Overview

Chandra Information

Getting Help

Data Acquisition

Data Preparation

reprocess
source detect
deflare
First, a quick detour on documentation and getting help...

cxc.harvard.edu/ciao
Science Analysis “Threads”

- Science Threads are the most important document type.
  - over 150 CIAO and Sherpa threads, designed to teach users the approach and concerns that go along with analysis
  - organized primarily based on science analysis categories
  - updated and added to as needed; look for “new” and “updated” icon tags

- A thread is *just an example* on approaching a problem.
“Guides” and “Why” Pages

- Analysis Guides are a roadmap to broad categories of analyses.

- Why Topics supplement threads with more detailed information.
  - some topics highlight common pitfalls and nuances in the software
  - others topics discuss aspects of Chandra and the data obtained with it
  - some of these topics will also discuss why certain science decisions are made, enabling the user to tailor the analysis to a particular dataset
“ahelp” — AXAF Help in CIAO

- CIAO and Sherpa comes with the command-line “ahelp” system.
  - ahelp has corresponding online counterpart, which is updated between software releases
    *[cxc.harvard.edu/ciao/ahelp & cxc.harvard.edu/sherpa/ahelp]*

- Python-environments also supports document strings; Sherpa’s primary documentation system.

```
unix% ahelp <toolname>
unix% ahelp <context>
unix% ahelp -c
```

- In Sherpa the string must be in quotes:

```
sherpa> ahelp “toolname”
sherpa> ahelp(“toolname”)  
sherpa> help(“docstring”)```

Tip: if you run a tool in the default interactive mode, when prompted for a parameter, entering ‘?’ opens the tool’s ahelp file.

