Background Treatment of Large Solid-Angle Contiguous Surveys

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An XXL Extragalactic Survey: Prospects for the XMM Next Decade

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General Principles

- Large scale surveys will attempt to pull a useful signal out of low S/N data
- The useful mosaicking of multiple pointings requires all individual observations to be accurately analyzed
- Modeling of the background must be accurate and repeatable
- Using off-source regions as a background estimate will usually not be feasible for diffuse emission.
- Blank-sky field background subtraction will also not be feasible for diffuse emission.

Backgrounds

- Quiescent Particle – Internal – High energy penetrating particles deposit energy directly in the detectors. Variable, but not strongly so except for some CCDs at energies < 1keV

- Fluorescent – Internal – High energy penetrating particles fluoresce elements of the telescope with detection of the resultant X-rays. Variable but not strongly so. Dominated by Al Kα and Si Kα.

- Soft Proton – Internal – Soft protons penetrating down the light path of the telescope tube, penetrate the filters, and deposit their energy directly in the detectors. Highly variable at levels from "hardly there" to "toss out the observation".

Background pages from the EPIC Background Working Group (BGWG)

http://xmm.esac.esa.int/external/xmm_sw_cal/background/index.shtml

http://www.star.le.ac.uk/%7Eamr30/BG/BGTable.html

Backgrounds (cont.)

- Solar Wind Charge Exchange – External – Highly ionized atoms of the solar wind interact with interstellar neutrals in the solar system and exospheric material in Earth's magnetosheath, gain an electron in an excited state, and emit an X-ray. Strongly variable at levels from "hardly there" to "incorrect scientific results".

- Diffuse X-ray Background – External – Multiple sources at various distances from the solar system. Comprised of thermal emission from interstellar, intergalactic, and cosmological plasmas as well as the superposition of discrete sources at cosmological distances. Constant in time but strongly variable in spectrum across the sky for $E<2$ keV.

- Electronic Noise – Internal – Ignore Here

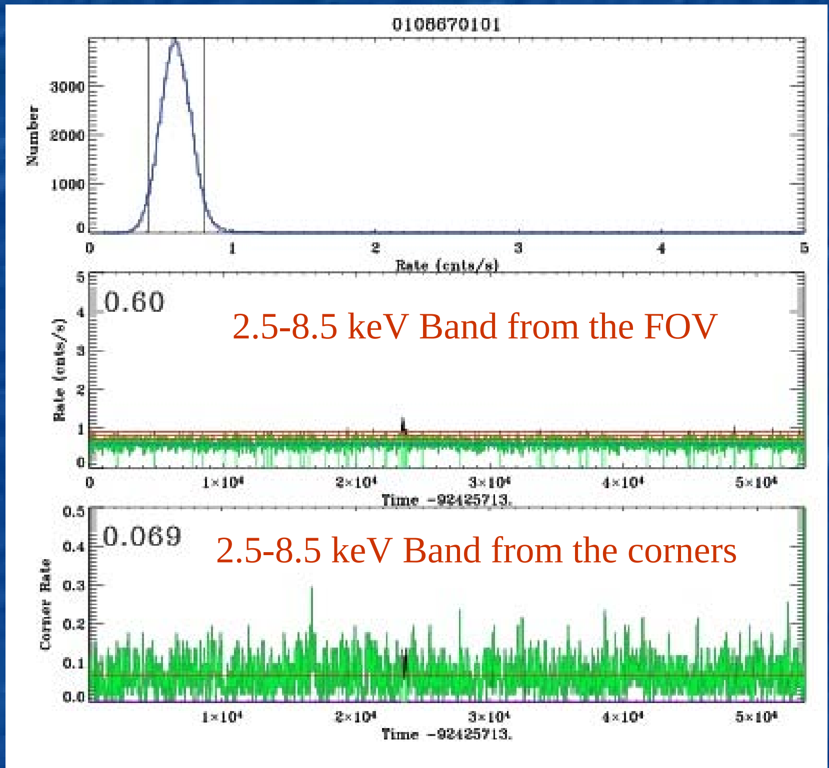
Deterministic Background Treatment

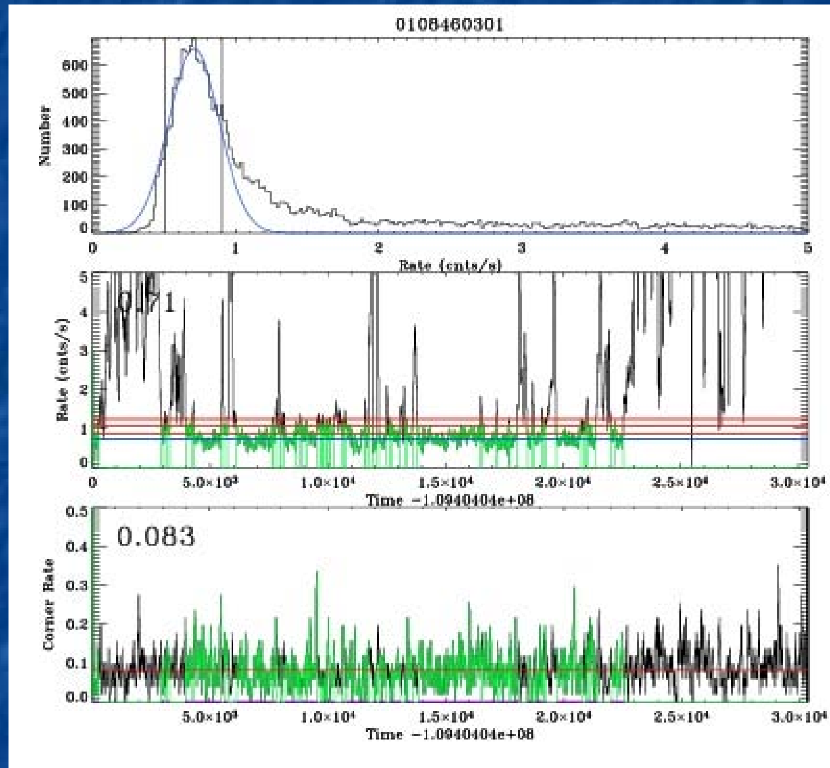
- Use as many known parameters as possible rather than relying on local background determinations and one-size fits all background data sets
- E.g., FWC Data, RASS, Soft Proton Calibration, Archived Observation Data Sets
- Calibrate the backgrounds to the greatest extent possible, e.g., Kuntz & Snowden 2008, A&A, 478,575 for the quiescent particle and soft proton backgrounds
- The XMM-ESAS background modeling package will do this to the greatest extent currently possible
- Presented in: Snowden et al. 2008, A&A, 478, 615

Step 1 – Filter the Data

- Nearly any reasonable method will work to remove soft-proton contamination including the new SAS task espfilt – most if not all observations have some soft-proton background, so the question is a tradeoff between the cleanliness of the data and how much data are available for analysis.
- Contributing Factors – brightness, angular extent of the source
- We use the 2.5-12.0 keV band for the filtering, although a bright, hard, and variable source could cause problems.
- Create a light curve and then a light-curve histogram
- Fit a Gaussian to the main peak
- Exclude time periods where the count rate is greater than 2.5 times the Gaussian width above and below the mean of the Gaussian

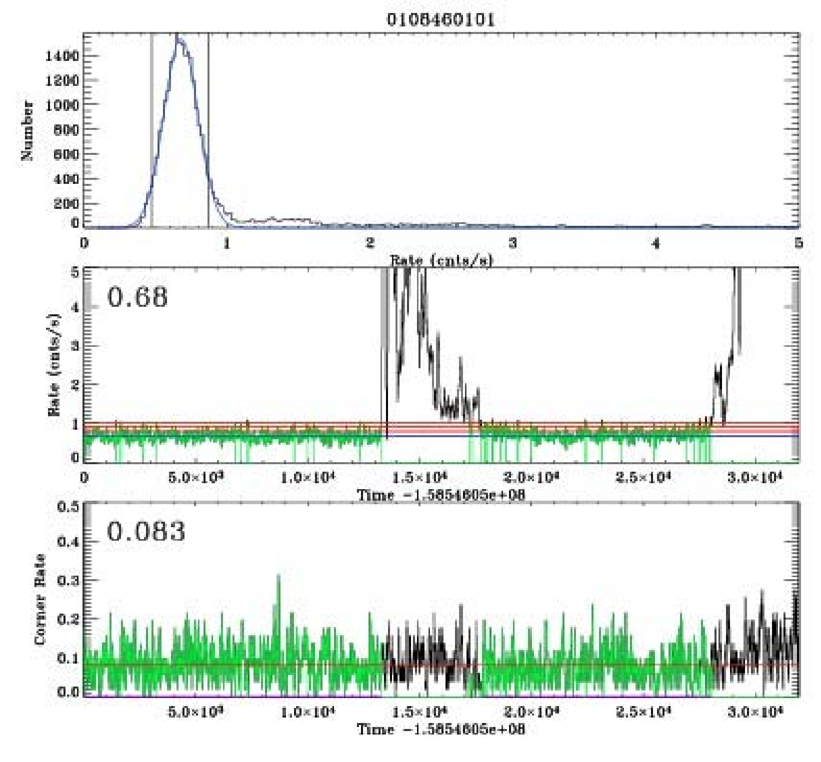
Step 1 – Filter the Data

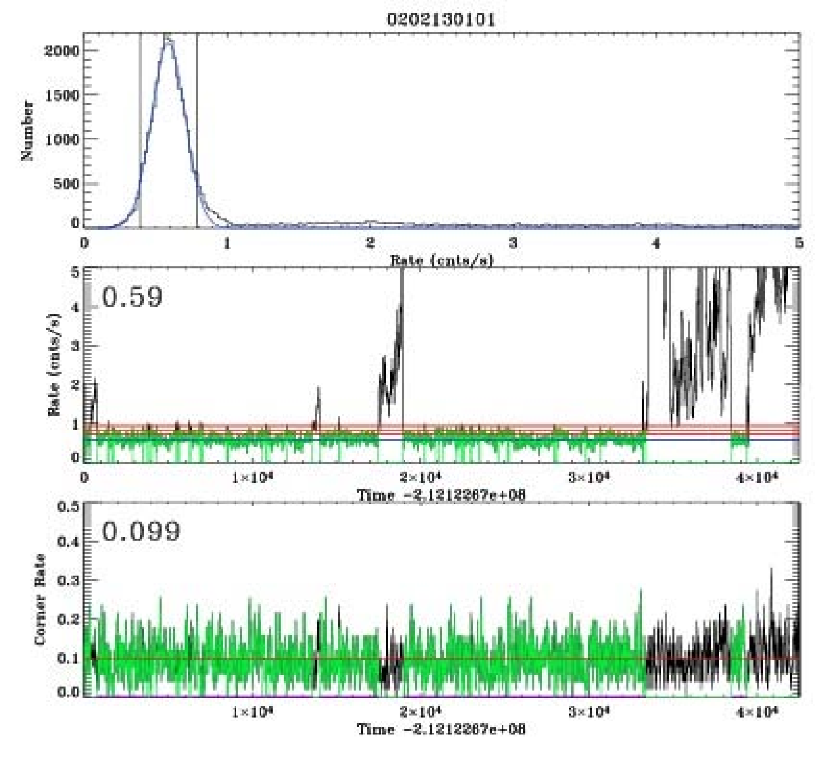




Light curves can range from very clean to incredibly ugly, some with very little, or no useful time

