An EPIC Tale of the Quiescent Particle Background

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Extended Source Analysis Software
Use Based Empirical Investigation

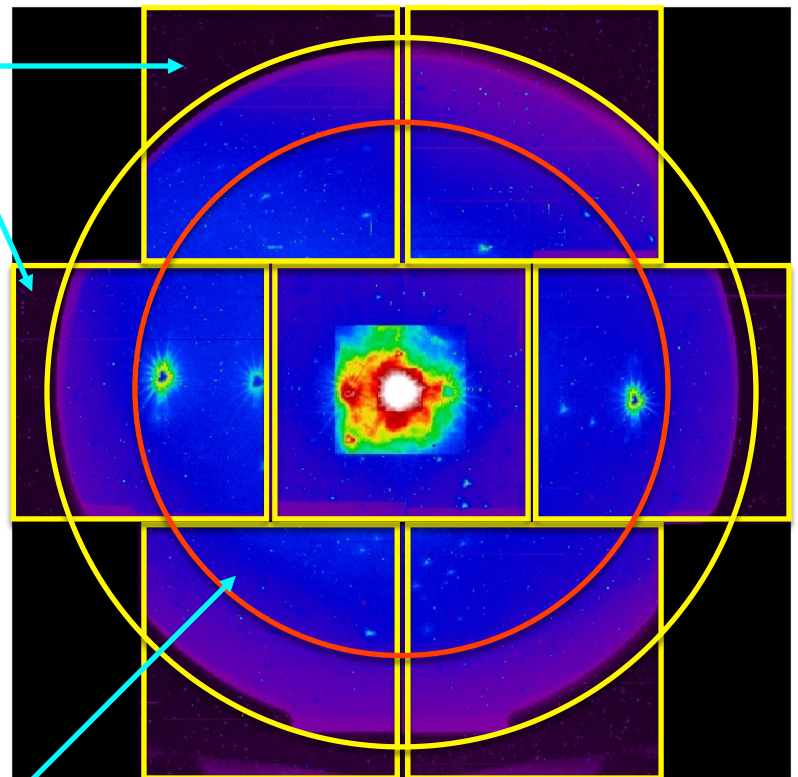
- Builds quiescent particle background (QPB) spectra and images for observations of extended sources that fill (or mostly fill) the FOV – i.e., annular background subtraction won't work
- Uses a combination of Filter Wheel Closed (FWC) and corner data to capture the spectral, spatial, and temporal variation of the quiescent particle background

New Work:

- Improved understanding of the QPB (aided by adding a whole lot of data since 2008)
- Significantly improved statistics (did I mention a LOT more data?)
- Better characterization and identification of anomalous states
- Builds backgrounds for some anomalous state
- New efficient method for non-anomalous states

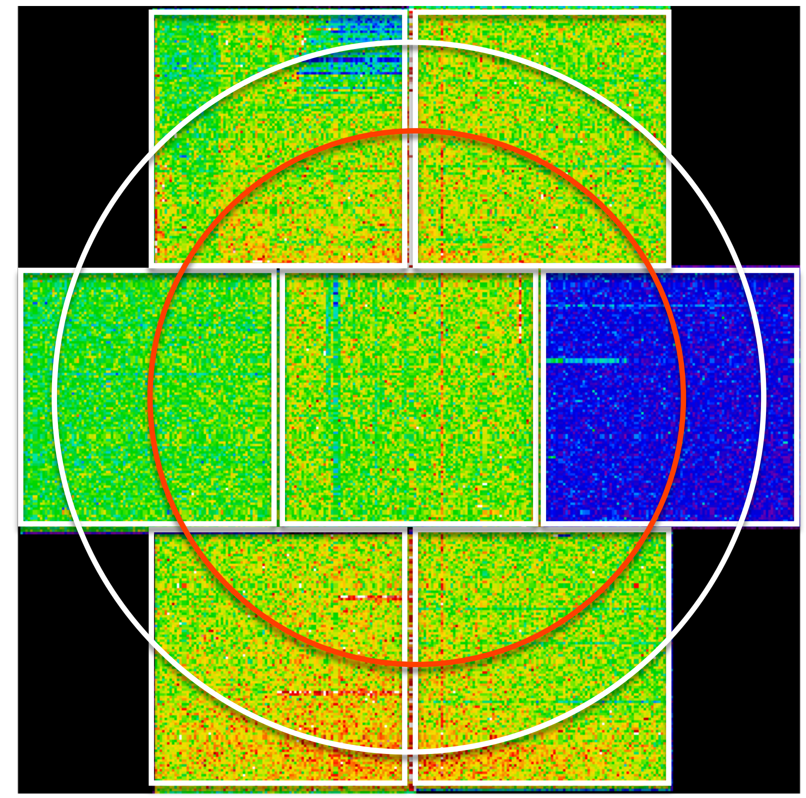
Review of Current (Original) Method

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…

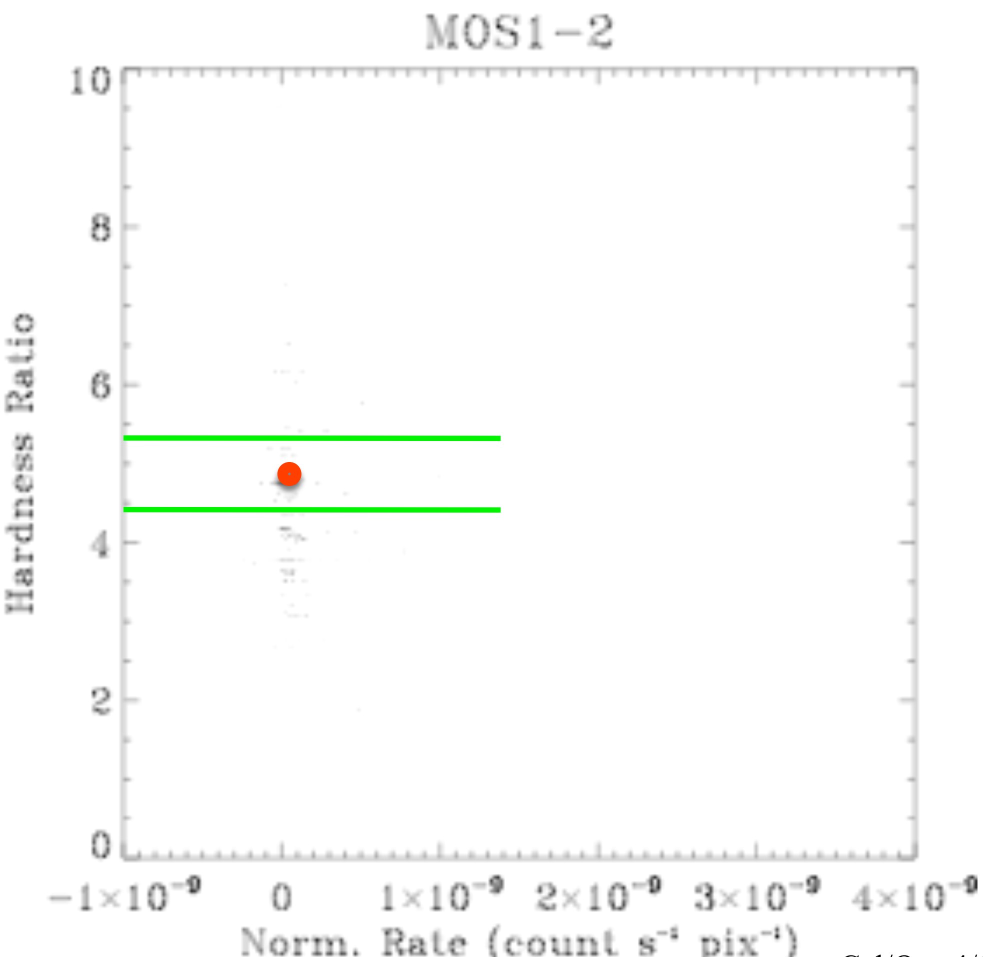
…and typical values are ~5x10^{-13} /pixel/energy bin/s

Current Method

However, the corner data from an individual observation have very poor statistics!

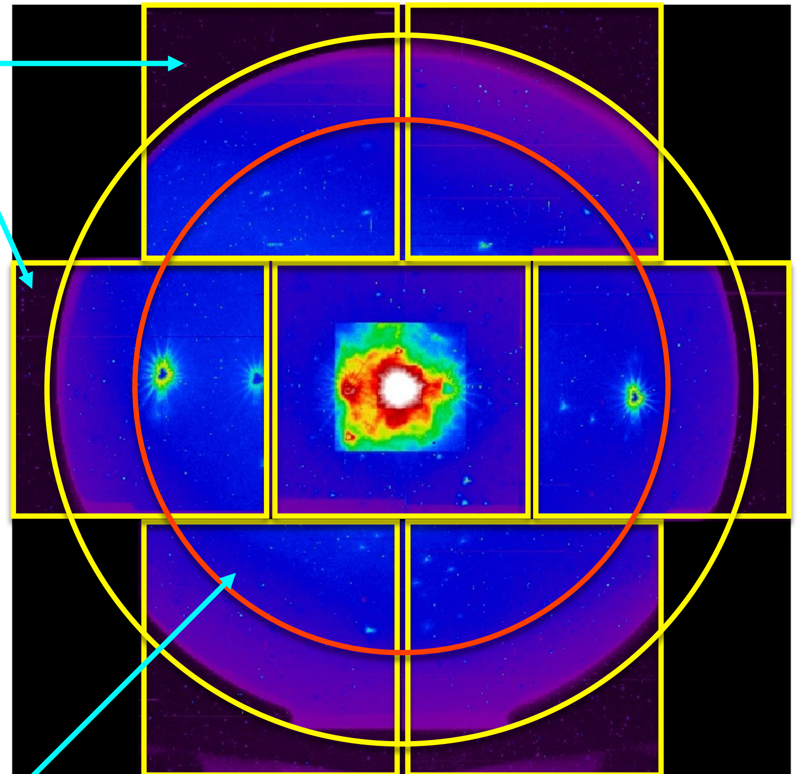
So, we:

- Build a database of corner data from all observations
- Characterize the shape of each spectrum
  - The (2.5-5.0 keV)/(0.4-0.8 keV) hardness ratio sufficient
- Then for any given observation
  - Measure hardness ratio (red dot)
  - Can sum all spectra with similar spectral shape (points between green lines)
- This “augmented” corner spectrum has significantly better S/N!