```
unix% dmextract
Input event file (): ?
```
A Typical *Chandra*-user’s Focus…

- Threads answer more detailed issues that may affect science
- `ahelps` give the details behind the tool itself

Don’t blindly follow the examples verbatim, the threads are not strict recipes!
CIAO Release Notes

- CIAO release notes are revised whenever a new version or patch of a package is updated.

- CalDB components are updated periodically, but will vary from one release to the next.

- More details on the CalDB can be found at:
  cxc.harvard.edu/caldb

- Details of changes to contributed scripts can be seen at:
  cxc.harvard.edu/ciao/download/scripts/history.html

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A Word of Caution...

cxc.harvard.edu/ciao

▶ forwards to the most recent release version of CIAO
▶ version-specific website can be found at: cxc.harvard.edu/ciaoX.Y

▶ similar address structure for Sherpa pages: cxc.harvard.edu/sherpa cxc.harvard.edu/sherpaX.Y

▶ Be careful with search engine results!
The Chandra Helpdesk
cxc.harvard.edu/helpdesk

Provides support for:
- proposals & proposal planning
- observation scheduling and issues
- proprietary data
- data archive
- data analysis and DS9
Contents of a Ticket

- software information
  - CIAO version
  - CalDB version
  - Sherpa—stand alone or CIAO distribution

- platform and operating system

- question
  - what is the problem or concern encountered?
  - contextualize the question: what are you trying to do, what is your goal?
    - if referencing a document, include citation beyond just the authors (journal, volume, page)

- what did you do?
  - describe what you’ve done and the steps taken
  - provide commands used
    - copy-and-paste text or provide a log file; no screenshots of terminal, please
  - include any messages returned by tool, including warning and error messages
  - provide supporting data files
Finally...

- Please reply back if you’re satisfied with the answer/solution so we can go ahead and close the ticket.

- If you have a completely unrelated question, instead of adding to an existing ticket, just open a new ticket.

- Help us help you!
  - the more information you’re able to provide up front means a quicker resolution to the concern

- Ultimately, the documentation, software, and helpdesk are meant to help you get to a specific data product.
  - what you do with the data product will be determined by your science goals and judgement
  - doing science is outside the scope of what helpdesk can support
The Chandra Data Archive

cxc.harvard.edu/cda
ChaSeR: Chandra Search and Retrieval System
cda.harvard.edu/chaser
browse the observation catalog with a variety of search criteria

cone search or range of coordinates around a celestial position or target name
  target name can be resolved to a position with SIMBAD and NED
  a list of up to 5000 positions can also be supplied to query the catalog

syntax for a range of dates: $T_1/T_2$, $T_1/$, /$T_2$
  $T_n$ format: YYYY-MM-DD
  between $T_1$ and $T_2$, after $T_1$, before $T_2$
ChaSeR (continued)
ChaSeR ObsID Entry

- Details of the instrument configuration for the observation.
- V&V—Verification and Validation—report includes a summary of any anomalies during the observation, usually noted in the Comments section.
- Preview images.
- List of ADS links to publications that have made use of the observation data.
- Shows a table which indicates if any problems were identified in the observation during pipeline processing.
ChaSeR ObsID Entry

- for non-proprietary data:
  - option to stage primary, secondary, or customized set of data products for retrieval
  - for typical analysis, once you have the ObsID of interest, just use:
    `download_chandra_obsid`

- ChaSeR is required to obtain proprietary data.

- If the existing archive interfaces do not meet your needs, the archive team may consider a special request:
  `cxc.harvard.edu/cgi-gen/cda/specreq`
unix% find_chandra_obsid 4C19.44

# obsid sepn inst grat time obsdate piname target
2140   0.0 ACIS-S NONE   9.1  2001-01-08    Sambruna  1354+195
6903   0.1 ACIS-S NONE   43.7 2006-04-01    Harris  4C19.44
6904   0.1 ACIS-S NONE   34.8 2006-03-20    Harris  4C19.44
7302   0.1 ACIS-S NONE   68.9 2006-03-28    Harris  4C19.44
7303   0.1 ACIS-S NONE   41.5  2006-03-30    Harris  4C19.44

Parameters for ${HOME}/cxcds_param4/find_chandra_obsid.par

arg = RA, ObsId, or name of source
dec = Dec of source if arg is not the ObsId/name
(radius = 1.0) Radius for search overlap in arcmin
(download = none) What ObsIDs should be downloaded?
(instrument = all) Choice of instrument
(grating = all) Choice of grating
(detail = basic) Columns to display
(mirror = ) Use this instead of the CDA FTP site
(verbos = 1) Verbose level
(mode = h)
Beyond ChaSeR: Chandra Footprint Service

cxcffps.cfa.harvard.edu/cda/footprint/cdaview.html

A search by position or object name overlays the footprints of Chandra Observations on Digitized Sky Survey images, allowing further selection and retrieval of observations.
Uses the AAS’s WWT interface to explore the sky coverage and source properties of CSC 2.0

Provides links for ObsIDs to ChaSeR

Provides info to access catalog data products via CSCView
- Includes all publicly available gratings observations
- Provides calibrated spectra and responses
- Provides quick-look visualization and summary products
**NASA’s HEASARC Archive**

(High-Energy Astrophysics Science Archive Research Center)

heasarc.gsfc.nasa.gov/docs/archive.html

- Primary portal to all data from EUV/X-ray/γ-ray missions (past and present) with NASA involvement and supported with public funds.
  - also provides access to data archives of other space agencies

- NASA’s primary repository of the observations of relic CMB radiation from space missions, balloons, and ground-based facilities in the sub-mm, mm, and cm bands.
Threads of Analyses

cxc.harvard.edu/ciao/threads
cxc.harvard.edu/sherpa/threads
Analyses:

Initial Data Preparation

- The data contained in the events list informs us of the types of data products we can generate.
  - **Image**—bin on spatial-axes, lose energy and temporal information
  - **Spectra**—bin on spectral-axis, lose spatial and temporal information
  - **Lightcurves**—bin on time-axis, lose spatial and energy information
  - **Source Lists**—identify regions in spatial, energy, and time coordinates corresponding to sources