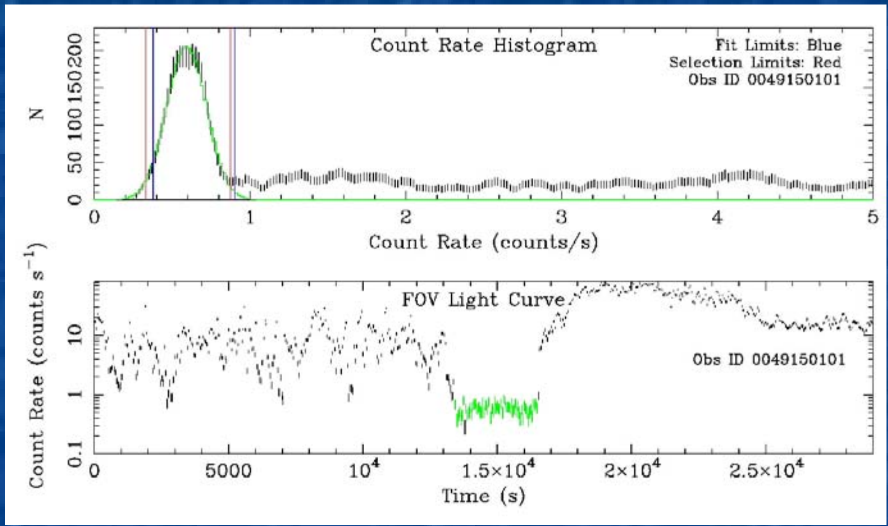
Step 1 – Filter the Data

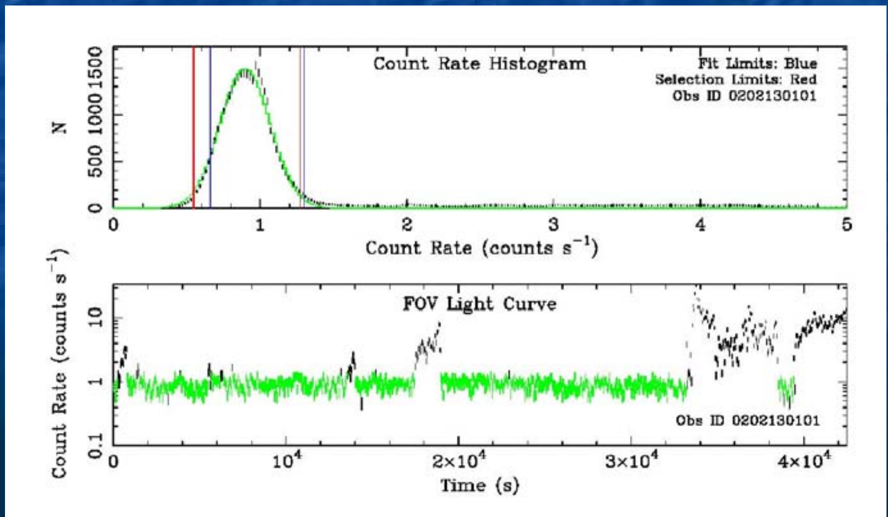




But most of the time the light curve will be somewhere in between.

Step 1 – Filter the Data



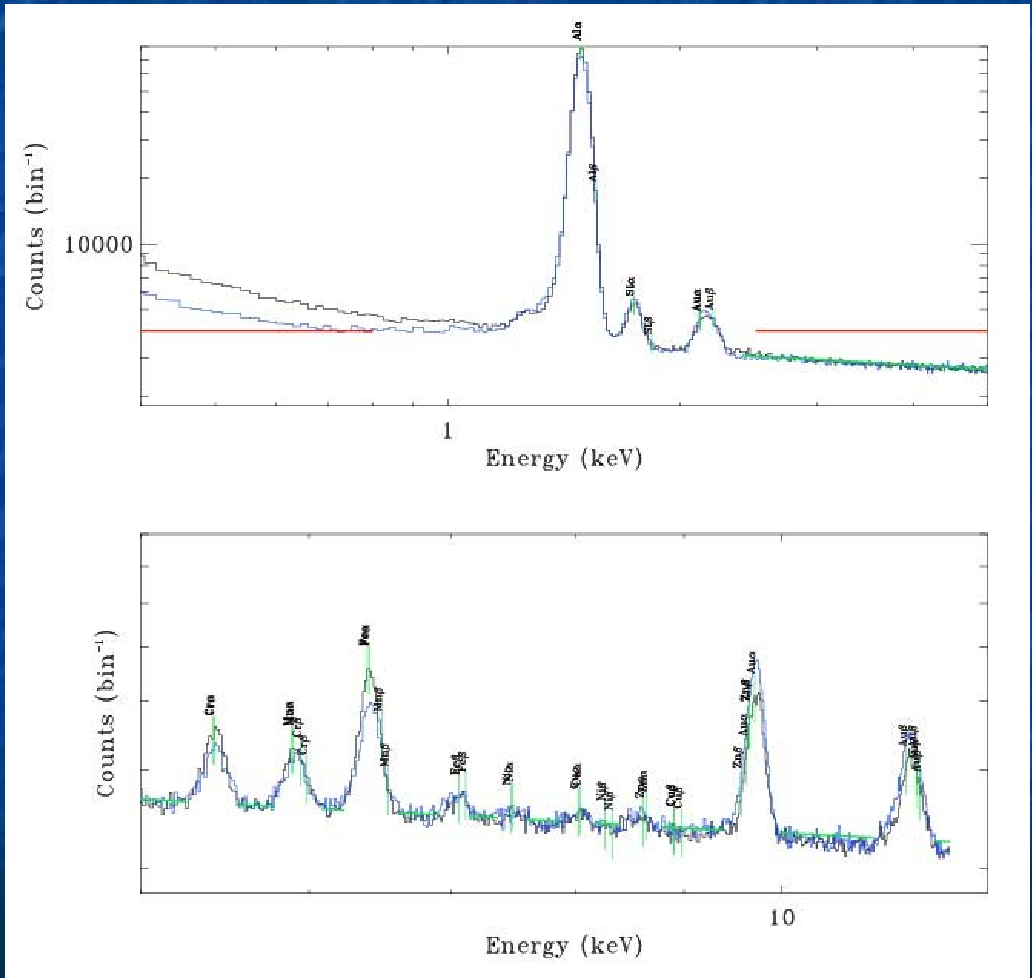


- Visual inspection of the light curve often isn't sufficient to determine the presence of residual soft-proton contamination.
- The two light curves are from observations of the same direction on the sky.
- The accepted time period (green) in the top observation is "cleaner" than the accepted time period in the lower observation.

Step 2 – Model the Quiescent Particle Background

- Determine the corner spectral parameters: high-energy power law slope [2.4-12.0 keV] and hardness ratio
- [(2.5-5.0)/(0.4-0.8)] from the observation data set
- Search a archived-observation data base for observations with similar parameters
- Augment the observation data set corner spectra with data from a second archived-observation data base
- Scale the FWC spectra (treat each CCD separately) for the region of interest by the ratio of the augmented observation corner spectra to the FWC corner spectra
- Use the corner spectra from the outside CCDs to model the background for the central CCD

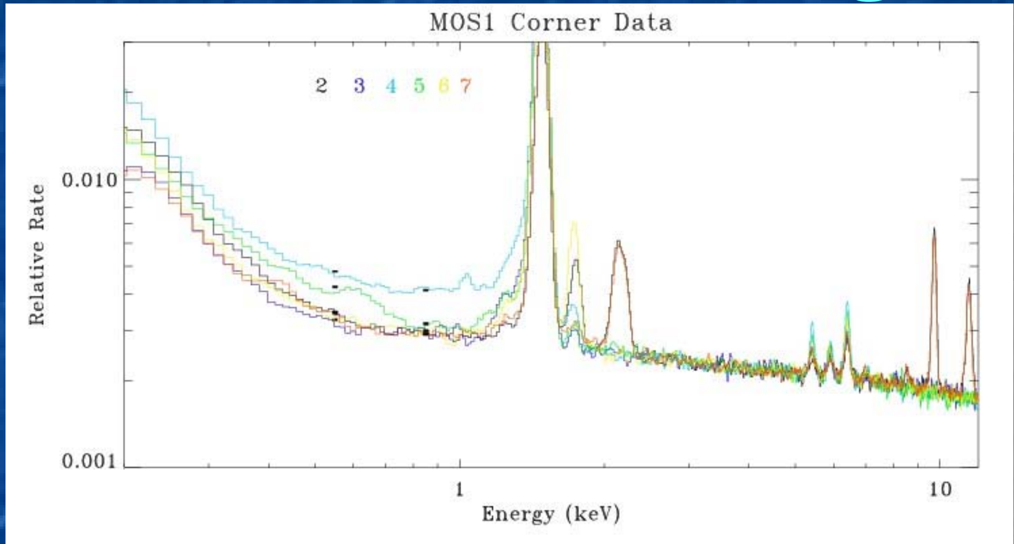
Step 2 – Model the Quiescent Particle Background

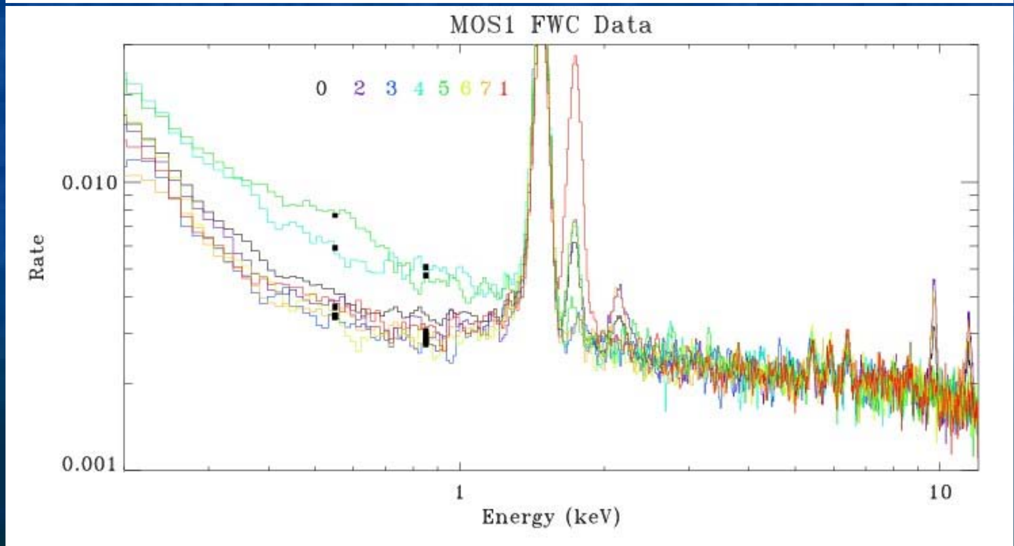


The mean quiescent particle background spectrum derived from the corner pixel data in two spectral regions: 0.2-5.0 keV and 5-12.5 keV

