An EPIC Background

S.L.Snowden & K.D.Kuntz

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

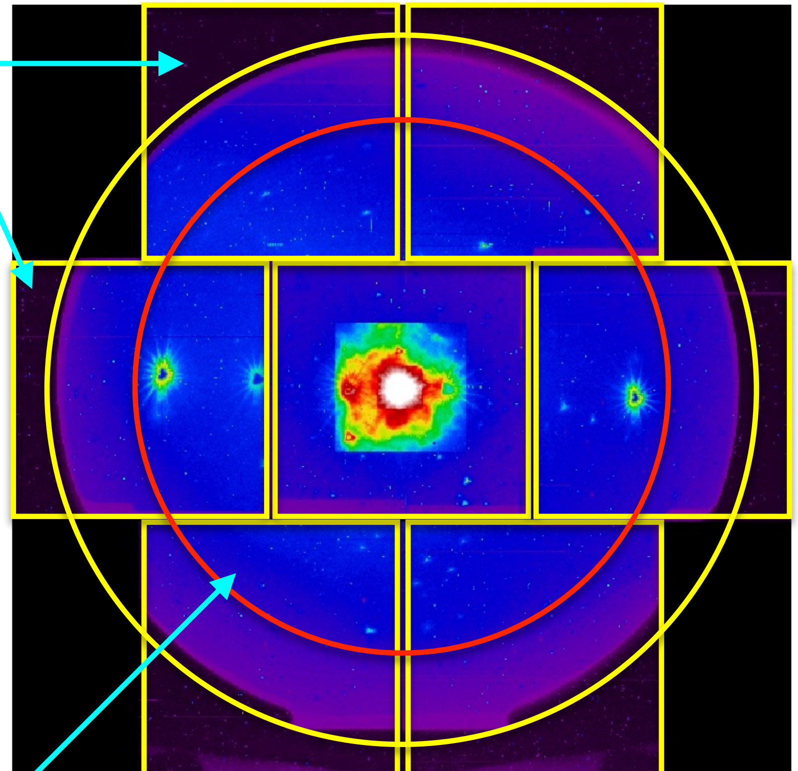
Now:
- new understanding of QPB
- significantly improved statistics
- better identification of anomalous states
- builds backgrounds for some anomalous state
- new method for non-anomalous states

Outline

1. Review the understanding of the QPB from ESAS v1
2. Describe the complex method of creating the spectrum
3. Explain why it is complicated
   - spatial and temporal variation of the background
   - anomalous states
4.

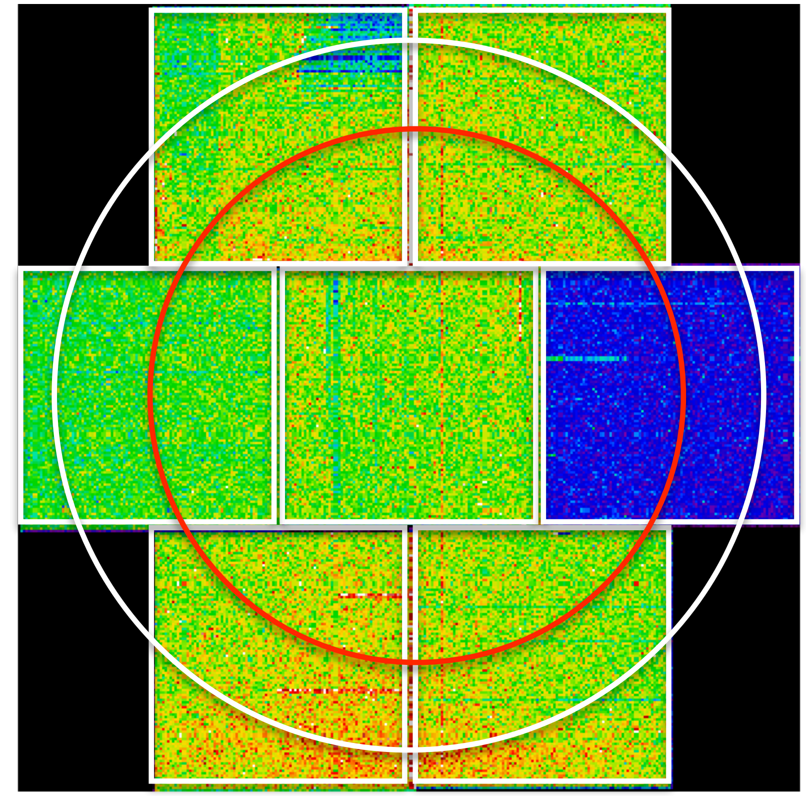
Method

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 X.XXe-XX /pixel/energy bin/ks

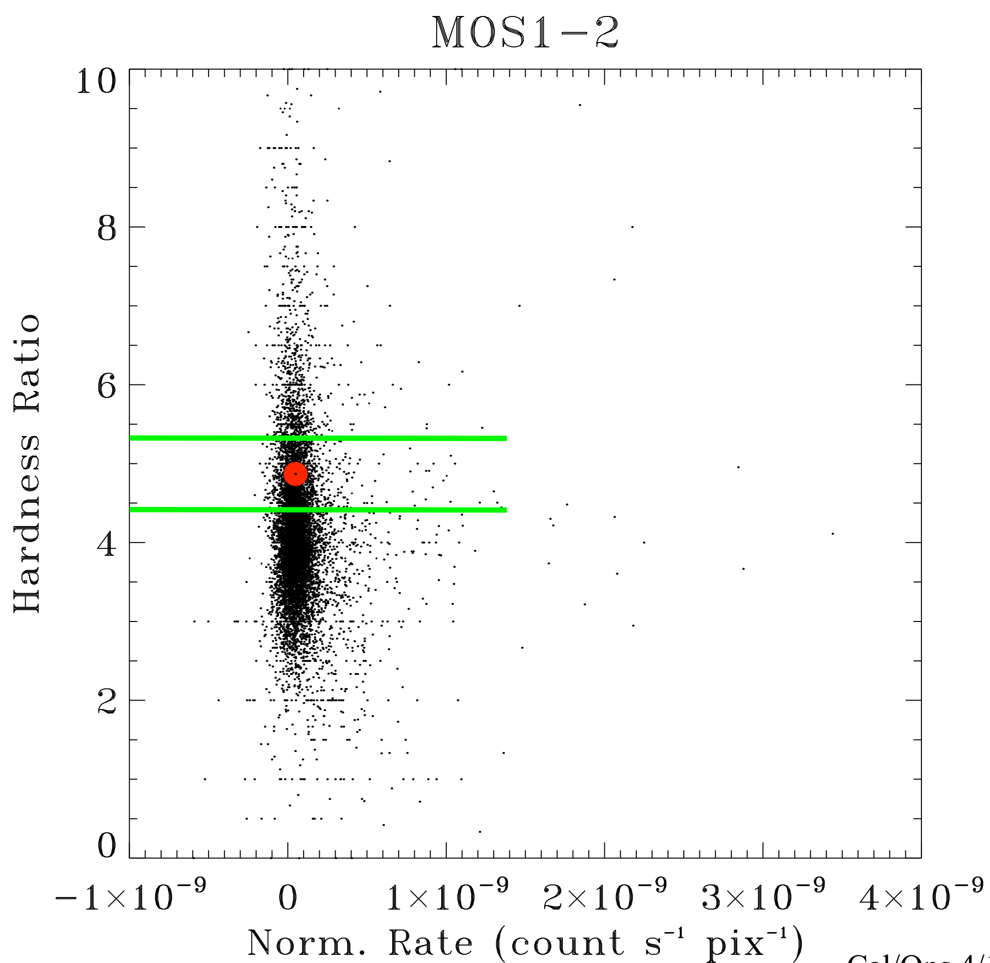
Method

Corner data from an individual observation has v. poor stats!
However -

- can 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

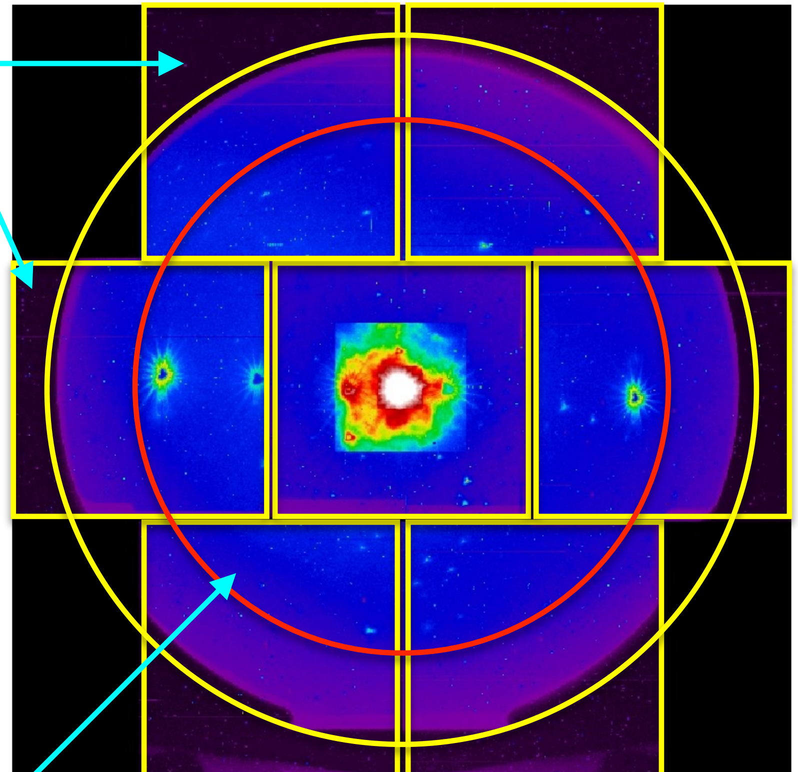
Then for any given observation

- 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!



