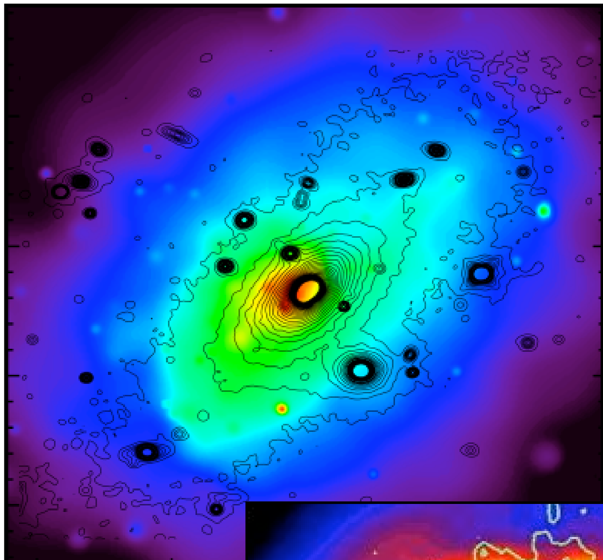
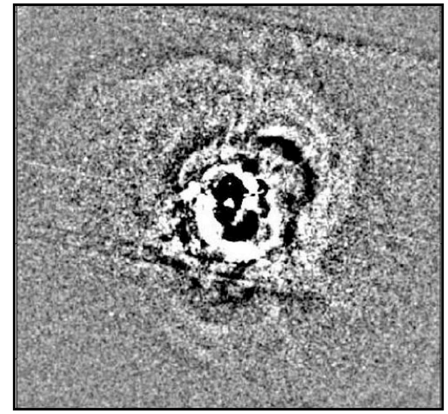
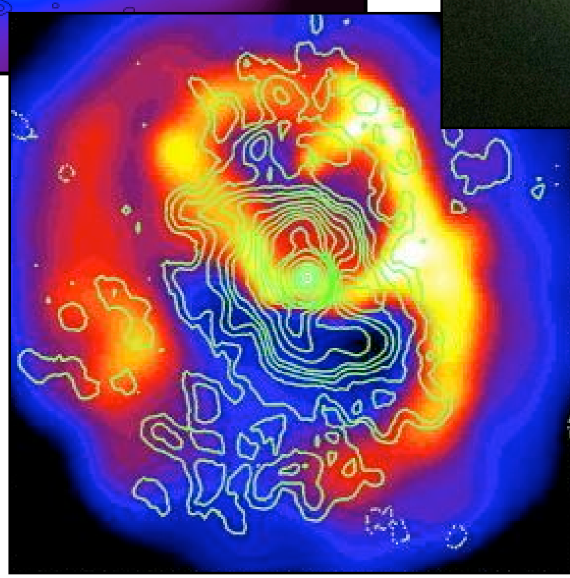
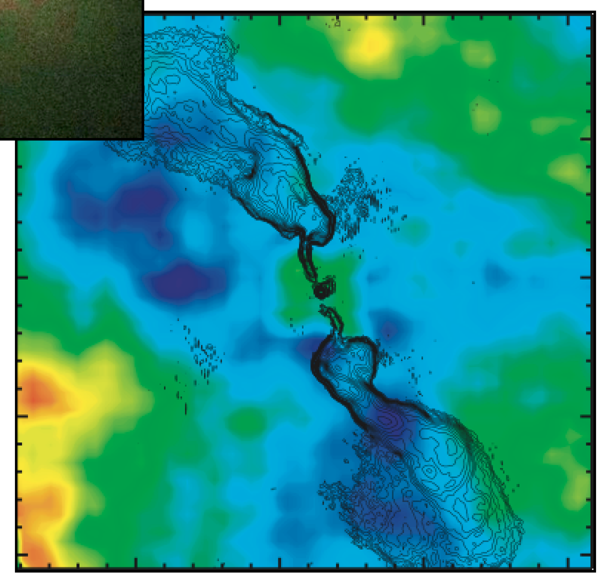
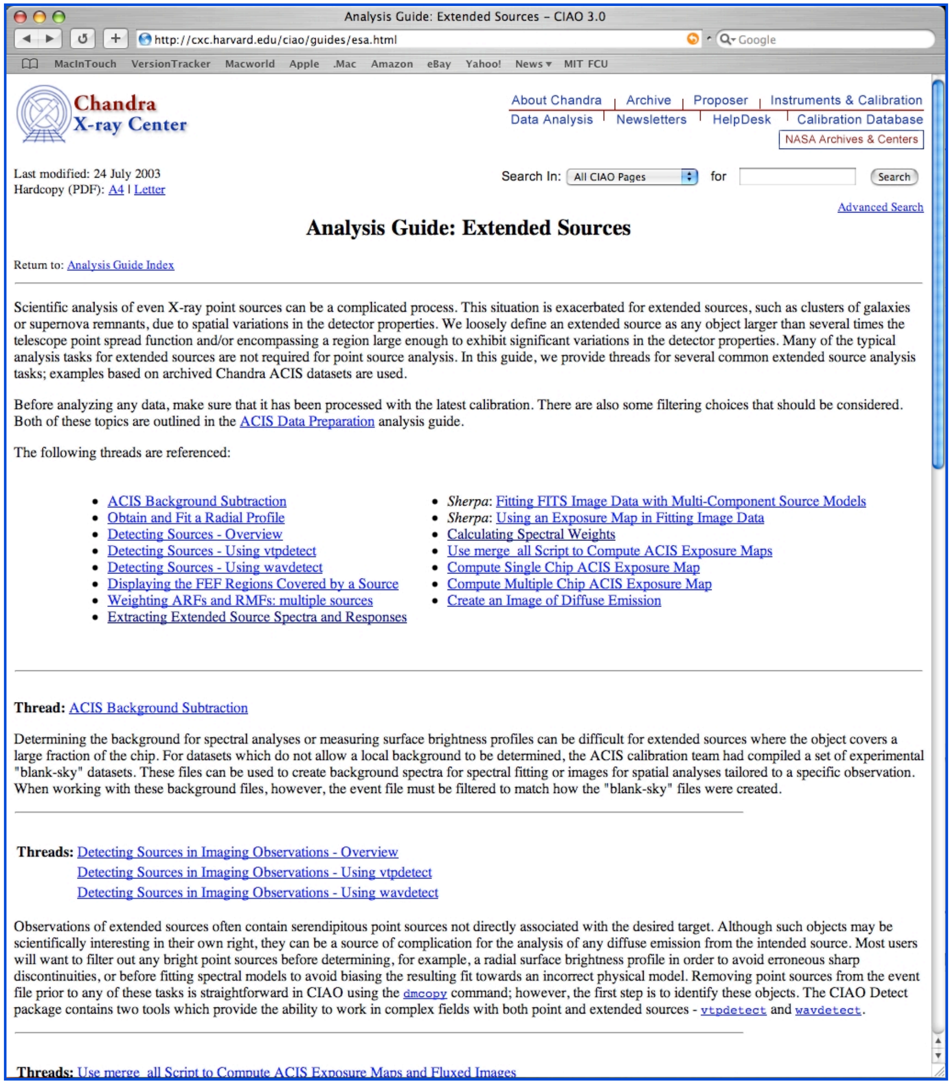
Analysis of Extended Sources










