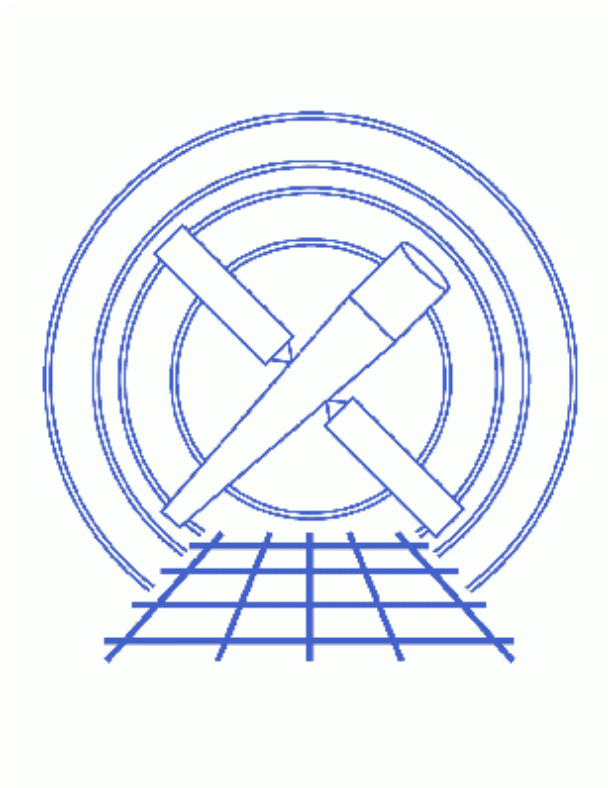


Simulating an ACIS Spectrum for an On-axis Point Source, Including Pileup for Proposal Purposes



POG Threads

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Proposal Threads for

1. Thread Overview


Please note that although RPS forms and roll/visibility results have been updated for Cycle 9, this thread uses calculated values based on Cycle 7 effective area curves. The steps you need to take to complete the thread are the same for this cycle, however you may see slight differences in numerical results if you use Cycle 9 curves. If you have any questions about the results you get by following this thread, please contact the [HelpDesk](#).

This thread shows how to simulate a simple ACIS spectrum, including pileup. Our target for this example is a highly variable AGN, RX JXXXX.X-XXX. We do not give the coordinates of this source to protect proprietary proposal information. This object was detected in the ROSAT All Sky Survey, and subsequent observations with ASCA show it to be very highly variable. Our goal is to monitor this source to characterize its variability (a total of 2 observations). We need to determine the length of an exposure required to constrain the power law spectral index to within 30%.

Because the source is so variable we need to simulate the spectrum in both low and high flux states. In the low state the spectral slope has a power law photon index of 1.6, and the 2–10 keV flux is $2.7E-14$ ergs/s/cm². Note that JXXXX.X-XXX has been observed to vary by at least a factor of 30 on timescales of weeks. For the high state, we will assume a 2–10 keV flux of $2.0E-12$ ergs/s/cm². This is 100 times the low state flux.

2. Preliminary Considerations

Here are some of the things you should consider when you begin the proposal process.

- You need to have CIAO installed
- Download the [Cycle 7 instrument responses](#). These are provided for proposal purposes only; THEY SHOULD NOT BE USED FOR DATA ANALYSIS.
- Check for previous observations of JXXXX.X-XXX. You will need to justify additional observations if any are found. For detailed instructions, please refer to the ["Proposing to Observe an On-Axis Point Source with ACIS"](#) thread.
- Check for other bright sources in the field-of-view. The Observation Visualizer ([obsvis](#)) is available for this task. For further information, please refer to the ["Proposing to Observe an On-Axis Point Source with ACIS"](#) thread. For this target, the FoV looks like [this](#) .
- Find the column density of galactic neutral hydrogen, N_H. The tool [colden](#) is available at: <http://cxc.harvard.edu/toolkit/colden.jsp>. For this source, we obtained a galactic N_H of 2.57e20 cm⁻².
- See the CIAO [FAKEIT](#) thread and [Pileup](#) thread for more information on the FAKEIT command and fitting a piled spectrum within sherpa.

