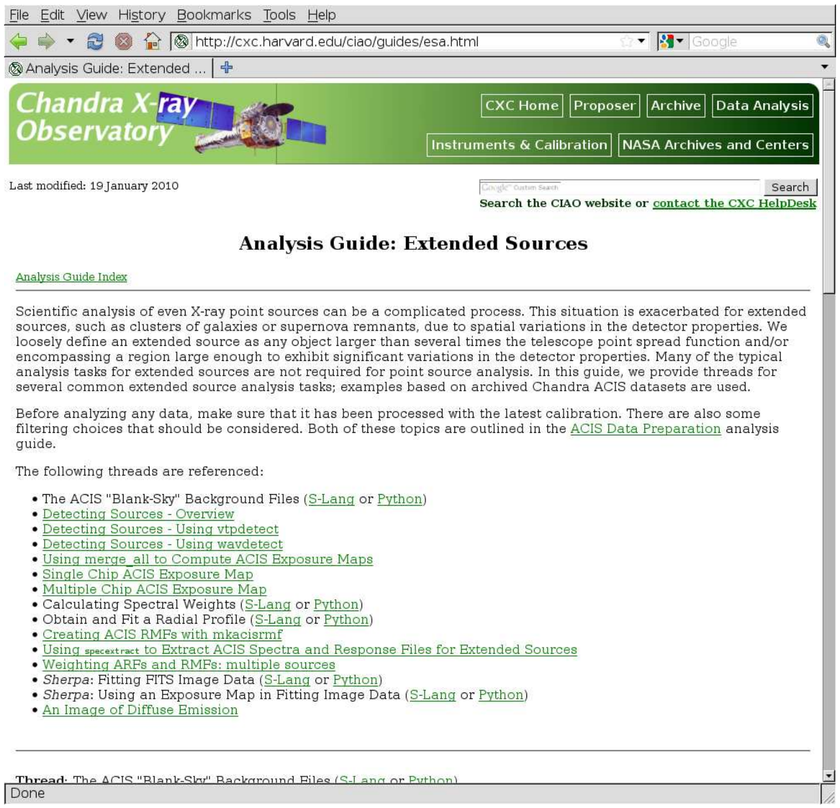
Analysis of Extended Sources

John C. Houck
<houck@space.mit.edu>



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http://cxc.harvard.edu/ciao/guides/esa.html

Analysis Guide: Extended ...

Chandra X-ray Observatory

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Analysis Guide: Extended Sources

Analysis Guide Index

Scientific analysis of even X-ray point sources can be a complicated process. This situation is exacerbated for extended sources, such as clusters of galaxies or supernova remnants, due to spatial variations in the detector properties. We loosely define an extended source as any object larger than several times the telescope point spread function and/or encompassing a region large enough to exhibit significant variations in the detector properties. Many of the typical analysis tasks for extended sources are not required for point source analysis. In this guide, we provide threads for several common extended source analysis tasks; examples based on archived Chandra ACIS datasets are used.

Before analyzing any data, make sure that it has been processed with the latest calibration. There are also some filtering choices that should be considered. Both of these topics are outlined in the ACIS Data Preparation analysis guide.

The following threads are referenced:

- The ACIS "Blank-Sky" Background Files (S-Lang or Python)
- Detecting Sources - Overview
- Detecting Sources - Using vtpdetect
- Detecting Sources - Using wavdetect
- Using merge_all to Compute ACIS Exposure Maps
- Single Chip ACIS Exposure Map
- Multiple Chip ACIS Exposure Map
- Calculating Spectral Weights (S-Lang or Python)
- Obtain and Fit a Radial Profile (S-Lang or Python)
- Creating ACIS RMFs with mkacisrmf
- Using specextract to Extract ACIS Spectra and Response Files for Extended Sources
- Weighting ARFs and RMFs: multiple sources
- *Sherpa*: Fitting FITS Image Data (S-Lang or Python)
- *Sherpa*: Using an Exposure Map in Fitting Image Data (S-Lang or Python)
- An Image of Diffuse Emission

