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# Analysis of Extended Sources

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Analysis Guide: Extended Sources - CIAO 4.0 - Mozilla Firefox

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

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## Analysis Guide: Extended Sources

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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](#)
- [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 \[CIAO 3.4\]](#)
- [Obtain and Fit a Radial Profile](#)
- [Creating ACIS RMFs with mkacisrmf](#)
- [Using specextract to Extract ACIS Spectra and Response Files](#)
- [Weighting ARFs and RMFs: multiple sources](#)
- [Sherpa: Fitting FITS Image Data](#)
- [Sherpa: Using an Exposure Map in Fitting Image Data \[Sherpa 3.4\]](#)
- [An Image of Diffuse Emission](#)

## Web Documentation

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

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



## Important Issues

### 1. Position-dependent response

- work in  $PI$  space
- weighted responses

### 2. Background

- remove flares, point-sources
- local measurement *vs.* *ACIS* blank-sky background

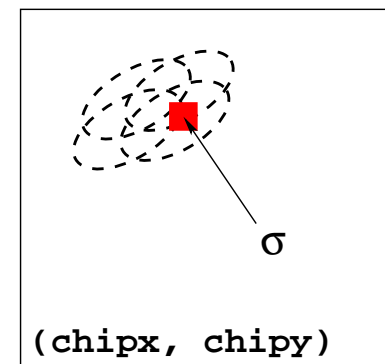
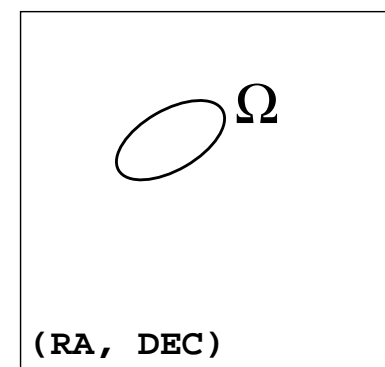


## Response Spatial Variation

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

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

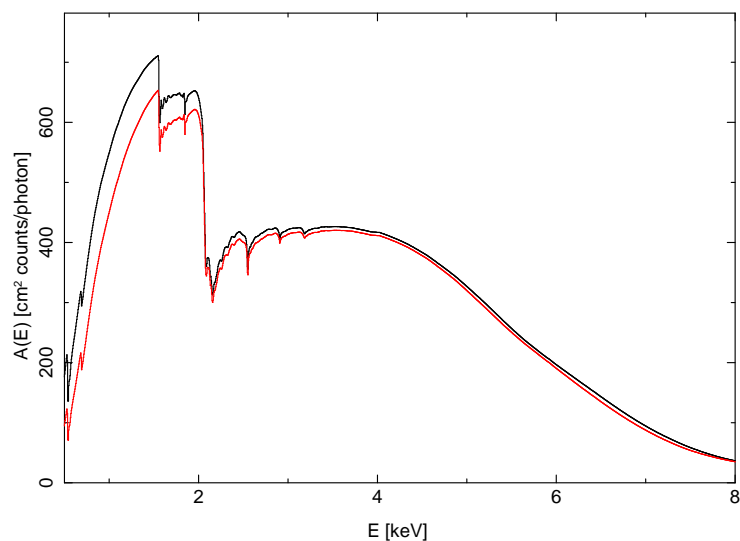
$$C_{\Omega}(h) = B(h) + \tau_{\text{eff}} \int dE R_{\Omega}(h, E) A_{\Omega}(E) S_{\Omega}(E)$$