3. Simulate Spectrum with Source in Low State

Run Sherpa and Read Instrument Response Files

Run sherpa:

```
unix% sherpa

-----
Welcome to Sherpa: CXC's Modeling and Fitting Program
-----
Version: CIAO3.3

Type AHELP SHERPA for overview.
Type EXIT, QUIT, or BYE to leave the program.

Notes:
  Temporary files for visualization will be written to the directory:
  /tmp
  To change this so that these files are not deleted when you exit Sherpa,
  edit $ASCDS_WORK_PATH in your 'ciao' setup script.

Abundances set to Anders and Grevesse
```

The CXC provides a set of instrument responses for use in proposal planning. For this thread we use responses appropriate for ACIS-S on-axis. These are the Area Response File ``aciss_aimpt_cy07.arf" and the Redistribution Matrix ``aciss_aimpt_cy07.rmf". The Area Response File contains the effective area information and the Redistribution Matrix gives the PHA to energy mapping.

The following command defines a name ``aciss" for the responses (instrument files).

```
sherpa> rsp[aciss](aciss_aimpt_cy07.rmf,aciss_aimpt_cy07.arf)
The inferred file type is ARF. If this is not what you want, please
specify the type explicitly in the data command.
```

These two responses can be referenced by their name ``aciss", as shown below.

```
sherpa> show aciss
rspld[aciss]
  Param  Type  Value
  -----
  1      rmf  string: "aciss_aimpt_cy07.rmf" (N_E=1024,N_PHA=1024)
  2      arf  string: "aciss_aimpt_cy07.arf" (N_E=1024)
```

The following command assigns the instruments files ``aciss" to dataset number 1.

```
sherpa> instrument 1 = aciss
```

Define the Model

In Sherpa, model components are defined and labeled, allowing different model components to be applied differently to each dataset. The following command creates a model named ``pl". This is the XSPEC powerlaw function, with parameters photon index and normalization. Note that the normalization is currently set to 1.0 and

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will be adjusted later so that the fake spectrum has the correct flux. Sherpa will prompt for the parameters:

```
sherpa> xspowerlaw[pl]
pl.PhoIndx parameter value [1] 1.6
pl.norm parameter value [1]
```

Similarly, the following creates a model of the galactic absorption, `g_abs`, using the result obtained from `colden`:

```
sherpa> xswabs[g_abs]
g_abs.nH parameter value [0.1] 0.026
```

Then tell Sherpa that the model source for dataset 1 is the galactic absorption modifying the power law

```
sherpa> source 1 = g_abs*pl
```

Run FAKEIT

Having defined a model for dataset 1, we can now create a fake datafile using the command `FAKEIT`. `FAKEIT` creates a simulated 1-D dataset from the source model and instrument model, and then adds Poisson noise to the modeled data. `FAKEIT` has two parameters:

```
sherpa> show fakeit
Fakeit exposure time: 1 seconds.
Fakeit backscale: 1
```

The exposure time should be set to the required value (exposure time in seconds.) The backscale parameter is taken from the header of the background PHA file (if one is in use), but can also be set manually.

Set the exposure time to be 80 ks. This is an initial guess and might need to be changed later:

```
sherpa> fakeit time=80000
```

Now run `FAKEIT`:

```
sherpa> fakeit
```

The simulated dataset can be inspected using `show data`. Note that the data is NOT written to disk until the `write` command is given.

```
sherpa> show data
Y Column: Counts/sec/keV
Dimensions: 1
Total Size: 1024 bins (or pixels)
Axis: 0; Name: Energy (keV)
Length: 1024 bins (or pixels)
File Name: fake
SubSection (if any):
File Type: PHA
Exposure:      80000 sec
Background Scale:      1
[0.010950] =      0
[0.021900] =      0
[0.036500] =      0
[0.051100] =      0
[0.065700] =      0
[0.080300] =      0
[0.094900] =      0
[0.109500] =      0
```

