CIAO Exercises

Table of Contents

Introduction

These exercises are designed to familiarize students with Chandra data and some of the basics of X-ray data analysis using CIAO with Chandra data.

Students will use a variety of tools and scripts to perform typical Chandra data analysis tasks. These exercises are not intended to be a *Cookbook* for all Chandra data analysis, but rather are meant to expose students to basic X-ray analysis techniques.

Students should already have CIAO installed on their systems. The exercises here have been developed with **CIAO 4.9**, using the **CIAO-4.9.4 contributed scripts** package, with Chandra **CALDB 4.7.6**. These exercises can be performed with either the Python 2 or the Python 3 editions of CIAO. Students should also have MARX installed. These exercises have been developed using **MARX 5.3.2**. The `install_marx` script in CIAO can be used to automate the installation process.

Getting to know Chandra data

In this section students will obtain Chandra data and learn some techniques to inspect the quality of the data and how to reprocess their dataset.

Download dataset

Exercise 1

Obtain the standard data distribution for Chandra `OBS_ID` **`13858`**

Q: How did you obtain the data (Chaser, download_chandra_obsid, FTP)?

____

Students may want to uncompress, `gunzip`, all of the files in the top-level directory, along with the primary and secondary directories at this point.

Review V&V report

Exercise 2

Read the Chandra Verification and Validation report in the top level directory of the data distribution: `axaff13858N001_VV001_vv2.pdf`

Q: Summarize the V&V comments: ___________________________________

Q: What is the target of this observation? _______________________________

Q: What is the sequence number SEQ_NUM of this observation? ____________

Display data in `ds9`

Locate the event files. There are two event files included in the standard data distribution. The Level 1 event file, evt1, is in the secondary/ directory, the Level 2 event file, evt2, is in the primary/ directory.

Exercise 3

Display the Level 2 event file using ds9. Make sure to use Log scale.

Q: Using the cursor, record the coordinate of the bright source in the center of the image: ____

Exercise 4

By default, ds9 only shows part of the Chandra dataset. Use the Bin menu to bin the data by a factor of 4 and then by a factor of 8.

Binning is different than Zooming. Zooming is done to the image (so after the event file has been binned). Set bin=1, and then zoom to ⅛.

Q: Describe why the Bin 8 image is different than the image Zoom'ed by ⅛:

____

Exercise 5

ds9 bins all the events in the event file into an image. That includes all events for all time and with all energies.

Use the Bin → Binning Parameters menu to add an `energy=500:7000` as a Bin Filter.

Q: Describe the difference in the images compared to the unfiltered image:

____

____

Q: What unit is energy in? ____________________

Extra Credit

Try different energy ranges.

Try different time ranges.

Exercise 6

1. With the Level 2 event file still loaded, create a new frame.
2. Open the Level 1 event in the new frame.
3. Use Frame →Tile Frames to display the two datasets side-by-side.
4. Bin both frames by 4. Both using Log scaling.

Q: Describe the difference between the Level 1 and Level 2 event files:

____

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Students can now exit from ds9 or put ds9 into the background.

Inspect headers

Most Chandra data products are FITS files, specifically FITS binary tables, with extensive headers that fully describe the dataset. Students should become familiar with some of the basic keywords and tool used to examine those keywords

Exerise 7

Open the Level 2 event file in `prism`

The EVENTS extension is automatically selected. The Header Keywords are shown in the top, right pane.

Q: Record the value for the following keywords:

MISSION ____

TELESCOP ____

INSTRUME ____

DETNAM ____

GRATING ____

DATAMODE ____

READMODE ____

DATE-OBS ____

OBSERVER ____

ONTIME ____

Q: What units are the ACIS focal plane temperature, ***FP_TEMP****, recorded in?* _____

Students can exit `prism` now.

Exercise 8

Use `dmlist` with the header option to display the header.

Q: Record the value for the following header keywords:

RA_TARG ____

DEC_TARG ____

RA_NOM ____

DEC_NOM ____

RA_PNT ____

DEC_PNT ____

ROLL_PNT ____

SIM_X ____

SIM_Y ____

SIM_Z ____

DTCOR ____

ASCDSVER ____

CALDBVER ____

Q: This is an "ACIS-S" observation. How can you tell this from the event file header information? ____

Extra Credit

Use `dmkeypar` with `echo=yes` to get the value for the `TIMEDEL` keyword in the Level 2 event file.

Use `dmmakepar` to get a copy of the `EVENTS` extension in the Level 2 event file. Use `plist`, `pdump`, and `pget` to get the same header keyword values.

