A New ESAS Implementation

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Outline

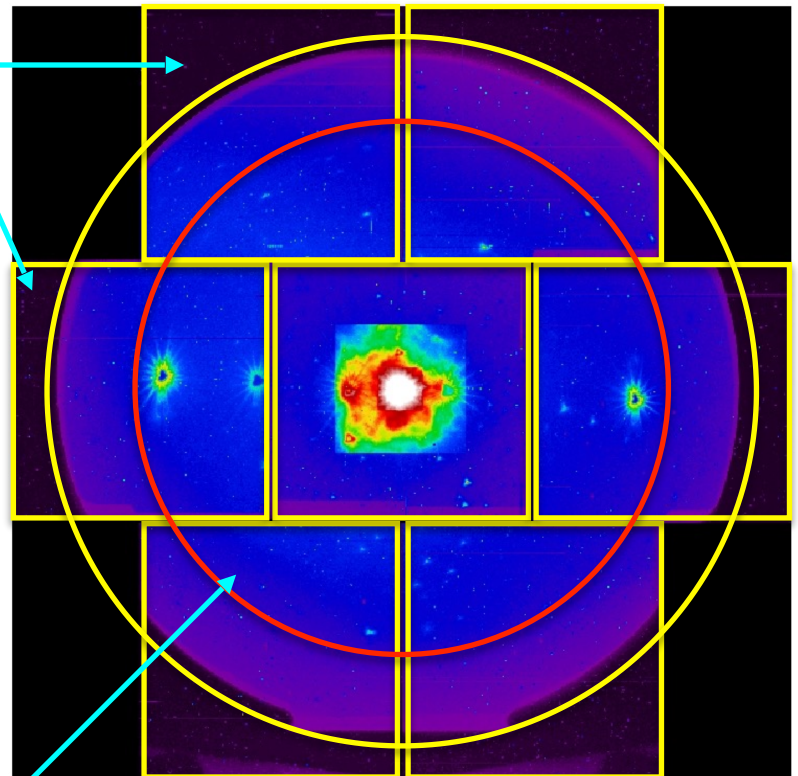
- Review of general procedure
- Review of MOS changes
- ab initio work on the pn

Extended Source Analysis Software

- builds quiescent particle background (QPB) spectra for observations of diffuse emission that fills (or mostly fills) the field of view
- uses a combination of Filter Wheel Closed (FWC) and "Corner Data" to capture the spatial and temporal variation of the quiescent particle background spectrum

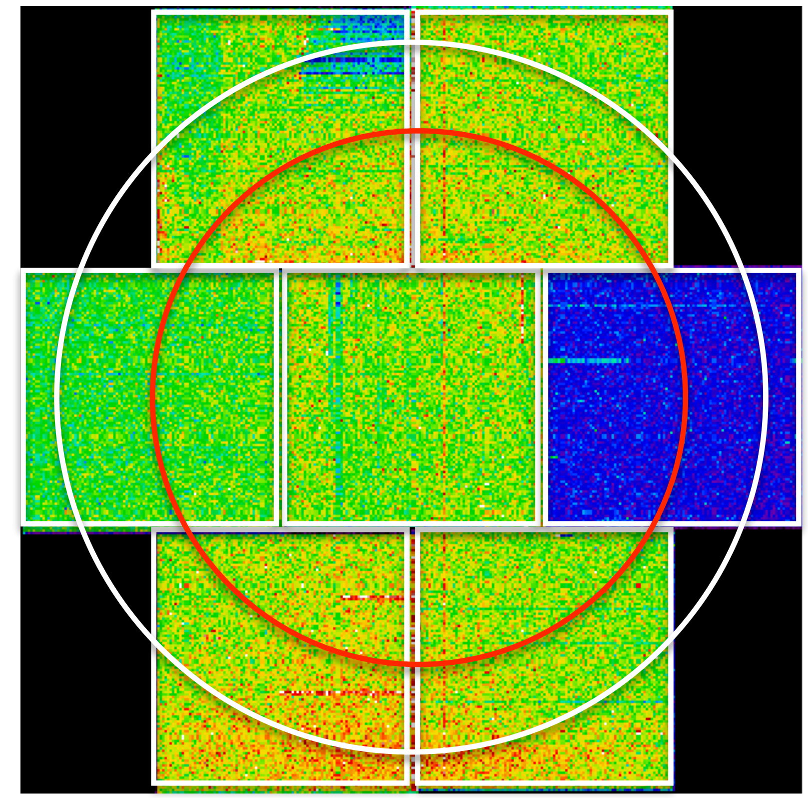
Method

Corners



FOV of interest

Observation



Filter-Wheel-Closed Data

really poor stats

$$\text{background} = \frac{\text{FWC FOV}}{\text{FWC corner}}\text{observation corner}$$

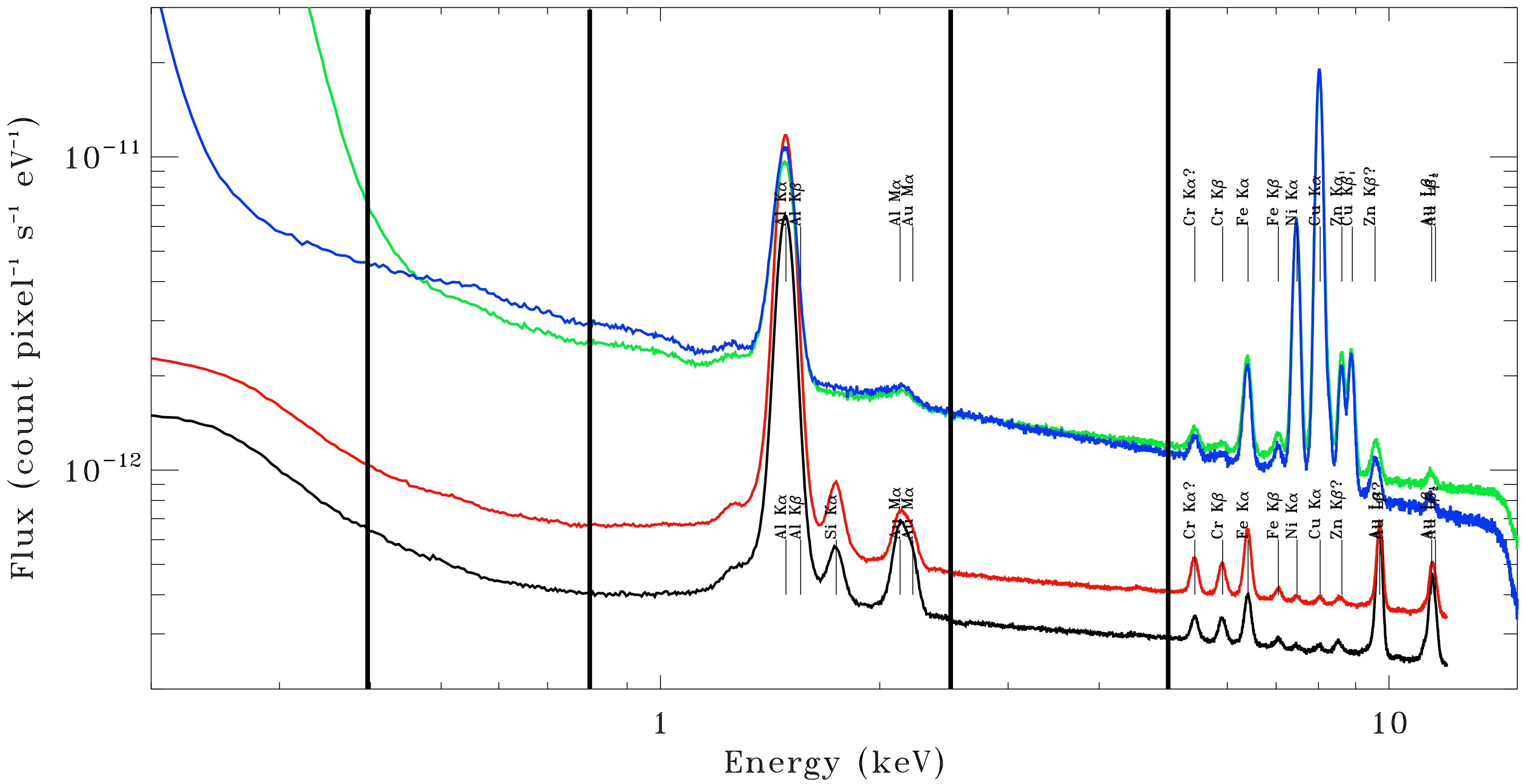
poor stats

Where all of these quantities are spectra…

…and typical values are ~3×10^{-12} count/pixel/energy bin/s or ~0.2 count/chip/energy bin/ks

Method

- Little to be done about the poor statistics of FWC data (except wait for more FWC data to be taken)
- Statistics of corner data can be improved!
  add together corner data from multiple observations
  BUT
  the 2.5-5.0 keV/0.4-0.8 keV hardness ratio (HR) showed greater than statistical variation



Method

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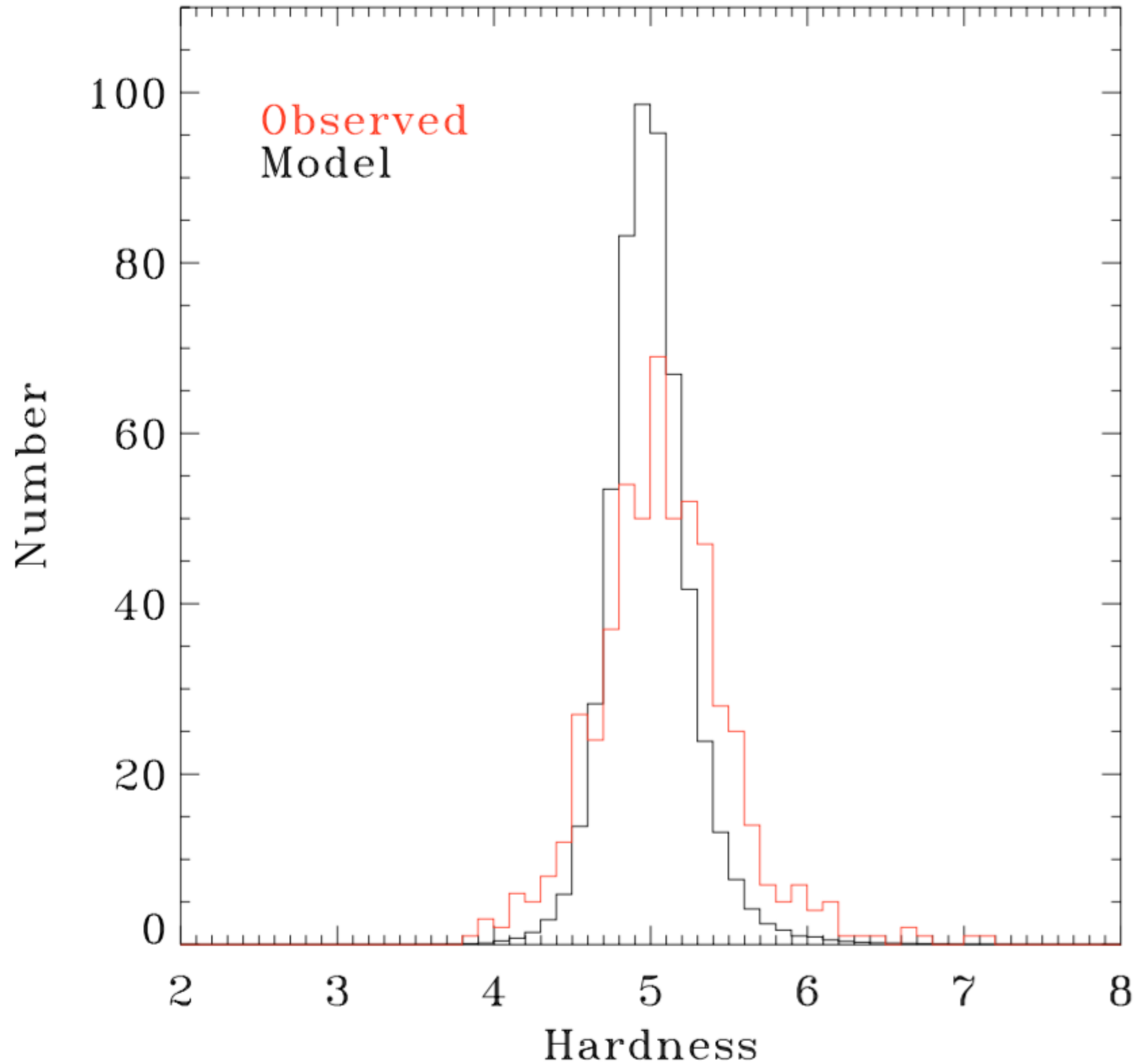
  (except wait for more FWC data to be taken)
- Statistics of corner data can be improved!
  add together corner data from multiple observations
  BUT
  the 2.5-5.0 keV/0.4-0.8 keV hardness ratio (HR) showed
  greater than statistical variation
- Solution
  calculate HR from observation,
  find other observations with
  similar HR and rate,
  then coadd the similar spectra
  → "augmentation"
- Augmentation the basis of the
  previous versions of ESAS

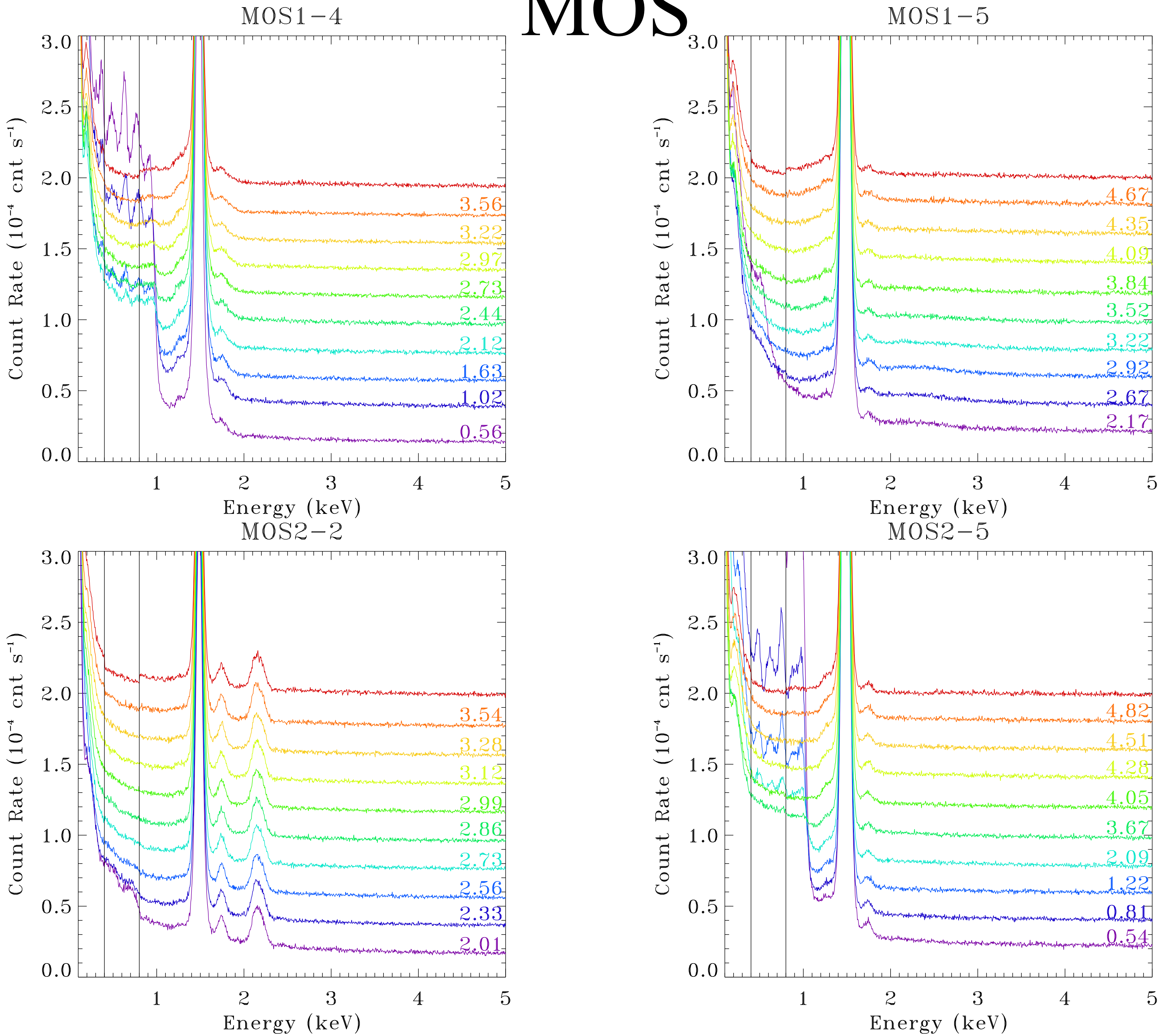


MOS

Starting mid-2016 - a complete renovation of ESAS
- available obsids increased by 5.4X (time by 7X)
- allows higher statistics on everything
- allows better anomalous state detection
- used accumulated experience to improve implementation