Analysis Guide: Extended Sources – CIAO 3.0

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:

- ACIS Background Subtraction
- Obtain and Fit a Radial Profile
- Detecting Sources - Overview
- Detecting Sources - Using vtpdetect
- Detecting Sources - Using wavdetect
- Displaying the FEF Regions Covered by a Source
- Weighting ARFs and RMFs: multiple sources
- Extracting Extended Source Spectra and Responses
- *Sherpa*: Fitting FITS Image Data with Multi-Component Source Models
- *Sherpa*: Using an Exposure Map in Fitting Image Data
- Calculating Spectral Weights
- Use merge_all Script to Compute ACIS Exposure Maps
- Compute Single Chip ACIS Exposure Map
- Compute Multiple Chip ACIS Exposure Map
- Create an Image of Diffuse Emission

Thread: ACIS Background Subtraction

Determining the background for spectral analyses or measuring surface brightness profiles can be difficult for extended sources where the object covers a large fraction of the chip. For datasets which do not allow a local background to be determined, the ACIS calibration team had compiled a set of experimental "blank-sky" datasets. These files can be used to create background spectra for spectral fitting or images for spatial analyses tailored to a specific observation. When working with these background files, however, the event file must be filtered to match how the "blank-sky" files were created.

Threads: Detecting Sources in Imaging Observations - Overview
Detecting Sources in Imaging Observations - Using vtpdetect
Detecting Sources in Imaging Observations - Using wavdetect

Observations of extended sources often contain serendipitous point sources not directly associated with the desired target. Although such objects may be scientifically interesting in their own right, they can be a source of complication for the analysis of any diffuse emission from the intended source. Most users will want to filter out any bright point sources before determining, for example, a radial surface brightness profile in order to avoid erroneous sharp discontinuities, or before fitting spectral models to avoid biasing the resulting fit towards an incorrect physical model. Removing point sources from the event file prior to any of these tasks is straightforward in CIAO using the `dmcopy` command; however, the first step is to identify these objects. The CIAO Detect package contains two tools which provide the ability to work in complex fields with both point and extended sources - `vtpdetect` and `wavdetect`.

Threads: Use merge_all Script to Compute ACIS Exposure Maps and Fluxed Images

Online documentation

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

- Background subtraction
- Fitting radial profiles
- Source detection
- Weighted RMFs and ARFs
- Computing exposure maps
- 2-D fitting in `Sherpa`

Data preparation

- Standard re-processing (bad aspect, flares, etc.)
- CTI-correct data (if ACIS-I chips) [`acis_process_events`]
- Correct temporal drift in gain [`corr_tgain`, `acis_process_events`]
- Re-calculate PI values [`acis_process_events`]