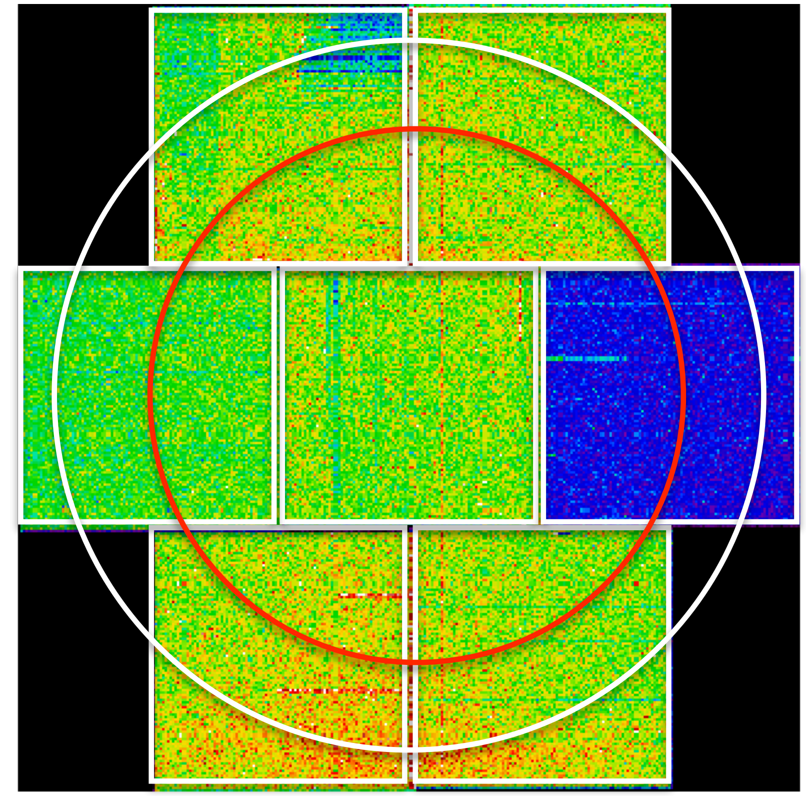
Method

Corners



FOV of interest

Observation



Filter-Wheel-Closed Data

really *good* stats

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

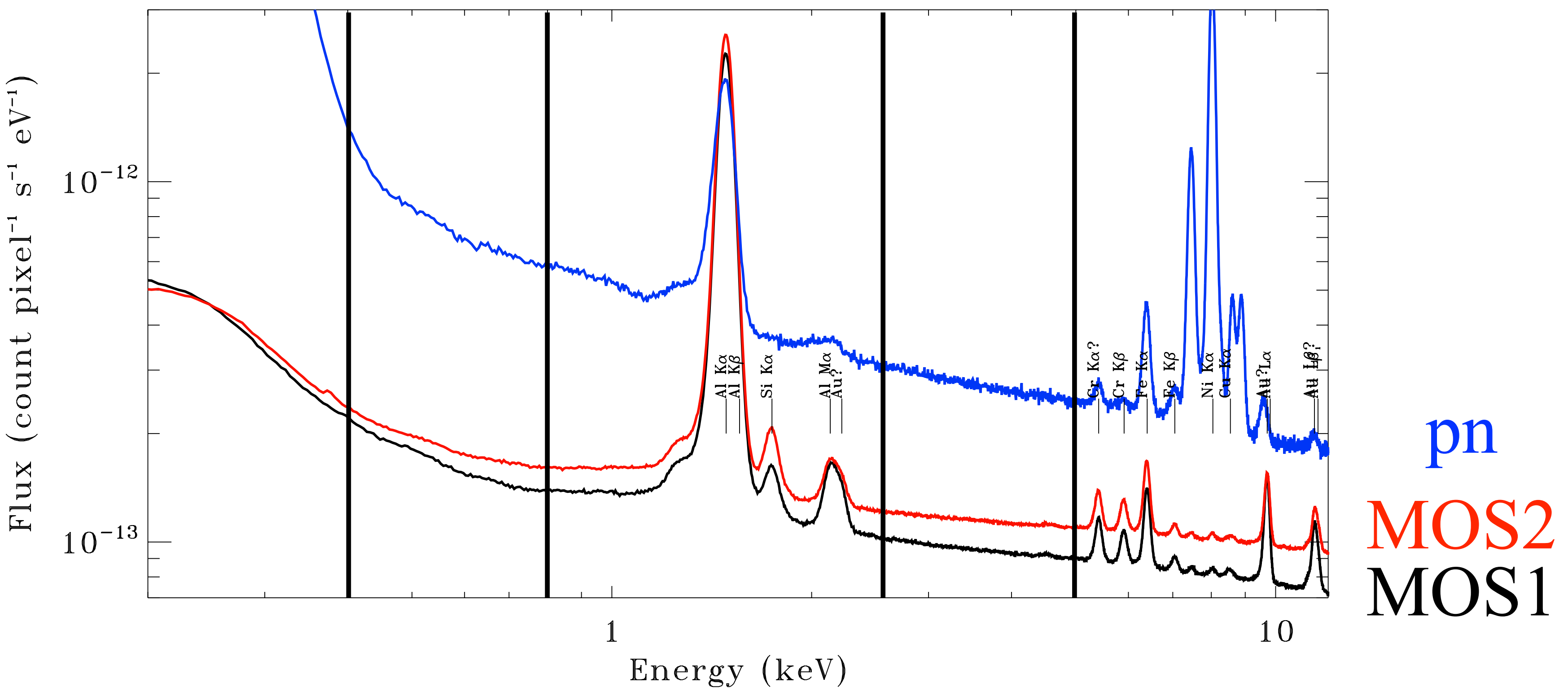
poor stats

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

Why so Complicated?

Why not just one background spectrum?

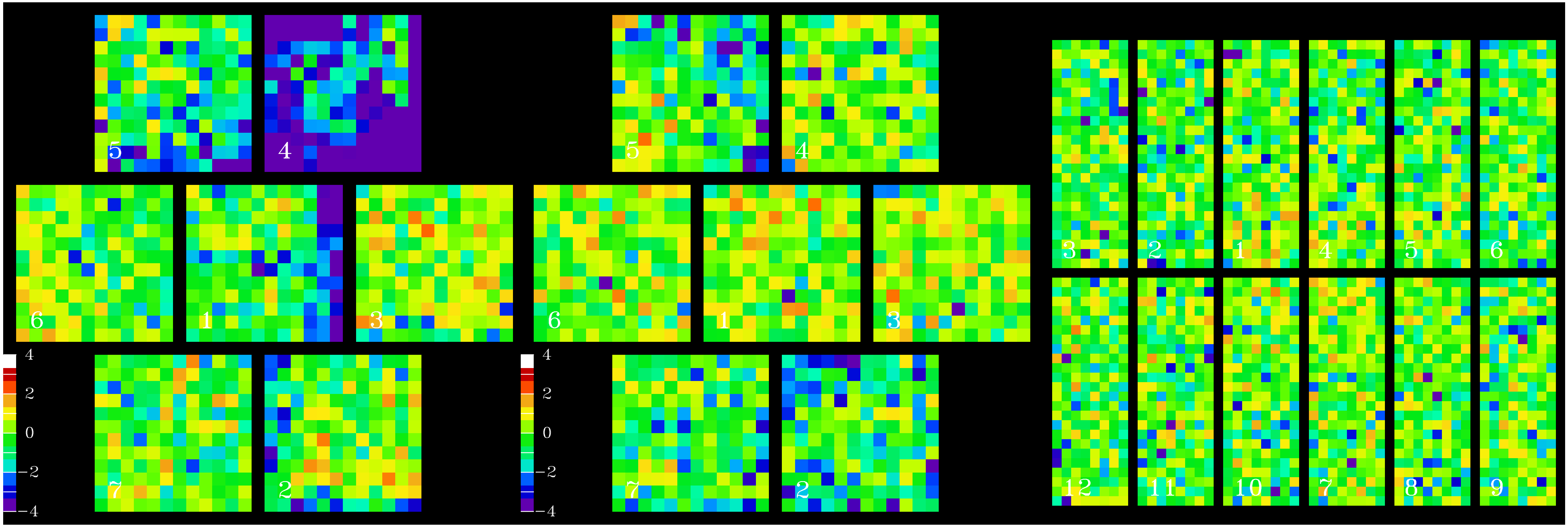
Mean Quiescent Particle Background



Spectra composed of lines and continuum
- lines sensitive to gain variation so should be fit in the observed spectrum rather than subtracted (not ESAS)
- continuum can be characterized by total count rate (R) and the (2.5-5.0 keV)/(0.4-0.8 keV) hardness ratio (H)

The QPB Varies

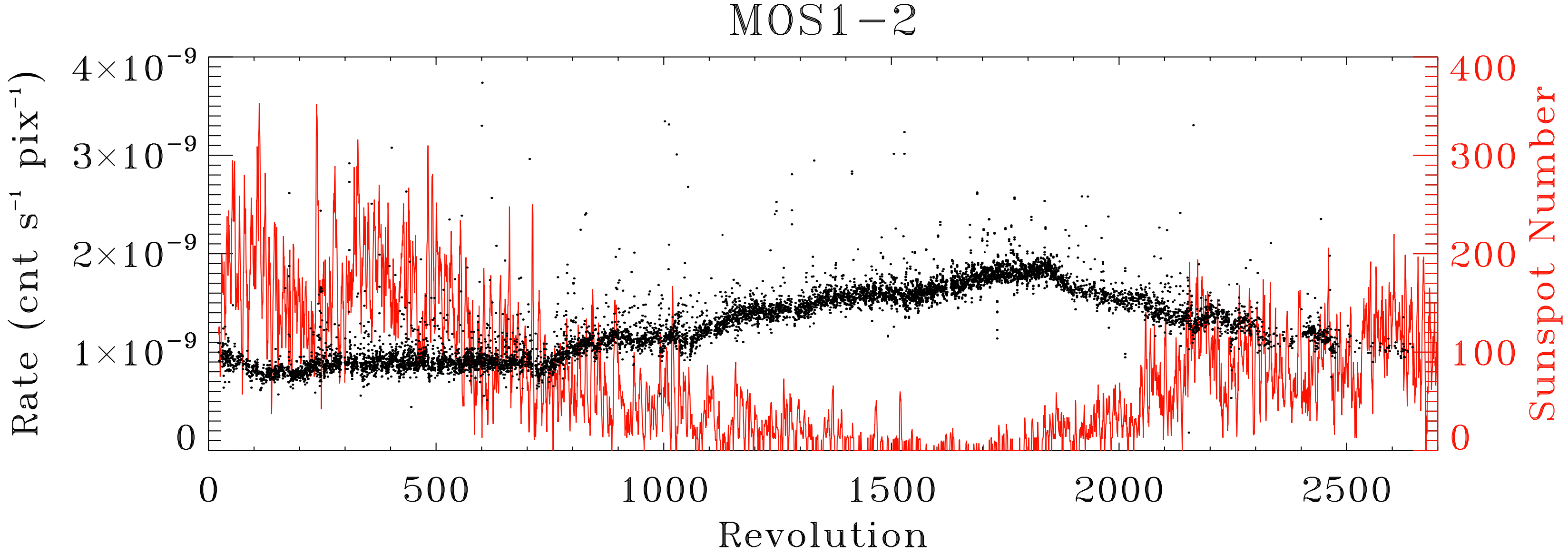
Filter-wheel closed (FWC) "continuum" data shows some spatial variation in count-rate and significant variation in hardness ratio (MOS1&MOS2)



The QPB Varies

Corner data shows

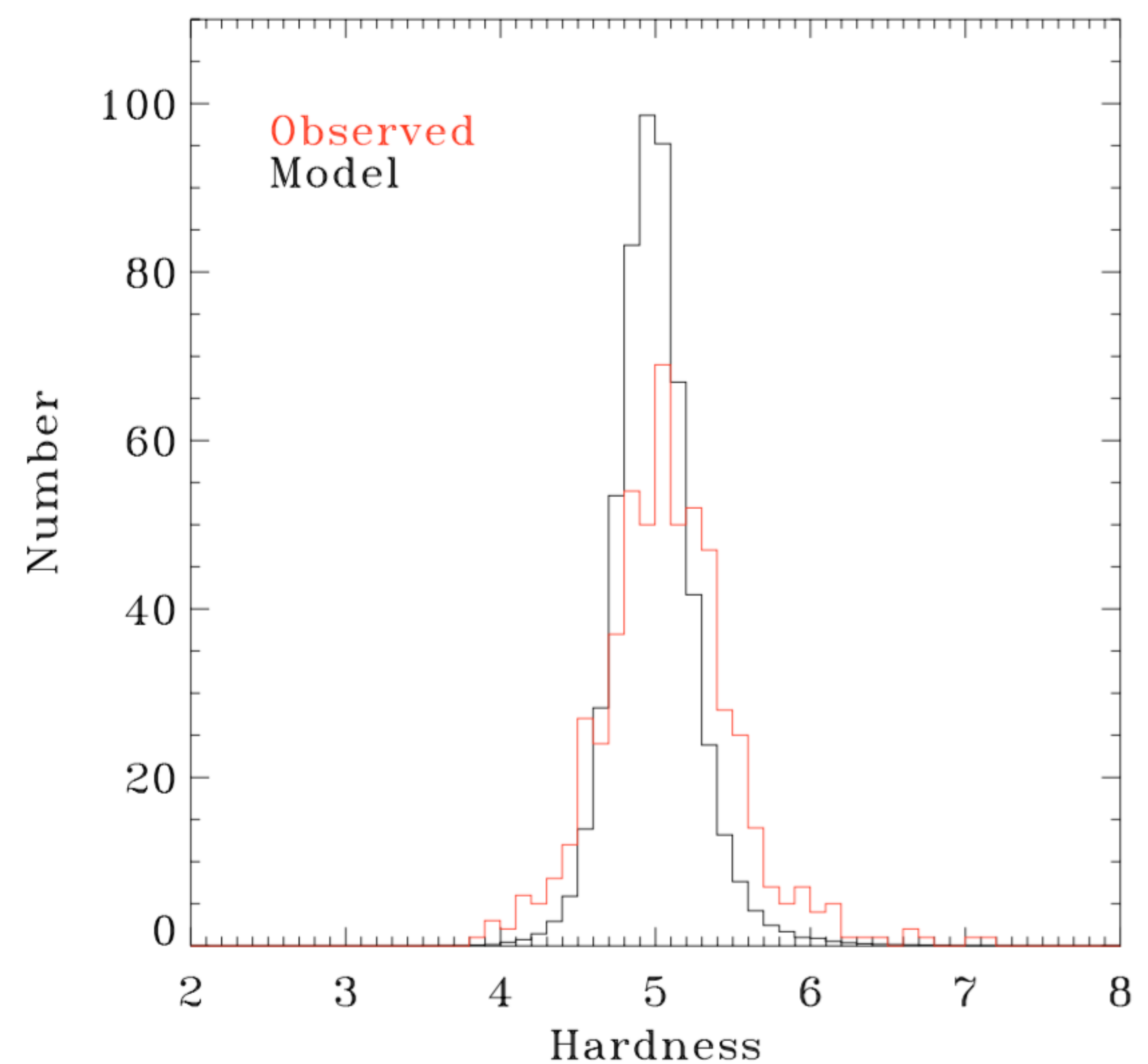
- long-term temporal variation (due to solar cycle)



- temporal variation in hardness ratio
  - anomalous states in chips 1-4, 1-5, 2-2, & 2-5
  - (as of 2008) in non-anomalous chips

The QPB Varies

Corner data shows
- 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) in non-anomalous chips
    - e.g., distribution of measured hardness ratio was broader than expected from Poisson statistics after anomalous states had been removed
    - caveat: our understanding of this last point has changed!