ESAS Changes
- no soft proton flare removal for MOS corners required
    - still filter on high background periods in corners
    → increases available data by at ~1.5
- new anomalous state definitions
    - three categories: non, intermediate, & problematic

MOS



MOS1−4
MOS1−5
MOS2−2
MOS2−5
Count Rate (10⁻⁴ cnt s⁻¹)
Energy (keV)
3.56
3.22
2.97
2.73
2.44
2.12
1.63
1.02
0.56
4.67
4.35
4.09
3.84
3.52
3.22
2.92
2.67
2.17
3.54
3.28
3.12
2.99
2.86
2.73
2.56
2.33
2.01
4.82
4.51
4.28
4.05
3.67
2.09
1.22
0.81
0.54

MOS

TABLE 4
ANOMALOUS STATE CRITERIA

Chip	Non-anomalous	Intermediate	Problematic
MOS1-4	HR$\gtrsim$3.4	2.5 <HR< 3.0	HR< 0.6
MOS1-5	HR$\gtrsim$3.0	2.0 <HR< 3.0	HR< 1.4
MOS2-2	HR$\gtrsim$2.5	Soft limit	
MOS2-5	HR$\gtrsim$3.5	3.0 <HR< 3.5	HR< 1.4?

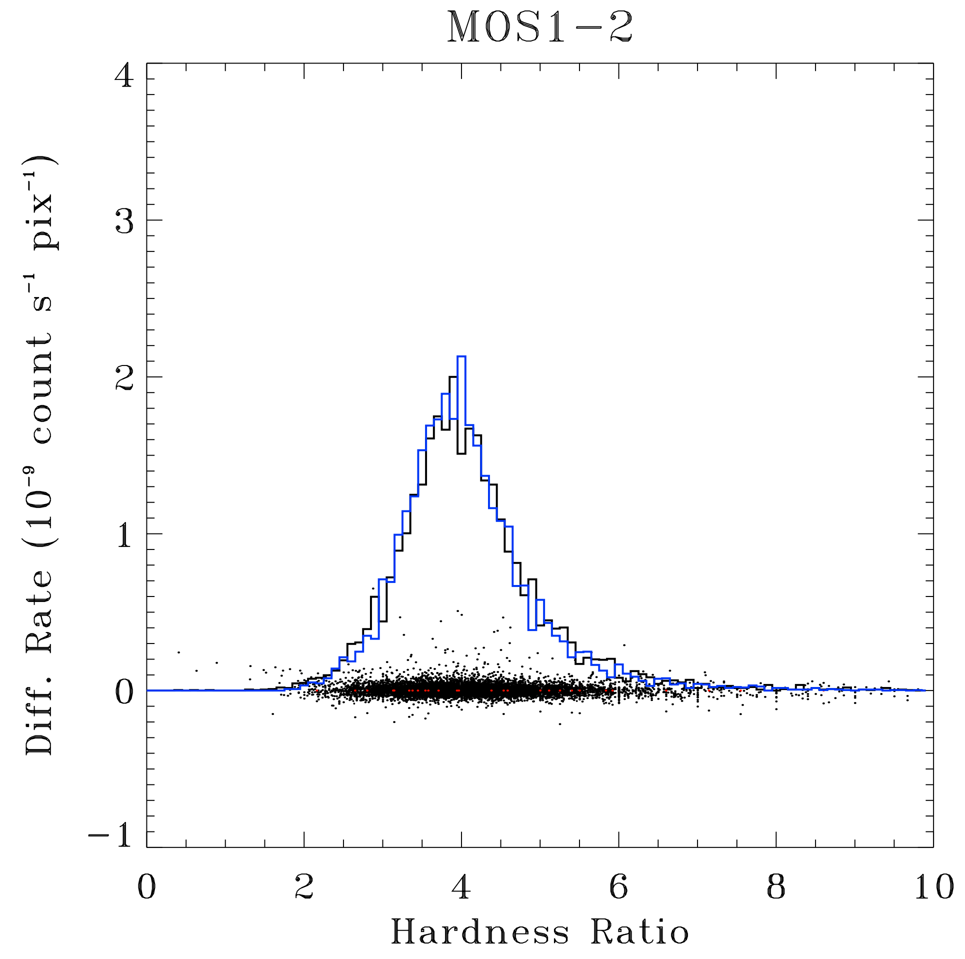
Problematic - little hope of ever constructing a QPB spectrum
- insufficient data, strong variation of shape with HR

Intermediate - probably can construct a QPB spectrum
- use usual augmentation scheme
- select similar spectra very carefully
- no guarantees!

MOS

Given new anomalous spectrum criteria
(and being more careful with data from early revs)
- reconsider temporal variation of HR

For a non-anomalous chip

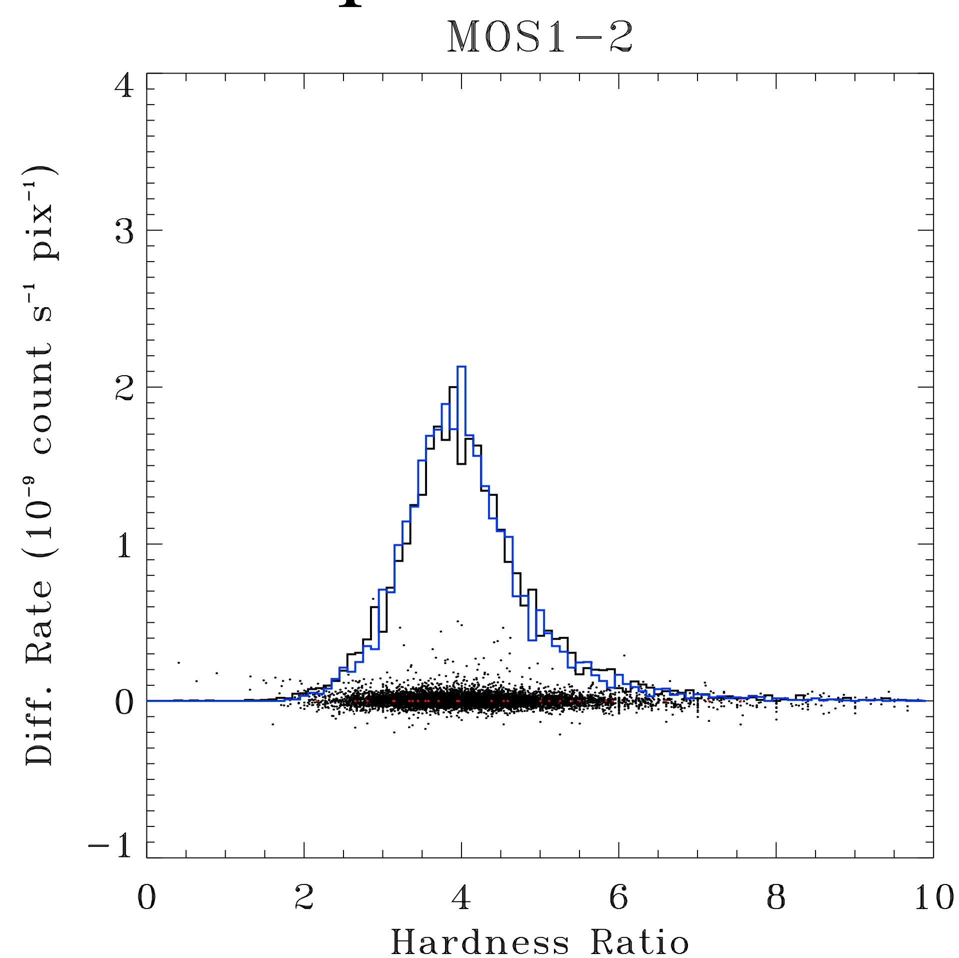


the distribution of the HR is exactly that expected from stats!

MOS

Given new anomalous spectrum criteria
(and being more careful with data from early revs)
- reconsider temporal variation of HR

For a non-anomalous chip

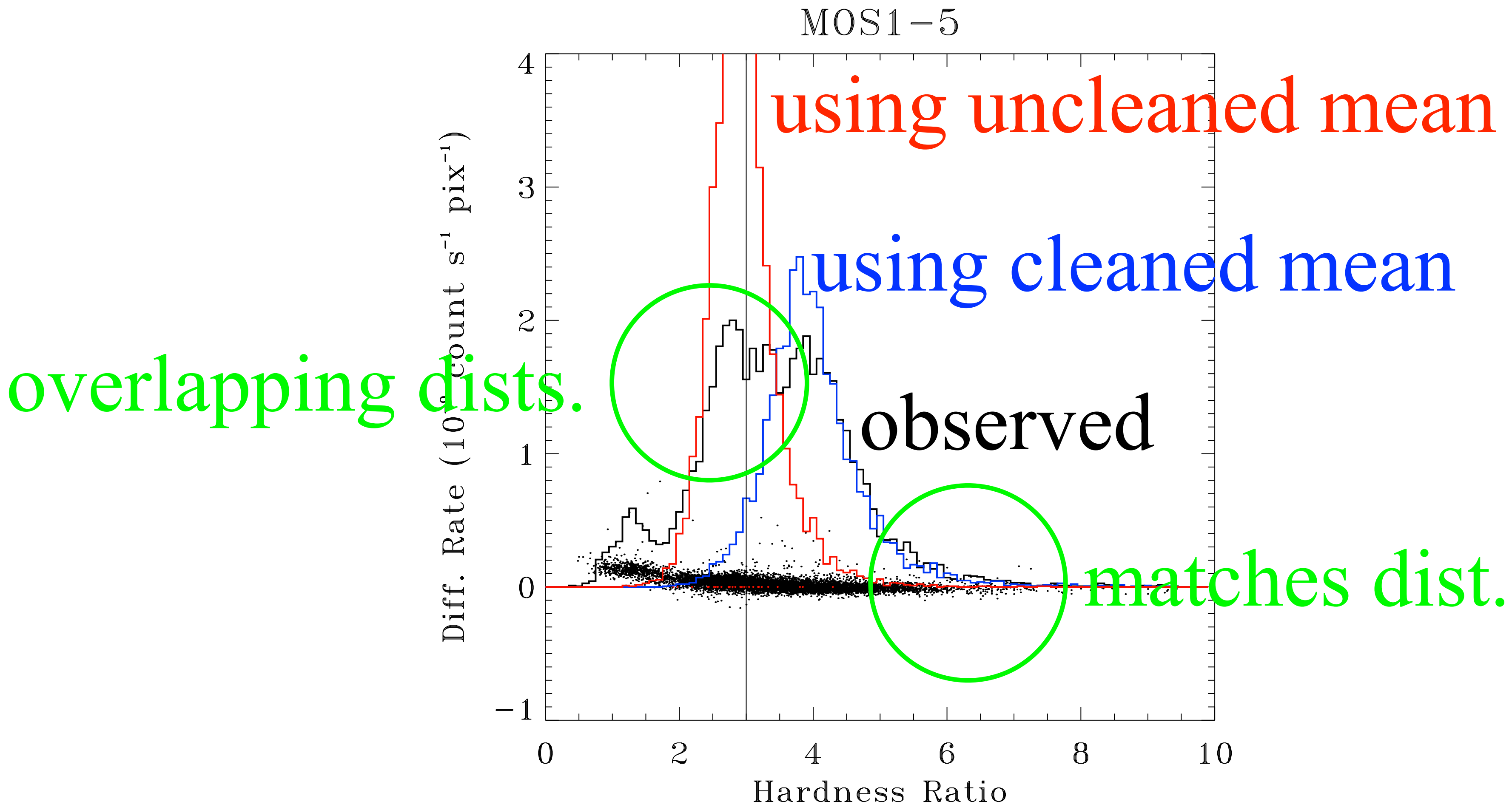


The mean QPB spectrum for the chip is sufficient!

