

Part I

CHANDRA  
X-RAY OBSERVATORY



# CIAO Analysis

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SAO/*Chandra* X-ray Center  
Science Data Systems

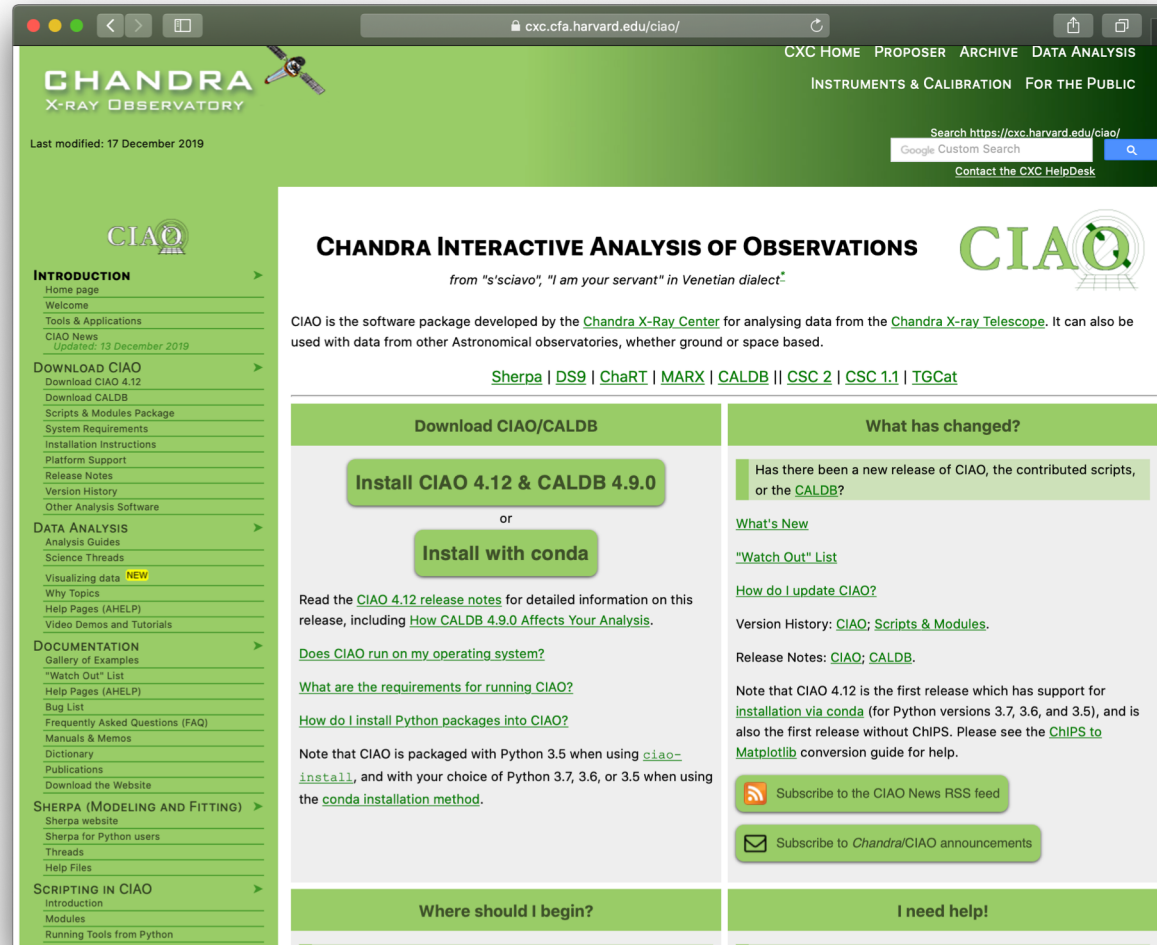
*The 2nd AAS Chandra/CIAO Workshop—Honolulu, Hawai'i, January 3-4, 2020*



CENTER FOR **ASTROPHYSICS**

HARVARD & SMITHSONIAN

# First, a quick detour on documentation and getting help...



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INSTRUMENTS & CALIBRATION FOR THE PUBLIC

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Contact the CXC HelpDesk

CHANDRA X-RAY OBSERVATORY

Last modified: 17 December 2019

CIAO

## CHANDRA INTERACTIVE ANALYSIS OF OBSERVATIONS CIAO

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

CIAO is the software package developed by the [Chandra X-Ray Center](#) for analysing data from the [Chandra X-ray Telescope](#). It can also be used with data from other Astronomical observatories, whether ground or space based.

[Sherpa](#) | [DS9](#) | [ChaRT](#) | [MARX](#) | [CALDB](#) || [CSC 2](#) | [CSC 1.1](#) | [TGCat](#)

### Download CIAO/CALDB

**Install CIAO 4.12 & CALDB 4.9.0**

or

**Install with conda**

Read the [CIAO 4.12 release notes](#) for detailed information on this release, including [How CALDB 4.9.0 Affects Your Analysis](#).

[Does CIAO run on my operating system?](#)

[What are the requirements for running CIAO?](#)

[How do I install Python packages into CIAO?](#)

Note that CIAO is packaged with Python 3.5 when using `ciao-install`, and with your choice of Python 3.7, 3.6, or 3.5 when using the [conda installation method](#).

**Where should I begin?**

### What has changed?

Has there been a new release of CIAO, the contributed scripts, or the CALDB?

[What's New](#)


["Watch Out!" List](#)


[How do I update CIAO?](#)

Version History: [CIAO](#); [Scripts & Modules](#).

Release Notes: [CIAO](#), [CALDB](#).

Note that CIAO 4.12 is the first release which has support for [installation via conda](#) (for Python versions 3.7, 3.6, and 3.5), and is also the first release without ChIPS. Please see the [ChIPS to Matplotlib](#) conversion guide for help.

 Subscribe to the CIAO News RSS feed

 Subscribe to Chandra/CIAO announcements

**I need help!**



# “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, which Sherpa has migrated to as its primary documentation system.
- ▶ Every component of CIAO has a help text: tools, packages (Sherpa), scripts and Python modules, and concepts (regions, coords, datamodel, etc.).

```
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 (): ?
```





### INTRODUCTION

- Home page
- Welcome
- Tools & Applications
- CIAO News  
Updated: 13 December 2019

### DOWNLOAD CIAO

- Download CIAO 4.12
- Download CALDB
- Scripts & Modules Package
- System Requirements
- Installation Instructions
- Platform Support
- Release Notes
- Version History
- Other Analysis Software

### DATA ANALYSIS

- Analysis Guides
- Science Threads
- Visualizing data **NEW**
- Why Topics
- Help Pages (AHELP)
- Video Demos and Tutorials

### DOCUMENTATION

- Gallery of Examples
- "Watch Out" List
- Help Pages (AHELP)
- Bug List
- Frequently Asked Questions (FAQ)
- Manuals & Memos
- Dictionary
- Publications
- Download the Website

### SHERPA (MODELING AND FITTING)

- Sherpa website
- Sherpa for Python users
- Threads
- Help Files

# Science Analysis “Threads”

- ▶ Science Threads are the most important document type. Primarily organized based on science analysis categories.
  - ▶ over 150 CIAO and Sherpa threads, designed to teach users the approach and concerns that go along with analysis
  - ▶ all threads begin with a “quick overview” to provide a synopsis, purpose, and ‘when to use’ the thread
  - ▶ updated and added to as needed; look for “new” and “updated” icon tags



# More on Science Analysis Threads



- ▶ Threads are just an example on approaching a problem. Don't blindly follow the examples verbatim, the threads are not strict recipes.
- ▶ Threads answer more detailed issues that may affect science; they help give the details behind the tool itself.
- ▶ An effort in the last few years is to wrap laborious thread analysis steps with a single command-line script.

The screenshot shows a stack of Chandra X-ray Observatory website pages. The top page is titled "Estimate Source Counts in an Event File" and is part of the "CIAO 4.6 Science Threads" section. The page includes a navigation bar with links like "CXO Home", "Proposer", "Archive", "Data Analysis", "Instruments & Calibration", and "For the Public". The main content area has a "Synopsis" section, a "Purpose" section, and a "Related Links" section. The "Synopsis" section states: "This quick method for estimating source counts may be useful as the first step in a more detailed analysis procedure. The thread is not intended to provide accurate photometric results; for that analysis, careful exposure and PSF corrections are necessary." The "Purpose" section states: "To estimate net source counts in user-defined regions of event lists or image files for HRC or ACIS imaging observations. Running this thread on LETG and HETG observations is *not* recommended." The "Related Links" section includes links to "srcflux" script, "HRC Imaging", and "Using CIAO Region Files thread".

srcflux script

Last modified: 17 December 2019



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#### SHERPA (MODELING AND FITTING)

Sherpa website  
Sherpa for Python users  
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Help Files

## “Guides” and “Why” Pages

- ▶ Analysis Guides are a roadmap to broad categories of analyses; organized based on detector and instrument configuration or source morphology, providing links to more detailed documents, such as science threads.
- ▶ 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





# 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.
  - ▶ categorized by detector and instrument configuration
  - ▶ describes files changed and affects on tools, analysis type, and threads
  - ▶ since calibrations evolve with time, note the dates calibration files go into effect for the observation
  - ▶ more details on the CalDB can be found at:  
`cxsc.harvard.edu/caldb`
- ▶ Details of changes to contributed scripts can be seen at:  
`cxsc.harvard.edu/ciao/download/scripts/history.html`

/ [ciao](#) / [releasenotes](#) / [ciao\\_4.12\\_release.html](#)

## CIAO 4.12 Release Notes

[Version History](#)

CIAO 4.12 is distributed for the following platforms:

- Linux 64 bit
- Apple macOS 10.12 (Sierra) through macOS 10.15 (Catalina)

**NEW** A beta edition of CIAO is now available via the [conda package manager](#): conda builds are available for Linux and Mac for Python 3.7, 3.6, and 3.5. More information can be found in the [conda section of the Installation notes](#) below.