Done

Web Documentation

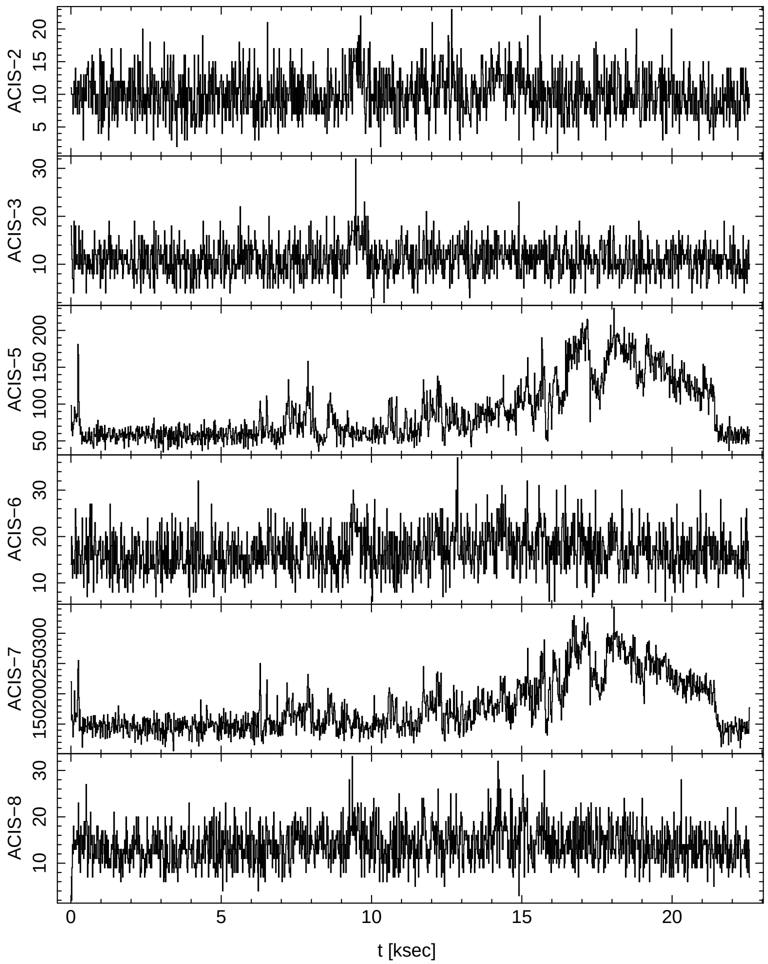
http://cxc.harvard.edu/ciao/guides/esa.html

- *ACIS* blank-sky background
- Point-source detection
- Exposure maps
- Weighted responses
- Radial profiles
- Image fitting

Important Issues

1. Background
   - remove background flares, point-sources
   - consider local background measurement *vs. ACIS* blank-sky
2. Position-dependent response
   - usually extract *PI* spectra, not PHA
   - consider weighted responses

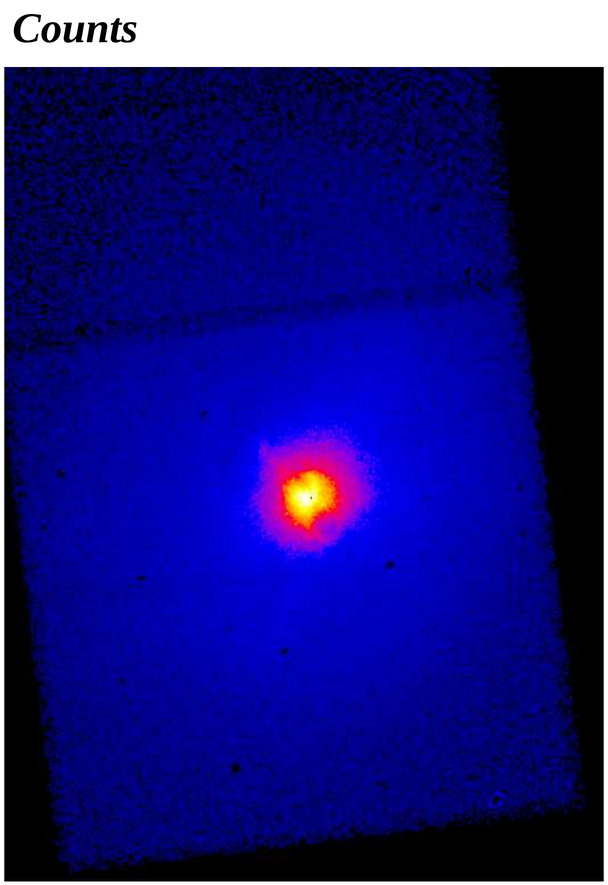
Exclude high background intervals:



- extract light-curve [dmextract]
- determine *GTI*s [lc_sigma_clip()]
- filter [dmcopy]

```
dmcopy "evt2.fits[@lc_dmgti.gti]"
       evt2_clean.fits
```

Filtered Counts Image



- reprocess [acis_process_events]
- apply custom filters (flares, bad pixels, ...) [dmcopy]
- remove point sources [wavdetect]

Remember...