MOS

Given new anomalous spectrum criteria
(and being more careful with data from early revs)
- reconsider temporal variation of HR

For a chip with anomalous states

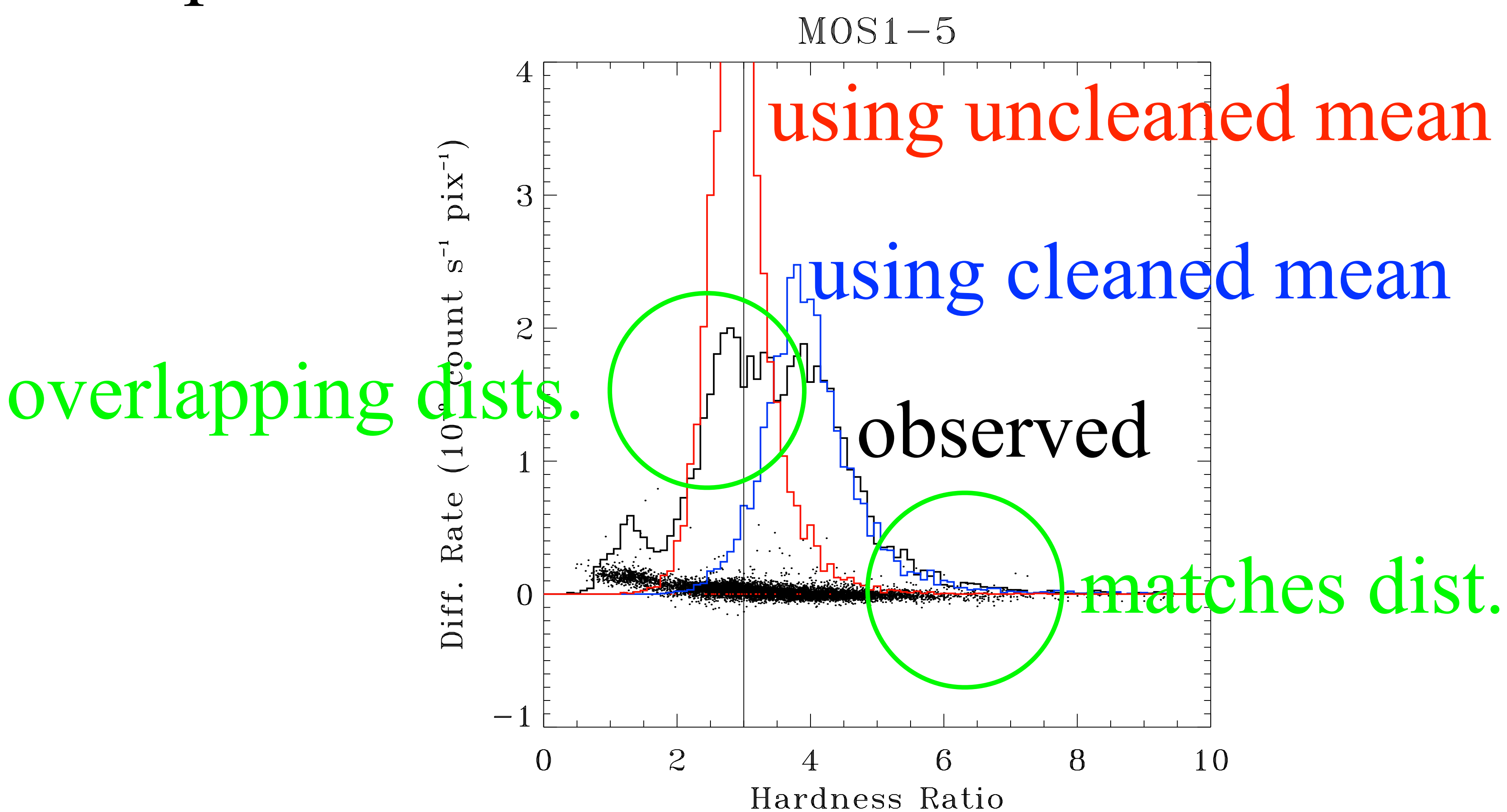


the situation is still difficult.

MOS

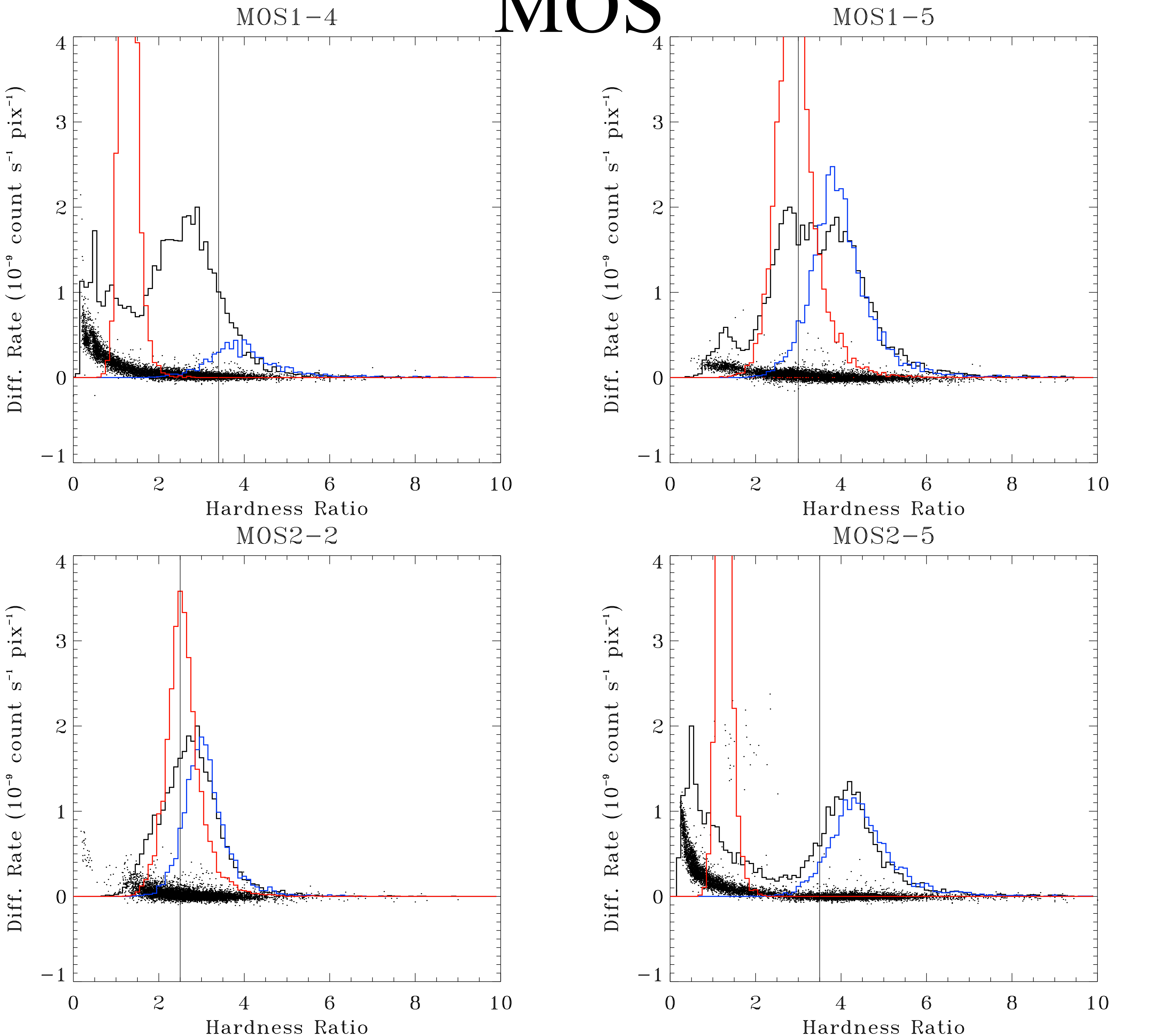
Given new anomalous spectrum criteria
(and being more careful with data from early revs)
- reconsider temporal variation of HR

For a chip with anomalous states



→Region of overlap does not show bimodal behavior.

MOS


MOS1-4
MOS1-5
MOS2-2
MOS2-5
Diff. Rate (10^{-9} count s^{-1} pix^{-1})
Hardness Ratio
0
2
4
6
8
10
-1
1
3

MOS

Starting mid-2016 - a complete renovation of ESAS
- available obsids increased by XXX (time by XXX)
- allows higher statistics on everything
- allows better anomalous state detection
- used accumulated experience to improve implementation

ESAS Changes
- no soft proton flare removal for MOS corners required
  - still filter on high background periods in corners
  → increases available data by at ~1.5
- new anomalous state definitions
  - three categories: non, intermediate, & problematic
- non-anomalous states use a mean background spectrum
  - still on a chip-by-chip basis
- no longer use corner count rates in augmentation

pn

Original implementation was built on the MOS methods

- much less corner data due to soft-proton flare problem
- some short cuts were taken
    - PATTERN<=4 used (without sufficient consideration)
    - FLAG=XMMEA_EP (ditto)
    - Full Frame & Extended Full Frame conflated (ditto^2)

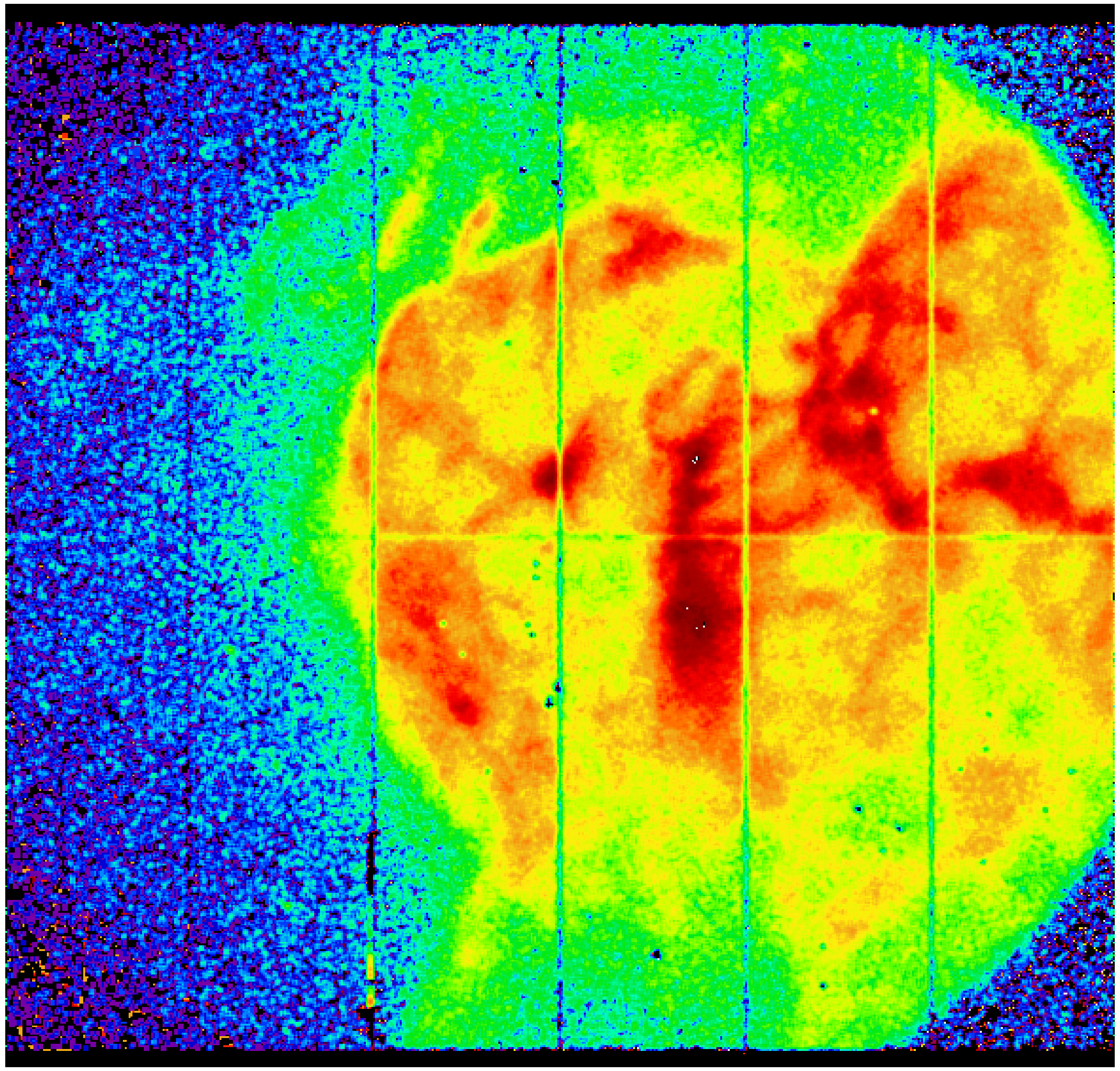
Since last CalOps efforts focussed on the pn

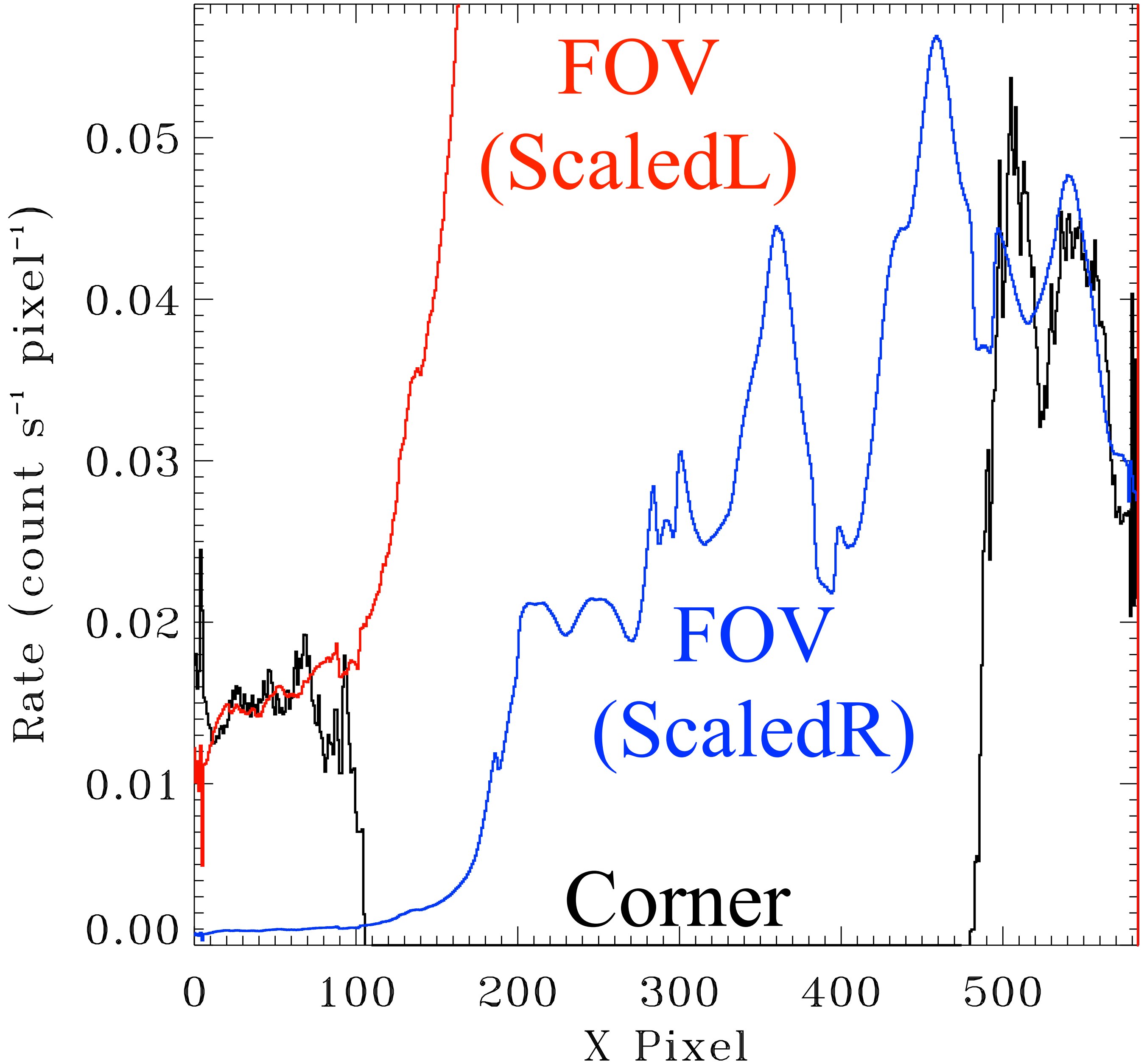
pn, Back to Basics

Good things about the pn (making analysis simpler)
- no anomalous states
- strong soft response

Bad things about the pn (complexifying analysis)
- soft proton flares (especially given OOT events)
- smaller corner regions
- greater scattered light problem
- OOT correction not always sufficient (?!?!?!?)
- pattern selection issues (counts versus noise feature)
- flag selection issues
- window modes exclude corner data

pn - OOT Problem?





