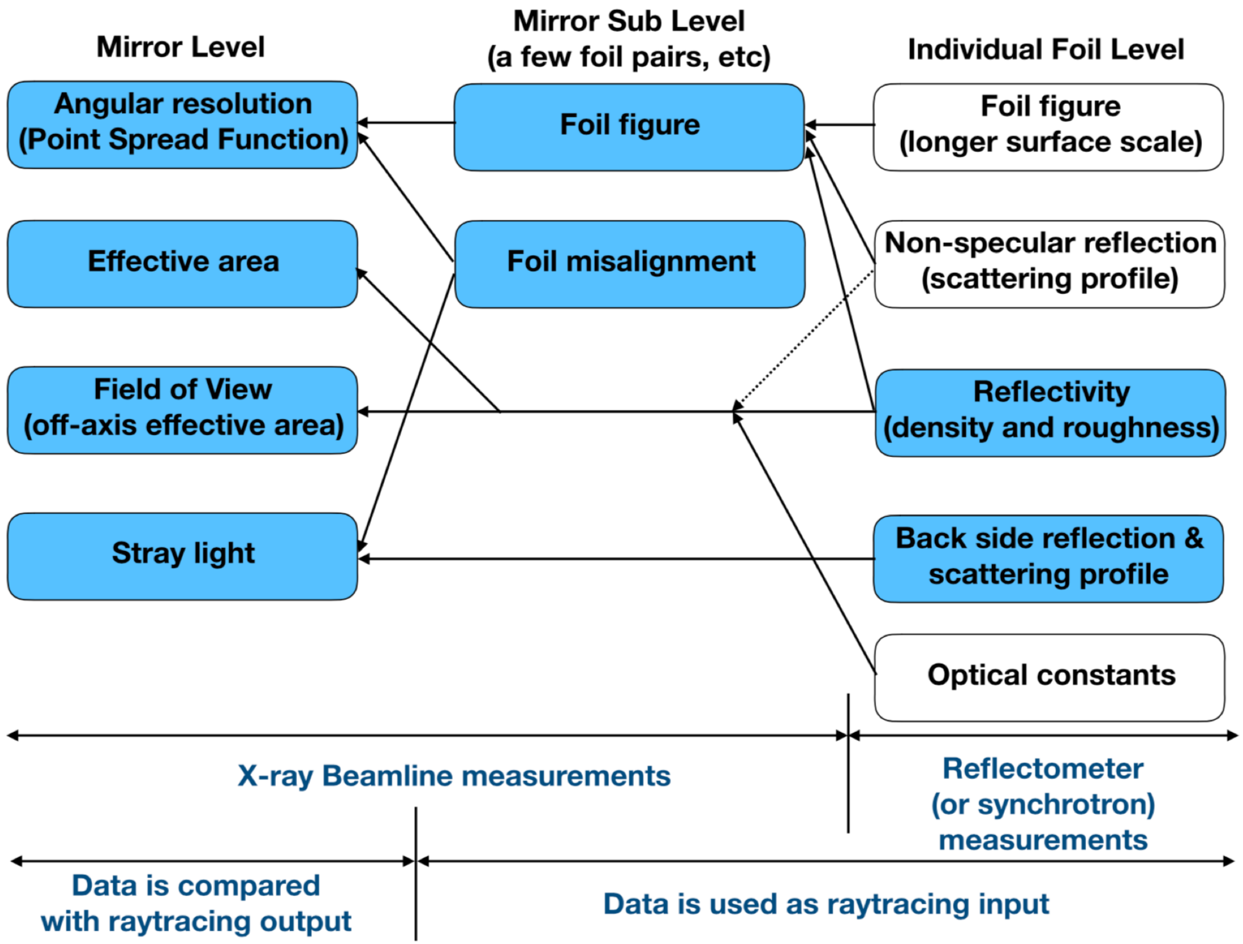
Resolve block diagram



Outline

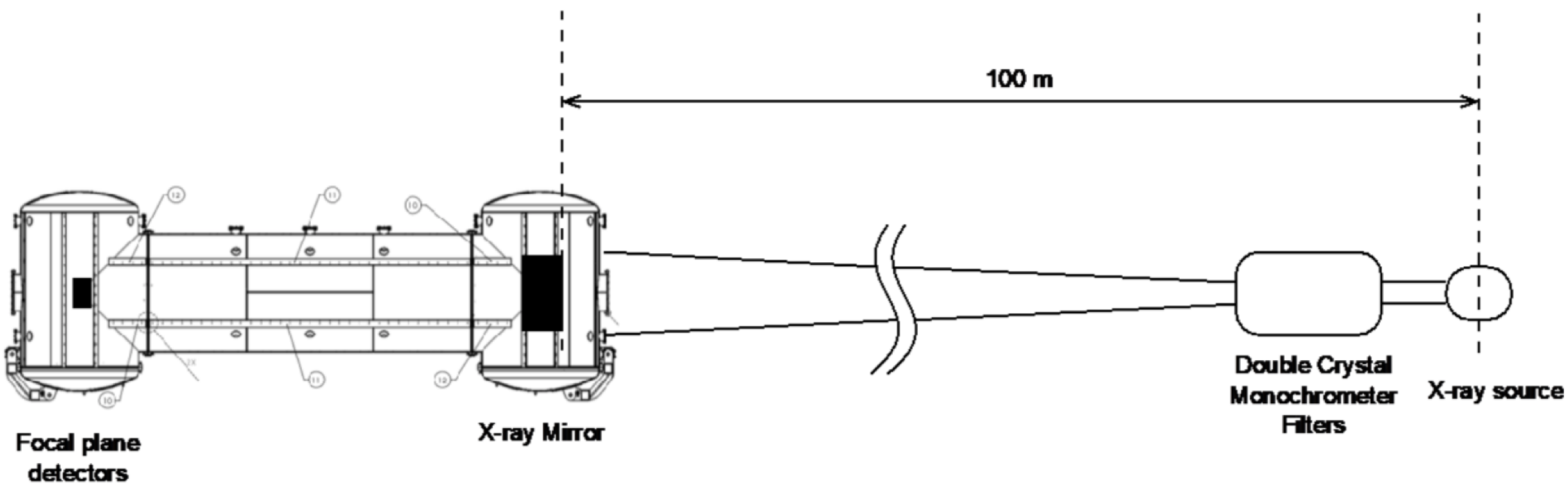
- What is not covered here:
  - Gate valve (T. Midooka)
  - Timing (M. Sawada)
  - Filter wheel
- Telescope (PSF, effective area)
- Optical blocking filters, telescope thermal shield, absorber QE
- Line spread function (core, extended)
- Gain

XRISM mirror calibration strategy



Upgraded GSFC 100 m mirror calibration beamline

Using 5 mm slit, divergence is 10”
(cf. mirror PSF ~ 1’)
Will be used for pencil beam scan



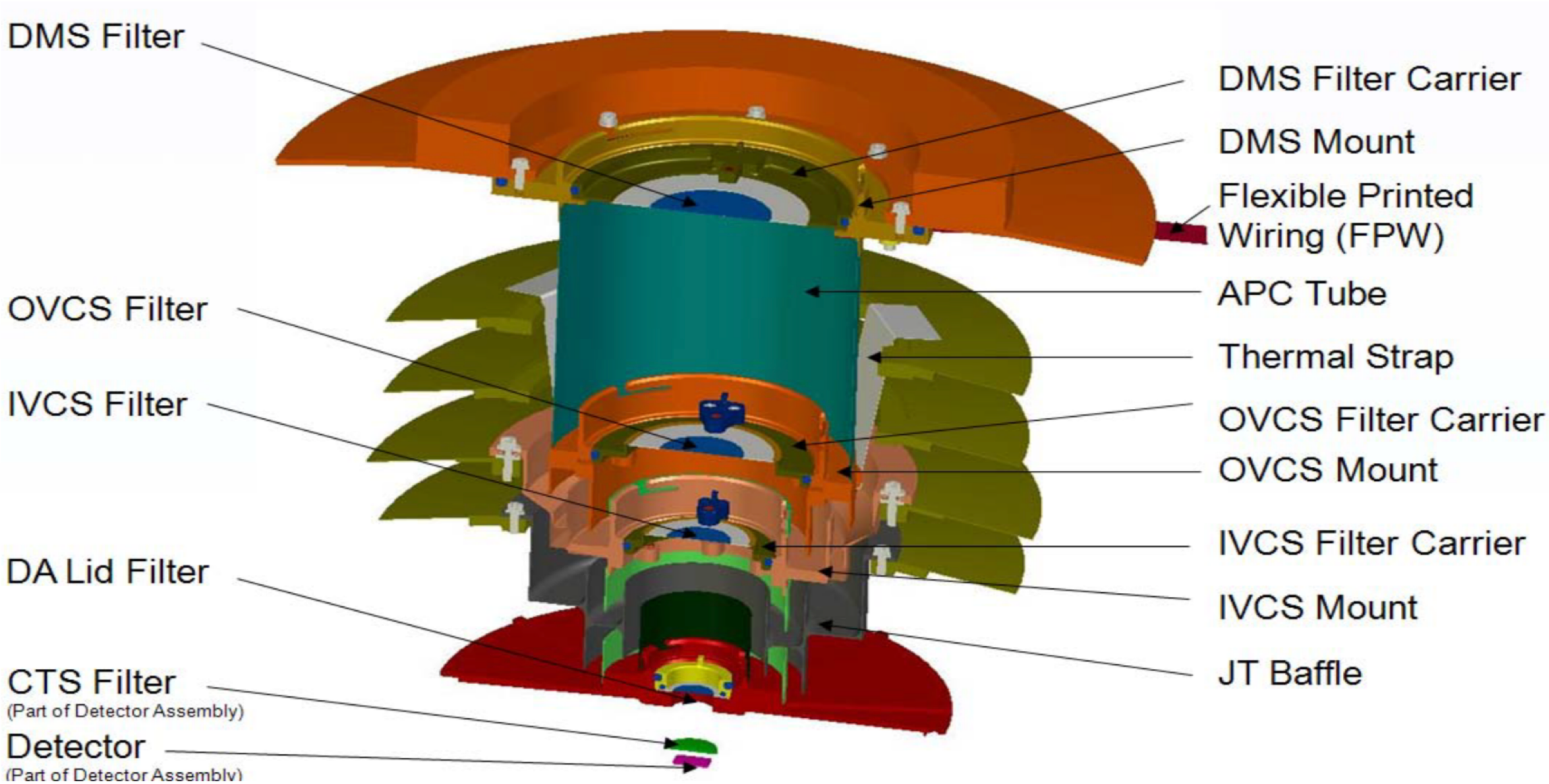
Mirror calibration status

- Upgrade of beamline still ongoing
- Mirrors will be finished soon
- Calibration will start in December 2019

Resolve Dewar optical/thermal blocking filter and telescope thermal shield X-ray transmission

- There are five different internal dewar filters held at different temperatures ranging from 50 mK to ~ 300 K (CTS, DA, IVCS, OVCS, DMS)
- There are four flight candidates of each (20 total filters to calibrate!)
- Inner two filters are freestanding aluminized polyimide film; outer three are same film on two-level hexagonal Si support mesh
- Thermal shield is Al/PI on square Ni mesh; subdivided into 8 octants; two telescopes (Resolve and Xtend), so 16 octants total

Resolve Dewar aperture



Resolve Dewar optical/thermal blocking filter and telescope thermal shield X-ray transmission

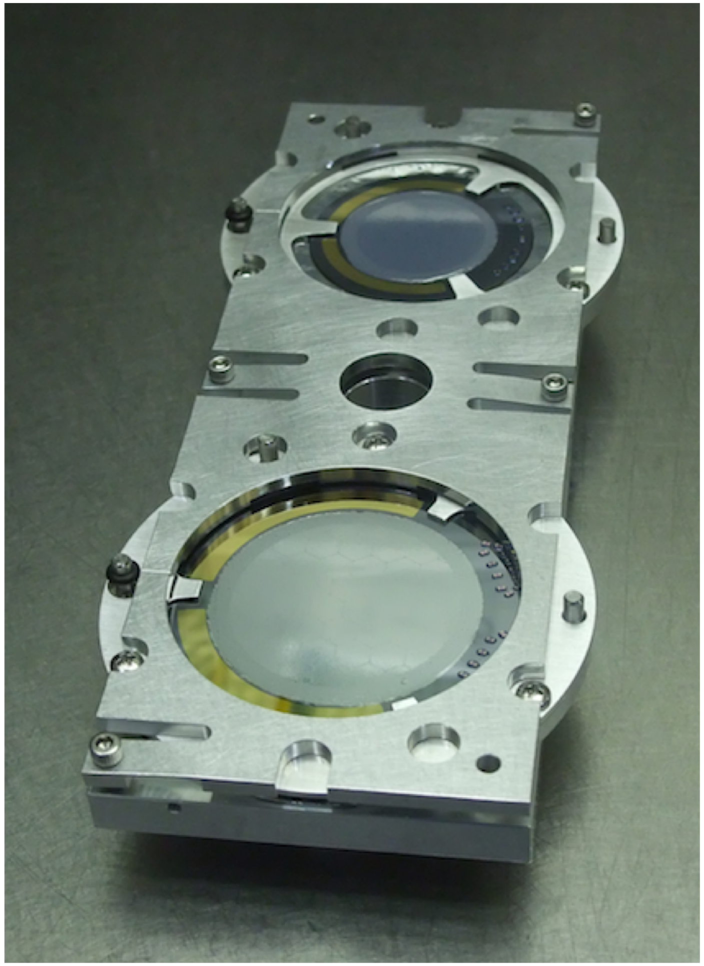
- Strategy:
  - inner filters: measure directly
  - thermal shield: measure witness samples
  - outer filters: measure witness samples and also flight filters (to get mesh filling fraction and nonuniformity)
  - photoelectric absorption edge fine structure: measure calibration standards (Al, PI); also measure as function of temperature

Resolve Dewar optical/thermal blocking filter and telescope thermal shield X-ray transmission

- Facilities: intended to use Canadian Light Source, REIXS beamline, but due to manufacturing issues, need to measure filters immediately upon completion; because of CLS downtime some measurements were done at ALS beamline 6.3.2 (CXRO)