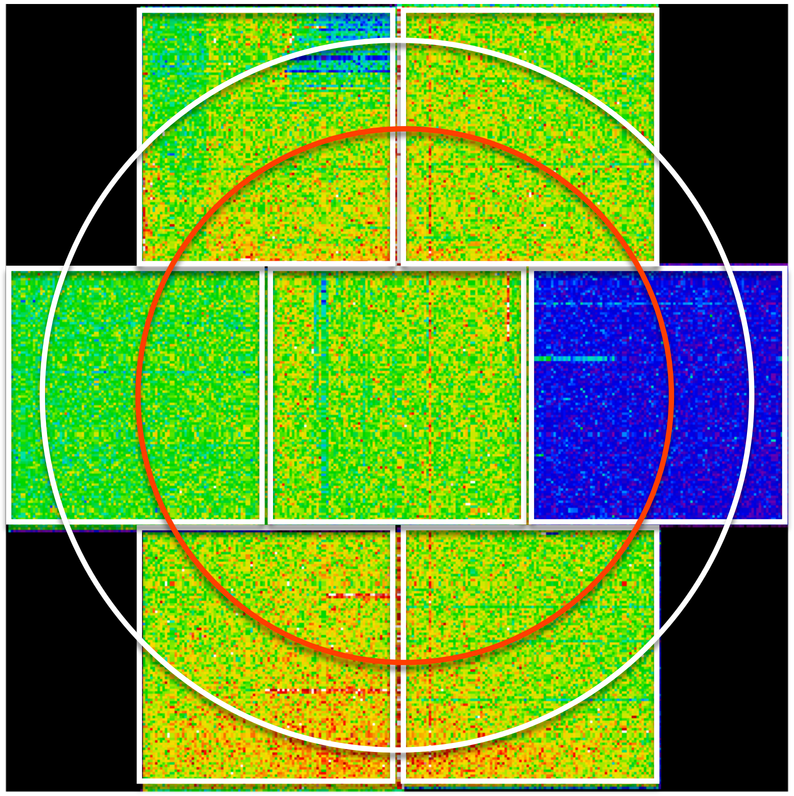
Current Method

Corners



FOV of interest

Observation



Filter-Wheel-Closed Data

Now really *good* stats

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

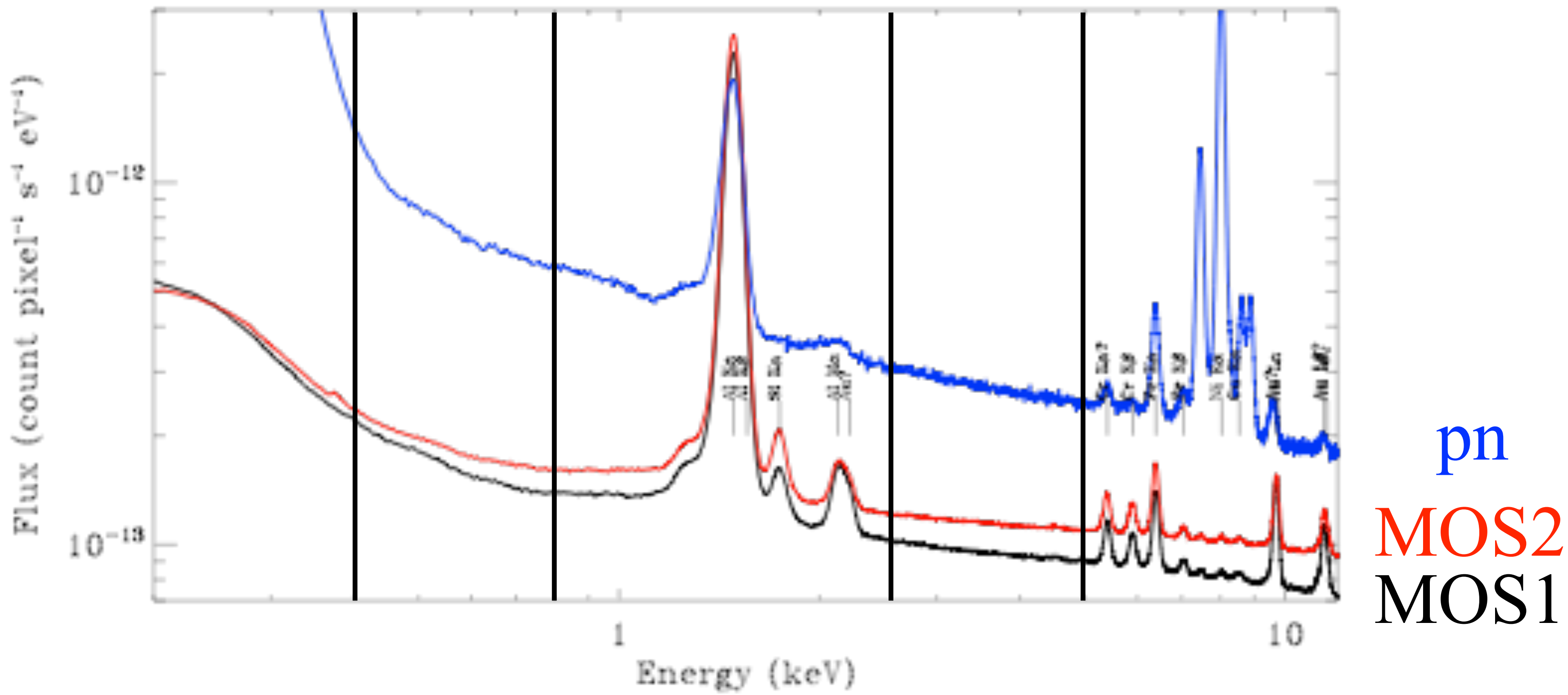
poor stats

Where all of these spectra are created on chip-by-chip basis

Why so Complicated?

Why not just one background spectrum?

Mean Quiescent Particle Background

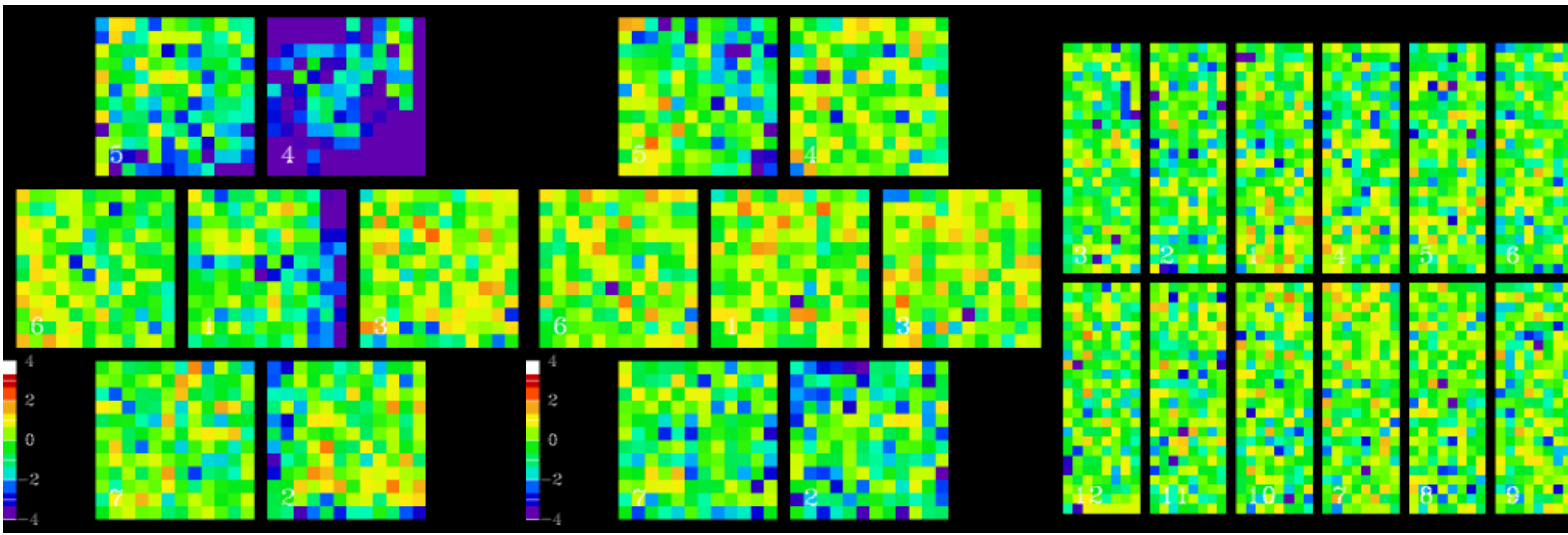


Spectra are composed of lines and continuum

- Lines are sensitive to ewsidual gain variation so should be fit in the observed spectrum rather than subtracted (not ESAS)
- The continuum is characterized by total count rate (R) and the (2.5-5.0 keV)/(0.4-0.8 keV) hardness ratio (H)

The QPB Varies

Filter-wheel closed (FWC) “continuum” data shows some spatial variation in count-rate and significant variation in hardness ratio (MOS1&MOS2)

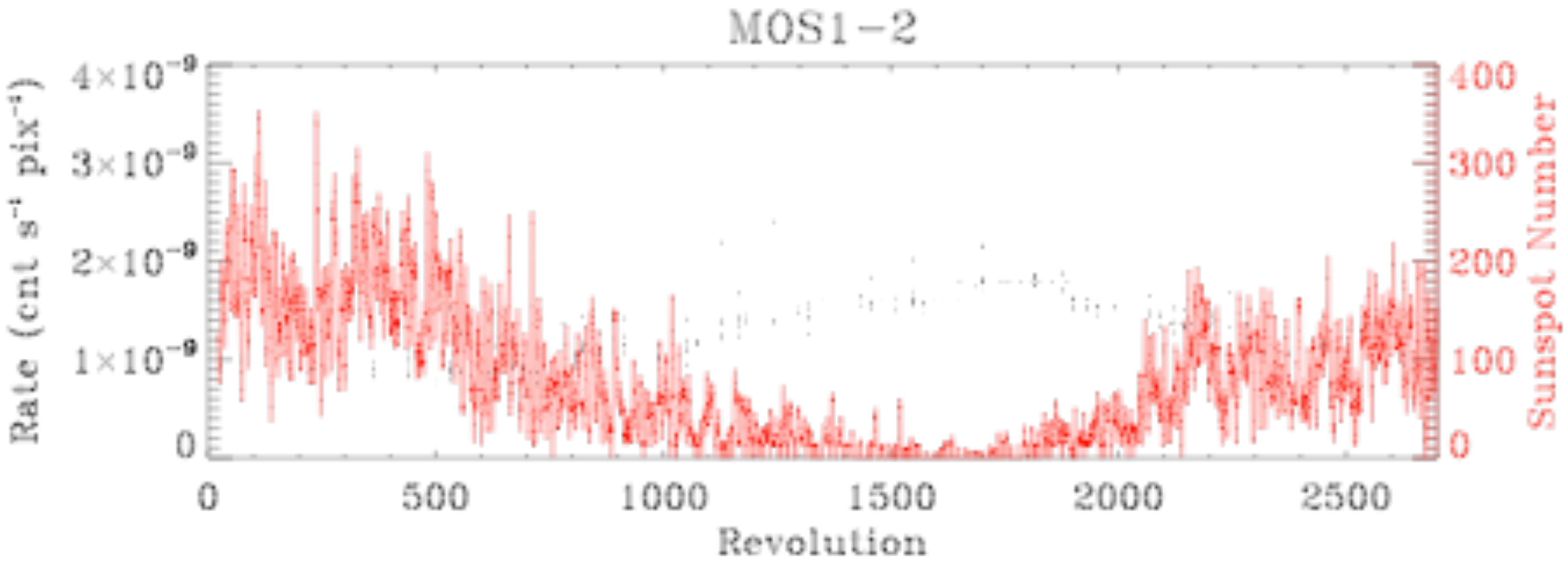


Hardness ratio (H) for the MOS1, MOS2, and pn (H-meanH)

The QPB Varies

Corner data show:

- Long-term temporal variation due to solar cycle

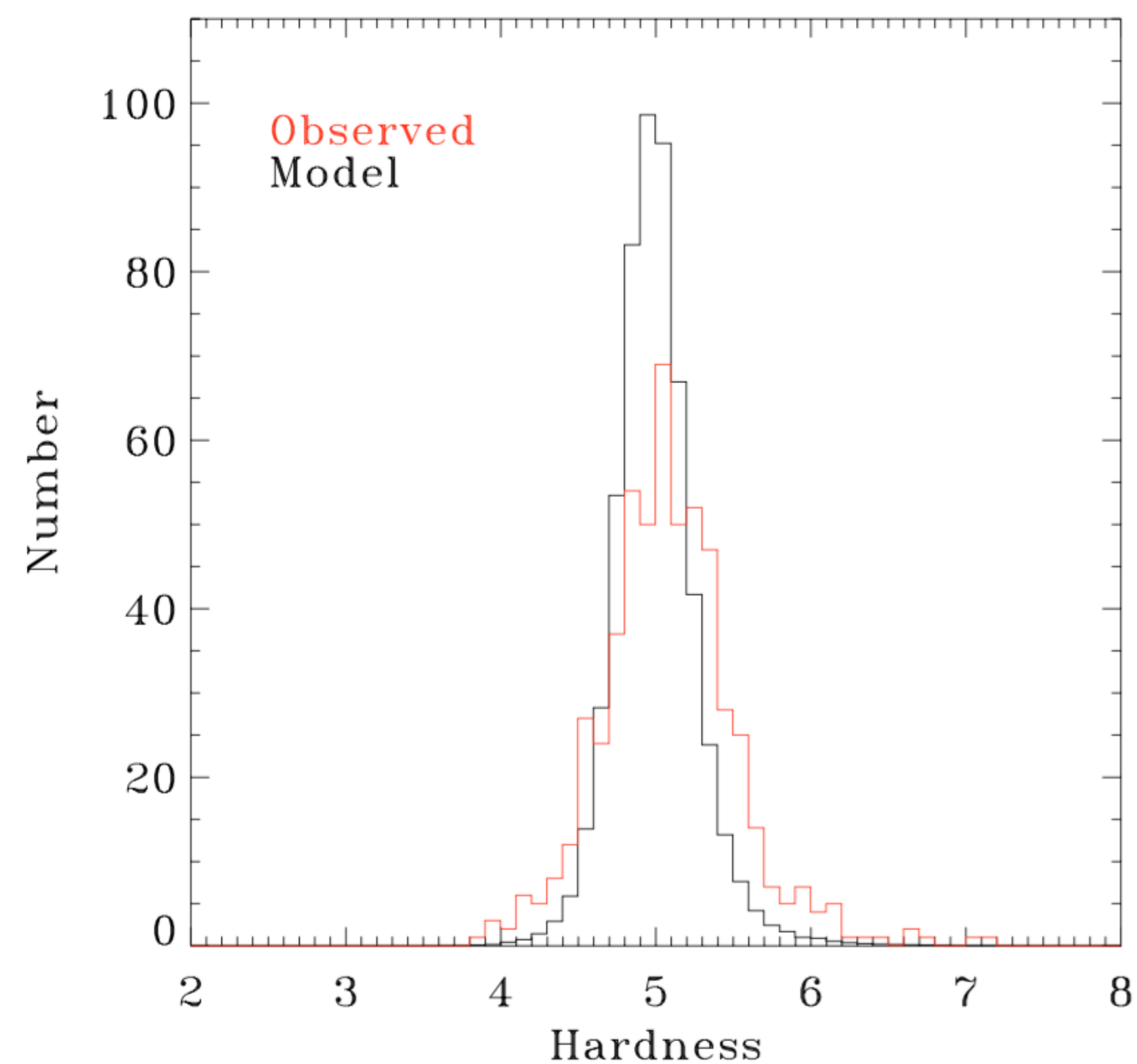


- Temporal variation in hardness ratio
  - Anomalous states in chips 1-4, 1-5, 2-2, & 2-5
  - As of 2008, apparently also in non-anomalous chips