Counts and photons are *not the same!* ($QE < 1$)

Flux Images

(For details, see Davis, 2001, ApJ, 548, 1010)

When mirror area & PSF vary slowly with position,

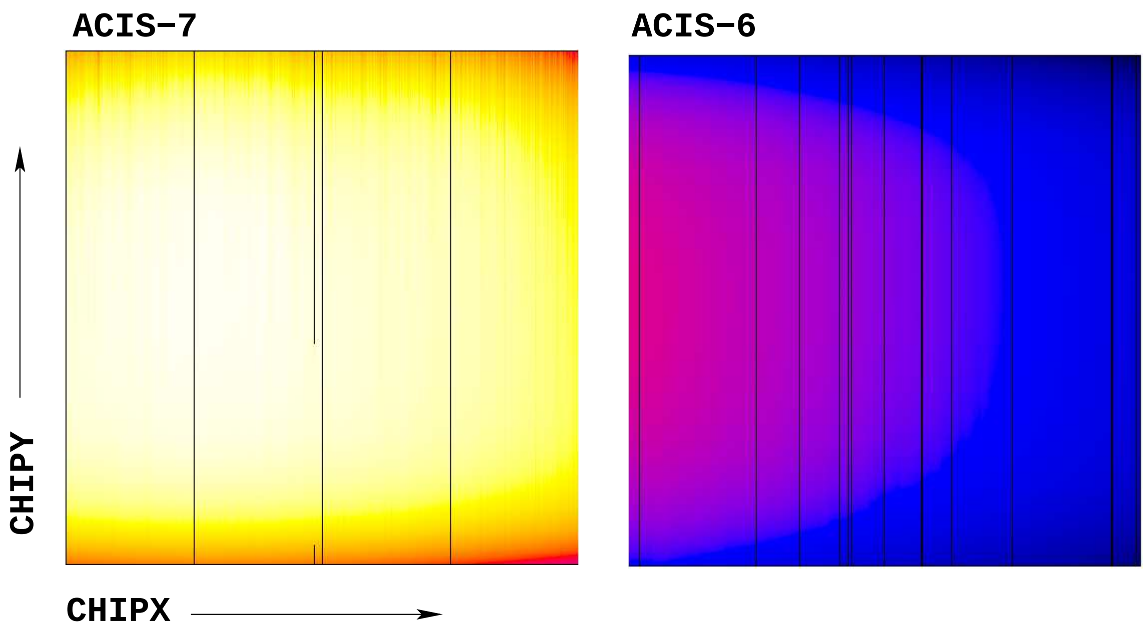
$$C(h, \hat{\mathbf{p}}) = \tau_{\text{eff}} \int dE \, \mathcal{A}(h, E, \hat{\mathbf{p}}) \, \mathcal{S}_{\text{PSF}}(E, \hat{\mathbf{p}}).$$

If $\mathcal{A} \approx$ *constant within* ΔE then, summing over Δh, ΔE:

$$\text{“Flux”} \equiv \int_{\Delta E} dE \, \mathcal{S}_{\text{PSF}}(E, \hat{\mathbf{p}}) \approx \frac{1}{\tau_{\text{eff}}} \frac{C(\Delta h, \hat{\mathbf{p}})}{\mathcal{A}(\Delta h, \Delta E, \hat{\mathbf{p}})}.$$

$\mathcal{A}(\Delta h, \Delta E, \hat{\mathbf{p}})$ is the *exposure map*.