Photos from CLS/REIXS facility

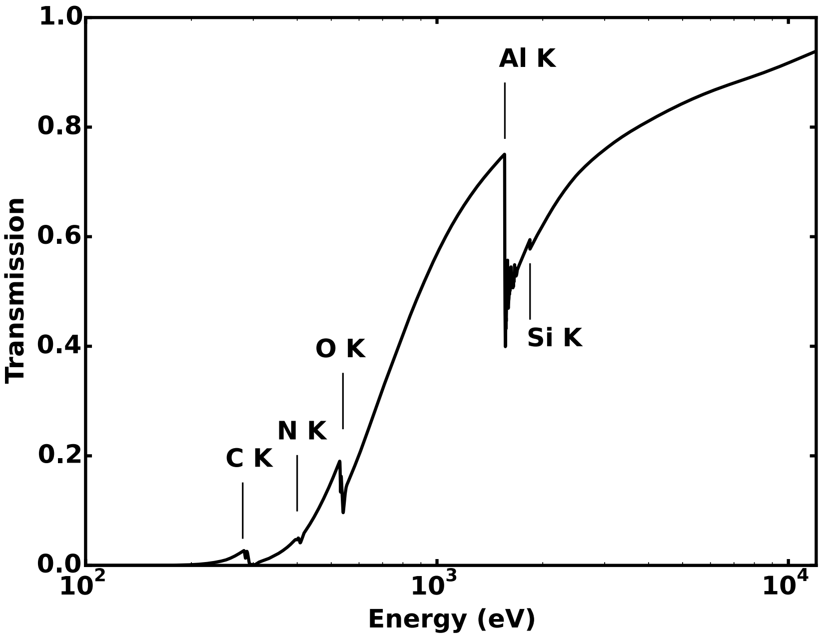
Cryogenic measurements performed on calibration scientists

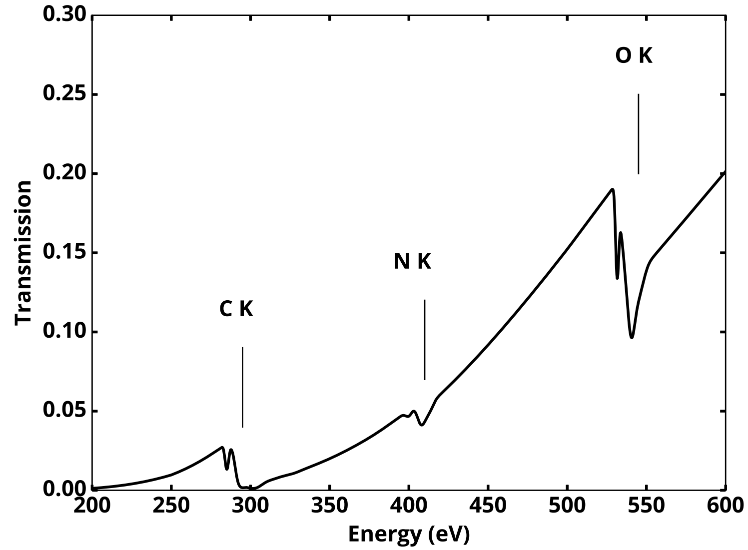


Two filters installed in mounting fixture.

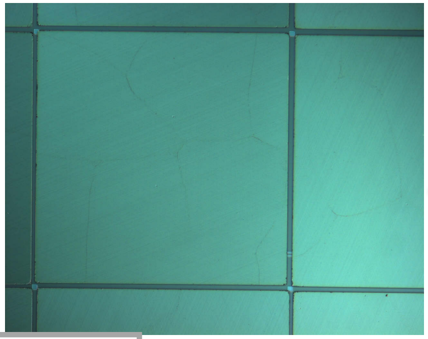
Mounted in chamber for individual measurement.

SXS Dewar blocking filter transmission (Resolve still in progress)



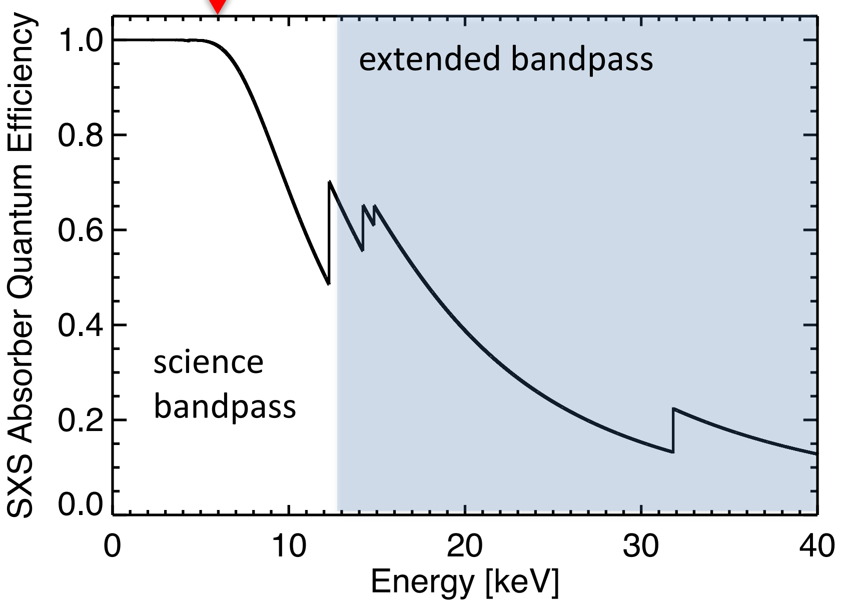


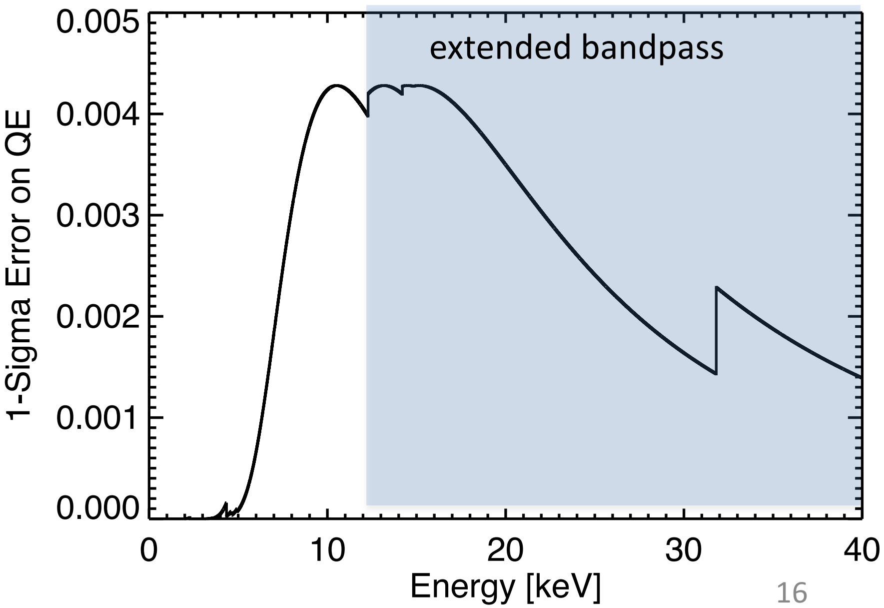
Detector Quantum Efficiency (QE) for Astro-H SXS



Fill fraction = 97%
measured absorber size, compared to pixel pitch

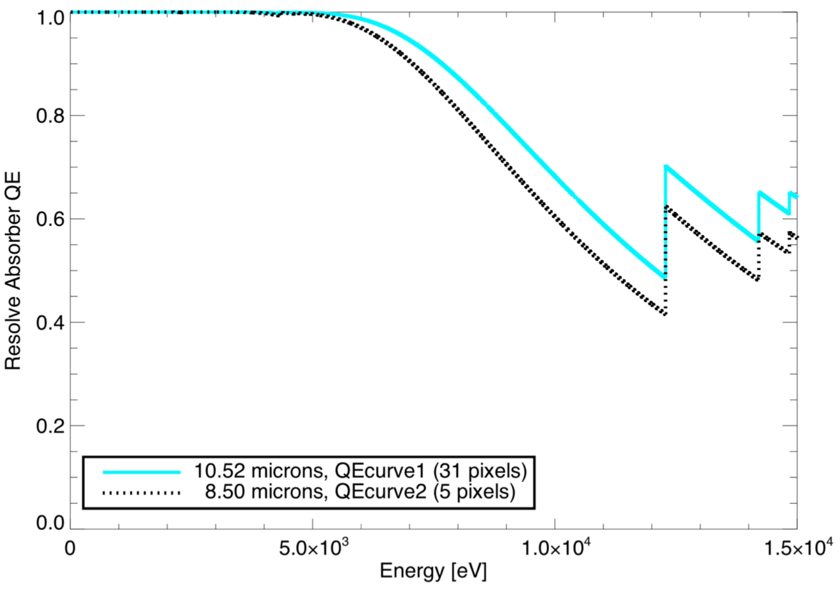
Absorber x-ray stopping power: measured HgTe absorber weight and area. **Areal density = 85.7 ± 1 μg/mm^2.**
Implies thickness of d~10.5 ± 0.1 μm.
Assume nominal stoichiometry column number density of HgTe.





QE for Resolve

- Two different absorber lots used
- Spares also weighed to obtain areal density
- X-ray transmission measurements of spares



Line Spread Function

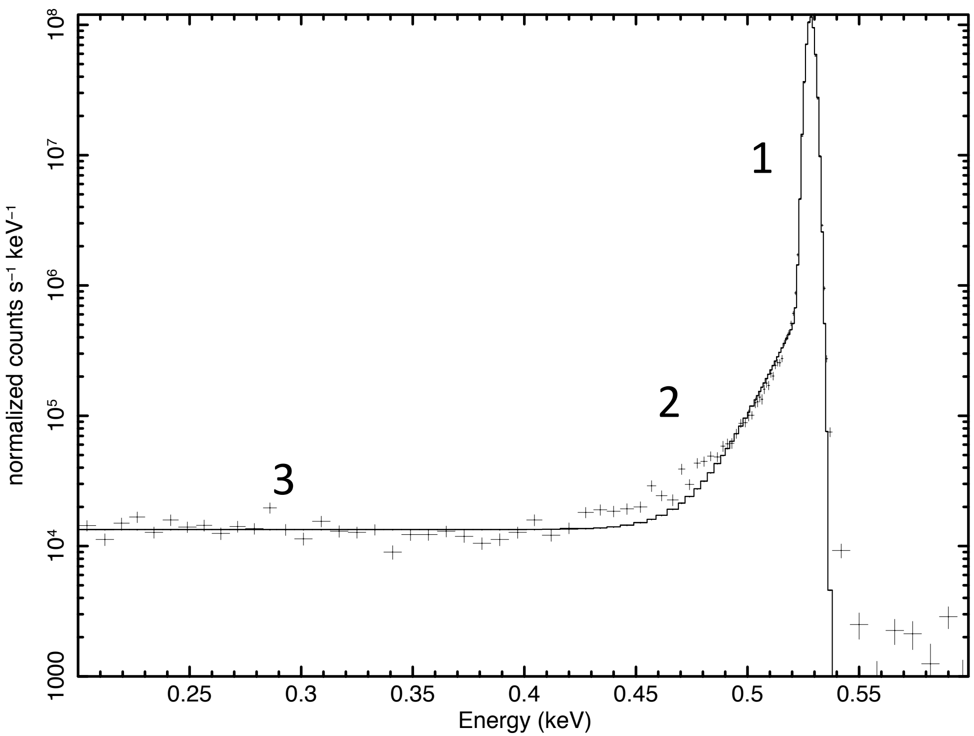
- Overview – core, extended components
- Ground calibration of core
- On-orbit calibration of core
- Extended LSF model and validation

Extended LSF components

1. Gaussian core ("energy resolution")

2. exponential tail (< 2.5%)
   tau ~ 12 eV
   effect is negligible at high energies

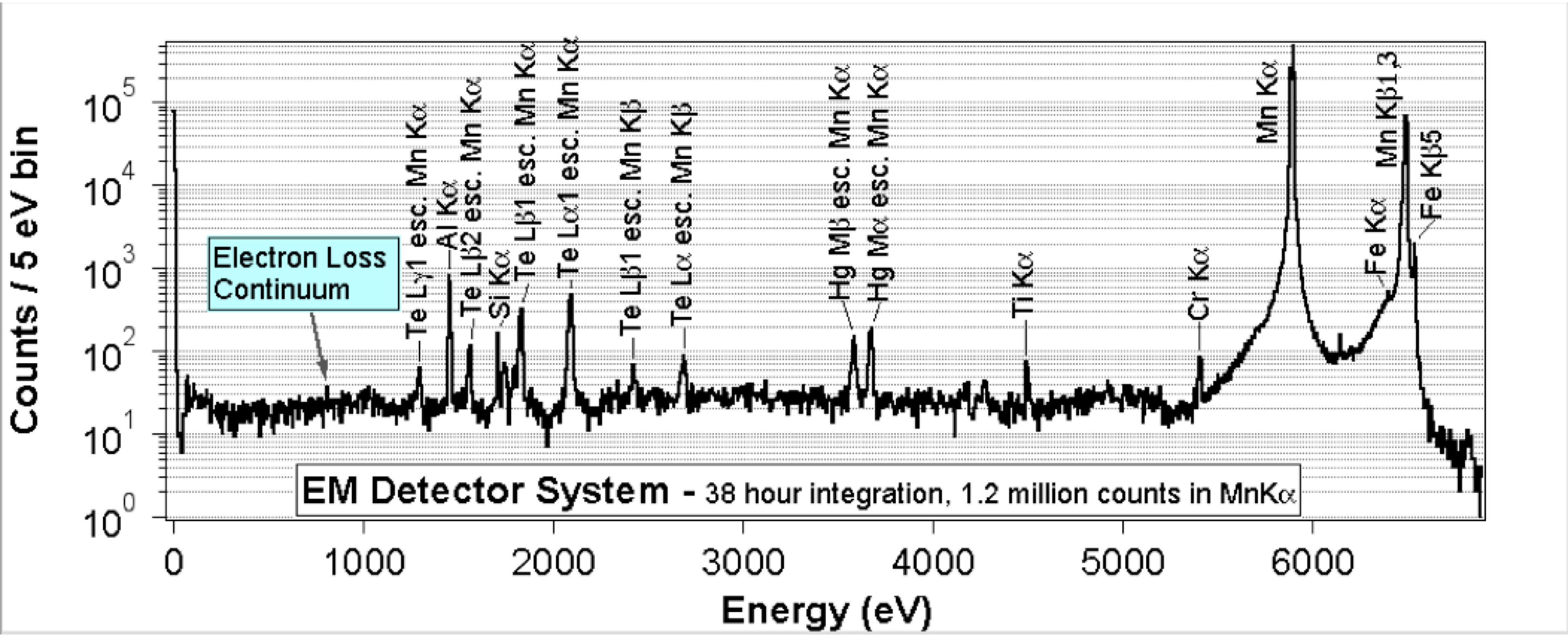
3. electron loss continuum (< 5%)



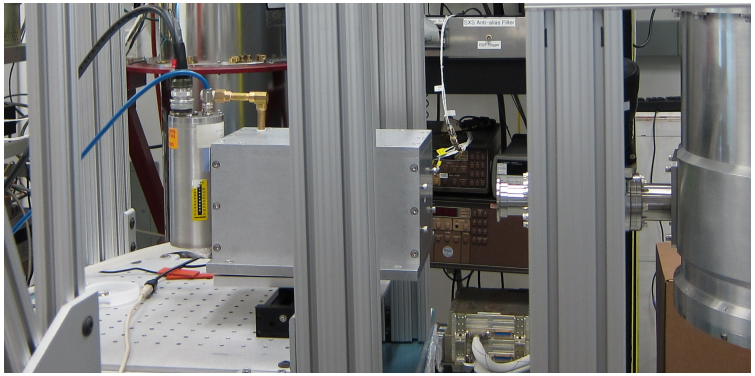
Extended LSF effects are due to absorber physics and will not change. Measured during DA subsystem testing and further measurements or monitoring from the complete system is not required.