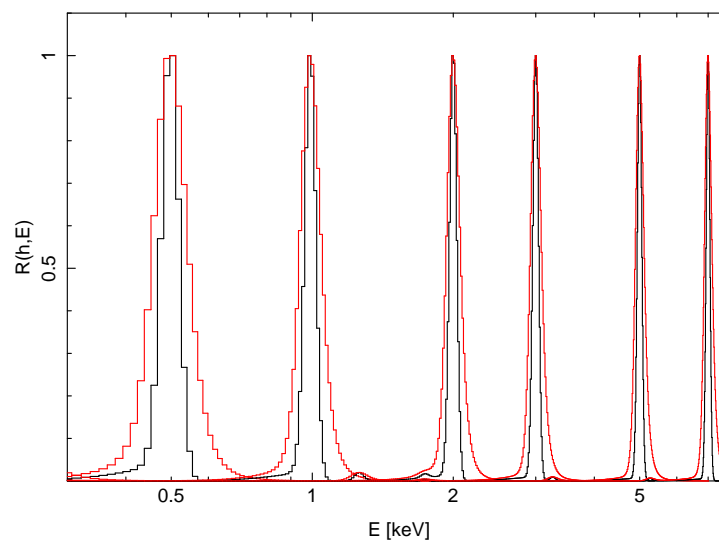


# Response Spatial Variation

Contamination (*ACIS-7 ARF*)



CTI (*ACIS-3 FI-RMF*)





## Weighted Responses

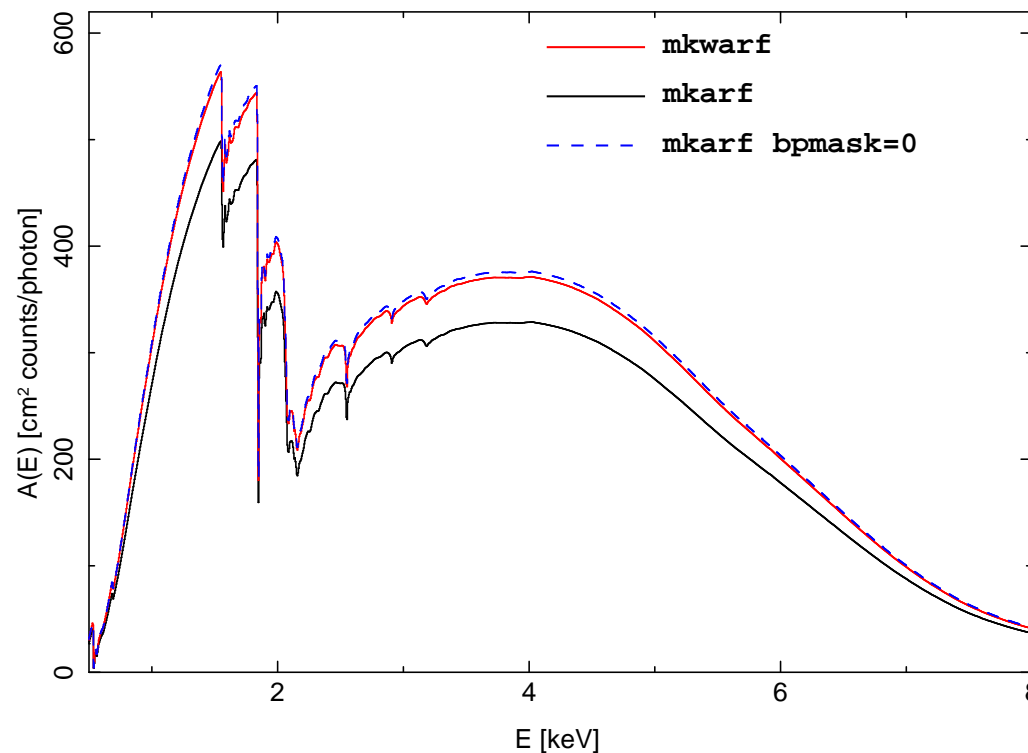
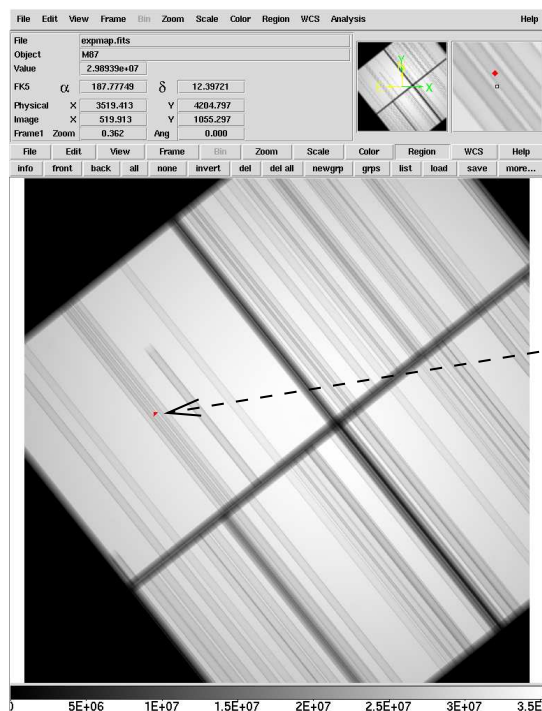
$R_{\Omega}(h, E)$  and  $A_{\Omega}(E)$  can be defined in terms of a *weight map* (*WMAP*).