- Both continuum and line contributions are both position and temporally varying

Step 2 – Model the Quiescent Particle Background



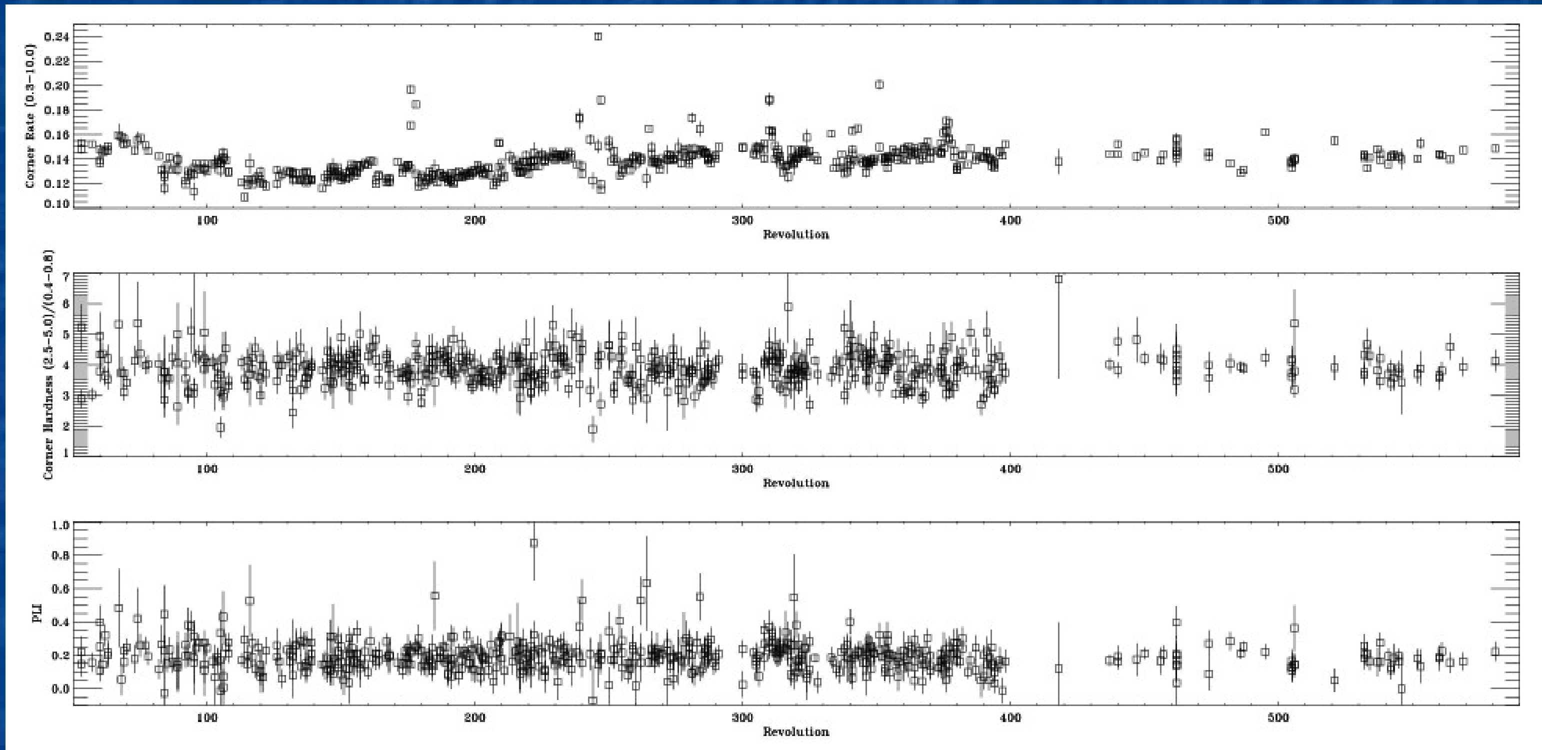


The mean “nominal” spectra from the corners and field of view from the MOS1 CCDs.

The spectra have been normalized in the 2.5-9.5 keV band. The vertical black bands indicate the uncertainty in the continuum level in 0.3 keV wide regions.

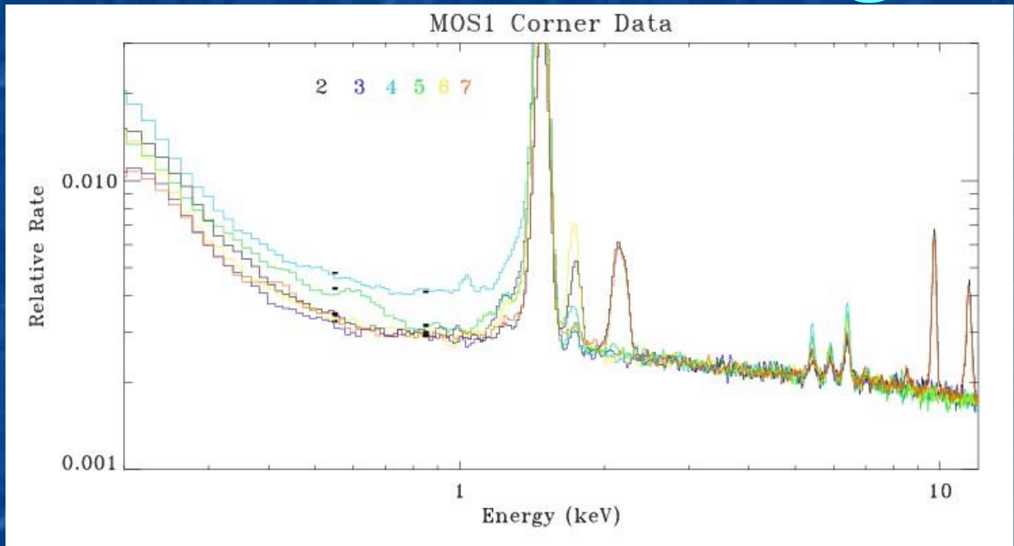
- Both continuum and line contributions are both spatially and temporally varying
- The corner quiescent particle background spectra differ significantly from those in the field of view

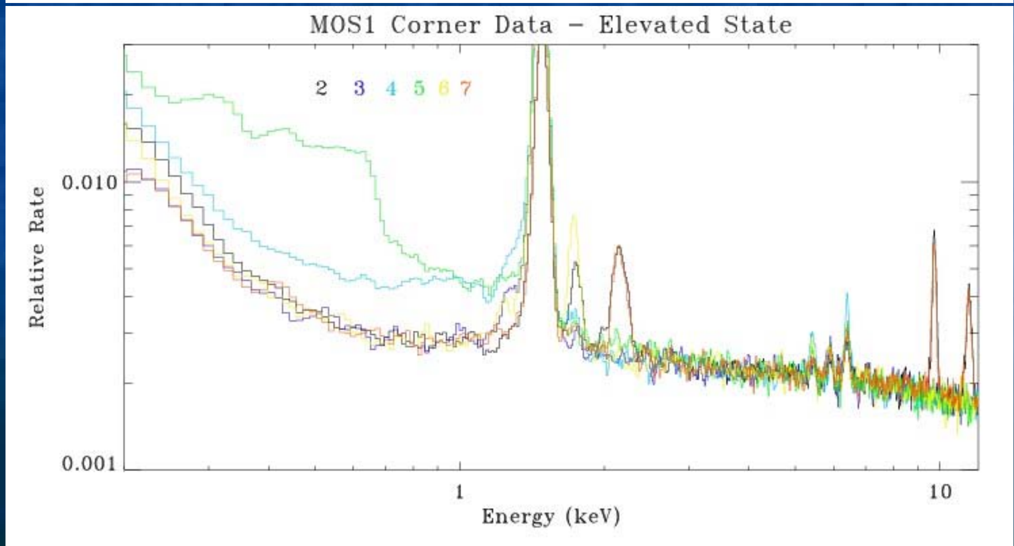
Step 2 – Model the Quiescent Particle Background



Temporal variation of the (top) 0.3-10.0 keV rate, (middle) the (2.5-5.0 keV)/0.4-0.8 keV) hardness ratio, and (bottom) 24.-12.0 keV power law index

Step 2 – Model the Quiescent Particle Background

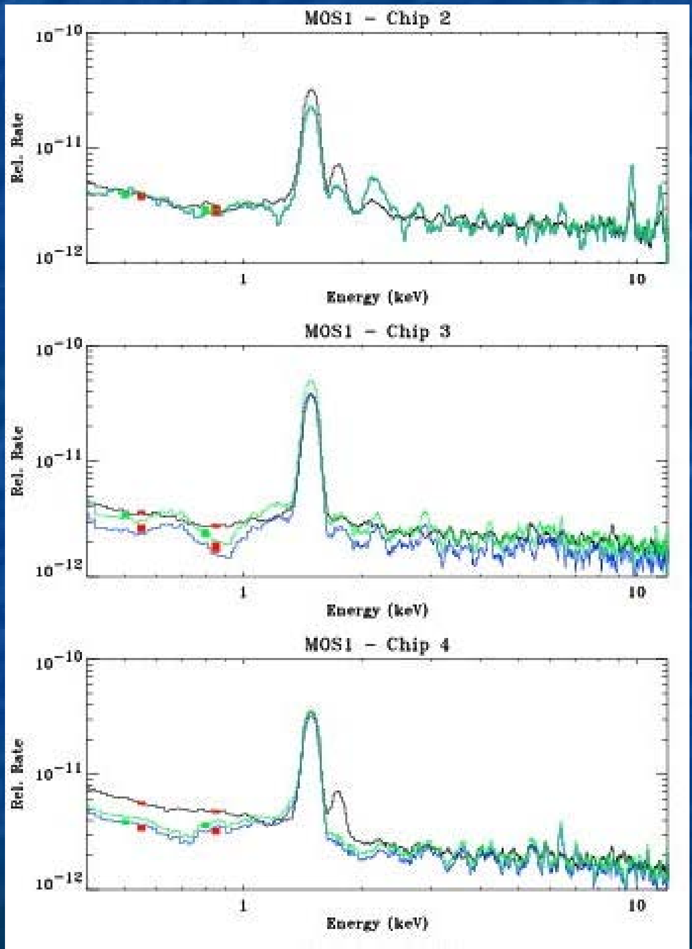


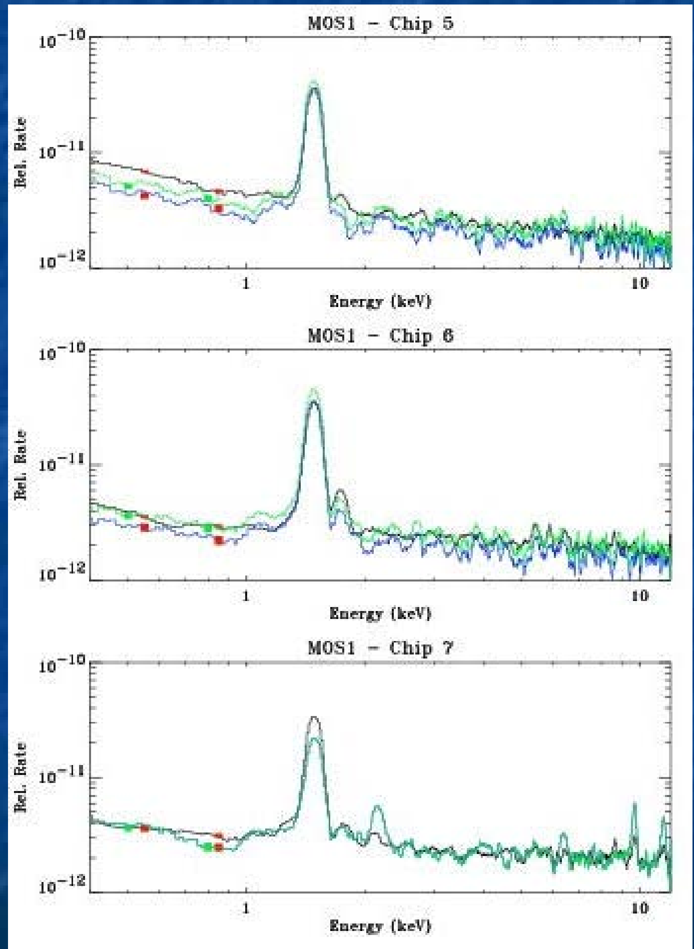


"Nominal" and "Elevated" spectra from the corners plotted for the MOS1 CCDs 2-7. The data have again been normalized in the 2.5-9.5 keV band

