Imaging Spectral Analysis

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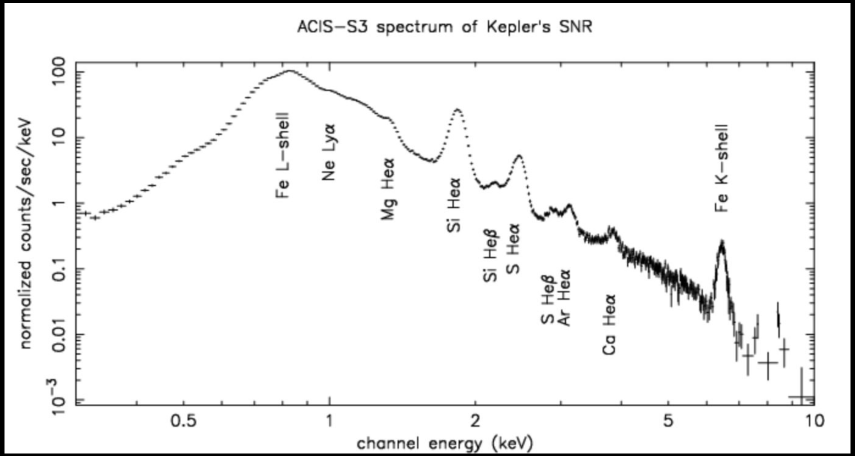


- **What Is a Spectrum?**
  A spectrum is a chart or graph that shows the intensity of light (or number of photons) detected across a range of energies.

- **Why Spectroscopy Matters**
  Spectroscopy is essential for understanding how astrophysical objects emit X-rays. It helps us determine:

  - What elements are present
  - The temperature and density of the emitting material
  - The velocity and motion of gas or plasma
  - And much more about the physical conditions of the source

- This talk focuses on imaging spectroscopy.
  Spectroscopy using Chandra gratings will be covered in a separate talk.

What is the goal?

The Fundamental Equation of Astronomy:

We observe the sky – a field of incoming light which varies with celestial lon/lat x,y, time t and energy E

S(x,y,t,E)

[n.b. Energy, wavelength, frequency, color interchangeable]

Our telescope/instrument/data pipeline gives us a signal as a function of **instrumental** position, time, energy

N(x’,y’,t’,E’)

The observation multiplies S with a sensitvity (“Effective Area”) A and convolves (smears) it with the observational response R

$$N(x',y',t',E') = \int S(x,y,t,E)\, A(x,y,t,E) R(x,y,t,E,x',y',t',E')\, dx\, dy\, dt\, dE$$

Our game is to invert this integral (we want S but we have N).

$$C(h) = \int_0^\infty \sum_i R_i(h,E) A_i(E)\, S_i(E)\, dE\, dT + B(h)$$

DETECTED COUNTS

RESPONSE MATRIX

EFFECTIVE AREA

SOURCE SPECTRA

BACKGROUND COUNTS

CAN “OVERLAP”

- Extract an X-ray spectrum of a source observed with ACIS imaging or the zeroth-order of a grating observation (HRC provides only very limited energy resolution)

- Generate the appropriate response files, which describe how the instrument modifies the incoming X-ray signal:

    - ARF (Ancillary Response File): accounts for the effective area of the telescope as a function of energy
    - RMF (Redistribution Matrix File): describes the instrument’s energy resolution and how it maps photon energies to detector channels

- These products allow the spectrum to be modeled and fit, helping to derive key physical properties of the source (like spectral slope, temperature, elemental abundances, absorption and more)

REMINDER!

When we start with an event file that includes detailed information for each event — position (x, y), energy (E), and time (t) — binning the data causes some of that information to be lost.

Depending on the type of analysis:

Spatial analysis: loses time and energy information

Spectral analysis: loses time and spatial information

Timing analysis: loses energy and spatial information

Each analysis focuses on certain dimensions of the data while discarding others.

An entire section of the CIAO Data Analysis Threads is devoted to this subject!

READ THE THREADS line by line at least the first time!

READ THE AHELP line by line at least once!