1. *WMAP* from `dmextract`
2. weighted *ARF* from `mkwarf`
3. weighted *RMF* from `mkacisrmf`

Limitation: `mkwarf` requires the *WMAP* in DETX, DETY coordinates;  
CHIPX, CHIPY would be better (Davis 2001).



*Current WMAP neglects bad pixels:*

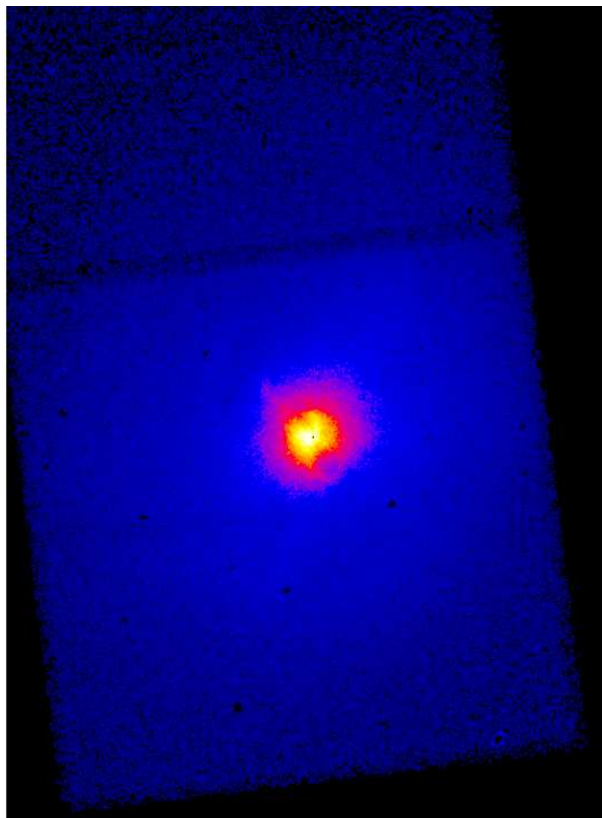


obsid 5827, ACIS-3, box(3514,4214,2,2,128), fracexpo=0.847



# Event Filtering

## *Counts*



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

