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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:

- [Using the ACIS "Blank-Sky" Background Files](#)
- [Detecting Sources – Overview](#)
- [Detecting Sources – Using vtpdetect](#)
- [Detecting Sources – Using wavdetect](#)
- [Use merge\\_all Script to Compute ACIS Exposure Maps](#)
- [Compute Single Chip ACIS Exposure Map](#)
- [Compute Multiple Chip ACIS Exposure Map](#)
- [Calculating Spectral Weights](#)
- [Obtain and Fit a Radial Profile](#)
- [Displaying the FEF Regions Covered by a Source](#)
- [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](#)
- [Create an Image of Diffuse Emission](#)

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**Thread:** [Using the ACIS "Blank-Sky" Background Files](#)

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.

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**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](#).

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**Threads:** [Use merge\\_all Script to Compute ACIS Exposure Maps and Fluxed Images](#)

[Compute Single Chip ACIS Exposure Map and Fluxed Image Step-by-Step](#)

[Compute Multiple Chip ACIS Exposure Map and Fluxed Image Step-by-Step](#)

[Calculating Spectral Weights](#)

Determining the properties of diffuse emission from extended sources can be complicated by spatial variations in the exposure. For example, a uniform source of illumination will still show a radial variation in the number of detected counts due to the telescope vignetting. Similarly, detector features such as chip gaps can create erroneous spatial structure in the observed source. Users may correct for these effects by "flat-fielding" a given image using an exposure map appropriate for the observation, resulting in a fluxed image [ $\text{photons cm}^{-2} \text{s}^{-1} \text{pixel}^{-1}$ ] of the source. Integration of the resulting flux image values in a given region provides the total flux in that region. The exposure map for a given dataset represents the time-averaged effective area at given sky position over the course of the observation.

Since the Chandra effective area is a function of energy as well as position, determination of accurate flux values will depend on the spectrum of the source. For sources with relatively flat spectral energy distributions, an exposure map created at a single energy (such as the peak of emission) may suffice. For sources which exhibit significant spectral variation over the desired bandpass, an energy weighted exposure map may yield more accurate flux values. In such cases, if the broad features of the incident spectrum are known (e.g. thermal emission from a cluster) and if the spectral variations within the image are not too large, one can reduce the systematic errors by computing an exposure map which is weighted according to a specific model for the incident spectrum.

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**Thread:** [Obtain and Fit a Radial Profile](#)

One of the most basic analysis tasks for an extended source is the calculation of a radial surface brightness profile. For objects such as clusters of galaxies, this profile is the basic measurement for determining such quantities as the underlying gas density or the total mass of the cluster. In this thread, we illustrate how to calculate a radial profile in CIAO for a series of concentric elliptical annuli. The resulting surface brightness profile may then be

imported into *Sherpa* and fit to a specified analytic model, e.g. the standard Beta model distribution often used to describe cluster profiles.

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***Thread:*** [Displaying the FEF Regions Covered by a Source](#)

The ACIS [redistribution matrix file](#) (RMF) provides the redistribution function of the CCD detectors, defining a mapping from the source photon energy to the detected pulse height ([PHA](#)) of the observed X-ray events. Spectral fitting packages like *Sherpa* and XSPEC use this redistribution function, plus an accompanying effective area function (the [ARF](#)), to predict the counts spectrum produced by a given source model. The RMF depends on several instrumental factors, such as the ACIS focal plane temperature, and must be matched to the user's specific observation. It is therefore necessary to select the appropriate calibration file (FEF) from the Chandra calibration database (CALDB) before running `mkrmf`. The [Extract ACIS Spectra for Pointlike Sources](#) thread gives an example of this process.

The ACIS detector response depends on the CCD type (front illuminated versus back illuminated) and varies with position on the CCD. For spectral analysis, the impact of these position-dependent variations in energy scale and energy resolution depends on several factors, including the type of CCD (ACIS-I versus ACIS-S imaging), the size of the imaged source (point sources versus extended sources), the signal to noise ratio of the dataset (few counts versus many), and the type of spectral analysis (line dominated spectra versus continuum dominated sources).

Since the calibration of the ACIS response varies over the chip (as captured in the FEF), it can often be useful to examine the FEF regions covered by the source. Such an examination can indicate whether the variations in the CCD response are significant over the region of interest. This thread illustrates how to determine the different response calibration regions covered by a given source.

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***Thread:*** [Using `specextract` to Extract ACIS Spectra and Response Files](#)

[Weighting ARFs and RMFs: multiple sources](#)

Several different options are available in CIAO for treating the CCD response, depending on the type of observation and the science goals of the analysis. In some cases, a single RMF/ARF pair may be a reasonable choice. In other instances, a simultaneous fit using multiple RMFs and ARFs may yield better results.

The [Using `specextract` to Extract ACIS Spectra and Response Files](#) thread illustrates how to use `specextract` script to create a source and background spectrum, plus the corresponding weighted responses, for an extended source. The [help file](#) outlines the script's many parameters and gives other examples of its use.

For a more detailed approach, refer to the [Weighting ARFs and RMFs](#) thread. This thread gives step-by-step instructions about how to calculate a set of weighted RMFs and ARFs such as might be appropriate for analysis of a large source region or the combined spectrum from multiple regions.

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***Thread:*** [Creating ACIS RMFs with `mkacisrmf`](#)

The tool `mkacisrmf`, available since CIAO 3.2, represents an entirely new method for creating ACIS imaging response matrices. This tool contains all the functionality of the previous tool `mkrmf`. Unlike its predecessor, however, `mkacisrmf` separates the RMF calculation process into two components: an "ideal" component which describes the CCD spectral response prior to the effects of CTI, and a spatially varying component which incorporates the changes in the response produced by CTI.

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Technical details on `mkacisrmf` are available from the [Creating ACIS RMFs with `mkacisrmf`](#) why topic.

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### **Threads:** *Sherpa*: [Fitting FITS Image Data](#)

#### *Sherpa*: [Using an Exposure Map in Fitting Image Data](#)

Once the appropriate response files have been created, it is possible to load the spatial data into *Sherpa* and fit it. If an exposure map has been created for the dataset, it may be input and used directly as a model component in the fitting.

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### **Thread:** [Create an Image of Diffuse Emission](#)

Creating a "pretty picture" of the diffuse emission for an impending paper is frequently the final step in dealing with extended sources. It is possible to detect and remove any point sources in the emission, filling in the holes via interpolation of the background. The final product, an exposure-corrected image, should be used cautiously for scientific purposes since it is highly processed.

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