Instrument Map

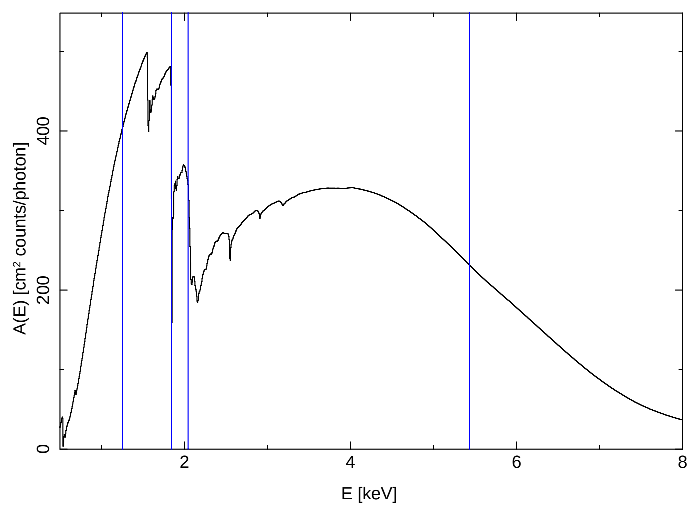


Spectrum-Weighted Instrument Map

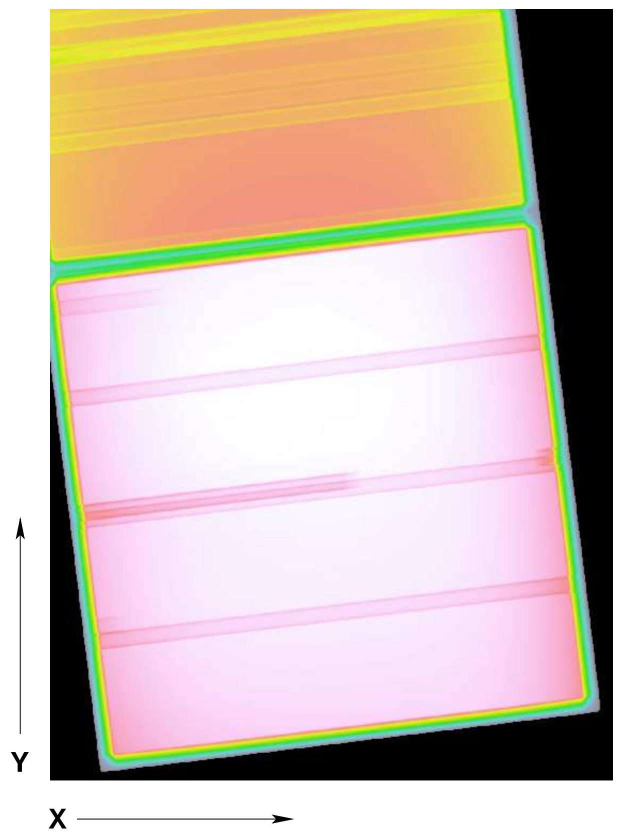
Approximating the effective area, $A(E)$, as piecewise constant,

$$C(h) = \tau \sum_k \int_{\Delta E_k} A(E) s(E) dE \approx \left(\tau \sum_k A_k w_k \right) \int_{E_{\rm min}}^{E_{\rm max}} s(E) dE$$

using weights defined by: $w_k \equiv \frac{1}{s_{\rm tot}} \int_{\Delta E_k} s(E) dE$ where $1 = \sum_k w_k$.

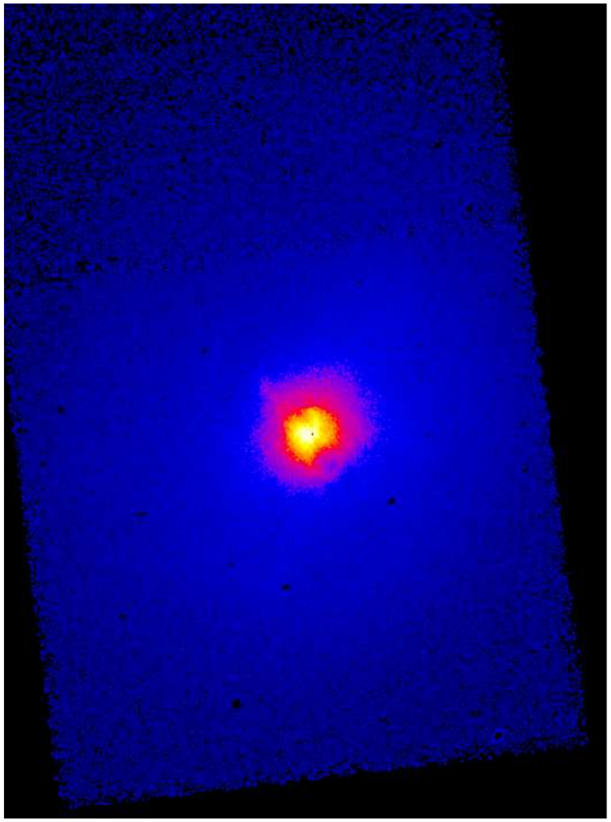


Exposure Map $\mathcal{A}(\Delta h, \Delta E, \hat{\mathbf{p}})$:



- `mkexpmap` projects the instrument maps onto the sky and includes dither.

"Flux"



- extract counts image for ΔE of interest [dmcopy]
- Divide counts by exposure map:

$$\mathcal{F}(\Delta E, \hat{\mathbf{p}}) = \frac{C(\Delta h, \hat{\mathbf{p}})}{\tau_{\rm eff}\mathcal{A}(\Delta h, \Delta E, \hat{\mathbf{p}})}$$

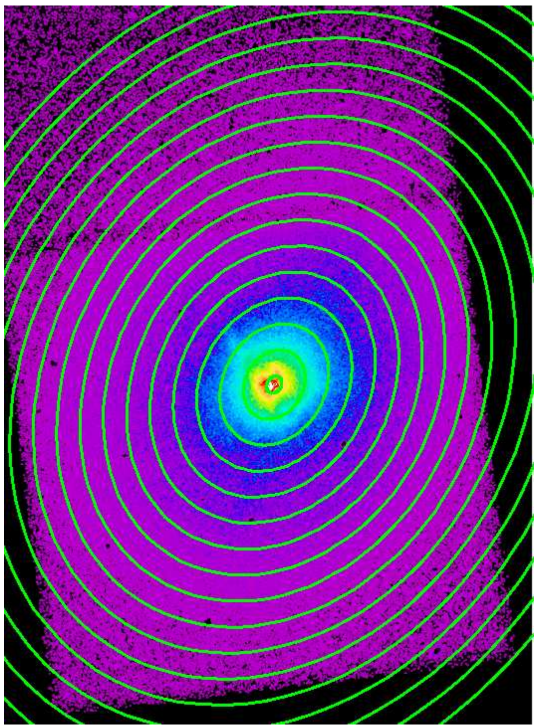
[photons s^{-1} cm^{-2}]
[dmimgthresh, dmimgcalc]