*Just to be clear...*

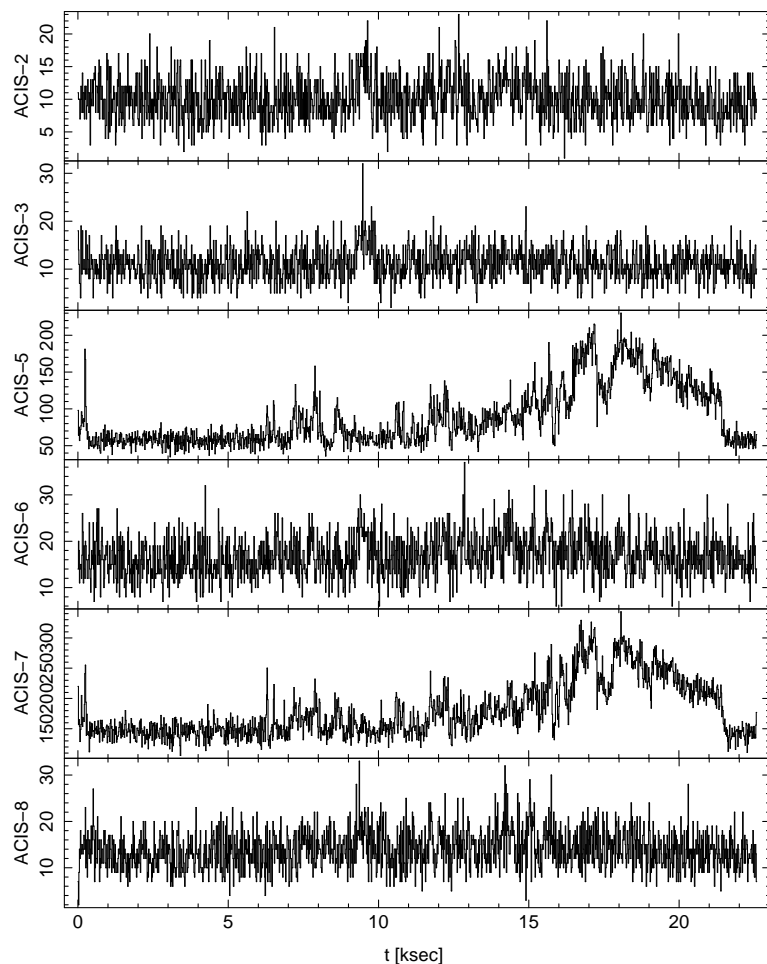
Counts and photons are  
NOT the same!

$$(QE < 1)$$





## Exclude high background intervals:

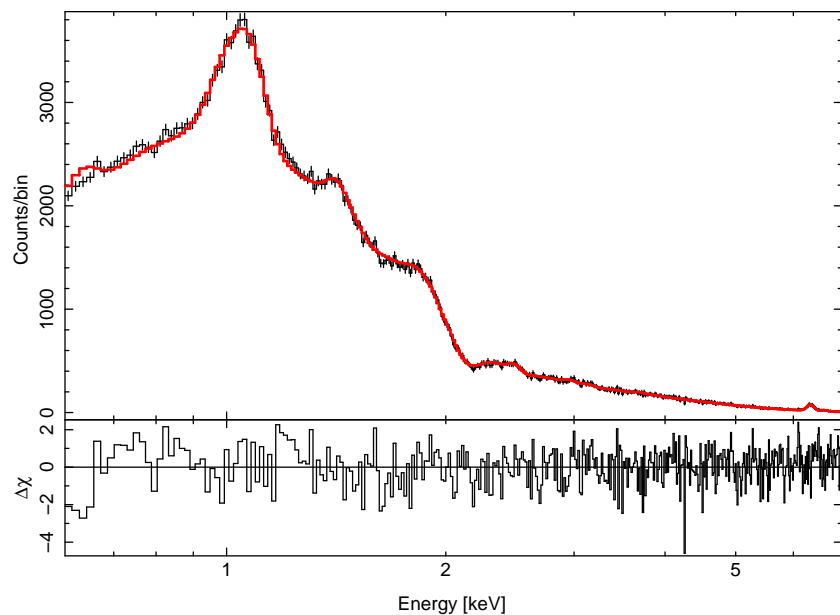


- extract light-curve [dmextract]
- determine *GTIs* [analyze\_ltcrv.sl]
- filter [dmcopy]

```
dmcopy "evt2.fits[@new_gtis.txt]"  
      evt2_clean.fits
```