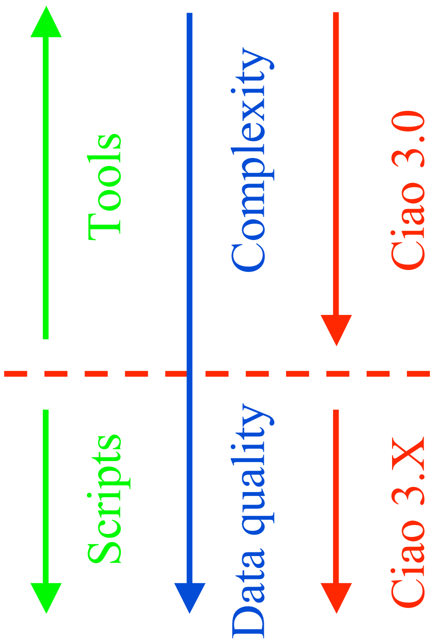
Free advice

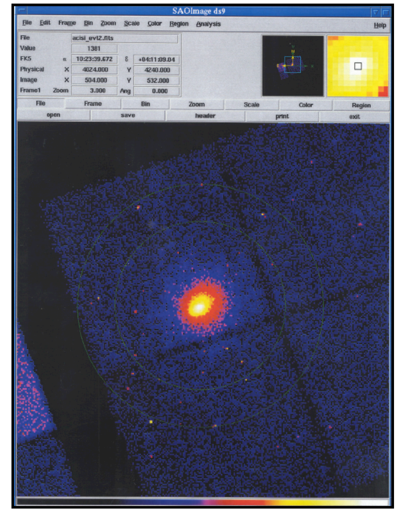
- Work in PI units
- Analyse FI and BI spectra jointly (not combined)
- Analyze multiple OBSIDs jointly (not combined)
- Be suspicious of fits below ~0.6 keV
- Save your receipt

Typical Cluster analysis scenario

- Integrated spectral analysis
- Flux-corrected images
- Surface brightness profiles
- Annular spectral analysis

- Deprojected spectral analysis
- 2D spectral mapping





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THE INSIGNIFICANCE OF GLOBAL REHEATING IN THE ABELL 1068 CLUSTER: X-RAY ANALYSIS

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To appear in the January 10, 2004 issue of the Astrophysical Journal

ABSTRACT

We report on a *Chandra* observation of the massive, medium redshift ($z = 0.1386$) cooling flow cluster Abell 1068. We detect a clear temperature gradient in the X–ray emitting gas from $kT \sim 5$ keV in the outer part of the cluster down to roughly 2 keV in the core, and a striking increase in the metallicity of the gas toward the cluster center. The total spectrum from the cluster can be fit by a cooling flow model with a total mass deposition rate of $\sim 150\ M_\odot\ yr^{-1}$. Within the core ($r < 30$ kpc), the mass depositon rate of $\sim 40\ M_\odot\ yr^{-1}$ is comparable to estimates for the star formation rate from optical data. We find an apparent correlation between the cD galaxy's optical isophotes and enhanced metallicity isocontours in the central ~ 100 kpc of the cluster. We show that the approximate doubling of the metallicity associated with the cD can be plausibly explained by supernova explosions associated with the cD's ambient stellar population and the recent starburst. Finally, we calculate the amount of heating due to thermal conduction and show that this process is unlikely to offset cooling in Abell 1068.

Subject headings: cooling flows — galaxies: clusters: general — galaxies: elliptical and lenticular, cD — intergalactic medium — X–rays: galaxies

1. INTRODUCTION

Galaxy clusters frequently have high X-ray surface brightness cores due to thermal emission from dense gas. Absent a substantial and persistent heat source, this high density, relatively low temperature gas should cool on a timescale that is much less than the age of clusters, leading to a so-called "cooling flow" (Fabian 1994). The cooling rates reported from the low resolution X-ray observatories that operated throughout the previous two decades were often extraordinarily large, and frequently exceeded several hundred to over two thousand solar masses per year. Such large cooling rates posed a dilemma. They imply the presence of enormous sinks of cold gaseous and stellar matter in the cD galaxies found at the centers of cooling flows. Although substantial amounts of cold gas and vigorous star formation are now found commonly in cD galaxies centered in cooling flows (Edge 2001, Edge et al. 2002, Jaffe & Bremer 1997, Jaffe, Bremer, & Van der Werf 2001, Donahue et al. 2000, Falcke et al. 1998, Crawford et al. 1999, Cardiel, Gorgas, & Aragon-Salamanca 1998, McNamara & O'Connell 1989), they are found in quantities that are much smaller than these earlier cooling rates would imply (cf., McNamara 2002).

This large discrepancy between the cooling and star formation rates is one of the primary questions behind what has become known as the "cooling flow problem". Simply stated, it is either a violation of mass continuity, assuming the matter is in fact not cooling at the rates implied by the X–ray data, or a missing light problem, if the matter is indeed cooling at these historically large rates but is hidden in some exotic state. Recent high spatial and spectral resolution cluster observations made with the *Chandra* and *XMM-Newton* X–ray observatories have changed this canonical dilemma and suggested a third possibility. The absence of detected emission lines from gas at temperatures less than about 3 keV in *XMM-Newton* RGS and *Chandra* HETG observations of cluster cores implies that a large fraction of the cooling gas does not in fact cool below X-ray emitting temperatures (Peterson et al. 2001, Peterson et al. 2003, Wise et al. 2004). Instead, this gas is assumed to be reheated to ambient temperatures by one or more of several possible agents that are now being extensively studied. These agents include mechanical and cosmic ray reheating from supernova explosions, heat conduction from the hot outer layers of clusters, and mechanical heating by the central radio sources in cD galaxies.