The QPB Varies (as of 2008)

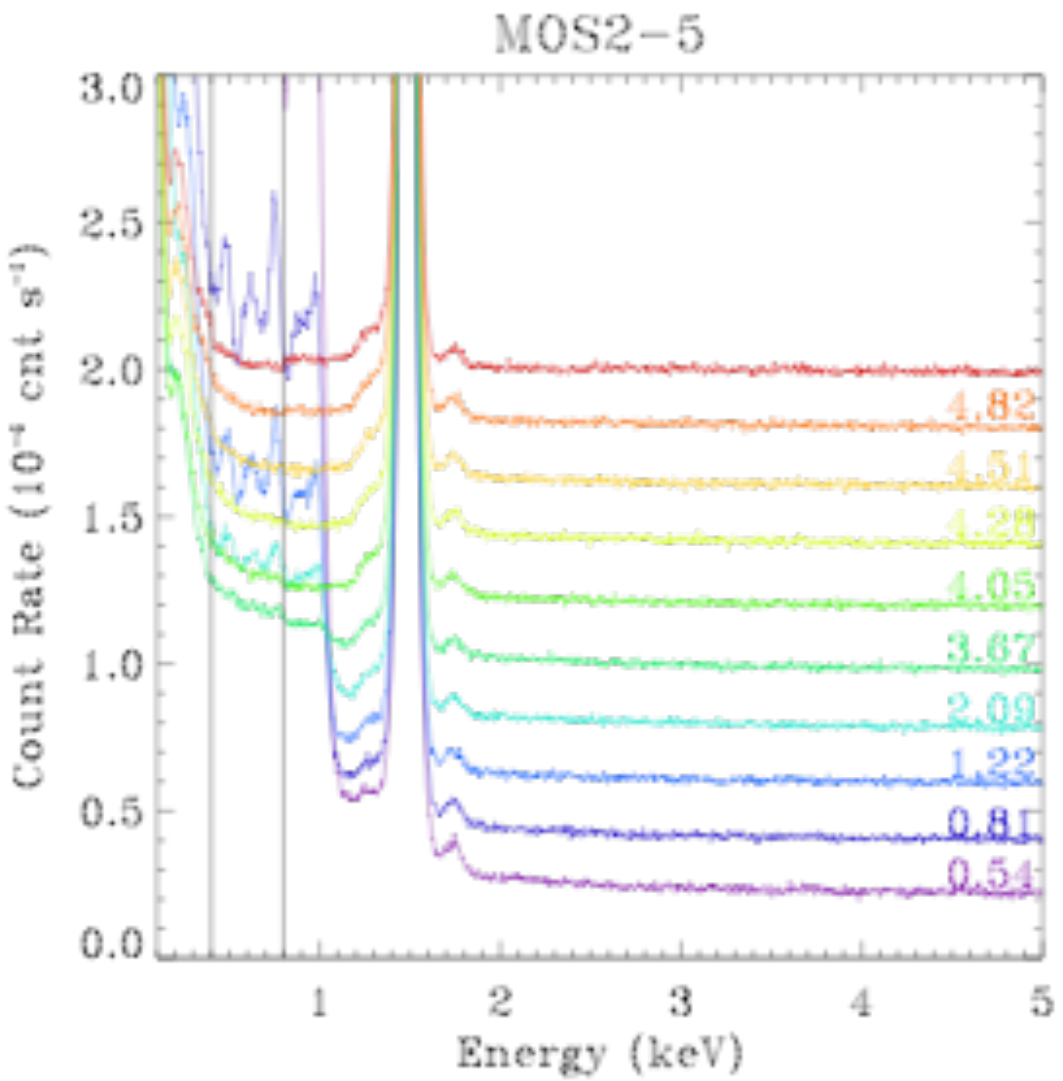
Corner data show:

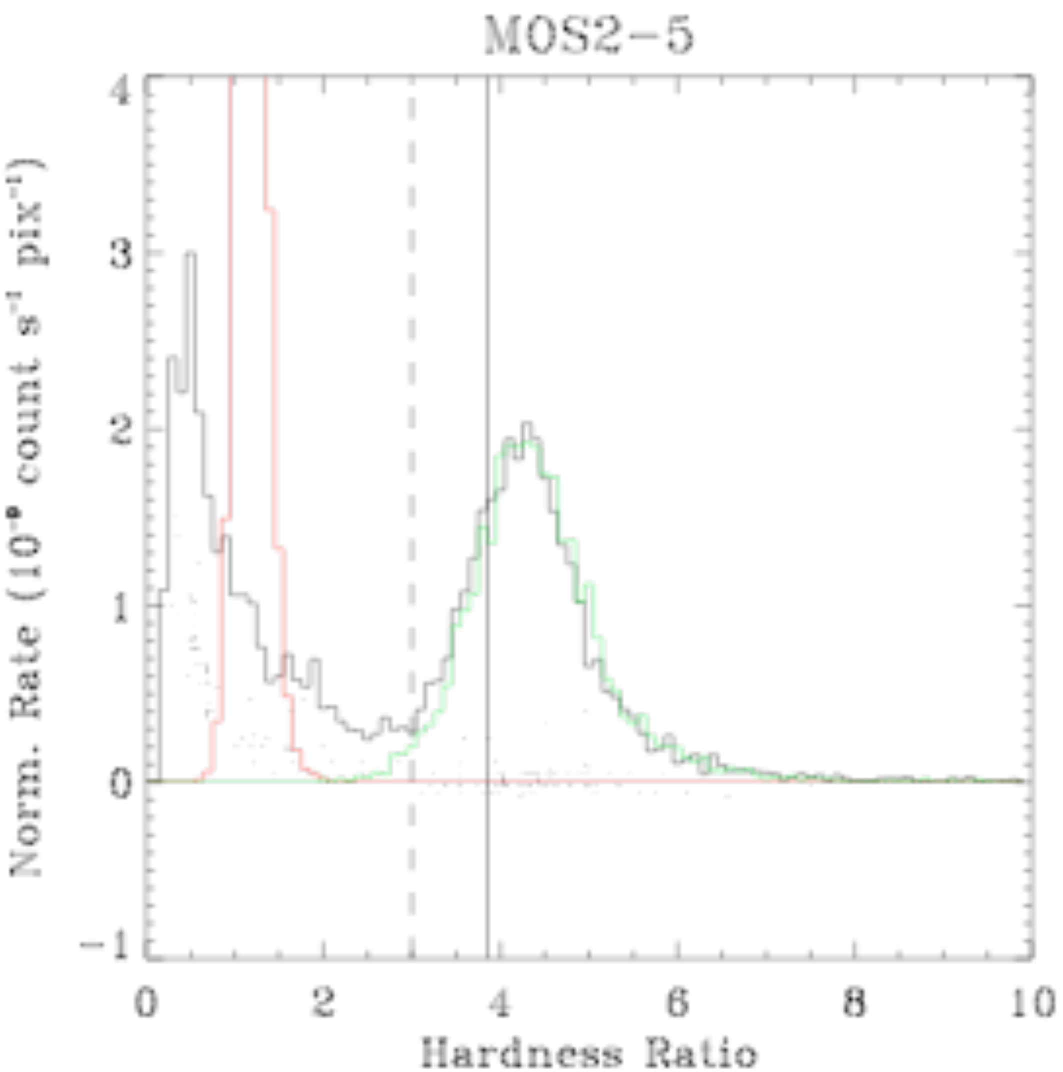
- Long-term temporal variation (due to solar cycle)
- Temporal variation in hardness ratio
- Anomalous states in chips 1-4, 1-5, 2-2, & 2-5
- Apparently also in non-anomalous chips
  - e.g., distribution of measured hardness ratio
  - was broader than expected
  - from Poisson statistics after
  - anomalous states had been
  - Removed
- Spoiler: Our understanding of this last point has changed!



Anomalous States

- Some chips show an intermittent low-energy “noise” feature
- Typically seen as:
  - higher than usual count rate
  - lower than usual hardness ratio
- States identifiable in plots of hardness ratio vs. count rate





So What’s New?

Start With:

Perennial ESAS Tasks

To keep ESAS up to date, periodically

- Update FWC data (no longer a Goddard responsibility)
- Update databases of corner spectra
- Reprocess as SAS defaults/procedures change
  - Check for significant changes in behavior
  - Update anomalous state definitions

Original methods described in Kuntz & Snowden (2008)

- Irregular updates every several years
- Finishing up(?) last(?) significant change (2017)

Perennial ESAS Tasks

Compare 2008 and with 2017 for corner data sets

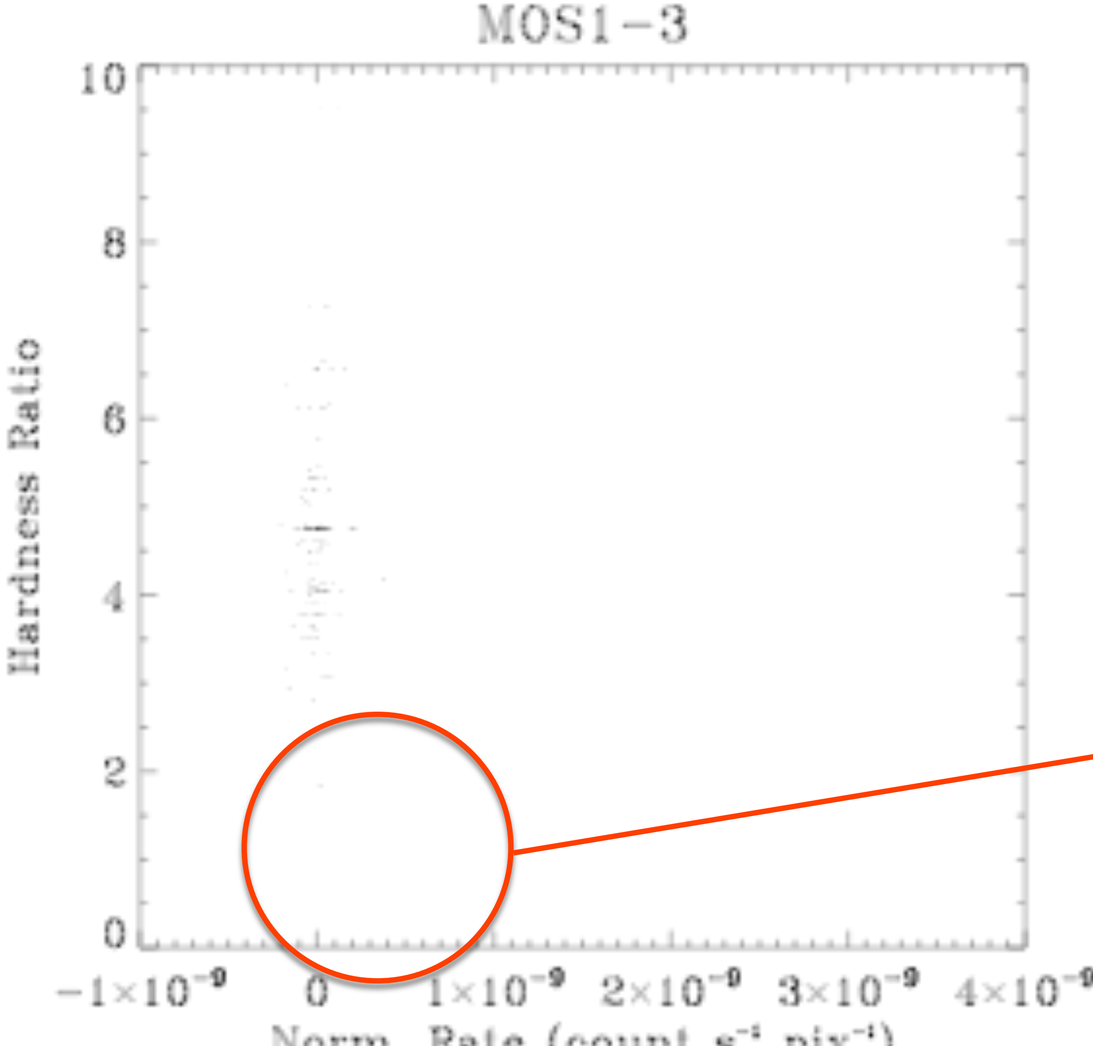
Instrument	2008	2017
MOS1	42.2 Ms	303.1 Ms
MOS2	44.4 Ms	303.8 Ms
pn	——	36.2 Ms
Observations	~2200	~12230