# Spectral Analysis



- choose sky region,  $\Omega$
- 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  $S_{\Omega}(E) \rightarrow \min(\chi^2)$



## 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  $\mathcal{A} \approx \text{constant within } \Delta E$  then, summing over  $\Delta h, \Delta E$ :*

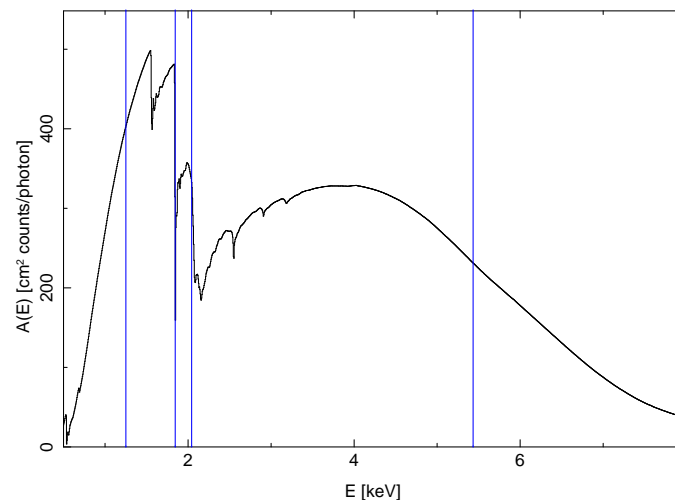
$$\int_{\Delta E} dE \mathcal{S}_{\text{PSF}}(E, \hat{\mathbf{p}}) \approx \frac{1}{\tau_{\text{eff}}} \frac{C(\Delta h, \hat{\mathbf{p}})}{\mathcal{A}(\Delta h, E, \hat{\mathbf{p}})}.$$



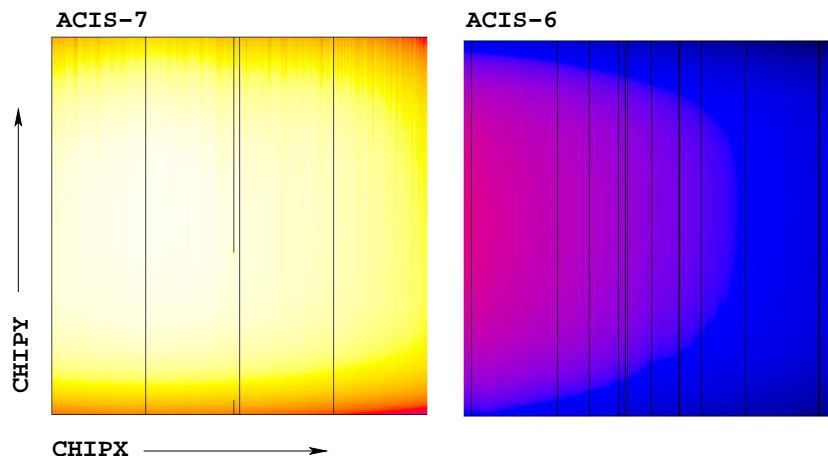
# Instrument Map

Use spectrum model,  $s(E)$ , to weight  $\Delta E_j$  intervals where the  $ARF$  is “slowly” varying:

$$f_j \equiv \frac{1}{s_{\text{tot}}} \int_{\Delta E_j} s(E) dE$$

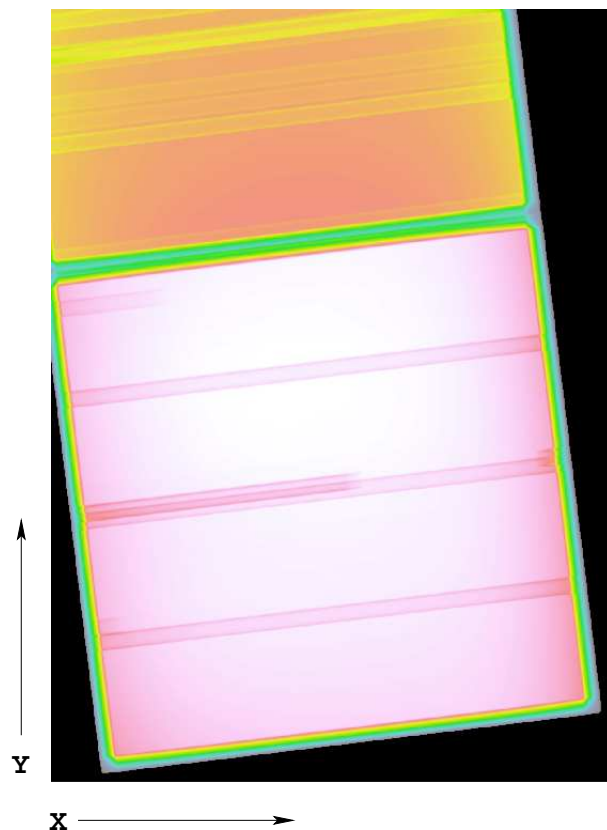


*Instrument Maps*





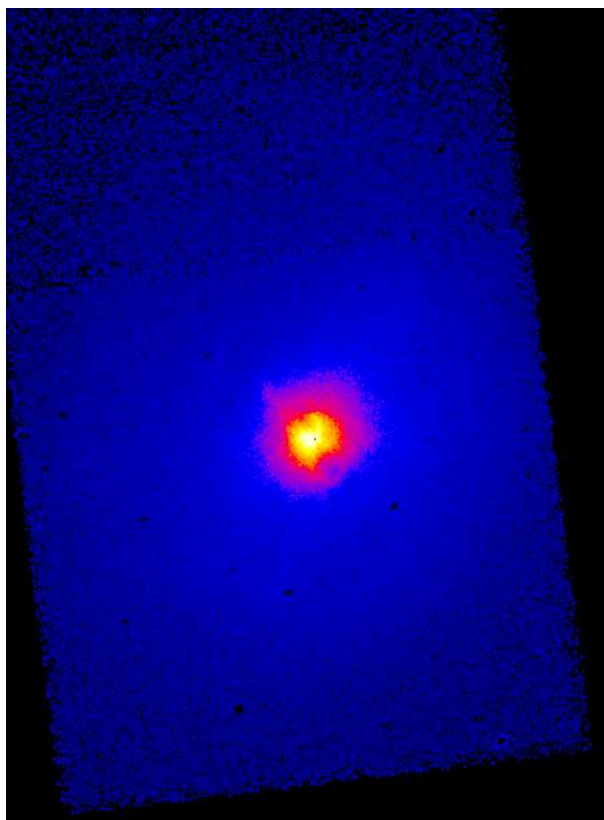
*Exposure Map*



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



*"Flux"*



- extract counts image for  $\Delta E$  of interest  
`[dmcopy]`
- Divide counts by exposure map:

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

[photons s<sup>-1</sup> cm<sup>-2</sup>]