Use `dmhistory` to extract the `acis_process_events` history records.

Reprocess dataset

The Chandra calibration database (CALDB) is continually updated. The then most recent CALDB is used for observations as they are taken. Some calibrations, such as the time dependent gain calibrations, can only be definitively computed based on historical observations; thus the file in the current CALDB is always predicted. These calibrations are later updated to be definitive post facto.

The CIAO team strongly advises users to always reprocess data obtained from the archive.

Exercise 9

Use `chandra_repro` to reprocess the dataset.

Q: Compare the header keyword values in the _repro_evt2.fits file with the evt2 file obtained from the archive. Discuss the differences:

____

____

____

Q: What version of the CALDB is installed? What is the value of the CALDBVER keyword? ____

Q: Compare the number of events in the reprocessed Level 2 event file with the number of events in the archived Level 2 event file.   Why are they same (or not the same)?

Imaging Basics (Spatial analysis)

In this section students will exercise some of the basic CIAO tools and scripts needed to perform basic imaging tasks.

Detect Sources

One of the most common analysis tasks is to detect sources.

Please keep in mind: CIAO detect tools only detect **candidate** sources and they are **not** photometric tools. The output from the detect tools should be used to guide further analysis.

See also:

- Wavdetect thread: http://cxc.cfa.harvard.edu/ciao/threads/wavdetect/
- Using detect output: http://cxc.cfa.harvard.edu/ciao/threads/detect_output/

Exercise 10

In this exercise students should complete the following steps

1. Create image and exposure map. Run the `fluximage` script on the dataset. Students should be sure to set the `binsize=1` and set `bands=default` or `bands=broad`.
2. Create the psfmap. Run `mkpsfmap` using the `fluximage` output image as input. Students should use `energy=1.4967 ecf=0.393`
3. Detect Sources. Run `wavdetect` on the `fluximage` output counts image, using the exposure map and psfmap. Students should select a set of wavelet scales to use that is appropriate for the dataset being analyzed.

Q: Display the PSF map in ds9. Why does it look the way it does?

____

____

Q: Record choice of wavelet scales and why that set was selected:

____

____

Q: Open the broad-band image in ds9 and load the source list as a region file. Comment on the detected sources and any missed detections:

____

____

Q: Are the ellipses the position error or the apparent size of the source?

____

Extra Credit

Try different wavelet scales.

Try different significance thresholds, `sigthresh`.

Try different `ecf` values when making the PSF map.

Try different energy bands.

Try using the `celldetect` tool.

Try using the `vtpdetect` tool.

Create regions in ds9

The detect tools are one way to create regions automatically. However, often users analyzing a single source in an observation will simply create their own region in ds9 and then use those regions with the CIAO tools.

Exercise 11

1. Open the broad-band counts image in ds9.
2. Create a source region. Draw a circular source region around the bright source in the center of the image.
3. Save the region, `ds9_src.reg`. Use ds9 format and celestial (world) coordinates.
4. Delete the source region.
5. Create a background region. Draw an annulus around the same source. The inner annulus region should be larger than the source region. The outer region should be large enough to get a large number of counts, but should be small enough to avoid any nearby source or any instrumental features (like the gaps between chips).
6. Save the region, `ds9_bkg.reg`. Use CIAO format and physical coordinates.

Q: Record the source location used: ________________________________

Q: Describe the differences between the CIAO format and the ds9 format regions:

____

Exercise 12

Compute source centroid. In this exercise students will use the `dmstat` tool to compute the source centroid in their region.

1. Use `dmcopy` to filter the flux image thresh.img using the source region file.

2. Use `dmlist` with the `blocks` option to display info about the filtered output image.
3. Use `dmstat` with the `centroid=yes` option to compute the centroid of the counts in the filtered image.
4. Use `dmcopy` to filter the Level 2 event file using the source region file and to bin it into an image with binsize=1.
5. Use `dmlist` with the `blocks` option to display info about the filtered and binned image.
6. Use dmstat with `centroid=yes` option to compute the centroid of the counts in the filtered and binned image.

Q: Is the filtered image the same size as the fluximage output image size? Why?

____

Q: Record the centroid of fluximage output filtered image: ______________________

Q: What are the good and null values that dmstat reports?

____

Q: Is the image created by filtering and binning the event file the same size as the other images? Why?

Q: Record the centroid of the event file filter and binned image: ___________________
Q: Is the centroid the same for the two images? Why? [Hint: what energies are being used?]