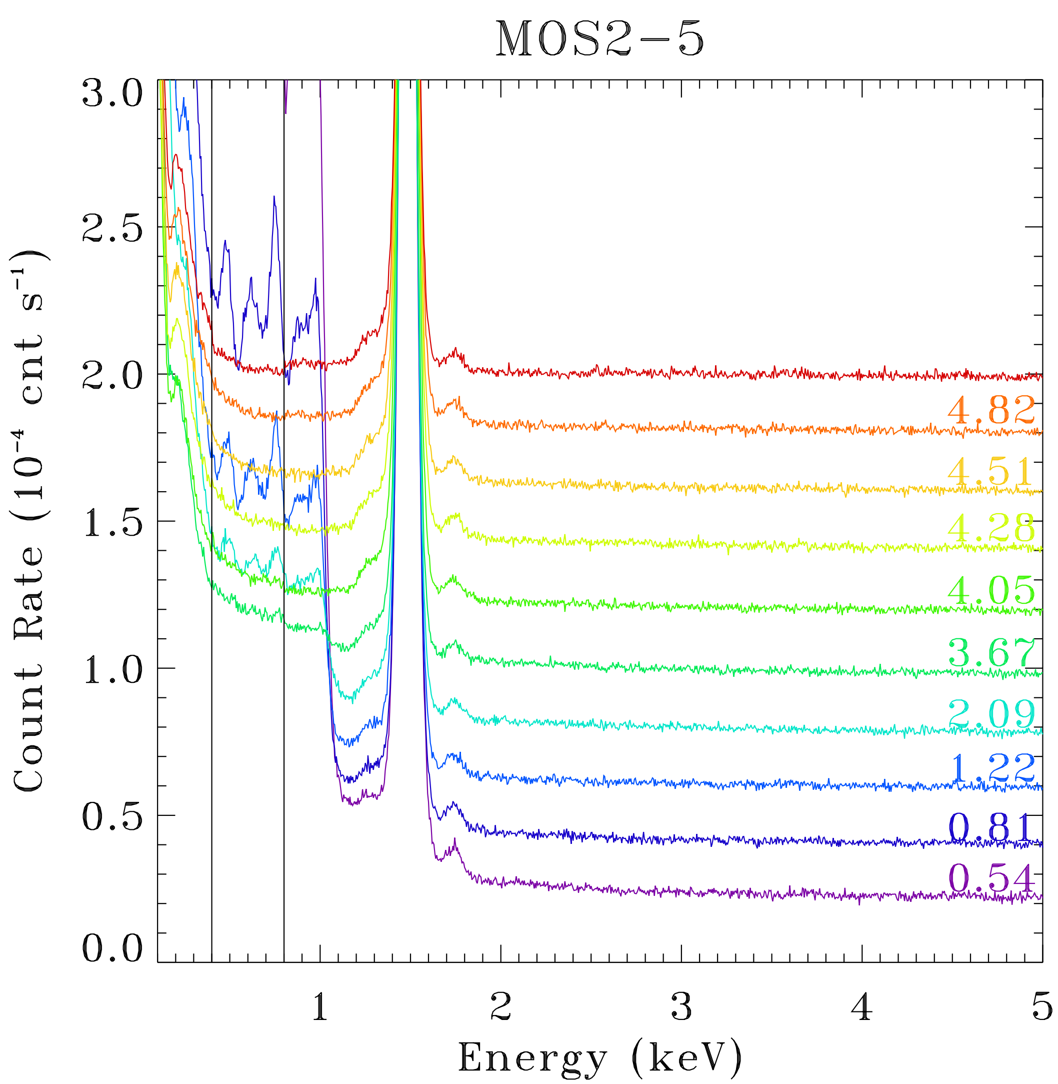
Anomalous States

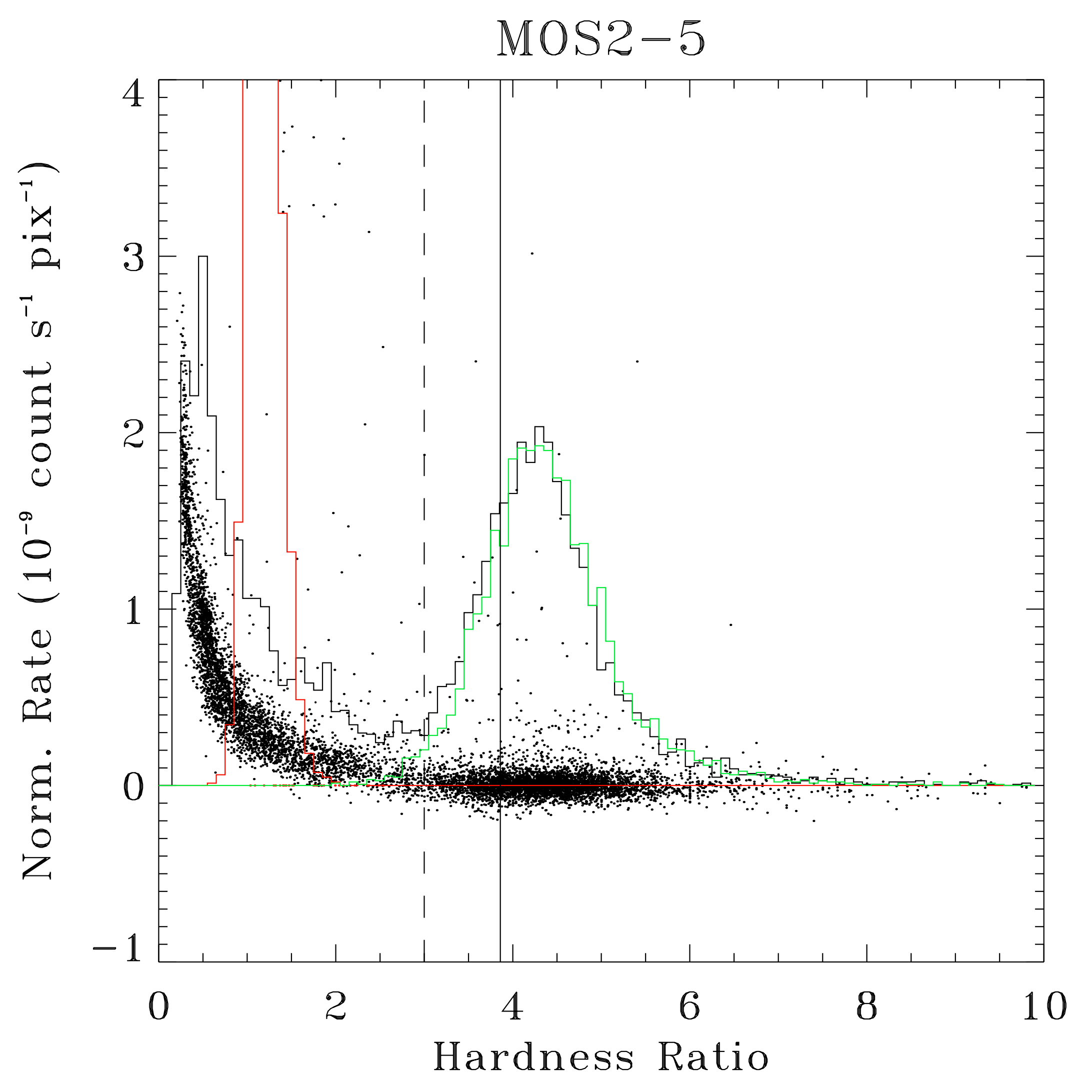
Some chips show an intermittent low-energy “noise” feature

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?

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

First version described in Kuntz & Snowden (2008)
- irregular updates every several years
- finishing up(?) last(?) significant change (2017)

Perennial ESAS Tasks

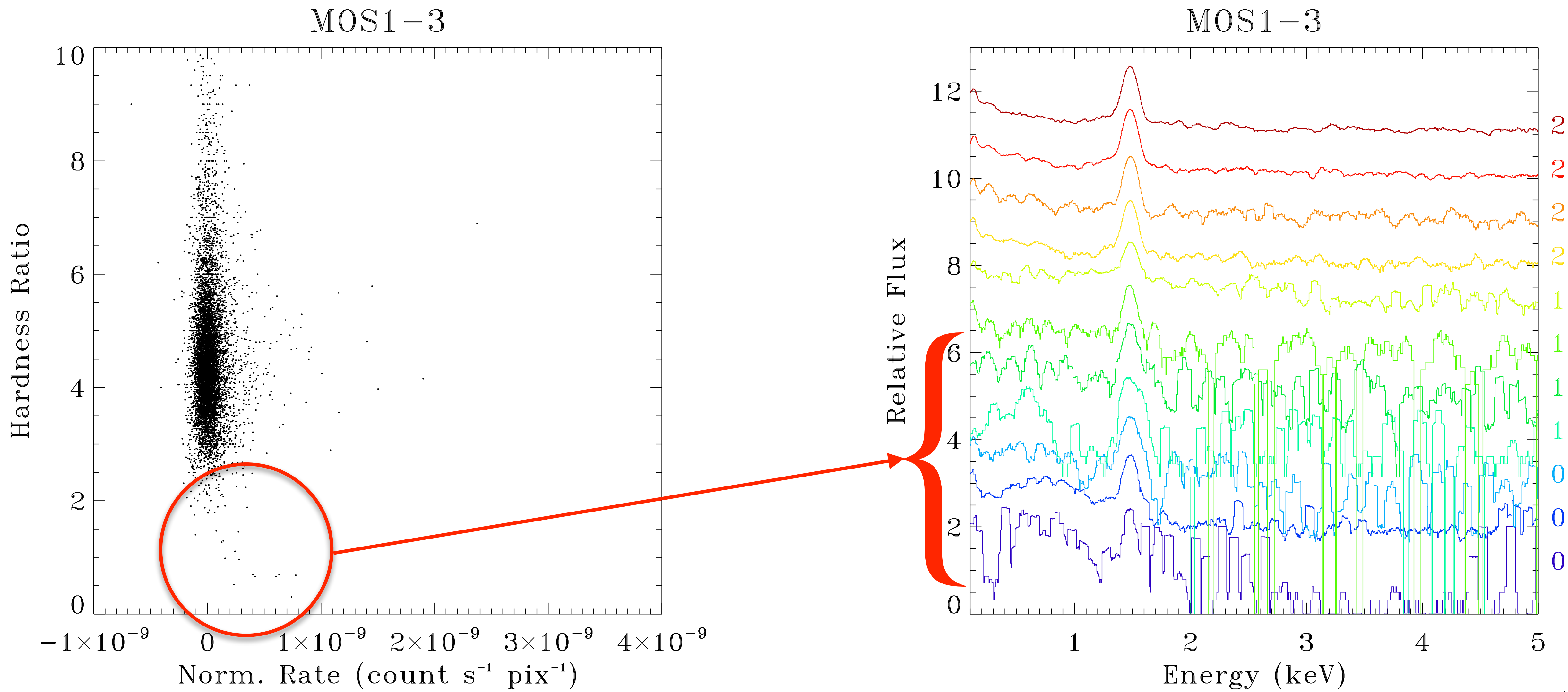
Compare 2008 and with 2017 for corner data sets

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 did flare removal 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)