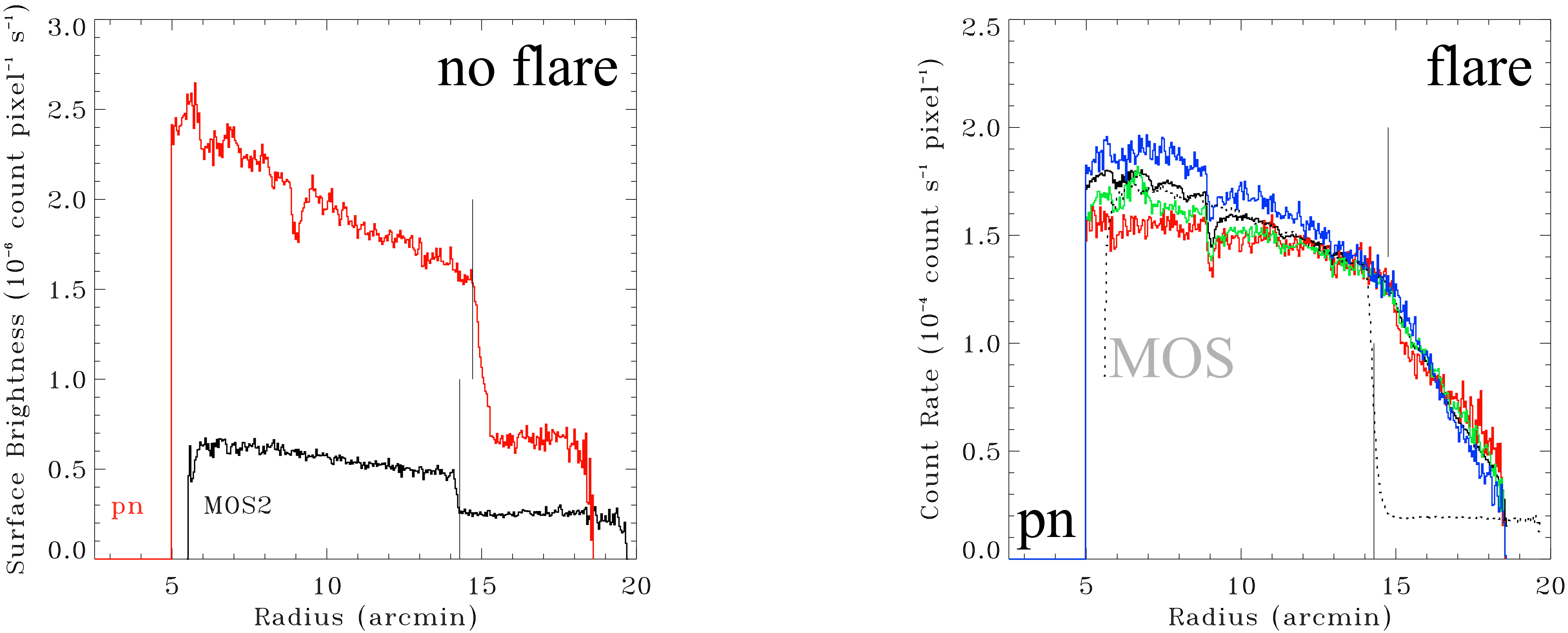
Structure in the FOV seen as well in corner data after OOT corr.

- compared mean row in FOV with mean row of corner data

Only seen for very bright diffuse emission

- probably occurs for bright point sources as well (haven't checked)

pn - Scattered light



Mask for MOS is closer to detector than for the pn

- can this be verified?

For X-rays, ¾-1' shows strong vignetting (wider than MOS)

For SPF, scattered into entire corner region (unlike MOS)

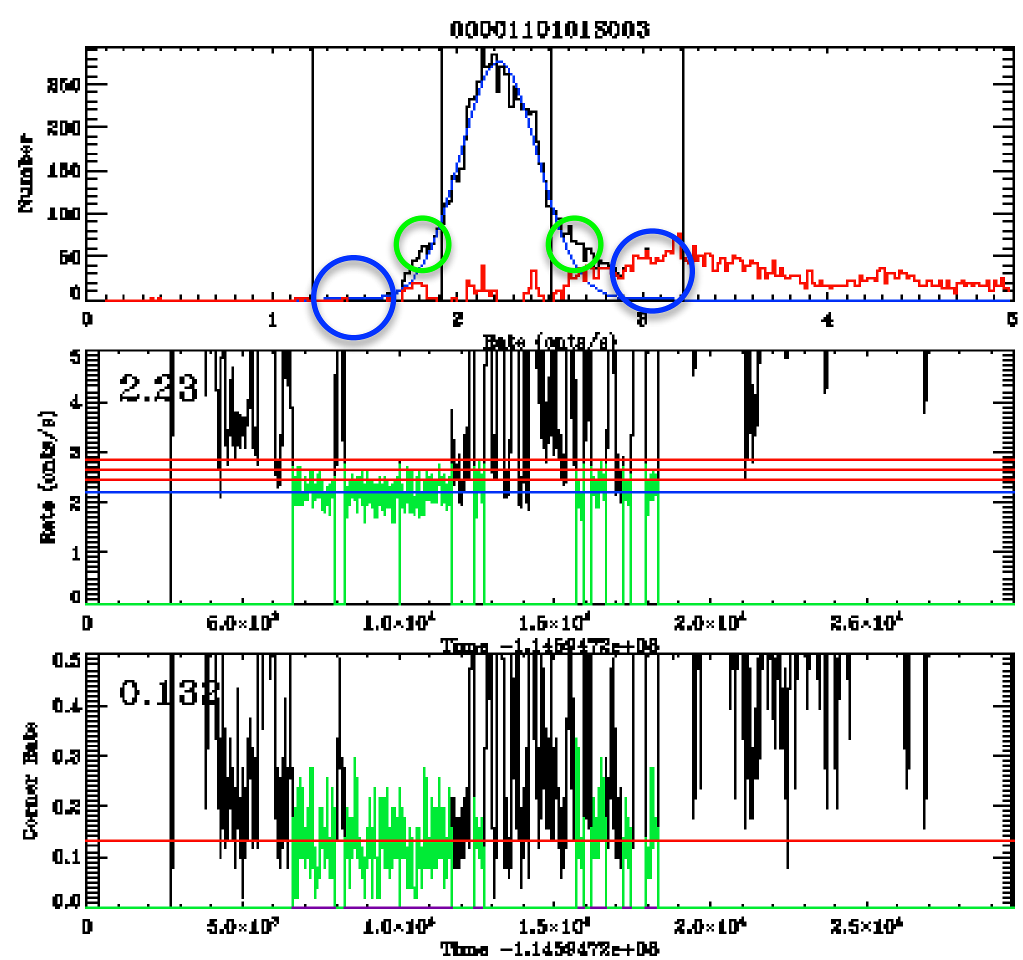
→ must be very careful to remove soft proton flares!

pn - SPF cleaning

Use the standard method for cleaning but…

use extra statistics to determine whether cleaning adequate

- make histogram from smoothed light-curve
- fit Gaussian to peak (not full distribution)
- measure residuals in near wings (shoulders) of Gaussian
- measure residuals in far wings (tails) of Gaussian



FOV

Corner

pn - SPF cleaning

Used ~1000 pn observations as a “training set”

- graded the SPF fits for those observations
- plotted distribution of fit parameters and residuals

Can set criteria to select the ‘excellent’ and ‘good’ fits:

mode=PrimeFullWindow||mode=PrimeFullWindowExtended

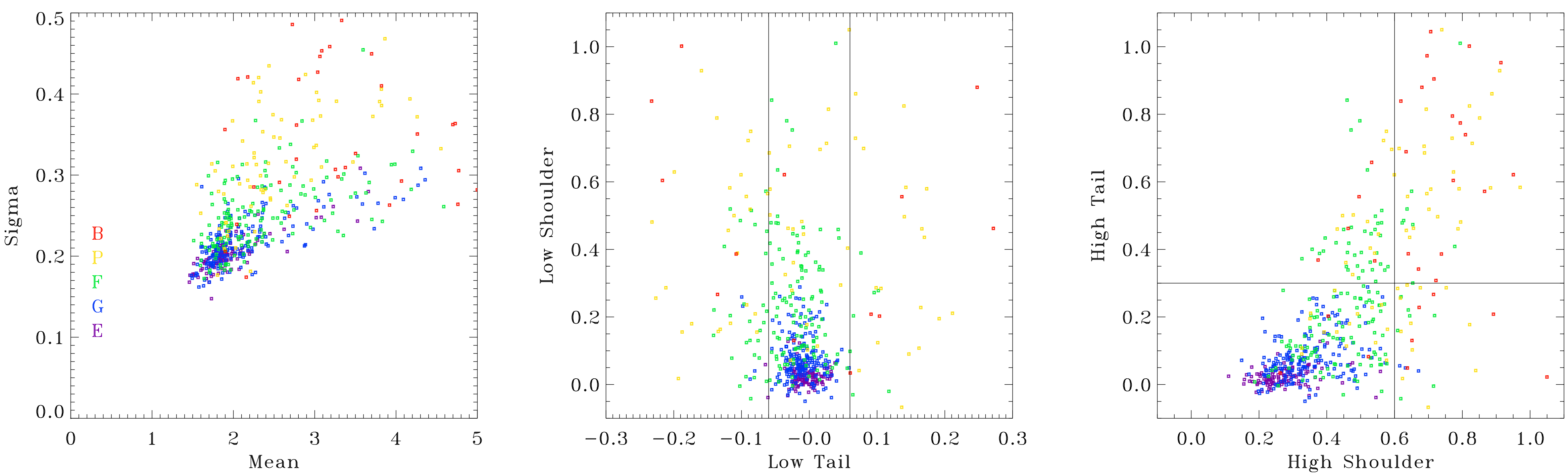
filter∉CalX

cleaned time>2 ks

histogram peak<5.0 && histogram σ<0.35

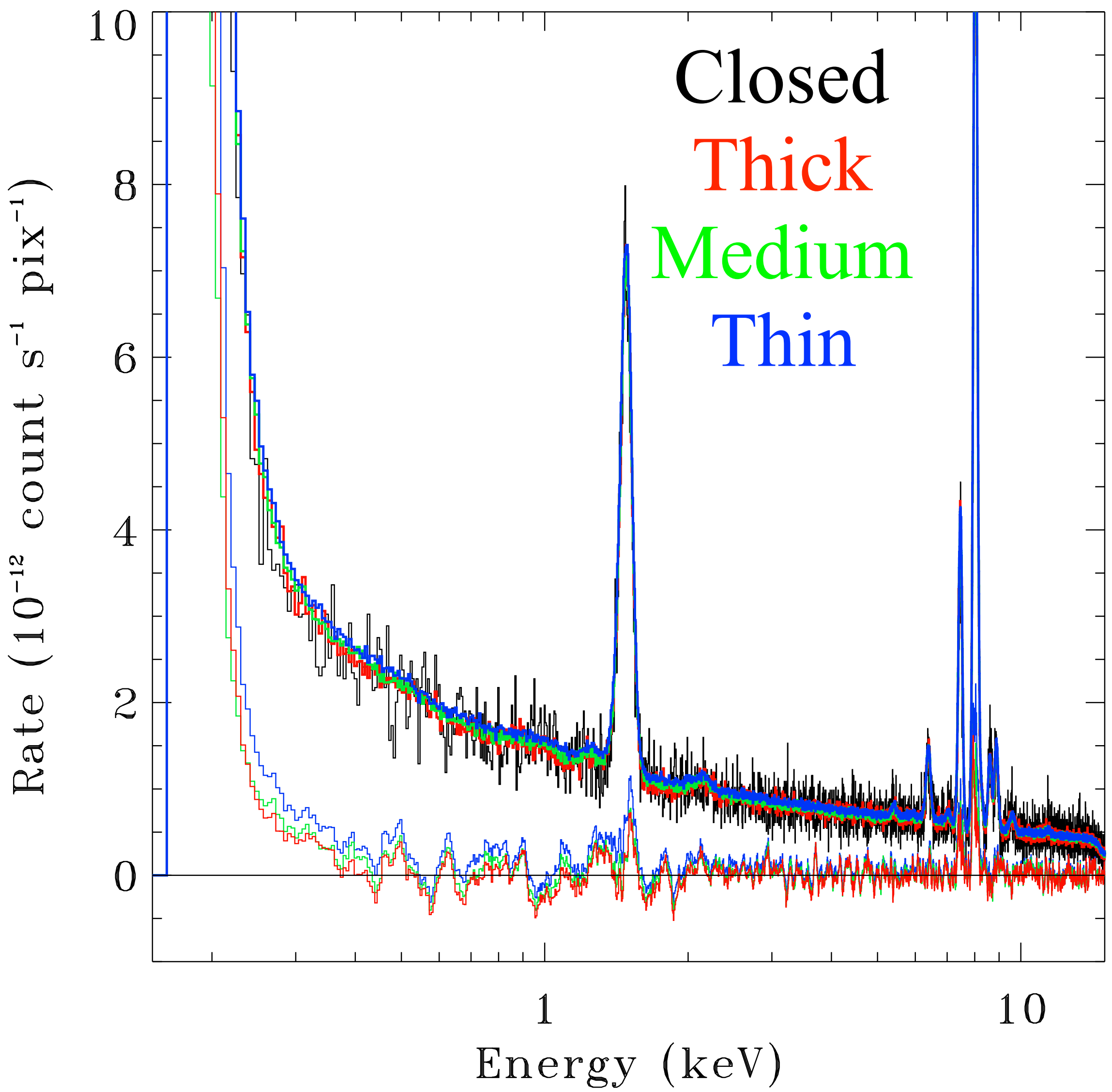
low tail residual<0.06 && high shoulder residual<0.6

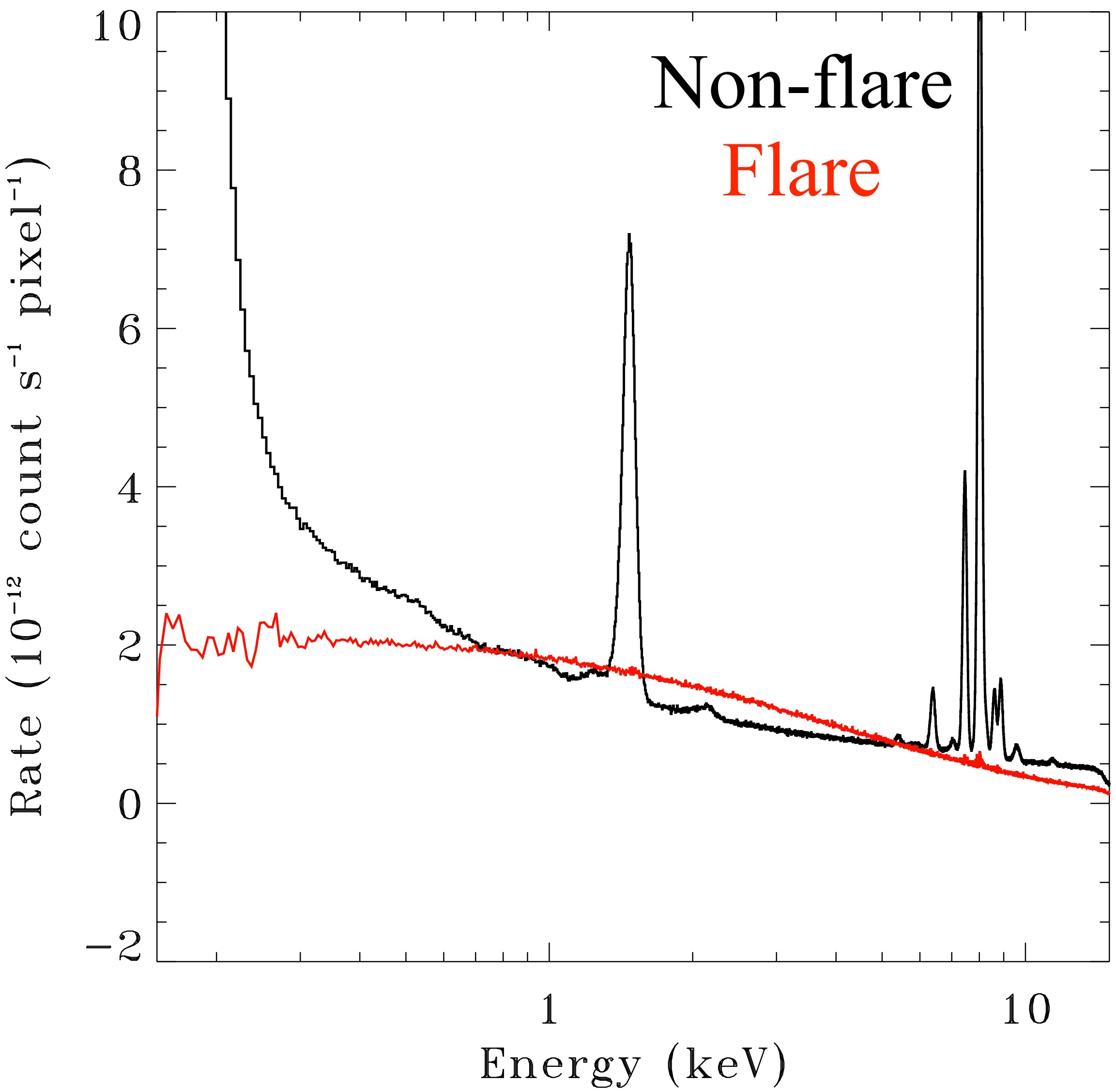
Less than ~35% of observations survive filter



pn - How good is SPF Removal?