There is no support for 32 bit operating systems, older Linux (CentOS 5 era) or older macOS platforms (OS-X El Capitan and earlier). More details can be found on the [Platform Support page](#).

- [Notable changes and improvements in CIAO 4.12](#)
- [How CALDB 4.9.0 Affects Your Analysis](#)
- [Installation](#)
- [Tools](#)
- [Parameter Files](#)
- [ChIPS](#)
- [Sherpa](#)
- [Graphical User Interfaces](#)
- [Analysis Scripts](#)
- [Python Modules](#)
- [Libraries](#)
- [Environment](#)
- [Documentation](#)

### Notable changes and improvements in CIAO 4.12

- CIAO 4.12 has several important event processing updates including ACIS badpixel updates to exclude frame-store shadow region, HRC updates to gain calibration, HRC degap calibration file changes, and improvements to the ACIS temperature dependent CTI correction.

**! CALDB 4.9.0 version requirements**

CIAO 4.11 and earlier users analyzing ACIS data should **NOT** upgrade to CALDB 4.9.0. While the new format of the temperature dependent CTI correction calibration files can be read by earlier versions CIAO, the higher order coefficients are not included. The new columns are ignored resulting in an inaccurate temperature adjustment being applied.

CIAO 4.12 HRC users must update to CALDB 4.9.0 due to the changes in the degap file. Similarly, CALDB 4.9.0

# A Word of Caution...

[cxc.harvard.edu/ciao](http://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](http://cxc.harvard.edu/ciaoX.Y)
- ▶ similar address structure for Sherpa pages:
  - ▶ [cxc.harvard.edu/sherpa](http://cxc.harvard.edu/sherpa)
  - ▶ [cxc.harvard.edu/sherpaX.Y](http://cxc.harvard.edu/sherpaX.Y)
- ▶ Be careful when using search engines!
  - ▶ mostly leads to out-of-date pages
  - ▶ check the software version of top indexed pages
  - ▶ use search field embedded in page

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X-RAY OBSERVATORY



CHANDRA X-RAY OBSERVATORY

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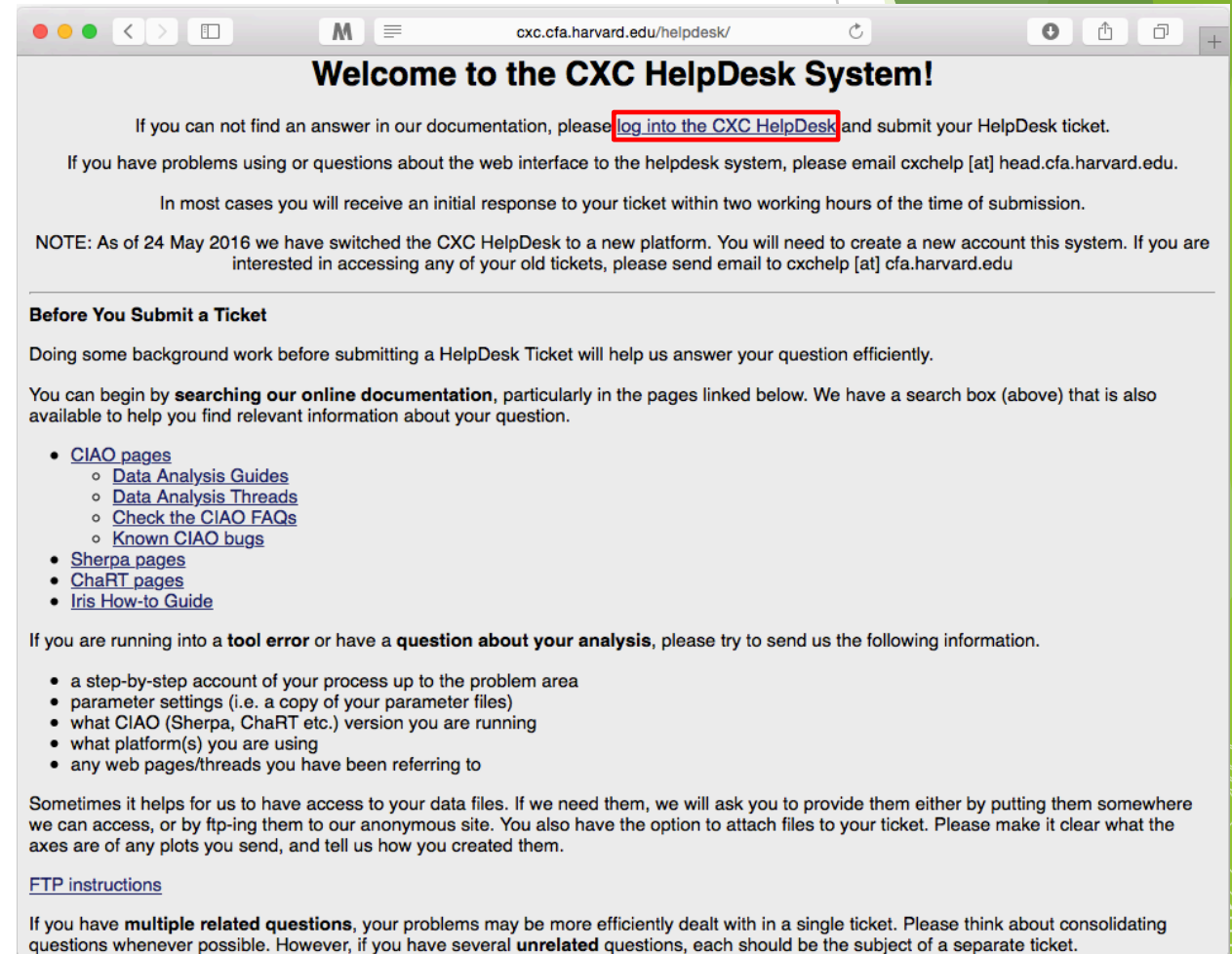


# The *Chandra* Helpdesk

[cxc.harvard.edu/helpdesk](http://cxc.harvard.edu/helpdesk)

Provides support for:

- ▶ proposals
- ▶ proposal planning
- ▶ observation scheduling and issues
- ▶ proprietary data
- ▶ data archive
- ▶ data analysis and DS9
  - ▶ help with data processing steps and to understand why they are applied
  - ▶ help highlight and understand the kinds of mistakes that are made during analysis



[cxc.cfa.harvard.edu/helpdesk/](http://cxc.cfa.harvard.edu/helpdesk/)

## Welcome to the CXC HelpDesk System!

If you can not find an answer in our documentation, please [log into the CXC HelpDesk](#) and submit your HelpDesk ticket.

If you have problems using or questions about the web interface to the helpdesk system, please email [cxchelp \[at\] head.cfa.harvard.edu](mailto:cxchelp@head.cfa.harvard.edu).

In most cases you will receive an initial response to your ticket within two working hours of the time of submission.

NOTE: As of 24 May 2016 we have switched the CXC HelpDesk to a new platform. You will need to create a new account this system. If you are interested in accessing any of your old tickets, please send email to [cxchelp \[at\] cfa.harvard.edu](mailto:cxchelp@cfa.harvard.edu)

---

### Before You Submit a Ticket

Doing some background work before submitting a HelpDesk Ticket will help us answer your question efficiently.

You can begin by **searching our online documentation**, particularly in the pages linked below. We have a search box (above) that is also available to help you find relevant information about your question.

- [CIAO pages](#)
  - [Data Analysis Guides](#)
  - [Data Analysis Threads](#)
  - [Check the CIAO FAQs](#)
  - [Known CIAO bugs](#)
- [Sherpa pages](#)
- [ChaRT pages](#)
- [Iris How-to Guide](#)

If you are running into a **tool error** or have a **question about your analysis**, please try to send us the following information.

- a step-by-step account of your process up to the problem area
- parameter settings (i.e. a copy of your parameter files)
- what CIAO (Sherpa, ChaRT etc.) version you are running
- what platform(s) you are using
- any web pages/threads you have been referring to

Sometimes it helps for us to have access to your data files. If we need them, we will ask you to provide them either by putting them somewhere we can access, or by ftp-ing them to our anonymous site. You also have the option to attach files to your ticket. Please make it clear what the axes are of any plots you send, and tell us how you created them.

[FTP instructions](#)

If you have **multiple related questions**, your problems may be more efficiently dealt with in a single ticket. Please think about consolidating questions whenever possible. However, if you have several **unrelated** questions, each should be the subject of a separate ticket.

