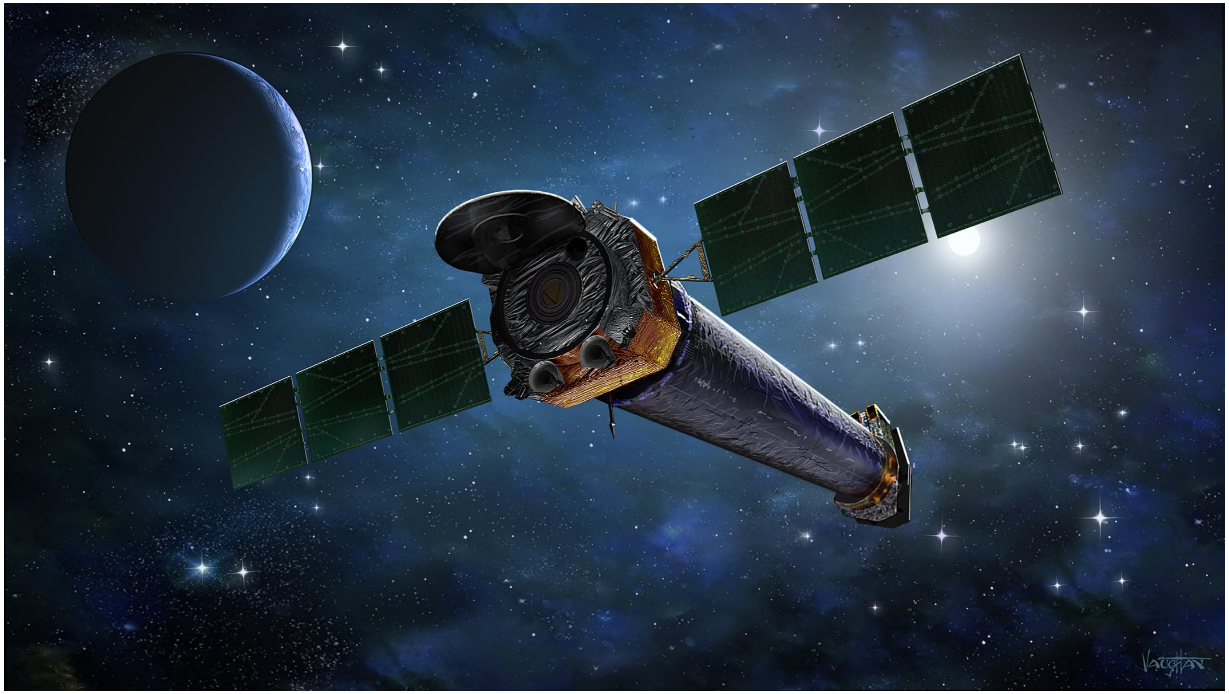
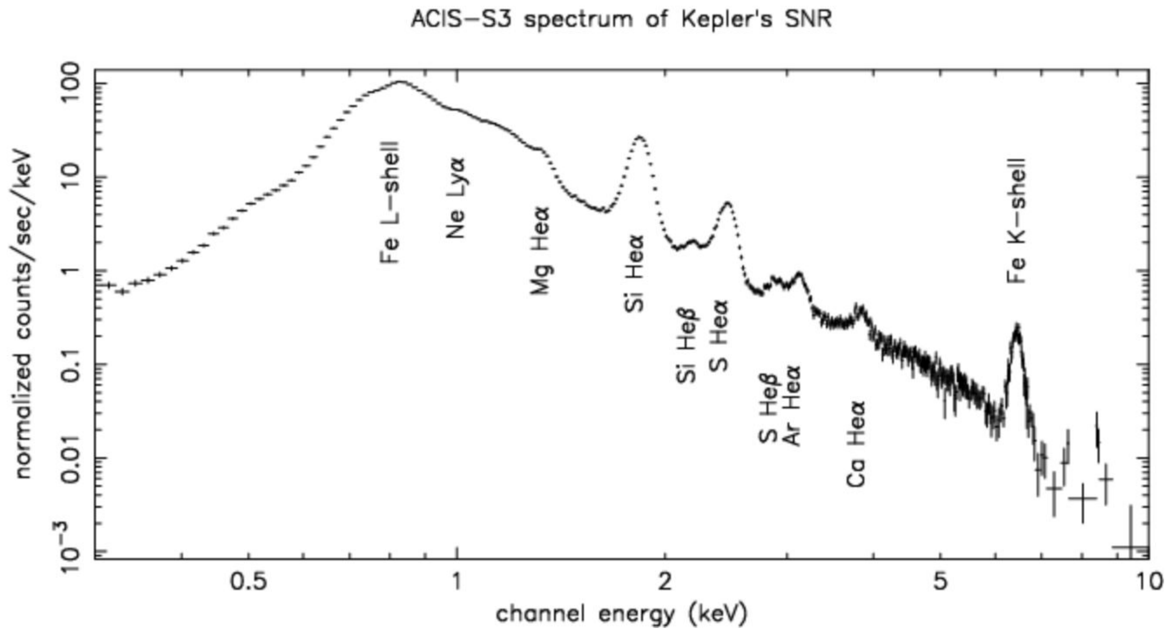
Imaging Spectral Analysis
Flux Calculation

and a bit more



1. Imaging Spectral Analysis



- A **spectrum** is a chart or a graph that shows the intensity of light being emitted over a range of energies.
- Spectroscopy is crucial to understand how different objects emit x-ray light, what elements they are mostly composed of, the temperature and the density, the velocity of the material and so forth.
- I am concentrating here on imaging spectroscopy, while spectroscopy with the Chandra gratings will be covered in a different talk.

What is the goal?

- Extract an X-ray spectrum of a source detected in an ACIS imaging observation (very limited energy information on the HRC instrument) or a zeroth-order grating observation

- Create the appropriate response files (which describe the effects of the instrument on the input spectrum)

  ✓ ARF: Ancillary Response File
  ✓ RMF: Response Matrix File

So that the spectrum can be modeled and fit to derive physical information about the source (spectral slope, temperature, abundances, absorption, etc.)

REMINDER!