Monochromatized O K fluorescence

Extended LSF – escape peaks



Monochromators used for Resolve

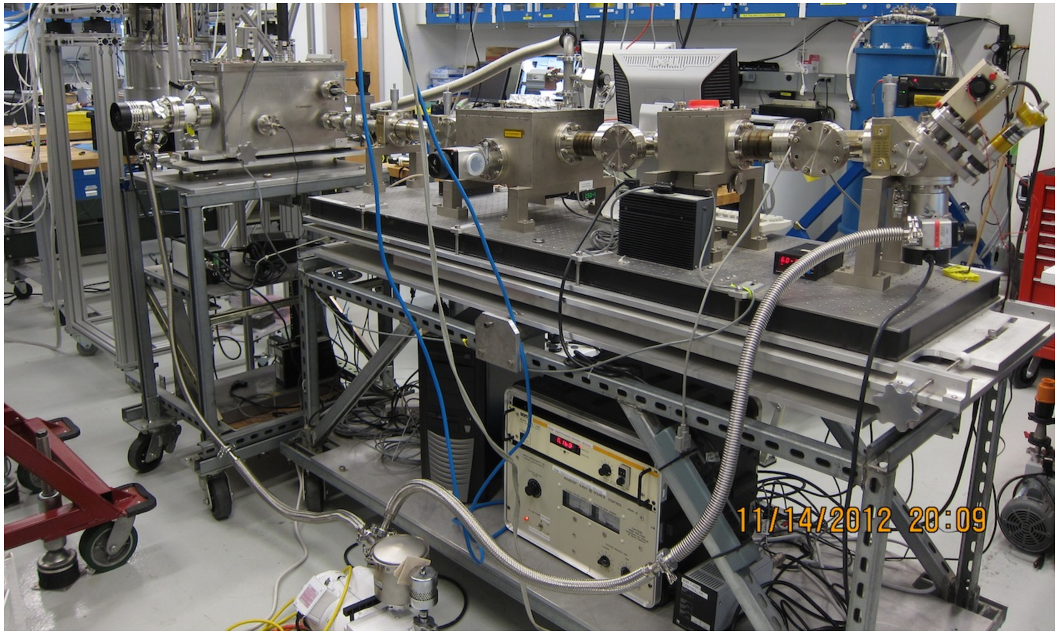


Channel-Cut Crystal Monochromator (CCCM; configured for Cr Ka1)

Used two monochromatic instruments for line-spread function measurements:

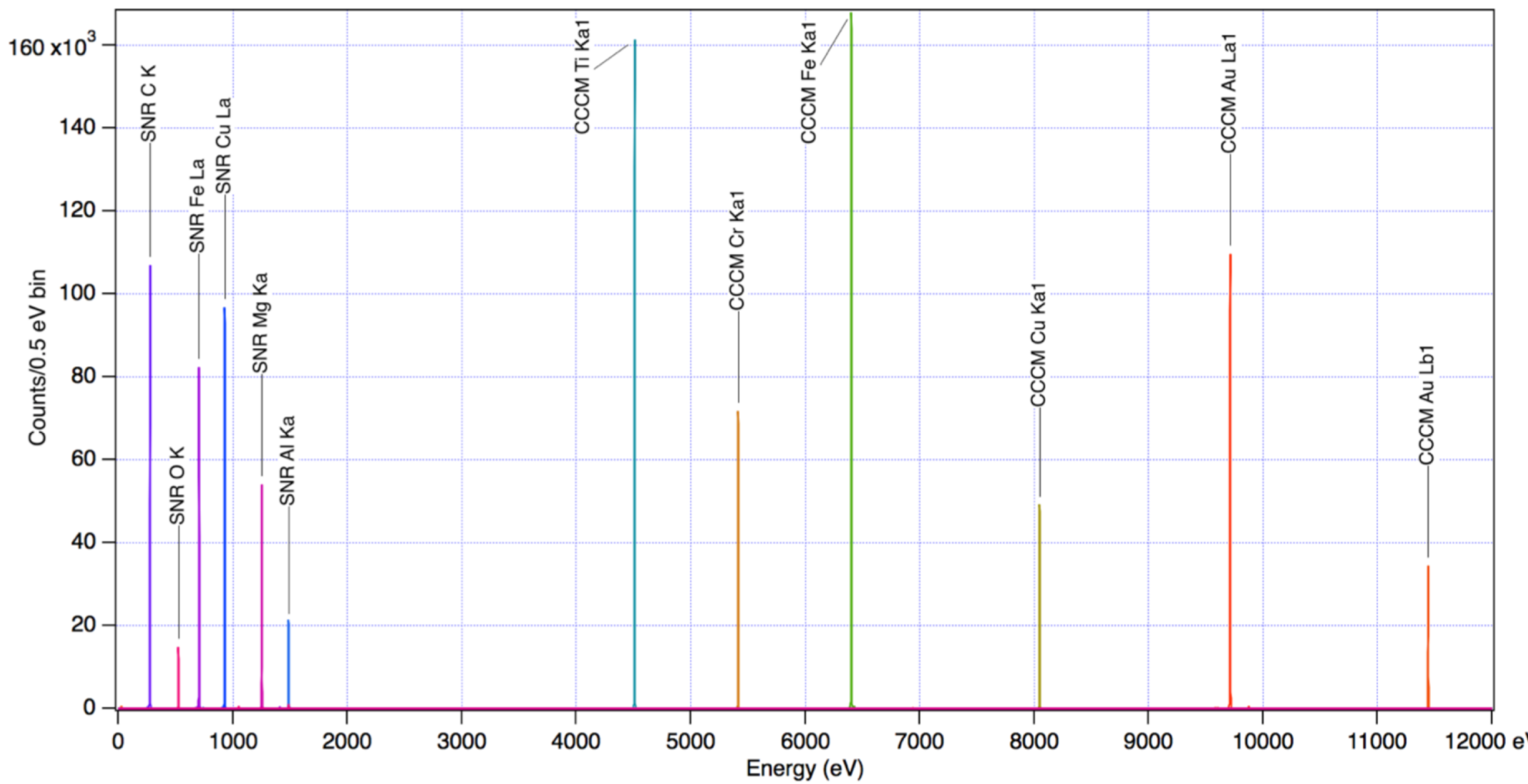
1) Portable Channel-Cut Crystal Monochromators (CCCM): provides <0.5 eV-width photons at 4.5 keV, 5.4 keV, 6.4 keV, 8.0 keV, 9.7 keV, 11.4 keV; portable and will be brought to Japan

2) Surface Normal Rotating (grating) monochromator (SNR): narrow lines for selected lines from 0.28 keV – 1.5 keV; not portable



Surface Normal Rotating Monochromator (SNR; E<1.5 keV)

Composite spectrum from all monochromators used on Resolve DA



Resolve DA energy resolution measurements

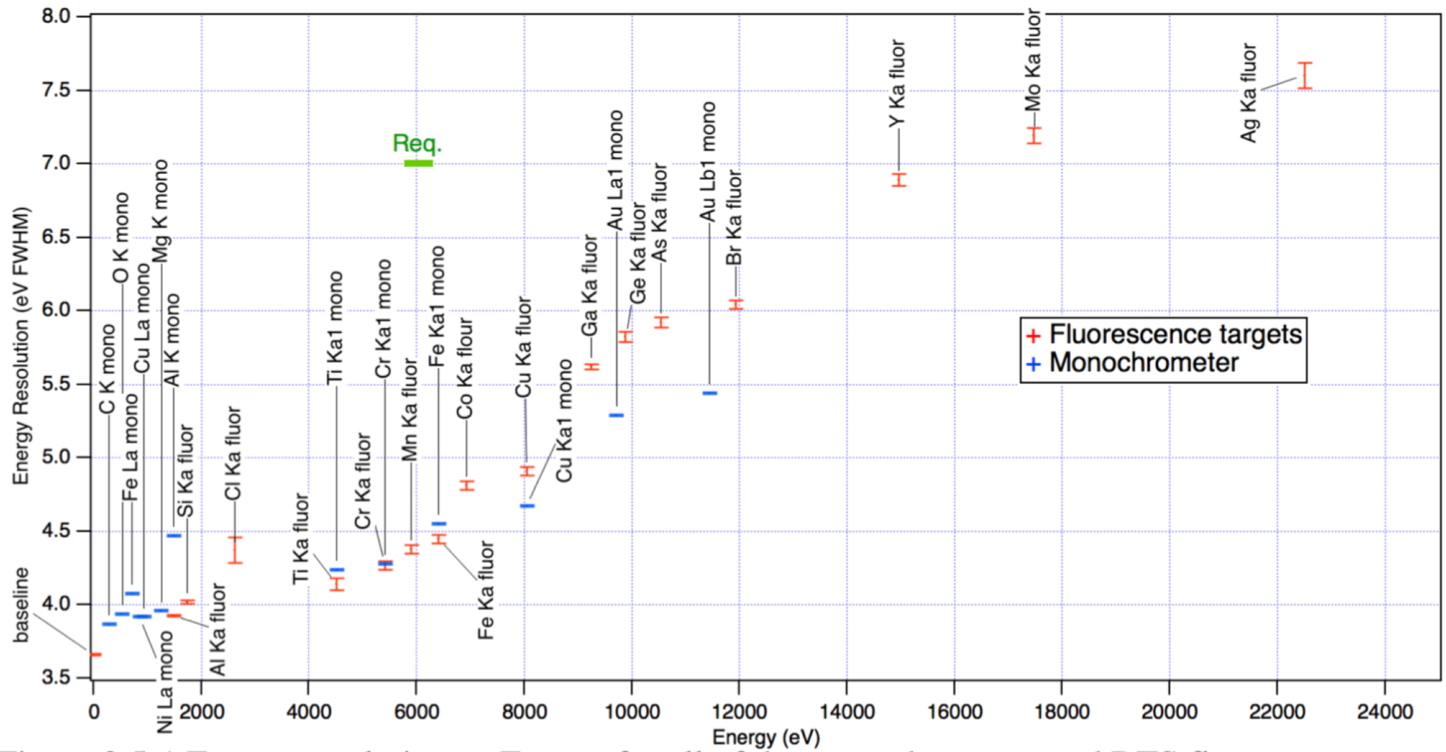
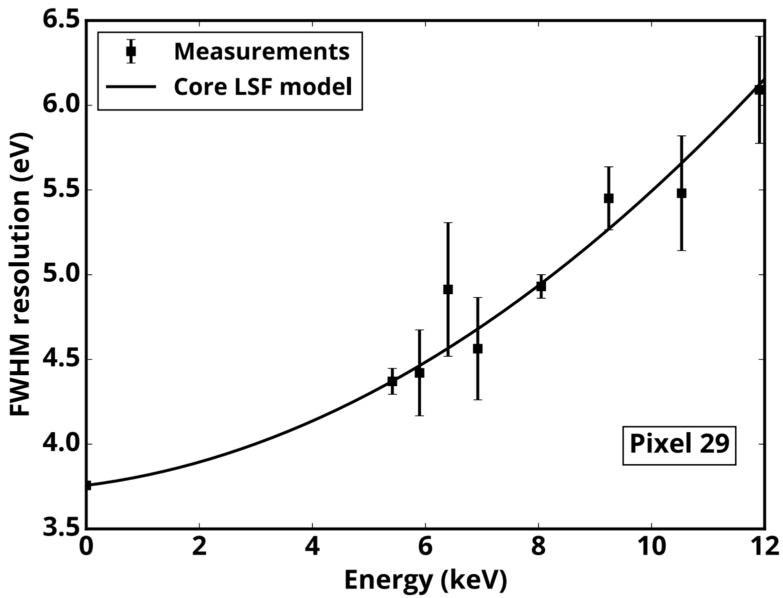


Figure 3.5-1 Energy resolution vs Energy for all of the monochrometer and RTS fluorescent emission ines measured during DS performance and calibration testing during the fall of 2018.

Core LSF pre-flight measurements

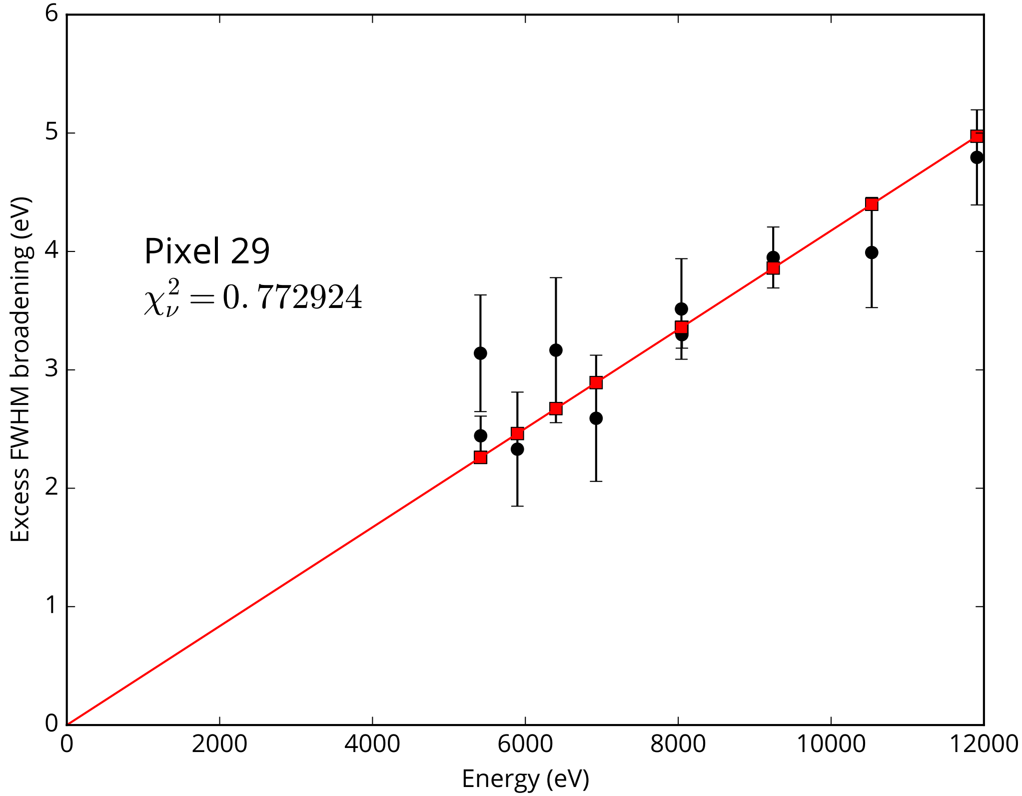
Hitomi SXS Pixel 29 HR events



- Measurements are:
  - per pixel
  - per event grade
  - sensitive to noise environment
  - dependent on onboard pulse processing template