# 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](http://cxc.harvard.edu/cda)



# ChaSeR: *Chandra* Search and Retrieval System

[cda.harvard.edu/chaser/](http://cda.harvard.edu/chaser/)



Chandra X-ray Center [New Search](#) [Retrieval List](#) [Help](#)

**Observation Search**

Search Reset

[File Upload](#)   no file selected

---

[Target Name](#)   [RA/Long/l](#)  [Dec/Lat/b](#)

[Name Resolver](#)  [Coord System](#)  [Equinox](#)  [Radius](#)  arcmin

---

[Observation ID](#)  [Sequence Number](#)  [Proposal Number](#)

[Proposal Title](#)  [PI Name](#)  [Observer Name](#)

[Start Date](#)  [Public Release Date](#)

[Exposure Time \(ks\)](#)  [Approved Time \(ks\)](#)  [Avg. Count Rate \(hz\)](#)

---

[Status](#)

[Science Category](#)

[Instrument](#)

[Grating](#)

[Exposure Mode](#)

[Type](#)

[Observing Cycle](#)

[Joint Observatories](#)

[Proposal Cycle](#)

---

**Customize Output:**

[Sort Order](#)   ascending  descending

[Row Limit](#)

[Coord System](#)  [Equinox](#)  [Format](#)

[Save As](#)

For online support please contact the [CXC Helpdesk](#).





# ChaSeR: *Chandra* Search and Retrieval System

[cda.harvard.edu/chaser](http://cda.harvard.edu/chaser)

- ▶ browse the observation catalog with a variety of search criteria
- ▶ search fields are self-explanatory, links lead to description of usage and input format
- ▶ 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  $T_2$





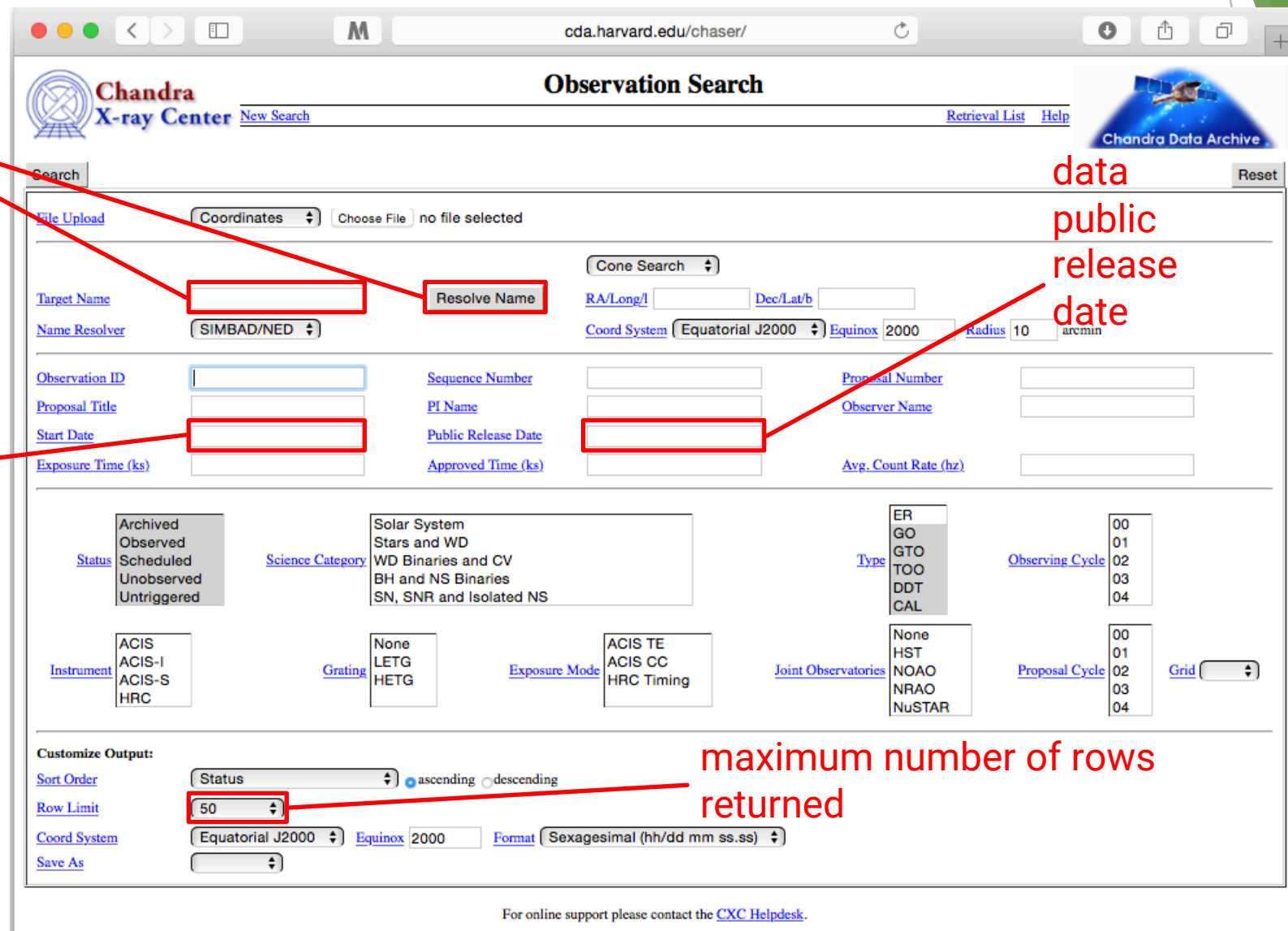
# ChaSeR (continued)

source name and name resolver

data public release date

observation start date

maximum number of rows returned



The screenshot shows the Chandra Observation Search web interface. Red boxes and arrows highlight several key fields:

- Target Name** and **Resolve Name** fields are highlighted with red boxes and an arrow pointing to the text "source name and name resolver".
- Start Date** field is highlighted with a red box and an arrow pointing to the text "observation start date".
- Public Release Date** field is highlighted with a red box and an arrow pointing to the text "data public release date".
- Row Limit** dropdown menu is highlighted with a red box and an arrow pointing to the text "maximum number of rows returned".

The interface includes a search bar, various filters (Status, Science Category, Instrument, etc.), and a "Customize Output" section at the bottom.

# ChaSeR (continued)



M87

Chandra X-ray Center [New Search](#) [Retrieval List](#) [Help](#)

Observation Search

Search Reset

[File Upload](#)  Choose File no file selected

[Target Name](#)  [Resolve Name](#) [Cone Search](#)

[Name Resolver](#)  [RA/Long/l](#)  [Dec/Lat/b](#)

[Coord System](#)  [Equinox](#)  [Radius](#)  arcmin

[Observation ID](#)  [Sequence Number](#)  [Proposal Number](#)

[Proposal Title](#)  [PI Name](#)  [Observer Name](#)

[Start Date](#)  [Public Release Date](#)

[Exposure Time \(ks\)](#)  [Approved Time \(ks\)](#)  [Avg. Count Rate \(h/z\)](#)

[Status](#)

[Science Category](#)

[Type](#)

[Observing Cycle](#)

[Instrument](#)

[Grating](#)

[Exposure Mode](#)

[Joint Observatories](#)

[Proposal Cycle](#)      [Grid](#)

**Customize Output:**

[Sort Order](#)   ascending  descending

[Row Limit](#)

[Coord System](#)  [Equinox](#)  [Format](#)

[Save As](#)

For online support please contact the [CXC Helpdesk](#).

# ChaSeR Query Results



Chandra X-ray Center [New Search](#) [Search Results](#) [Retrieval List](#) [Help](#)

View Observation Information  Add Products to Retrieval List  Primary package  Secondary package  Custom selection

[Select all](#) | [Unselect all](#)

Select	Row	Seq Num	Obs ID	Instrument	Grating	Appr Exp	Exposure	Target Name	PI Name	RA	Dec	Status	Data Mode	Exp Mode	Avg Cnt Rate	Evt Cnt
<input type="checkbox"/>	1	700656	3977	ACIS-S	NONE	5.0	5.28	M87	Harris	12 30 49.00	+12 23 30.00	archived	FAINT	TE	12.10	63
<input type="checkbox"/>	2	700657	3978	ACIS-S	NONE	5.0	4.85	M87	Harris	12 30 49.00	+12 23 30.00	archived	FAINT	TE	12.42	60
<input type="checkbox"/>	3	700658	3979	ACIS-S	NONE	5.0	4.49	M87	Harris	12 30 49.00	+12 23 30.00	archived	FAINT	TE	12.34	55
<input type="checkbox"/>	4	700659	3980	ACIS-S	NONE	5.0	4.79	M87	Harris	12 30 49.00	+12 23 30.00	archived	FAINT	TE	12.07	57
<input type="checkbox"/>	5	700660	3981	ACIS-S	NONE	5.0	4.68	M87	Harris	12 30 49.00	+12 23 30.00	archived	FAINT	TE	11.77	55
<input type="checkbox"/>	6	700661	3982	ACIS-S	NONE	5.0	4.84	M87	Harris	12 30 49.00	+12 23 30.00	archived	FAINT	TE	11.91	57
<input checked="" type="checkbox"/>	7	700998	4917	ACIS-S	NONE	5.0	5.03	M87	Biretta	12 30 49.00	+12 23 30.00	archived	FAINT	TE	13.02	65
<input type="checkbox"/>	8	700686	4007	ACIS-S	NONE	40.0	36.18	NGC 4486B	Fabbiano	12 30 31.80	+12 29 26.00	archived	VFAINT	TE	6.97	252
<input type="checkbox"/>	9	700999	4918	ACIS-S	NONE	5.0	4.68	M87	Biretta	12 30 49.00	+12 23 30.00	archived	FAINT	TE	12.45	58
<input type="checkbox"/>	10	701000	4919	ACIS-S	NONE	5.0	4.7	M87	Biretta	12 30 49.00	+12 23 30.00	archived	FAINT	TE	12.91	60
<input type="checkbox"/>	11	701002	4921	ACIS-S	NONE	5.0	5.25	M87	Biretta	12 30 49.00	+12 23 30.00	archived	FAINT	TE	13.29	69
<input type="checkbox"/>	12	701003	4922	ACIS-S	NONE	5.0	4.54	M87	Biretta	12 30 49.00	+12 23 30.00	archived	FAINT	TE	12.70	57

**110 observations found**  
 Position=cone of radius 10 arcmin around RA: 12 30 49.42, Dec: +12 23 28.04 (frame=j2000 equinox=2000)  
 Start Date=2003-01-01/2020-01-02  
 Public Release Date=/2020-01-03  
 Status=archived; observed; scheduled; unobserved; untriggered  
 Instrument=ACIS  
 Grating=NONE  
 Type=GO; GTO; TOO; DDT; CCT; CAL  
 Exposure Mode=TE  
 Sort Order=Start Date ascending

For online support please contact the [CXC Helpdesk](#).