Imaging Spectroscopy

WHAT'S NEW | WATCH OUT

Top | All | Intro | Data Prep | Imag | Imag Spec | Grating | Timing | psf | TTT || Sherpa | PSF Central

After extracting source and background PI or PHA spectra from an imaging observation, the appropriate response files (ARF, RMF) are created so that the data may be modeled and fit. In the case of multiple or extended sources, a weighted ARF and RMF are built for the spectral analysis.

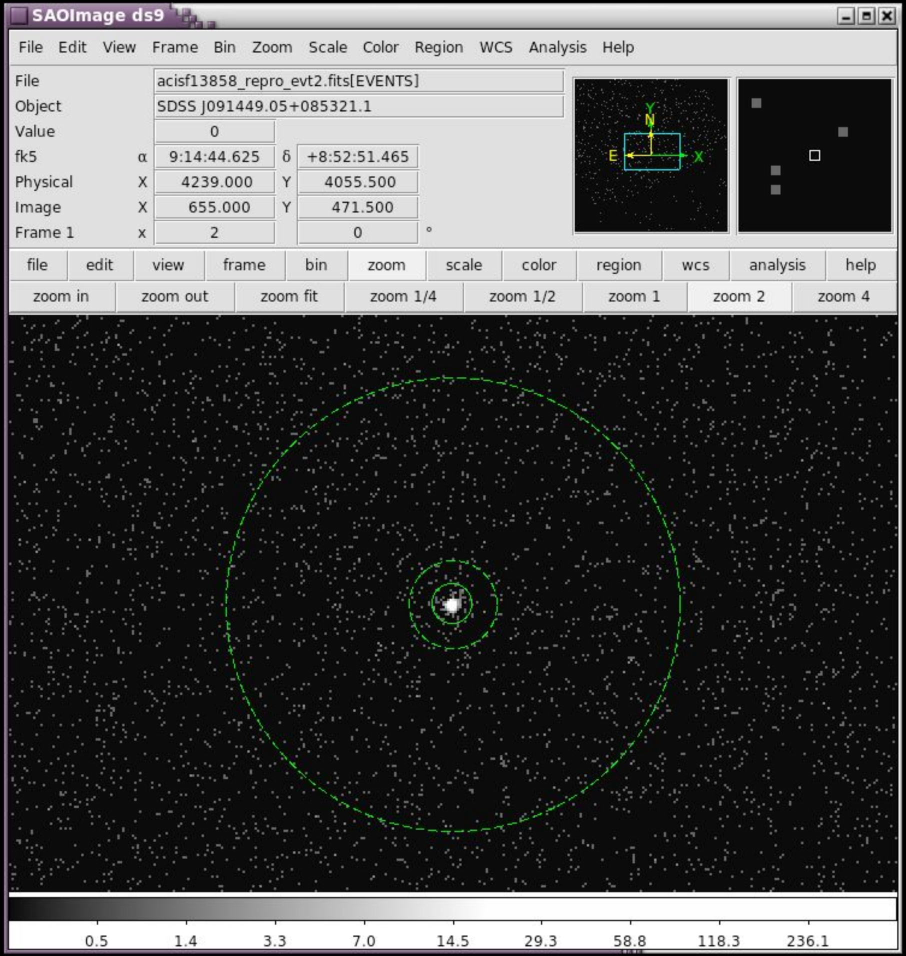
- **Extracting ACIS Spectra & Creating Response Files:**
  - Extract Spectrum and Response Files for a Pointlike Source UPDATED (13 Dec 2024)
  - Extract Spectrum and Response Files for an Extended Source UPDATED (13 Dec 2024)
  - Extract Spectrum and Response Files for Multiple Sources
  - Coadding Spectra and Responses
  - A Note on Responses for XSpec Users
- **Special Science Cases:**
  - Analysing the ACIS Background with the "Blank-Sky" Files
  - Extract a Spectrum from the ACIS Readout Streak UPDATED (10 Dec 2024)
  - Extracting a Spectrum of a Solar System Object
  - A Note on HRC Spectra
  - Adding Old Chandra Calibration Data to PIMMS UPDATED (20 Dec 2024)
- **Modeling & Fitting Spectral Data with Sherpa (from the Sherpa analysis threads):**
  - Introduction to Fitting PHA Spectra
  - Changing the grouping scheme of a data set within Sherpa
  - Introduction to Fitting ASCII Data with Errors: Single-Component Source Models
  - Simultaneously Fitting Two Data Sets
  - Simulating 1-D Data: the Sherpa FAKE_PHA Command
  - Simulating Chandra ACIS-S Spectra with Sherpa
  - Fitting PHA Data with Multi-Component Source Models
  - Independent Background Responses
  - Using A Pileup Model