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```
[0.124100] = 1.1986e-02
[0.138700] = 0.9623
[0.153300] = 10.6361
[0.167900] = 40.5659
[0.182500] = 67.6721
[0.197100] = 88.952
[0.211700] = 105.4478
[0.226300] = 121.3458
[0.240900] = 146.2835
---output truncated---
```

Normalize the Simulated Data

The simulated data file currently does not have the correct normalization—the flux of the simulated data is incorrect because the power law normalization was arbitrarily set to 1.0. To correct the flux we need to adjust the normalization. First compute the flux predicted by the model in units of photons/cm**2/s and ergs/cm**2/s, respectively, using the FLUX and EFLUX commands:

```
sherpa> flux(2:10)
Flux for source dataset 1: 0.681421 photons/cm**2/s
sherpa> eflux(2:10)
Flux for source dataset 1: 4.77528e-09 ergs/cm**2/s
```

The 2–10 keV flux of this source has been measured at $2.70\text{E}-14$ ergs s⁻¹ cm⁻² in the low state. Therefore the correct normalization is $2.7\text{e}-14/4.77528\text{e}-09=5.65\text{e}-6$. The normalization of the model can now be adjusted and FAKEIT run again:

```
sherpa> pl.norm=5.65e-6
sherpa> fakeit
```

Now check that the flux is correct using FLUX and EFLUX as above:

```
sherpa> flux(2:10)
Flux for source dataset 1: 3.85003e-06 photons/cm**2/s
sherpa> eflux(2:10)
Flux for source dataset 1: 2.69803e-14 ergs/cm**2/s
```

The flux is now correct.

The total number of counts in the simulated dataset created by fakeit can be derived using the DCOUNTS command ([dcounts](#)). The following gives the number of counts between 0.3 and 8keV:

```
sherpa> dcounts(0.3:8)
Observed counts for source dataset 1: 344 counts
```

Since DCOUNTS yields results from a single randomized simulation, you may wish to compute the number of counts predicted by the model, using the MCOUNTS command ([mcounts](#)). The "theoretical" total number of counts is calculated here:

```
sherpa> mcounts(0.3:8)
Model counts for source dataset 1: 369.537 counts
```

Fit the Simulated Spectrum and Calculate Uncertainties

This is a small number of counts for a spectral fit, but it should be possible to constrain the spectral slope. To estimate the uncertainties in the slope when the source is in the low state, freeze the galactic absorption and fit the fake spectrum.

```

sherpa> freeze g_abs.nh
sherpa> fit
LVMQT: V2.0
LVMQT: initial statistic value = 57.0609
LVMQT: final statistic value = 55.7574 at iteration 4
      pl.PhoIndx  1.77026
      pl.norm    5.2662e-06 photons/keV/cm**2/s at 1 keV

```

Now use the covariance command to get 1 sigma uncertainties. Setting the set_verbose parameter allows you to view covariance matrix and eigenvector information:

```

sherpa> set_verbose(2)
sherpa> covariance
Information Matrix (Second Derivatives of Fit Statistic):

      pl.PhoIndx      pl.norm
      22.6705         -96724.3
      -96724.3       3.20401e+12

Eigenvectors (Principal Axes) of the Covariance Matrix:

      pl.PhoIndx      pl.norm
      1              -3.01885e-08
      3.01885e-08     1

Eigenvalues of the Covariance Matrix:

      0.044116       3.12109e-13

Covariance Matrix (Inverse of Information Matrix):

      pl.PhoIndx      pl.norm
      0.044116       1.3318e-09
      1.3318e-09     3.12149e-13