Excess broadening is linear in E

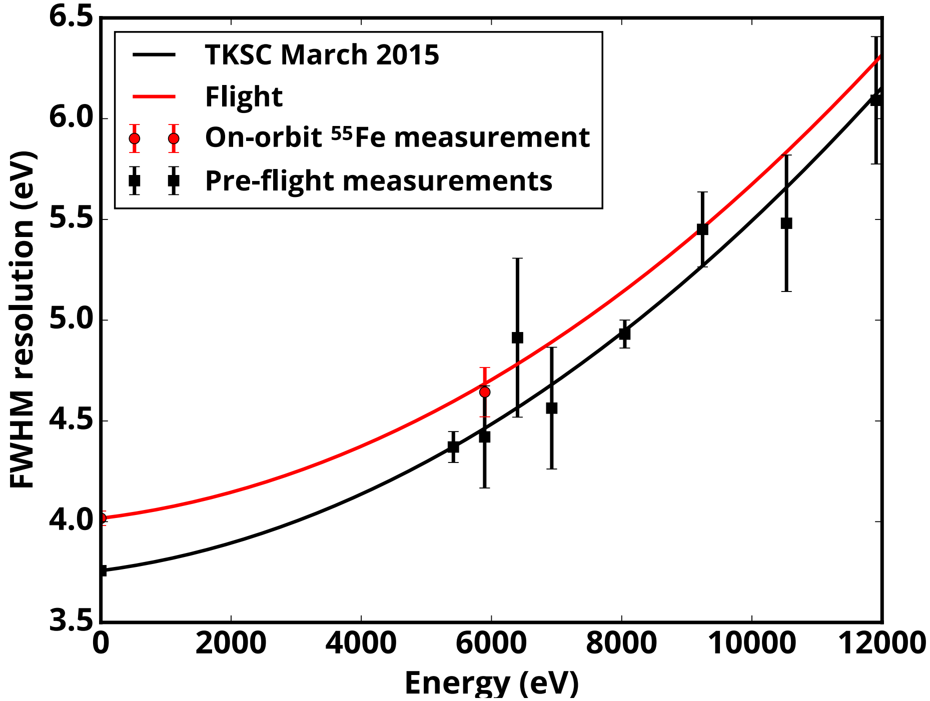
$$dE_{exc}^2 = dE^2 - dE_{base}^2$$



Hitomi SXS Pixel 29

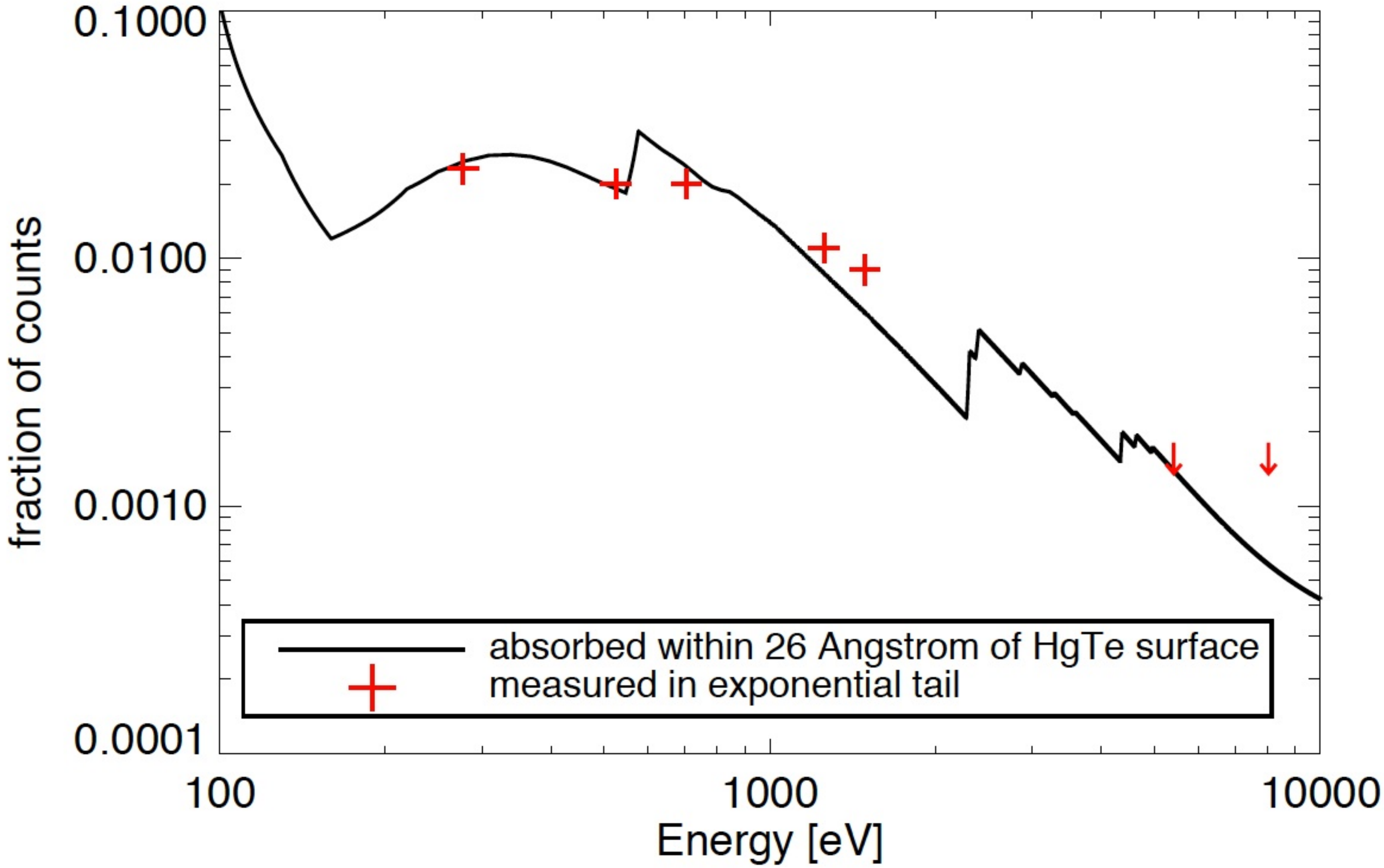
Hitomi SXS on-orbit measurements

Consistent with slightly higher noise due to interference from spacecraft
Excess broadening at ^{55}Fe (almost?) consistent with pre-flight measurement

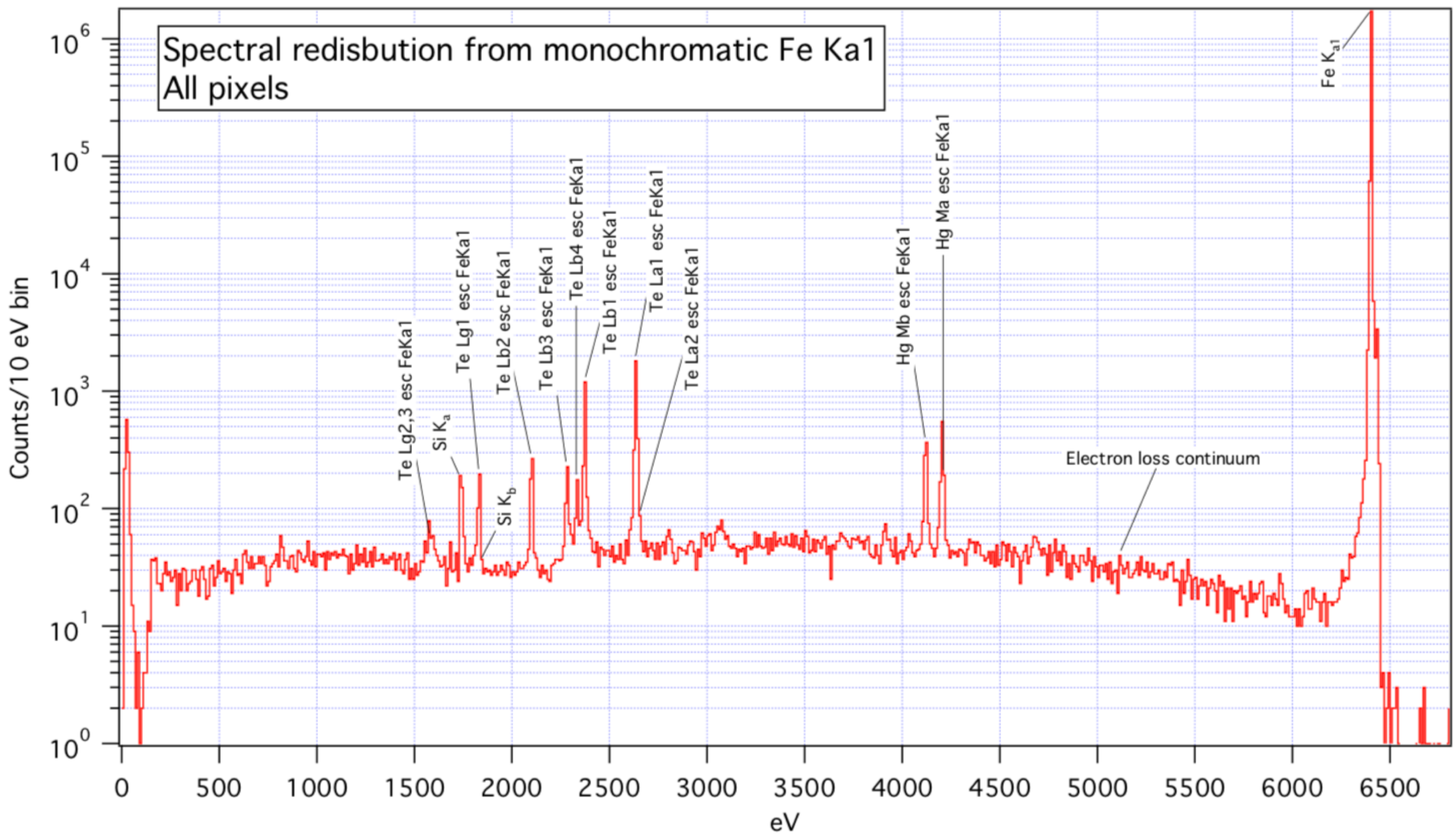


Pixel 29 HR events

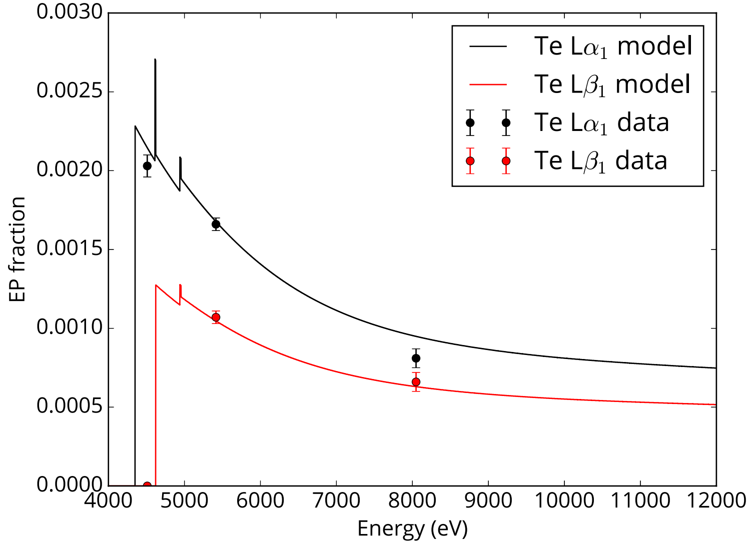
Extended LSF measurements – exponential tail

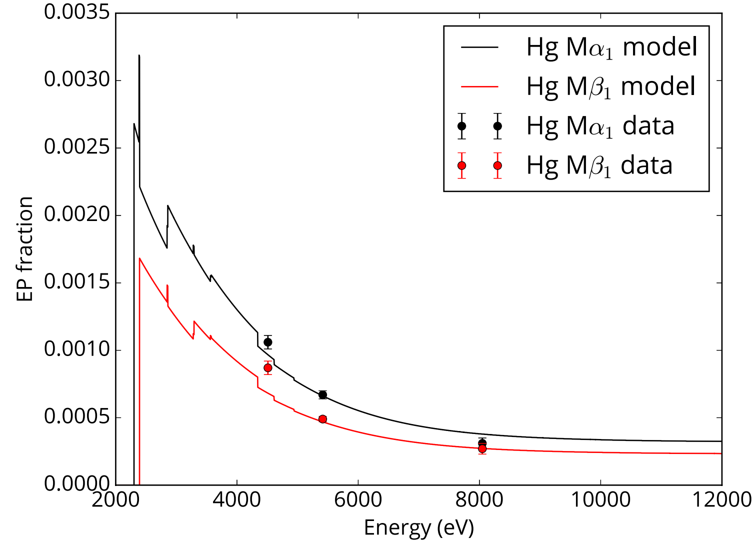


Extended LSF measurements – electron loss continuum, escape peaks



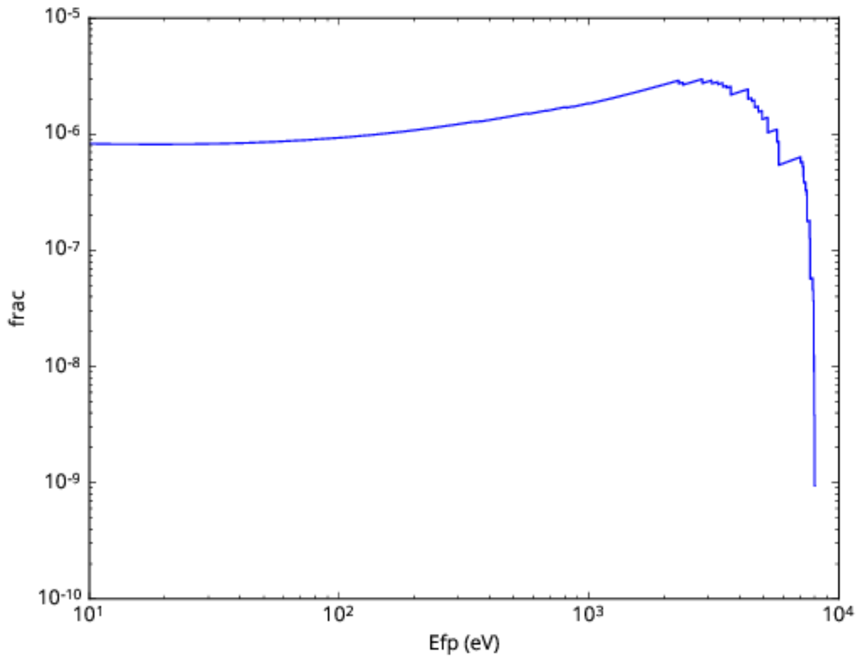
Escape peak strength measurements and model





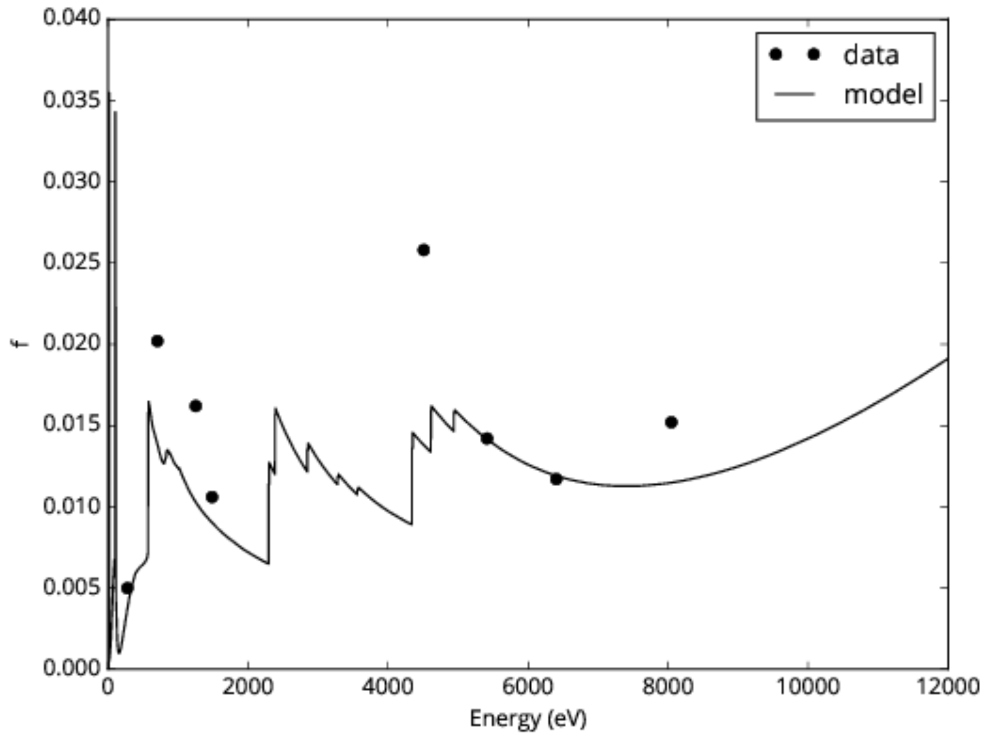
Preliminary physical model and measurements based on Hitomi SXS ground calibration data. Measurements are preliminary and may have significant systematic errors that can be corrected; more measurements now available from Resolve as well.