```
unix% dmlist evt.fits cols
```

- Available data products determine possible types of analysis.
  - [cxc.harvard.edu/ciao/data_products_guide](http://cxc.harvard.edu/ciao/data_products_guide/) provides description of files and columns from standard archive download
Analyses Paths

- image
  - radial profiles
  - smoothing & PSFs
  - cross-correlation & auto-correlation
  - flux maps
- spectrum
  - model fitting
  - spectral deprojection for 3D source properties
- lightcurve
  - Gregory-Loredo variability tests
  - power spectrum
  - phase-resolved spectroscopy
- reprocess downloaded data to ensure latest calibration products are applied to the data set
- background flares
  - most likely to affect extended sources, particularly diffuse features
  - weak point sources more likely to be affected than bright point sources
Download and Reprocess (single ObsID)

Unix% download_chandra_obsid 7302

... SCREEN OUTPUT (DOWNLOAD PROGRESS)...

Unix% dmkeypar primary/acisf07302N002_evt2.fits.gz DATAMODE echo+Faint

Unix% chandra_repro indir=7302 outdir=7302/repro check_vf_pha=no
Processing input directory ‘${HOME}/Work/Example/7302’

... MORE SCREEN OUTPUT ...  

The data have been reprocessed.
Start your analysis with the new products in
${HOME}/Work/Example/7302/repro

- Can download multiple datasets using a comma-separated string of ObsIDs and specify file types.
- check_vf_pha controls whether acis_process_events flags potential events near the event island as cosmic rays that are filtered out by the tool.
unix$ chandra_repro indir=7302 outdir=7302/repro check_vf_pha=no
Processing input directory ‘${HOME}/Work/Example/7302’

. . . MORE SCREEN OUTPUT . . .

The data have been reprocessed.
Start your analysis with the new products in
${HOME}/Work/Example/7302/repro

- Latest version of time-dependent gain applied.
- Latest temperature-dependent CTI correction applied.
- Ensures common set of calibration files used.
- Caveat: check new CalDB warning notes for use cases to avoid.
Quick Glance:

- quasar 4C +19.44/PKS 1354 +195
  - ~69 ks observation of a ~190 ks joint CXO program with HST and VLA
- ACIS-S3, sub-array
  - other special cases:
    - multi-ObI
    - Interleaved (aka "alternating exposure") mode
    - spatial window
    - ACIS CC-mode and HRC-S Timing mode
- readout streak
  - events detected during frame readout have correct column, random row
  - source bright enough to have readout streak will have some degree of pile up
ACIS Continuous-Clocking Mode

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Spatial Window Filters
Background Flares and Source Detection

- Create lightcurve of the background events.
  - exclude sources in the field
  - exclude readout streak

- X-ray source detection
  - identify statistically significant brightness enhancements over local background
  - source properties, like intensity and size, may also be reported, but may be more reliably evaluated separately

Note: source properties derived from source detection aren't intended for photometric usage!
Background Flares and Source Detection

- **CIAO source detection algorithms**
  
  - **wavdetect**—wavelet correlation
    
    **Pros**
    - works well in crowded fields
    - works well with point sources embedded in diffuse emission
    - only requires an approximate PSF shape
    - not strongly affected by detector edge effects
    
    **Cons:**
    - slow, especially if many wavelets are used
    - memory intensive
    - no recursive blocking built-in, so running on entire image may require multiple, binned images. Source lists must then be combined.

  - **celldetect**—sliding cell
    
    **Pros**
    - fast and robust
    - works well for point sources
    - only requires an approximate PSF shape
    - can handle very large images easily
    
    **Cons**
    - extended sources are difficult without careful cell size selection
    - can get confused in crowded fields
    - exposure maps needed to reduce edge effects
    - not very sensitive unless background maps are used, which may be difficult to construct

  - **vtpdetect**—Voronoi tessellation and percolation
    
    **Pros**
    - works well for extended sources and irregularly shaped sources
    - works on large areas at full resolution
    - works well on low surface brightness extended sources
    
    **Cons**
    - can get confused in crowded fields
    - slow, especially if there is a large number of photons and the contrast between background and sources is low

Reality is X-ray source detection is often a difficult — or at least challenging — task. A reliable source list may require running more than one tool, or one tool multiple times.
Source Detection (cont.)

- Reducing spurious source detections
  - All CIAO detection tools can use an optional exposure map reduces false source detections from detector effects
  - PSF maps can be used by celldetect and wavdetect
    PSF info allows for more reliable characterization of source; does not affect detection
  - fluximage provides an easy interface to generate these data products