Covariance Matrix Determinant (Product of Eigenvalues): 1.3769e-14

Computed for sherpa.cov.sigma = 1
-----
Parameter Name      Best-Fit Lower Bound      Upper Bound
-----
      pl.PhoIndx      1.77026  -0.210038  +0.210038
      pl.norm        5.2662e-06  -5.58703e-07  +5.58703e-07

```

With this many counts, the photon index can be measured to about 30%, as required. This means that even if the source is in the lowest observed state the slope can be meaningfully constrained. If the source is brighter, then the uncertainties will be reduced.

Alternate Strategy: Normalize Spectrum Using Predicted Count Rate

The spectrum can also be normalized to the Chandra predicted count rate. In this case the steps are:

- Obtain predicted Chandra count rate (e.g. from PIMMS).
- Follow steps outlined above to get a fake spectrum with normalization of 1.0.
- Use the Sherpa SHOW command to get the count rate in the fake spectrum with normalization=1.0.
- Adjust the normalization so that the count rate in the new spectrum is correct.

4. Simulate Spectrum with Source in High State

Getting Started

In the high state the flux is 100 times that of the low state and pileup must be considered. If you haven't followed the first part of the thread, repeat the first four steps as in the low state case above (Read Responses through Normalize Simulated Data) using a power law normalization of 100 times the low state normalization ($5.65e-4$). If you have followed the steps above, reset the slope to 1.6, set the normalization to $5.65e-4$, and rerun FAKEIT.

```
sherpa> pl.phoindx=1.6
sherpa> pl.norm=5.65e-4
sherpa> fakeit
```

Check that normalization is as expected:

```
sherpa> flux(2:10)
Flux for source dataset 1: 0.000385003 photons/cm**2/s
sherpa> eflux(2:10)
Flux for source dataset 1: 2.69803e-12 ergs/cm**2/s
```

Define Pileup Model

Pileup can be included in the simulation by defining a pileup model, which is treated in the same way as any other spectral model. The model, `jdpileup`, was developed by John Davis at MIT. The parameter `alpha` is the probability that two piled photons are assigned a "bad" grade and rejected. It should be left at the default value of 0.5 and frozen. One means of pileup mitigation is to change the frame time parameter, `ftime`. It is strongly recommended that the other four parameters be frozen at the default values unless the proposer is thoroughly familiar with the pileup model. A detailed discussion is provided by [Davis \(2001, ApJ, 562, 575\)](#).

Here we define a pileup model (`jdp`).

```
sherpa> jdpileup[jdp]
jdp.alpha parameter value [0.5]
jdp.g0 parameter value [1]
jdp.f parameter value [0.95]
jdp.n parameter value [1]
jdp.ftime parameter value [3.241]
jdp.fracexp parameter value [0.987]
```


Here we use the command `pileup` to tell sherpa which pileup model to use (`jdp`, defined above) and to freeze `alpha`.

```
sherpa> pileup = jdp
sherpa> freeze jdp.alpha
```

Simulate Spectrum with Pileup

Now simulate the piled spectrum and plot the results (ignoring energies higher than 8 keV):

```
sherpa> fakeit
sherpa> ignore energy 8:
sherpa> lplot data 1
```

The plot is shown [here](#) . To illustrate the effect of pileup we have also plotted the spectrum without pileup. The unpiled spectrum has a peak count rate of slightly more than 0.3 counts/sec/keV. In contrast, the piled spectrum has a peak count rate of 0.1 counts/sec/keV because many photons are rejected and/or many low energy photons are mistakenly counted as high energies. Additional information about pileup is available in the ACIS chapter of the POG.

Pilup information for the simulated spectrum can be displayed with the SHOW command.