Occasionally CCD #5 goes weird, and must be treated separately (we don't have a good method yet)

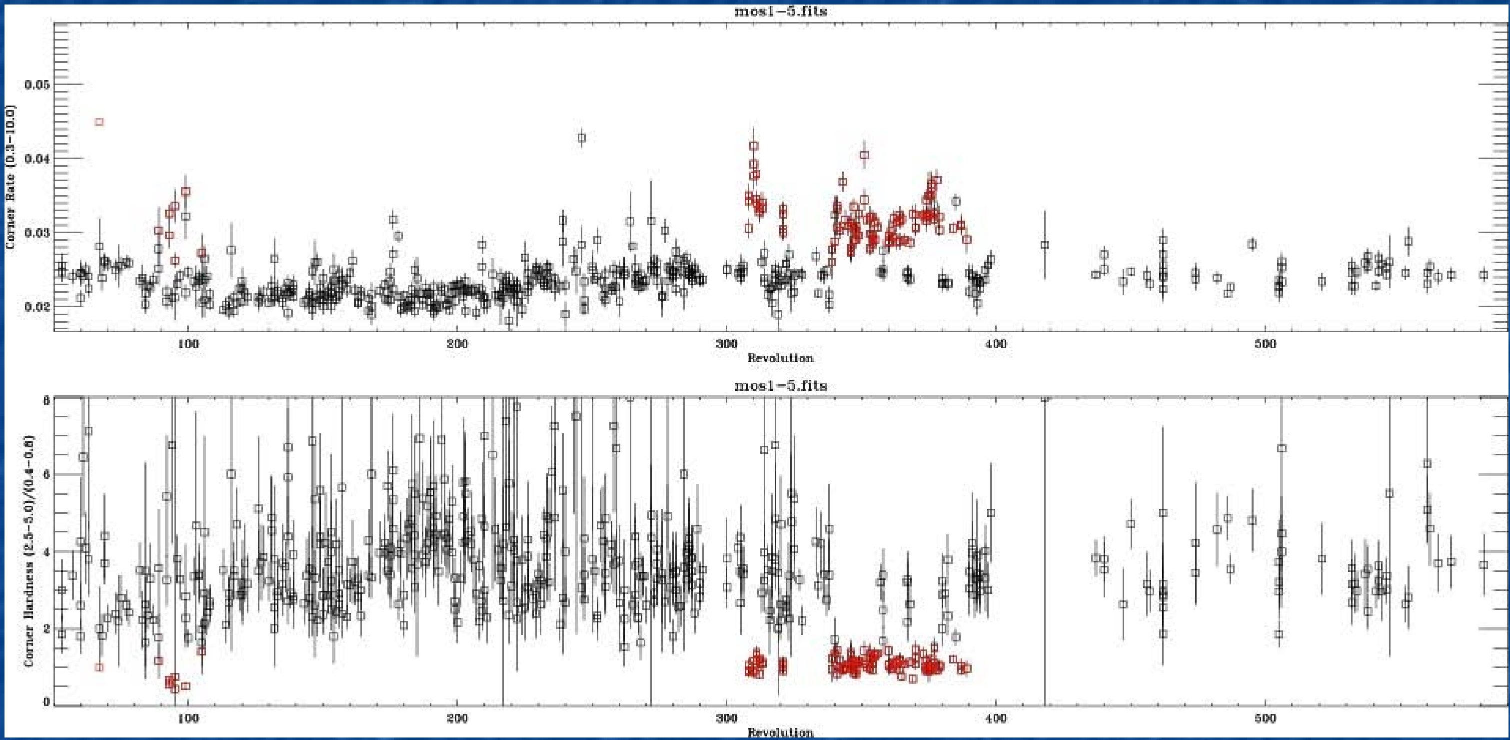
Step 2 – Model the Quiescent Particle Background





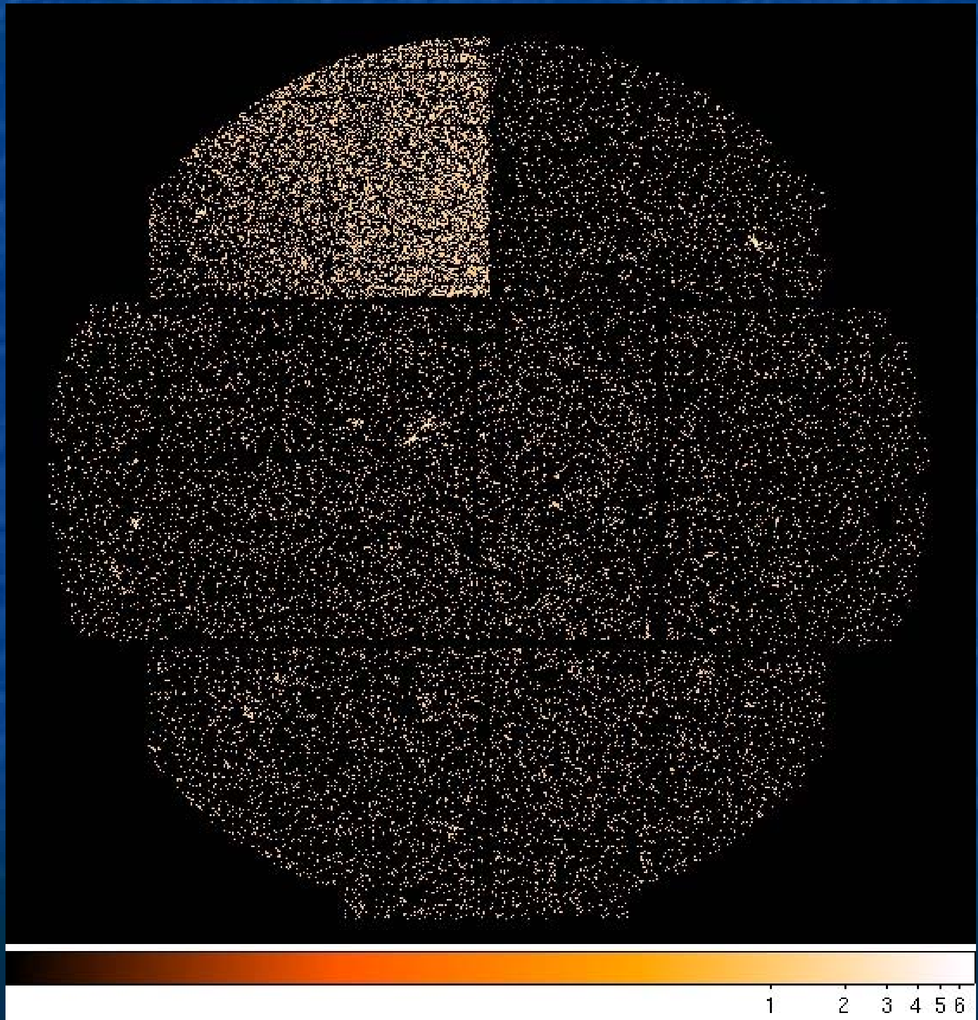
Comparison of the quiescent particle background in the FOV (black line) and corner regions (blue line). The green line is the corner spectrum normalized to the FOV spectrum in the 2.0-10.0 keV band.

Step 2 – Model the Quiescent Particle Background



The temporal variation of the quiescent particle background measured by MOS1 CCD #5. (Top) the 0.3-10.0 keV band count rate and (bottom) the (2.5-5.0 keV)/(0.4-0.8 keV) band ratio. In red are those observations for which the hardness ratio is <1.5.

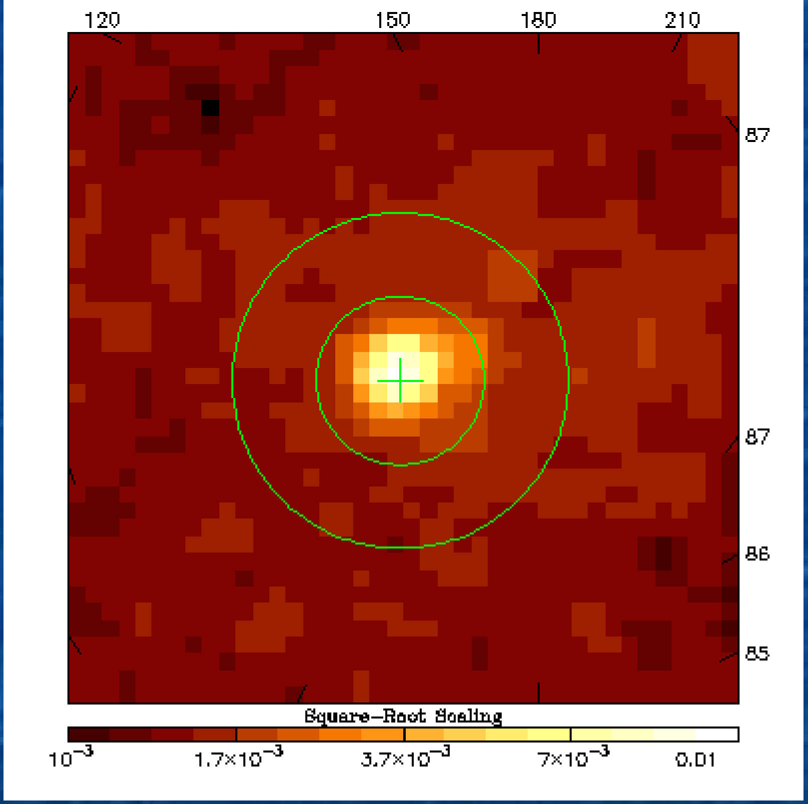
Step 2 – Model the Quiescent Particle Background



Data should be screened for CCDs operating in a high background mode. MOS 2 image when CCD #5 is acting up. Data were extracted with (FLAG == 0)&&(PATTERN <= 12)&&(PI in [200:1000]). These data are unlikely to be modeled correctly so data from the affected CCDs should probably be excluded from any analysis.