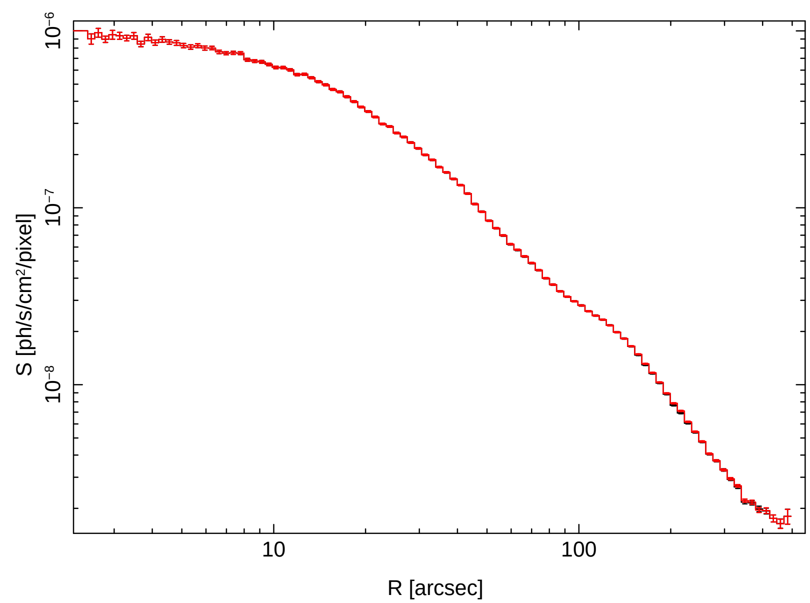
Surface Brightness Profiles

In i^{th} elliptical annulus, compute the surface brightness,

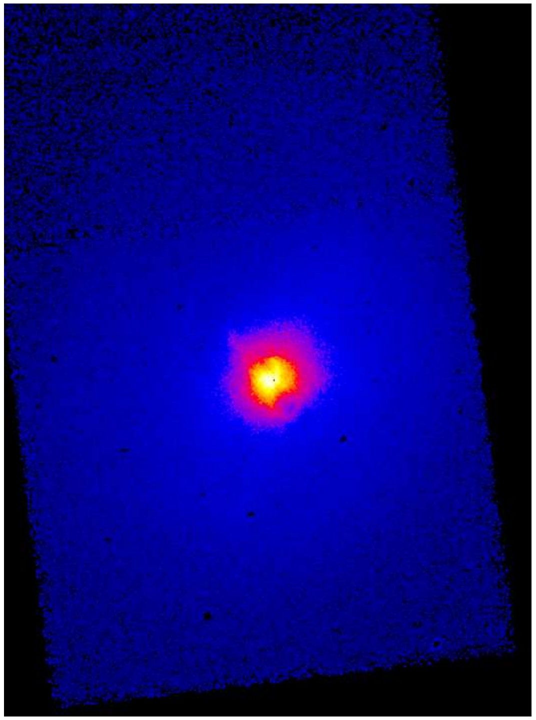
$$S_i = \frac{\sum_{k \in i} C_k}{\tau_{\text{eff}} \sum_{k \in i} \mathcal{A}_k}.$$