```
sherpa> show pileup
1: 0.337707 0.676622
2: 0.248657 0.249101
3: 0.122059 0.0611385
4: 0.0449365 0.0112542
5: 0.0132349 0.00165731
6: 0.00324831 0.000203382
7: 0.00068336 2.13932e-05
8: 0.000125791 1.969e-06
*** pileup fraction: 0.323378
```

The last line gives the pileup fraction. Lines 1–7 give further details of the pileup statistics. Line 1 indicates that 34% of the frames contained 1 photon in the pileup region, and 68% of the events were single photon events. Line 2 shows that 25% of the frames contained 2 photons, and 25% of the events were 2 photon events. For further details please see [the ISIS manual](#).

Pileup Mitigation

There are a number of ways to configure ACIS to minimize pileup. These are discussed in the POG and include offset pointing, using a transmission grating, using CC mode, alternating exposures, and reducing the frame time with a subarray. For the case of JXXXX.X–XXX, we do not know in advance whether the spectrum will be piled. The source might actually be quite faint. In this case, we wouldn't use the first four options because they are not optimized for faint sources. We are therefore left with only two choices — either use a subarray or do not take any steps to mitigate pileup. Most of the ACIS field-of-view is lost if a subarray is chosen. This would be a big disadvantage if there were other sources in the field which formed part of the proposal. Since JXXXX.X–XXX is a point source, a subarray is a good choice.

Sometimes, regardless of whether or not a subarray has been used, the pileup fraction is larger than anticipated. In this case, it is possible to estimate the pileup and recover the source spectrum using the pileup model described earlier in this section. Please see the CIAO "[Fitting Spectral Data: Using A Pileup Model](#)" thread on fitting a piled spectrum for details.

Simulating Pileup with Subarray

A subarray reduces pileup by shortening the frame time. With a shorter frame time, the probability that two photons are detected as a single event decreases. Here we simulate a 1/8 subarray, which corresponds to a frame time of 0.4 sec. Set the frame time to be 0.4 sec and then run FAKEIT again:

```
sherpa> jdp.ftime=0.4
sherpa> fakeit
sherpa> show pileup
1: 0.151544 0.95528
2: 0.0137714 0.0434052
3: 0.000834313 0.00131481
*** pileup fraction: 0.04472
```

The pileup fraction is now reduced significantly. This can also be seen in [the simulated spectrum](#) .

Finally, check the number of counts between 0.3 – 8 keV for the simulated source spectrum (High state):