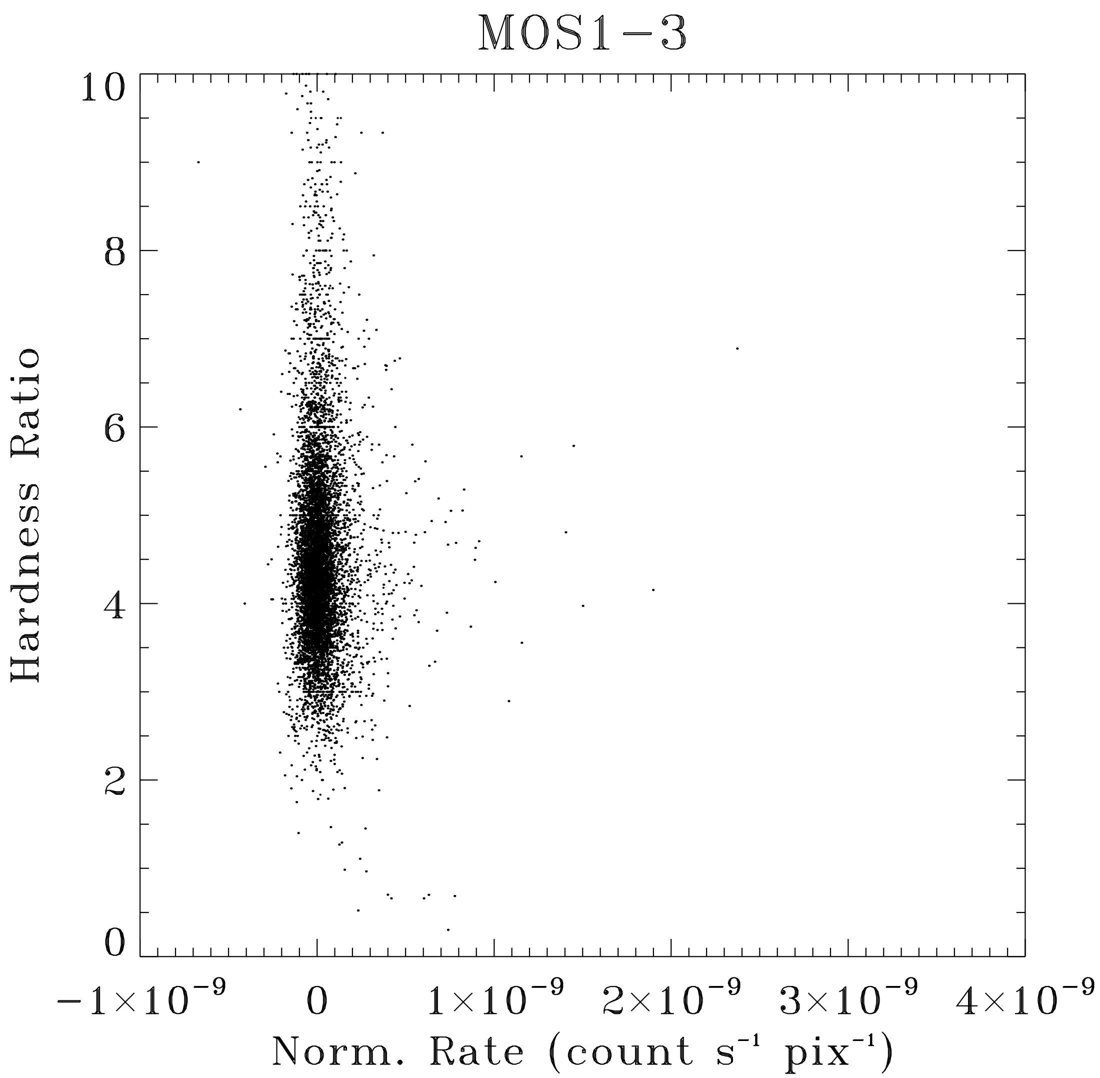
With More Statistics - Changes

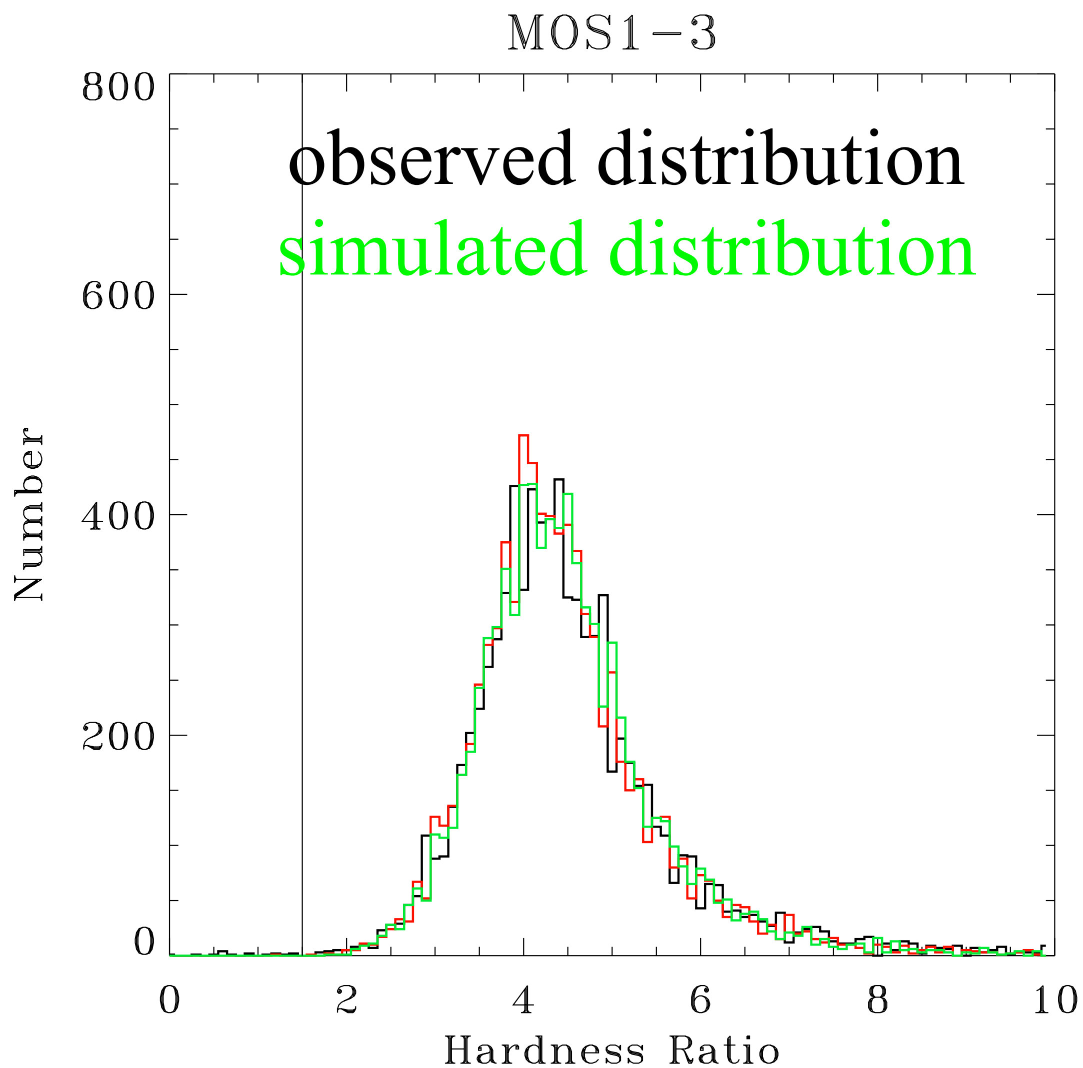
With greater number of observations
- greater number of extreme states observed
- even for chips w/o anomalous states
- had proposed ‘pseudo-anomalous’ label
  but no clear “noise” feature
  statistics may not be sufficient for good background



With More Statistics - Changes

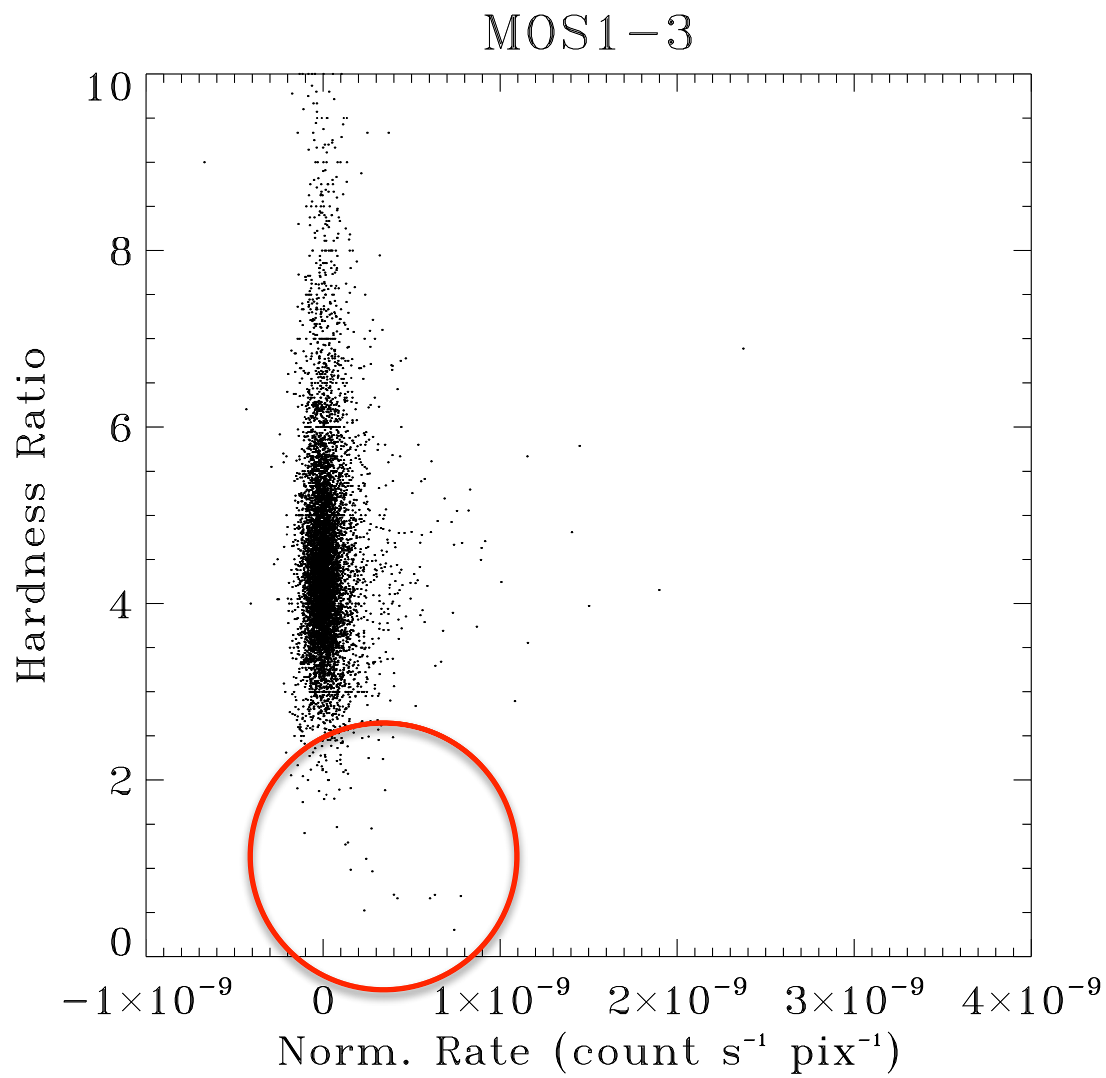
Prompted to revisit issue of distribution of hardness ratio
- for chips with no anomalous states
- find that the distribution is consistent with a single mean spectrum and counting statistics for *most* chips
- non-anomalous states of 1-4, 1-5, 2-2, 2-5 not so clear