Step 3 – Get the RASS Spectrum for the Area

- Use the HEASARC X-ray Background Tool to create both a spectrum of the cosmic background for the region of interest and to download a ROSAT response matrix http://heasarc.gsfc.nasa.gov/cgi-bin/Tools/xraybg/xraybg.pl
- The X-ray Background Tool has both annuli and cone modes



Coma cluster plot with a 1-2 degree annulus produced by the X-ray Background Tool

Step 4 – Fit the Spectrum

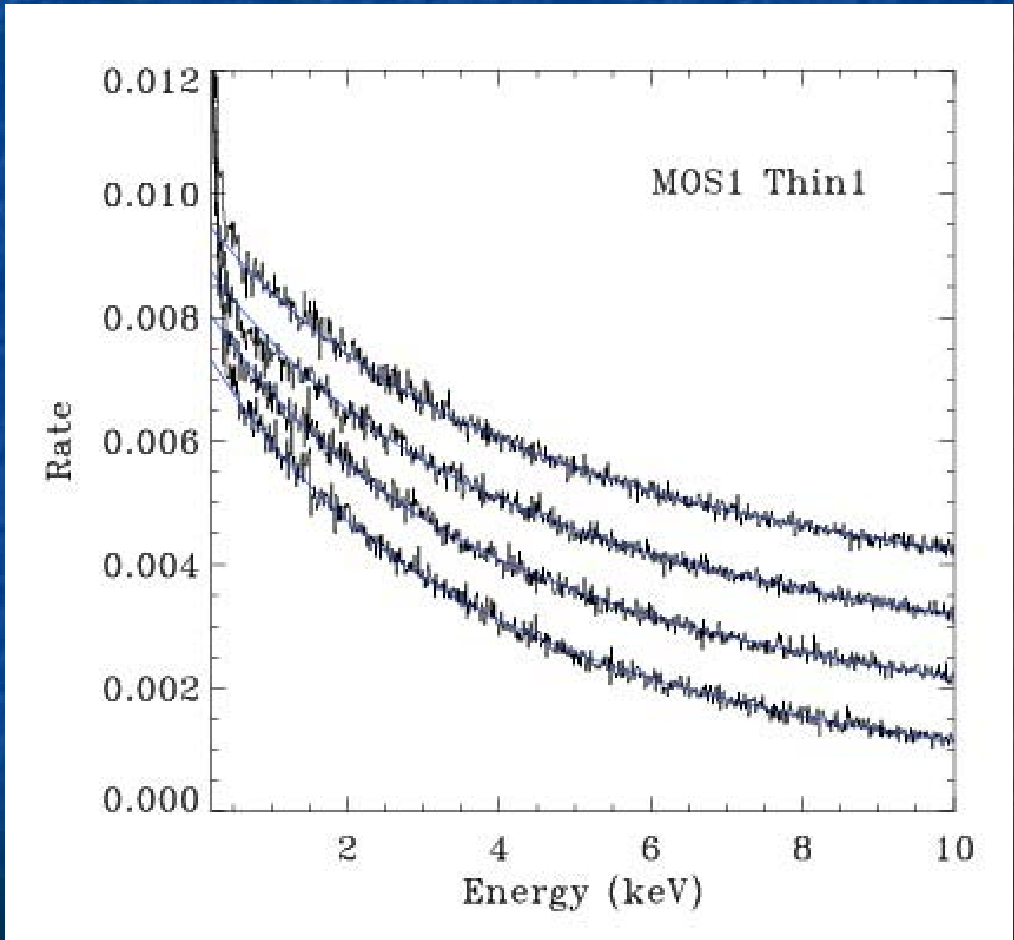
- The model should include spectra for the source of interest, the cosmic background, instrumental Al Kα and Si Kα, a scale factor for the solid angle, and an unfolded broken power law for any residual soft proton contamination.
- bknpow/b + gauss + gauss + con*(apec + (apec + apec + pow)*wabs) + source

Step 4 – Fit the Spectrum

bknpow/b + gauss + gauss + con*(apec1 + (apec2 + apec3 + pow)*wabs) + source (Xspec11)

- bknpow/b represents the residual soft proton contamination
- gauss + gauss are the Al Kα and Si Kα instrumental lines
- con scales for the different solid angles (in units of arc minutes)
- apec1 is the LHB, apec2 is the soft halo, apec3 is the hard halo
- pow is the extragalactic background
- wabs is the Galactic column density
- source is your favorite source spectrum

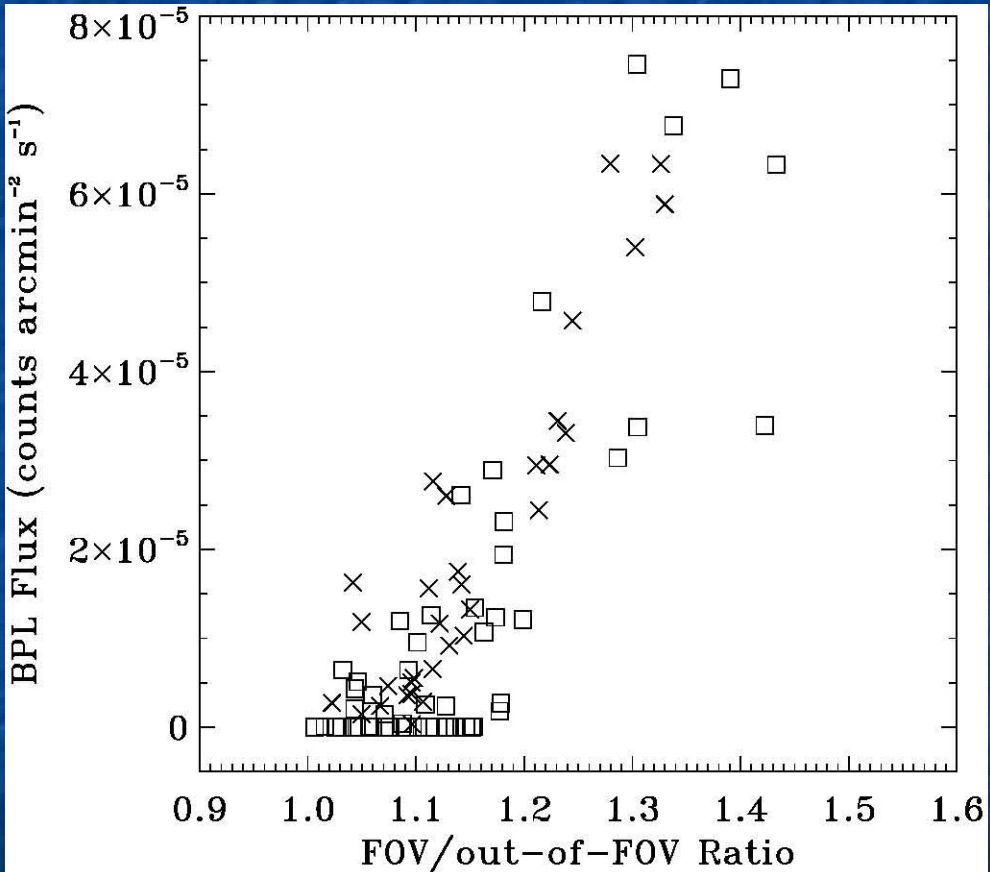
Step 4 – Fit the Spectrum



Average spectra of the residual soft proton flux from the MOS1 detector with the thin filter. The flare levels are at 1.0-2.0, 2.0-3.0, 3.0-4.0, and 4.0-5.0 counts per second

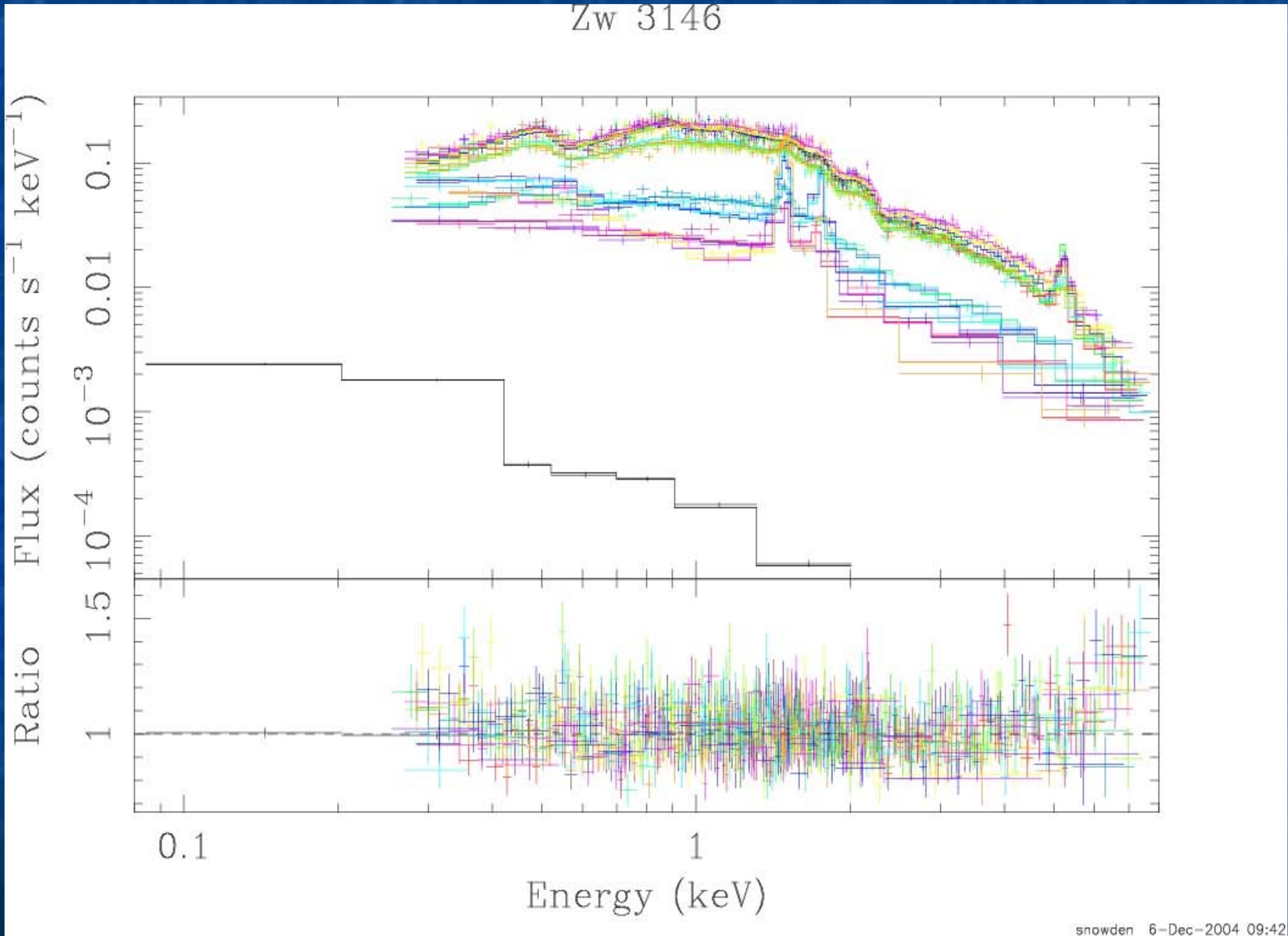
The fits here were done using two exponentials. As a practical matter, I've used a broken power law with the break energy fixed to 0.5 keV. The upper energy power law index is about 0.5 while the lower energy power law index tends to be 1.5-3.0

