

ANNOUNCEMENTS

The website for this workshop is https://cxc.cfa.harvard.edu/ciao/workshop/jan21/index.html

Quick way to get there...

cxc.harvard.edu —> Data analysis —> Workshops

You will find there

• All the presentations

Introduction

• A workbook with Exercises for the hands-on session

An Introduction to CIAO

(Chandra Interactive Analysis of Observations)







CIAO: Chandra's data analysis system Fruscione et al. 2006, SPIE Proc. 6270, 62701V, D.R. Silvia & R.E. Doxsey, eds.



What is CIAO?

First a linguistic note....

CIAO from "s'sciavo", "I am your servant" in Venetian language

And CIAO has been at the service of X-ray astronomers for more than 20 years!



From: http://cxc.harvard.edu/ciao/ahelp/ciao.html or

> ahelp ciao on the ciao command line

AHELP for CIAO 4.13

ciao

Context: concept

Synopsis

Chandra Interactive Analysis of Observations

Description

The remarkable science capabilities of the **Chandra X-ray Observatory** demanded **new**, **flexible**, **multi-dimensional**, software to analyze the data it returned. The result is CIAO - the Chandra Interactive Analysis of Observations - a system that has proven itself useful for the **analysis of data from other**, **non-X-ray missions**, because of the **mission independence** that is the basis of the CIAO design.



Introduction to CIAO Tools

CIAO is a data analysis system written for the needs of users of the Chandra X-ray Observatory.

Because Chandra is the first mission with 4-dimensional data (2 spatial, time, energy) in which each dimension has many independent elements, CIAO was **built to handle N-dimensional data** without concern about which particular axes were being analyzed. Also, **apart from a few Chandra instrument tools, CIAO is mission independent.**

In order to allow users of Chandra data to use pre-existing tools, all **CIAO tools read and write several formats**, including FITS tables (which includes event files), ASCII formats, and FITS images.



CIAO also needed to be able to **filter down and project the 4-D Chandra** event data to manageable sizes and convenient arrays. This has to be done flexibly, so we have built all CIAO tools to take a **`filtering and binning'** specification on the **command line**, making use of a general purpose **`regions'** syntax. See "<u>ahelp</u> <u>dm</u>" for information on the Data Model that makes all this possible.

Since Chandra data can be sliced and diced in so many ways, and because the Chandra calibration is spatially and energy dependent, we needed to **keep track** of just how the data had been filtered and binned, which we do in a `data subspace'. The tools keep track of this subspace automatically and allow users to review previous data processing. See <u>"ahelp subspace"</u>.

The CIAO design allows **close interconnection of tools**. For example, the output of any of the source DETECT programs can be fed into dmextract to create a summed spectrum which can then be fit in Sherpa.





Modeling and Fitting

The **modeling and fitting tool Sherpa is central to the CIAO system**. Sherpa performs forward fitting of models to data in N-dimensions. Refer to "ahelp sherpa" and <u>the Sherpa website</u> for complete details.

Altogether CIAO is a **powerful system for the analysis of all types of** data.



- A collection of Unix command line tools and Python applications
- Shares code with standard Chandra processing pipeline
- Allows Chandra instrument specific data reduction (eg ARF and RMF)
- Tailored to specialized X-ray astronomy data analysis, but not specific to Chandra (as been used with XMM)
- Coded with attention to standards and interoperability so that generic tools can be (and are) used for other X-ray data and even optical and radio data (e.g. multiwavelength analysis)
- Easy for beginners, yet powerful for advanced users
- Linux and Mac, annual releases
- Installed 1500+ times per year (single users to large institutions)