Extract Spectrum and Response Files for a Pointlike Source

https://cxc.cfa.harvard.edu/ciao/threads/pointlike

PURPOSE:

To generate source and, optionally, background spectra of a pointlike source and build the proper RMFs and ARFs.

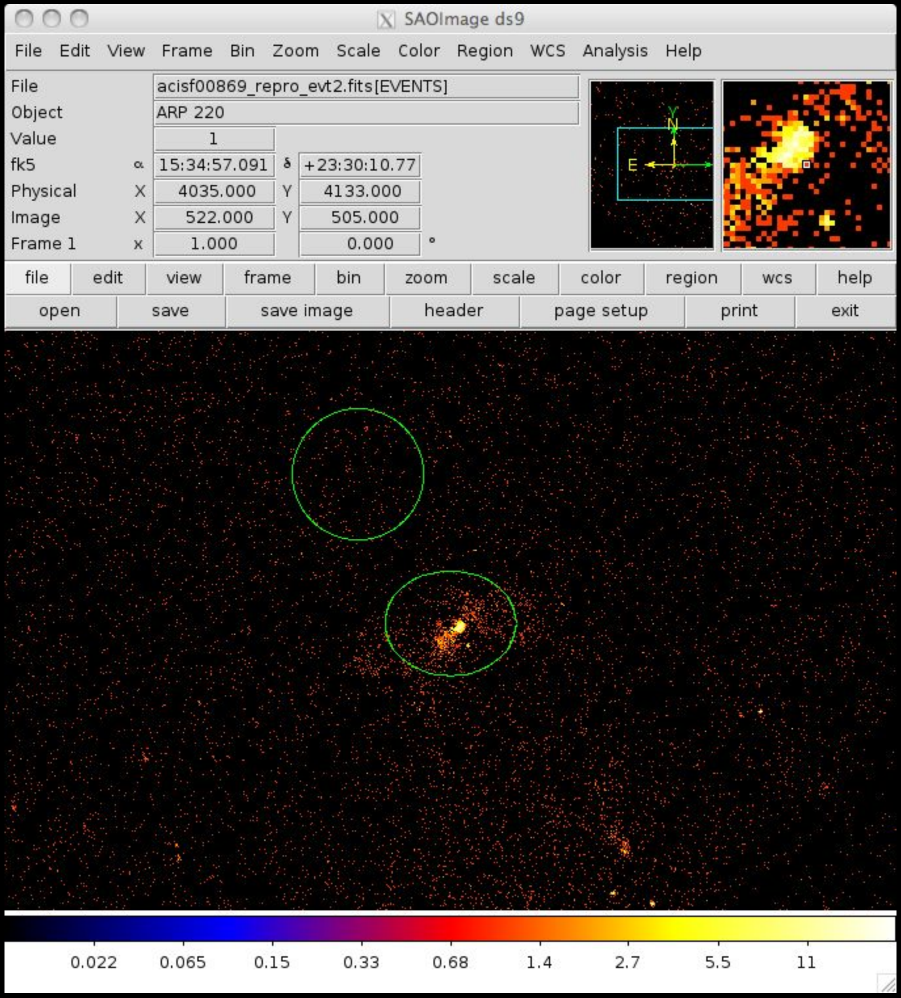


Extract Spectrum and Response Files for an Extended Source

https://cxc.cfa.harvard.edu/ciao/threads/extended/

PURPOSE:

To generate source and background spectra of an extended ACIS source and build the proper RMFs and ARFs.