Elliptical Annuli

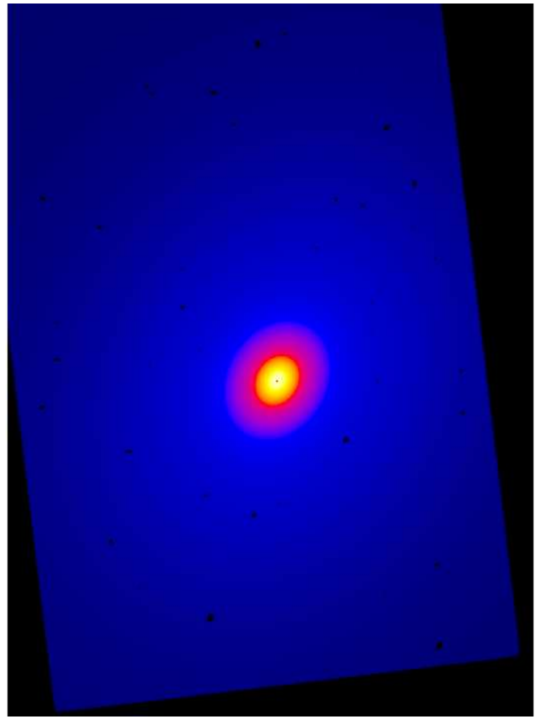




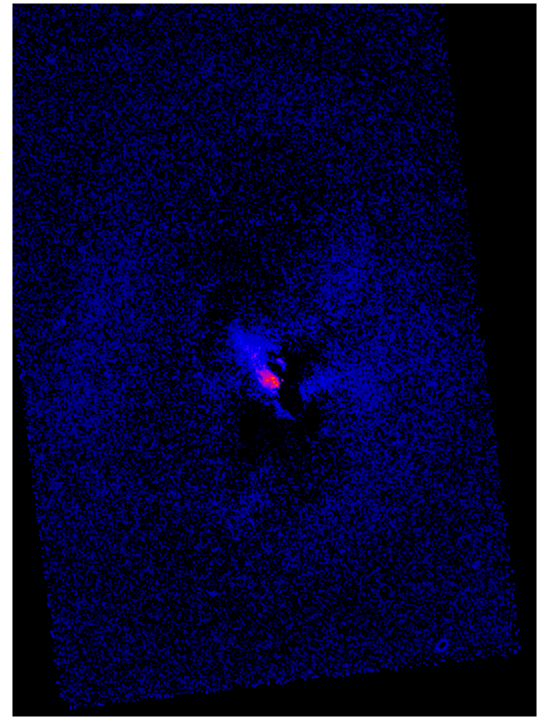
"Flux"



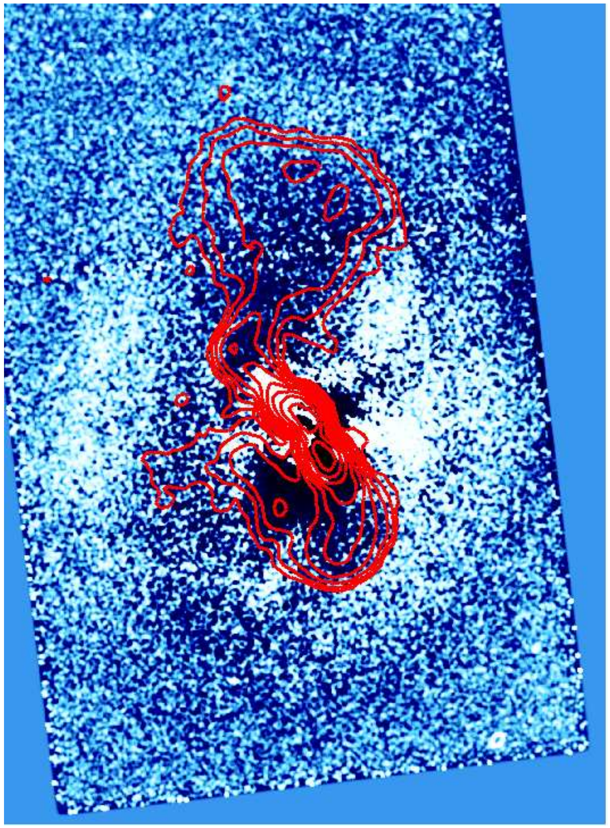
SB Profile Image



Flux residual



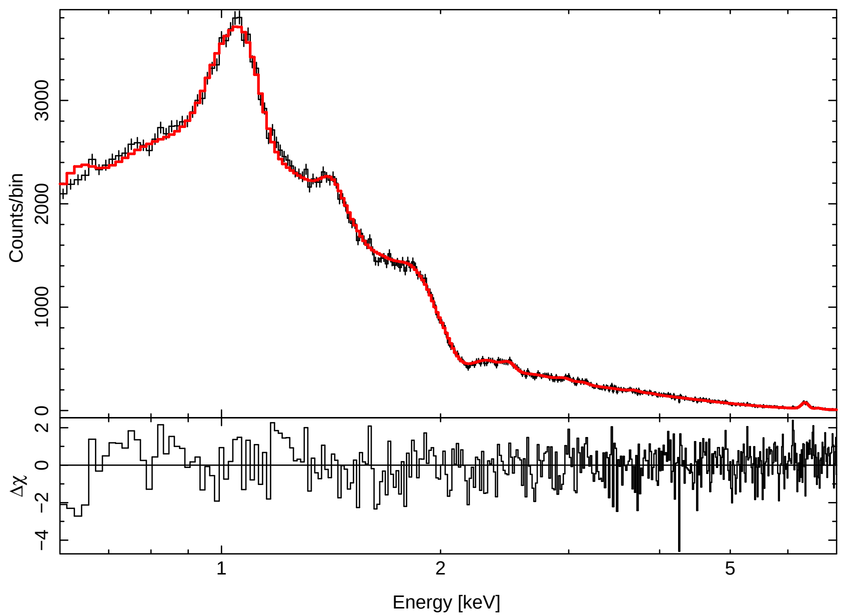
Overlay Radio Contours



[ds9]

- generate & save radio contours (RA, DEC)
- load contours & overlay on X-ray image
- Alternatively, use images as RGB components.