When starting from an event file which has information on **(x,y,E,t)** for each event

Spatial Analysis (*lose time and energy information*)

Spectral Analysis (*lose time and spatial information*)

Timing analysis (*lose spectral and spatial information*)

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 || ChIPS | Sherpa | Proposal | PSF Central

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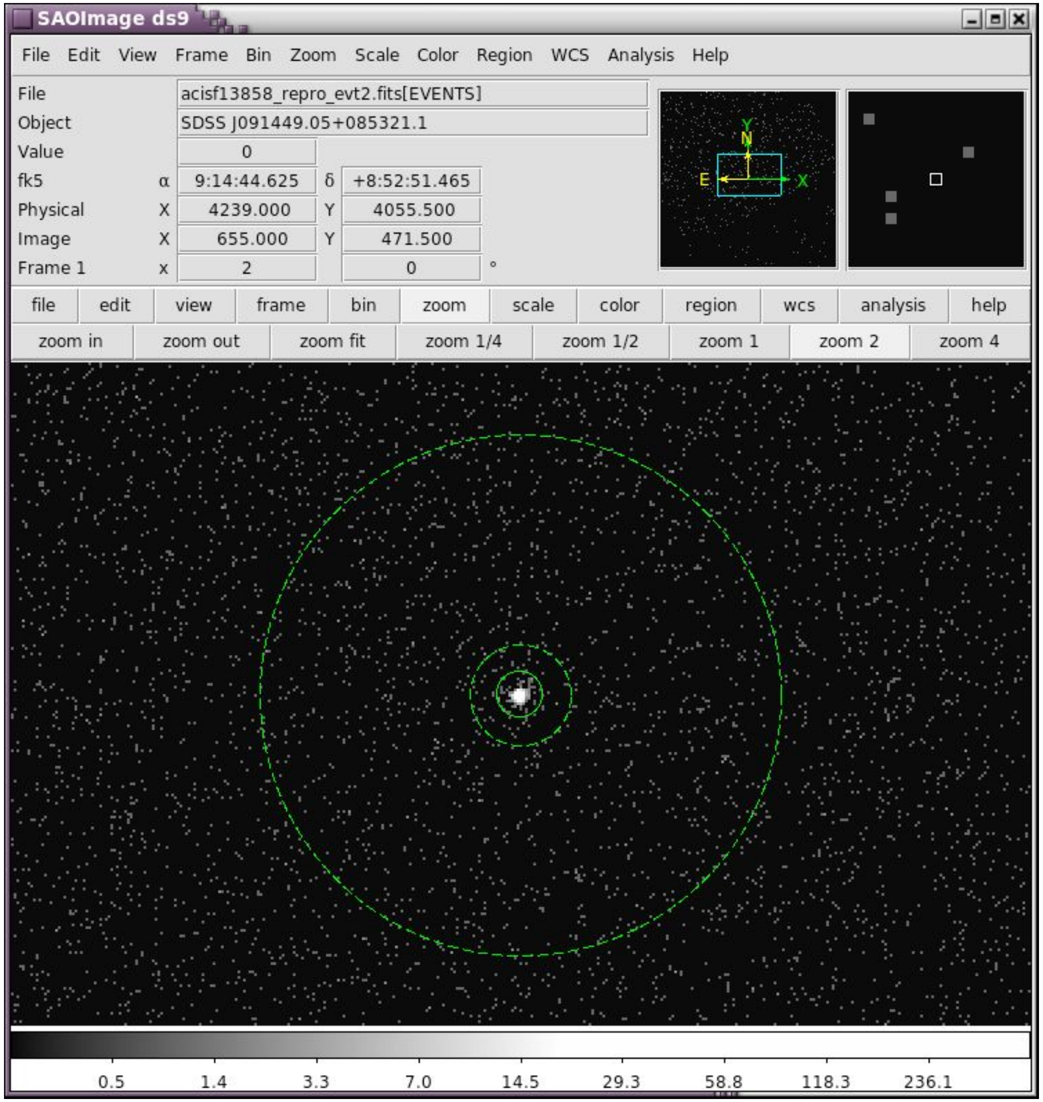
After extracting source and background PI or PHA spectra from an imaging observation, the appropriate response files (ARF, RMF) are created so that the data may be modeled and fit. In the case of multiple or extended sources, a weighted ARF and RMF are built for the spectral analysis.

- **Extracting ACIS Spectra & Creating Response Files:**
  - Extract Spectrum and Response Files for a Pointlike Source
  - Extract Spectrum and Response Files for an Extended Source
  - 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
  - Extracting a Spectrum of a Solar System Object
  - A Note on HRC Spectra
  - Adding Old Chandra Calibration Data to PIMMS
- **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