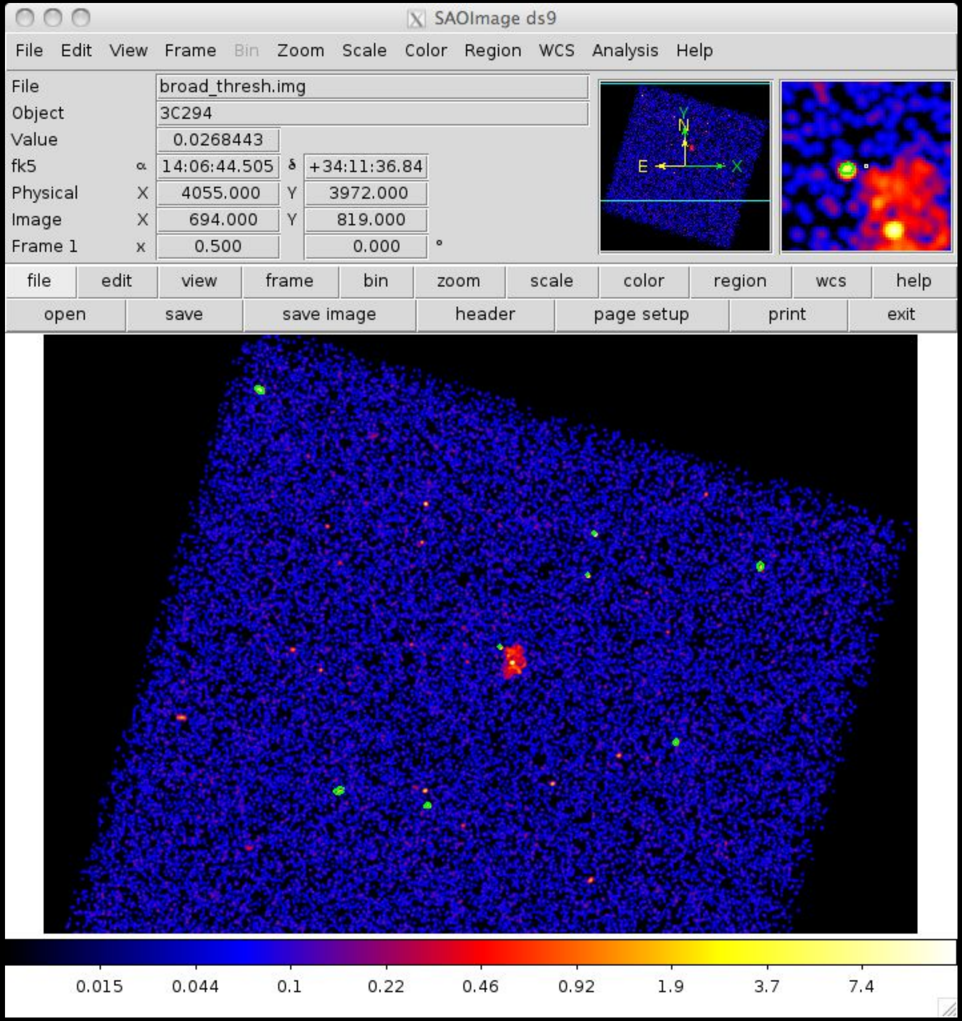
Extract Spectrum and Response Files for Multiple Sources

https://cxc.cfa.harvard.edu/ciao/threads/wresp_multiple_sources/

PURPOSE:

Create a spectrum for a set of sources in two ways:

- a number of point sources present in the field, coadded
- treating the field of sources as a single, extended object



SPECEXTRACT: your other best friend!

the old ways

`dmextract`, `acis_fef_lookup`, `acis_set_ardlib`, `mkrmf`, `mkacisrmf`, `dmstat`, `dmcoords`, `mkarf`, `arfcorr`, `asphist`, `sky2tdet`, `mkwarf`, `dmgroup`, and `dmhedit`

NOW

`specextract`

When given a source region (and optionally a background region), specextract:

- Extracts the source spectrum
- Extracts the background spectrum (optional)
- Generates response files (ARF and RMF)
- Optionally groups the spectrum (e.g., to a minimum number of counts per bin)
- Can combine results from multiple regions into a single spectrum

http://cxc.harvard.edu/ciao/ahelp/specextract.html

http://cxc.harvard.edu/ciao/bugs/specextract.html

SPECEXTRACT: your other best friend!