# 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

list of ADS links to publications that have made use of the observation data

Chandra X-ray Center [New Search](#) [Search Results](#) [Retrieval List](#) [Help](#)

Chandra Data Archive  
Not logged in [Login](#)

Observation ID: **4917**

Observation ID: 4917  
  
 [Primary package](#)  
 [Secondary package](#)  
 [Custom selection](#)

→ [Summary](#)  
[Details](#)  
[V&V Report](#)  
[Proposal Abstract](#)  
[Images](#)  
 Data packages  
   [Primary](#)  
   [Secondary](#)  
 External links  
   [Publications](#)  
   [Processing Status](#)  
   [Sequence Summary](#)  
 Related Observations  
   [By Sequence](#)  
   [By Proposal](#)  
   [By Monitor/Followup](#)  
   [By Group](#)  
   [By Grid](#)

<b>Sequence Number:</b>	700998	<b>Status:</b>	archived
<b>Observation ID:</b>	4917	<b>Proposal Number:</b>	05701072
<b>Type:</b>	GO	<b>Proposal Cycle:</b>	05
<b>PI Name:</b>	Biretta	<b>Observer:</b>	Harris
<b>Science Category:</b>	ACTIVE GALAXIES AND QUASARS	<b>Joint Observatories:</b>	CXO-HST
<b>Target Name:</b>	M87	<b>Grid Name:</b>	
<b>RA (J2000):</b>	12 30 49.00	<b>Data Mode:</b>	FAINT
<b>Dec (J2000):</b>	+12 23 30.00	<b>Observing Cycle:</b>	05
<b>Instrument:</b>	ACIS-S	<b>Public Release Date:</b>	2004-11-14 16:28:26
<b>Grating:</b>	NONE		
<b>Start Date:</b>	2003-11-11 19:45:02		
<b>Approved Time:</b>	5.00 ks		
<b>Exposure Time:</b>	5.03 ks		

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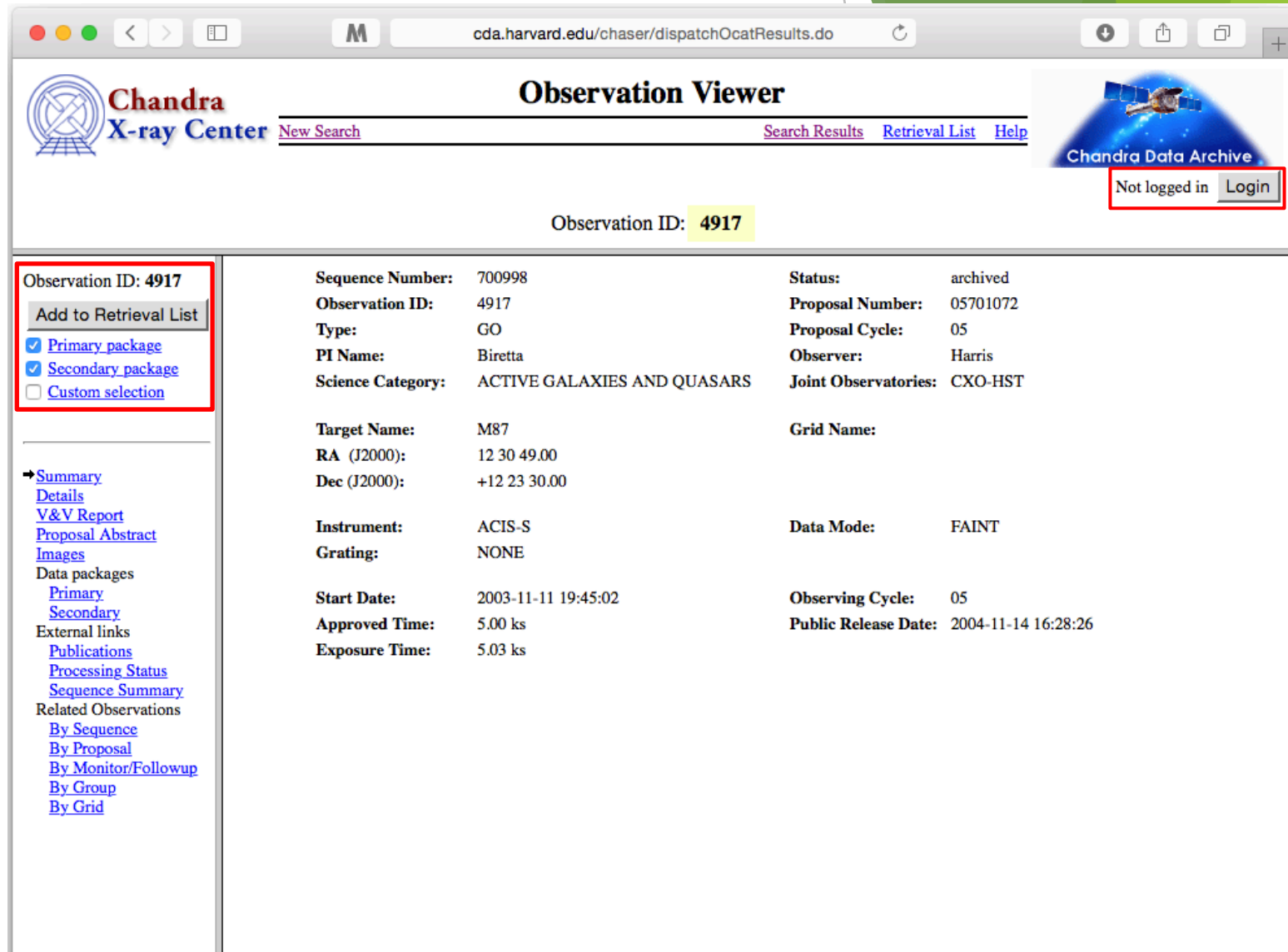


# ChaSeR ObsID Entry

- ▶ 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](http://cxc.harvard.edu/cgi-gen/cda/specreq)



The screenshot shows the Chandra X-ray Center Observation Viewer interface. The browser address bar displays `cda.harvard.edu/chaser/dispatchOcatResults.do`. The page title is "Observation Viewer". The Chandra X-ray Center logo is on the left, and navigation links for "New Search", "Search Results", "Retrieval List", and "Help" are in the center. On the right, there is a "Chandra Data Archive" logo and a "Not logged in Login" button.

The main content area displays "Observation ID: 4917". Below this, there is a table of observation details:

<b>Sequence Number:</b>	700998	<b>Status:</b>	archived
<b>Observation ID:</b>	4917	<b>Proposal Number:</b>	05701072
<b>Type:</b>	GO	<b>Proposal Cycle:</b>	05
<b>PI Name:</b>	Biretta	<b>Observer:</b>	Harris
<b>Science Category:</b>	ACTIVE GALAXIES AND QUASARS	<b>Joint Observatories:</b>	CXO-HST
<b>Target Name:</b>	M87	<b>Grid Name:</b>	
<b>RA (J2000):</b>	12 30 49.00	<b>Data Mode:</b>	FAINT
<b>Dec (J2000):</b>	+12 23 30.00	<b>Observing Cycle:</b>	05
<b>Instrument:</b>	ACIS-S	<b>Public Release Date:</b>	2004-11-14 16:28:26
<b>Grating:</b>	NONE		
<b>Start Date:</b>	2003-11-11 19:45:02		
<b>Approved Time:</b>	5.00 ks		
<b>Exposure Time:</b>	5.03 ks		

On the left side of the interface, there is a sidebar with a red box highlighting the "Add to Retrieval List" button and three checkboxes: "Primary package" (checked), "Secondary package" (checked), and "Custom selection" (unchecked). Below the sidebar, there are links for "Summary", "Details", "V&V Report", "Proposal Abstract", "Images", "Data packages", "Primary", "Secondary", "External links", "Publications", "Processing Status", "Sequence Summary", "Related Observations", "By Sequence", "By Proposal", "By Monitor/Followup", "By Group", and "By Grid".



# Beyond ChaSeR:

## find\_chandra\_obsid



```
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
    (verbose = 1) Verbose level
    (mode = h)
```





# Beyond ChaSeR: Chandra Footprint Service

[cxcfps.cfa.harvard.edu/cda/footprint/cdaview.html](http://cxcfps.cfa.harvard.edu/cda/footprint/cdaview.html)

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- ▶ A search by position or object name overlays the footprints of *Chandra* Observations on Digital Sky Survey images, allowing further selection and retrieval of observations.