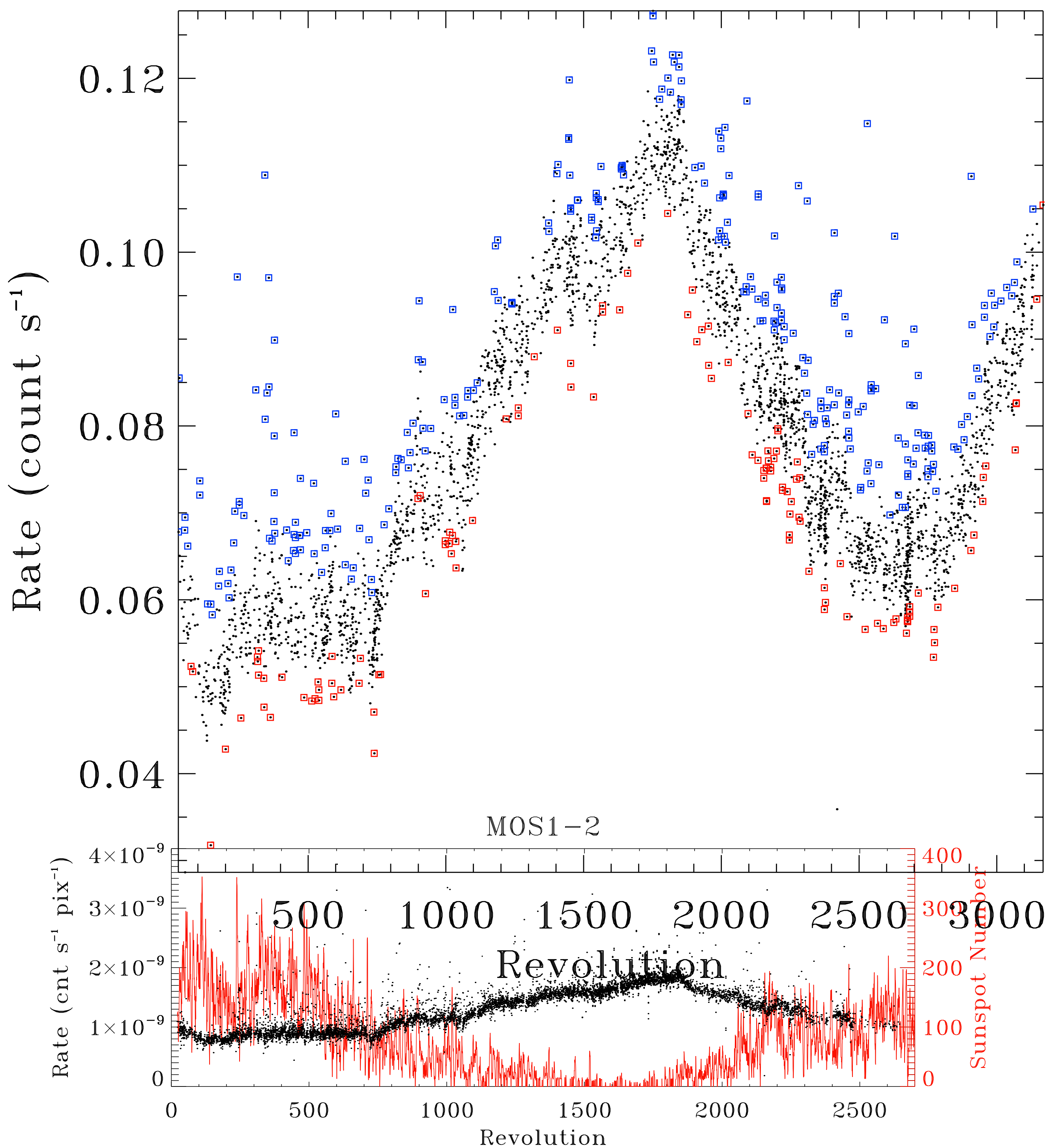
Mean spectrum for thinner filters is not > FWC spectrum AND residual does not have the same shape as SPF





pn - How good is SPF Removal?

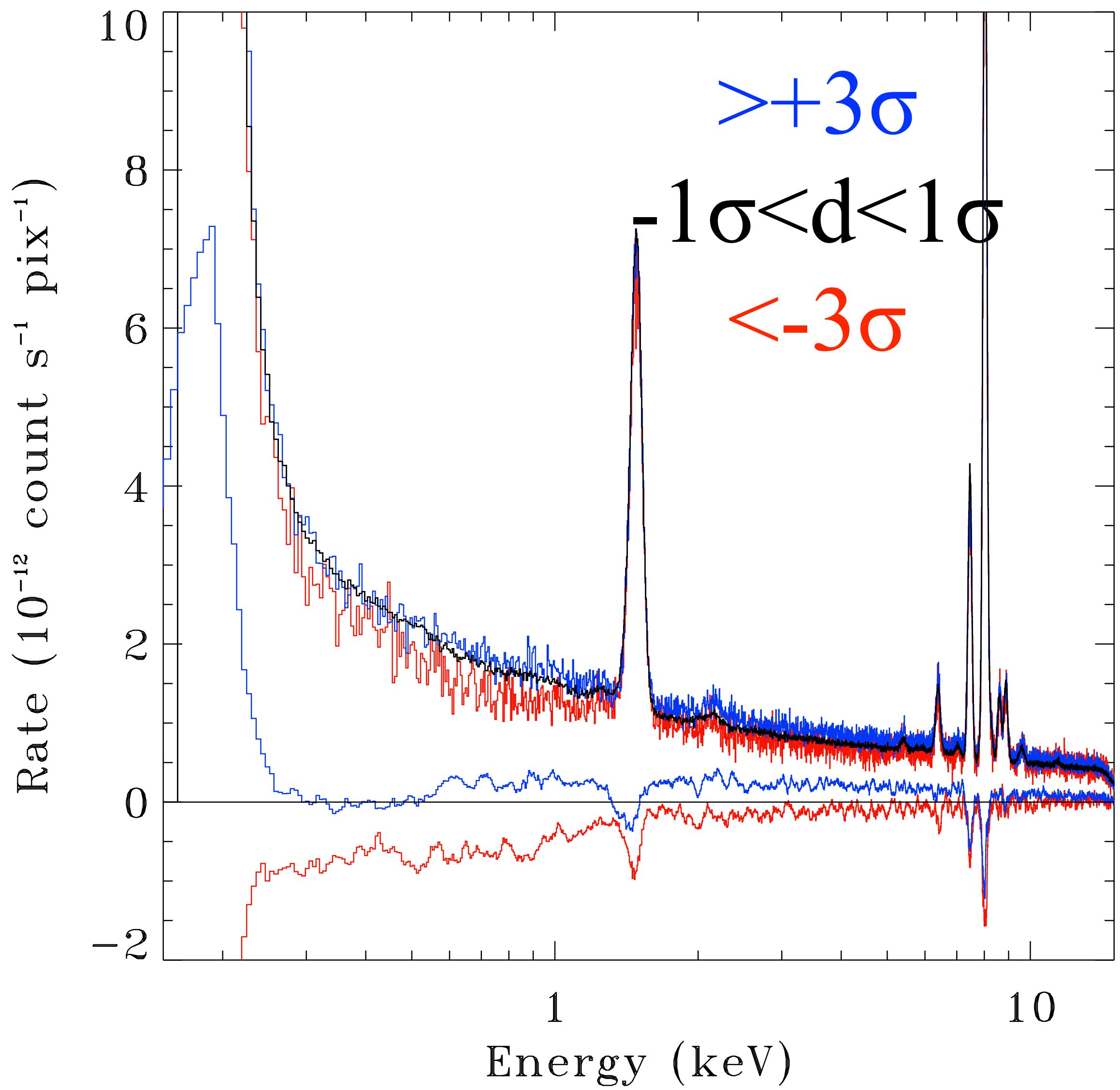
Might expect observations with higher normalized rates to be contaminated with residual soft proton flares



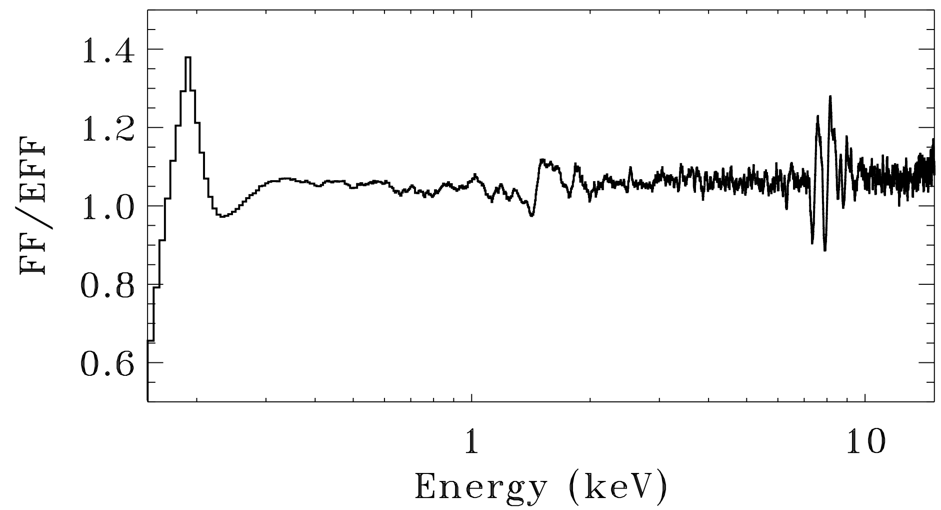
pn - How good is SPF Removal?

Might expect observations with higher normalized rates to be contaminated with residual soft proton flares

Mean spec from those with >+3σ compared to -1σ<devi<1σ residuals do not show SPF type spectrum