`[dmimgthresh, dmimgcalc]`

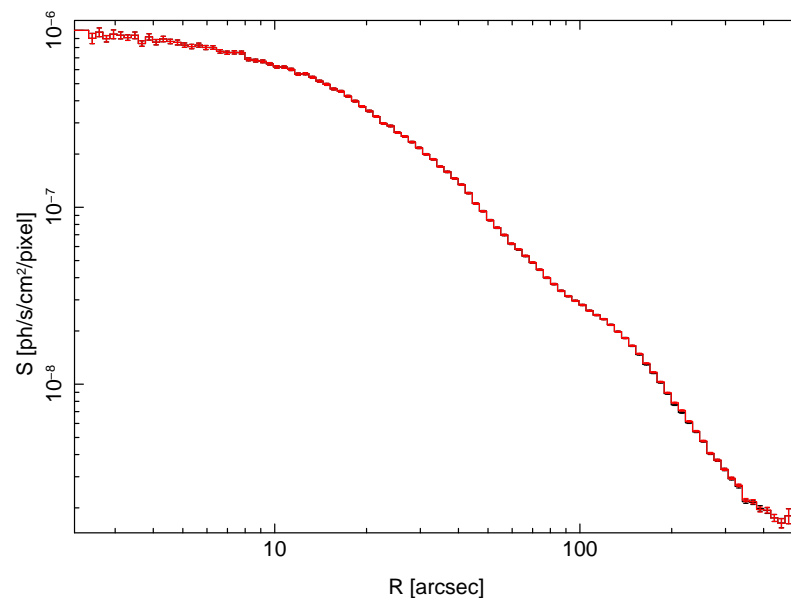
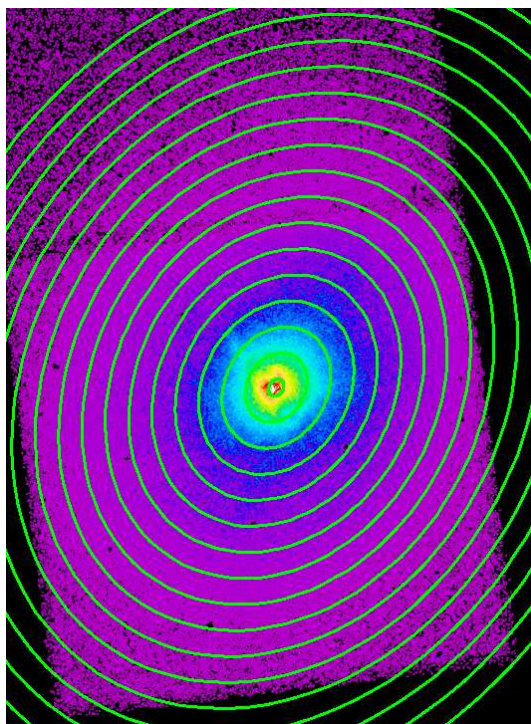


# Surface Brightness Profiles

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

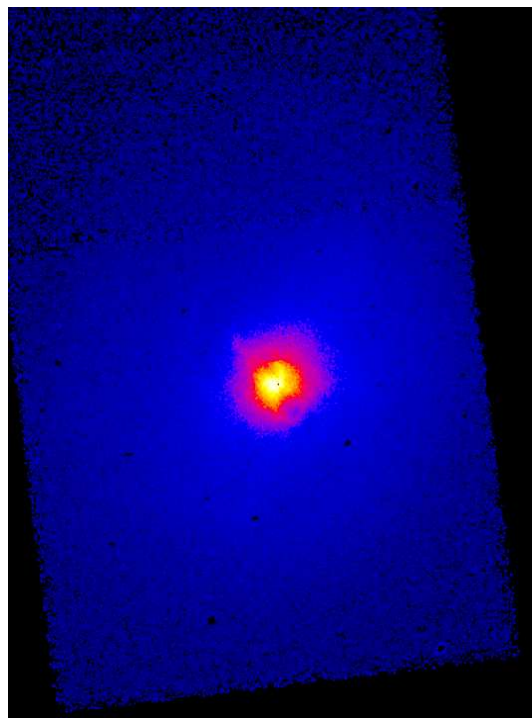
$$S_i = \frac{\sum_{k \in i} C_k}{\tau_{\text{eff}} \sum_{k \in i} \mathcal{A}_k}.$$