**Chandra Footprint Service**

CenA  
Examples: *Eta Carinae*, 10 45 03.591 -59 41 04.26  $r=0.5d$ , 122,22,1741-1743,1739  
Requires Firefox 3, Safari 4, or compatible browser

Footprints | Image Inventory | Preview Images/Download Data | Help | FAQ

CenA RA =201.365063 Dec = -43.019112  $r = 0.500000$  [13:25:27.615 -43:01:08.80]  
Instrument: RA 201.7991 DEC -43.9488 Search Radius (deg): 0.5

Footprints to display:  
 All Public Observations  
 CSC Coverage ?  
 Show DSS Image:   
 Get VOTable ?

Results 1 - 20 of 46 Show 20 results per page

Total Exposure Time for Selected Rows: ks  
 Click column heading to sort list - Click rows to select  
[Download Selected ObsIDs](#)  
 Show selected rows: [First](#) [Mixed](#) [Only](#) [Not](#) [Reset selection](#)  
 Text boxes under column headings allow specifying a filter to be applied to columns [Apply Filter](#) [Clear Filter](#)

ObsID	Target	Observation Date	RA	DEC	Proposal ID	PI Last Name	Instrument	Exposure	Grating	JPEG Preview
316	NGC 5128	1999-12-05T21:36:00	13:25:27.62	-43:01:09.0	1600065	Murray	ACIS-I	35.72	NONE	JPEG
463	CEN A	1999-09-10T07:48:00	13:25:27.61	-43:01:11.0	1700108	Calibration	HRC-I	19.52	NONE	JPEG
806	CEN A FILAMENTS	2000-01-23T07:46:00	13:26:03.71	-42:57:08.3	1700171	Evans	HRC-I	64.91	NONE	JPEG
962	NGC 5128	2000-05-17T22:57:00	13:25:27.62	-43:01:09.0	1600065	Murray	ACIS-I	36.5	NONE	JPEG
1253	CEN A	1999-09-10T14:06:00	13:25:27.61	-43:01:11.0	1700108	Calibration	HRC-I	6.83	NONE	JPEG
1412	CEN A	1999-12-21T18:11:00	13:25:27.61	-43:01:11.0	700006	Calibration	HRC-I	14.97	NONE	JPEG
1600	CENTAURUS A	2001-05-09T20:00:00	13:25:27.41	-43:01:11.0	2700083	Murray	ACIS-S	46.85	HETG	JPEG
1601	CENTAURUS A	2001-05-21T17:07:00	13:25:27.41	-43:01:11.0	2700083	Murray	ACIS-S	51.51	HETG	JPEG
2978	CEN-A	2002-09-03T02:42:00	13:25:28.7	-43:00:59.7	3700075	Murray	ACIS-S	44.59	NONE	JPEG
3965	CENTAURUS A	2003-09-14T13:44:00	13:25:28.7	-43:00:59.7	4700217	Kraft	ACIS-S	49.52	NONE	JPEG
7797	Centaurus A Jet	2007-03-22T08:59:00	13:25:19.15	-43:02:42.4	8700512	Kraft	ACIS-I	96.89	NONE	JPEG
7798	Centaurus A Jet	2007-03-27T09:53:00	13:25:51.8	-43:00:04.5	8700512	Kraft	ACIS-I	90.84	NONE	JPEG
7799	Centaurus A Jet	2007-03-30T02:32:00	13:25:51.8	-43:00:04.5	8700512	Kraft	ACIS-I	94.78	NONE	JPEG
7800	Centaurus A Jet	2007-04-17T15:00:00	13:25:46.01	-42:58:14.6	8700512	Kraft	ACIS-I	90.84	NONE	JPEG
8489	Centaurus A Jet	2007-05-08T18:41:00	13:25:32.8	-43:01:35.2	8700512	Kraft	ACIS-I	93.94	NONE	JPEG
8490	Centaurus A Jet	2007-05-30T02:01:00	13:25:18.8	-43:03:01.8	8700512	Kraft	ACIS-I	94.43	NONE	JPEG
10407	CEN A	2009-04-04T05:29:00	13:25:27.62	-43:01:08.9	10700750	Karowska	HRC-I	14.98	NONE	JPEG
10408	CEN A	2009-09-14T11:04:00	13:25:27.62	-43:01:08.9	10700750	Karowska	HRC-I	14.97	NONE	JPEG
10722	Centaurus A	2009-09-08T20:05:00	13:25:27.61	-43:01:09.1	10700038	Murray	ACIS-S	49.4	NONE	JPEG
10723	Centaurus A	2009-01-04T12:32:00	13:25:49.67	-42:59:14.8	10700038	Murray	ACIS-I	5.08	NONE	JPEG

# Beyond ChaSeR:

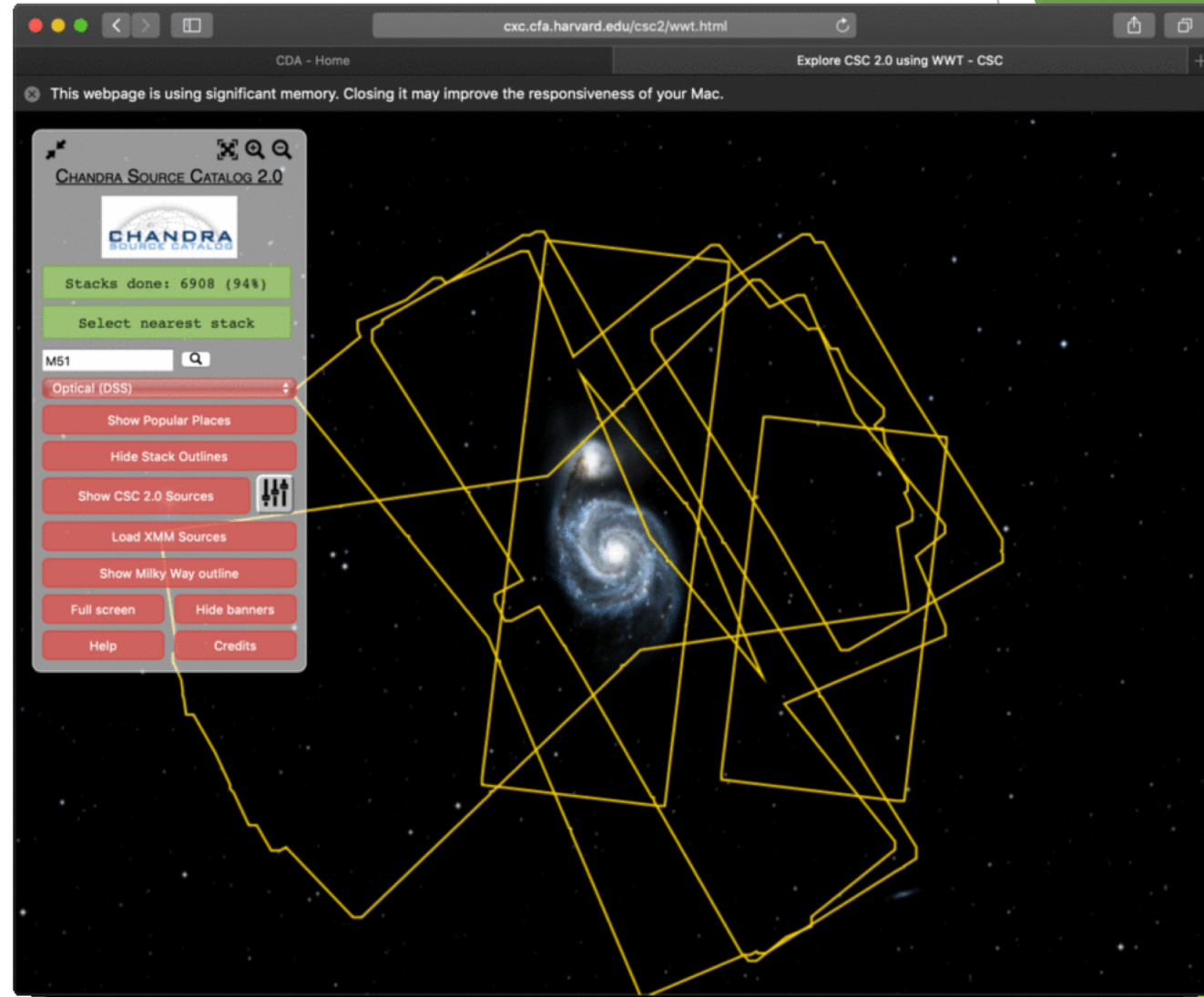
## Chandra Source Catalog-Worldwide Telescope

[cxc.harvard.edu/csc2/wwt.html](http://cxc.harvard.edu/csc2/wwt.html)

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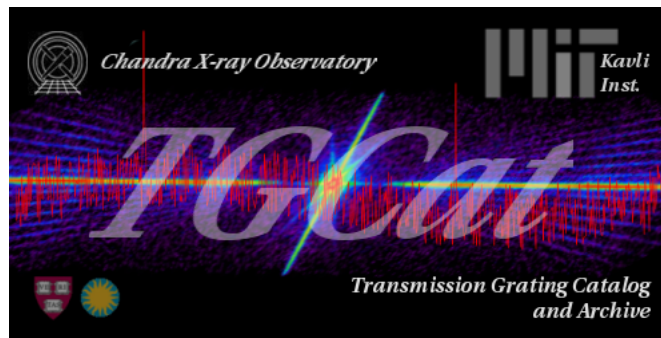


- ▶ Uses the AAS's WWT interface to explore the sky coverage and source properties of CSC 2.0.
- ▶ Provides links for ObsIDs to ChaSeR.
- ▶ Provides info to access catalog data products via CSCView.