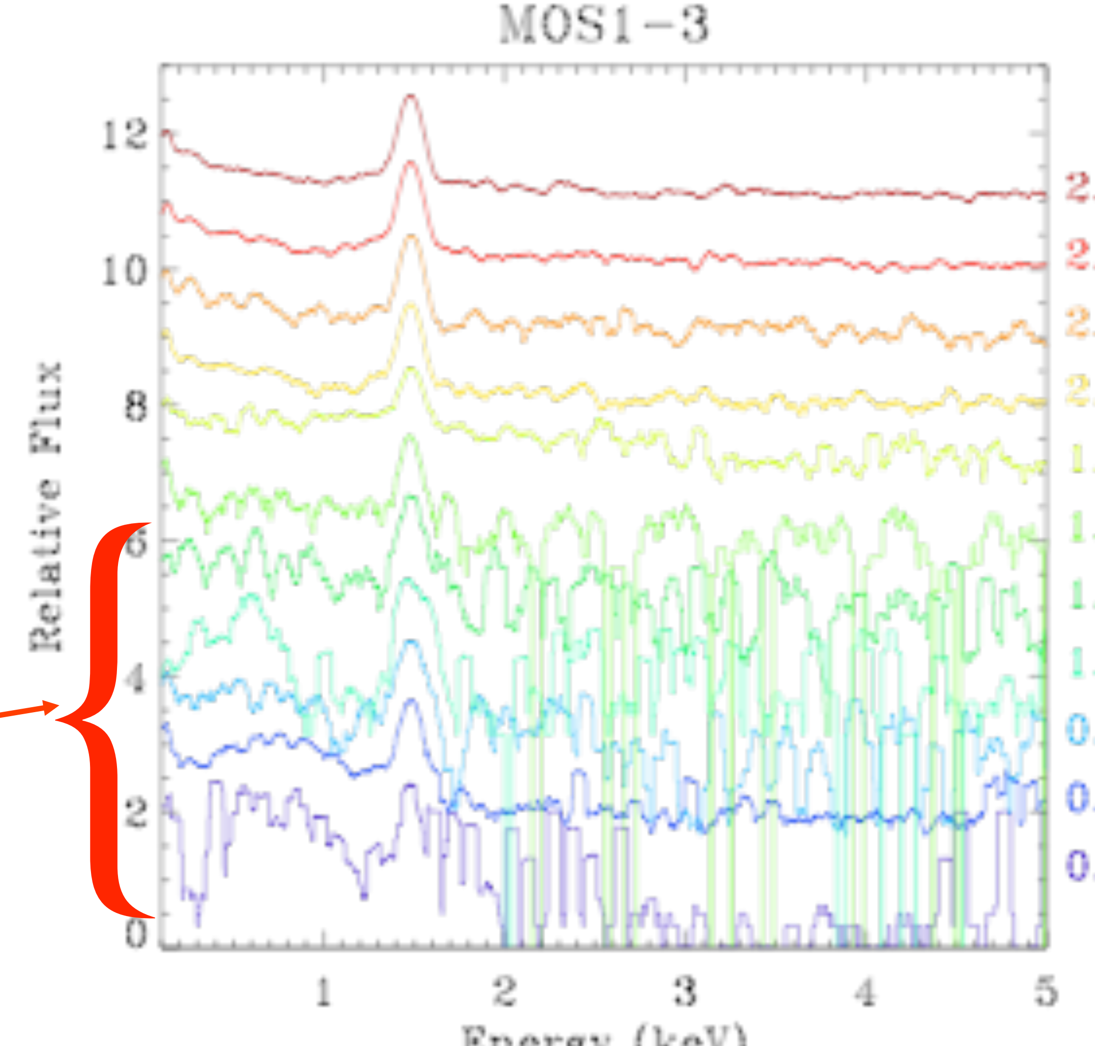
- Significant increase in statistics! Due to
  - Increase in number of public observations
  - Change in construction of MOS corner data sets

In 2008 flare removal done before extracting corners.
However - corner masks block soft proton flares.
Only filter out periods of high background in corners (typically entry to/exit from particle belts)

With More Statistics - Changes

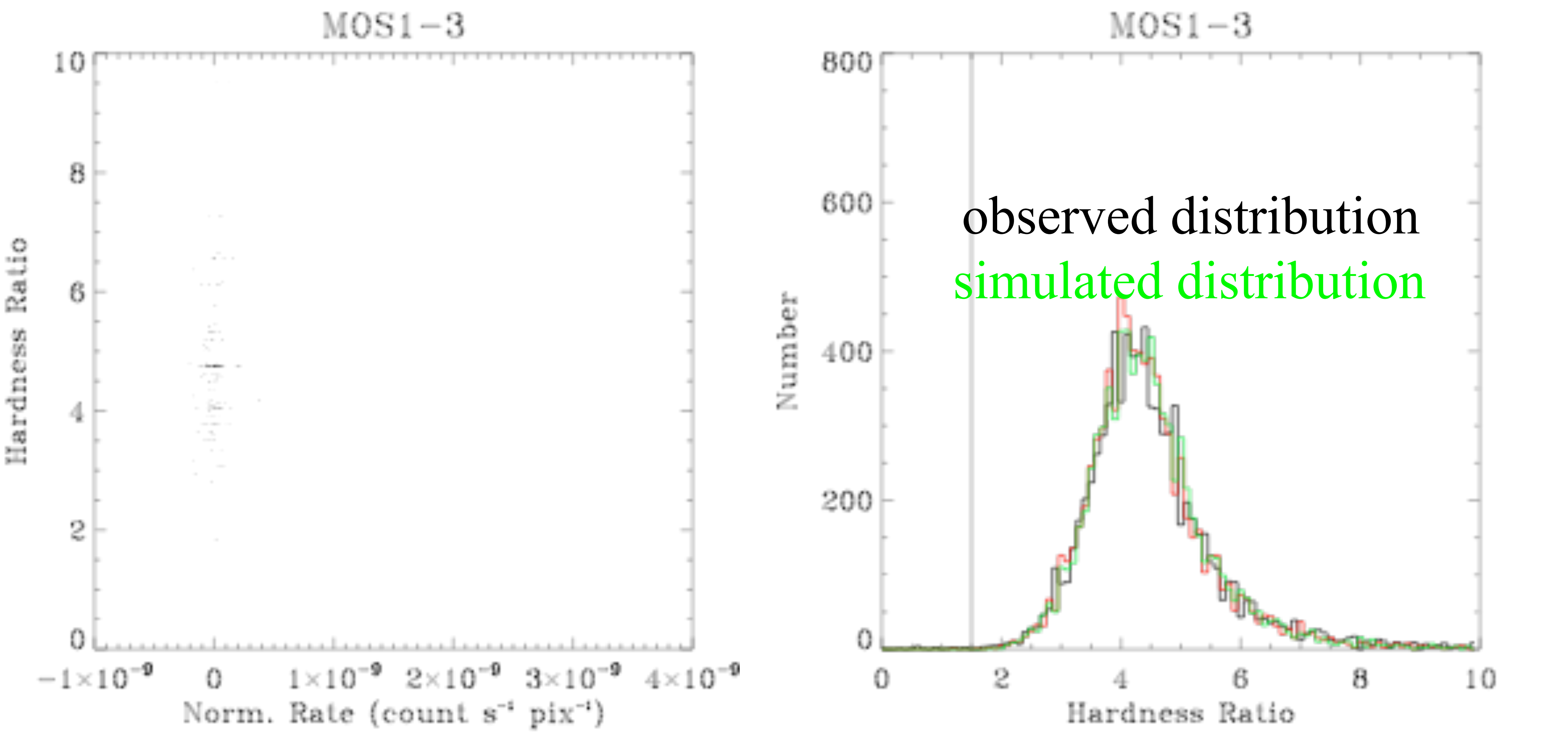
- With greater number of observations
  - Come greater number of extreme states observed
  - Even for chips w/o anomalous states
  - Had proposed ‘pseudo-anomalous’ label
- However, no clear “noise” feature
- Statistics may not be sufficient for good background





With More Statistics - Changes

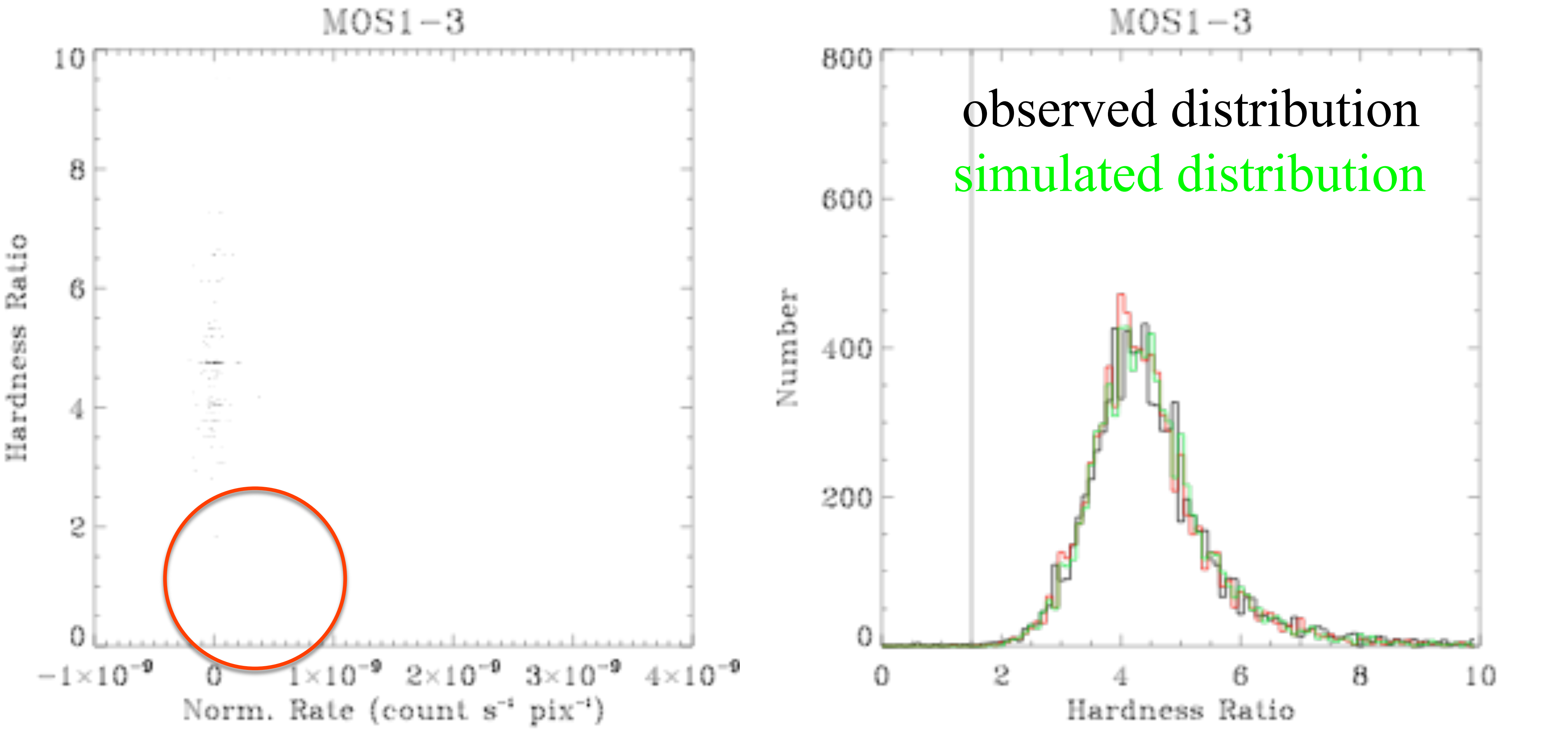
- Prompted to revisit issue of distribution of hardness ratio for chips with no anomalous states
  - Find that the distribution is consistent with a single mean spectrum and counting statistics for *most* chips
  - Non-anomalous states of 1-4, 1-5, 2-2, 2-5 not so clear