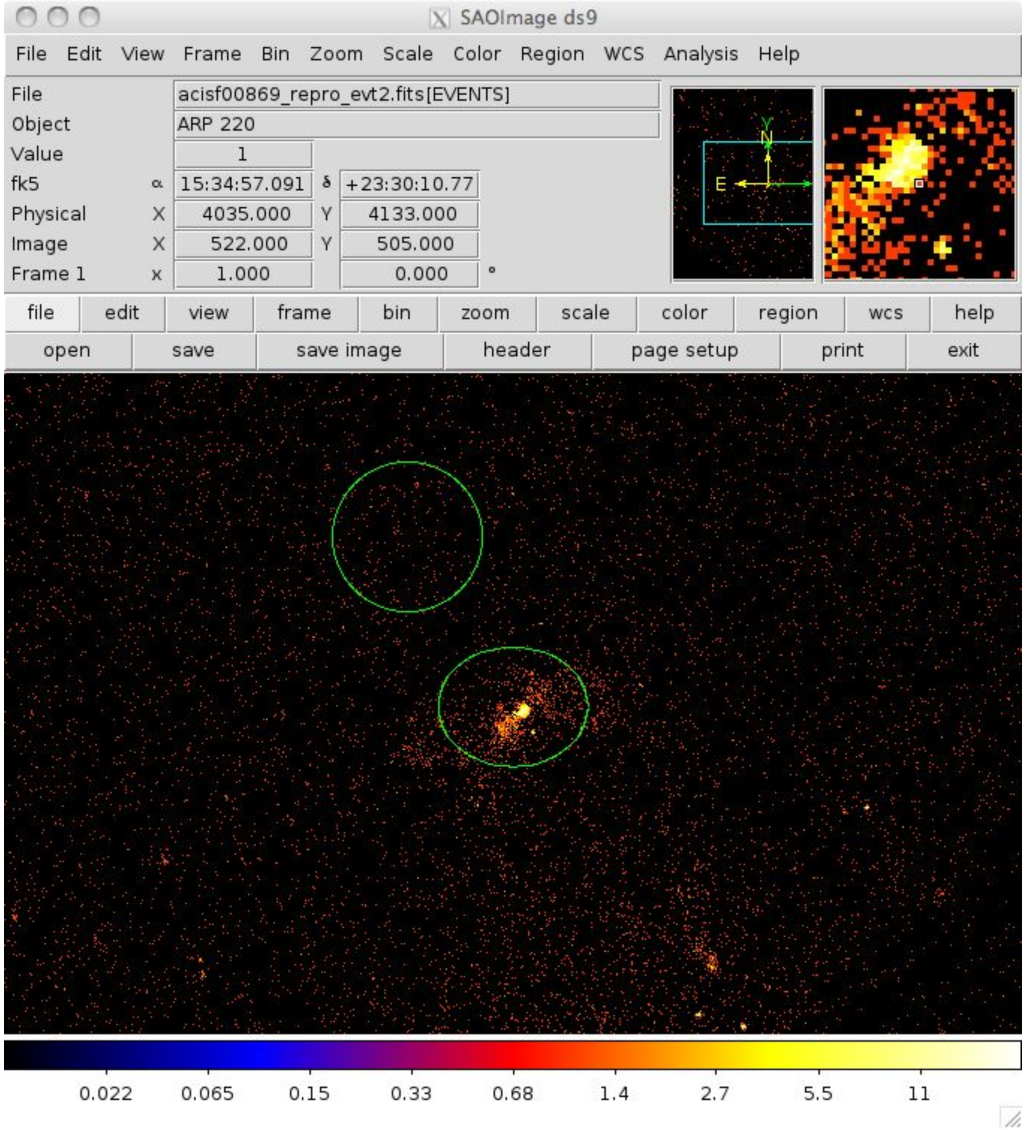
Extract Spectrum and Response Files for a Pointlike Source

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



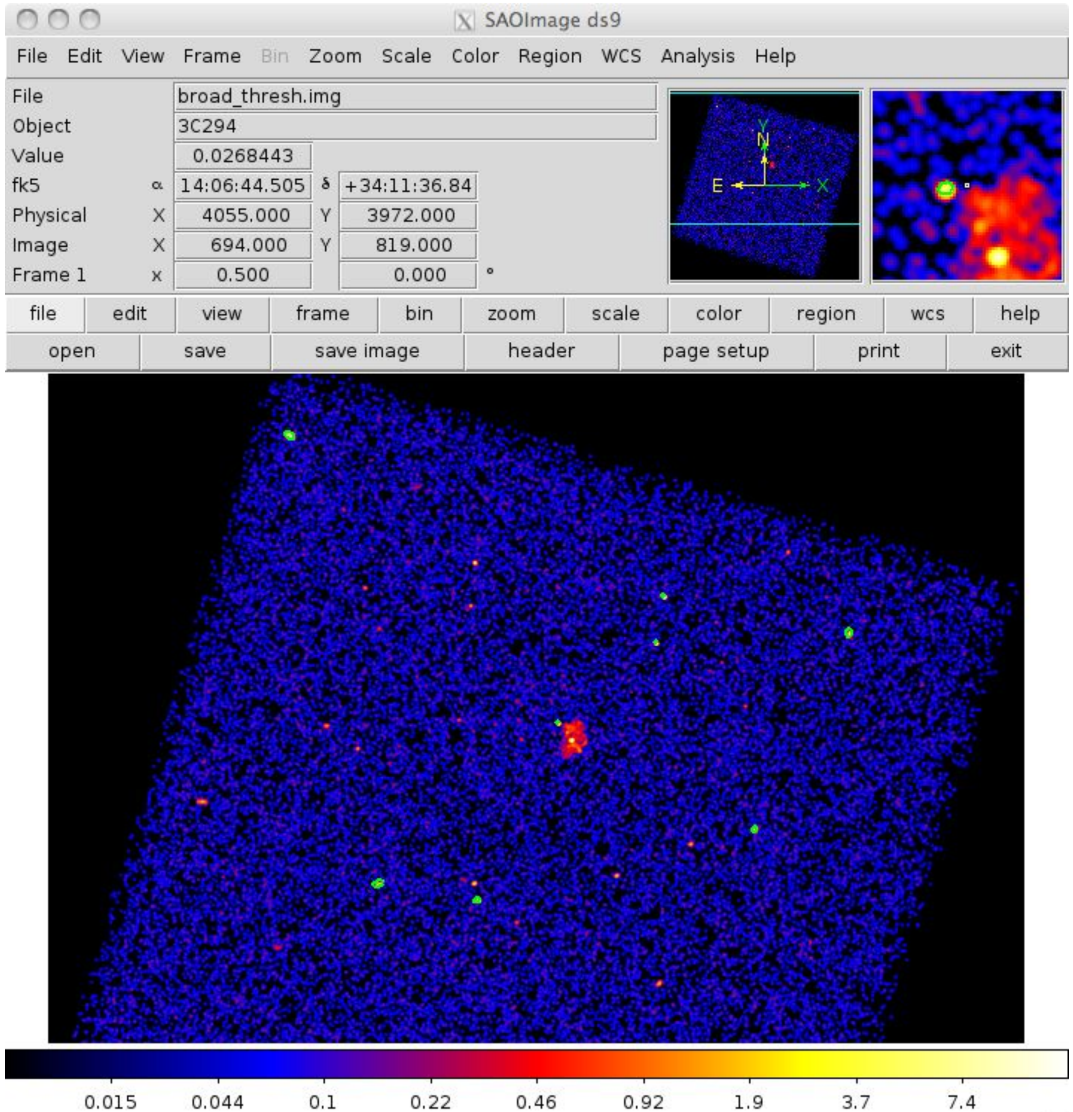
Extract Spectrum and Response Files for an Extended Source