```bash
unix$ fluximage acisf07302_repro_evt2.fits \  ? outroot=flux/7302 binsize=1 bands=broad psfecf=0.393
```

```
... SCREEN OUTPUT ...

The following files were created:

The clipped counts image is:
 flux/7302_broad_thresh.img

The clipped exposure map is:
 flux/7302_broad_thresh.expmap

The PSF map is:
 flux/7302_broad_thresh.psfmap

The exposure-corrected image is:
 flux/7302_broad_flux.img
```

Note: ECF=0.393 corresponds to the 1σ integrated volume of a 2D Gaussian
Source Detection Inputs

fluximage Data Products

- Binned counts map with clipping
- Exposure map (matching counts map)
  - units of $cm^2 \cdot s \cdot \frac{count}{photon}$ or $cm^2 \cdot \frac{count}{photon}$
  - analogous to optical/IR flat field image
- Exposure-corrected image (flux map): $\frac{counts\ map}{exposure\ map}$
- PSF map
  - provides the PSF size at each pixel of an image
  - size is the radius of an ECF circular region centered at the observation’s aimpoint
Source Detection
by way of wavdetect

```shell
unix% punlearn arlib
unix% acis_set_arlib 7302/repro/acisf07302_repro_bpix1.fits
unix% pset wavdetect(infile=7302_broad_thresh.img
unix% pset wavdetect(psffile=7302_broad_thresh.psfmap
unix% pset wavdetect(expfile=7302_broad_thresh.expmap
unix% pset wavdetect(outfile=detect/.
unix% pset wavdetect(scellfile=detect/.
unix% pset wavdetect(imagefile=detect/.
unix% pset wavdetect(defnbkgfile=detect/.
unix% pset wavdetect(regfile=detect/.
unix% pset wavdetect(scales="1.0 2.0 4.0 8.0 16.0 32.0"
unix% pset wavdetect(sigthresh=1e-6
unix% wavdetect clobber+ verbose=1 mode=h
```

... SCREEN OUTPUT ...

Output background image: detect/7302_broad_nbkg.img
Output source image: detect/7302_broad_image.img
Output source cell image: detect/7302_broad_scell.img
Output source list file: detect/7302_broad_src.fits
Output source regions file: detect/7302_broad_src.reg

Note: infile requires Z-valued pixels for valid results

fluximage results

output files, the "." in the arguments automatically names output files for wavdetect based on infile string

set bad pixel file for the tool to use in the terminal

set of wavelet scales

regfile is the ASCII region file and outfile is the source list
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wavdetect Results

- Explore the source list with DS9 and dmlist.

```
unix> dmlist detect/7302_broad_src.fits blocks
******************************************************************************
Dataset: detect/7302_broad_src.fits
******************************************************************************
   Block Name                      Type     Dimensions
----------  ----------------------  ----------  ----------------------
   Block 1: PRIMARY                    Null
   Block 2: SRCLIST                    Table    26 cols x 33 rows
unix>
```