____

____

Aperture Photometry

Obtaining the counts (or count rate) is the first step in computing the source flux.

Exercise 13

In this exercise students will use the CIAO analysis menu, aka dax, to get the net counts in their regions (from Exercise 11).

1. Open the fluximage thresh.img in ds9.
2. Load the source region file created in Exercise 11 step 3.
3. Load the background region file created in Exercise 11 step 6.
4. Double click on the background annulus to display the region properties.
5. Under the Property menu, select Background. The region will now be drawn with a dashed line. Close the properties window.
6. In the main ds9 window, goto Analysis →CIAO →Statistics → Net Counts.
7. A text window will be display containing the information about the current regions.
8. Try adjusting the source and background radii and repeating the analysis.

Q: From step 7, record the following information from the Net Counts task:
Net counts with error: ______________________________
Source counts: ______________________________
Background counts: ______________________________

Q: From step 8, describe how the net counts and net rates vary with changes to the source and background regions:

____
____
____

Exercise 14

In this exercise students will use the `srcflux` script to get various estimates of the flux of the source.

1. Obtain the source location in celestial coordinates from the source region file created in Exercise 11 step 3.
2. Run the `srcflux` script on the reprocessed level 2 event file, using the position, pos, from step 1. All other parameters should remain at their defaults.
3. Repeat step 2, using a different `outroot` and `psfmethod=arfcorr`
4. Repeat step 3, using a different `outroot`, `model="xsbbody.black_body"` and `paramvals="black_body.kT=1"`.
5. Repeat step 4, using `bands="hard"`.

Q: Record the net count rate, model independent flux, model flux from steps 2 through 5

	Step 2	*Step 3*	*Step 4*	*Step 5*
Count Rate				
Flux				
Model Flux				

Q: Discuss the differences in the estimated fluxes obtained in steps 2 through 5.

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Extra Credit

Try using `psfmethod=quick`, `psfmethod=arfcorr`, and `psfmethod=marx`.

Try other spectral model and other model parameters.

Try other energy bands (2-10 keV is a common band in the literature).

Simulate PSF

The Chandra Point Spread Function (PSF) varies spatially across the field of view as well with energy. There is no analytic model of the PSF. The only way to obtain an estimate of the Chandra PSF for detailed spatial analysis is by simulation.

The `psfmethod` used by `srcflux` are only appropriate when integrating over a region. The pixel-to-pixel variations used in those methods is insufficient for any type of analysis that requires detailed spatial information.

There are two different simulators users can use.

1. SAOTrace is the definitive mirror model and is made available to users via the ChaRT web interface.
2. MARX is the end-to-end Chandra simulator used to calibrate the HETG gratings and includes a fairly accurate mirror model and detector models.

Exercise 15

In this exercise Students will simulate the PSF using ChaRT and with MARX. The `simulate_psf` script is used to create PSF images that are appropriate for further data analysis.

1. Ensure that MARX is installed and that `MARX_ROOT` is set.
2. Run ChaRT. http://cxc.cfa.harvard.edu/ciao/PSFs/chart2/index.html To run ChaRT users need to know the source location (celestial coordinates), an estimate of the photon flux (from the srcflux .flux output files), and an estimate of the energy. Students may be provided with a set of ChaRT output ray files.
3. Run the `simulate_psf` script. Use the reprocessed level 2 event file as the `infile` and the coordinates of the source, in decimal degrees, for the `ra` and `dec` parameters. Use `simulator=file` and provide the *stack* of ray files obtained from ChaRT for the `rayfile` parameter. Set `minsize=128` to obtain a reasonable size output image.
4. Display the reprocessed level 2 event file in one ds9 frame and the simulate_psf output PSF in a 2nd frame. Tile the frames horizontally and save the image as a PNG file.
5. Run `simulate_psf` with a different `outroot`, this time using `simulator=marx` and set the `numiter` parameter to the same number of iterations as were used with ChaRT. `monoenergy=1.0` and `flux=1e-4` can be used for the spectral model.
6. Repeat step 4 using the MARX generated PSF.

Q: Comment on a visual comparison of the ChaRT/SAOTrace PSF to the observation:

____

Q: Comment on a visual comparison of the MARX PSF to the observation:

____

Q: Describe any differences between the MARX and ChaRT PSFs:

____

Q: Is this a point source? ____

Extra Credit

Try setting `simulate_psf readout_streak=yes`. Try `pileup=yes`. Try `blur=0.20`

Run the Lucy-Richardson deconvolution tool `arestore` using the broad band flux image and the PSFs simulated here. Try with different numbers of iterations.