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



Extract Spectrum and Response Files for Multiple Sources

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



You can achieve this goal by

A. running *many* different tools to perform the various steps
B. running one “script”

SPECEXTRACT

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

However…

- Run the Step-by-Step Guide at least once!
- You also want to use the step-by-step guide as reference in case you have a special case, you want to check a specific output, etc.
- You want to understand some of the **specextract** parameters in more depth

But in general…

1. Open **ds9** and identify the extraction regions for the source and the background (**src.reg**, **bkg.reg**)

2. Set the **specextract** parameters and run the tool

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

Main decisions a user has to make

- Is a background spectrum needed? (is the source much brighter than the background? is my source extended?) (**bkg*** parameters)

- Should the ARF be corrected for events falling outside the finite size and shape of the aperture (**correctpsf** parameter)

- Is the source extended enough or far off-axis so that the responses need to be weighted by the count distribution within the aperture? (the **weight** and **weight_rmf** parameters) - useful but computationally expensive

- Do I want a single spectrum or many spectra (for multiple regions) (**combine** parameter)

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 binning 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)

Extract Spectrum and Response Files for a Pointlike Source

```
% pset specextract infile=“acisf13858_repro_evt2.fits[sky=region(src.reg)]"

% pset specextract bkgfile=“acisf13858_repro_evt2.fits[sky=region(bkg.reg)]"

% pset specextract outroot=spec

% pset specextract correctpsf=yes

% pset specextract weight=no

% specextract

Source event file(s) (acisf13858_repro_evt2.fits[sky=region(src.reg)]):
Output directory path + root name for output files (spec):
Running specextract
[…]
```

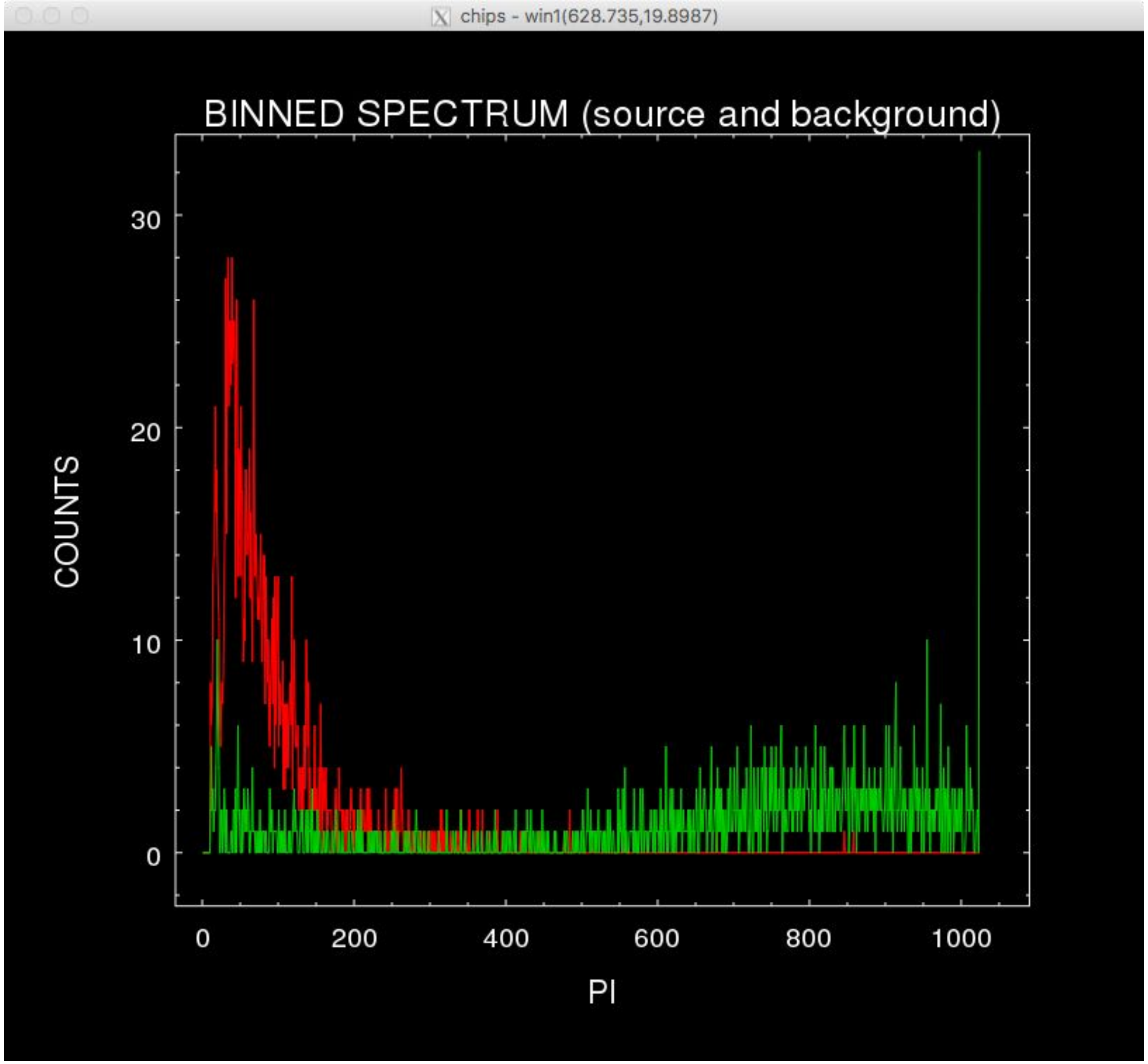
OUTPUT of SPECEXTRACT

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)