A success story – non-anomalous MOS1 CCD #3

With More Statistics - Changes

- For most chips a single mean corner spectrum is sufficient
  - Observations with extremely low hardness ratios may not be well modeled with a mean spectrum but
  - Most (non-anomalous) observations with very low hardness ratios are short - so a problem anyway

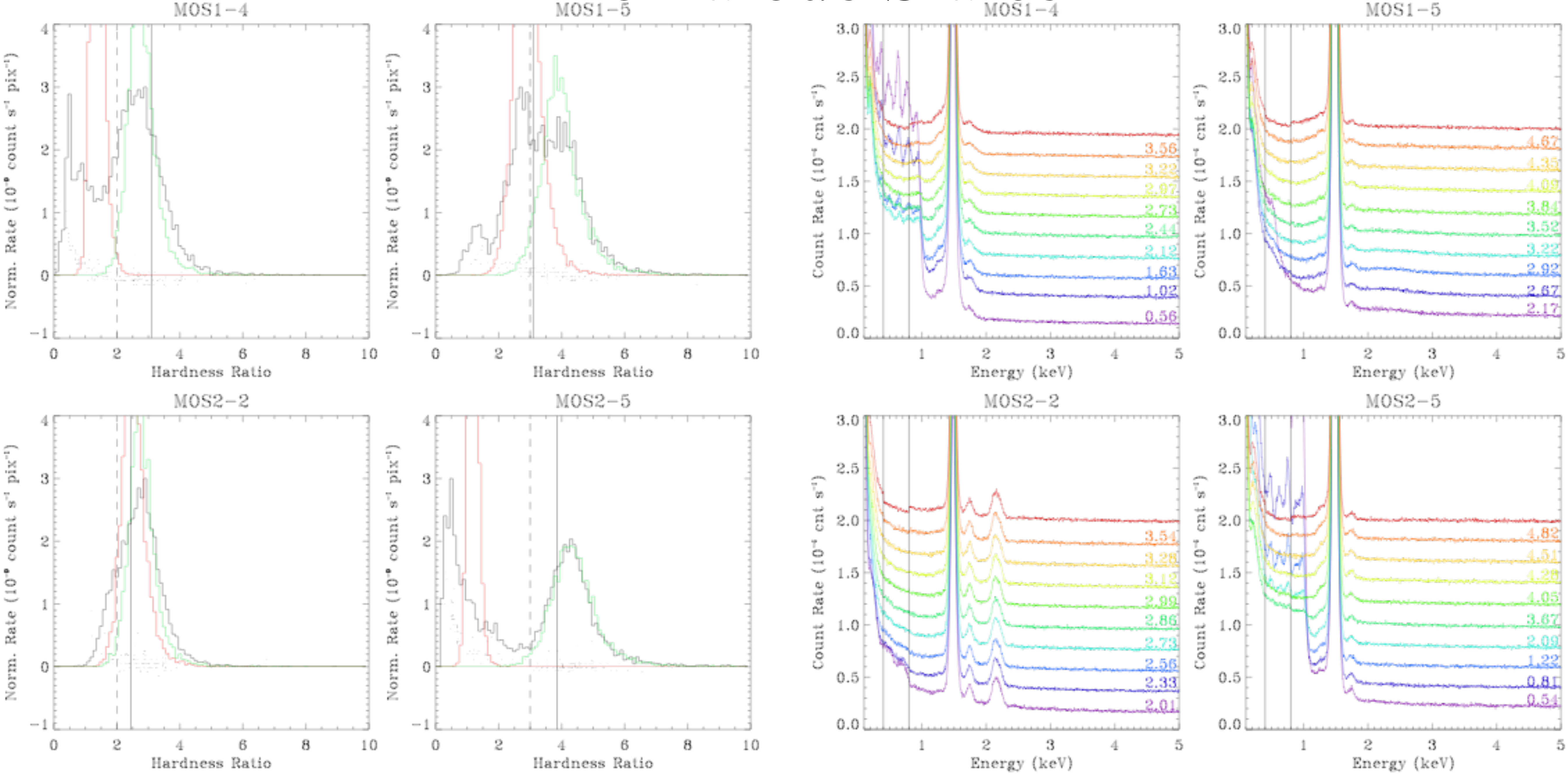


With More Statistics - Changes

- This is a significant change from ESAS V1, only possible
  - With the greater statistics
  - Better definitions, identification and removal of anomalous states

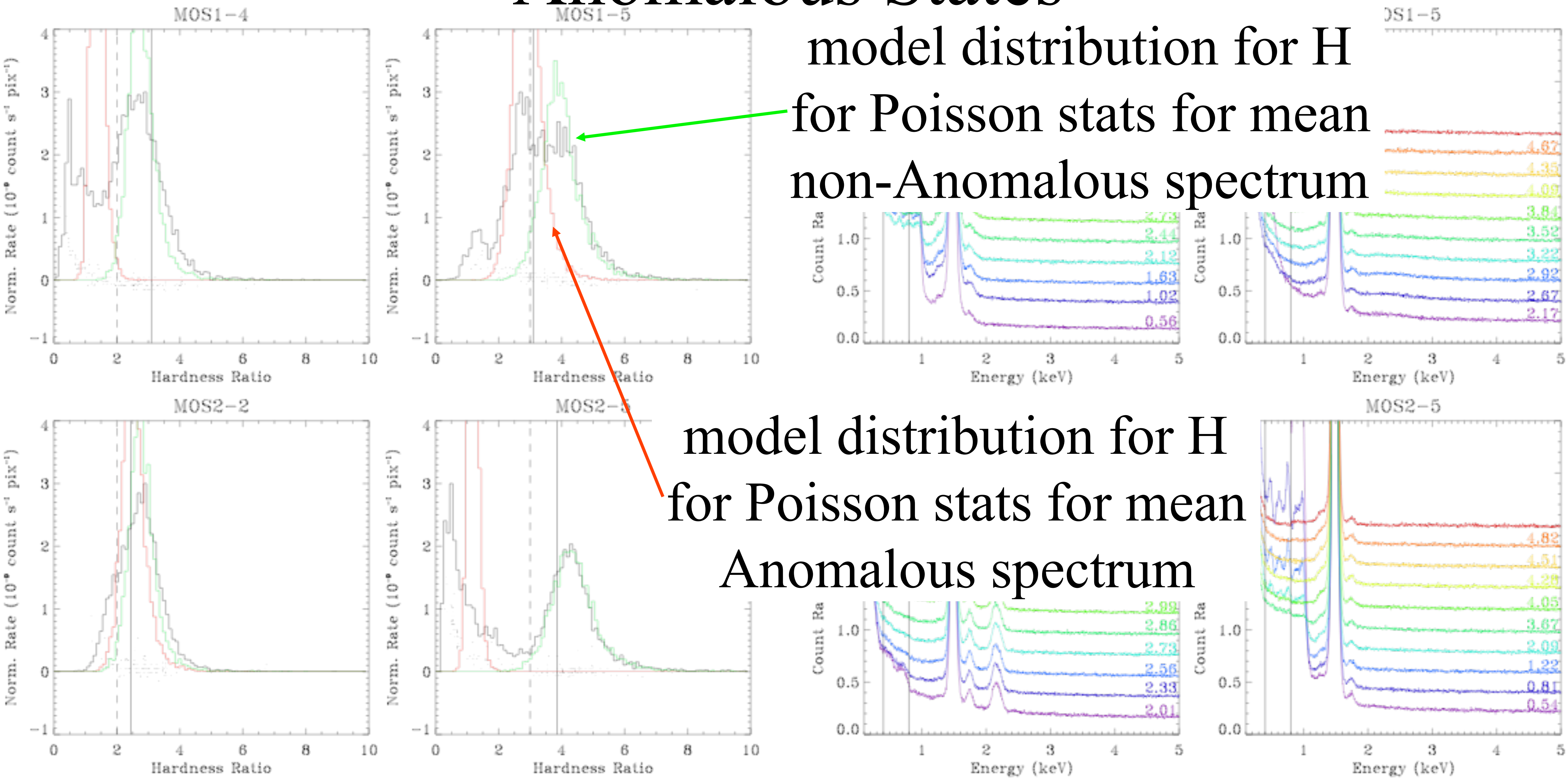
- However the method used in ESAS V1 still applicable to observations/chips in anomalous states but…
  - Do we know enough about the anomalous states?
    - Maybe
  - Do we have sufficient statistics to implement?
    - Maybe

Anomalous States



Comparison of hardness ratio/rate diagrams and mean spectra as a function of hardness ratio show no clear boundary between anomalous and non-anomalous states.

Anomalous States

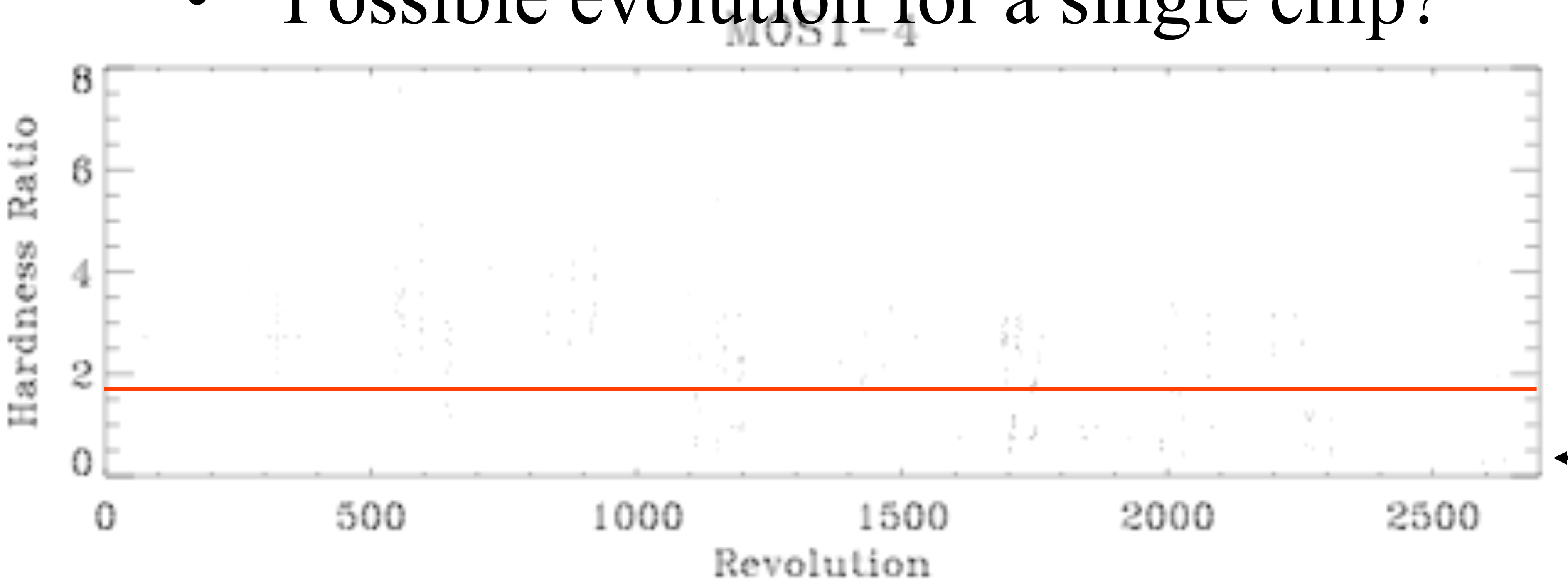


The distribution of the hardness ratio H is consistent with a mean non-anomalous spectrum given Poisson statistics… but the distribution of H is *not* consistent with a single mean anomalous spectrum