Images of the cooling flow regions of clusters now show a great deal of structure, including the large cavities or bubbles in the X-ray emission associated with the radio sources harbored by the central cluster galaxies (e.g., McNamara et al. 2000, Fabian et al. 2000). The strong interactions between the radio sources generated in the nuclei of cD galaxies and the surrounding X-ray emitting gas may reduce the cooling rates and bring them more in line with the star formation rates (David et al. 2001, Nulsen et al. 2002). In addition, *Chandra*'s superb spatial resolution provides the capability to map the temperature structure of the keV gas on fine spatial scales, which permits a direct comparison between the sites of star formation seen at optical and ultraviolet wavelengths, and sites of rapid cooling. In essence, we can now reevaluate the proposition that cooling flows are fueling star formation by comparing the cooling and star formation rates on the same spatial scales. In addition, the newly revealed complexity of the gas in cluster cores has sparked a revaluation of several possible heating mechanisms, such as AGN heating (Brighenti & Mathews 2002, Ruszkowski & Begelman 2002), heat conduction from the hotter outer layers of clusters (Narayan & Medvedev 2001, Zakamska & Narayan 2003), and supernovae.

In this paper, we present a detailed examination of the X-ray structure of the core of the Abell 1068 galaxy, and present

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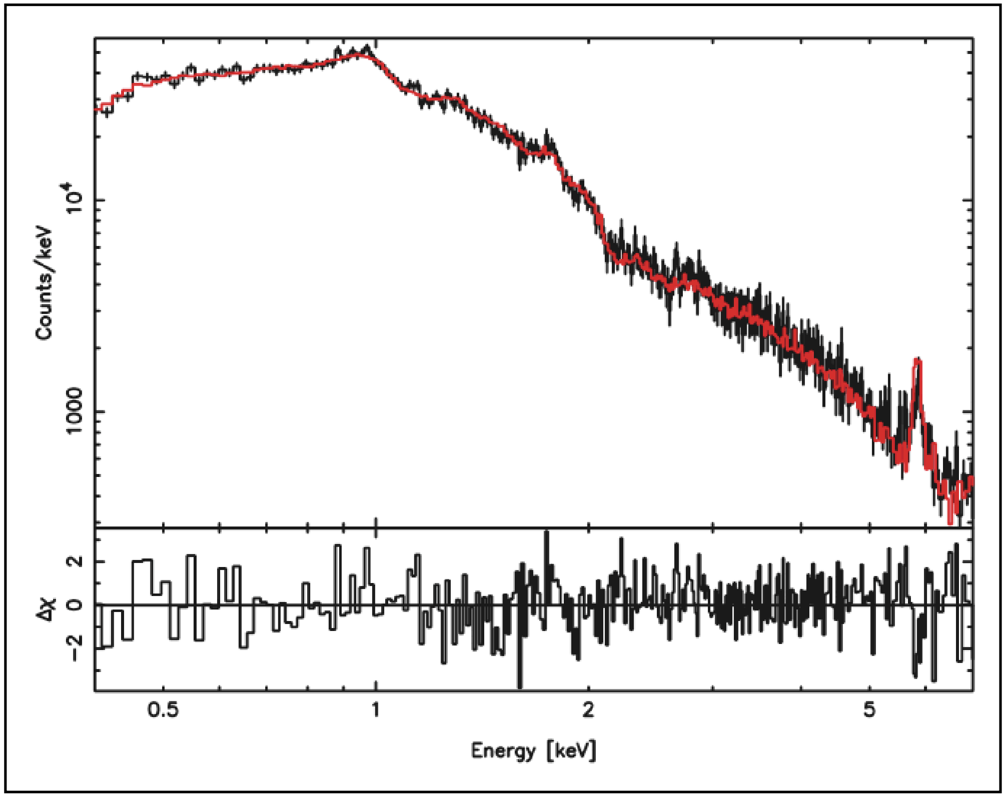
Integrated spectral analysis