spec.pi

spec_bkg.pi

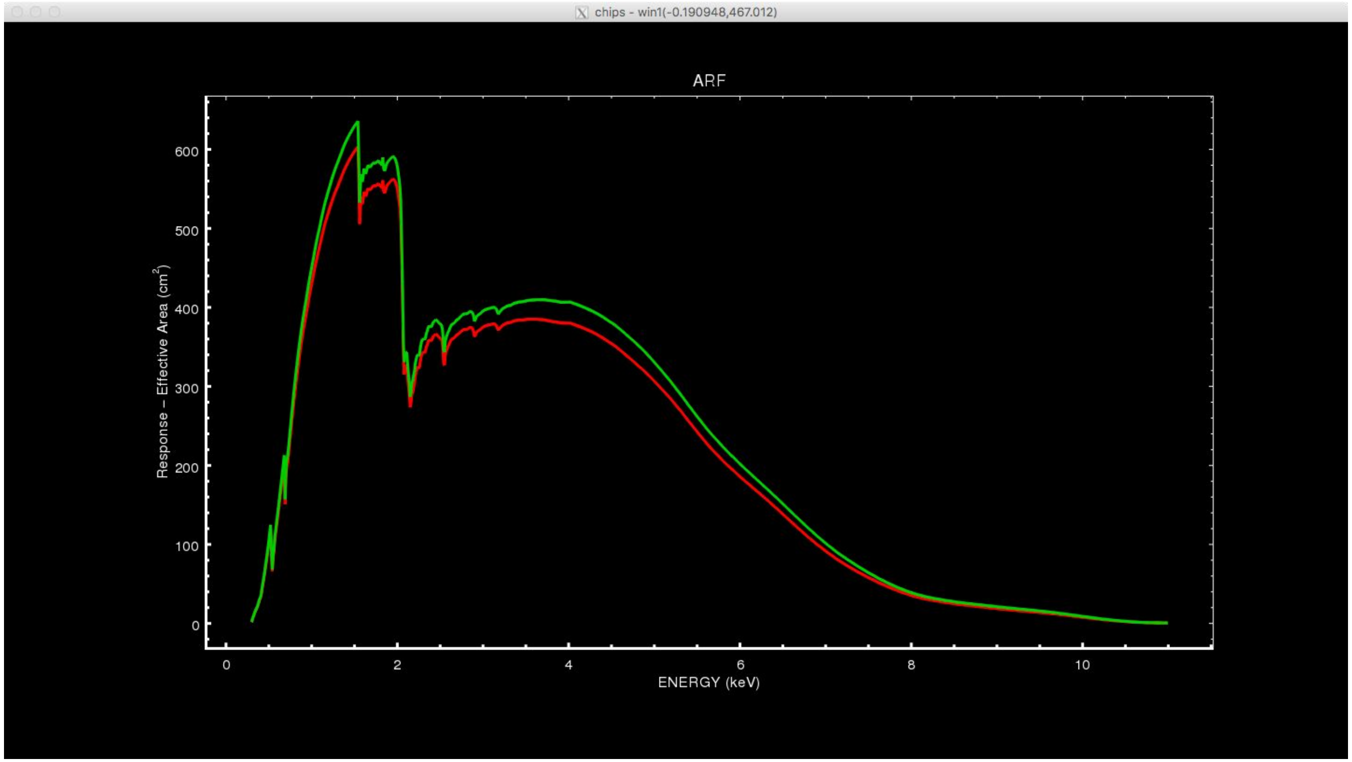


PI (pulse invariant) = [(energy/14.6 eV) + 1]

https://cxc.cfa.harvard.edu/ciao/dictionary/pi.html

ARF: Auxiliary Response File

spec.arf spec.corr.arf



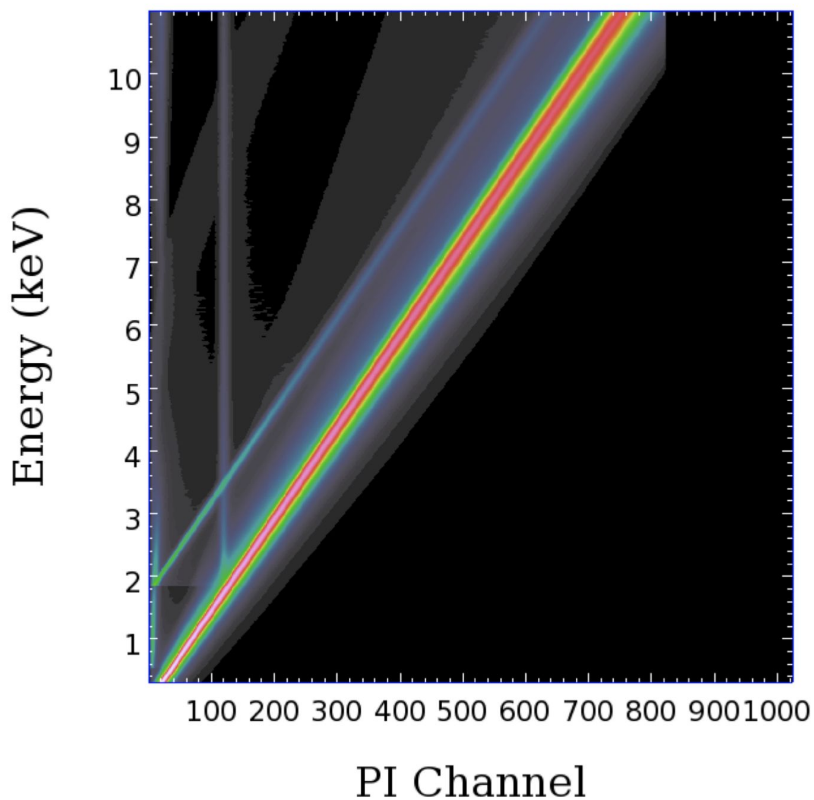
- combined telescope/filter/detector areas ("effective area") and the quantum efficiency (QE) as a function of energy. The effective area is [cm^2] and the QE is [counts/photon]; they are multiplied together to create the ARF, resulting in [cm^2 counts/photon].
- When the input spectrum is multiplied by the ARF, the result is the distribution of counts that would be seen by a detector with perfect (i.e. infinite) energy resolution.
- The RMF (which describes the energy resolution) is then needed to produce the final observed spectrum.

RMF: Redistribution Matrix File

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

- Maps from energy space into detector channel (position) space.
- Since detectors are not perfect, this involves a spreading of the observed counts by the detector resolution, which is expressed as a matrix multiplication.
- For CCD detectors, such as ACIS, most of the response is almost diagonal, but escape peaks and low energy tails adding significant contributions.