Anomalous State Questions

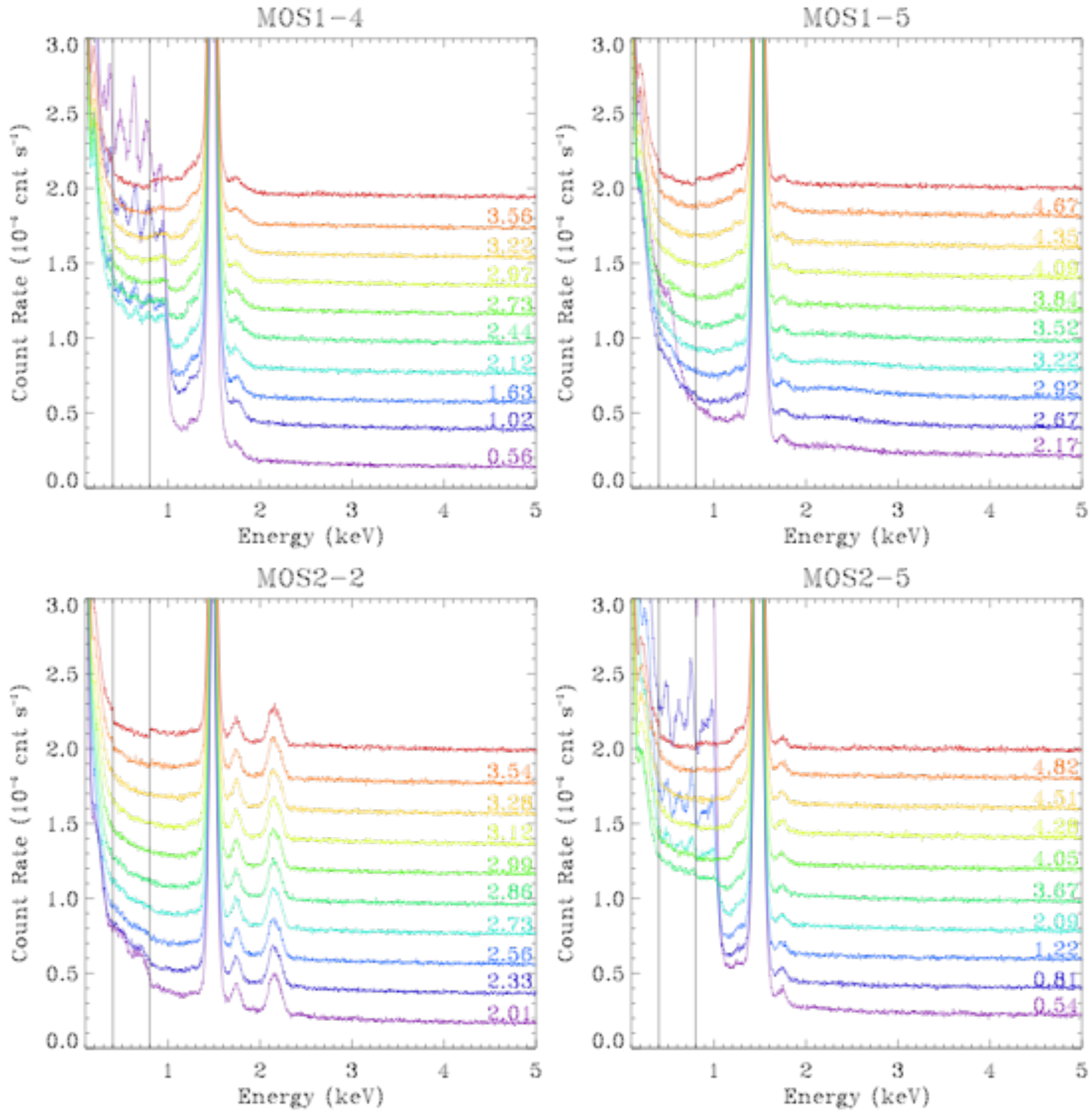
- At a given value of H are some observations in anomalous states while others are not?
  - Seemingly not
- What governs the strength of the noise feature in the anomalous states?

- Do anomalous states evolve?
  - Have not seen anomalous states in chips other than the four identified in K&S 2008
  - Possible evolution for a single chip?



Change in mean H with time?

Anomalous States



- Structures in the noise features do not change significantly with hardness ratio
- Thus may be able to construct backgrounds for anomalous states *where there are sufficient data.*

So What About the pn?

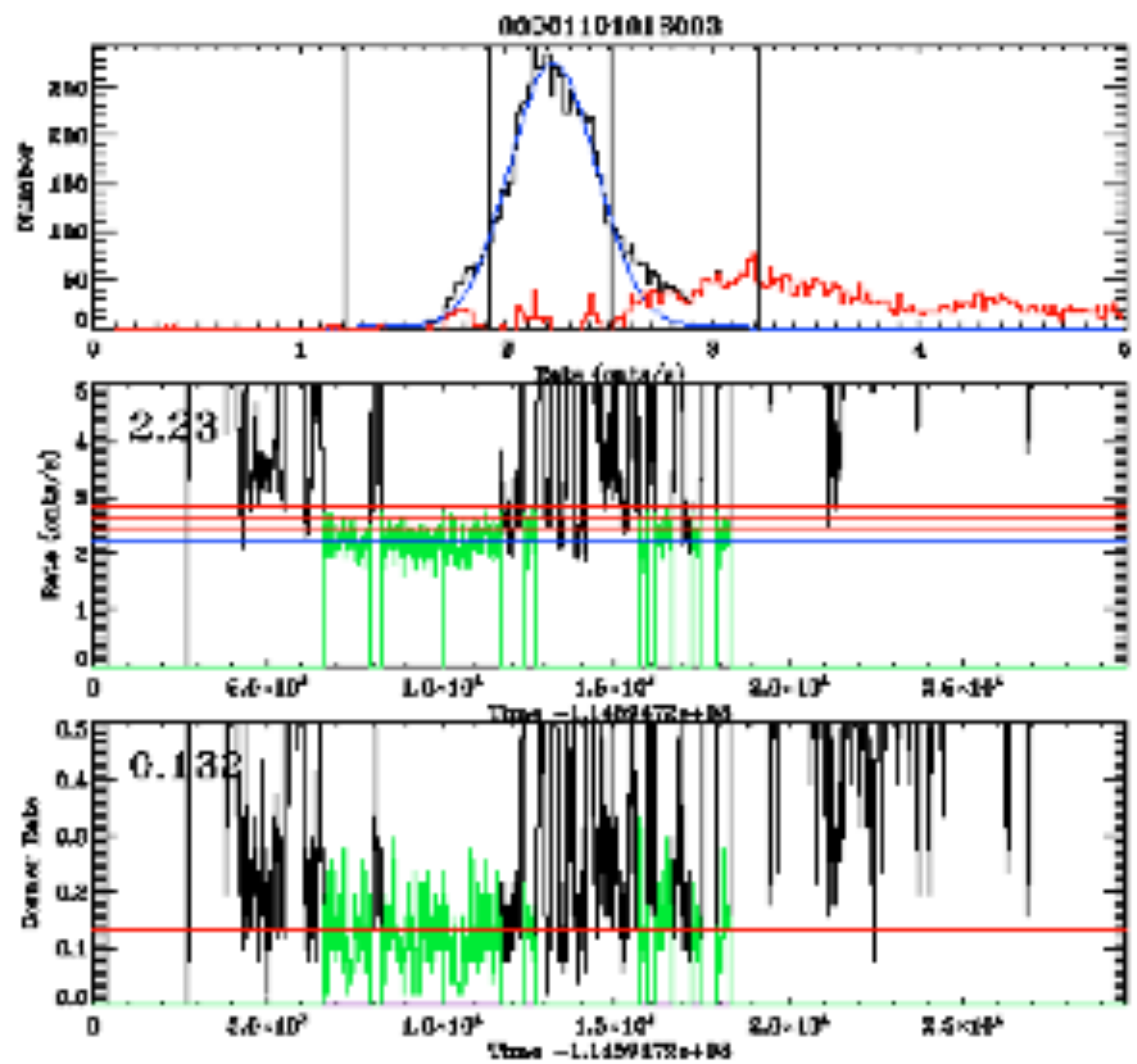
pn Issues

- Given the longer read time of the pn, OOT events a more significant problem
  - Corner data will be strongly contaminated by the spectrum within the FOV
    - Thus corner data can be strongly contaminated by soft proton flares

- Therefore need to do flare cleaning before corner extraction
  - Flare removal a very hands-on process
  - Prospect of handling 12000 observations daunting

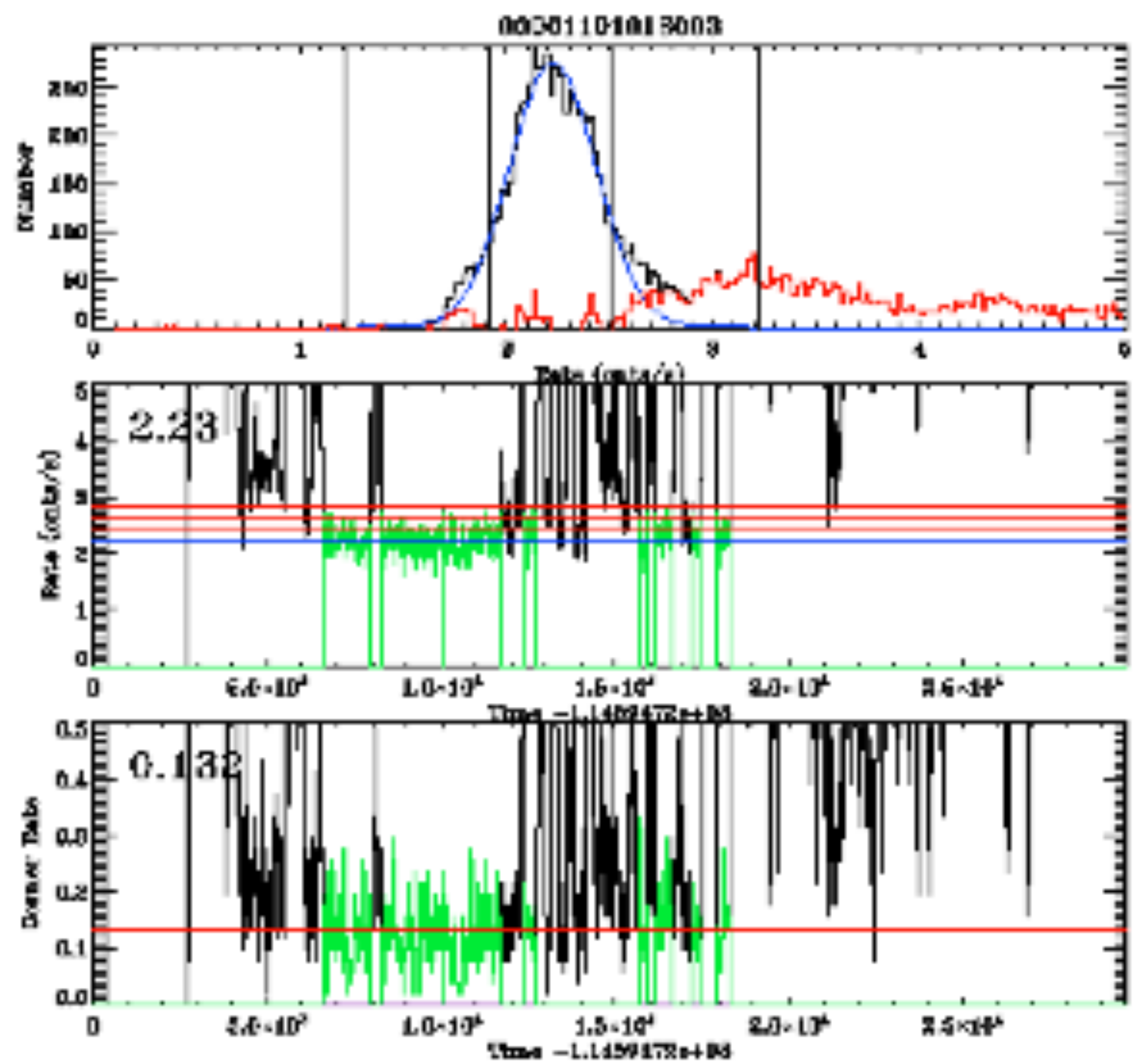
Flare Fitting Issues

- For region of interest, form light-curve in 2.5-8.5 keV
- Create histogram of values in light-curve
- Fit Gaussian to peak
- Remove time steps with values >3σ from mean
- For strong flaring - fit may fail in a number of ways