Procedure

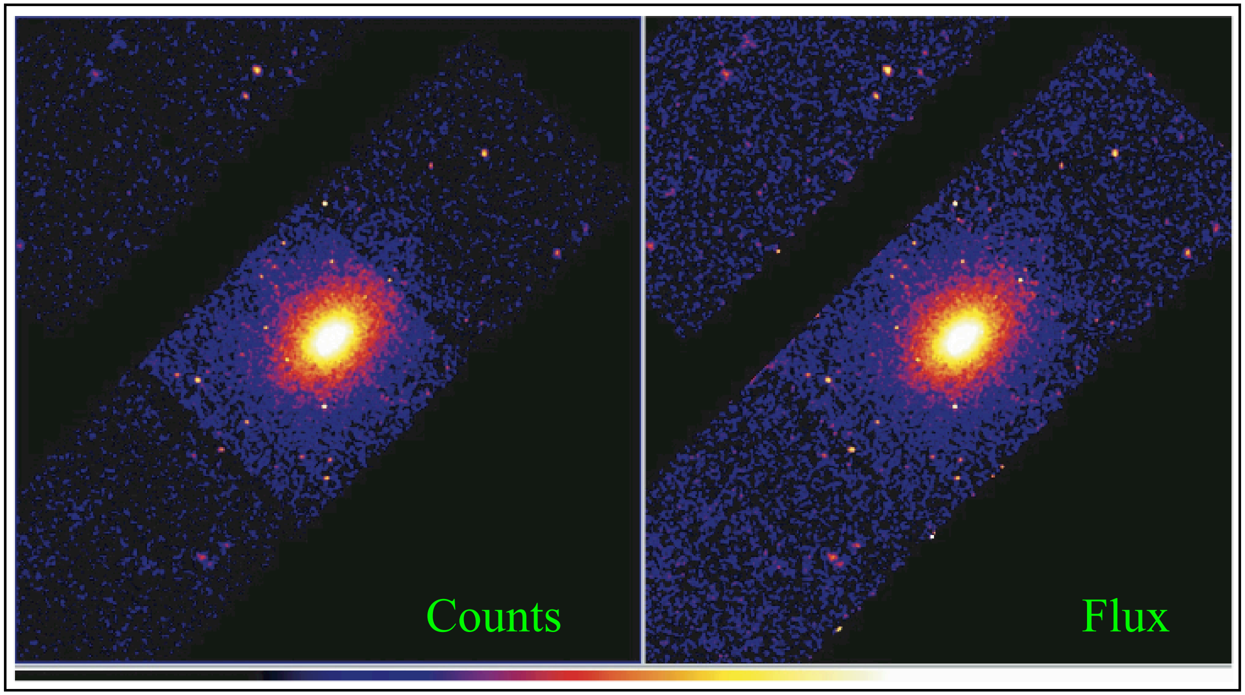
- Find and remove point sources
- Extract spectrum (and background)
- Create weighted ARF
- Create weighted RMF
- Correct ARF for contamination
- Define model and fit
- Save fitted spectrum

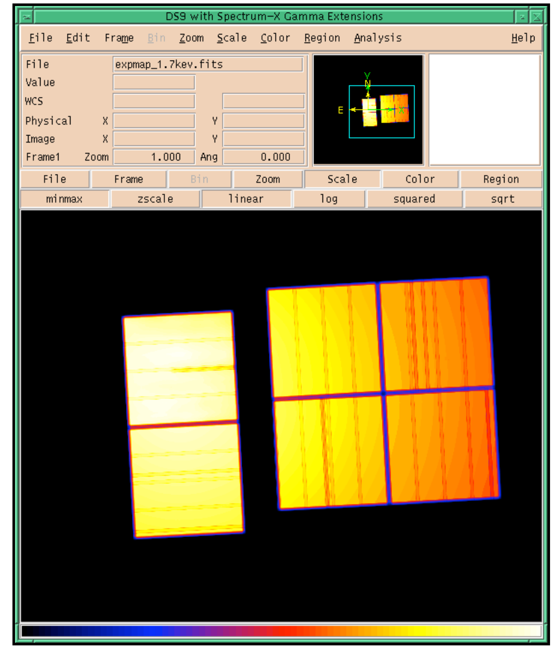
Tools

- `wavdetect, dmcopy`
- `dmextract`
- `mkwarf`
- `mkrmf`
- `contamarf, mkwarf, acisabs`
- `sherpa`

```
• dmextract infile="evt2.fits[sky=circle(4024.0,4240.0,300.0)][bin pi]" \
            outfile="spect.pi" wmap="det=8"
• mkwarf infile="spect.pi[WMAP]" outfile="spec.warf" weightfile="spect.wgt"
• mkrmf outfile="spect.wrmf" weights="spect.wgt"
```