What is CIAO? In practice

cxc.harvard.edu/ciao

CHANDRA XRAY DESERVATORY Last modified: 10 December 2020	3		CXC HOME PROPOSER ARCHIVE DATA ANALYSIS INSTRUMENTS & CALIBRATION FOR THE PUBLIC Search https://crc.haveraf.edu/dag/ publications.com/crc.haveraf.edu/dag/ publications.com/crc.haveraf.edu/dag/ contact.the.CXC.HeldDeak		
CLACE Former and Former and Control of the second secon	from "s CIAO is the software package developed by the <u>Chandra X-Ray Center</u> for a	Sociaro", "I am your servant" in Venetian dialect." Inalysing data from the <u>Chandra X-ray Telescope</u> . It can also be used with di Sherpa DS9 ChaRT MARX CALDB CSC 2 CSC 1.1 TGCa			
Download CALDB Script & Modules Package System Requirements Installation Instructions	Download CIAO/CALDB	What has changed?	Where should I begin?		
brazilation instructions Parlism Support Release Note Veration Heady Data Kanaky Sistem	Install CIAO 4.13 & CALDB 4.9.4 with conda or Install with ciao-install Read the CIAO 4.13 release notes for detailed information on this release, including How, CALDB 4.9.4 Affects Your Analysis. Does CIAO run on my operating system? What are the resultements for running CIAO2 How do Install Python nackages into CIAO2 Note that CIAO is packaged with Python 3.7 when using ciaco- install, and with your choice of Python 3.8, 3.7, or 3.6 when using the conda installation method.	Has there been a new release of CIAO, the contributed scripts, or the CALDB? What's New Watch Out' List How do Lundate CIAO? Version History: CIAO; Scripts & Modules. Release Notes: CIAO; ACLDB. CIAO 4.13 is primarily a maintenance release supporting newer complers and loaded Off. the Shell software. This includes Shepa improvements providing better integration with Jupyter: notebooks and SAOImage DS9 v8.2 which supports themes (including Dark Mode). Subscribe to the CIAO News RSS feed Subscribe to Chandra/CIAO announcements	For those new to X-ray astronomy and data analysis An X-ray Data Prime: What I Wish I Knew when Starting X-Ray Astronomy Useful links for those people who have never used CIAO before. Welcome to CIAO Introduction to the Tools & Applications Quick Start Guide Download CIAO 4.13 Installing CIAO 4.13 thread Introductory Science Threads Analysis Guides Sherpa: Modeling and Fitting Ds9: Interactive image display and analysis		
Running Tools from Python DATA PRODUCTS Data Basics	I need help!	I need more!	Citing CIAO		
Data Products Guide Data Crevests Chandra Data Archive TGGat: Grange Statalog & Archive PSF CENTRAL Understanding the Chandra PSF Understanding the Chandra PSF Chaneter/Ling the Chandra PSF Using the Chandra PSF Using the Chandra PSF Using the Chandra PSF	For anyone having trouble using CIAO or analysing Chandra data. CIAO Software Help.Pages Frequently Asked Questions (FAO) Known CIAO Bugs and Tool Caveats If the above links do not help you, then please contact the <u>CXC</u> Helpidesk. To help us help you, please include, where appropriate: the	For the expert CIAO user or person who needs more detailed information. Why Topics Manuals Understanding the <u>Chandra PSF</u> . Galleries (Tips & Tricks): CIAO; Sherpa.	If you are writing a paper and would like to cite the CIAO software, we recommend the following: CIAO: Chandra's data analysis system (ADS, PS) Fruscione et al. 2006, SPIE Proc. 6270, 62701V, D.R. Silvia & R.E. Doxsey, eds. Dotistem [Fruscione et al. (2006)](2006SPIE.6270E60F) Fruscione, A., et al.\ 2006, \procepie, 6270		



General Concepts

- 1. File format
- 2. Parameter Files

Introduction

- 3. Filtering and Binning (the Data Model)
- 4. Regions
- 5. Subspace
- 6. Good Times Intervals (GTI)
- 7. Scripting language (Python)



1. File Format

- Chandra data is stored in the (binary) FITS format however simple
 ASCII (text) files can be handled by many tools and applications.
- When CIAO operates on data it stores processing state and processing information along with the data (keywords, subspace)
- A single Chandra file can contain **multiple** "datasets" (e.g. data, Good Time Intervals, weight map, regions) which are **stored in** "**blocks**".
- Blocks can contain **image** or table data.
- dmlist (a command line tool) or prism (a GUI) are available to view file contents. As of CIAO 4.13 prism can be called via ds9.