# Beyond ChaSeR: TGCat

tgcat.mit.edu



CHANDRA  
X-RAY OBSERVATORY



- Includes all publicly available gratings observations.
- Provides calibrated spectra and responses.
- Provides quick-look visualization and summary products.

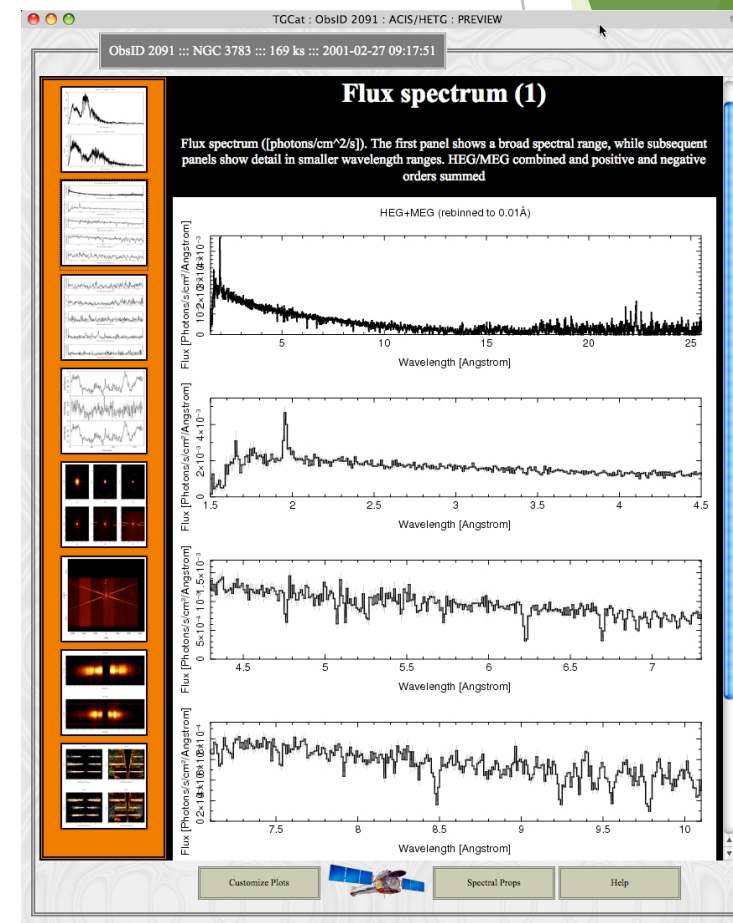
RESULTS: Found 152 matching extractions

checkbox	o p s	srcid	obsid	obscat	instr	grating	ra (h:m:s)	dec (d:m:s)	date_obs (y-m-d)	time (h:m:s)	exposure (s)
<input type="checkbox"/>	o p s	1673	2482	NGC 3516	ACIS	HETG	11:06:47.467	+72:34:7.176	2001-11-11	01:00:25	88011.4
<input type="checkbox"/>	o p s	1673	8451	NGC 3516	ACIS	HETG	11:06:47.484	+72:34:7.212	2006-10-11	09:49:34	47567
<input type="checkbox"/>	o p s	1673	7281	NGC 3516	ACIS	HETG	11:06:47.501	+72:34:7.284	2006-10-14	02:19:19	42509.5
<input type="checkbox"/>	o p s	1673	2080	NGC 3516	ACIS	HETG	11:06:47.501	+72:34:7.248	2001-04-10	17:55:54	73376.6
<input type="checkbox"/>	o p s	1673	8452	NGC 3516	ACIS	HETG	11:06:47.501	+72:34:7.176	2006-10-09	14:05:36	20754.8
<input type="checkbox"/>	o p s	1673	2431	NGC 3516	ACIS	HETG	11:06:47.501	+72:34:7.320	2001-04-09	14:12:05	35572
<input type="checkbox"/>	o p s	1673	7282	NGC 3516	ACIS	HETG	11:06:47.501	+72:34:7.212	2006-10-10	04:43:54	41454.5
<input type="checkbox"/>	o p s	1673	831	NGC 3516	ACIS	HETG	11:06:47.501	+72:34:7.104	2000-09-30	21:05:22	43893.8
<input type="checkbox"/>	o p s	1673	8450	NGC 3516	ACIS	HETG	11:06:47.501	+72:34:7.248	2006-10-12	07:00:26	38549.6
<input type="checkbox"/>	o p s	1666	2092	NGC 3783	ACIS	HETG	11:39:1.694	-37:44:18.960	2001-03-10	00:31:15	165454

Flux Spectrum ( Click to preview all Images )

press "go" to operate on selections:  limit  download  plot combined  view sources

Go Change Columns New Search Help







# NASA's HEASARC Archive

(High-Energy Astrophysics Science Archive Research Center)

[heasarc.gsfc.nasa.gov/docs/archive.html](https://heasarc.gsfc.nasa.gov/docs/archive.html)

- ▶ Primary portal to all data from EUV/X-ray/ $\gamma$ -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](http://cxc.harvard.edu/ciao/threads)

[cxc.harvard.edu/sherpa/threads](http://cxc.harvard.edu/sherpa/threads)



# Analyses:



- ▶ 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

- ▶ Available data products determine possible types of analysis.

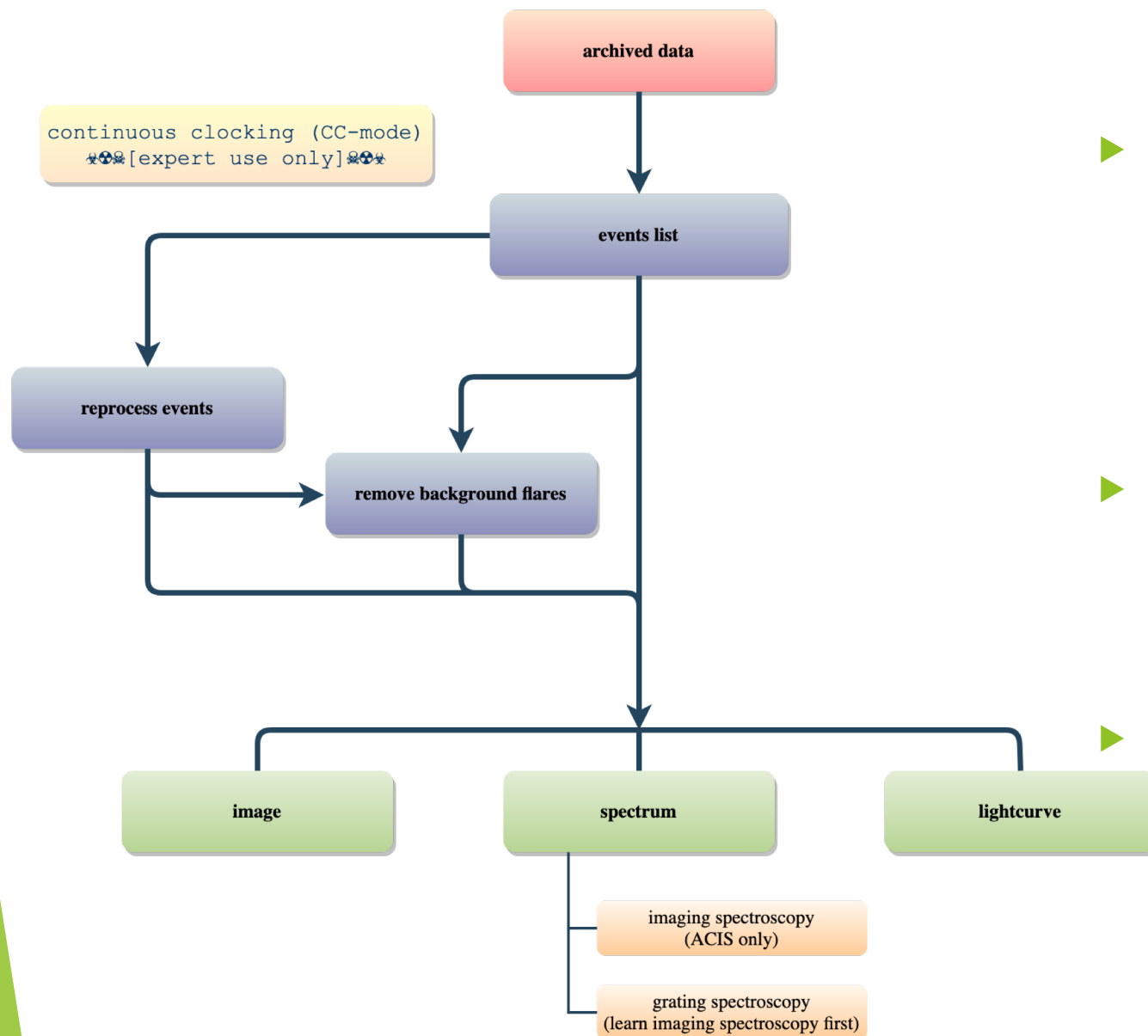
```
unix% dmlist evt.fits cols
```

- ▶ Example Overview: extract and fit a spectrum
  - ▶ download data
  - ▶ exclude serendipitous field sources and find periods of flaring background
  - ▶ define extraction regions
  - ▶ extract spectra and generate response files
  - ▶ spectral fitting and source flux