Modeled electron energy loss spectrum for Cu Ka1



Plot shows spectrum of escaping electrons,
i.e. large energies correspond to small detected photon energies

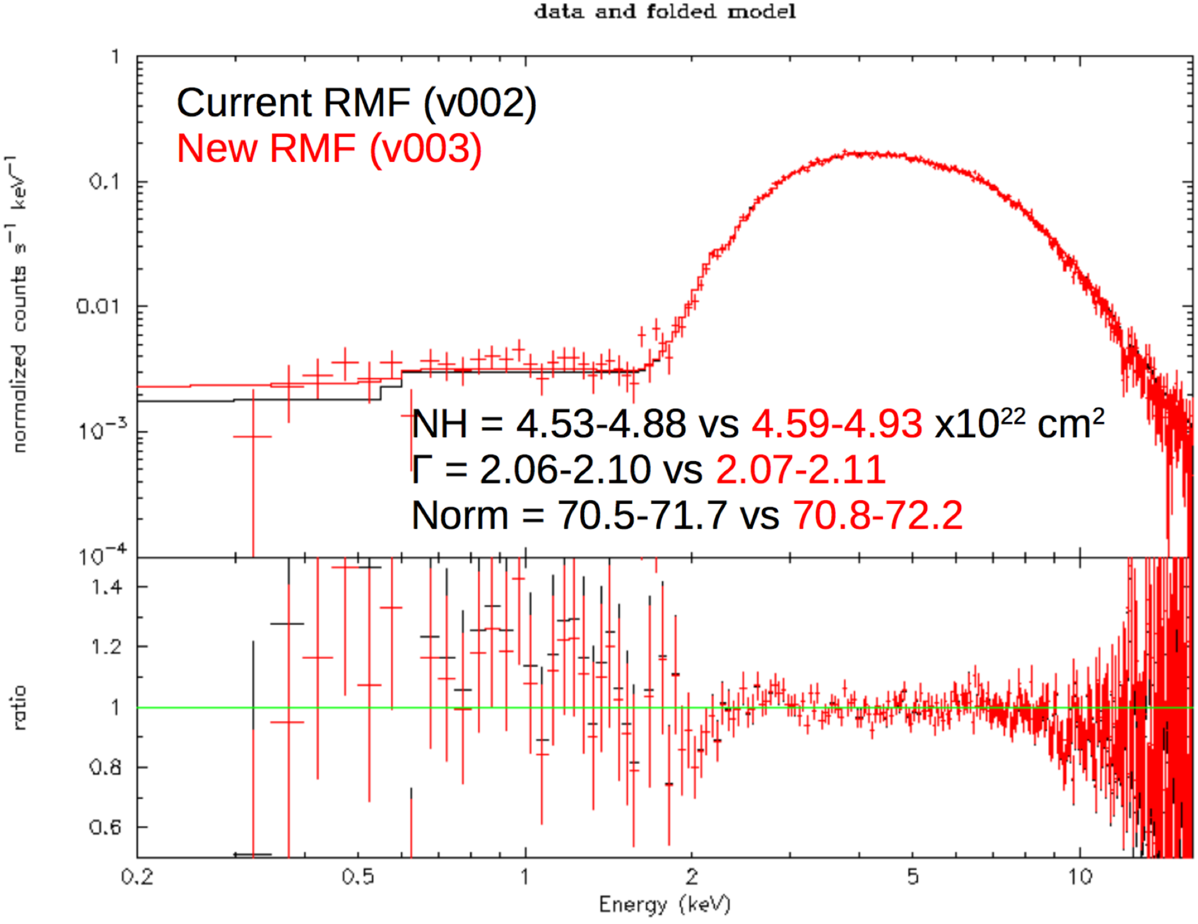
Electron loss fraction



Measurements are based on Hitomi data, are preliminary, and have significant systematic error.
Model depicted only accounts for total fraction of events with energy loss, does not predict spectrum.

Extended LSF agrees well with Hitomi SXS on-orbit data from G21.5-0.9

Observations with closed gate valve allow a test of the broad redistribution due to electron loss continuum and escape peaks

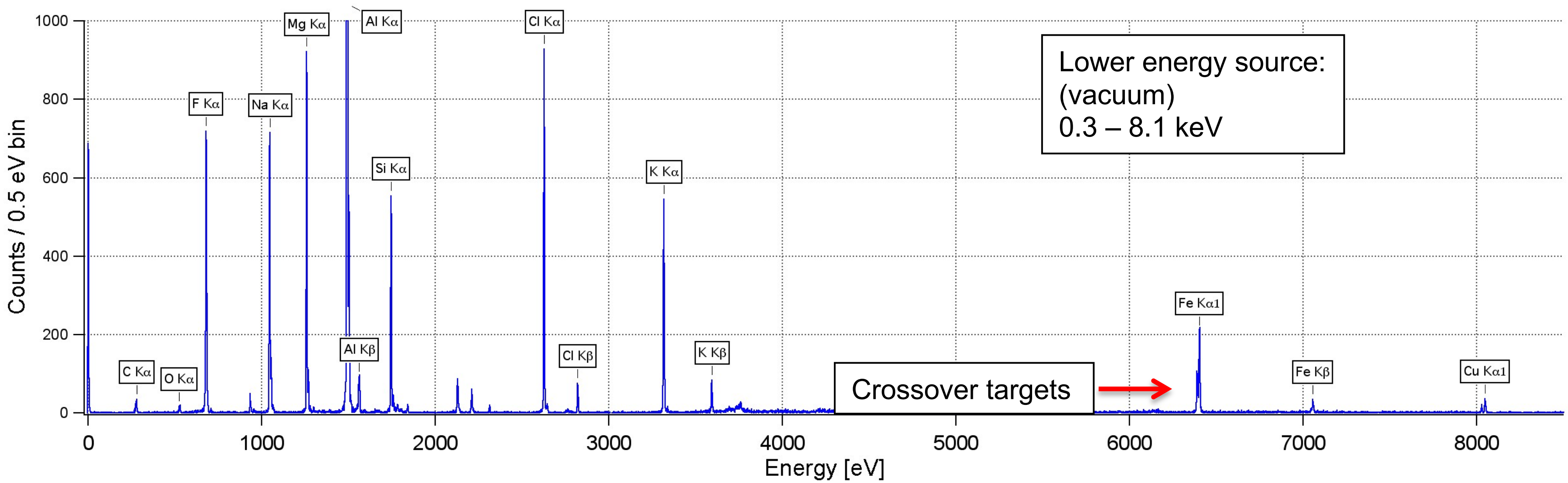


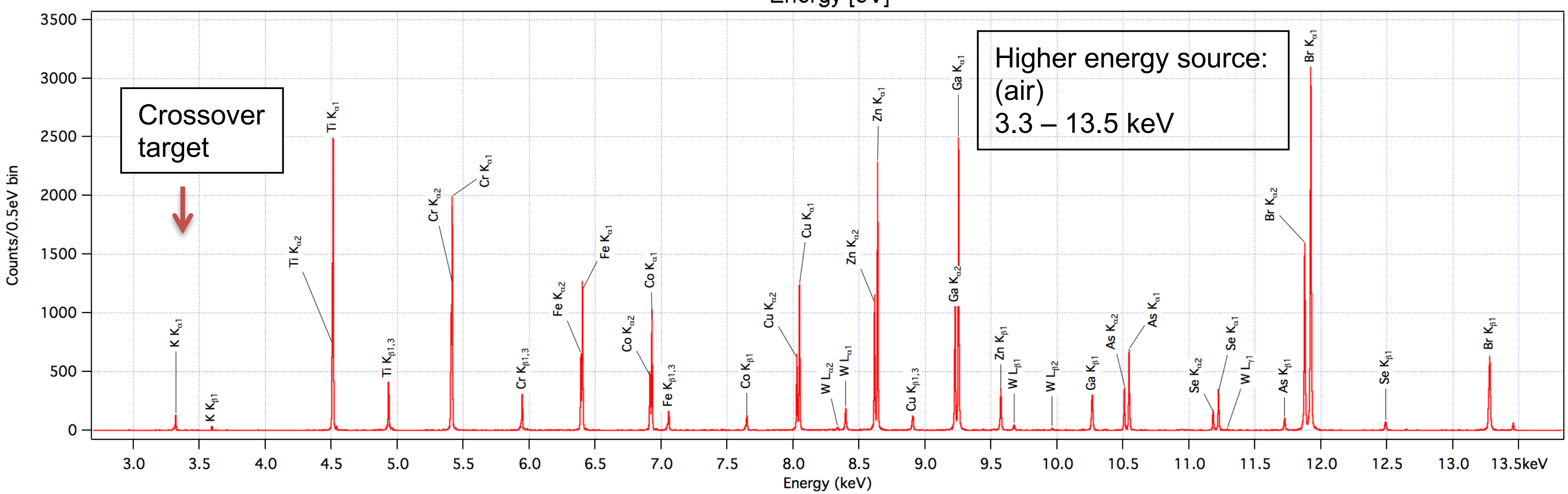
Gain calibration

- Strategy
- Ground calibration – non-linear drift correction algorithm
- On-orbit calibration

Gain Scale Ground Calibration

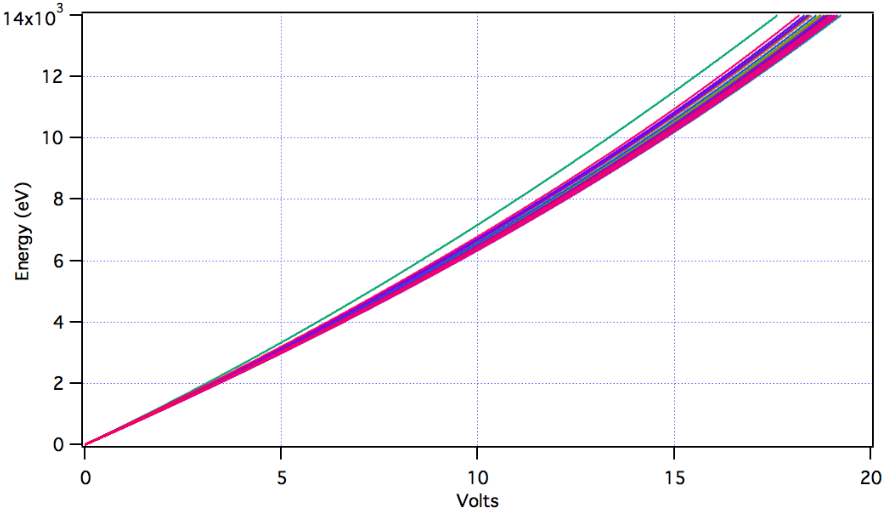
By using characteristic lines of known energies we calibrate the energy scale for a range of thermal conditions (bath, interface temperatures)



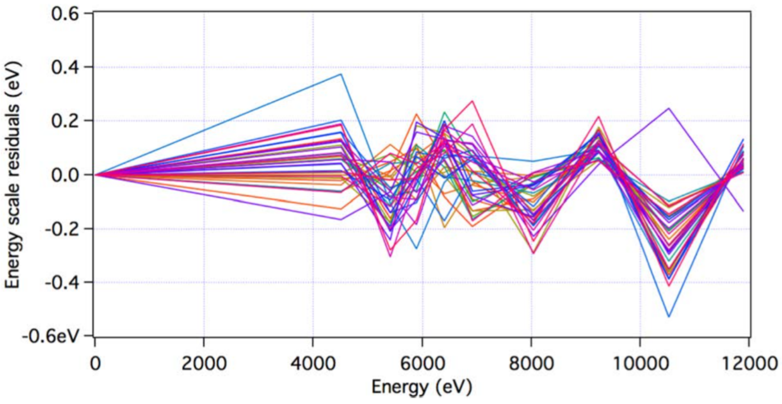


Gain scales generated from polynomial fit to measurements

Photon energy as a function of pulse height in engineering units (one for each pixel).
Fit function is a 4^{th} order polynomial