Flux-corrected images



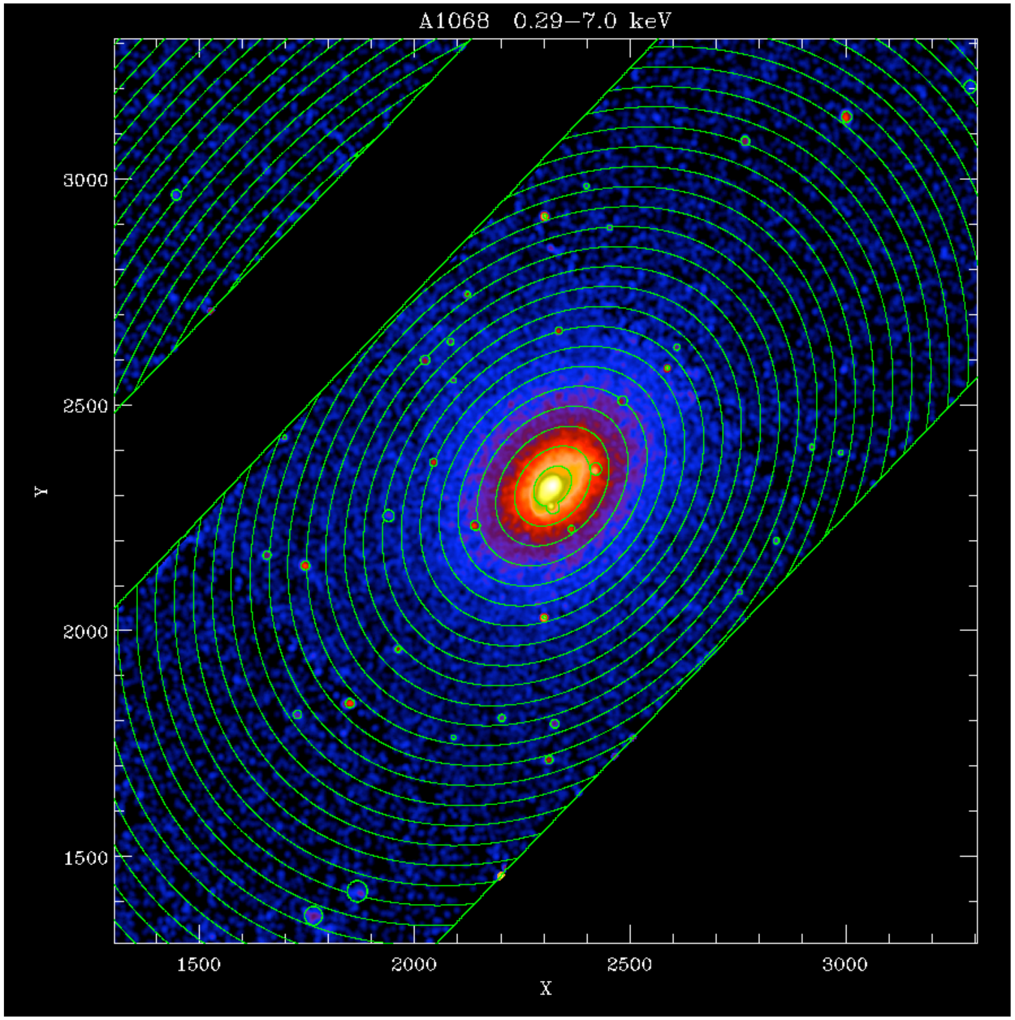


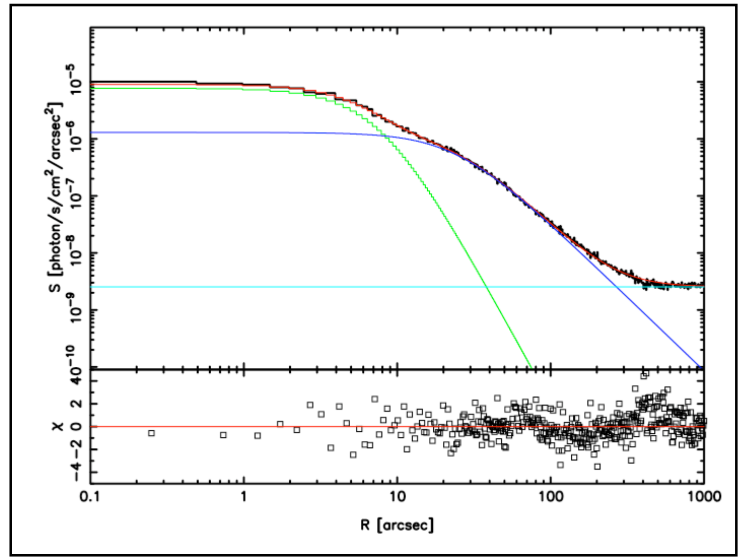
Exposure map

- Start with fitted spectrum (from integrated fit) [`sherpa`]
- Create counts image of field [`dmcopy`]
- Create instrument map for each chip [`mkinstmap`]
- Create exposure map for each chip [`mkexpmap`]
- Combine single exposure maps [`dmregrid`]
- Divide counts image by exposure map [`dmimgcalc`]

Caveat: `mkinstmap` does **not** currently account for the spatial dependence of ACIS contaminant

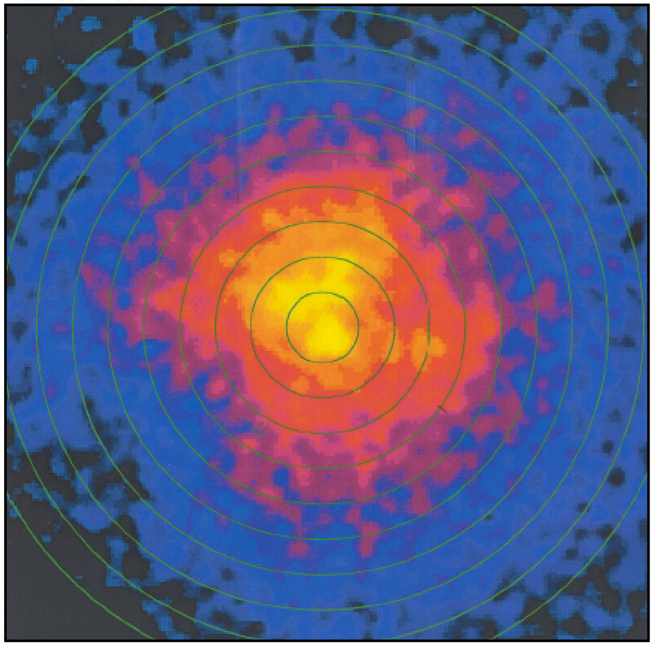
Surface brightness profiles





- Find and remove point sources
- Define annular regions
- Extract counts in each annulus
- Cut point source regions from exp. map
- Extract exposure in each annulus
- Divide counts by exposure
- Fit ▯ model to profile