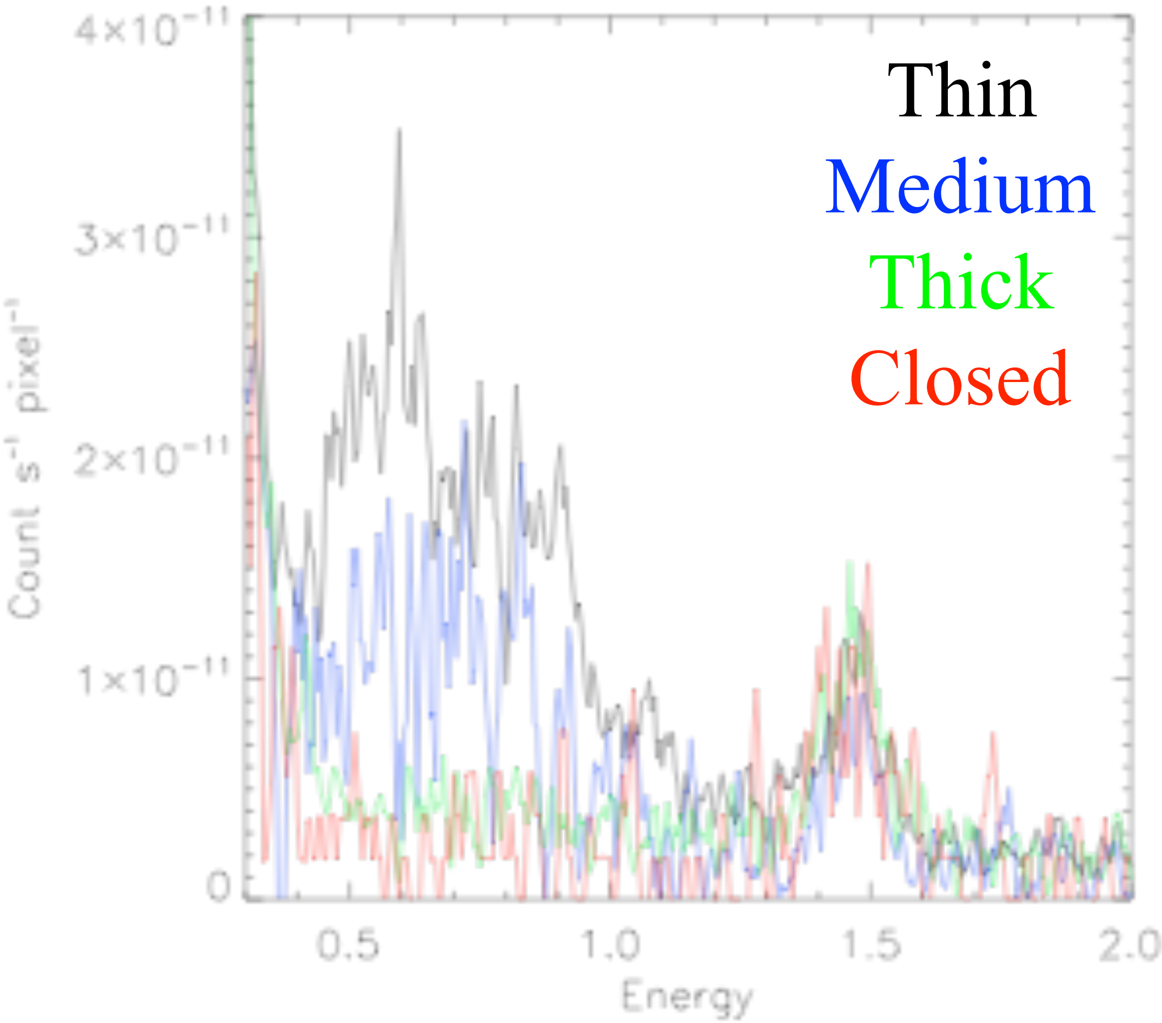
Flare Fitting Issues

- Using a training set of ~2000 observations where the fits were evaluated by hand
- Built a new fitting algorithm and residual measures to allow completely automated evaluation of the goodness of fit.
- Of 10216 observations only 3773 had good flare filtering.



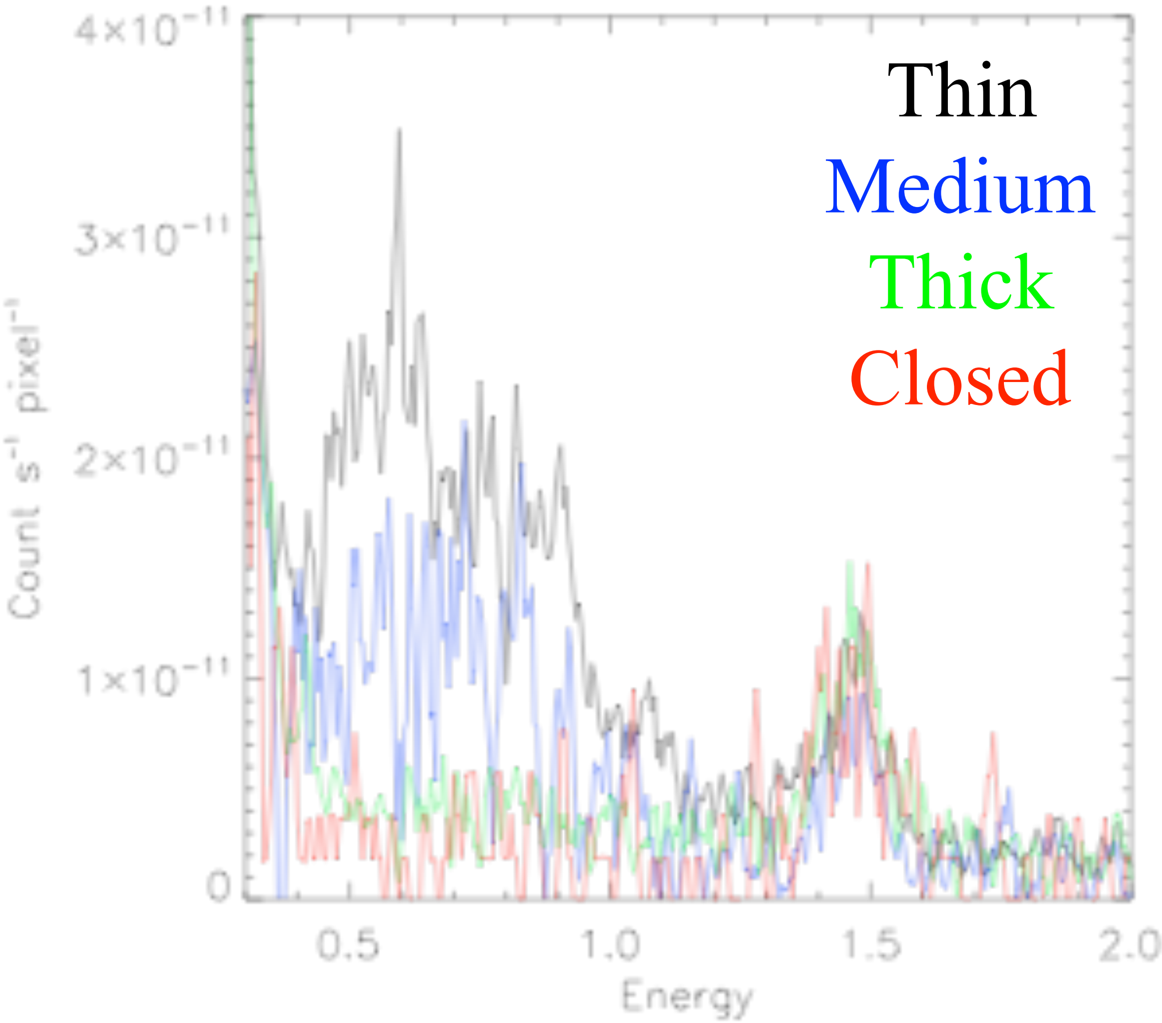
pn Issues

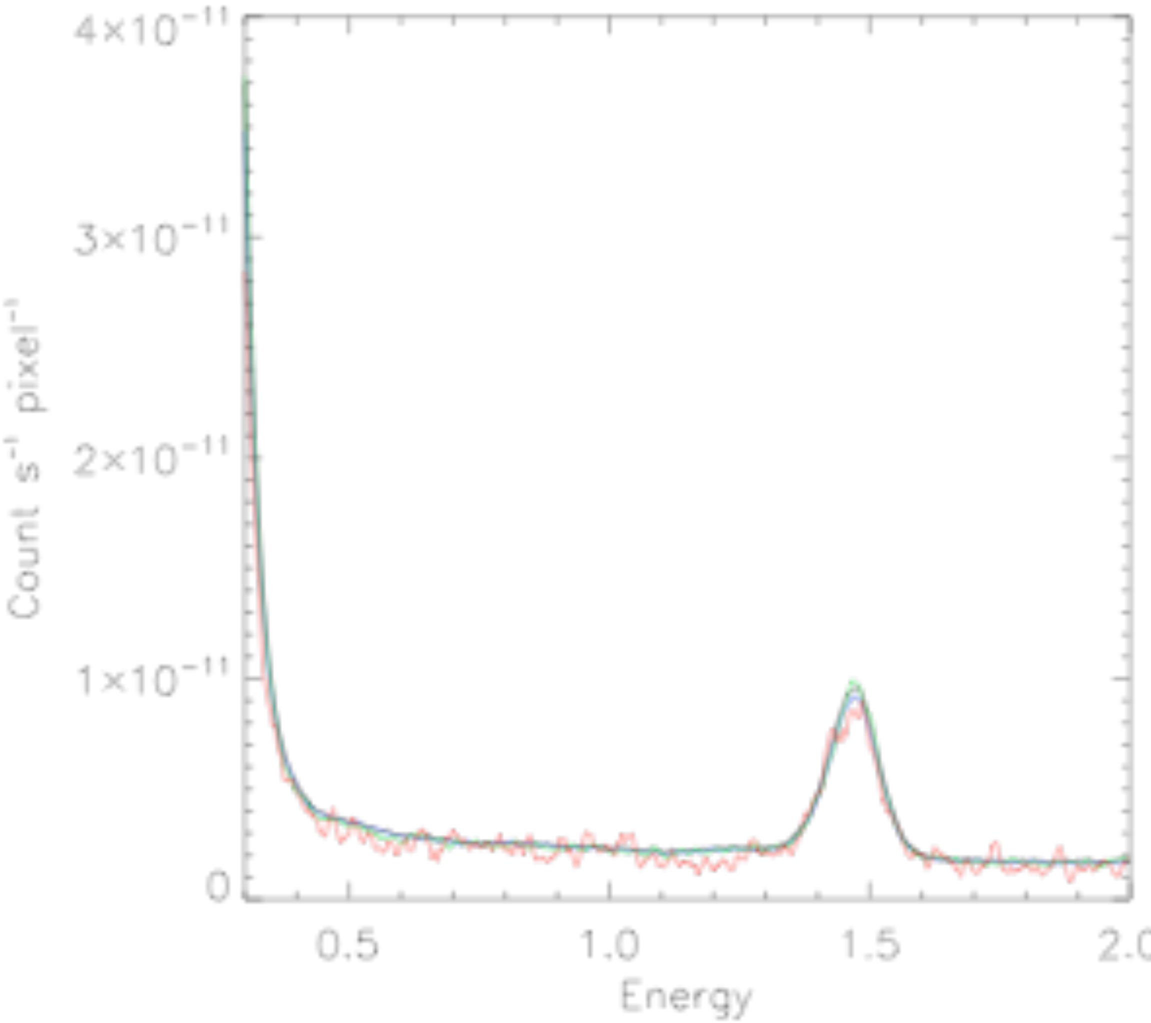
- To test goodness of flare filtering for corner data created mean corner spectrum for each FOV filter
- Here,
  - corner ≡ corner data - scaled corner data from randomized data
- If flare filtering good, expect all spectra to be the same, but that was not the result