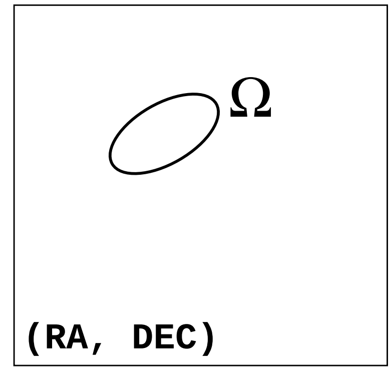
Spectral Analysis



- choose sky region, Ω
- extract source *PI* spectrum, $C_\Omega(h)$ [`dmextract`]
- compute *ARF*, $A_\Omega(E)$ [`mkarf/mkwarf`]
- compute *RMF*, $R_\Omega(h, E)$ [`mkacisrmf`]
- extract background *PI* spectrum, $B(h)$ (local *vs.* *ACIS* blank-sky background)
- Fit model $S_\Omega(E) \rightarrow \min(\chi^2)$

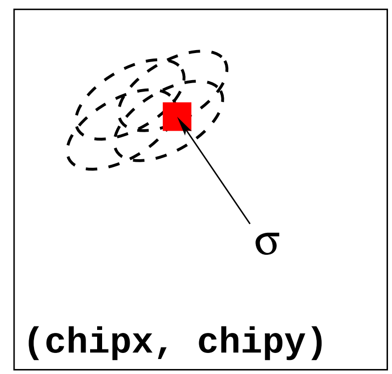
Response Spatial Variation

Extract spectrum, $C_\Omega(h)$, from sky region, Ω, that spans several calibrated detector regions, $\{\sigma\}$.



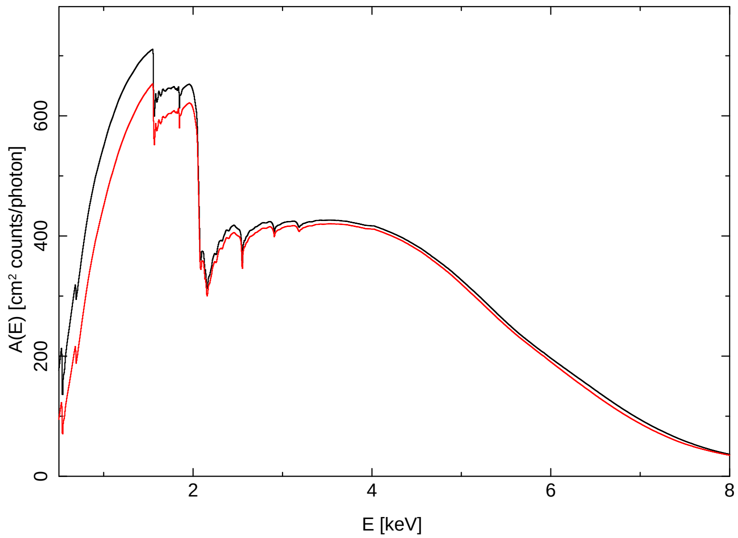
Problem: *Define $R_\Omega(h, E)$ and $A_\Omega(E)$ so that*

$$C_\Omega(h) = B(h) + \tau_{\text{eff}} \int dE \; R_\Omega(h, E) \; A_\Omega(E) \; S_\Omega(E)$$

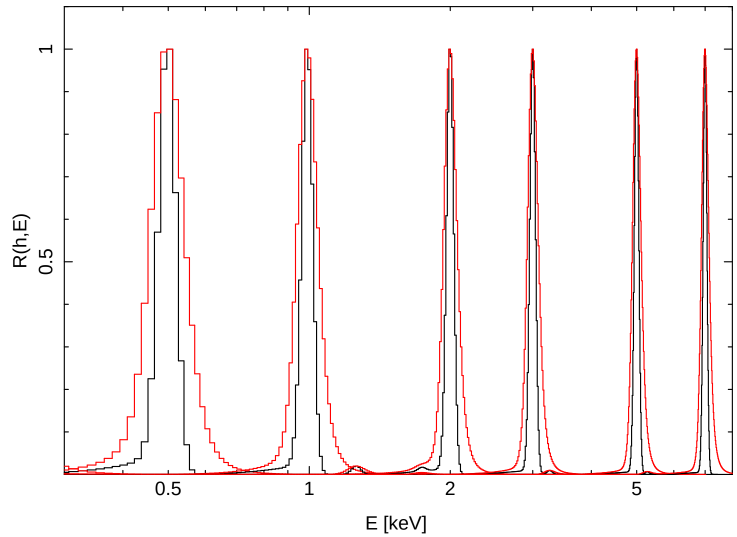


Response Spatial Variation

Contamination (*ACIS-7 ARF*)