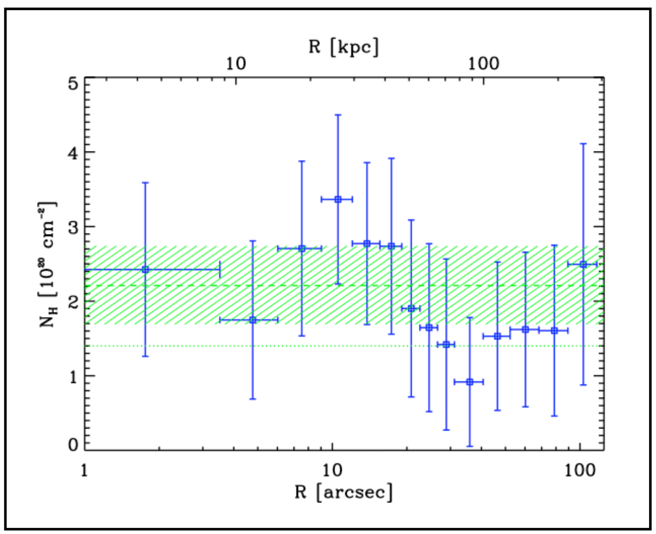
Tools: `dmcopy`, `ds9`, `dmextract`, `dmtcalc`, `sherpa`

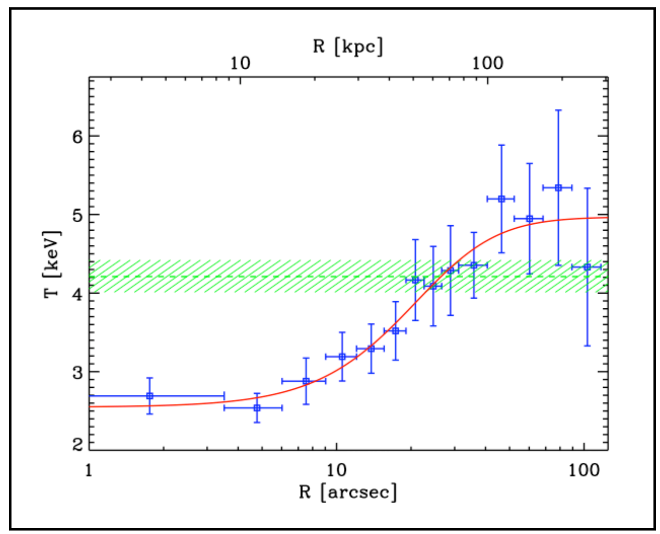


Annular spectral analysis

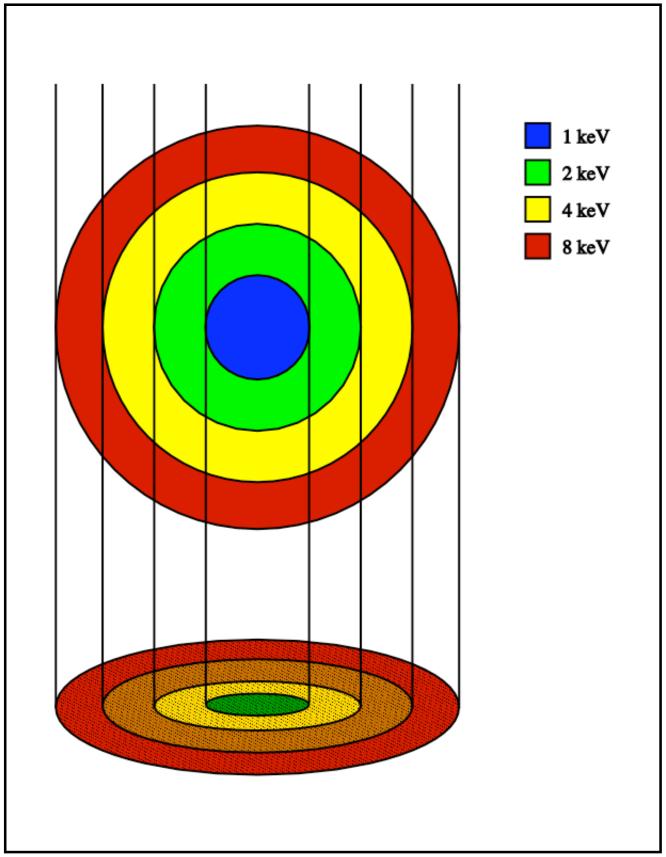
- Cut out point sources [`dmcopy`]
- Define annuli (equal counts?) [`ds9`, (S-Lang script)]
- Create PHA and weighted RMF/ARF for each annulus [`dmextract`, `mkrmf`, `mkwarf`]
- Define spectral model [`sherpa`]
- Repeat spectral fit for each annulus