Chandra/ACIS-I3 RMF

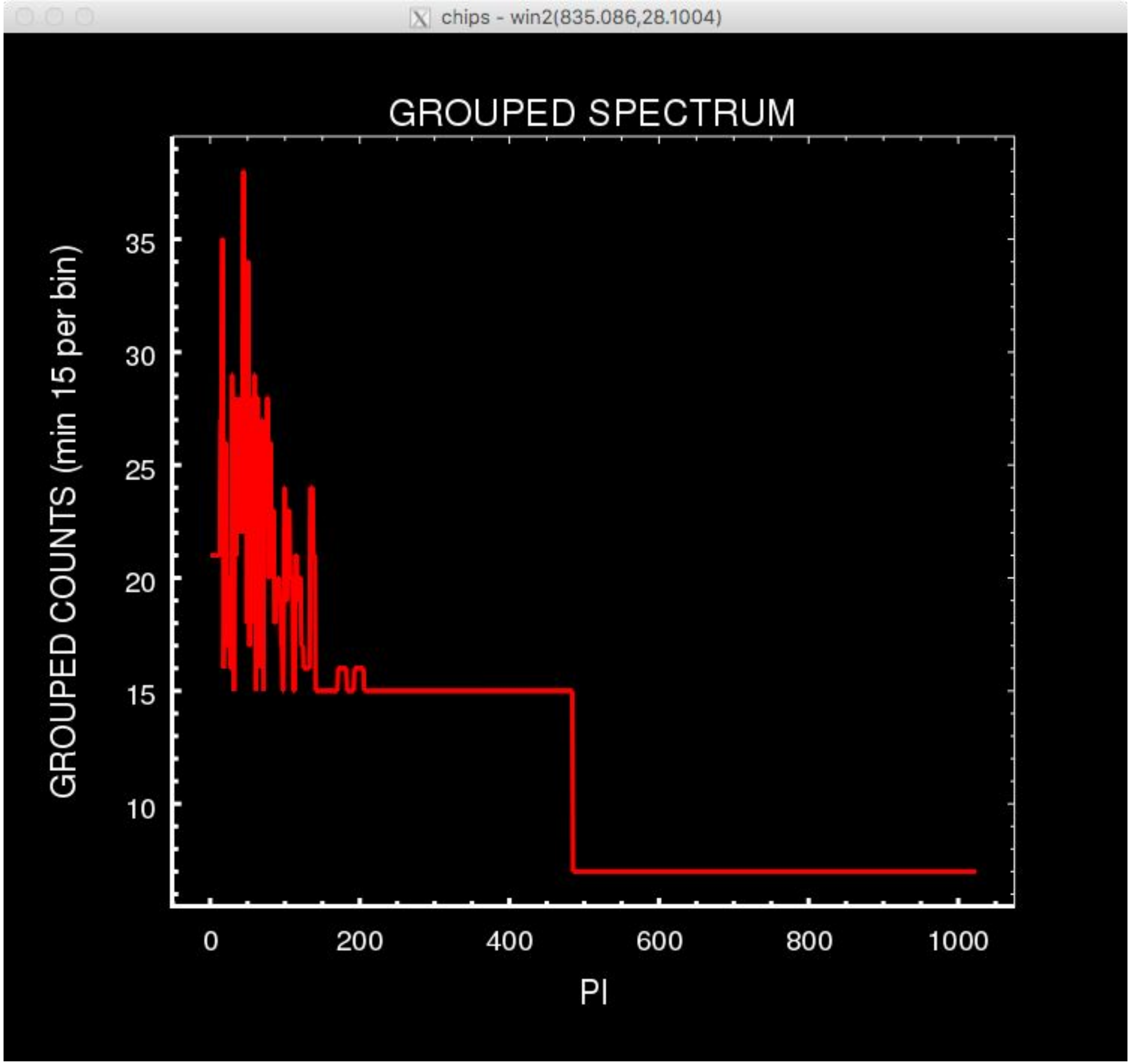


spec_grp.pi

To highlight certain features in the spectrum or certain portions of the spectrum counts can be “grouped” in arbitrary bins.

In this example each “group” contains at least 15 counts.

In the highest channels - where there are fewer counts - a single bin covers many channels.