*Elliptical Annuli*

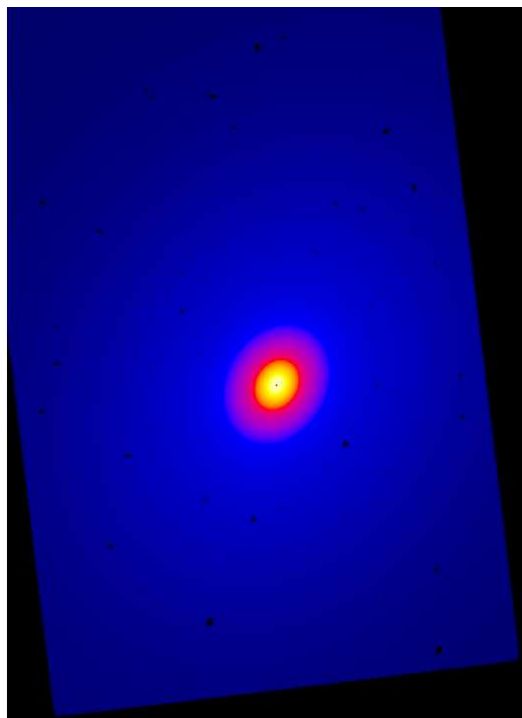




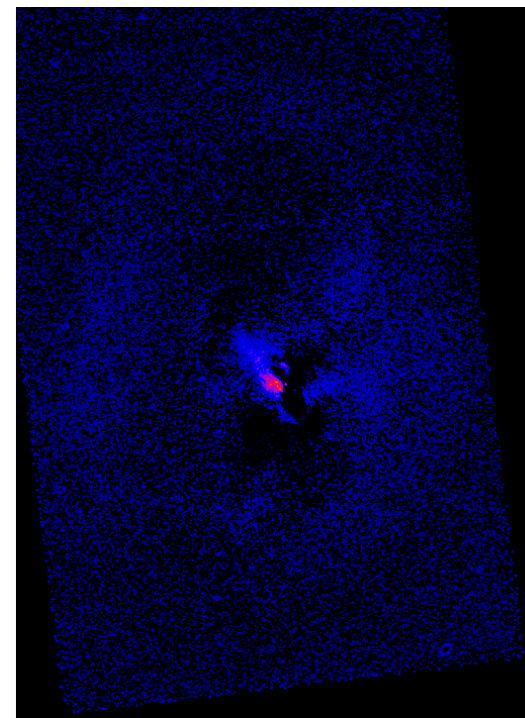
*"Flux"*



*SB Profile Image*



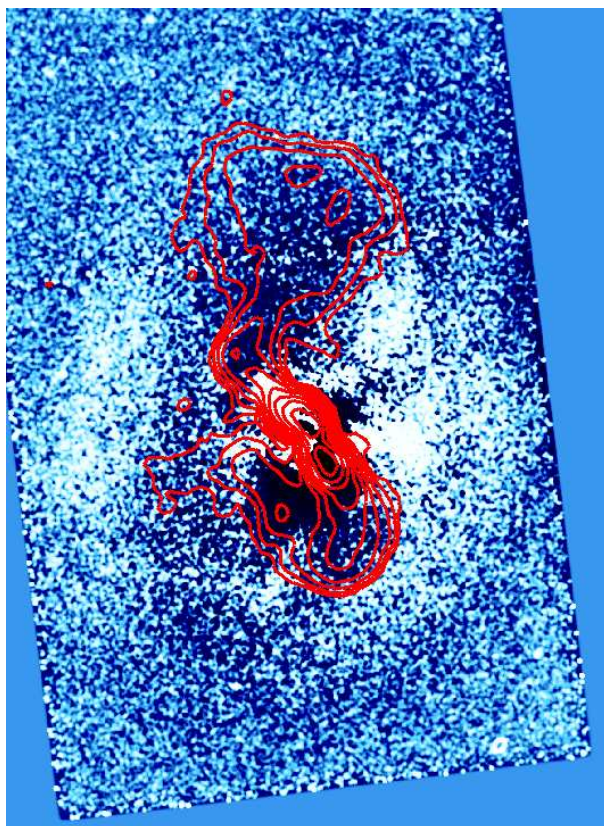
*Flux residual*







***Overlay Radio Contours***



[ds9]

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