Step 4 – Fit the Spectrum



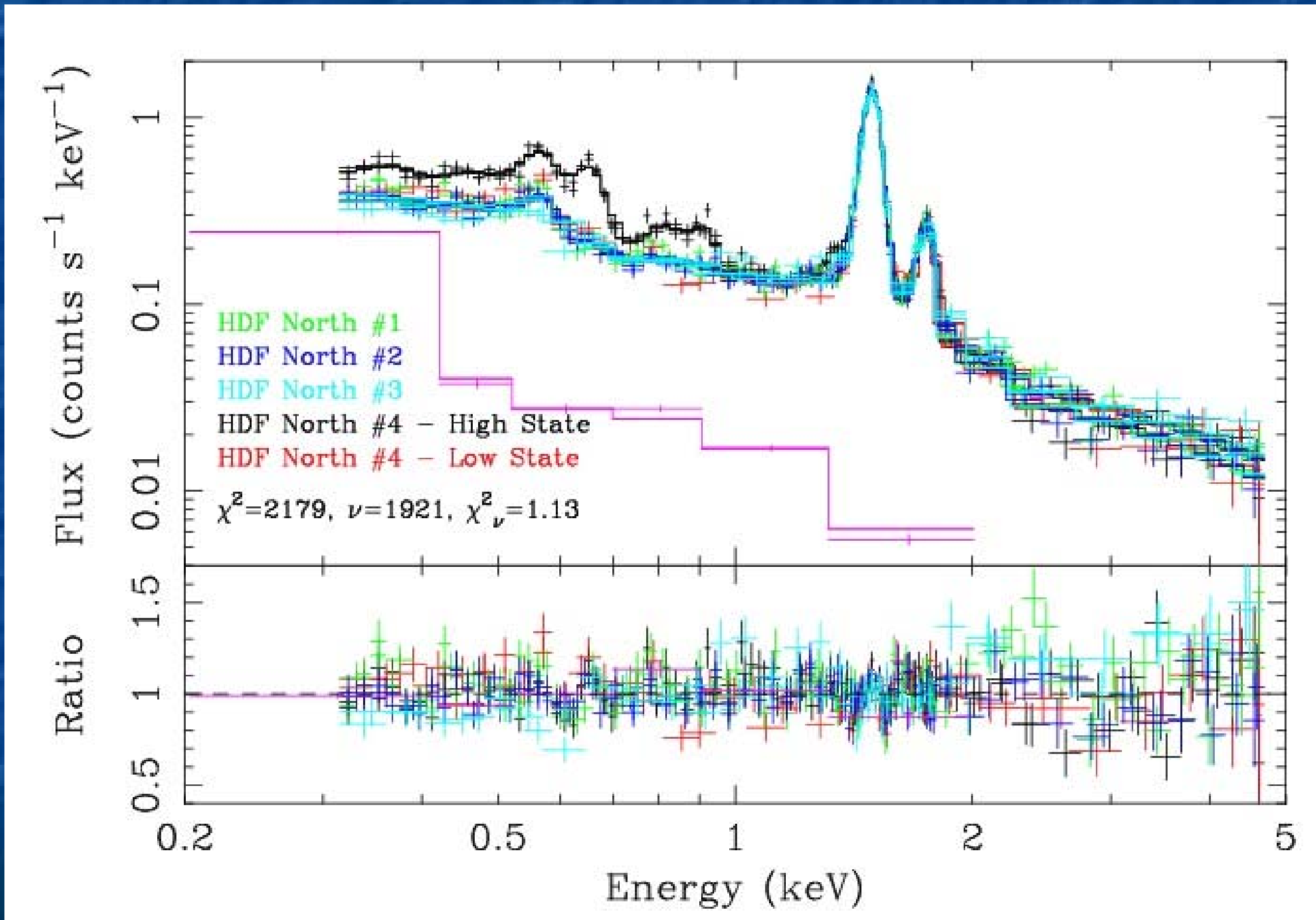
Comparing the de Luca and Molendi ratio criteria (8-12 keV band) and the fitted flux for screened observations shows that the dL&M criteria (FOV/out-of-FOV Ratio) is a good identification of observations affected by residual contamination.

Step 4 – Fit the Spectrum



Fitted spectra from the observation of Zw 3146 in seven (or so) annuli along with the RASS spectrum used to constrain the cosmic background.

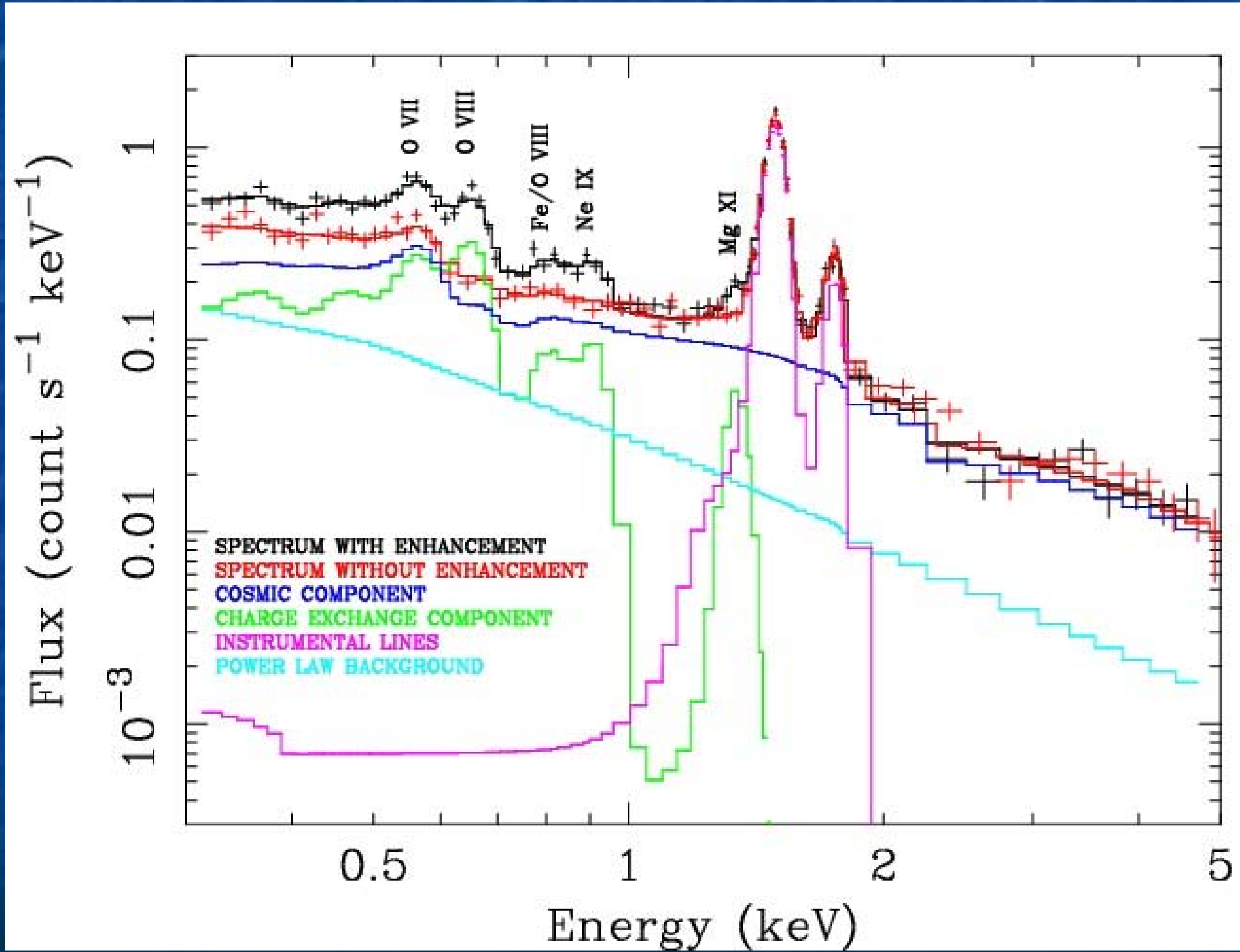
Step 4 – Fit the Spectrum



Plotted is the fitted spectrum of the Hubble Deep Field North with four separate observations one of which is separated into two parts. Also plotted is the RASS spectrum for the region.

The black curve shows the SWCX contamination.