Or…

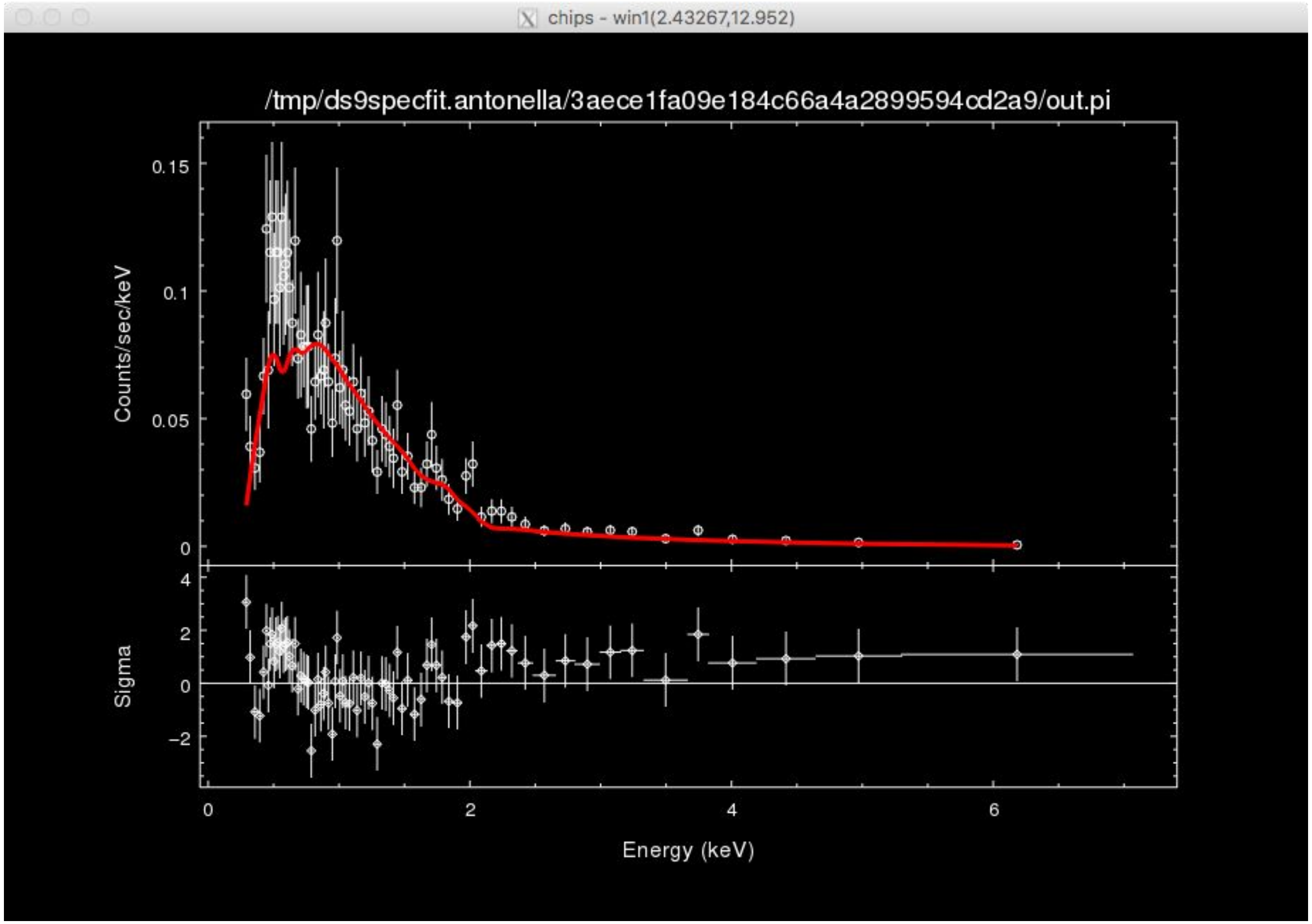
Do it all in ds9 via dax!

Quick demo

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

NEXT STEP

Go into the Sherpa application to perform modeling and fitting



2. X-RAY FLUX CALCULATION

or how bright is my source?

Luminosity (**L**) is the total amount of electromagnetic energy emitted per unit of time by an astronomical object ($\mathbf{L_X}$ generally in [*erg/sec*])

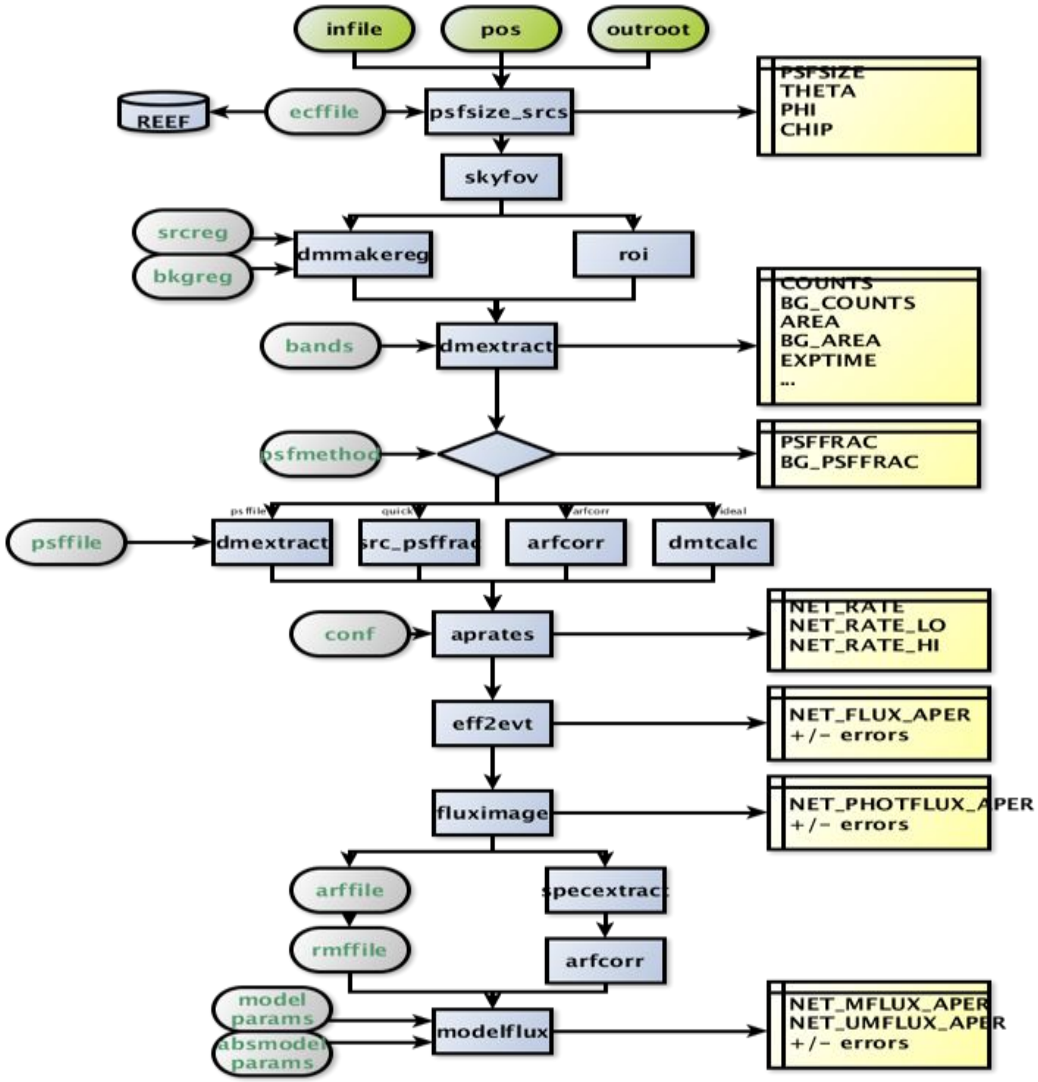
Flux (**F**) is the total amount of energy that crosses a unit area per unit time ($\mathbf{F_X}$ generally in [*erg/cm²/sec*])

$$\mathbf{F=L/4\pi d^2}$$

So the flux of a source is one its main defining properties which (X-ray) observers want to calculate, but it is not so simple to calculate when all the instrumental and other effects are taken into account.