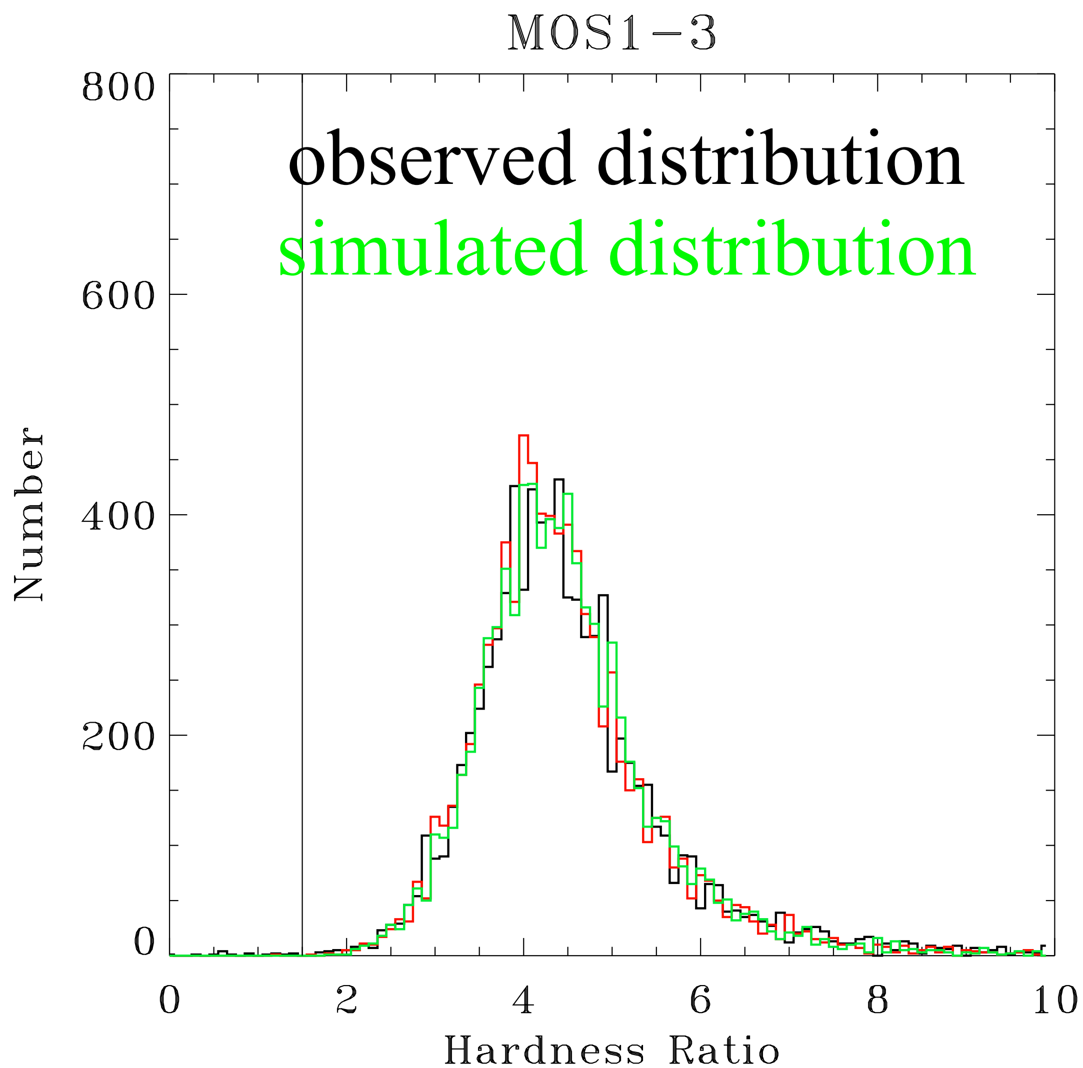




With More Statistics - Changes

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



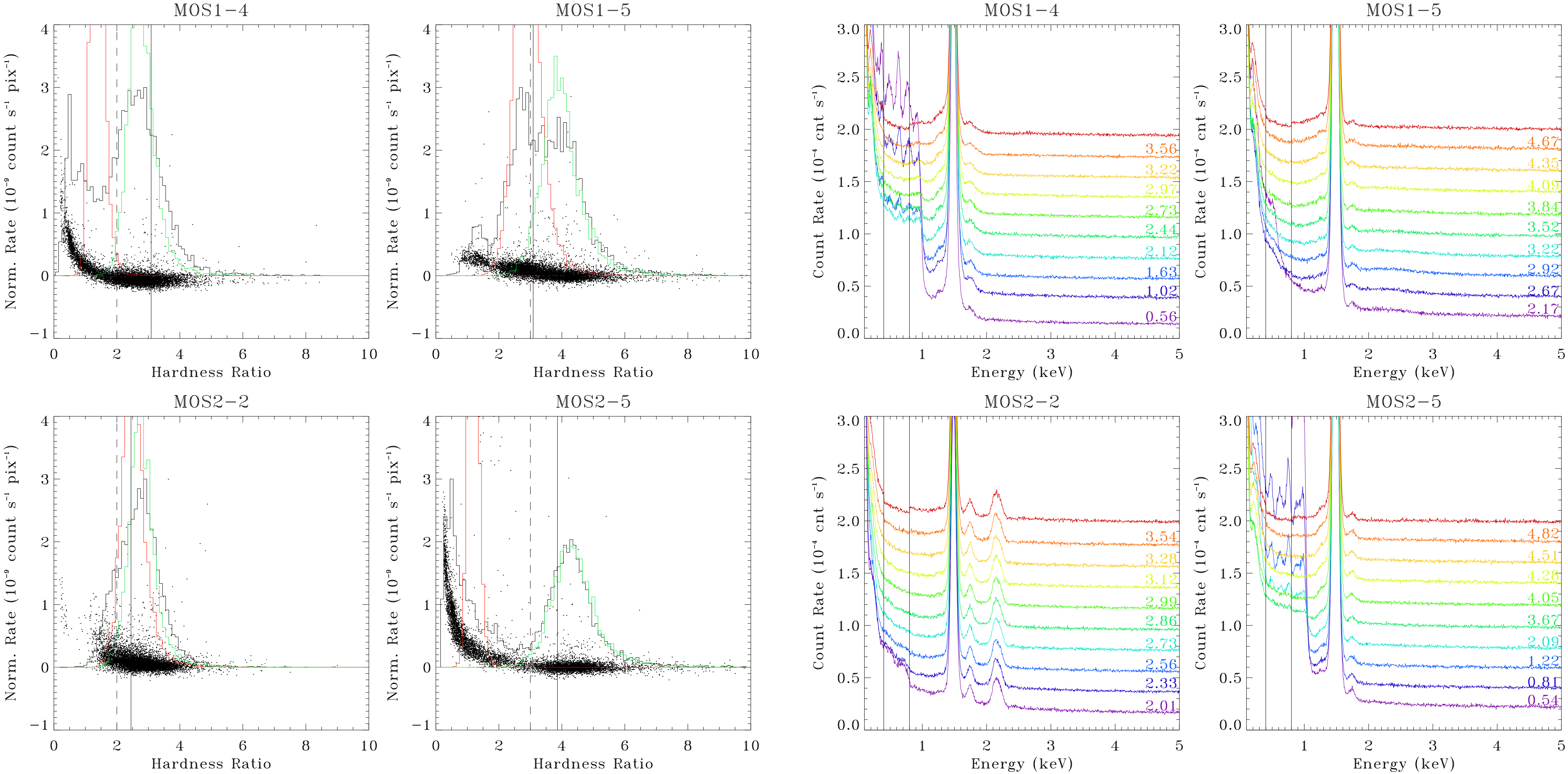


With More Statistics - Changes

This is a significant change from ESAS v1, only possible w/
- the greater statistics
- better definitions/removal of of anomalous states

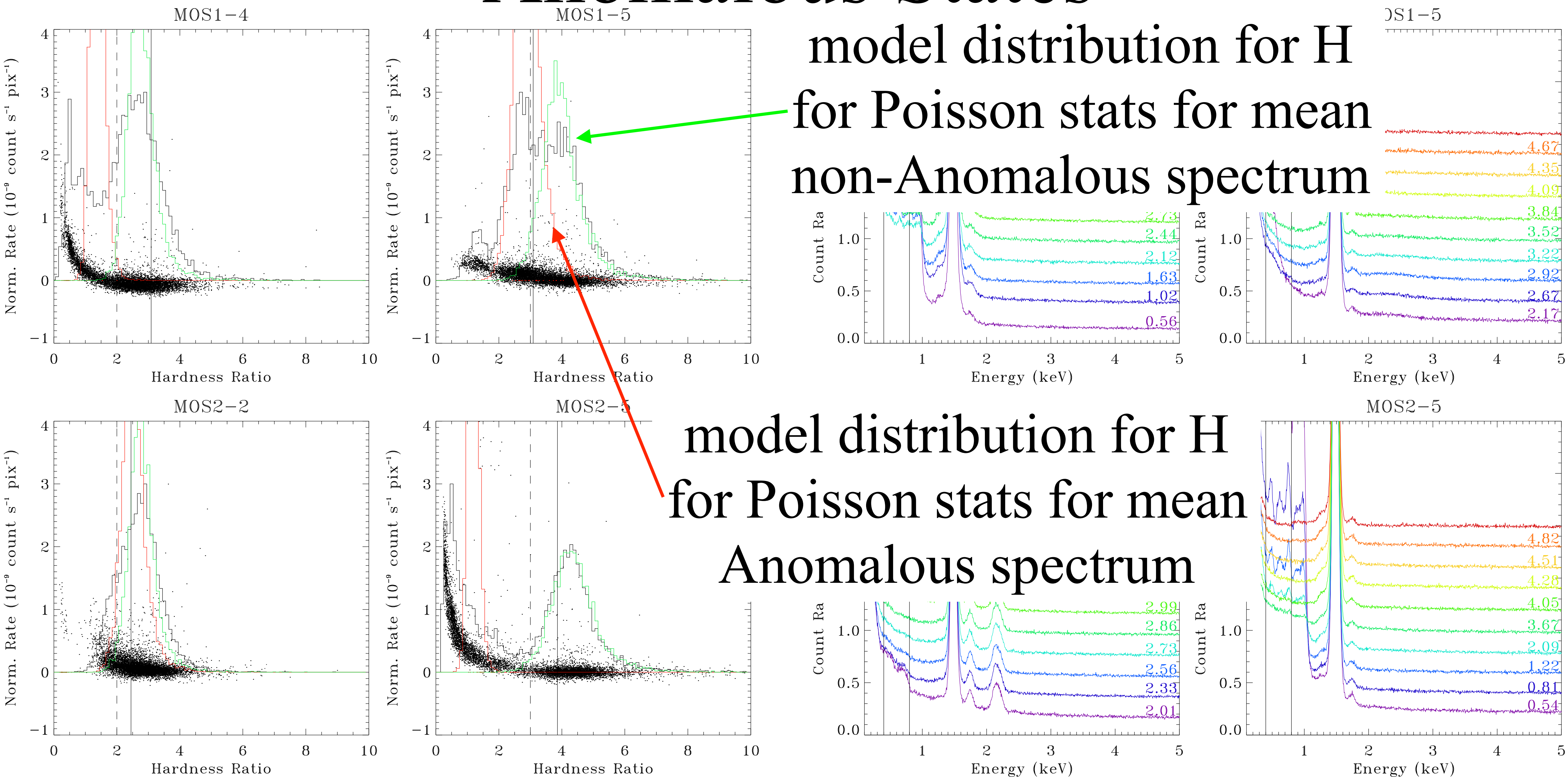
However the method used in ESAS v1 still applicable to observations/chips in anomalous states but…
- do we know enough about the anomalous states?
- do we have sufficient statistics to implement?