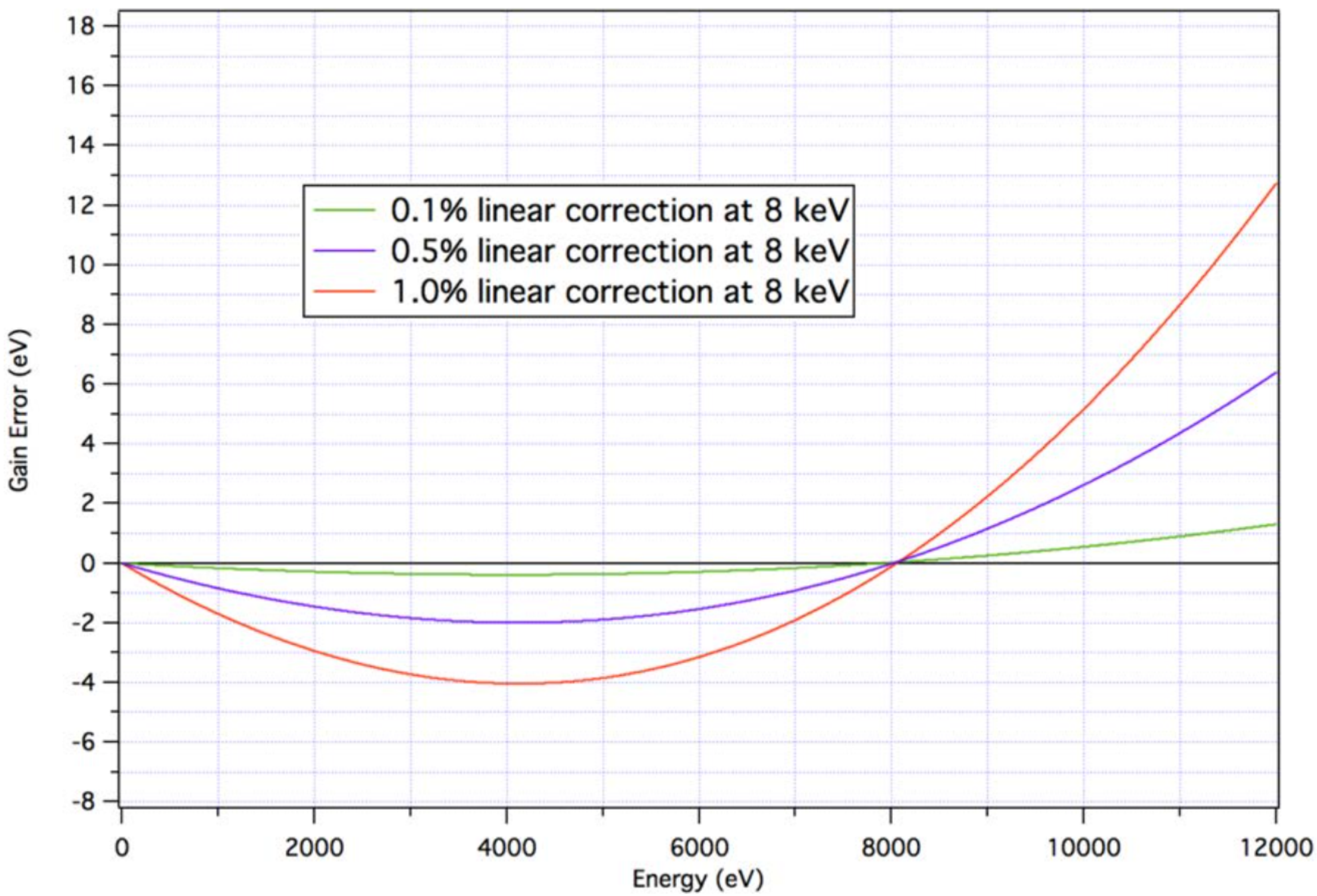
Typical residuals in gain curve generation



Strategy for dealing with gain drift on orbit

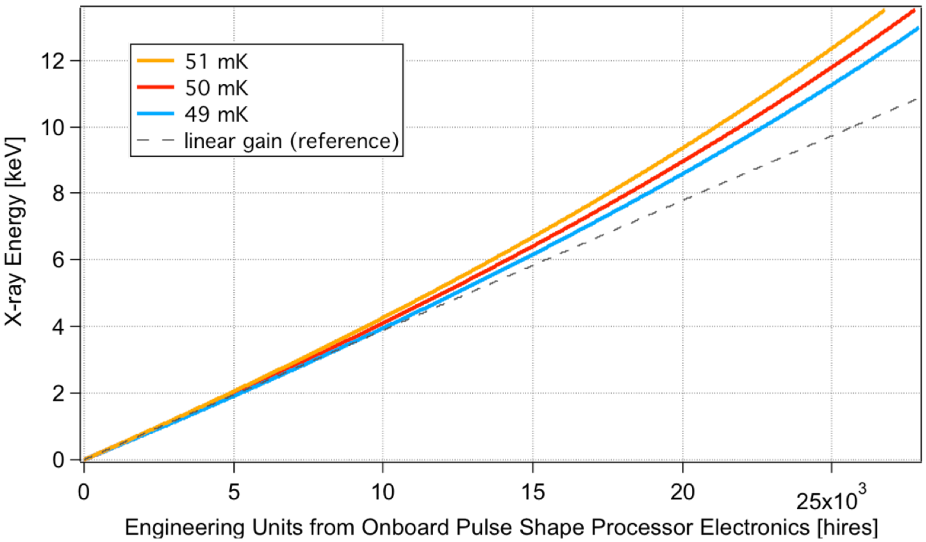
- Gain scale depends on many factors (detector temperature relative to detector heat sink control temperature, amplifier temperature, ...)
- Can’t easily measure all photon energies on orbit, so use ground calibration to get gain curve shape
- Want to use calibration pixel to measure time dependent effects (small perturbations)
- Also use onboard flood sources at a lower duty cycle

A pure linear correction doesn't work

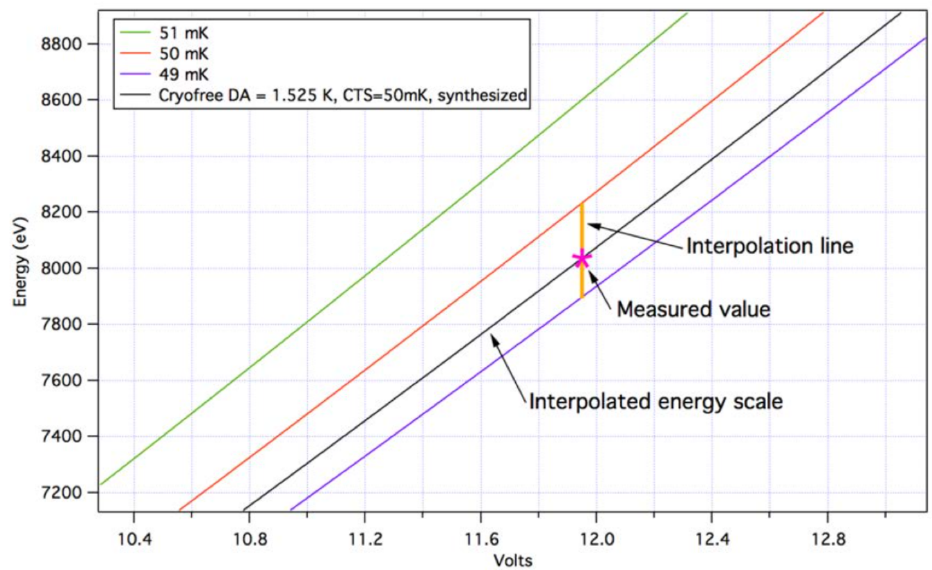


Non-linear gain interpolation method

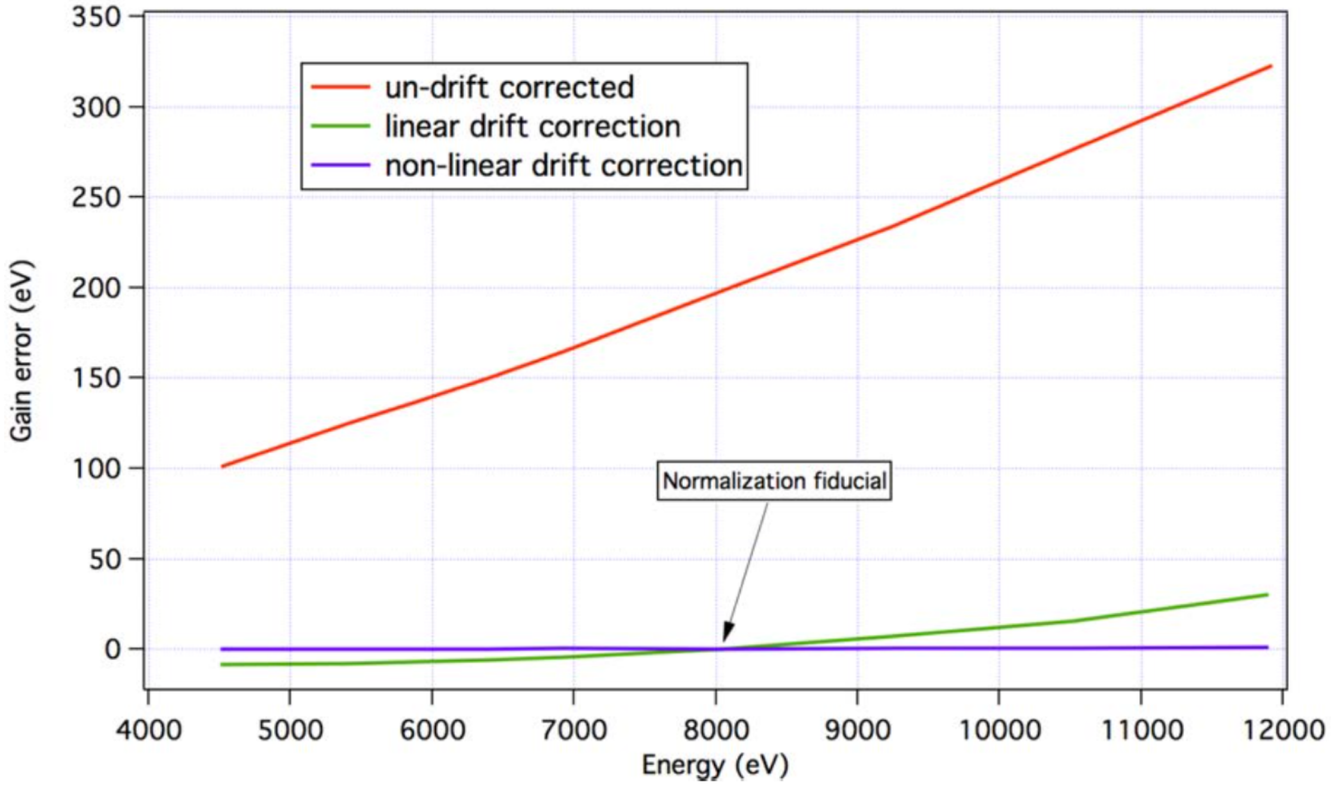
Measure gain curve for at least three heat sink temperatures



Interpolate to a new curve based on measurement of a fiducial line



Non-linear correction (interpolation) performs much better



Problem identified in Hitomi/SXS inflight performance

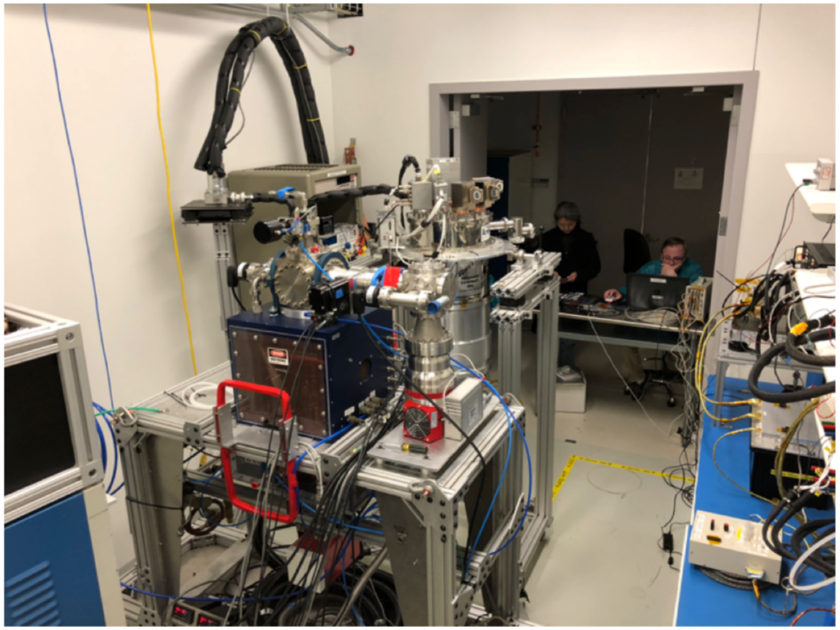
- Gain calibration at the instrument level was the basis of inflight calibration
- Gate valve could not be opened for this calibration, so low energies were not calibrated
- Therefore pre-flight gain curves were unconstrained at low energies, and inflight gain curves had few eV discrepancies near 2 keV
- (Inflight calibration would have fixed this)

Further problem with low energy gain

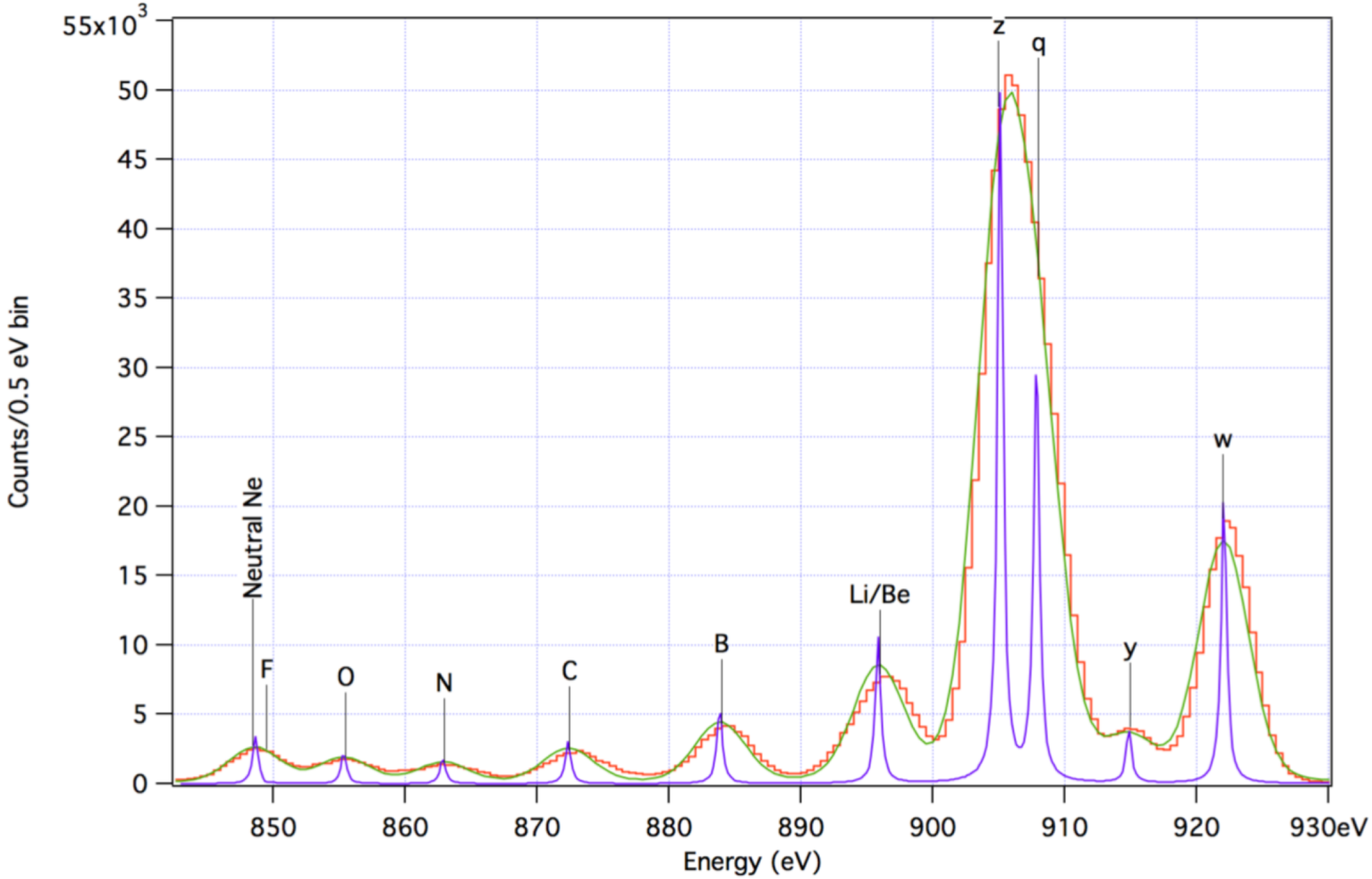
- Fluorescent lines used for low energy calibration (e.g. Si, Al, Mg, NaF, MgF_2, Al_2O_3, LiF, etc.) not well characterized; chemical shifts, non-diagram lines, etc.