Suggestions

- Run the Step-by-Step Guide at least once or at least read through the thread!
- Use the guide as a reference when you have a special case, want to verify a specific output, or encounter something unexpected.
- It is useful to understand the specextract parameters in more depth

SPECEXTRACT: your other best friend!

In general

- Open DS9
- Identify the extraction region(s) for the source and the background (src.reg, bkg.reg)
- Set the specextract parameters
- Run the tool

At the minimum run

```
specextract  evt2.fits[sky=region(src.reg)] output
```

When extracting a spectrum a users need to make choices:

Do I need a background spectrum?

Is the source much brighter than the background?
Is the source extended, possibly blending with the background?
→ Controls the *bkg* parameters.

Should I correct the ARF for PSF losses?

Should I account for photons falling outside the aperture due to the finite PSF?
→ Use the correctpsf parameter.
Recommended for compact sources, especially off-axis.

Is the source extended or far off-axis?
Do the responses need to be weighted by the count distribution within the aperture?
→ Set weight=yes and possibly weight_rmf=yes
Useful for extended or asymmetric sources
Computationally expensive

Do I want one spectrum or multiple?
→ Use the combine parameter to control whether the outputs are combined.

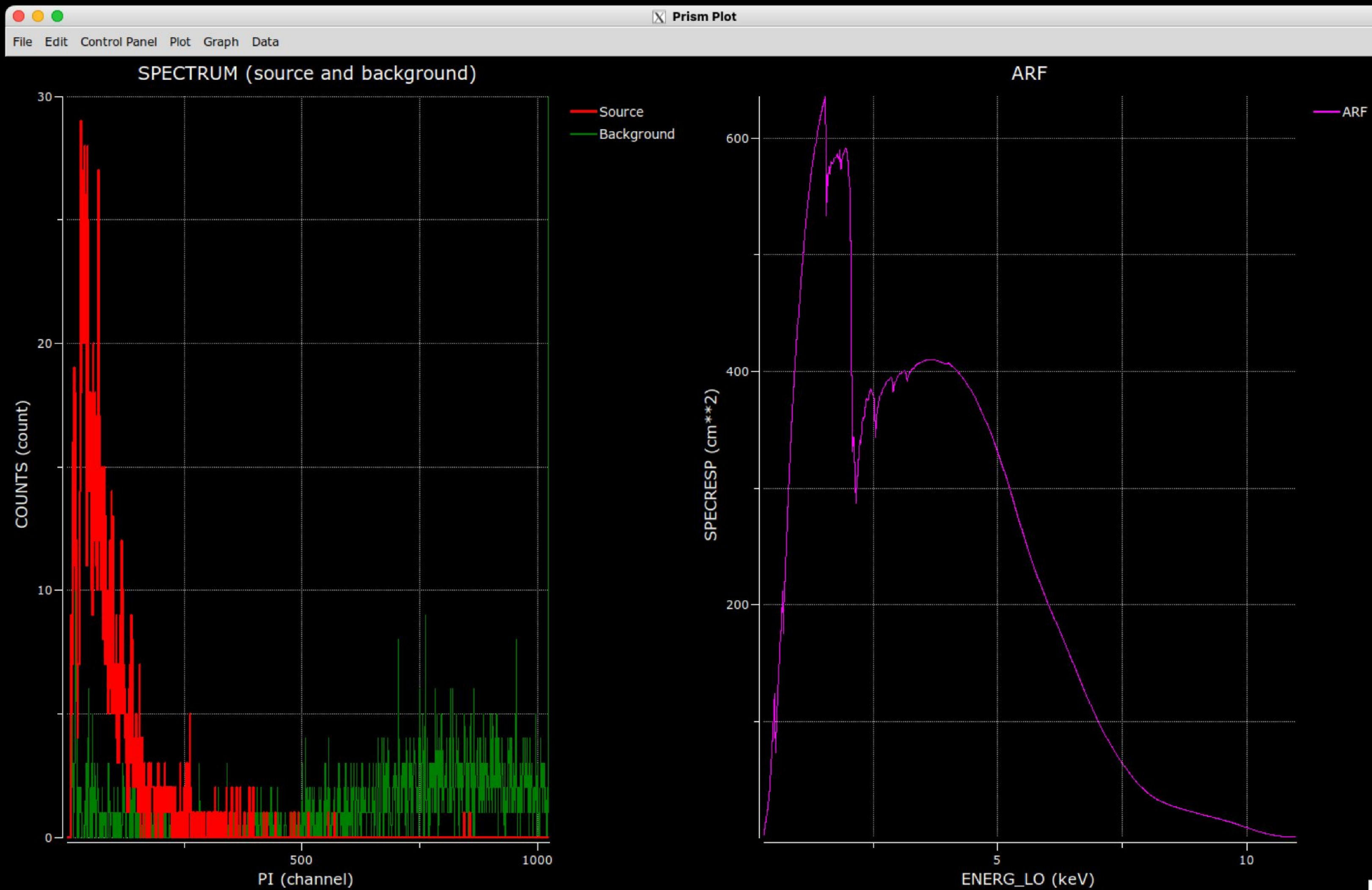
Parameters in specextract.par

infile =	Source event file(s)
outroot =	Output directory path + root name for output files
(bkgfile =)	Background event file(s)
(asp =)	Source aspect solution or histogram file(s)