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

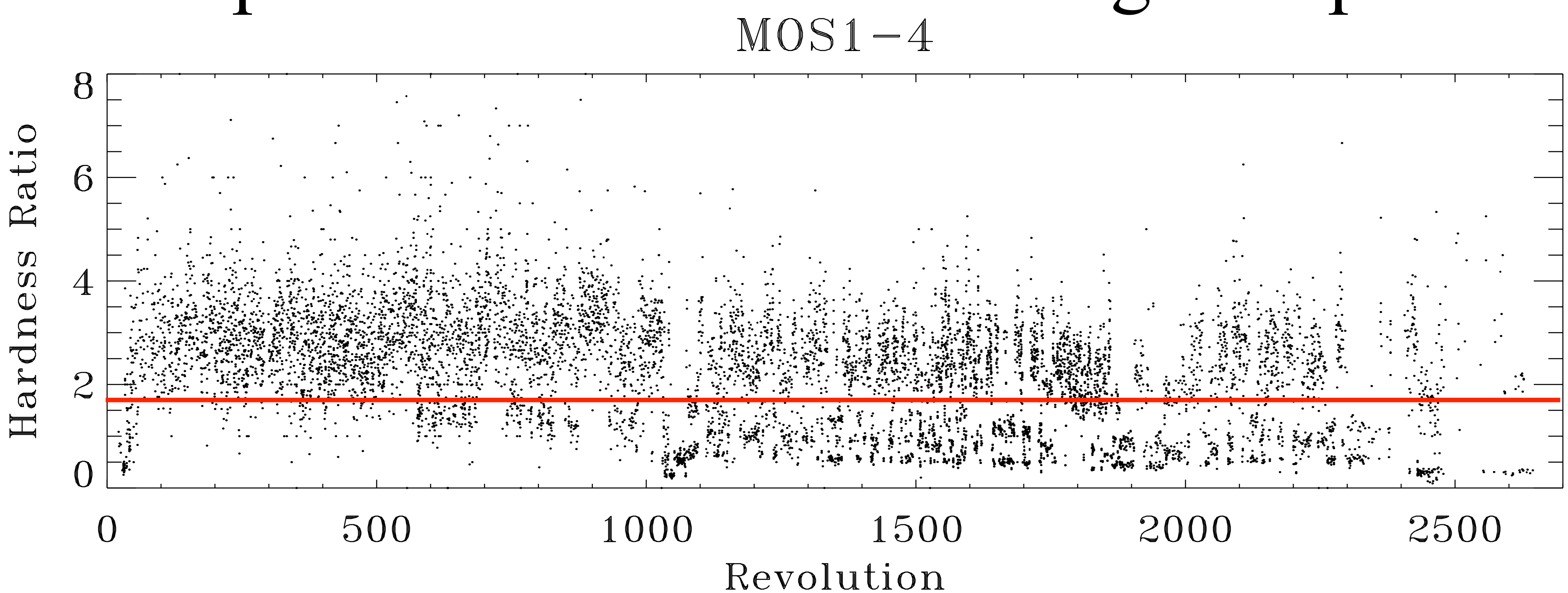
At a given value of H are some observations in anomalous states while others are not?

- seemingly not

What governs the strength of the noise feature in the anomalous states?

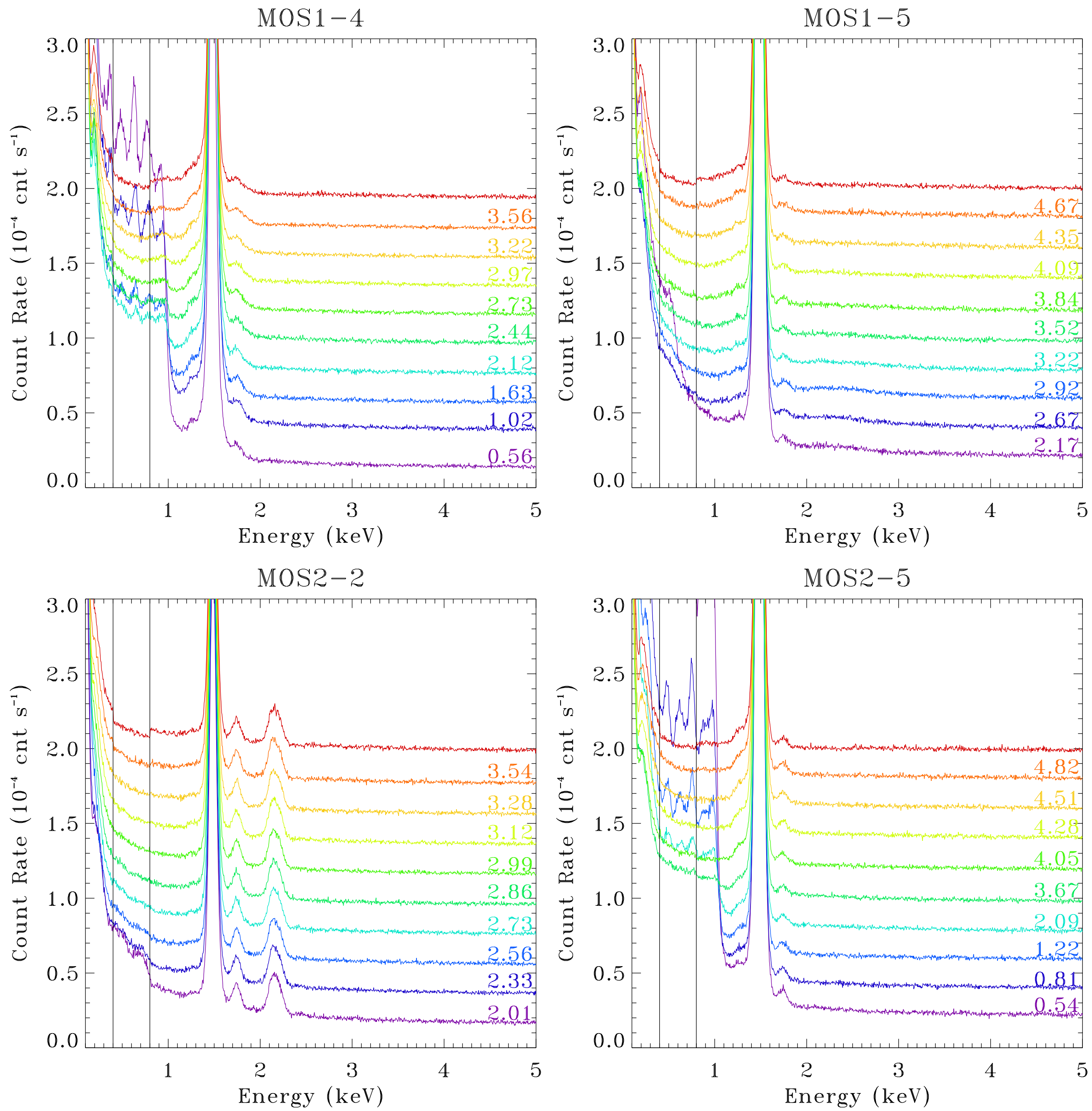
Do anomalous states evolve?

- 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?

ESAS Issues

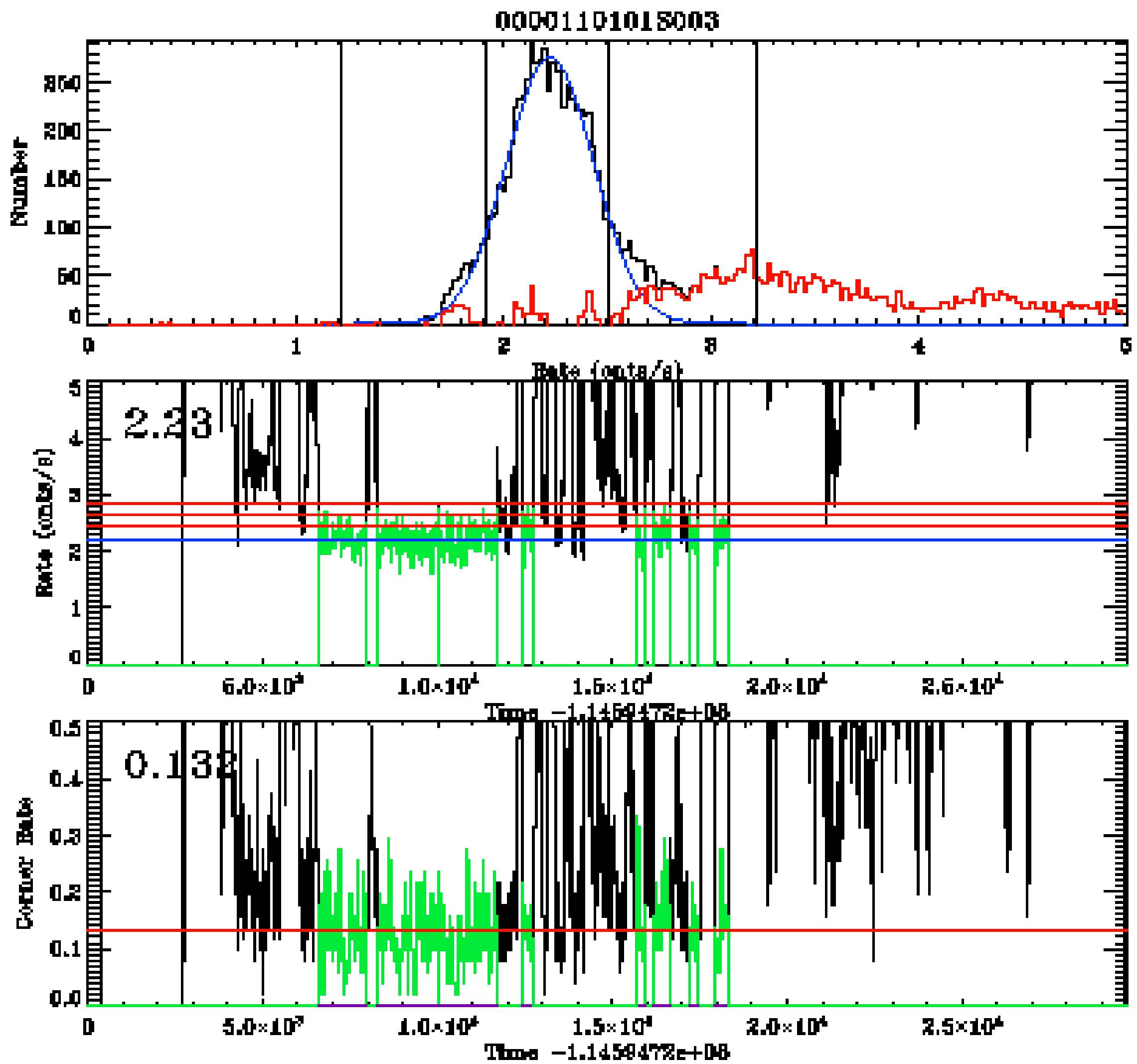
pn Issues

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
- corner data will be strongly contaminated by soft flares

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

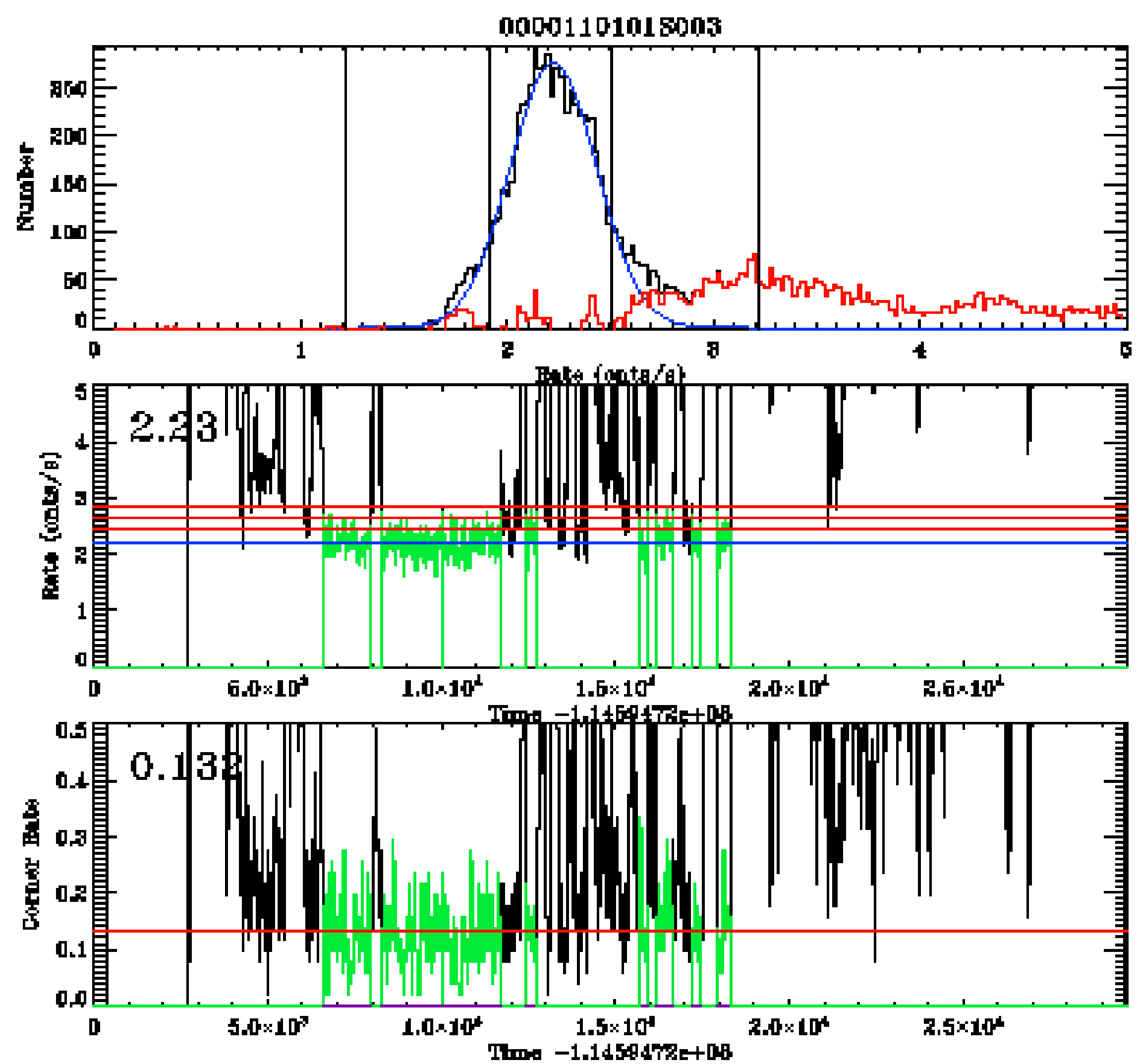
Flare Fitting Issues

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.