pn - FF versus EFF

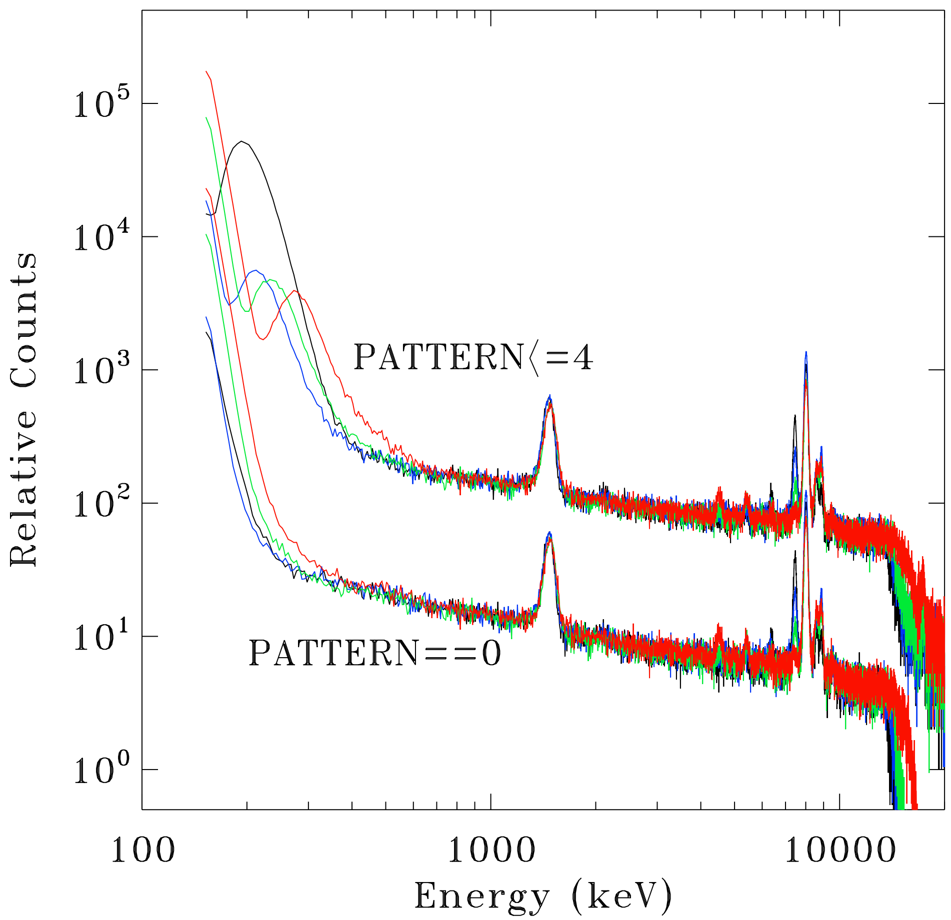


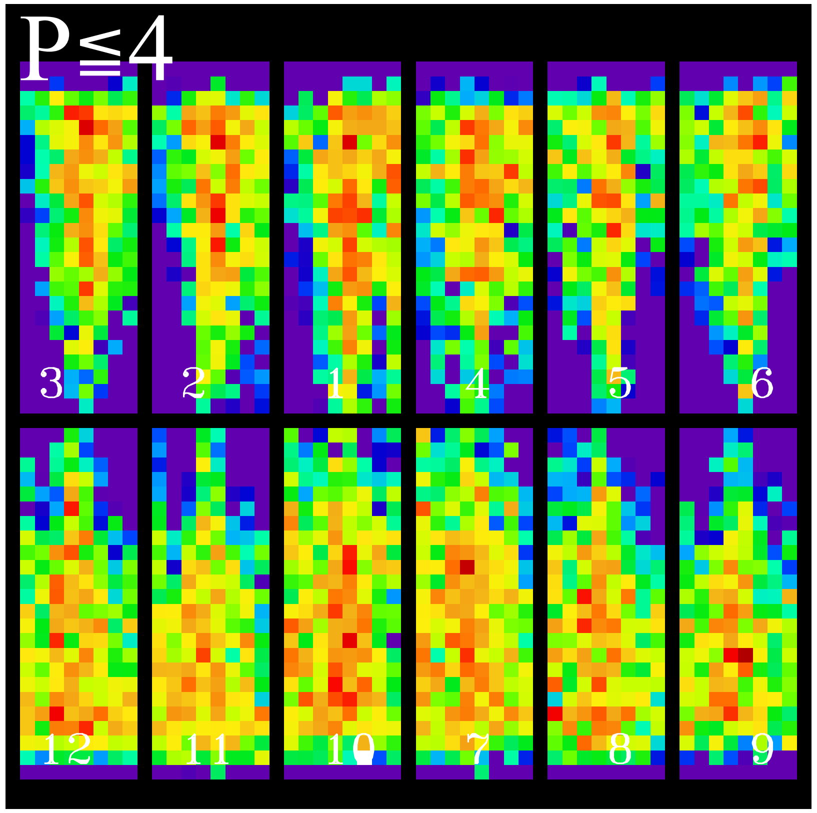
FWC, Flag=0,
Pattern=0

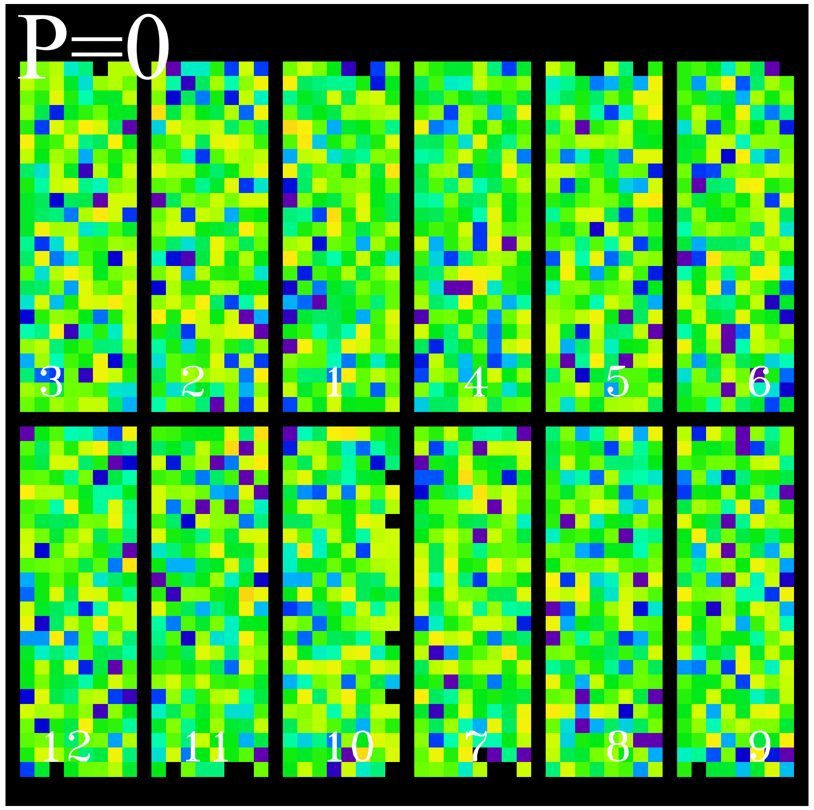
At low energies the full-frame mode has a different shape than the extended full-frame mode
FF/EFF increases slightly from 1 keV to higher energies.

→ FF and EFF QPB data should not be combined

pn - Pattern Selection

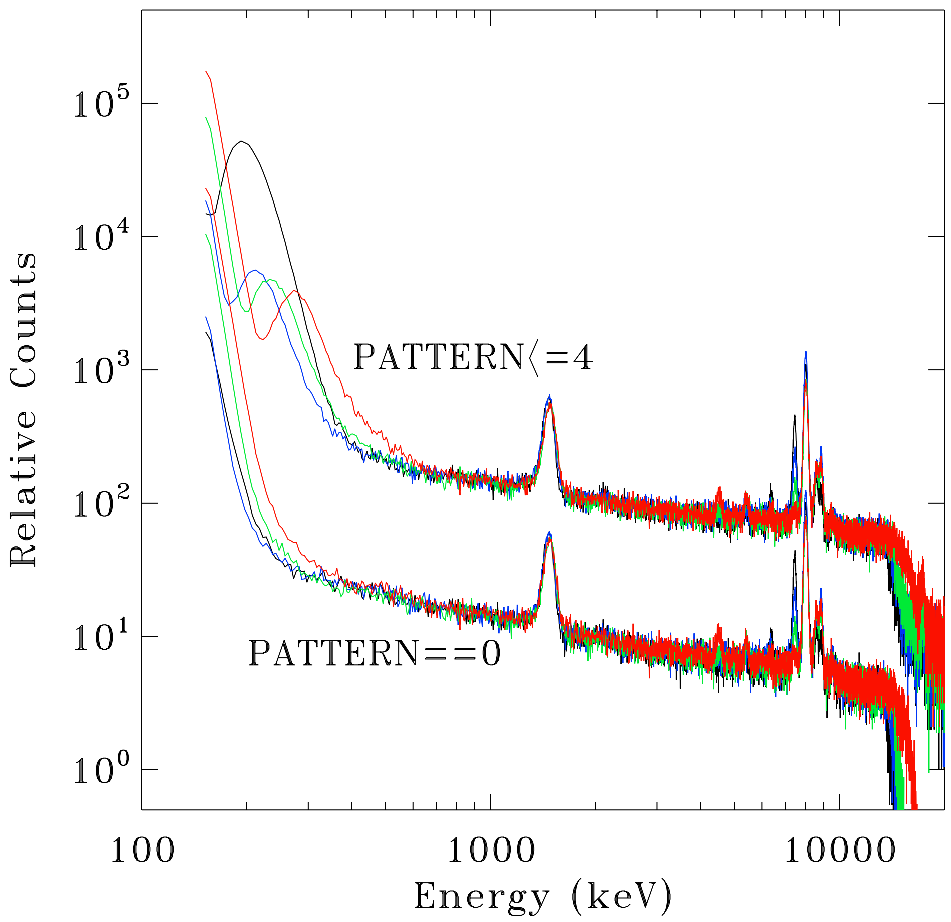


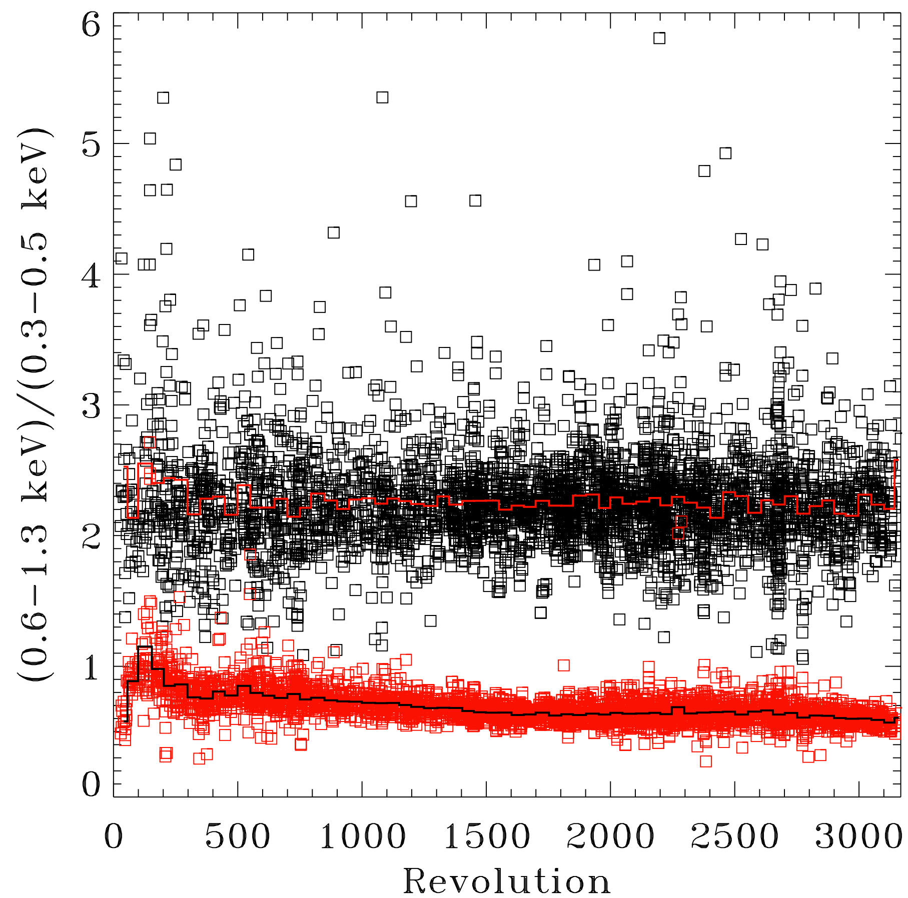




PATTERN<=4 selection produces a low-energy feature
PATTERN==0 removes that feature
 but reduces the count rate at all energies by 20%
Pattern strongly row dependent
Recommend P==0 for E<2 keV and P<=4 for E>1 keV
 and simultaneous fit of both

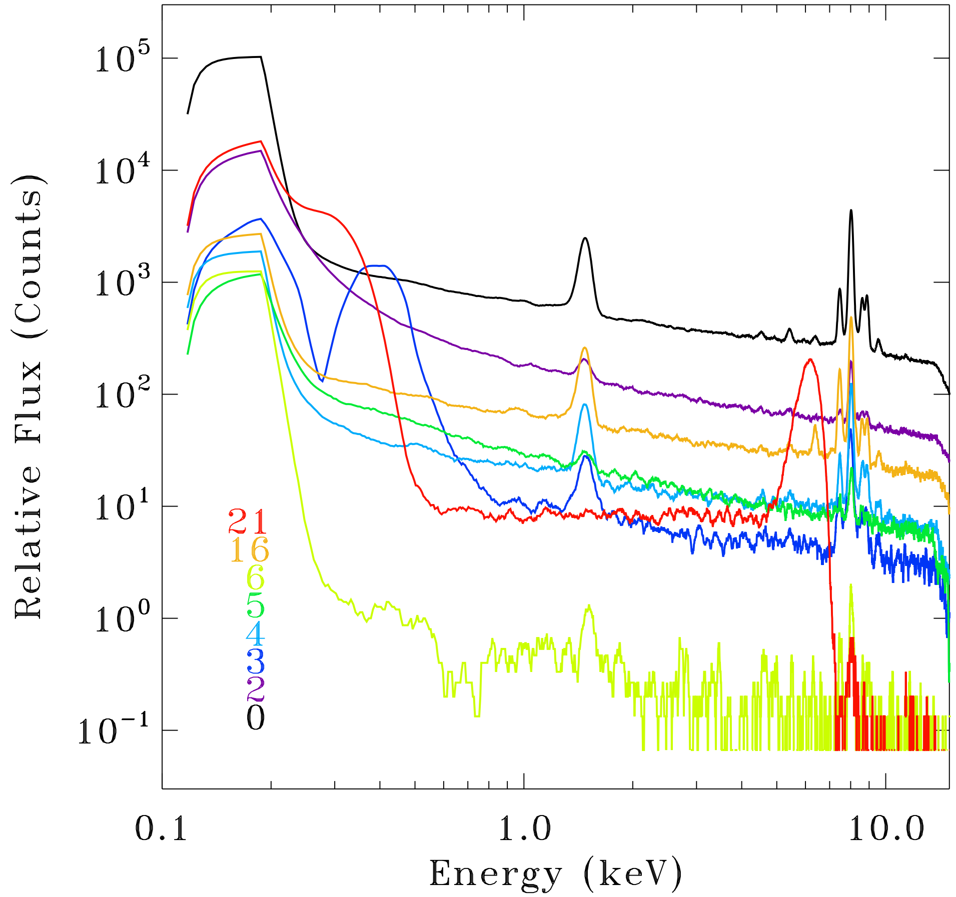
pn - Pattern Selection





PATTERN<=4 selection produces a low-energy feature
PATTERN==0 removes that feature
but reduces the count rate at all energies by 20%
The PATTERN<=4 feature has gotten strong with time

pn - Flag Selection



Pattern==0

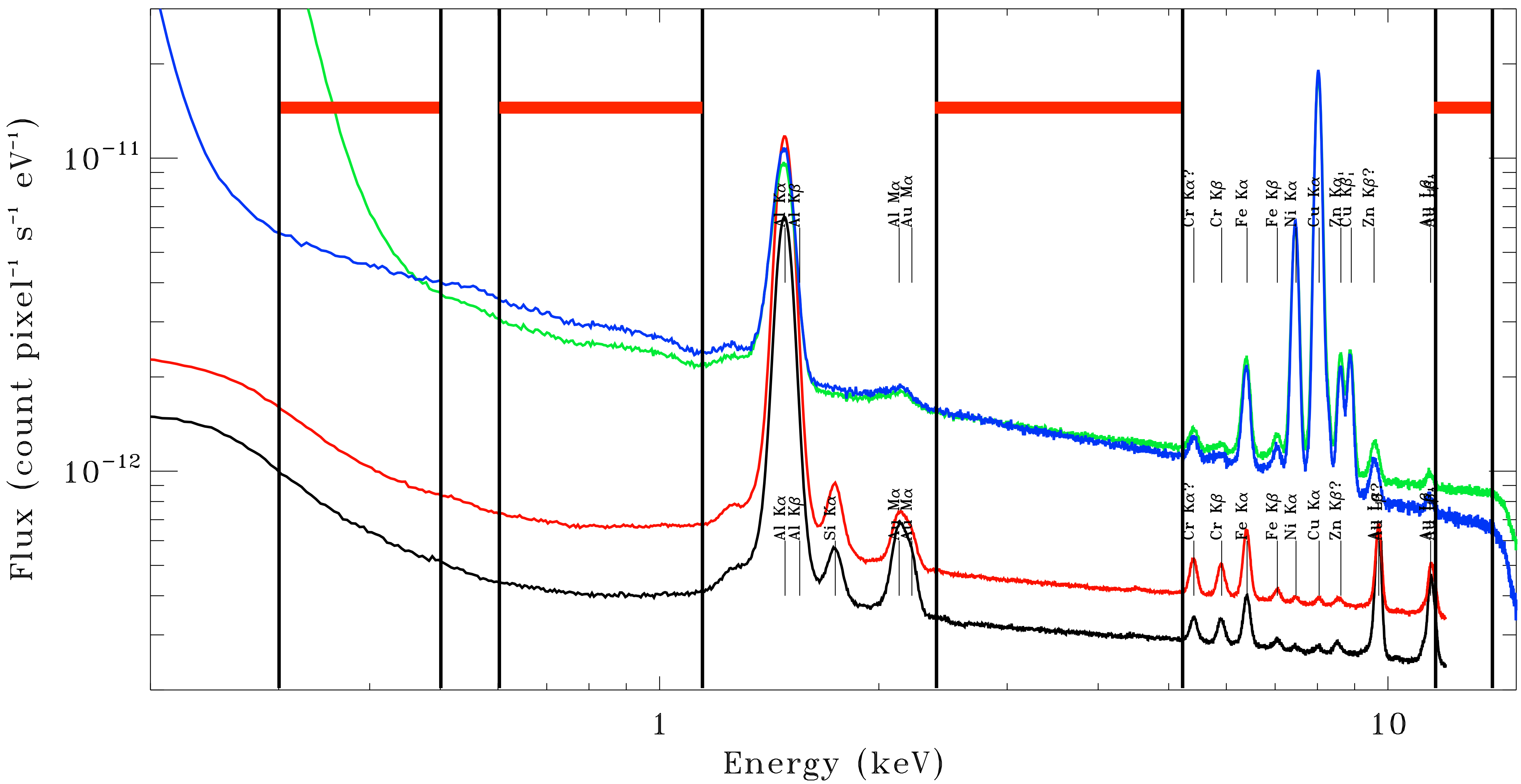
Compare the spectrum extracted with FLAG==0 to that with other flags allowed in FLAG==XMMEA_EP