Create a 3-color image

Three color (aka "true color" or "tri-color") images can be useful to help guide analysis by providing visual clues about changes in spectra.

Exercise 16

1. Obtain the data for `OBS_ID 13736`. These data will only be used for this exercise.
2. Reprocess the data using `chandra_repro`
3. Run `fluximage` on the reprocessed level 2 event file. Use `binsize=8` and `bands=csc`.
4. Load the soft, medium, and hard band flux.img images into ds9. This can be done in the GUI by creating a new RGB frame and then loading the files individually or on the command line

```
     $ ds9 -rgb -red root_soft_flux.img \
         -green root_medium_flux.img \
         -blue root_hard_flux.img
```

5. Log scale each of the images.
6. Use the `Analysis → Smooth` on each of the images.
7. Save the image in PNG format.
8. Exit ds9
9. Use `dmimg2jpg` to create a similar 3-color image.

*Q: Discuss the differences in the output from ds9 and **`dmimg2jpg`**.*

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Extra credit

Smooth the images with `aconvolve` before displaying

Smooth the images with `csmooth` before displaying

Smooth the images with `dmimgadapt` before displaying

Obtain overlapping multi-spectral images of this region from other archives. Use reproject_image to project the other datasets to the same tangent plane as the Chandra dataset. Create tri-color image using red for the lowest energy, and blue for the highest energy datasets.

Obtain the data for OBS_ID 635 and reprocess it with chandra_repro. Split the event file into 3 equal time intervals by filtering on the TIME column. Run fluximage on each time interval using the broad energy band. Use the 3 time-slices to create a 3 color image.

Timing Analysis

References

- http://cxc.cfa.harvard.edu/ciao/threads/timing.html

CIAO provides several tools to perform basic timing analysis.

Extract lightcurve

References:

- http://cxc.cfa.harvard.edu/ciao/threads/lightcurve/
- http://cxc.cfa.harvard.edu/ciao/threads/variable/
- http://cxc.cfa.harvard.edu/ciao/why/lightcurve.html

In X-ray astronomy the term "light curve" is used to describe the flux of a source vs time.

Exercise 17

1. Create a light curve using the `dmextract` tool with the reprocessed level 2 event file filtered with the source and background regions created in Exercise 11 steps 3 and 6. Use a 100 second bin width: `[bin time=::100]`.
2. Repeat 1, using the following bin widths: `200, 500, 1000, 1`.
3. Plot each of the light curves using `chips`.
   ```
   chips> make_figure("out_bin100.lc[cols dt,count_rate]")
   chips> print_window("out_bin100.png")
   ```

Q: Why is there a gap at the beginning and at the end of the light curves with count_rate=0? ____

Q: Is the delta-time, **`dt`***, column actually a column in the* **`dmextract`** *output file?*

____

Q: What can be learned from the light curve with 1 second time resolution?

____

Q: What energy events were used to make these light curves? Does using an energy filter change things and if so how?

____

____

Q: ACIS event files contain multiple good time intervals (one for each chip). Which GTI was use?

____

____

____

Exercise 18

1. Create a light curve using the glvary tool using the reprocessed level 2 event file with the source region.
2. Repeat 1 using the background region.
3. Plot the glvary source and background lightcurves using `chips`

Q: Describe how the glvary lightcurves differ from the dmextract light curves.

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Q: Could any variability in the source region be due to variability in the background?

____

____

Extra credit

Use the `dither_region` tool to compute the time resolved area fraction of the source and separately the background regions. Try using those as input to `dmextract` and `glvary` as exposure corrections. Compare to the results without those corrections.

Check for background flares

Reference:

- http://cxc.cfa.harvard.edu/ciao/threads/flare/

Background flares may influence results especially when working with large source regions such as supernovae remnants or clusters.

For an on-axis point source, users should carefully consider whether excluding time due to a background flare would be better than accepting the time in order to obtain higher signal to noise.

Exercise 19

In this exercise, students will extract a light curve for a background, source-free region and use it to search for any evidence of a background flare.

1. Using `dmcoords`, `dmstat`, `dmlist`, or `ds9+dax`, determine the `CCD_ID` where the bright source in the center of the field is located.
2. Use `dmcopy` to exclude the wavdetect sources detected in Exercise 10 step 3 from the reprocessed Level 2 event file.