Tip: Write a S-Lang script to loop over annuli





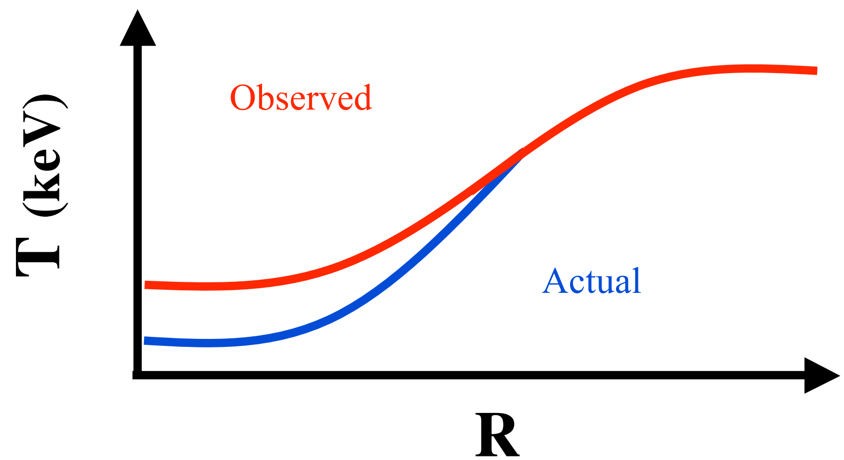
Deprojected spectral analysis



For an assumed geometry, one can calculate the partial volumes, V_{ij}, which contribute to any projected annulus

Problem: Projected spectra contain contributions for all annuli along line of sight

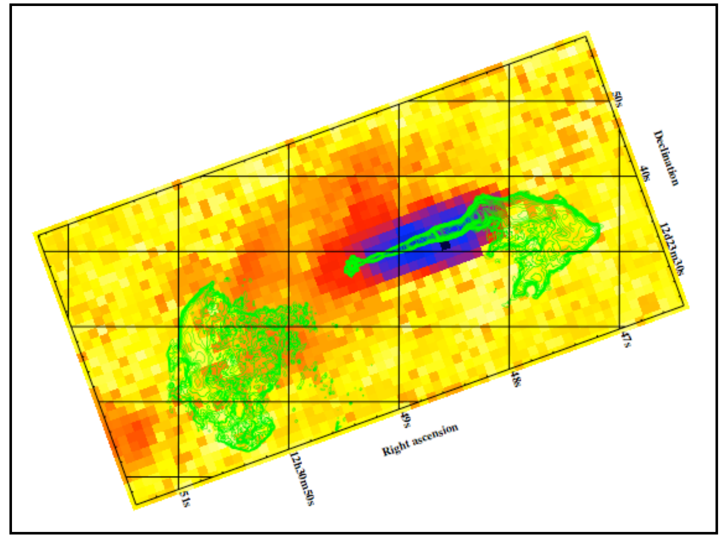
Effect: Measured <*T*> higher than true value



Solution:
- Calculate volume fractions
- Define custom spectral model
- Fit data from all shells simultaneously
- Implemented as S-Lang program
- Coming soon to a thread near you

2D spectral mapping

- Map is just **many** spectral fits
- Define grid of boxes containing counts
- Extract spectrum, calculate RMF/ARF for each box
- Fit model at each grid point
- Write out fit parameters as a function of position
- Can map any fit parameter
- Implemented as S-Lang program



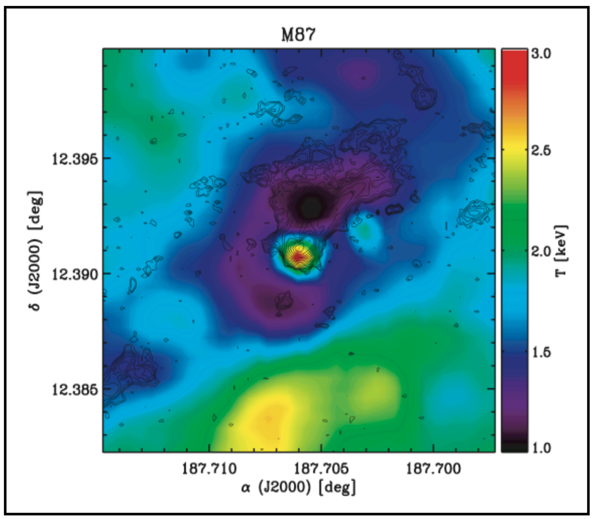
10^3-10^4 fits

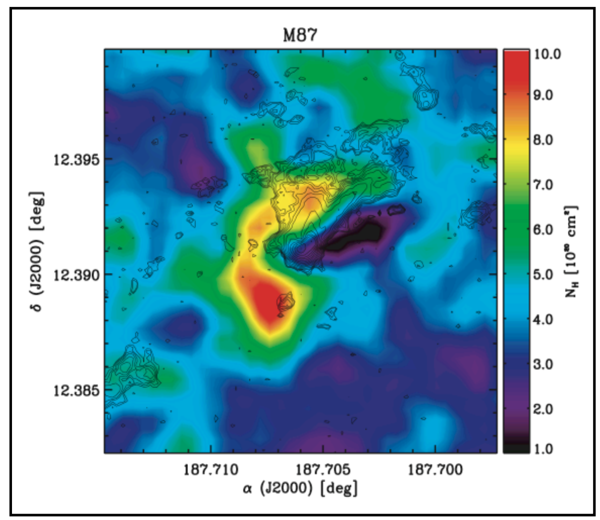
↓

CPU intensive

↓

Distributed processing





Future development

- Spatial dependence of ACIS contaminant
- S-Lang programs for advanced analysis
- Grating extended source analysis tools
- You tell us