Solution 1 – use EBIT

- Use warm EBIT from LLNL, share vacuum with dewar to get low energy lines that are well known
- Can't do this in Japan for integrated instrument, too cumbersome



EBIT spectrum of Ne K-shell emission



Solution 2 – open GV during instrument level testing

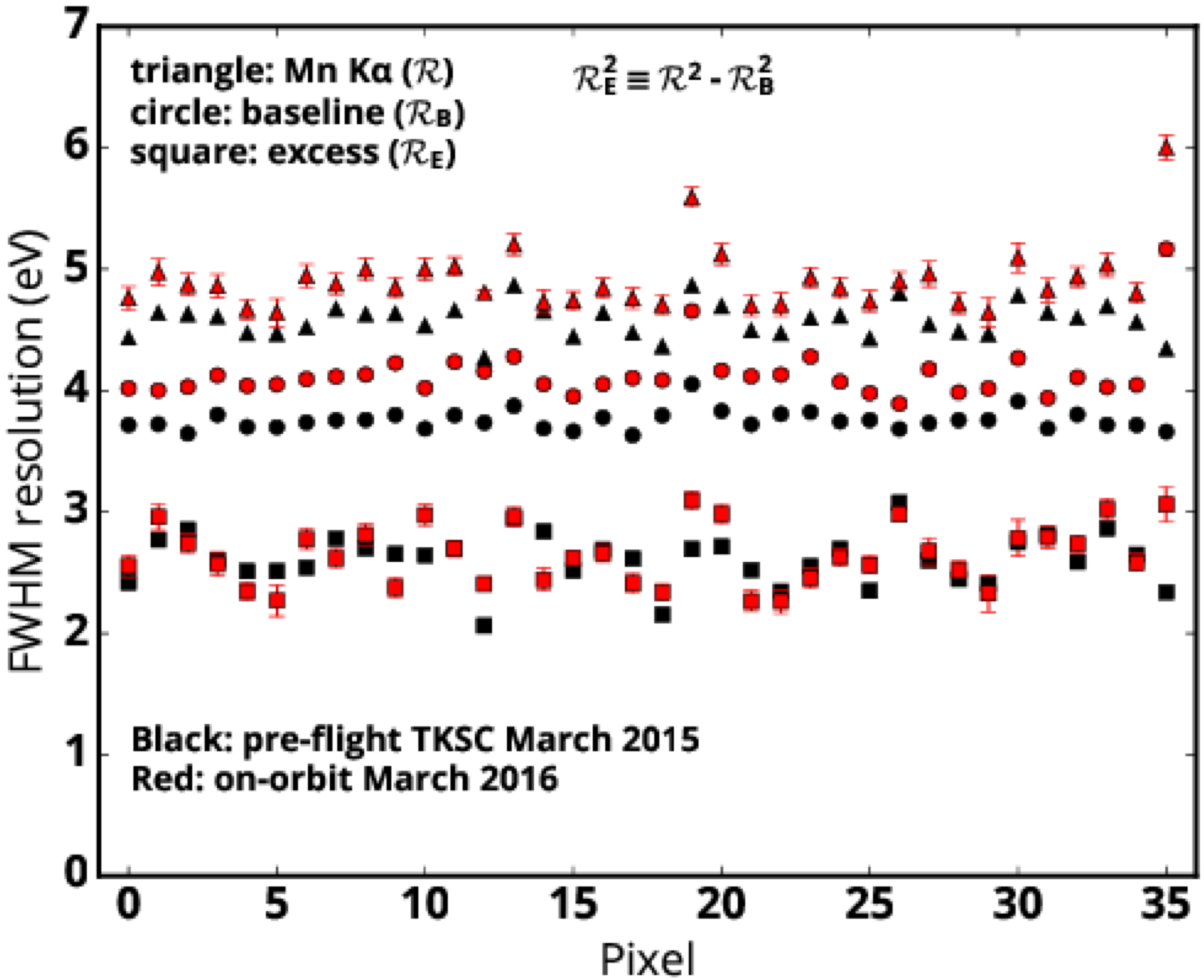
- Need to do this anyway to measure EMI in open GV configuration
- Will use soft X-ray fluorescence to characterize gain scale at low energies

Summary

- Resolve calibration activities are underway
- Upcoming: CSI level detector calibration; finish filter and thermal shield calibration; mirror calibration
- After CSI integration: Calorimeter instrument level calibration
- Key deficiencies in Hitomi SXS identified and mitigated in XRISM Resolve calibration plan

Backup slides

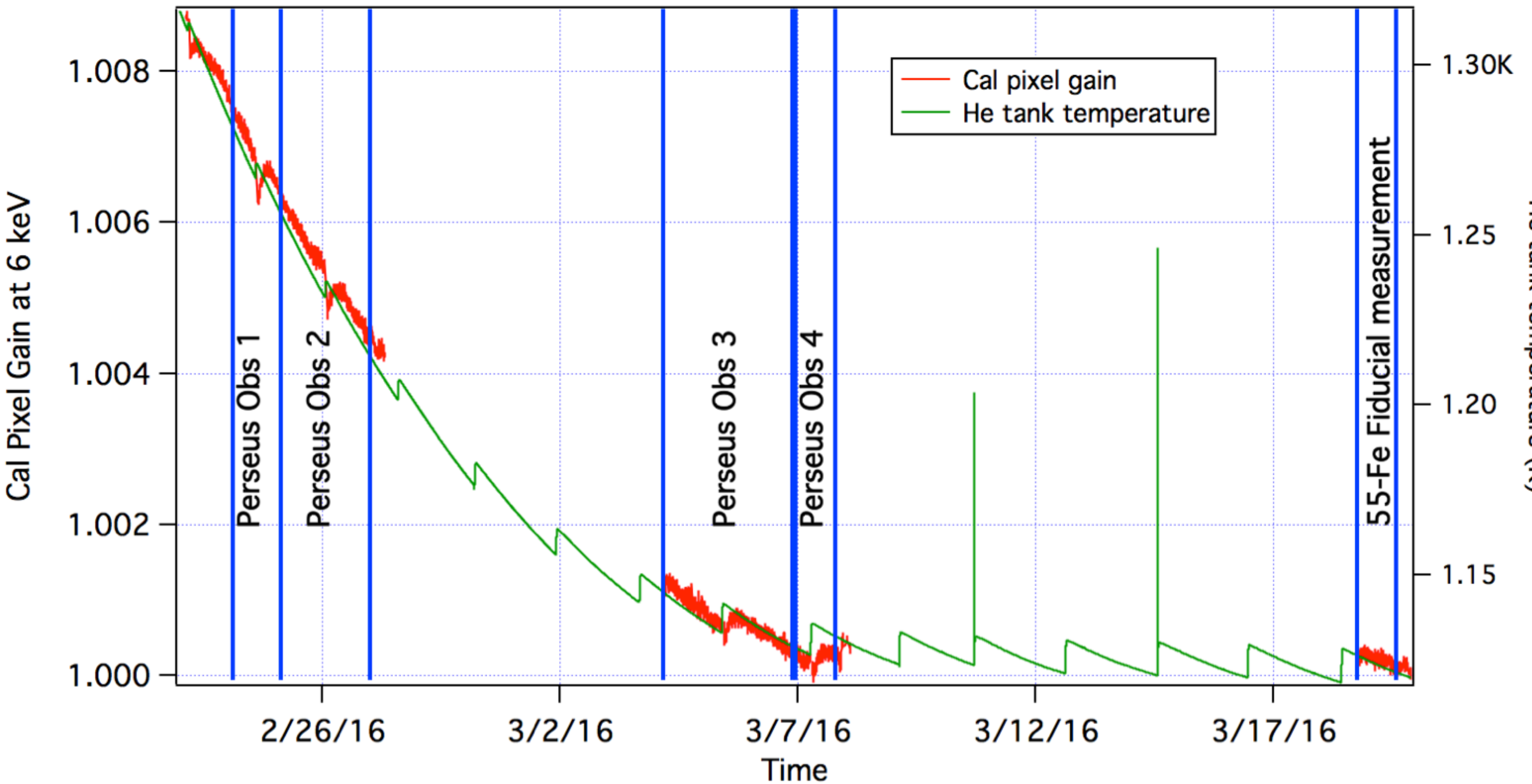
On-orbit measurements



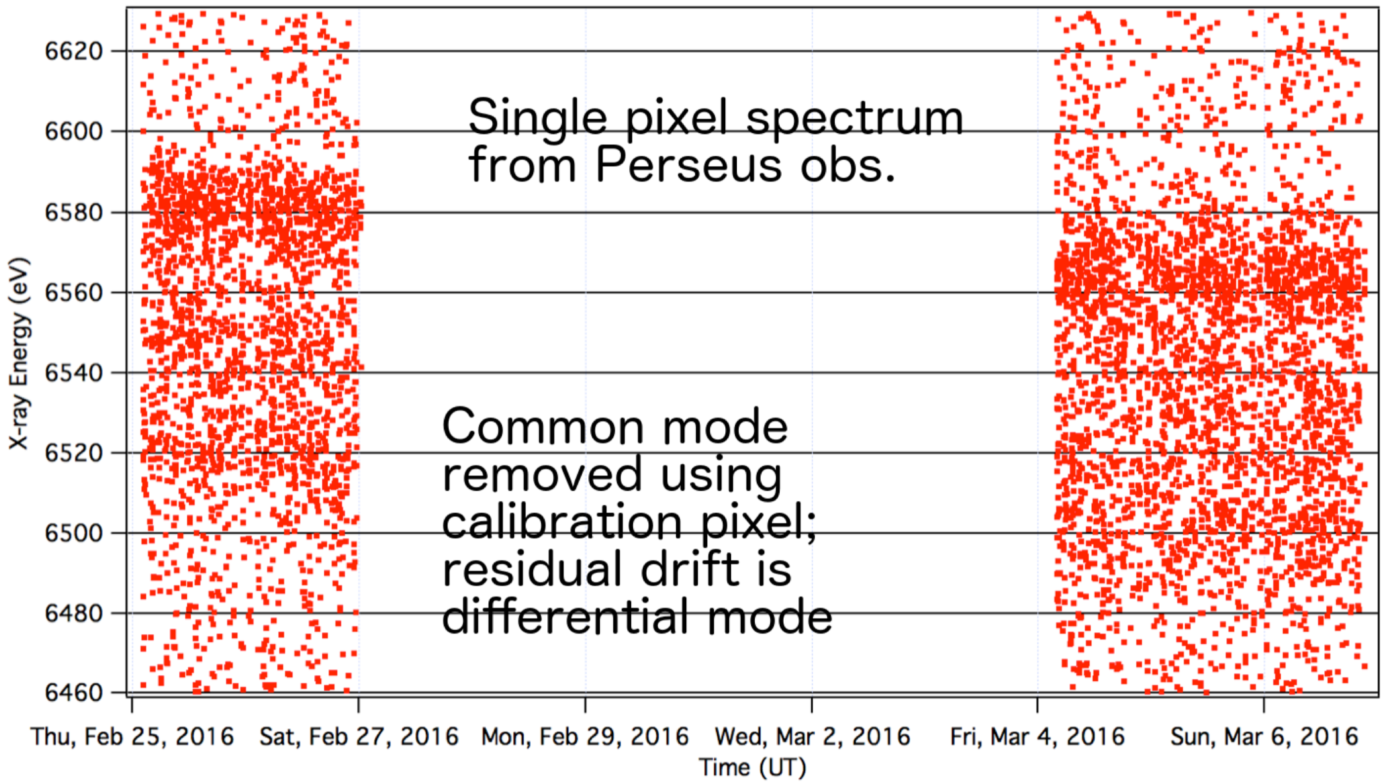
On-orbit gain calibration

- Mission was lost before in-flight calibration campaign could be executed
- Science data were taken without expectation of perfect calibration
- Needed to maximize science return from Perseus spectra

Calibration pixel traces He tank T

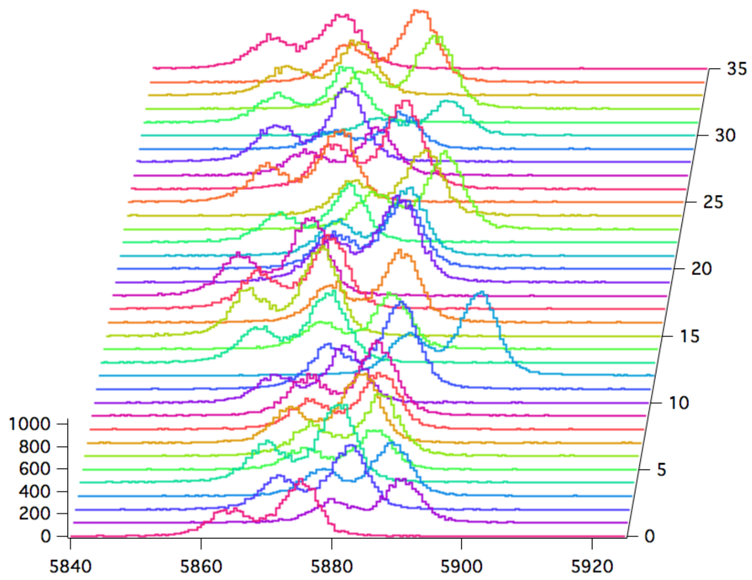


Need to deal with residual (differential) drift

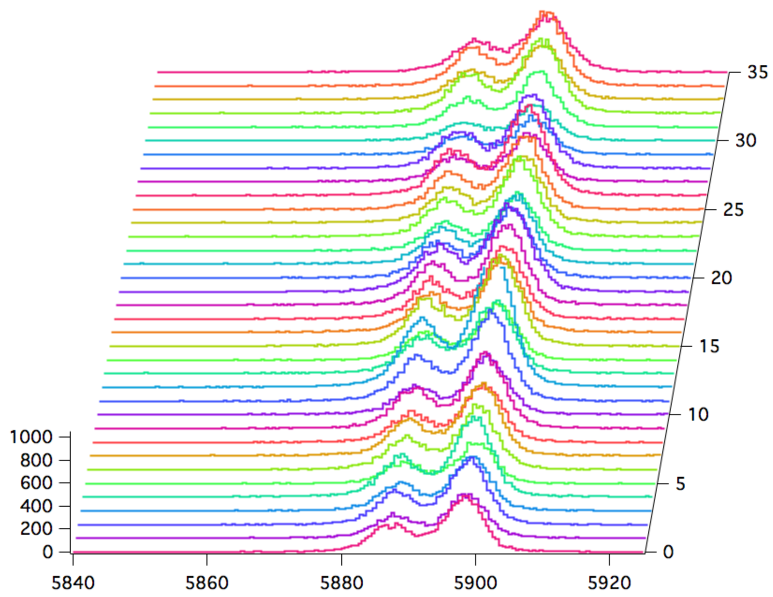


^{55}Fe calibration source on filter wheel

This measurement gives an absolute reference for the energy scale for each pixel at one point in time