FITS Format

(http://heasarc.nasa.gov/docs/heasarc/fits.html)

- Binary File Format that is "Self Documenting"
- Named Extensions, containing Headers and Data
- Extensions can be referred to by Name or Number
- Headers Describe Contents, Format, Processing History
- Keywords contain descriptive data
- Data are rows & columns containing values, arrays, images ...

Antonella Fruscione 12

CIAO	Introduction						Antone	ella Fru	scione	e 12	
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2. Parameter Files

From: http://cxc.harvard.edu/ciao/ahelp/parameter.html

- The CIAO tools use ASCII parameter files to get and store processing parameters (eg dmcopy.par, specextract.par)
- Parameters can be set via:

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- a number of routines (eg punlearn, pset, plist)
- the Python interface to the CXC parameter system (see ahelp paramio)
- Multiple values can be specified for a parameter if is listed in the help file as accepting stacks (see help stack)



Parameter file example: dmcopy.par

ciao% plist dmcopy

Parameters for /Users/antonella/cxcds_param4/dmcopy.par

```
infile = acisf00459N004_evt2.fits.gz[REGION] Input dataset/block specification
outfile = grating_reg.fits Output dataset name
(kernel = default) Output file format type
(option = ) Option - force output type
(verbose = 0) Debug Level
(clobber = no) Clobber existing file
(mode = ql)
```

ciao% dmcopy

Input dataset/block specification (acisf00459N004_evt2.fits.gz[REGION]): Output dataset name (grating_reg.fits): Clobber set to no, and output file grating_reg.fits exists.

ciao% pset dmcopy outfile=grating_reg2.fits
ciao% dmcopy

Input dataset/block specification (acisf00459N004_evt2.fits.gz[REGION]): Output dataset name (grating_reg2.fits):

Note the required (infile, opt) and optional parameters (the ones in parenthesis)



3. Filtering and Binning (the "Data Model")

http://cxc.harvard.edu/ciao/ahelp/dm.html http://cxc.harvard.edu/ciao/ahelp/dmfiltering.html http://cxc.harvard.edu/ciao/ahelp/dmbinning.html http://cxc.harvard.edu/ciao/threads/filter/

- **Filtering** (or the **removal of unwanted events**) is an essential part of X-ray analysis - e.g. to remove periods of high background or poor aspect solution, exclude uninteresting sources from an image etc.
- **Binning** is the action on event files which creates **histograms**, **images**, or **3D data cubes**. It is useful for visualizing and manipulating data
- The "CIAO Data Model" (DM) is the versatile interface used by CIAO to examine and manipulate FITS and ASCII datafiles.
- The Data Model enables **powerful filtering and binning**
- The name "Data Model" reflects the fact that the interface can be used on data files of different format (all described by a single abstract description the same "model") in a transparent way.



BENEFITS OF THE DATA MODEL

- Any program that asks for a data file name as input accepts a "virtual file" string which causes the program to see a filtered version of the file in question without the need to physically create a file on disk
- The "virtual file" syntax is also commonly used to create a filtered version of the input file on disk
- All columns of event lists are treated "equally": for example binning is allowed not only in spatial coordinates but also in e.g. time, or energy coordinate, giving the ability of creating multidimensional images in space-energy, or space-time, etc.



Data Model Syntax (ahelp dmsyntax)

- All CIAO tools use the DM library and therefore accept as input "virtual files" described using the DM syntax.
- In the DM context a "virtual file" in represented by a filename followed by a series of optional qualifiers in square brackets []:

"filename[block][filter][columns/binning][options]"

where:

block - is the "section" of the file to use

filter- is the filter to be applied

columns/binning - specifies either the columns from a table to be included in an output table or the binning. When binning the data to generate an n- dimensional image, the range and binsize (min:max:bin) must be specified.

options - a sequence describing special options for the DM library

the order of the qualifiers generally matters, however...