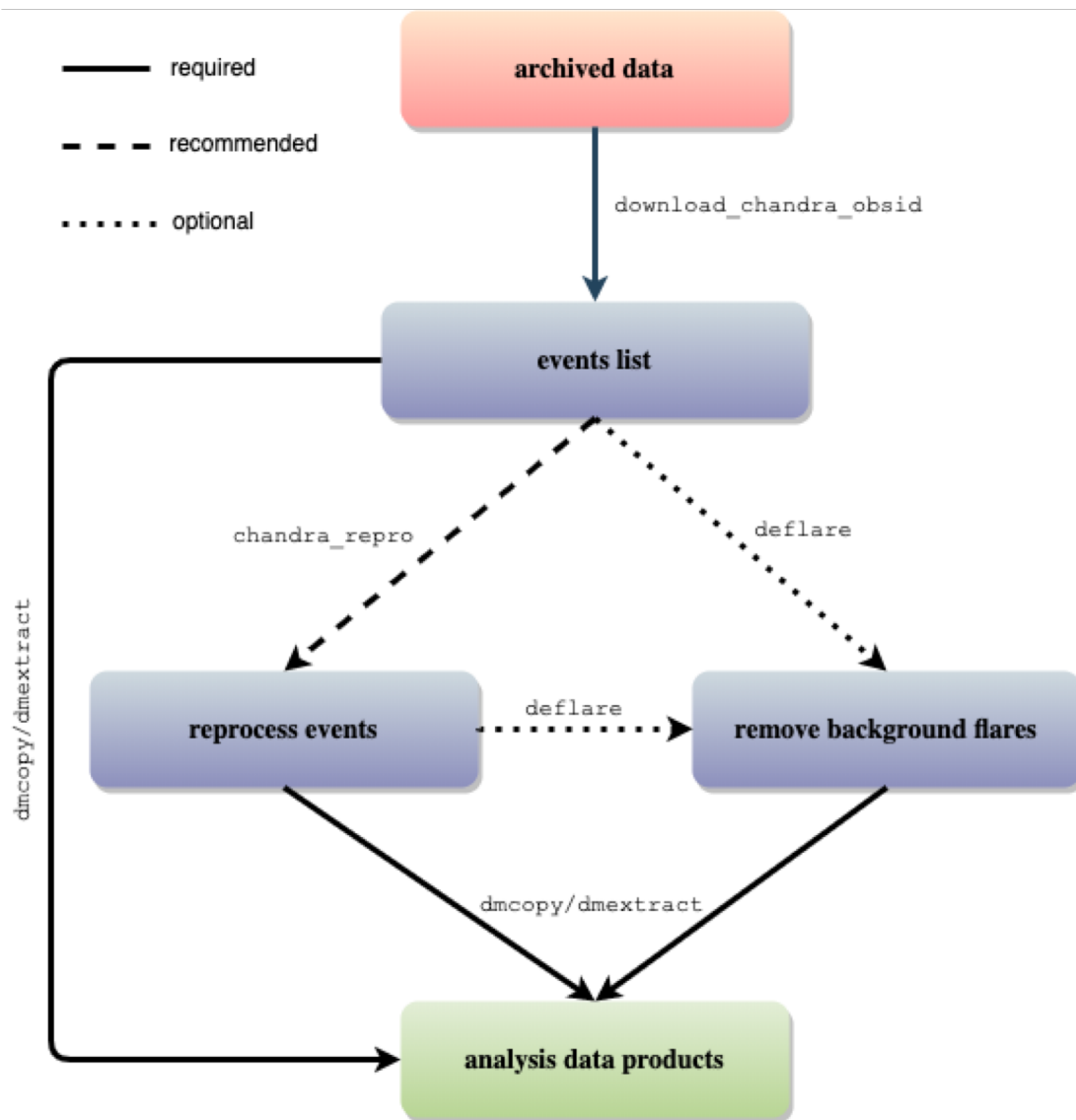
# Analyses Paths



- ▶ 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



# Data Product Extraction



- ▶ reprocess downloaded data to ensure latest calibration products are applied to the data set
  - ▶ rarely, the CalDB used by standard data processing pipeline is ahead of publicly available CalDB
  - ▶ occasionally, bug in a newly released CalDB causes erroneous values when applied to events
- ▶ background flares
  - ▶ most likely to affect extended sources, particularly diffuse features
  - ▶ weak point sources more likely to be than bright point sources





# Download and Reprocess (single ObsID)

[almost] always: reprocess, reprocess, reprocess

```

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
  
```

- ▶ Latest version of time-dependent gain applied.
- ▶ Latest temperature-dependent CTI correction applied.
- ▶ Ensures common set of calibration files used.

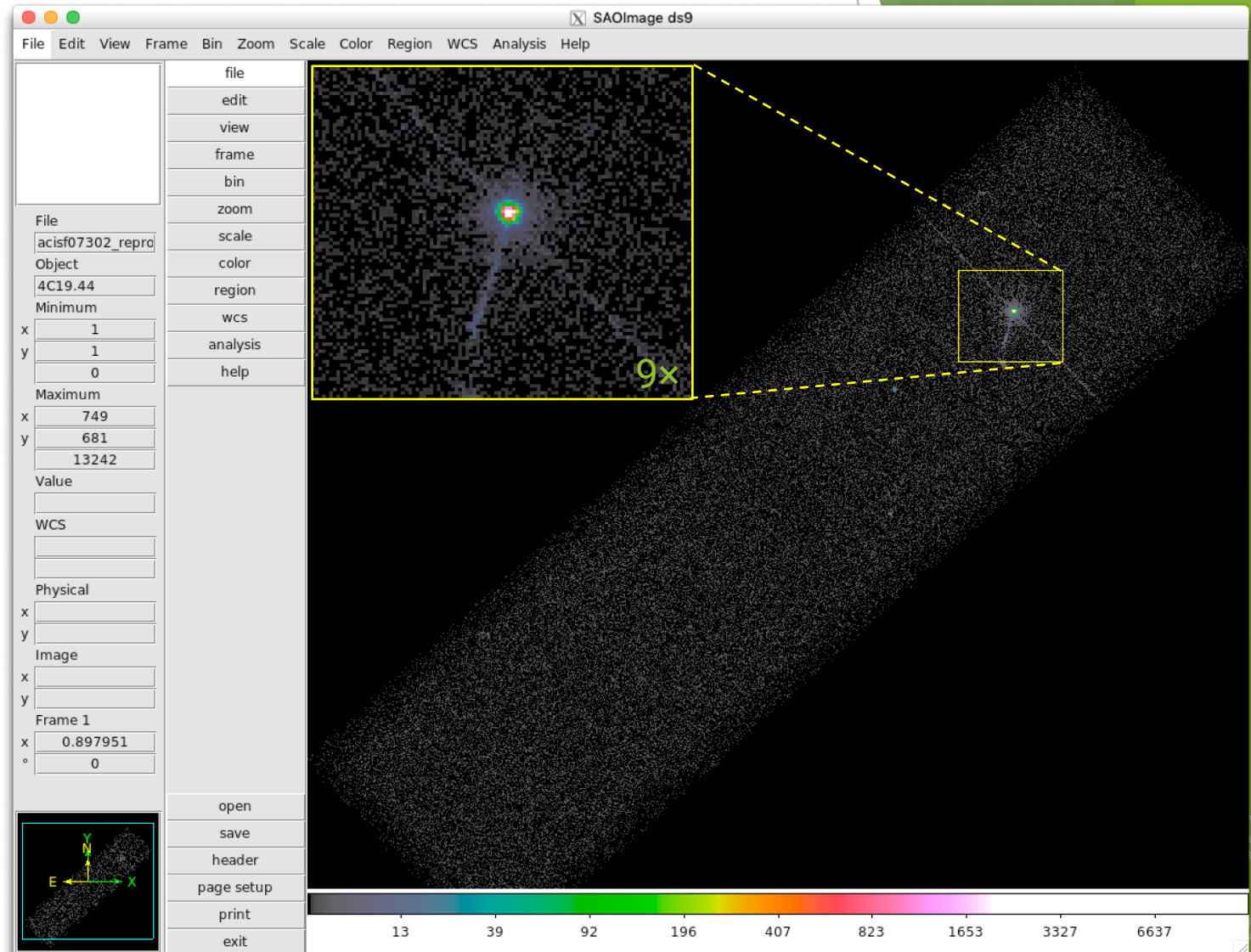
Tip: boolean arguments can also be recognized as for example:  
echo=yes/echo+ and echo=no/echo-

- ▶ 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.