(dtffile =)	Input DTF files for HRC observations
(mskfile =)	Maskfile (input to mkwarf)
(rmffile = CALDB)	rmffile input for CALDB
(badpixfile =)	Bad pixel file for the observation
(dafile = CALDB)	Dead area file (input to mkwarf)
(bkgresp = yes)	Create background ARF and RMF?
(weight = yes)	Should response files be weighted?
(weight_rmf = no)	Should RMF also be weighted?
(refcoord =)	RA and Dec of responses?
(correctpsf = no)	Apply point source aperture correction to ARF?
(combine = no)	Combine ungrouped output spectra and responses?
(grouptype = NUM_CTS)	Spectrum grouping type (same as grouptype in dmgroup)
(binspec = 15)	Spectrum grouping specification (NONE,1:1024:10,etc)
(bkg_grouptype = NONE)	Background spectrum grouping type (NONE, BIN, SNR, NUM_BINS, NUM_CTS, or ADAPTIVE)
(bkg_binspec =)	Background spectrum grouping specification (NONE,10,etc)
(energy = 0.3:11.0:0.01)	Energy grid
(channel = 1:1024:1)	RMF binning attributes
(energy_wmap = 300:2000)	Energy range for (dmextract) WMAP input to mkacisrmf
(binarfcorr = 1)	Detector pixel binnning factor for (arfcorr) to determine size and scale of PSF to derive aperture corrections at each energy step.
(binwmap = tdet=8)	Binning factor for (dmextract) WMAP input to mkacisrmf
(binarfwmap = 1)	Binning factor for (sky2tdet) WMAP input to mkwarf
(tmpdir = ${ASCDS_WORK_PATH} -> /tmp)	Directory for temporary files
(clobber = no)	OK to overwrite existing output file?
(verbose = 1)	Debug Level(0-5)
(mode = ql)	

OUTPUT of SPECEXTRACT

spec.pi [source binned spectrum]
spec.arf [source ARF]
spec.rmf [source RMF]