pn Issues

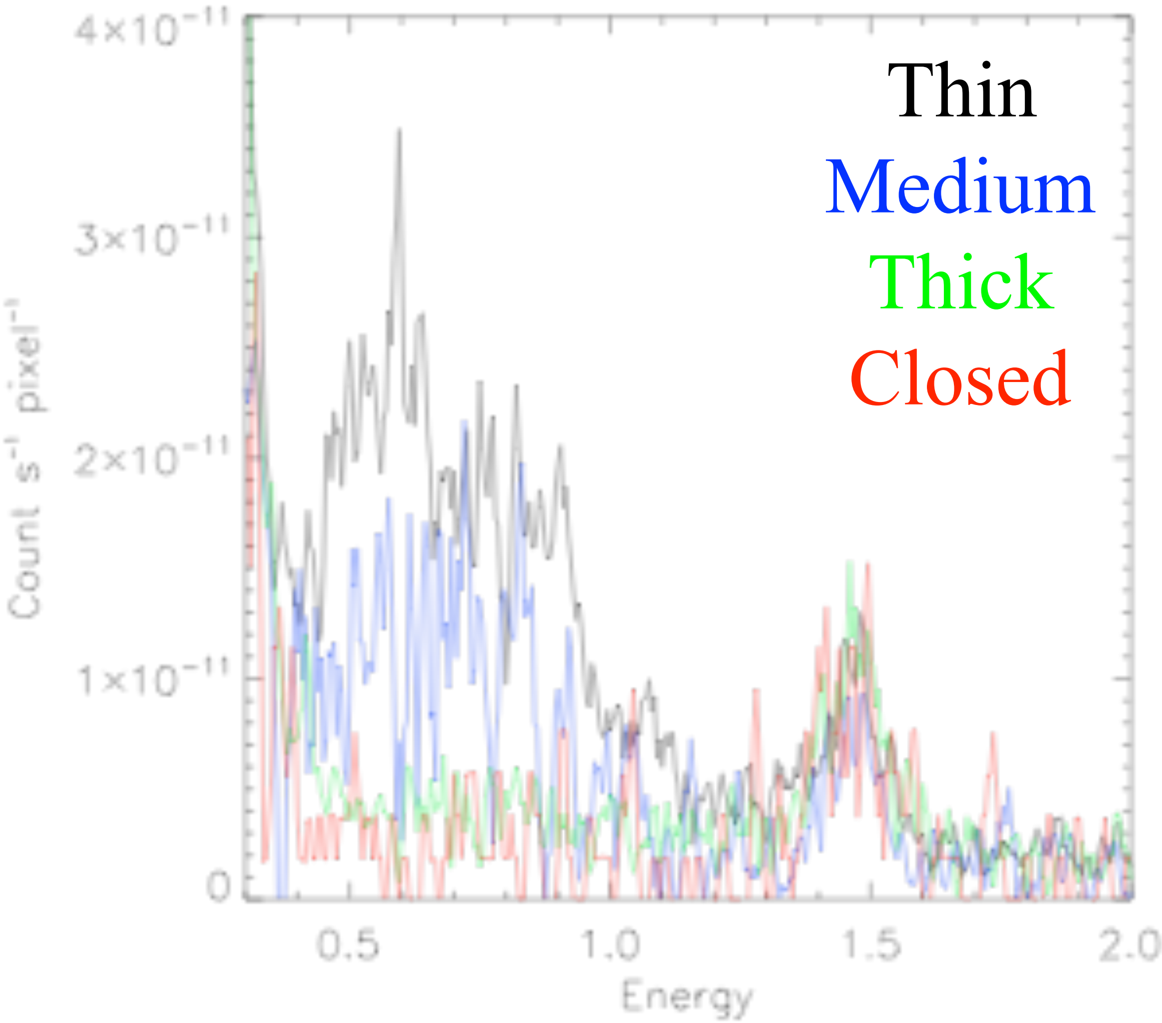
- Source of variation with filter:
  - Is it due to real problems with flare removal?
  - Is it due to problem with scaling and removing OOT?

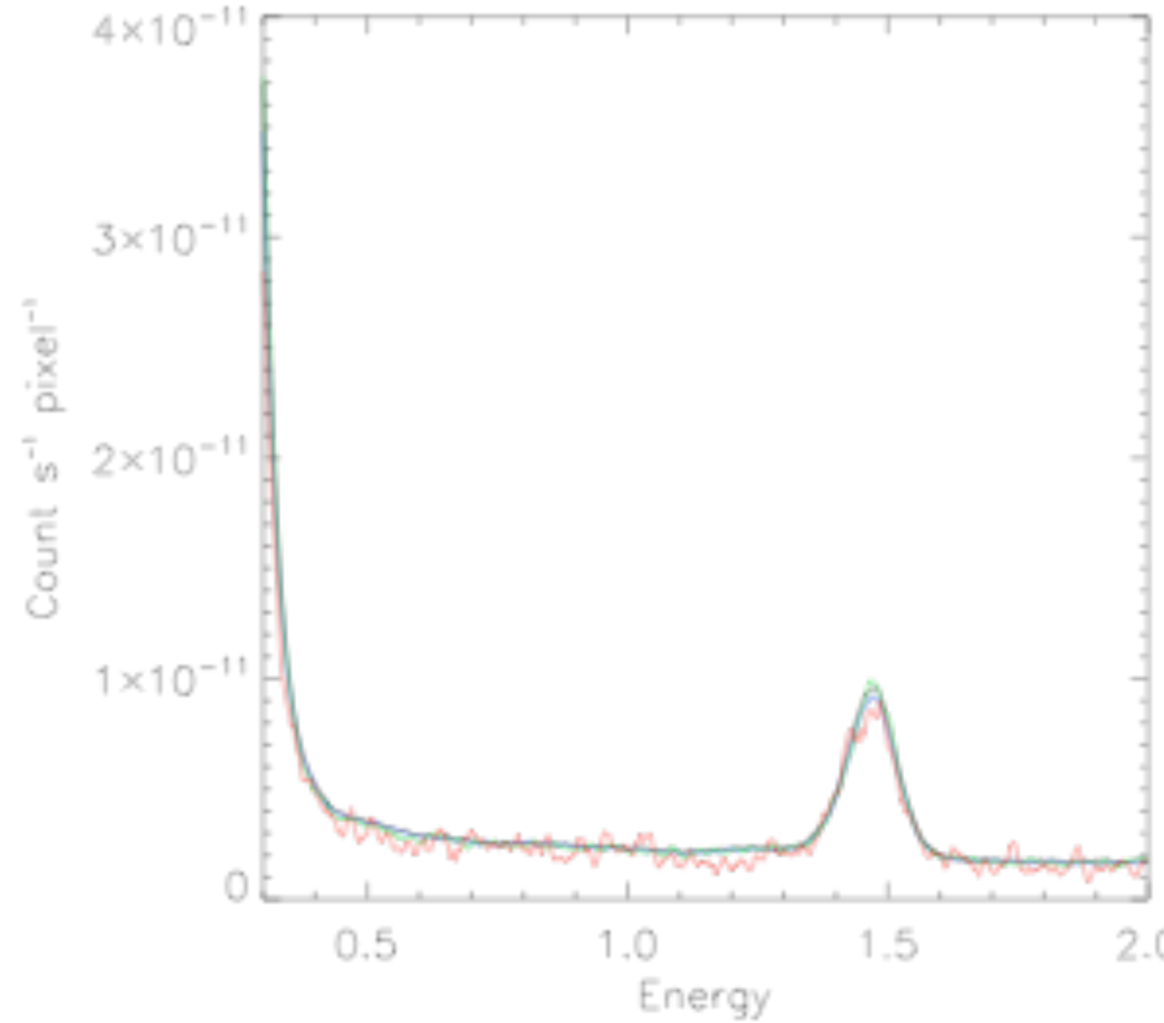




pn Issues

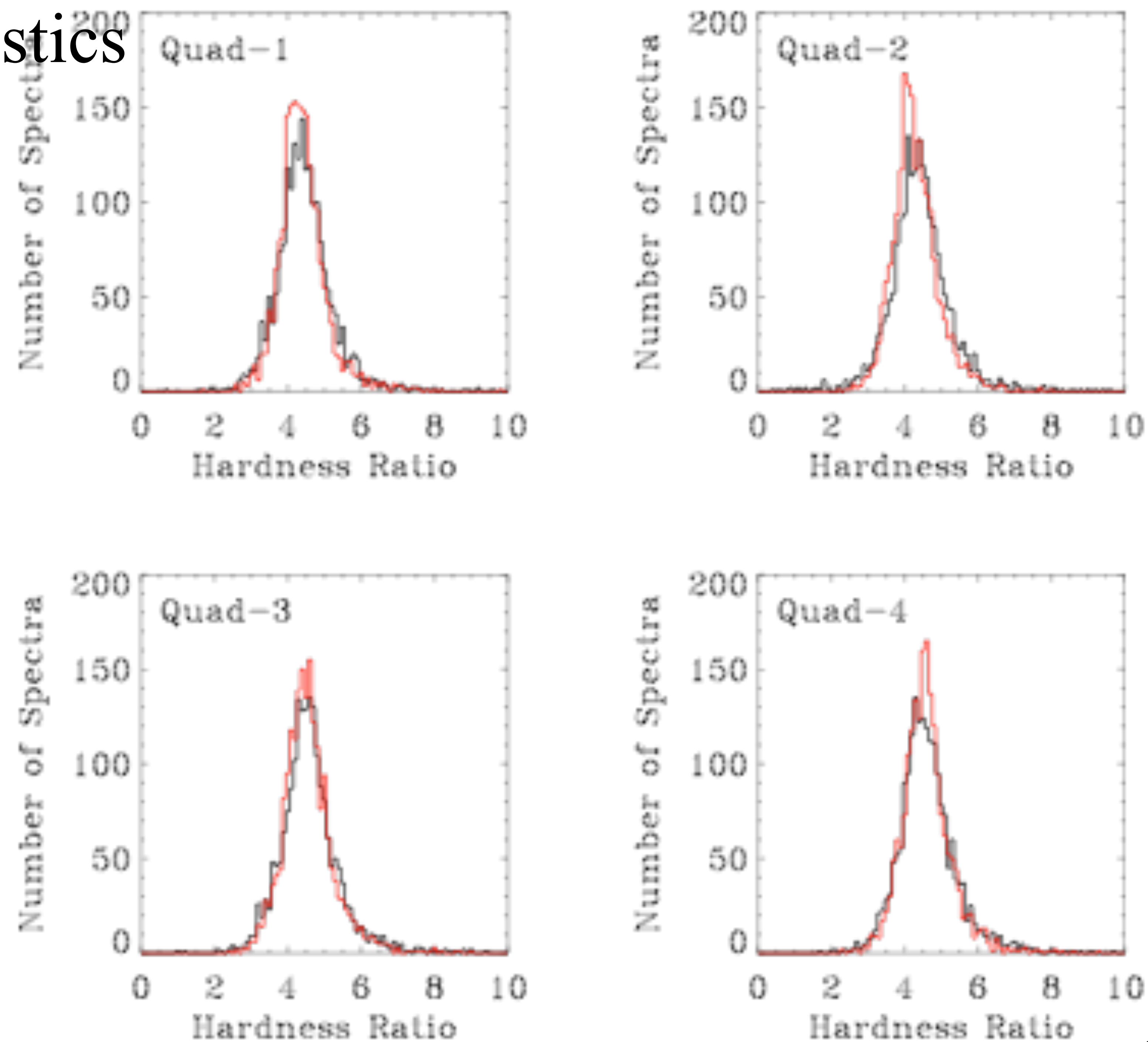
- Source of problem unresolved – however
  - Sort the spectra by hardness ratio and remove all that are more than 3σ different from spectra with same hardness resolves issue (slight over-simplification)
  - Only 1966 observations remain





pn Issues

- Consider the distribution of the hardness ratio of the remaining corner spectra (done quadrant-by-quadrant) -
- The distributions are consistent with a mean spectrum and counting statistics



The observed distribution of hardness ratios is nearly indistinguishable from the simulated distribution.

Summary

- Newest reprocessing increases the amount of data for study of the background by >6X
- Significant changes to the way ESAS works
  - For non-anomalous MOS chips and the pn use the mean corner spectrum
  - For anomalous states use the ESAS v1 augmentation scheme of finding corner spectra with the same spectra shape as that of the observation of interest

  - Still significant doubts about anomalous state spectra and non-anomalous state spectra with extreme values of the hardness ratio
  - Will construct backgrounds for those chips but
  - By default will produce warning and will not include in the total background spectrum

Future?

Reconsider the construction of FWC FOV/FWC corner part of the equation

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

in order to find ways of increasing the S/N

Spectral model of the QPB continuum and lines for use in simultaneous fits of background and source.

And, as always, periodic updates of corner spectra databases and anomalous state definitions