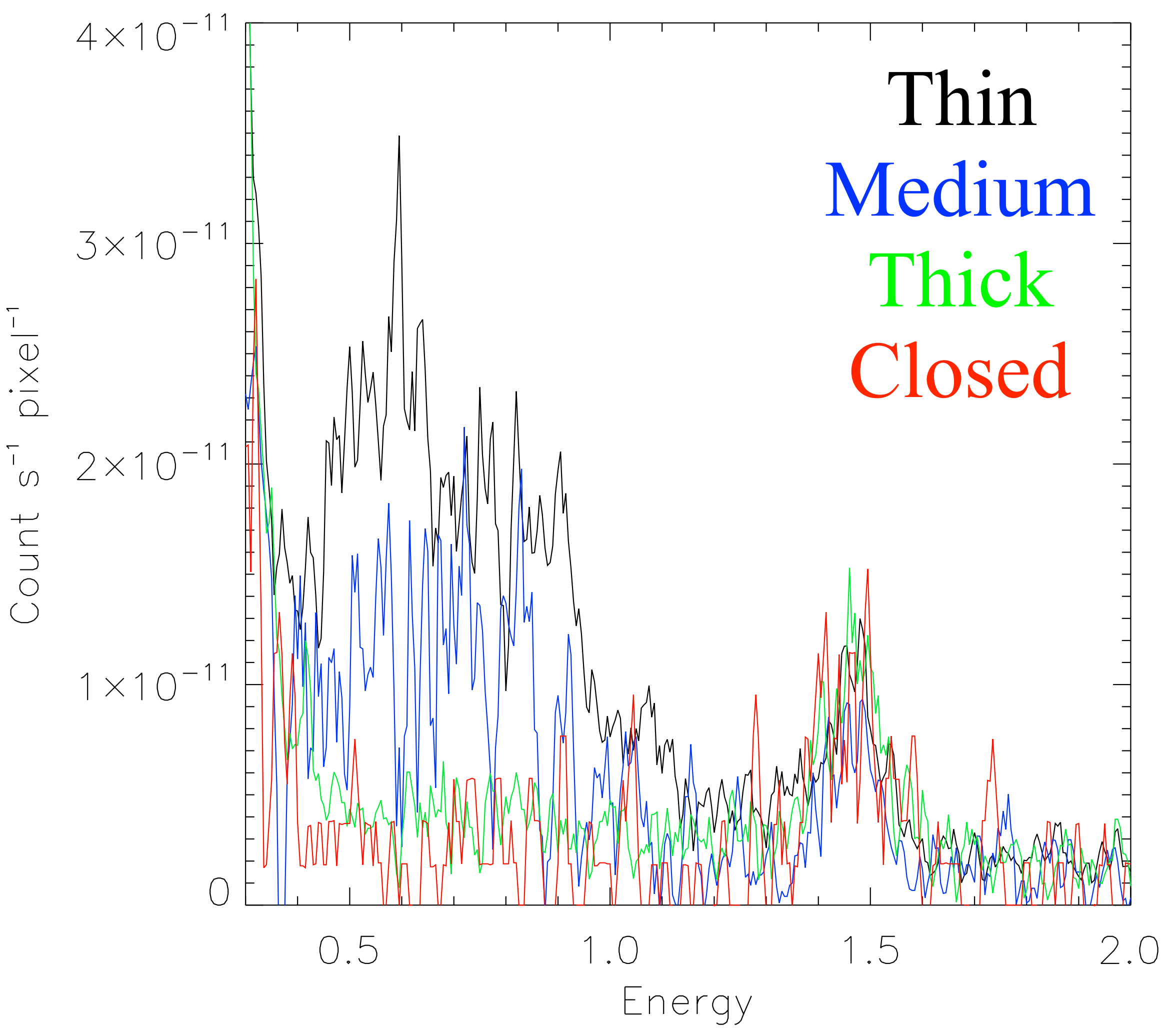
pn Issues

To test goodness of flare filtering for corner data
created mean corner spectrum for each FOV filter

Here,

corner ≡ corner date - scaled corner data from randomized data

If flare filtering good, expect all spectra to be the same,
but that was not the result



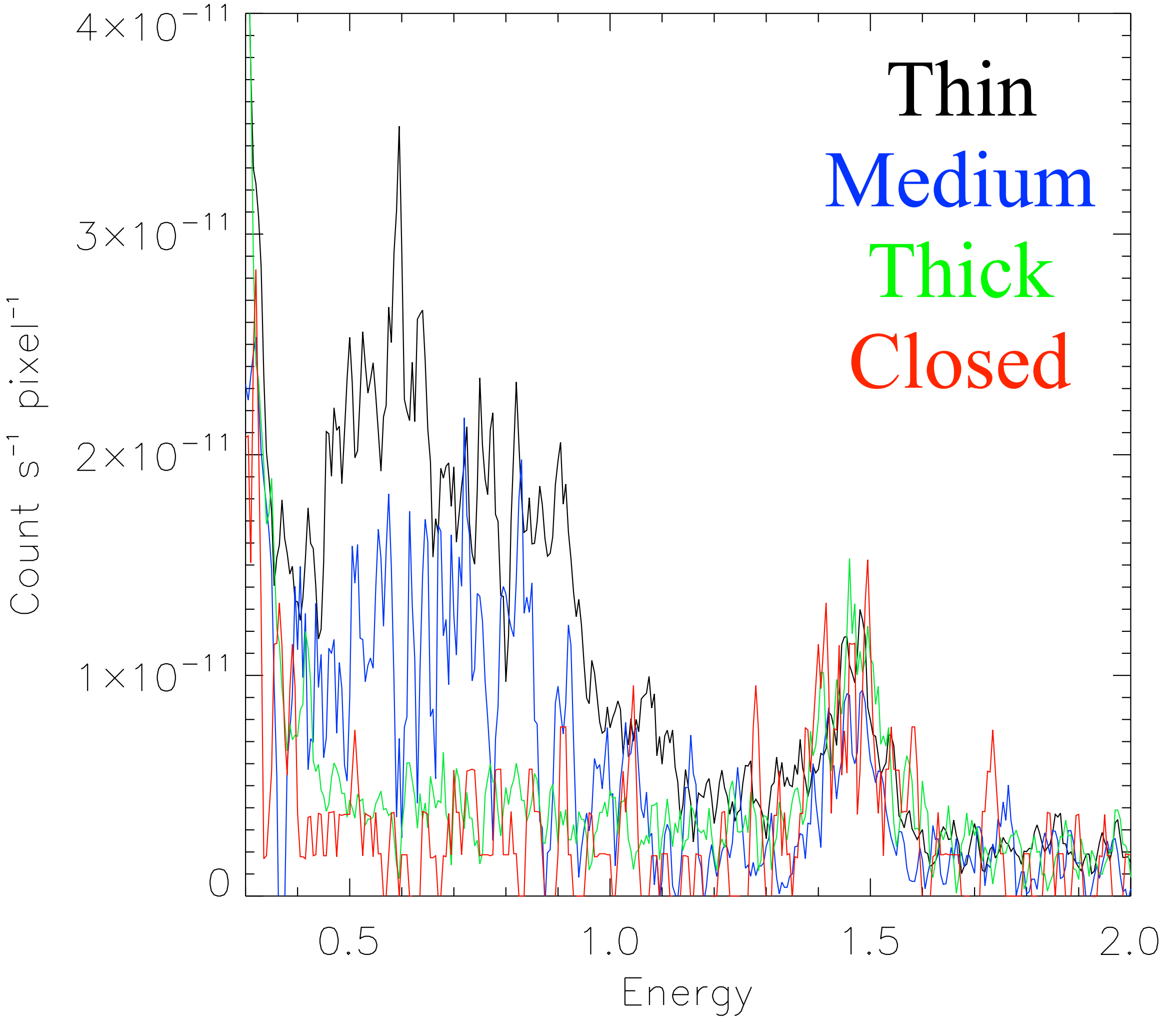
pn Issues

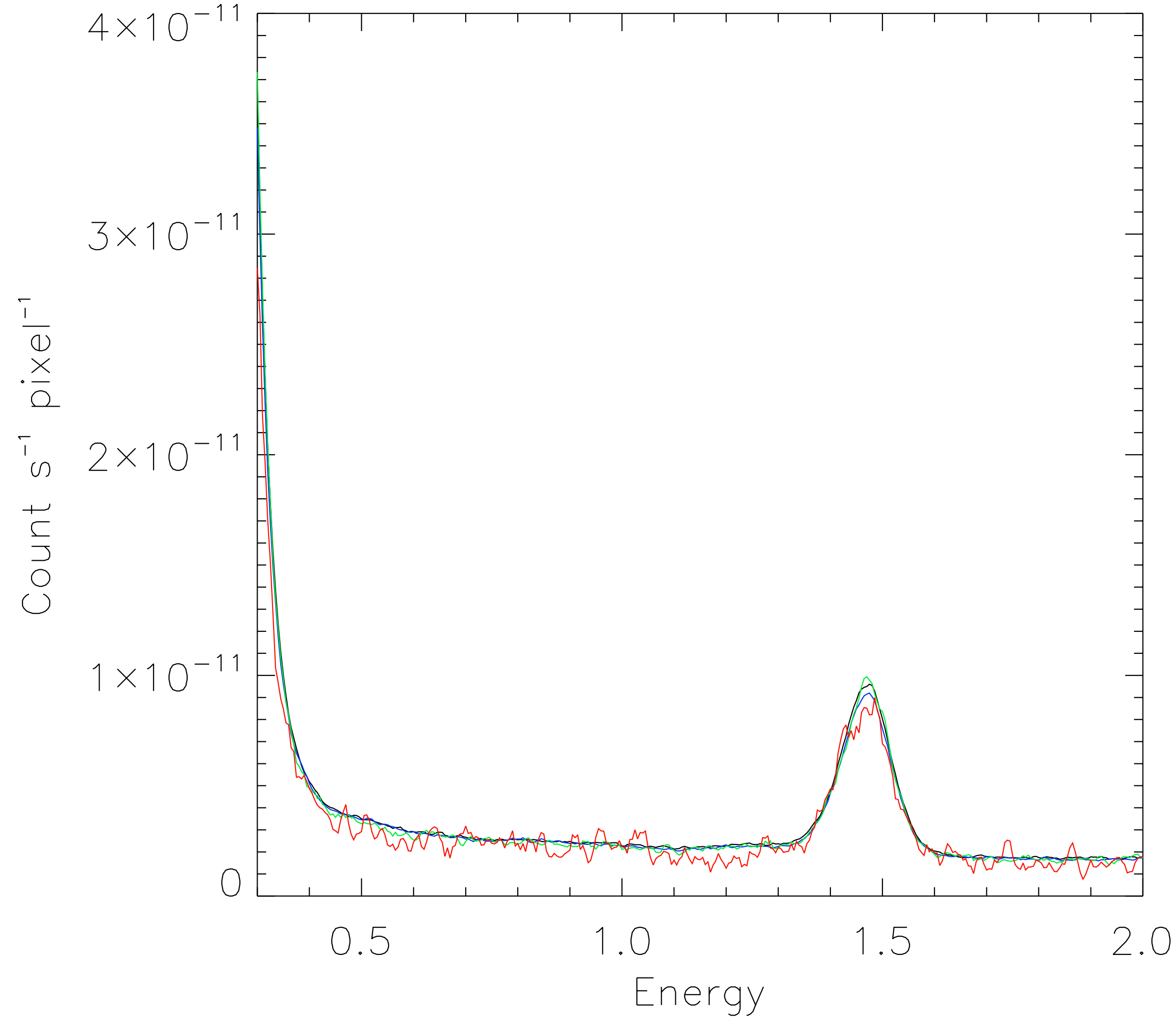
Source of variation with filter:

- is it due to real problems with flare removal?
- is it due to problem with scaling and removing OOT?