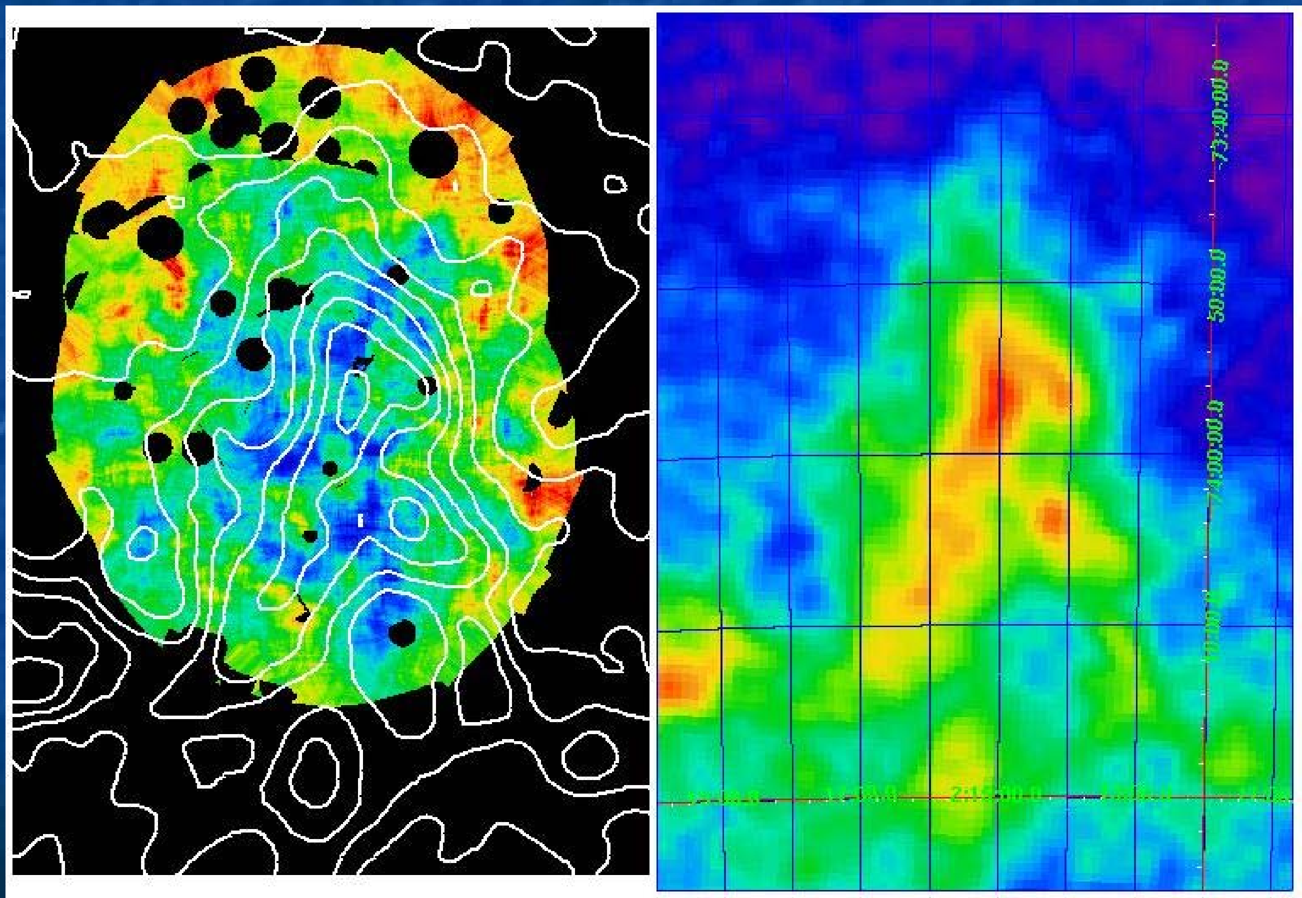
Step 4 – Fit the Spectrum



Plotted is the unfolded fitted spectrum of the Hubble Deep Field North with and without the SWCX contamination.

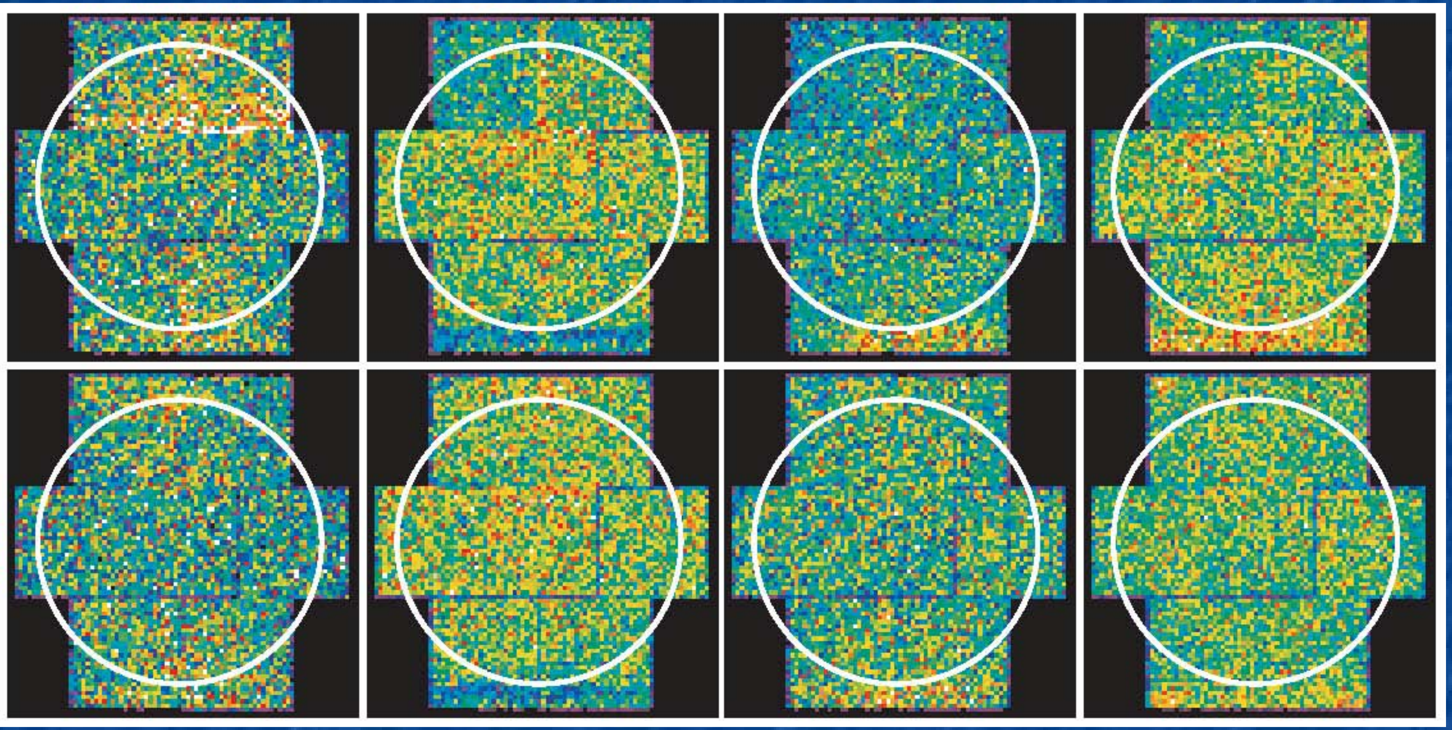
The strong OVII and OVIII emission can clearly significantly affect observations of extended sources and the diffuse background.

Background Subtracted Images



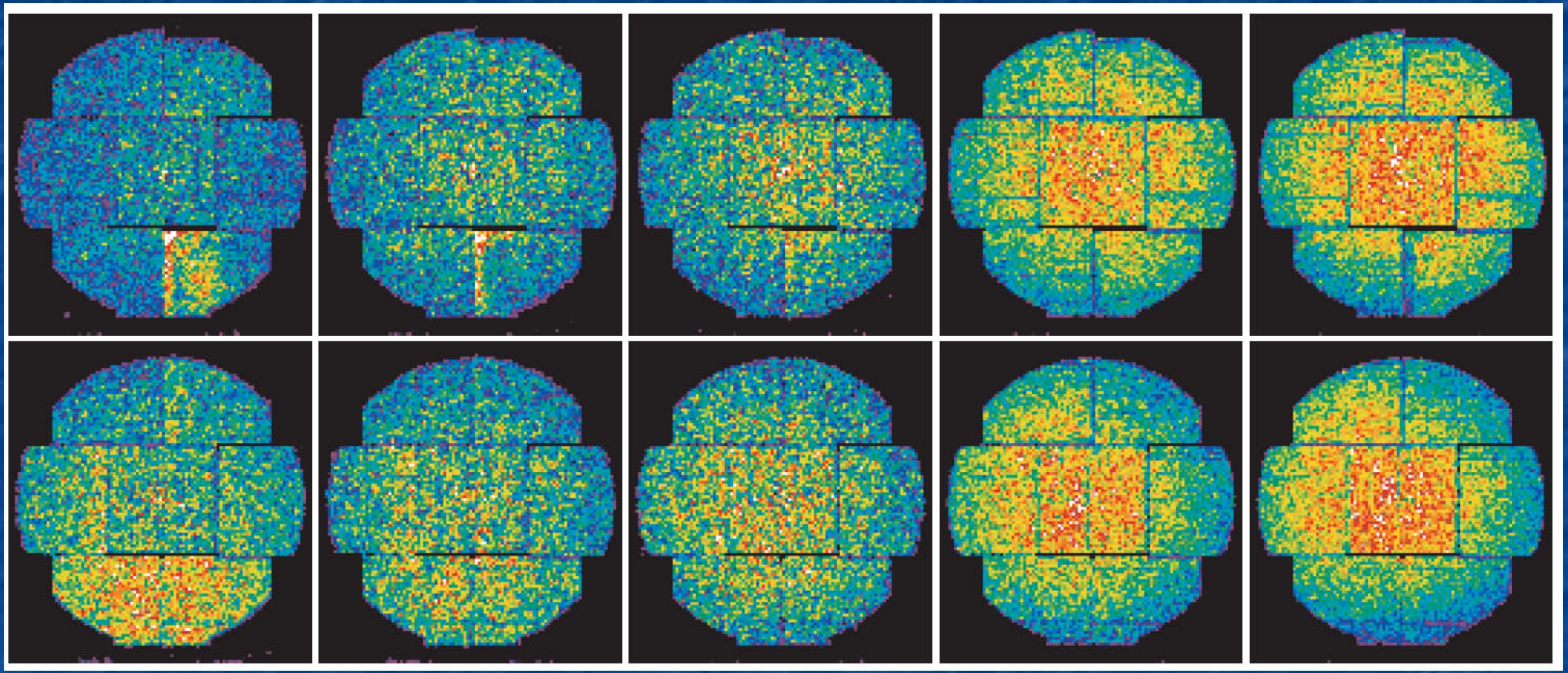
Background images are sometimes required, which adds a whole new level of complexity.

Particle Background Images



Detector map images of the quiescent particle background from FWC observations for the MOS1 (upper) and MOS2 (lower). From left to right the energy bands are 0.35-1.25 keV. 1.25-2.0 keV, 2.0-4.0 keV, and 4.0-8.0 keV.