• not all qualifiers need to be present always

A few examples:



Simple examples of "virtual files"

 A virtual file which contains the first three columns of the EVENTS block specified by number:

acisf01843N001_evt2.fits[EVENTS][time=84245787:84247000][cols #1,#2,#3]

• A virtual file which contains the first three columns of the EVENTS block specified by name:

acisf01843N001_evt2.fits[EVENTS][grade=0,2,3][cols time,ccd_id,node_id]

after the events are filtered in time or in grade

In the example above:

block: [EVENTS] filter: [time=84245787:84247000] [grade=0,2,3] columns/binning:

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[cols #1,#2,#3] [cols time,ccd_id,node_id]



 An event file binned on the column called "PI" (to create a "PI spectrum") for a specified region

acisf01843N001_evt2.fits[EVENTS][sky=region(mysrc.reg)][bin pi=1:1024:1]

(typical input to the tool dmextract)

• An event file binned in x,y coordinates to create an image

acisf01843N001_evt2.fits[EVENTS][energy<7000][bin x=320:480:4,y=320:480:4]

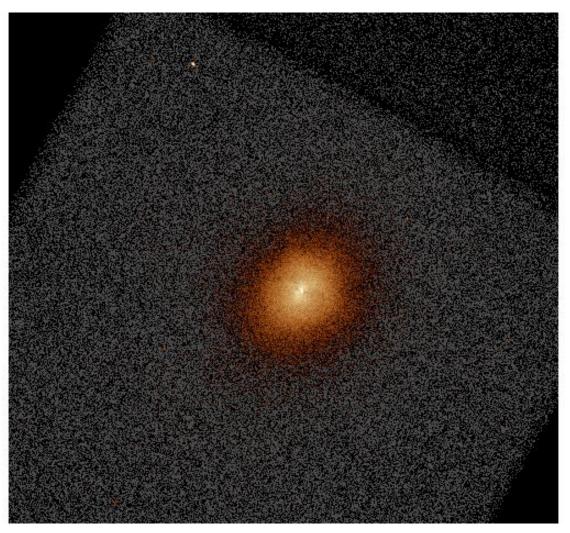
(typical input to the tool dmcopy)

In the example above:

```
block: [EVENTS]
filter: [sky=region(mysource.reg)]
     [energy<7000]
columns/binning:
     [bin pi=1:1024:1]
     [bin x=320:480:4,y=320:480:4]</pre>
```



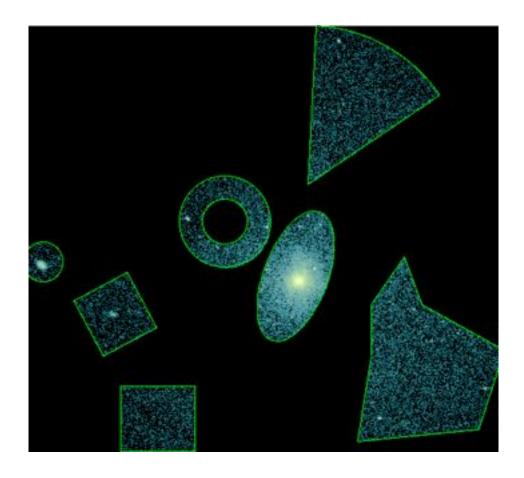
<u>dmcopy</u> "acisf06934N002_evt2.fits[bin x=3500:4500:2,y=3500:4500:2]" 6934_sky_binsize.fits







dmcopy "ngc1404.img[sky=region(ngc1404_sample.reg)]" ngc1404_regfile.img

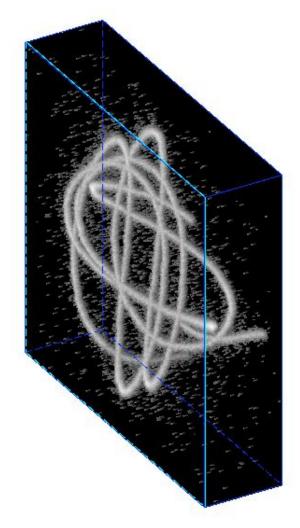




<u>dmcopy</u> "06540_evt.fits[(chipx,chipy)=box(8003.5,8137.5,512,512,0)]