```
sherpa> dcounts(0.3:8)
Observed counts for source dataset 1: 32377 counts
```

5. Complete Target Form

For general instructions on how to submit a proposal, please see the ["Using RPS to Prepare and Submit a Chandra Proposal"](#) thread.

For this observation, we will use ACIS chip S3 and the Very Faint telemetry format. Instrument configuration and telemetry formats are described in detail in the ACIS chapter of the POG.

RPS requires both the source count rate and the total field count rate (sources plus background). The purpose of these fields is to check that the total count rate does not exceed the telemetry limit. We therefore give the source count rate in the high state as $32377/80000=0.405$ cts/s.

In calculating the total field count rate, we need to consider all contributions to the background. Estimates of the background as a function of energy band are provided in the ACIS total background section of the POG. Table 6.10 gives the total background rate for the S3 BI chip to be 0.79 counts/sec/chip, for the energy band 0.3–10 keV. Since we are using a 1/8 subarray, our total background rate is 0.098 counts/sec. Therefore, the total field count rate is 0.503 counts/s.

The RPS target form should have the following parameter values for this observation. If a parameter isn't listed here, use the default RPS value or leave the field blank. Again, note that the target description keywords have been updated as of Cycle 7.

- Target Name --- JXXXX.X-XXX
- Total Observing Time (ksec) --- 160 ks
- Count Rate --- 0.405
- Total Field Count rate --- 0.503