```
unix> dmlist 7302_src.fits cols
--------------------------------------------------------------------------------
Columns for Table Block SRCLIST
--------------------------------------------------------------------------------
   ColNo   Name     Unit      Type        Range                      
----------  --------  --------  -----------  --------------------------
   1         RA       deg       Real18      0:      360.0        Source Right Ascension 
   2         DEC      deg       Real18      -90.0:       90.0    Source Declination 
   3         RA_ERR   deg       Real18      -Inf:+Inf  Source Right Ascension Err 
   4         DEC_ERR  deg       Real18      -Inf:+Inf  Source Declination Error     
   5         POS(X,Y)  pixel     Real18      3386.50:     4354.50  Physical coordinates 
   6         X_ERR    pixel     Real18      -Inf:+Inf  Source X position error     
   7         Y_ERR    pixel     Real18      -Inf:+Inf  Source Y position error     
   8         NPIXSOU  pixel     Int4       -           pixels in source region 
   9         NET_COUNTS count     Real4      -           Net source counts 
  10         NET_COUNTS_ERR count   Real4      -Inf:+Inf Error in net source counts 
  11         BKG_COUNTS count     Real4      -           Background counts 
  12         BKG_COUNTS_ERR count   Real4      -Inf:+Inf Error in BKG_COUNTS 
```

.. MORE INFO ..
Source Detection (cont.) by way of wavdetect—wavelet scales

- Wavelets are correlated with data image at each scale size.
  - scales are the radii of the Ricker (aka “Mexican Hat” or Marr) wavelet function
  - scales in units of image pixels
  - minimum and maximum scales chosen w.r.t. instrumental PSF sizes
    - smaller scales tend to detect small features and larger scales, large features
    - very large scales may be needed to characterize extended sources
  - scales typically separated by factor of 2 or $\sqrt{2}$

- large number of scales or large image size can drastically affect runtime
Source Detection (cont.)
by way of wavdetect

- **ellsigma** parameter affects the region size in `regfile` for visualization purposes.
  - scales the major- and minor-axes of the ellipses for each detection
  - does not affect source detection or source properties

- **sigthresh** parameter is the threshold that a pixel belongs to a source.
  - \( \text{sigthresh} \approx \frac{1}{\text{number of image pixels}} \)
The deflare script is a command-line interface to the lightcurves Python module to apply the \texttt{lc\_clean} and \texttt{lc\_sigma\_clip} algorithms.

- requires an input lightcurve of the background
- returns a GTI file that can be used to filter FITS tables
- done on a per CCD basis

Extract lightcurve for each CCD, excluding the field sources.

```
unix% dmcopy acisf07302_repro_evt2.fits'[energy=500:7000,ccd_id=7]' 7302_0.5-7.0keV.evt
unix% dmextract '7302_0.5-7.0keV.evt[exclude sky=region(detect/7302_broad_src.fits)][bin time::259.28]' \ 7302_bkg.lc opt=ltc1
```
Finding background flares (cont.)

run deflare

```bash
unix% deflare infile=7302_bkg.lc outfile=7302.gti \ 
? method=sigma plot=yes

... SCREEN OUTPUT ... 
```

Creating GTI file
Created: 7302.gti
Light curve cleaned using the lc_sigma_clip routine.

Optional: Applying GTI to events file

```bash
unix% dmcopy "acisf07302_repro_evt2.fits[@7302.gti]" \ 
? 7302_clean_evt.fits

unix% dmkeypar acisf07302_repro_evt2.fits EXPOSURE echo+ 68937.080789336
unix% dmkeypar 7302_clean_evt.fits EXPOSURE echo+ 68443.824820477
```
Should deflaring always be applied?

Generally: IF we have variable background, AND if it would be significant for the source region, THEN we exclude the affected times.

- Need to weigh the pros and cons.
  - reduced exposure time ⇒ less source counts
  - longer exposure time ⇒ higher uncertainty from background

- Point source
  - how much of the observed background will coincide with the point source?
  - how much brighter is the apparent surface brightness of the source over the background?

- Extended source
  - accounting for background more important than in point source analysis
  - complex spatial structure in source may dominate over background effects
  - does effects in embedded structure spillover to ambient background?
  - how much source free background available in observation?
Reprocessed Dataset

- `acisf07302_repro_evt2.fits`
- `7302_clean_evt.fits`

1. reprocess events
2. deflare
3. remove background flares
4. dmcopy/dmextract
5. analysis data products