   ```
   dmcopy "evt2.fits[exclude sky=region(wavdetect.src)]"\
       source_free_evts.fits
   ```
3. Use `dmextract` to create a light curve using the source free event file, use a CCD_ID filter to select events from chip you found in step 1. Use a bin-width of `259.28` seconds.
4. Use the `deflare` tool to search for background flares on the source chip using `method=clean`.
5. Use `dmcopy` to apply the deflare output good-time interval, GTI, file to the reprocessed level 2 event file.

Q: What CCD_ID was found in step 1? Which tool(s) were used?

____

____

Q: Was there any evidence of a background flare in this observation, on this chip? If so, describe the flare (when did it occur within the observation, duration, etc.):

____

____

Extra Credit

Try different bin-widths when creating the light curve. Does it affect the results?

Try different `deflare method` options.

Try looking for flares on the other CCD's used in this observation.

Spectral Analysis

The energy resolution and sensitivity of the ACIS detector allows for spectral analysis roughly in the 0.3 to 7.0 keV range.

Extract spectra

Reference

- http://cxc.harvard.edu/ciao/threads/pointlike/

Exercise 20

In this exercise Students will use the `specextract` tool to extract the spectrum, ARF, and RMF files for the source and background regions.

1. Run the `specextract` script using the reprocessed level 2 event file with the source region from Exercise 11 step 3 and the background region from step 6 with the default parameter settings.
2. Run `specextract` as in step 1 with a different `outroot` and setting `weight=no`
3. Run `specextract` as in step 2 with a different `outroot` and setting `correctpsf=yes`
4. Use `dmdiff` to compare the spectra (`.pha`) from steps 2 and 3 to the spectrum in step 1.
5. Use `dmdiff` to compare the auxiliary response file (`.arf`) from steps 2 and 3 to the ARF in step 1.
6. Use `dmlist` to get the `BACKSCAL` and `EXPOSURE` keywords from the source and background spectra.

Q: Record the BACKSCAL and EXPOSURE keywords. Why are these keywords important?

____

____

Q: Describe and discuss the differences, if any, from step 4.

Q: Describe and discuss the differences, if any, from step 5:

Extra Credit

Use the `rmfimg` tool to convert the RMF into an image and display in ds9.

Sherpa: Modeling and Fitting

References

- http://cxc.cfa.harvard.edu/sherpa/
- http://cxc.cfa.harvard.edu/sherpa/threads/pha_intro/

`sherpa` is the fitting and modeling package developed for CIAO. It allows users to obtain best fit model parameters based on a number of models, fitting methods, and statistics used for uncertainty.

The exercise shown here is an extremely simple `sherpa` use case. More advanced usage includes user supplied models, linked model parameters, simultaneously fitting multiple datasets, fitting images, etc.

Exercise 21

In this exercise Students will begin to use `sherpa` to model and fit the spectrum of the source.

1. Load the ungrouped source spectrum obtained from Exercise 20 step 1 into `sherpa`
   ```
   sherpa> load_data("source.pha")
   ```
2. Plot the spectrum using the `plot_data` command
3. Group the data using `group_counts()`. Select a reasonable number of counts for the dataset. Replot the data.

4. Restrict the energy range to a reasonable energy range using the `notice()` command. Replot the data.
5. Set the source model to be an absorbed powerlaw using the `set_source()` command.

   ```
       sherpa> set_source(xswabs.abs1*xspowerlaw.p1)
   ```
6. Set the absorption nH to the value listed in the header of the spectrum file.
7. Use `plot_model()` to see the model folded through the instrument responses (ARF and RMF).
8. Use `show_all()` to see all the data and model details.
9. `subtract()` the background. Replot the data.
10. `fit()` the data.
11. Use `plot_fit()` to see the data with the model overplotted.
12. Use `plot_fit_delchi()` to see the data with the error weighted residuals.
13. Use `conf()` to obtain uncertainties on the fitted parameters.
14. Use `set_method()` to try different minimization techniques and repeat the `fit()`.
15. Use `set_stat()` to try different fit statistics and repeat the `fit()`.
16. Try different grouping schemes.
17. Try different spectral models in the `set_source()` command.
18. Repeat this exercise using the spectrum, ARF and RMF obtain in Exercise 20 steps 2 and 3.

Q: Which fit method works best? ____

Q: Which spectrum fits best? ____

Q: Which model/param is best? ____

Q: How does grouping affect the results? __________________________________

Q: What are the advantages/disadvantages of one method over another?

____

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____