[bin chipx=::2, chipy=::2, time=::#50] " outfile=cube.fits

This example shows a 3D image (cube) of a point source shown in chip coordinates. Since Chandra dithers during the observation, the point source moves across the detector versus time, which is the 3rd dimension.



Here an HRC event file is filtered on the chip coordinates and then binned into a cube. The X and Y axes are the chipx and chipy values binned by 2, and the third axis is time binned into 50 bins.



Data Manipulation Tools

The four DM "core" tools

dmlist: list contents or structure of a file

dmcopy: filter and bin tables and images

dmextract: make a histogram table file (e.g. PHA file, lightcurve file) from a table column. Generate count histogram on supplied regions for a spatial table or image file.

dmstat: compute statistics for images and columns in tables

30+ data manipulation tools are included in CIAO



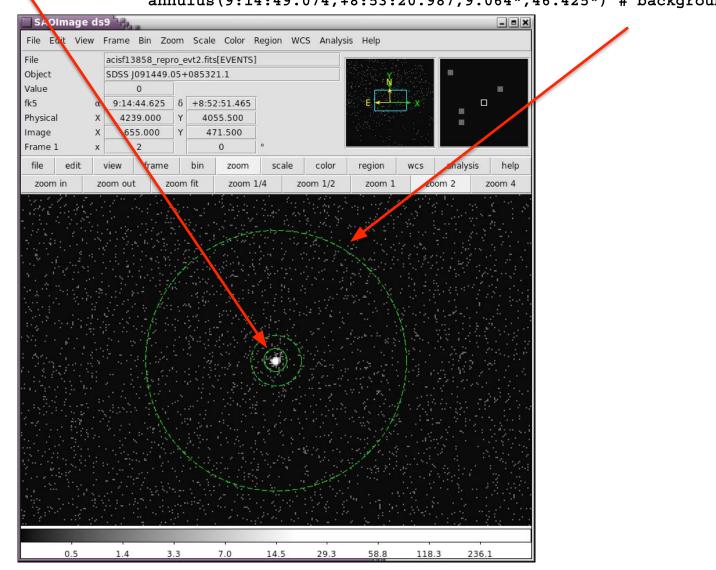
4. Regions

http://cxc.harvard.edu/ciao/ahelp/dmregions.html http://cxc.harvard.edu/ciao/threads/regions/

- Regions are two dimensional filters commonly used in CIAO data analysis to to include and/or exclude data
- For example regions are used to define the source and background areas in an image.
- They are text files or FITS files that can be created manually or within ds9, and can be used as a filter (e.g. "[sky=region(source.reg)]")
- Regions can be combined using boolean AND (intersection) or boolean OR (union) operations.



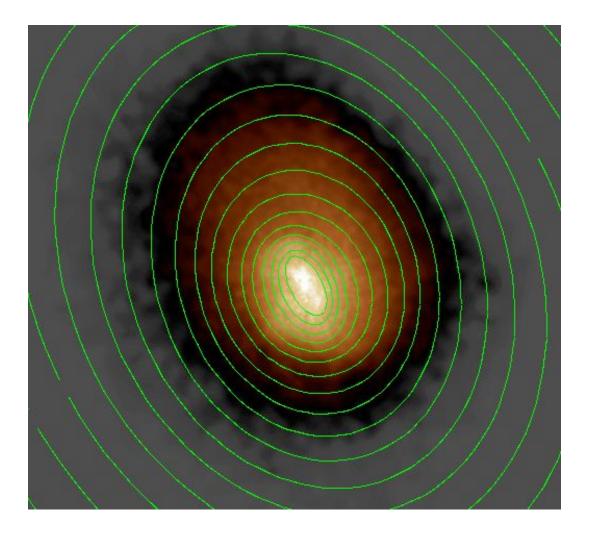
circle(9:14:49.090,+8:53:21.231,4.083")