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

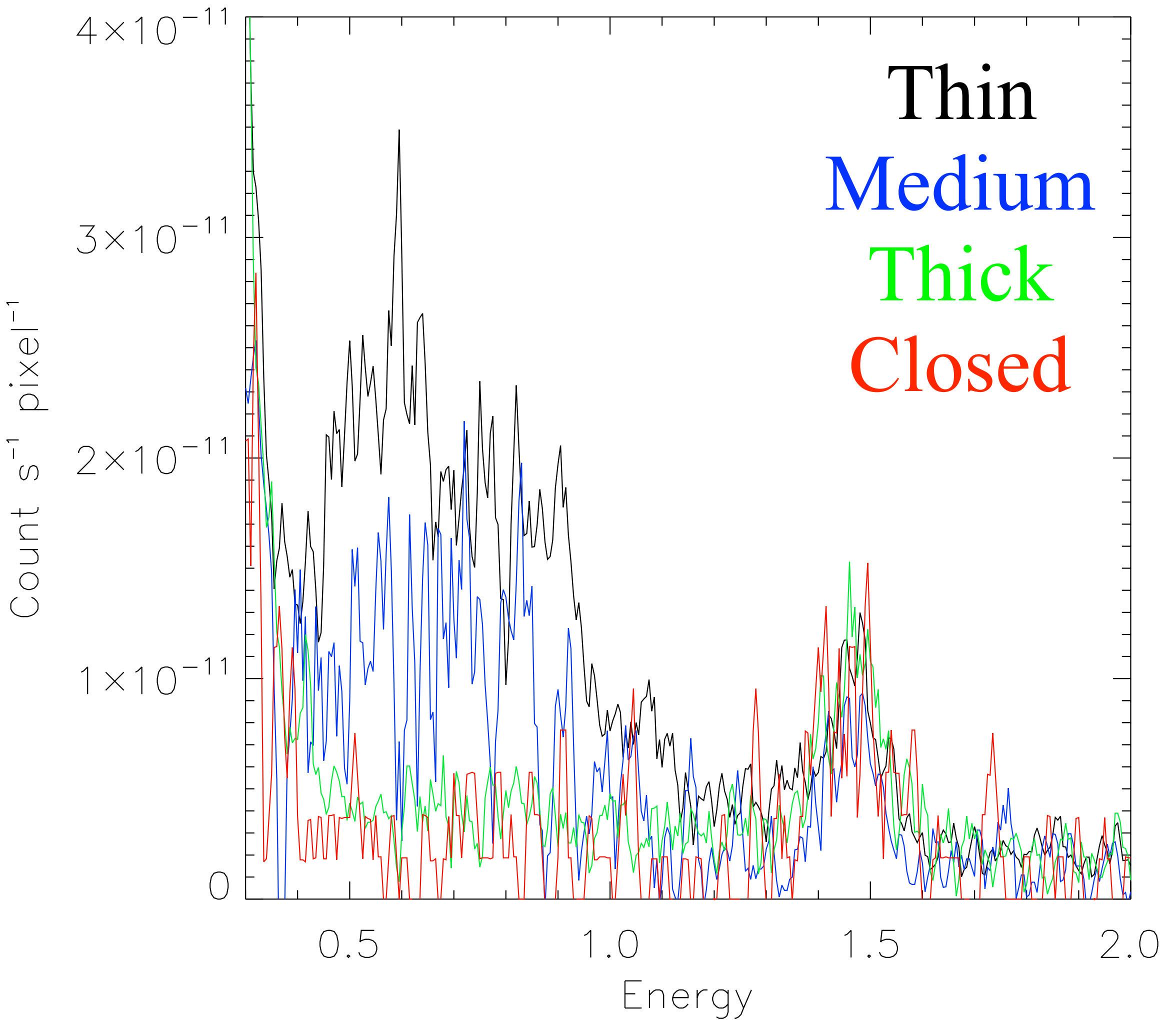


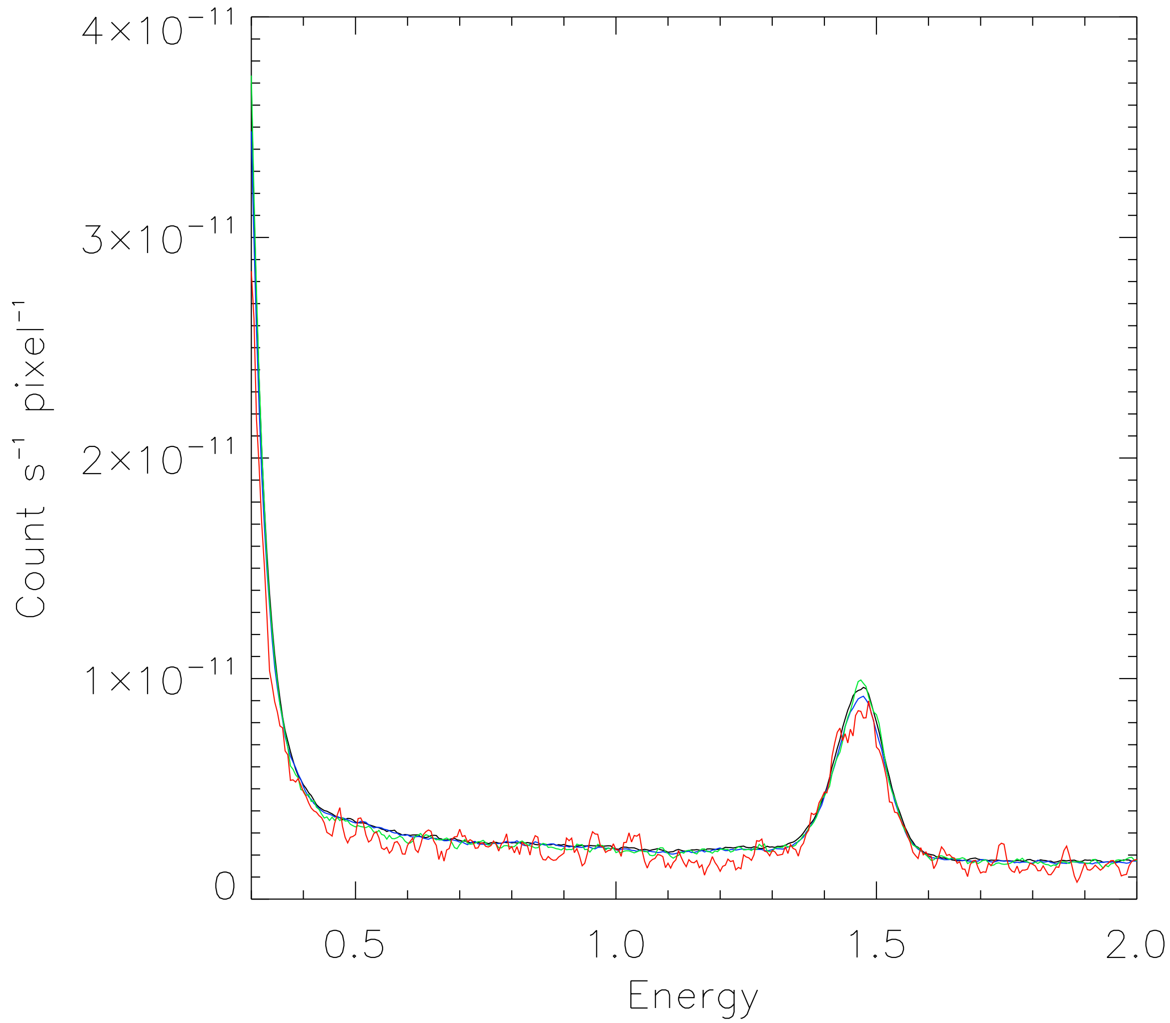


pn Issues

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

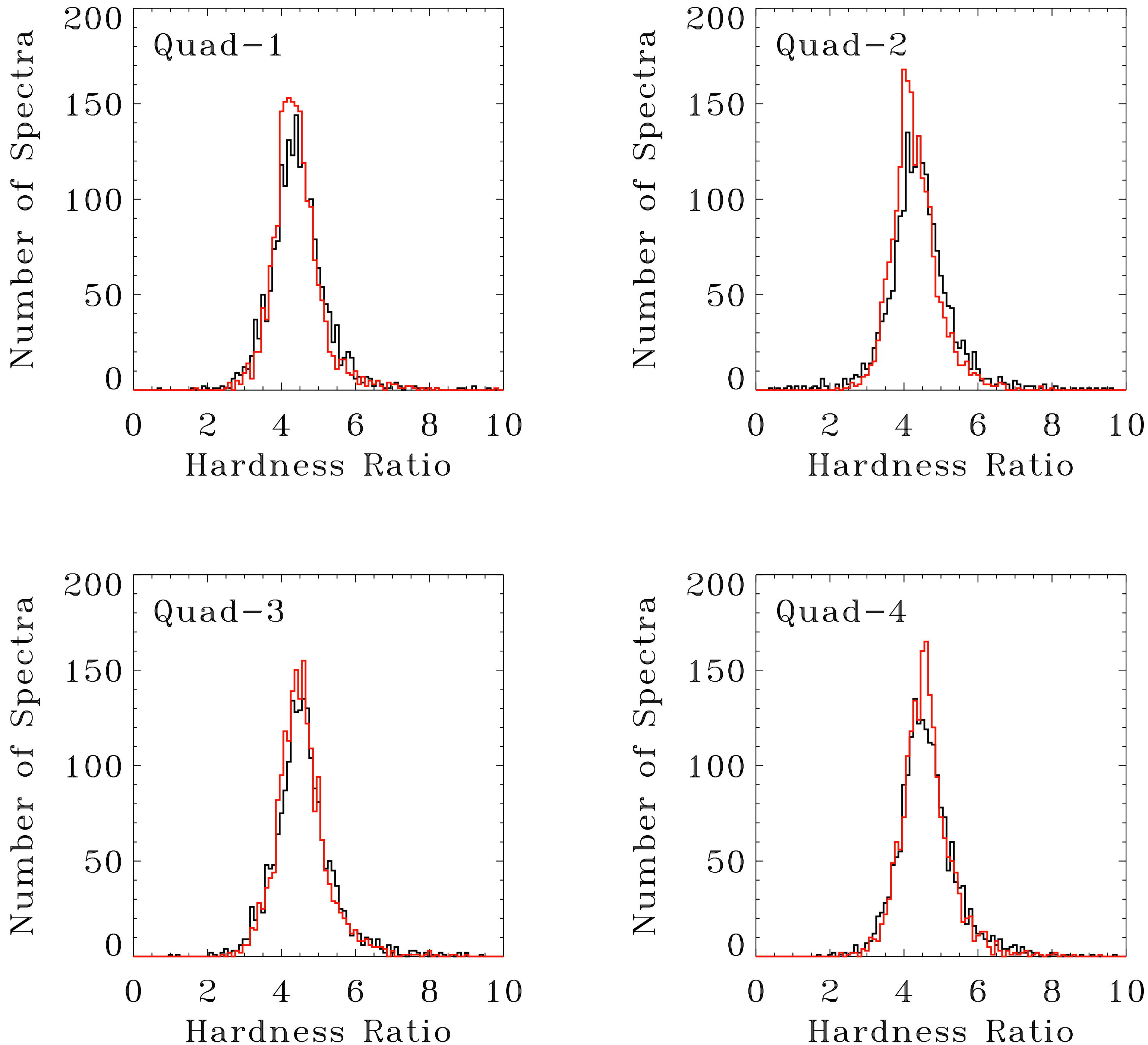




pn Issues

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

Extras

Anomalous State Questions

At a given value of H are some observations in anomalous states while others are not?

- Seemingly not because
- For spectra with a given value of the (2.5-5.0)/(0.4-0.8)=H ratio measure the (0.8-1.0)/(1.1-1.3)=H_2 ratio
-The distributions of H_2 are not bimodal