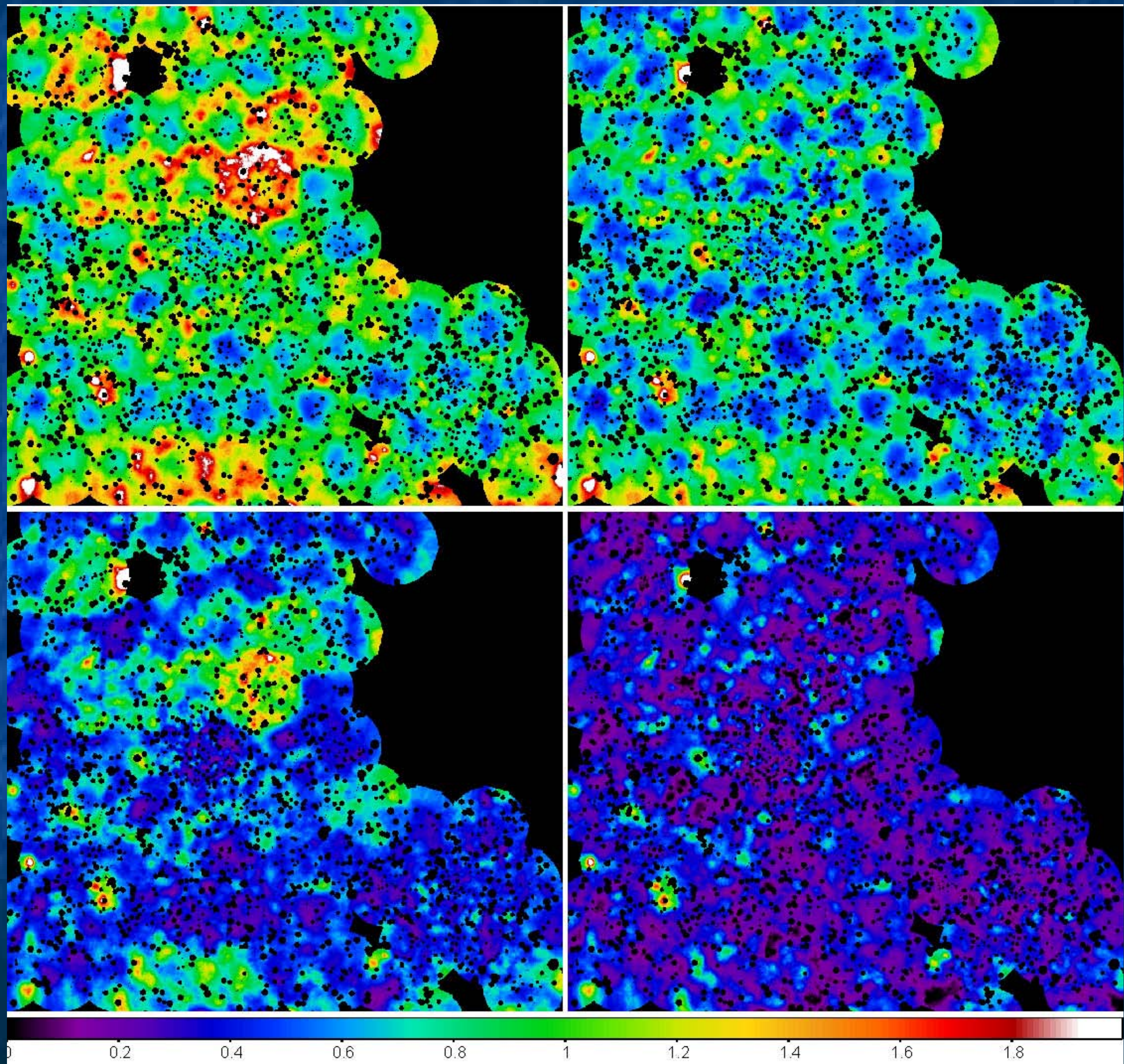
Soft Proton Contamination Images



Detector map images of the soft proton contamination for the MOS1 (upper) and MOS2 (lower). From left to right the energy bands are 0.35-0.8 keV, 0.8-1.25 keV. 1.25-2.0 keV, 2.0-4.0 keV, and 4.0-8.0 keV.

Examples – LSS

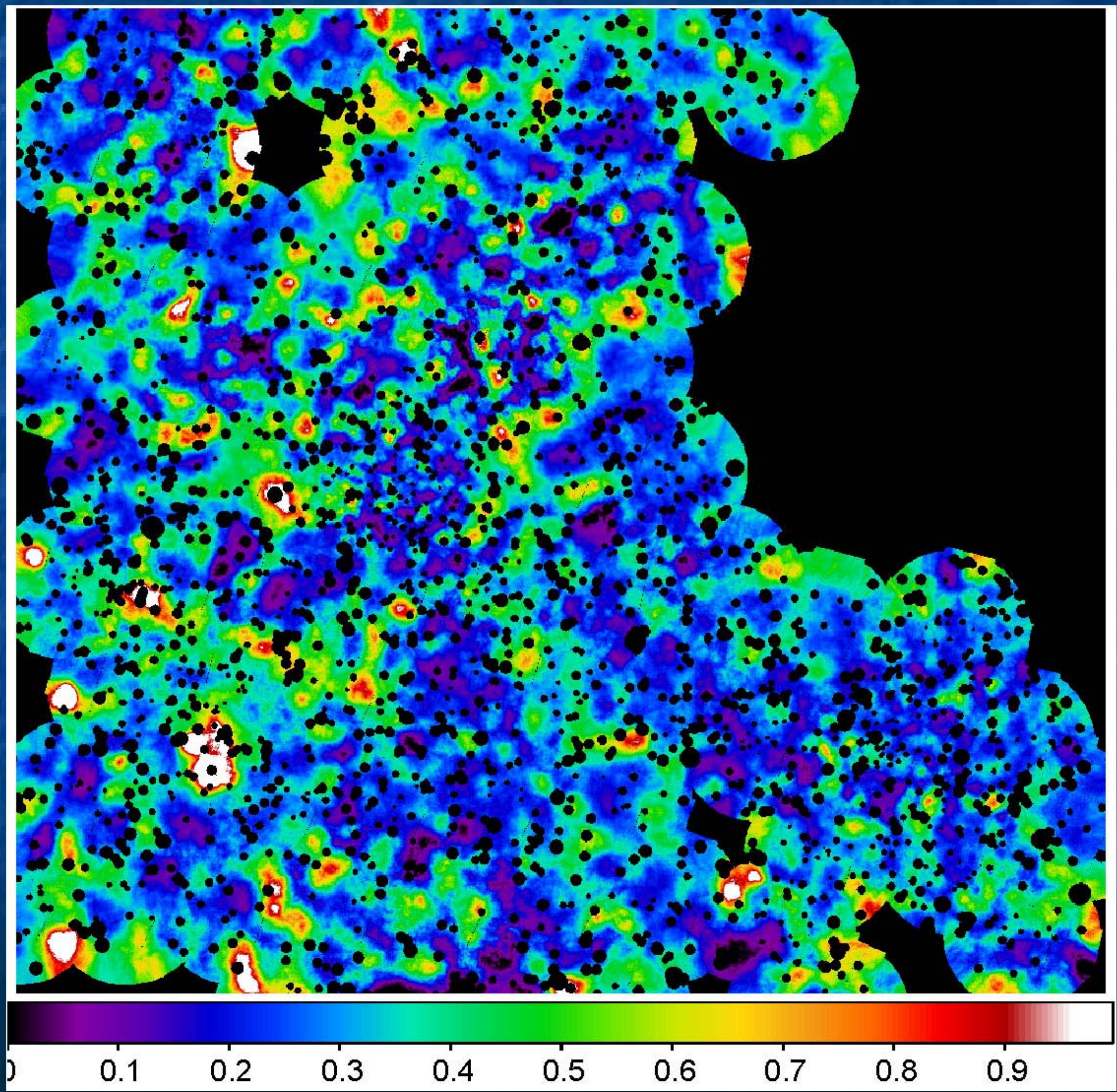
- LSS Field – MOS1 + MOS2 in the 0.8-1.25 keV band
- Upper Left: Exposure-corrected image (no background subtraction)
- Upper Right: Soft proton background modeled and subtracted
- Lower Left: Quiescent Particle background subtracted
- Lower Right: Background subtracted and exposure corrected image.
- Intensity Scale – counts s^{-1} deg^{-2}



Examples – LSS

LSS Field – MOS1 + MOS2 in the 0.8-1.25 keV band

Intensity Scale – counts s^{-1} deg^{-2}

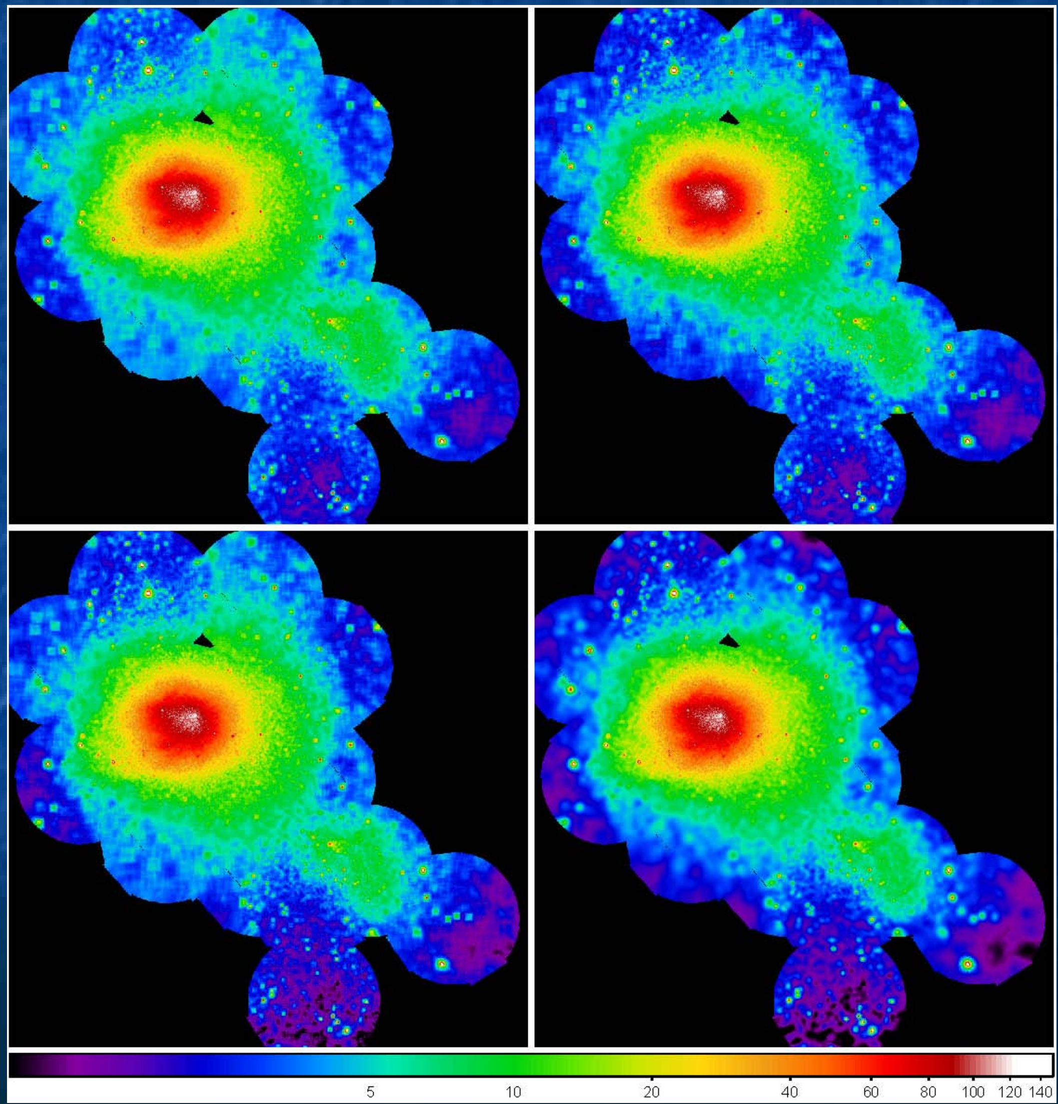


Examples – Coma Cluster

Coma Cluster – MOS1 + MOS2 in the 0.35-0.8 keV band

Upper Left: Exposure-corrected image (no background subtraction)
Upper Right: Soft proton background modeled and subtracted
Lower Left: Quiescent Particle background subtracted
Lower Right: Background subtracted and exposure corrected image.

Intensity Scale –
counts s-1 deg-2



What Now?

- Extend software to PN
- Refine treatment of SWCX – Diagnostic tools
- Refine treatment of soft proton flares
- Improve code, scripts, and documentation
- Include in SAS?