The most difficult part in the calculation is a correct estimate of the confidence interval.

Source Flux with **`srcflux`**



Source Flux with `srcflux`

$ **srcflux myevt2.fits "03:29:29.250 +31:18:34.73" myflux**
[...]
Summary of source fluxes

Position	0.5 - 7.0 keV
	Value 90% Conf Interval
3 29 29.25 +31 18 34.7	Rate 0.0398 c/s (0.0381,0.0415)
	Flux 5.17E-13 erg/cm2/s (4.94E-13, 5.39E-13)
	Mod.Flux 4.38E-13 erg/cm2/s (4.2E-13, 4.57E-13)

- Encodes the logic described in six different CIAO threads.
- Returns count rates, fluxes, and errors with all appropriate corrections.
- Can automatically determines PSF-appropriate extraction region size for source and background if user does not specify them
- Uses one of four methods to apply aperture correction
- Runs on multiple energy bands
- Accepts one position or a list
- Calculates fluxes in two different ways
- Calculates confidence intervals (including upper-limits)

On YouTube: DAX Photometry with srcflux

...and MORE

CIAO/CHANDRA on social media

https://twitter.com/chandraCIAO
https://www.facebook.com/ChandraCIAO/

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

https://twitter.com/chandraCDO
https://www.facebook.com/chandraCDO
https://twitter.com/chandraarchive

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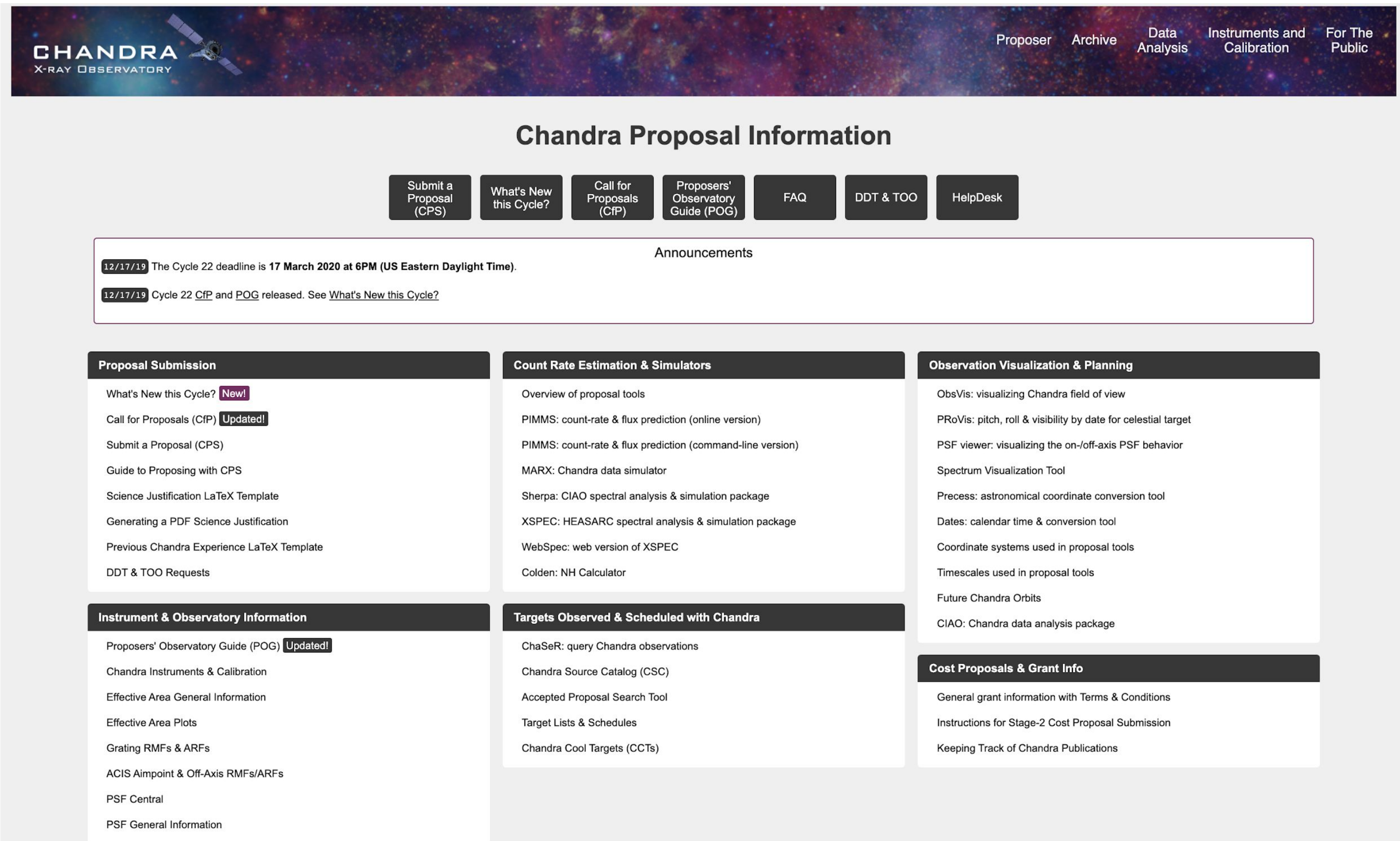
CHANDRA PROPOSALS

Call For Proposal ~December 15
Proposal Deadline ~March 15

THIS YEAR: Due Date: 16 March 2021, 6 p.m. EDT

Peer Review ~June
Results ~July
Observations start ~Nov

http://cxc.harvard.edu/proposer/



Call For Proposal (CfP)

http://cxc.harvard.edu/proposer/CfP/

Proposers' Observatory Guide (POG)

http://cxc.harvard.edu/proposer/POG/

Frequently Asked Questions

http://cxc.harvard.edu/proposer/faqs.html