annulus(9:14:49.074,+8:53:20.987,9.064",46.425") # background



dmellipse a1664.asm a1664.ellipses "lgrid(0.1:0.96:0.05)" step=100 clob+







From: http://cxc.harvard.edu/ciao/ahelp/subspace.html

- The subspace records the filters applied to a file into the header
- This allows subsequent tools to, for example, apply appropriate calibration information.
- **dmlist** can read the processing history using opt=subspace



dmlist "acisf13736_evt2.fits[ccd_id=3,sky=circle(4324,3676,50)"] subspace

Data subspace for block EVENTS: Components: 1 Descriptors: 16

	Component	1	
--	-----------	---	--

1 time	Real8	TABLE GTI3 444947637.1627430916:444970563.5344673395
[…] 3 ccd_id	Int2	3:3
4 node_id	Int2	0:3
5 chip	[1] chipx	1:1024
5 chip	[2] chipy	1:1024
6 tdet	[1] tdetx	1:8192
6 tdet	[2] tdety	1:8192
7 det	[1] detx	0.50: 8192.50
7 det	[2] dety	0.50: 8192.50
8 sky	Real4	Circle(4324,3676,50)
8 sky	Real4	Field area = 6.71089e+07 Region area = 7853.98
8 sky	[1] x	4274.0: 4374.0
8 sky	[2] y	3626.0: 3726.0
9 phas	Int2	-4096:4095
10 pha	Int4	0:36855
11 pha ro	Int4	0:36855
12 energy	Real4	0: 100000.0
13 pi	Int4	1:1024
14 fltgrade	Int2	0:255
15 grade	Int2	0:0,2:2,3:3,4:4,6:6



6. Good Time Intervals

http://cxc.harvard.edu/ciao/ahelp/times.html http://cxc.harvard.edu/ciao/dictionary/gti.html http://cxc.harvard.edu/ciao/ahelp/dmgti.html

- In a Chandra event file several 'times' are recorded both in the header via keywords [eg TSTART, TSTOP, EXPTIME etc.] and in one or several Good Time Intervals auxiliary files (the GTI blocks).
- GTIs are used to define what times periods of the observation can be used (i.e. contain valid data)
- The **dmgti** tool creates a Good Time Interval (GTI) filter file which represents the times of rows in the input file which pass a user-supplied constraints.



7. Python: the scripting language in CIAO

- The scripting (or interpreted = no compilation is necessary) language supported in CIAO is Python (Python 3.7 as of CIAO 4.13). The CIAO Conda edition supports Python 3.8, 3.7 and 3.6
- The software package is distributed with CIAO, but users may opt to run their own custom installation instead
- The <u>CRATES</u> and <u>TRANSFORMS</u> libraries provide access to the CIAO Data Model library and a high-level interface for performing World Coordinate System transformations.
- Access to CIAO's modeling package is available through the <u>Sherpa</u> module. Sherpa is an importable module for Python
- You DO NOT need to know Python to use Sherpa, but IF YOU DO, you will be able to use its capabilities in your analysis



CIAO 4.12 - CONDA Installation

•As of version 4.12, CIAO can be installed using <u>conda</u>

 conda is a package management and environment management system which allows users to create multiple environments with multiple versions of packages which can co-exist on the same system.

• With conda, Linux and Mac users can choose to install CIAO-4.12 using either Python 3.7, 3.6, or 3.5. Using the conda package manager users can also install additional third-party packages.

•We would like your feedback about the CIAO Conda installation: successes and problems. Send feedback to the CXC Helpdesk





Have fun using CIAO!