- several flags allow extra spectral “features”
- FLAG==2^{16} is the out of FOV

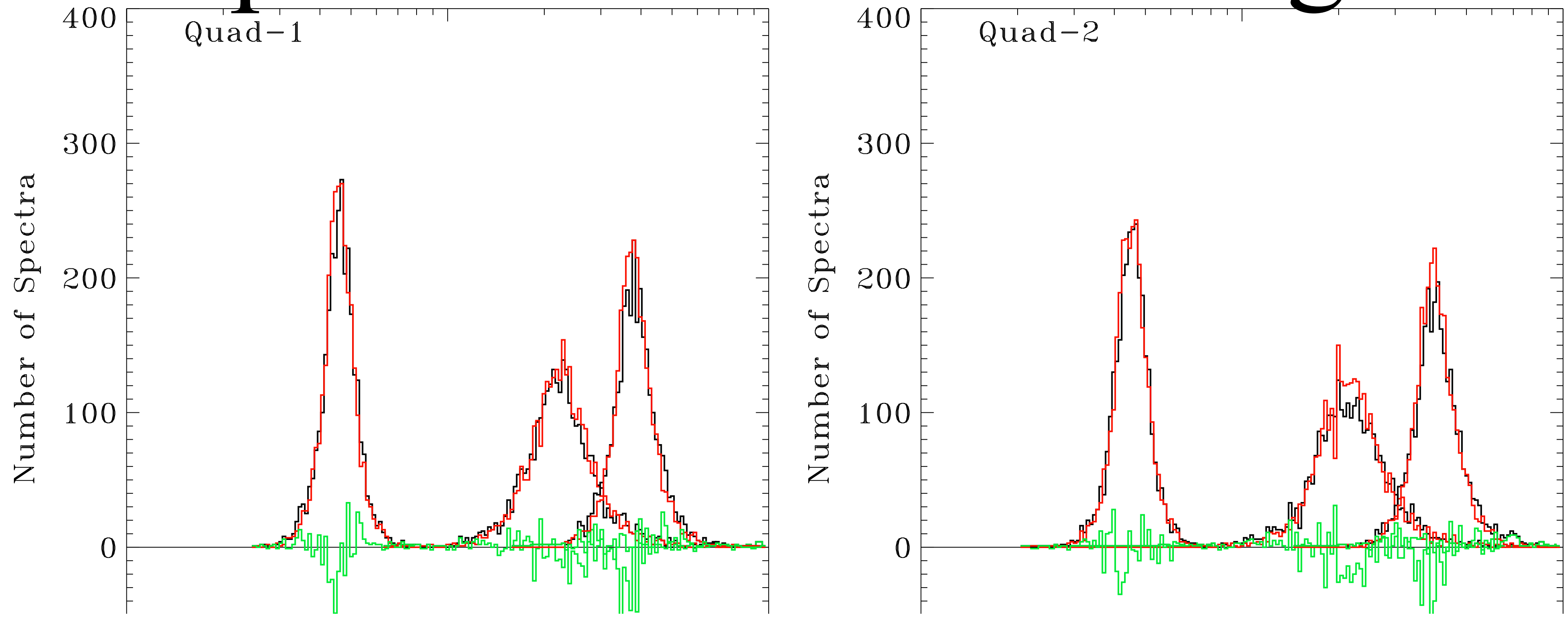
FLAG==0||FLAG==2^{16} produces cleanest spectrum

pn - Sumulations

Define four bands and three hardness ratios

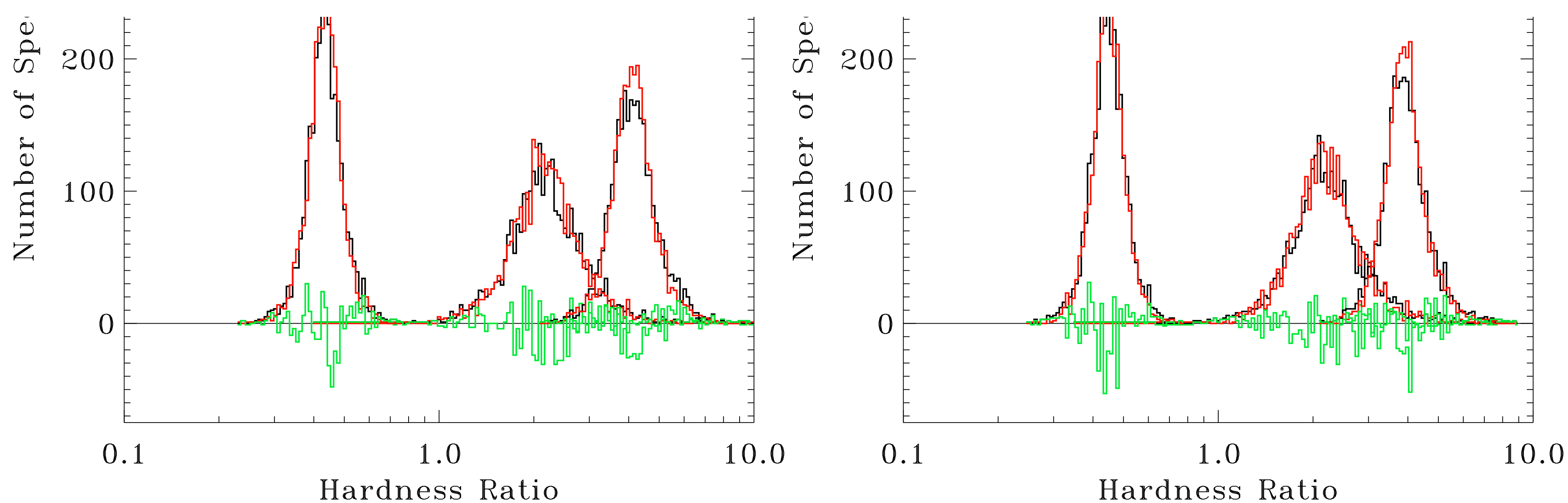


pn - Is the Mean Enough?



Distribution of HRs close to that expected from statistics alone

- suggests that the mean spectrum OK on quad-by-quad basis
- but KS tests suggest that otherwise! (typical probs~0.03)



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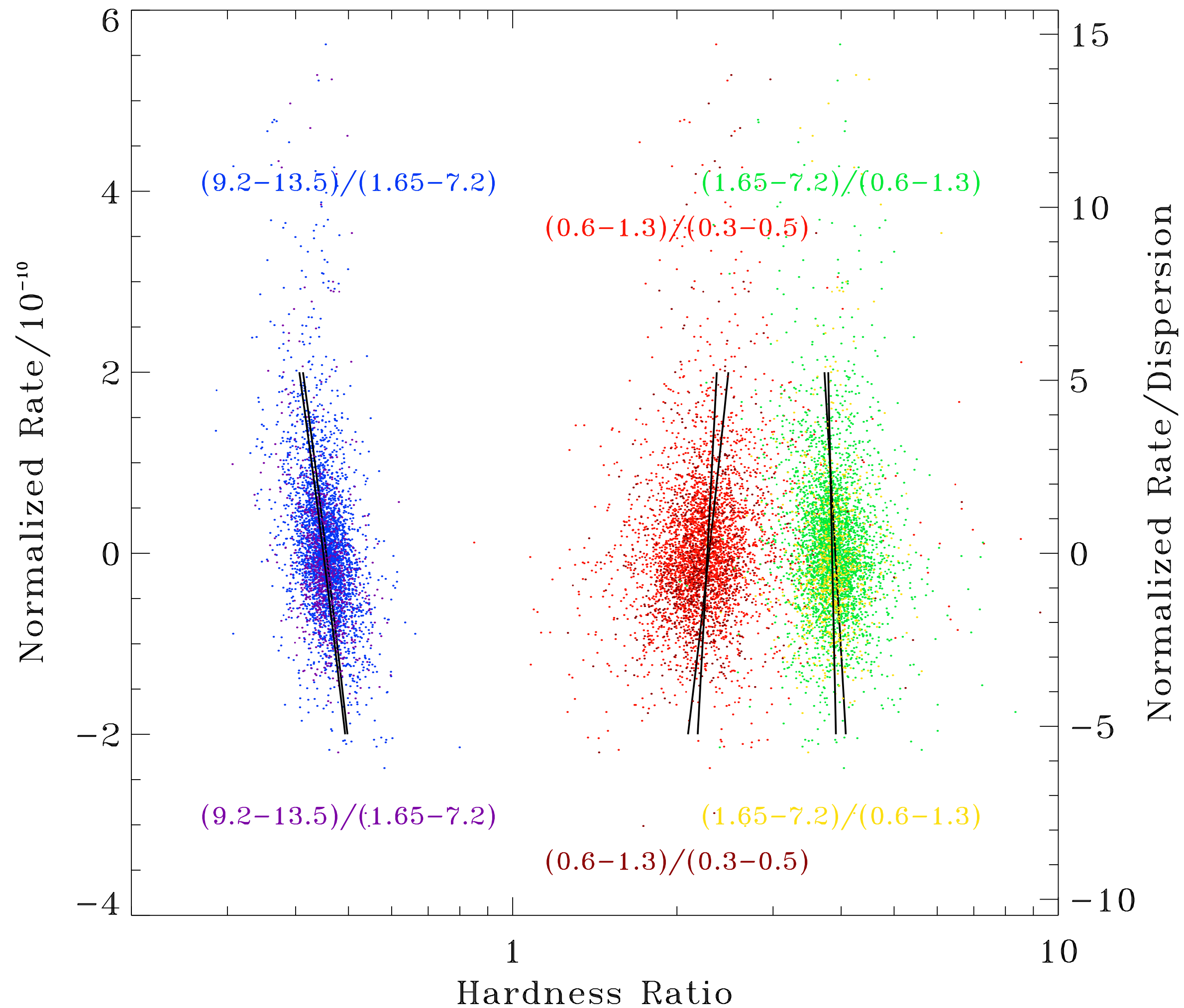
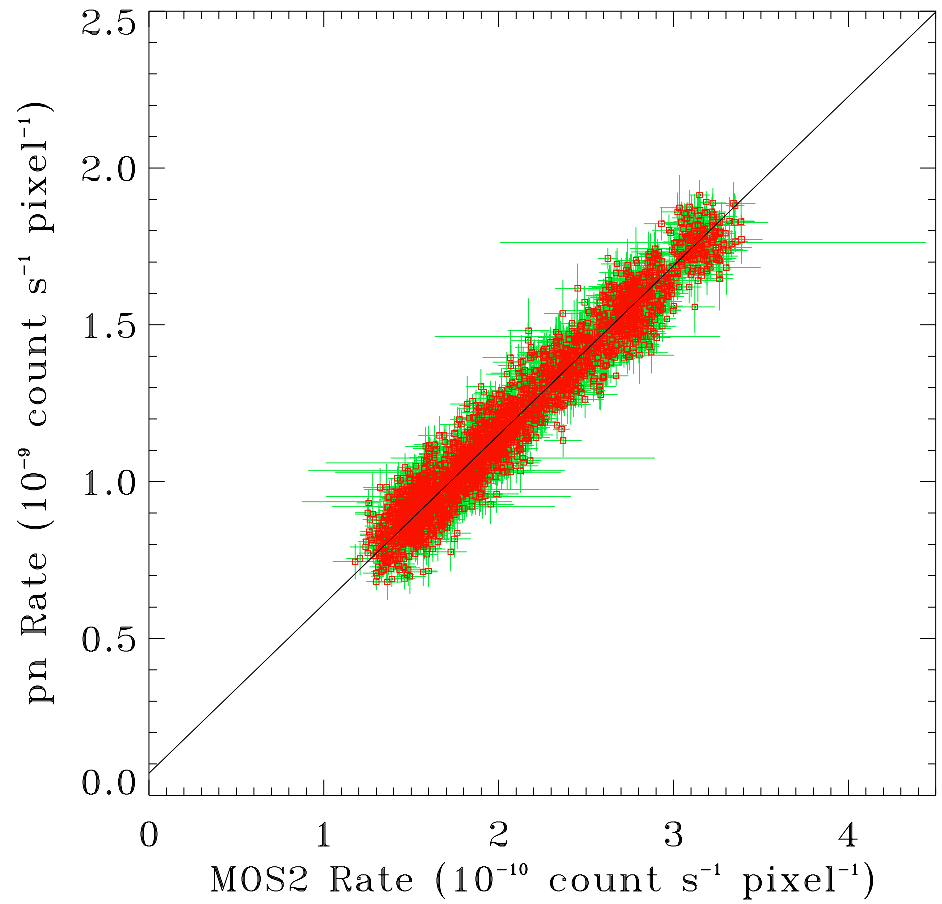


The hardness ratios depend on the normalized rate
(normalized rate = [rate - mean light curve]/dispersion)

Suggests that the spectrum depends on the normalized rate,
BUT still to be seen if introduced by the normalization method

pn - Window modes



There is a tight correlation between the pn corner rate and the MOS2 corner rate

- can normalize the mean pn QPB spectrum using the MOS2 data if the pn observation in window mode (w/o corners)

pn - Implementation

More careful data selection
- Revised corner definition (avoids scattered X-rays)
- Flag=0||Flag=2^{16} required, *not* XMMEA_EP
- Pattern=0 for E<2 keV, Pattern<=4 for E>1 keV

Use of mean QPB spectrum (tentatively)
- on a quadrant-by-quadrant basis

Use of augmented QPB spectrum, based on normaliz'd rates
- requires access to corner data from contemporary obsess in order to determine the mean light curve
- useful only for archival data