- Exposure Mode --- TE
- Event Telemetry Format --- Very Faint

- CCD's On --- ONLY S3 should be checked Y
- Subarray Type --- Standard 1/8 subarray
- Monitoring Observation --- Y
- Number of Observation --- 2
- Geometric Factor --- 1
- Time Interval (days) --- 45
- Tolerance(%) --- 33

Use this link to view the [completed Target Form](#).

6. Thread Summary

This thread shows how to simulate a simple ACIS spectrum, including pileup. Our target is an AGN which is known to have flux that varies over two orders of magnitude. The observational goal is to obtain two observations of the source, separated by a few weeks. We performed two spectral simulations, one with the source in the low state and one in the high state. We found that we could measure the power law slope in the lowest flux state to 30% with an 80 ks observation. In the high flux state we found that the source was highly piled. We found that we could reduce the pileup in the high flux state by using a 1/8 subarray. Since we do not know in advance what the flux will be, we choose both observations in subarray mode. Our total requested exposure time is 160 ks.

History

- 15 Jan 2003 Initial Version
- 15 Dec 2003 Updated for Cycle 6
- 15 Dec 2004 Updated for Cycle 7
- 15 Dec 2005 Updated for Cycle 8
- 15 Dec 2006 Updated for Cycle 9

URL: <http://cxc.harvard.edu/pog/threads/fakeit/>

Last modified: 15 December 2006

Image 1: The Target in the Field of View

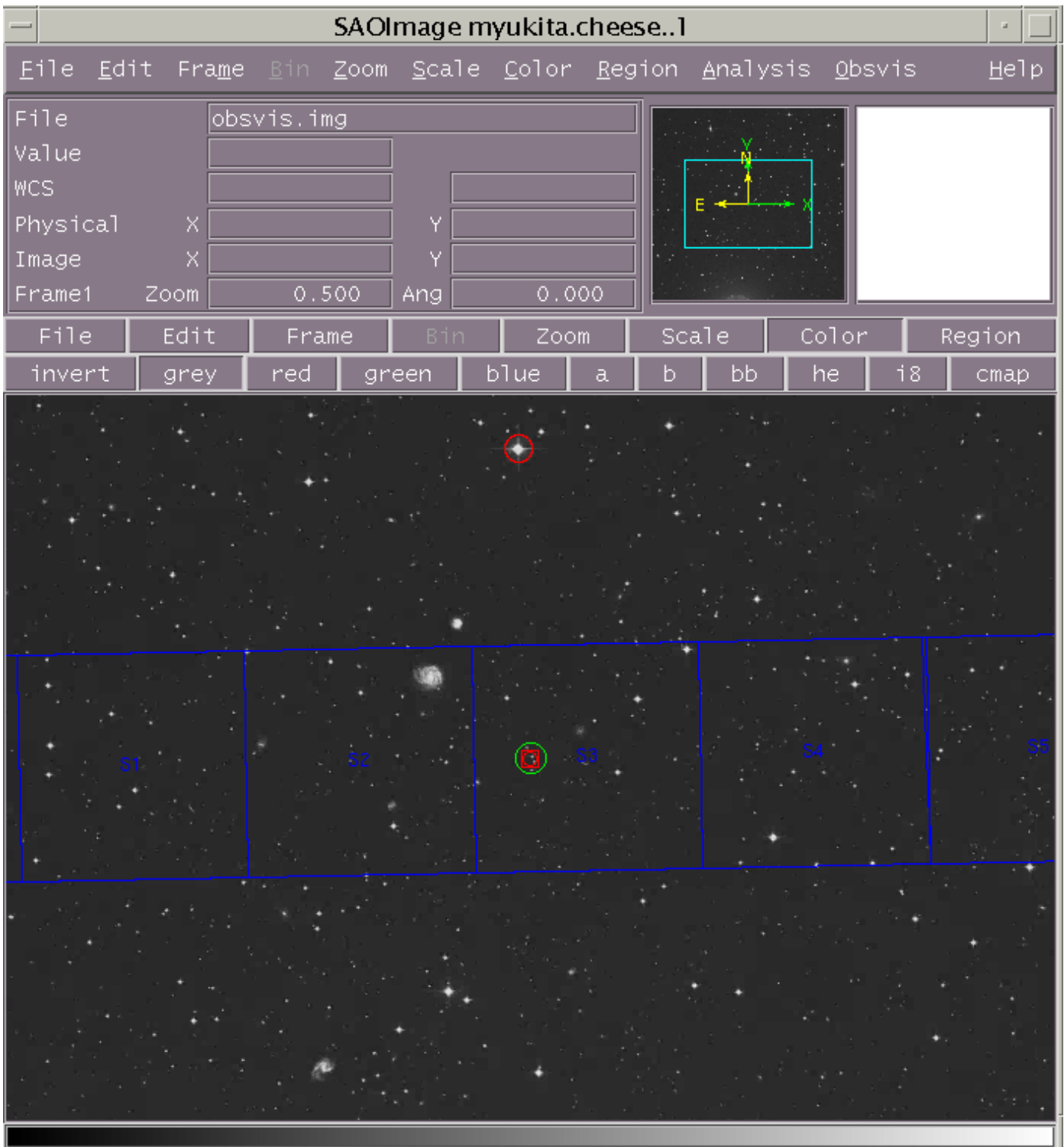


Image 2: The Piled/Unpiled Spectrum

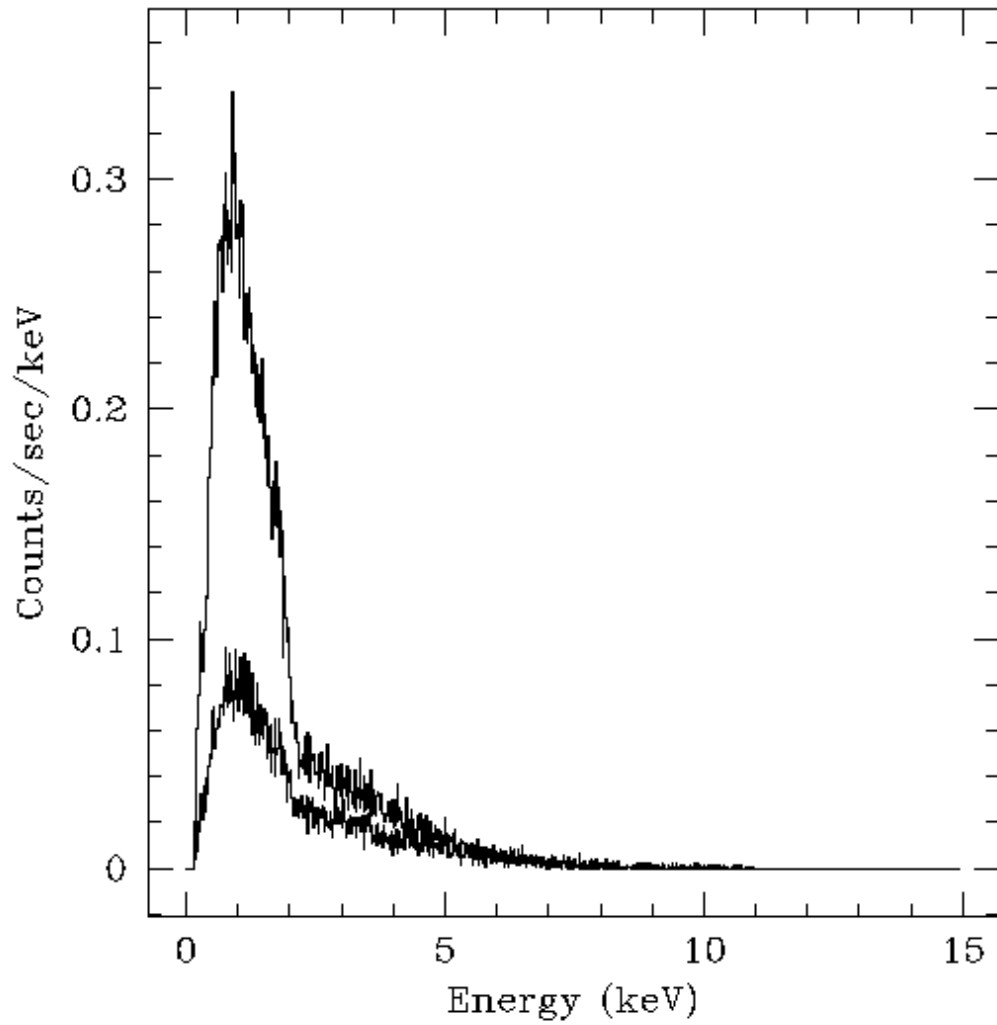


Image 3: The Piled Spectrum with Sub-array