CTI (*ACIS-3 FI-RMF*)

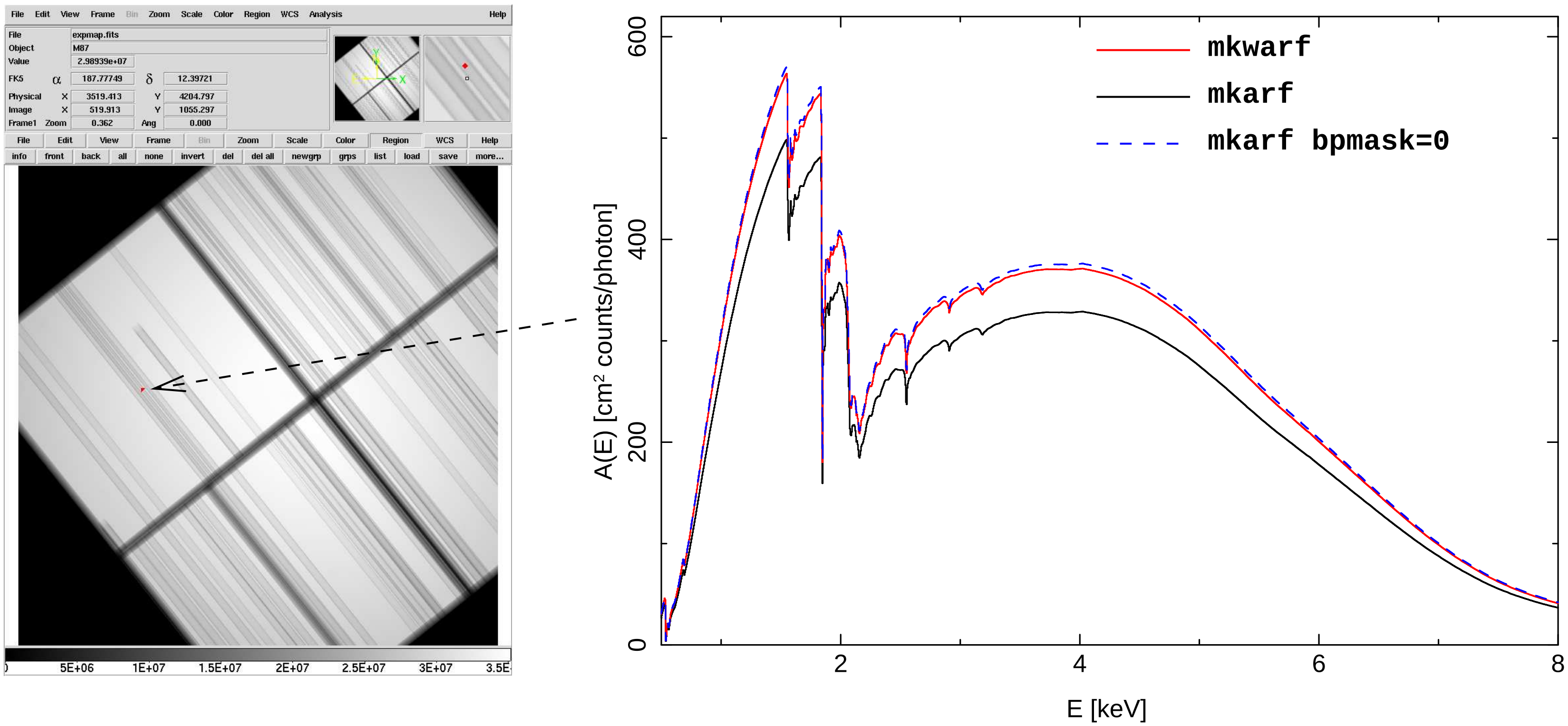


Weighted Responses

$R_\Omega(h, E)$ and $A_\Omega(E)$ can be defined in terms of a *weight map* ($WMAP$).

1. obtain $WMAP$ *e.g.* from `dmextract`
2. weighted RMF from `mkacisrmf`
3. weighted ARF from `mkwarf`

Default WMAP does not account for bad pixels:



obsid 5827, ACIS-3, box(3514,4214,2,2,128), fracexpo=0.892