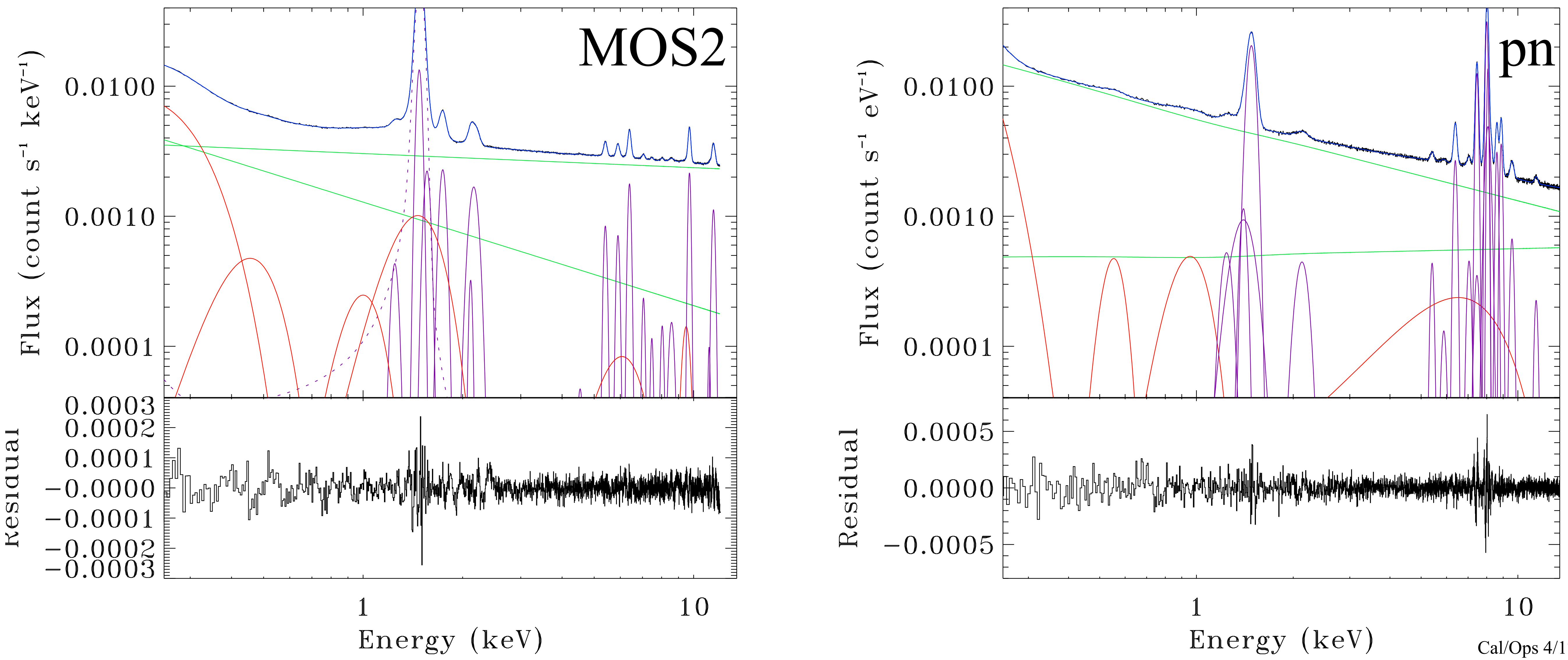
Use of MOS2 data for corner normalization for windows
- perhaps as the default method?

Spectroscopy

IACHEC best practices
- strongly discourages background subtraction
- strongly encourages simultaneous background fitting

How well can we do with current QPB?

χ^2=1.5,ν=2233,n=79 χ^2=1.45,ν=2585,n=70



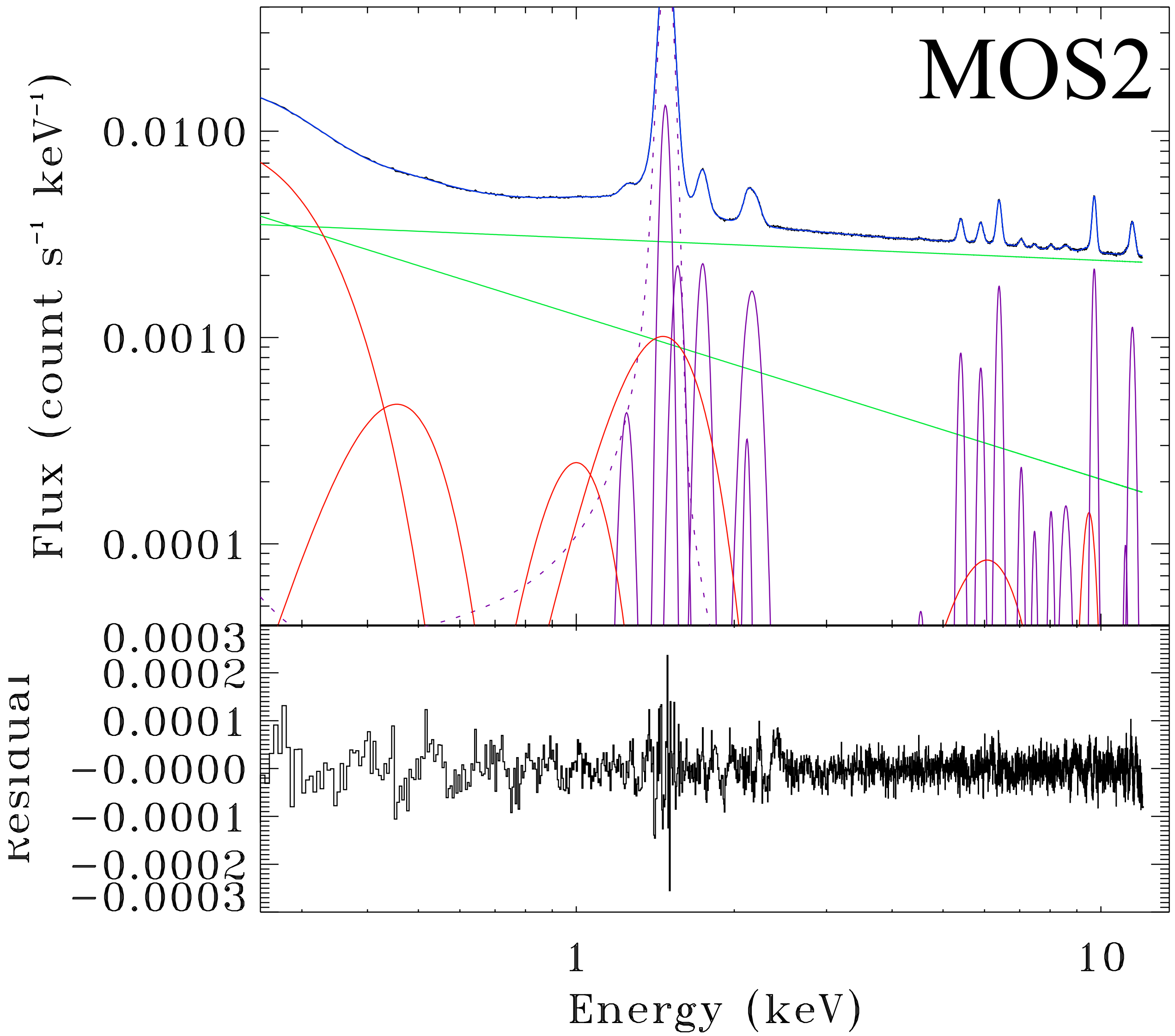
Spectroscopy

"Continuum" fit with two power laws & a low-E Gaussian
- used identity matrix for redistribution function

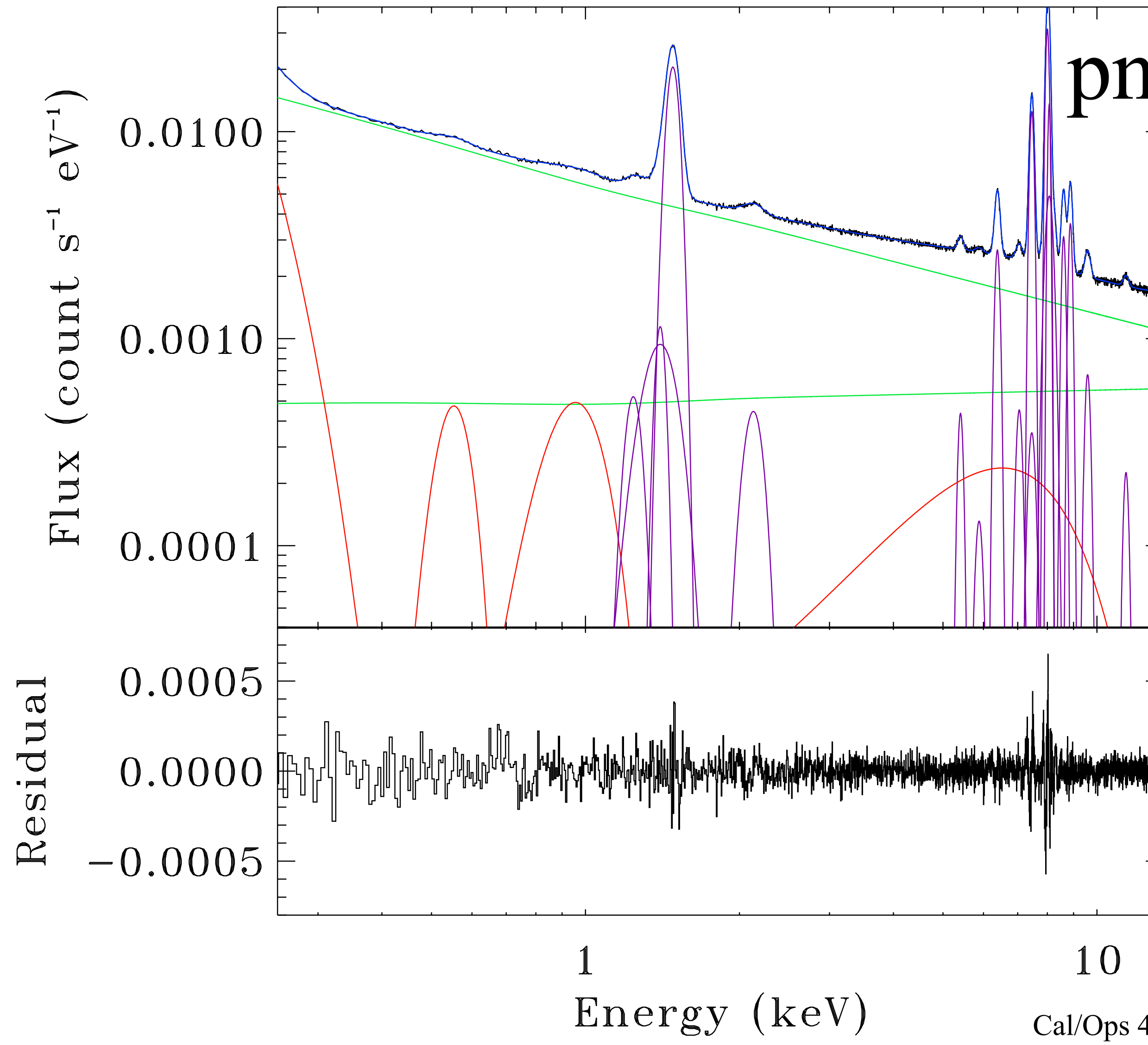
Instrumental redistribution matrix → lines too broad

→ used identity matrix

χ^2=1.5,ν=2233,n=79



χ^2=1.45,ν=2585,n=70

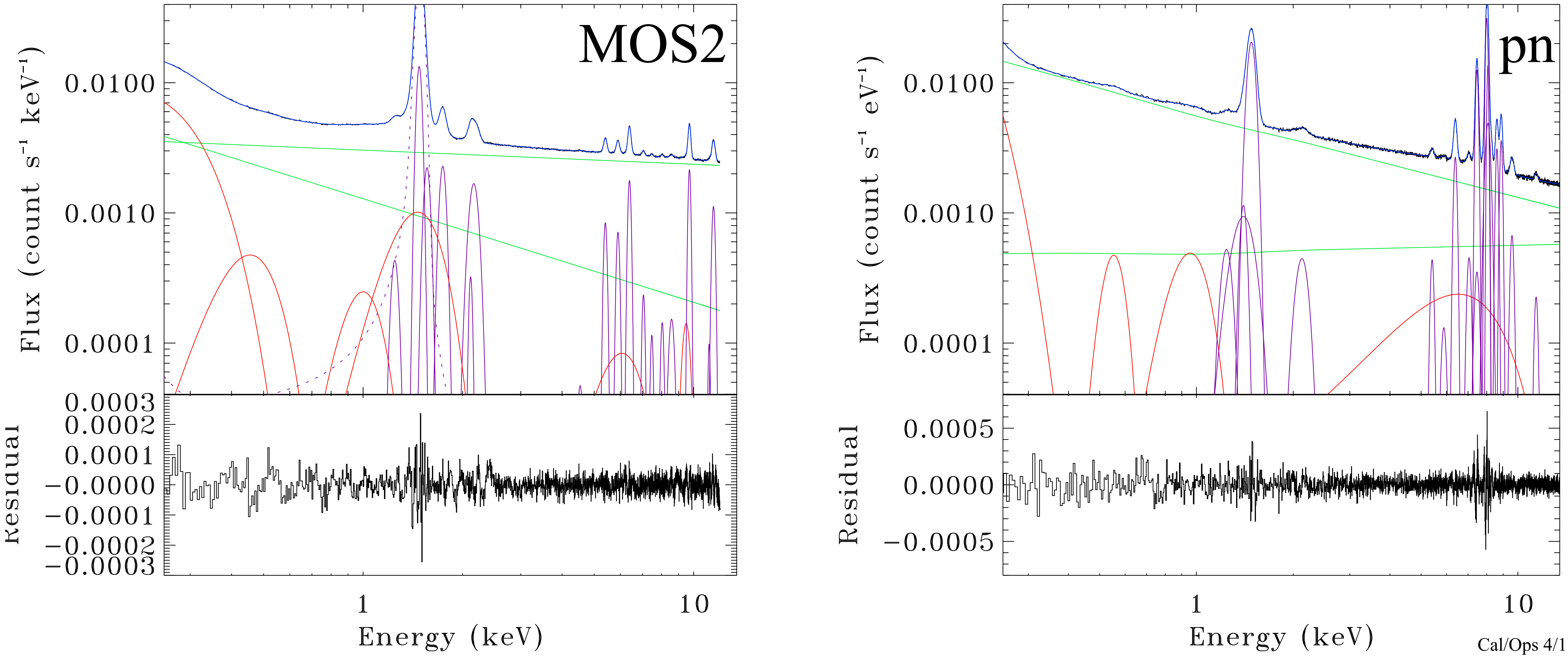


Spectroscopy

Have not yet tried simultaneous foreground/background fit
- many parameters can be fixed (line energies, widths)
- "continuum" normalizations float together

χ^2=1.5,ν=2233,n=79

χ^2=1.45,ν=2585,n=70



Summary

MOS methodology has changed
- new method of constructing the corner data
- use of mean corner data rather than augmentation
  (except in the case of anomalous chips)
- new anomalous chip criteria

pn methodology reconstructed
- new method of determining whether SPF cleaning worked
- corner data seems to be well cleaned
- more care taken with FLAG and PATTERN selection
- FF and EFF modes separated
- mean corner data may be acceptable but…

Remaining Open Issues

FWC data
- need to determine whether existing FWC data format (i.e. that found on the web-site) can be made compatible with ESAS requirements.
- determine balance between number of files and computational efficiency
- discuss(?) the FWC priorities for the pn?

QPB data
- databases being reconstructed
- mean QPB spectra soon to be updated
- ESAS code being updated to use mean QPB spectra
 - augmentation option retained for intermediate anomalous MOS chip/states and (possibly) pn archival

What the heck is going on with M1-4?