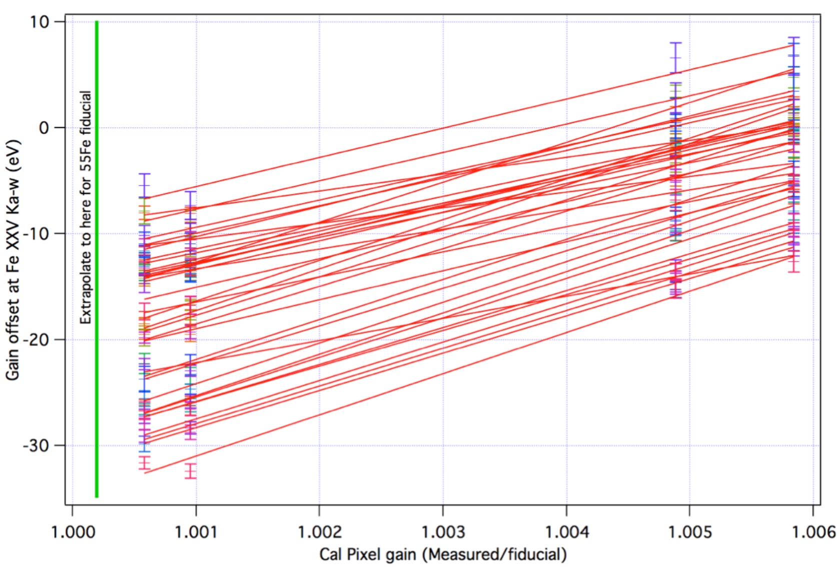
Before correction



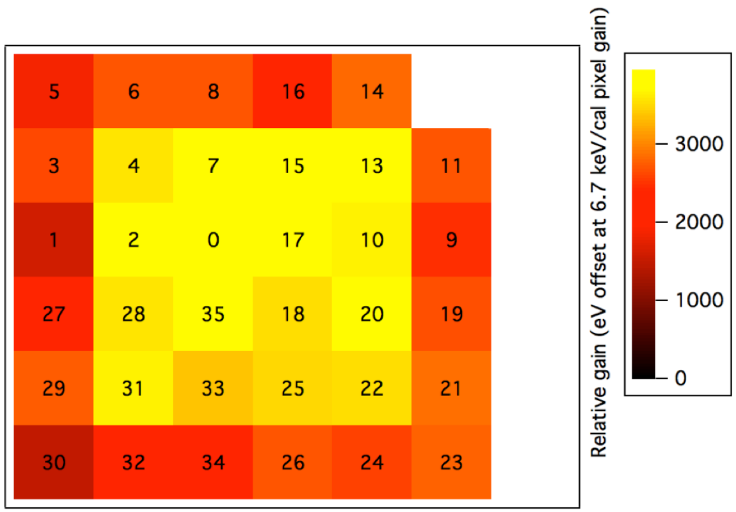
After correction

Use ^{55}Fe and Perseus to get overall drift correction

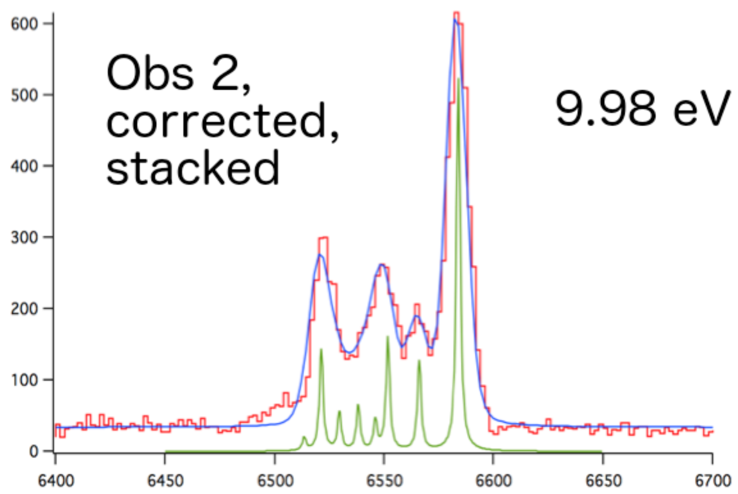
Relative differential drift measured with Perseus; absolute measured with ^{55}Fe

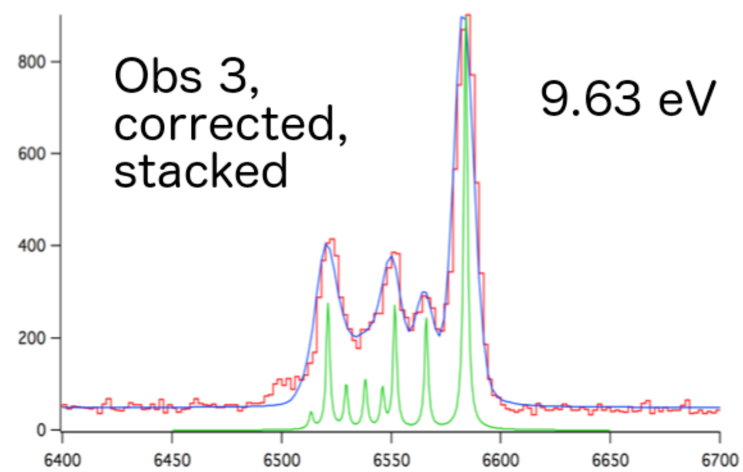


Map of slopes indicates differential drift primarily due to radiative load



Measured line width gives estimate of the residuals in the gain determination



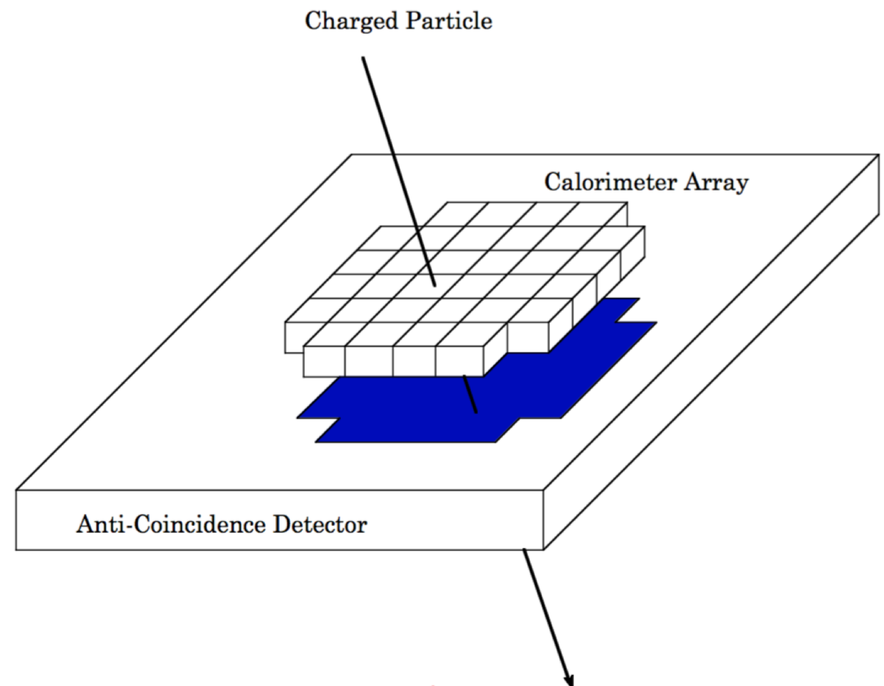


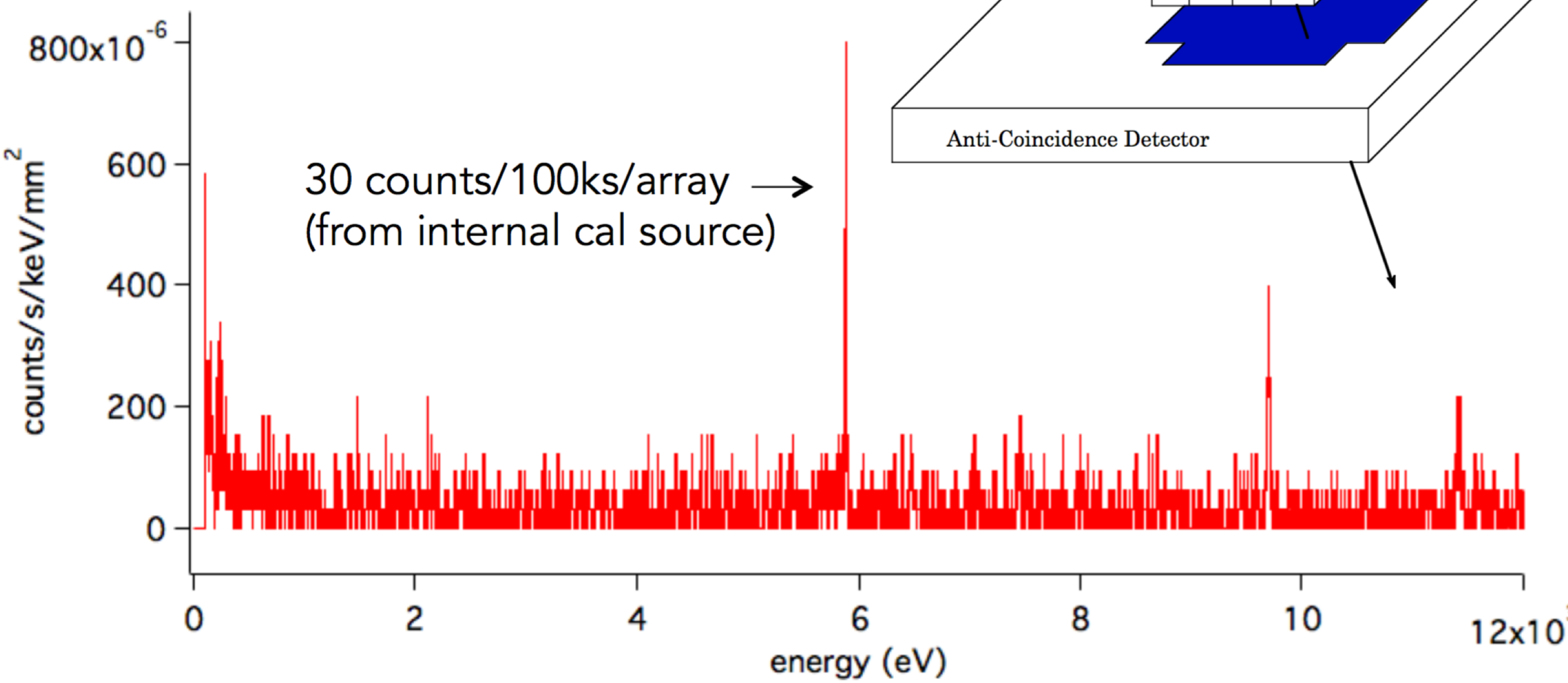
The anti-coincidence detector sits just behind the calorimeter array.

SXS In-flight:

0.03 counts/10eV/100ks/pix

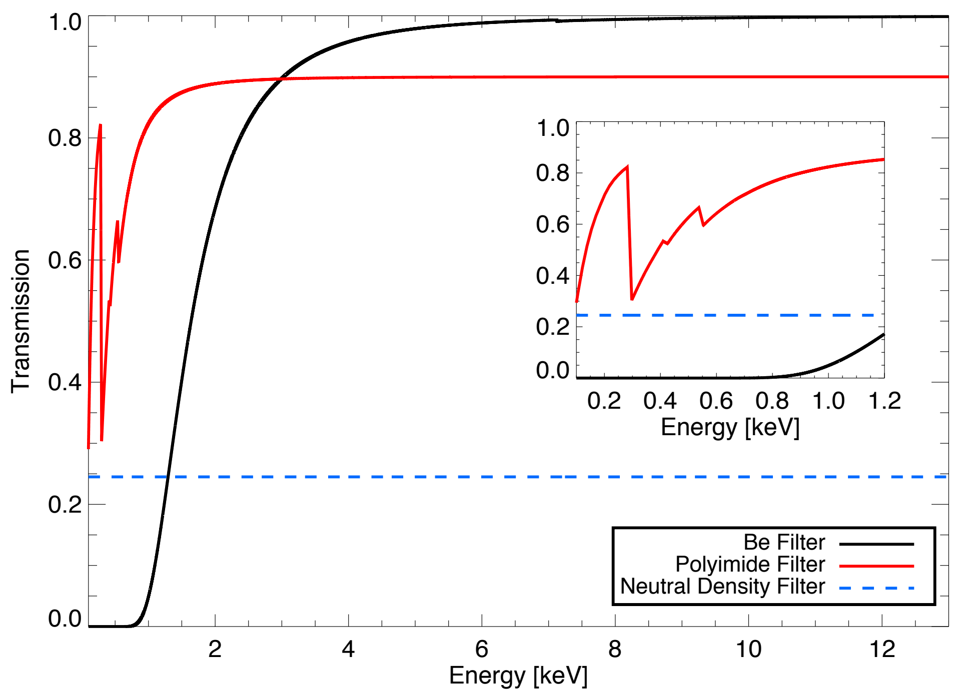
0.9 counts/10eV/100ks/array





Astro-H SXS Filter Wheel Filters and Calibration Curves

Filter Position	Filter Type	Purpose	Support Structure	Calibration Measurement
1	open			
2	polyimide	block contamination	stainless mesh	transmission at BESSY
3	neutral density	E-independent attenuation (75.5%)	250 µm-thick Mo with holes	raytrace based on drawing
4	open			
5	25 µm Be	attenuate low-E photons	none	transmission map at BESSY
6	^{55}Fe source	provide calibration lines on array	cross	raytrace based on drawing



Astro-H SXS Gate Valve Be Window

Be window: ~262 μm thick
Window support structure:
- 0.2 mm-thick stainless mesh (71% open)
- 2 mm-wide, 6 mm-thick Al cross

Intended for ground tests and commissioning phase only; X-ray transmission not calibrated; transmission estimates based on spare Be window measurements, mesh geometry, and raytrace calculations of support cross.