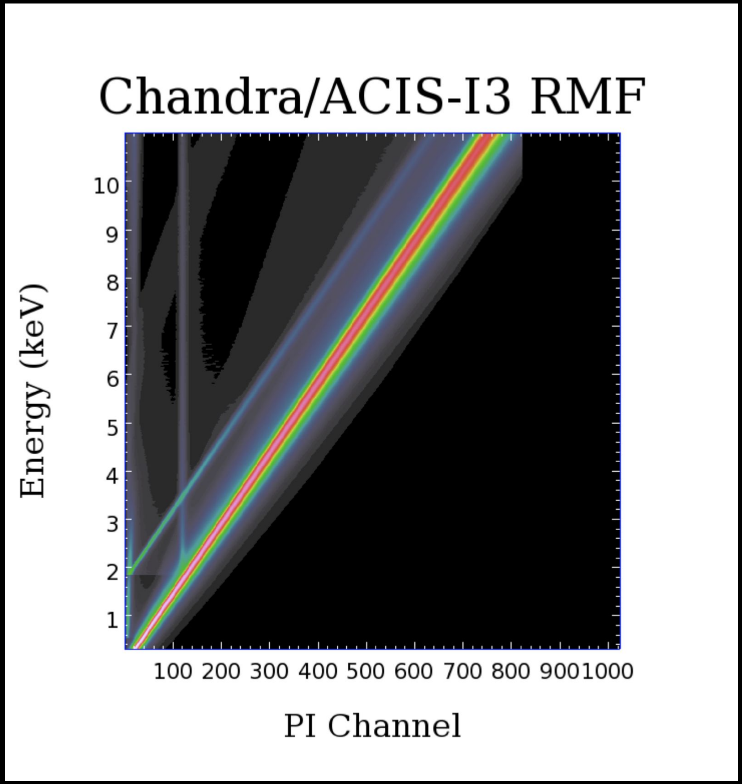
spec.corr.arf [corrected ARF] (if correctpsf=yes)
spec_grp.pi [“grouped” source spectrum] (if grouptype is given)
spec_bkg.arf [background ARF] (if bkgresp=yes)
spec_bkg.pi [background binned spectrum] (if bkgfile is given)
spec_bkg.rmf [background RMF] (if bkgresp=yes)

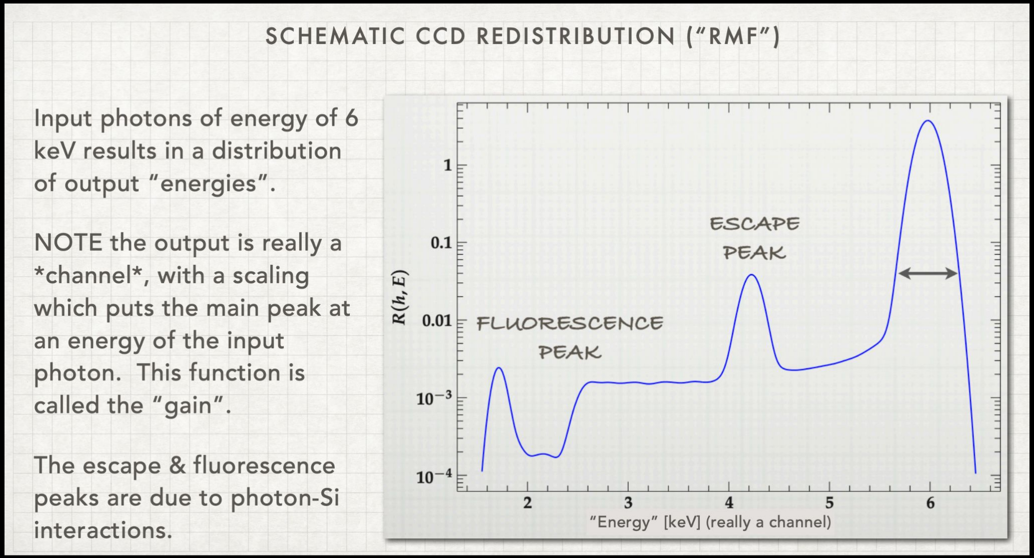

Prism Plot
File Edit Control Panel Plot Graph Data
SPECTRUM (source and background)
Source
Background
COUNTS (count)
PI (channel)
0
10
20
30
500
1000
ARF
ARF
SPECRESP (cm**2)
ENERG_LO (keV)
200
400
600
5
10

RMF: Redistribution Matrix File

An image representation of spec.rmf (generated with **`rmfimg`**)

- Maps from energy space into detector channel (position) space.
- For CCD detectors, such as ACIS, most of the response is almost diagonal, but escape peaks and low energy tails adding significant contributions.





EVEN EASIER METHOD!

Do it all in ds9 via `dax`!

Quick demo

https://www.youtube.com/user/4ciaodemos

NEXT STEP

Go into the **Sherpa** application to perform modeling and fitting