# 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, and 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
  - ▶ extract streak spectrum
  - ▶ `acisreadcorr` used to remove readout streak for cosmetic or source detection purposes, but has issues with sub-array mode



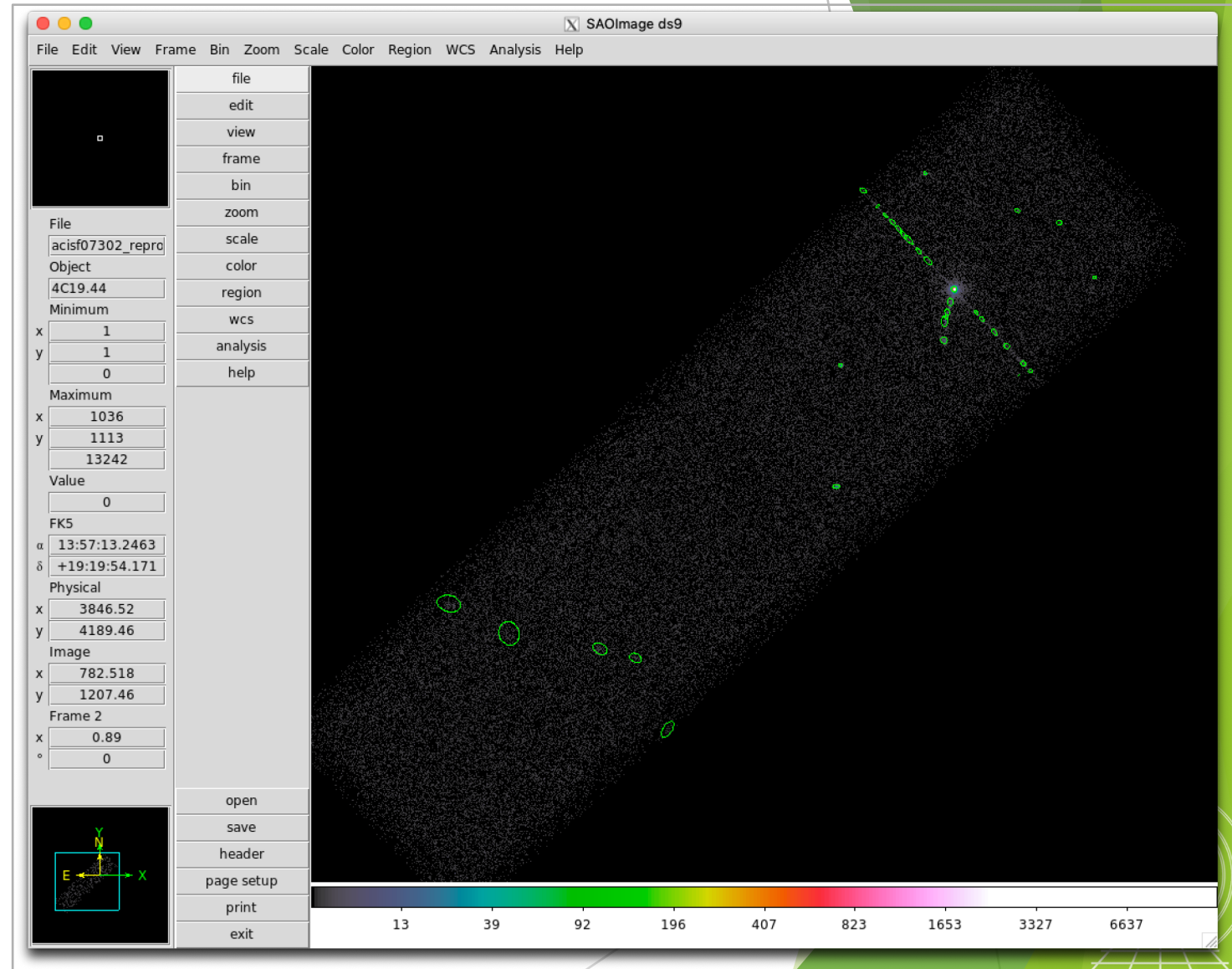


# Background Flares and Source Detection



- ▶ 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, deriving from both unresolved & resolved and point & extended X-ray sources.
  - ▶ Other 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

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X-RAY OBSERVATORY



## ► 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

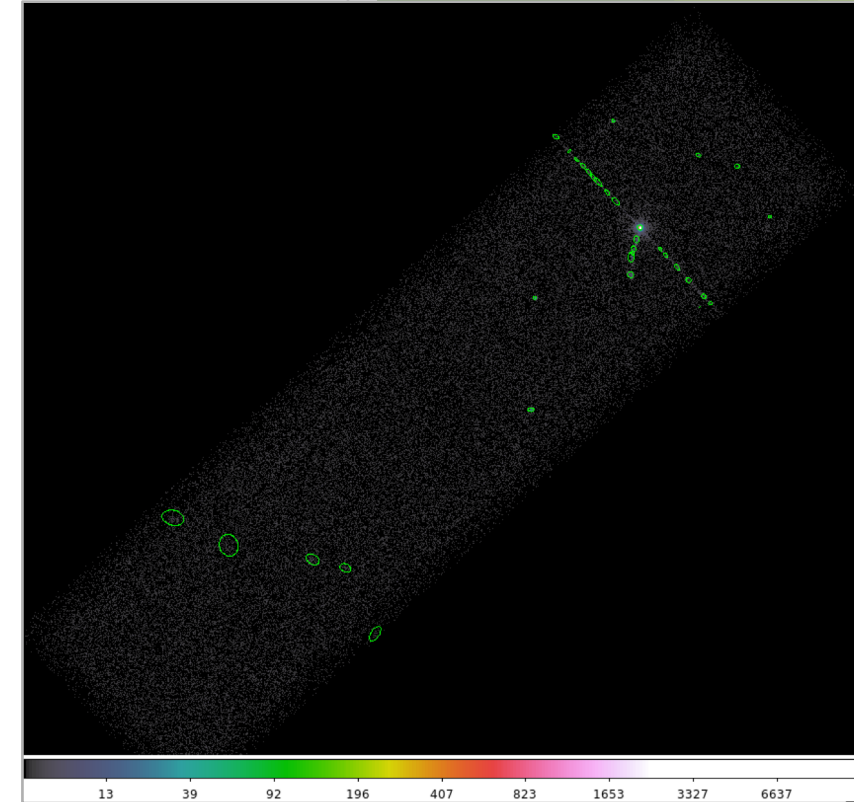
### ► vtpdetect — Voronoi tessellation and percolation

#### 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
  - ▶ PSF maps can be used by `celldetect` and `wavdetect`
- ▶ `fluximage` provides an easy interface to generate these data products.

reduces false source detections from detector effects

PSF info allows for more reliable characterization of source; does not affect detection

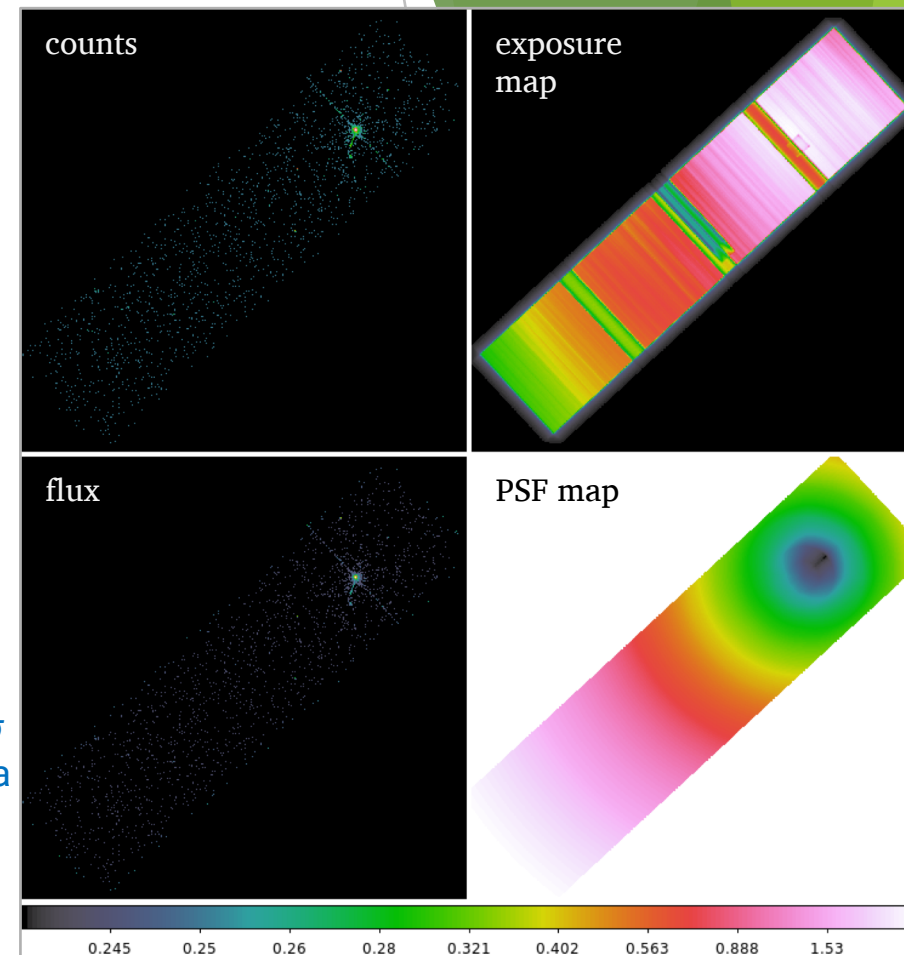
```
unix% fluximage acisf07302_repro_evt2.fits \
? outroot=flux/7302 binsize=1 bands=broad psfecf=0.393
. . . SCREEN OUTPUT . . .
The following files were created:
The clipped counts image is:
flux/7302_broad_thresh.img
The clipped exposure map is:
flux/7302_broad_thresh.expmap
The PSF map is:
flux/7302_broad_thresh.psfmap
The exposure-corrected image is:
flux/7302_broad_flux.img
```

Note: prior to CIAO 4.11, the separate `mkpsfmap` tool needs to be run to generate the PSF map.

ECF=0.393 corresponds to the  $1\sigma$  integrated volume of a 2D Gaussian

```
unix% mkpsfmap infile=7302_broad_thresh.img \
? outfile=7302_broad_thresh.psfmap \
? energy=2.3 ecf=0.393
```

effective energy used for exposure map (2.3 keV for CSC broad band)





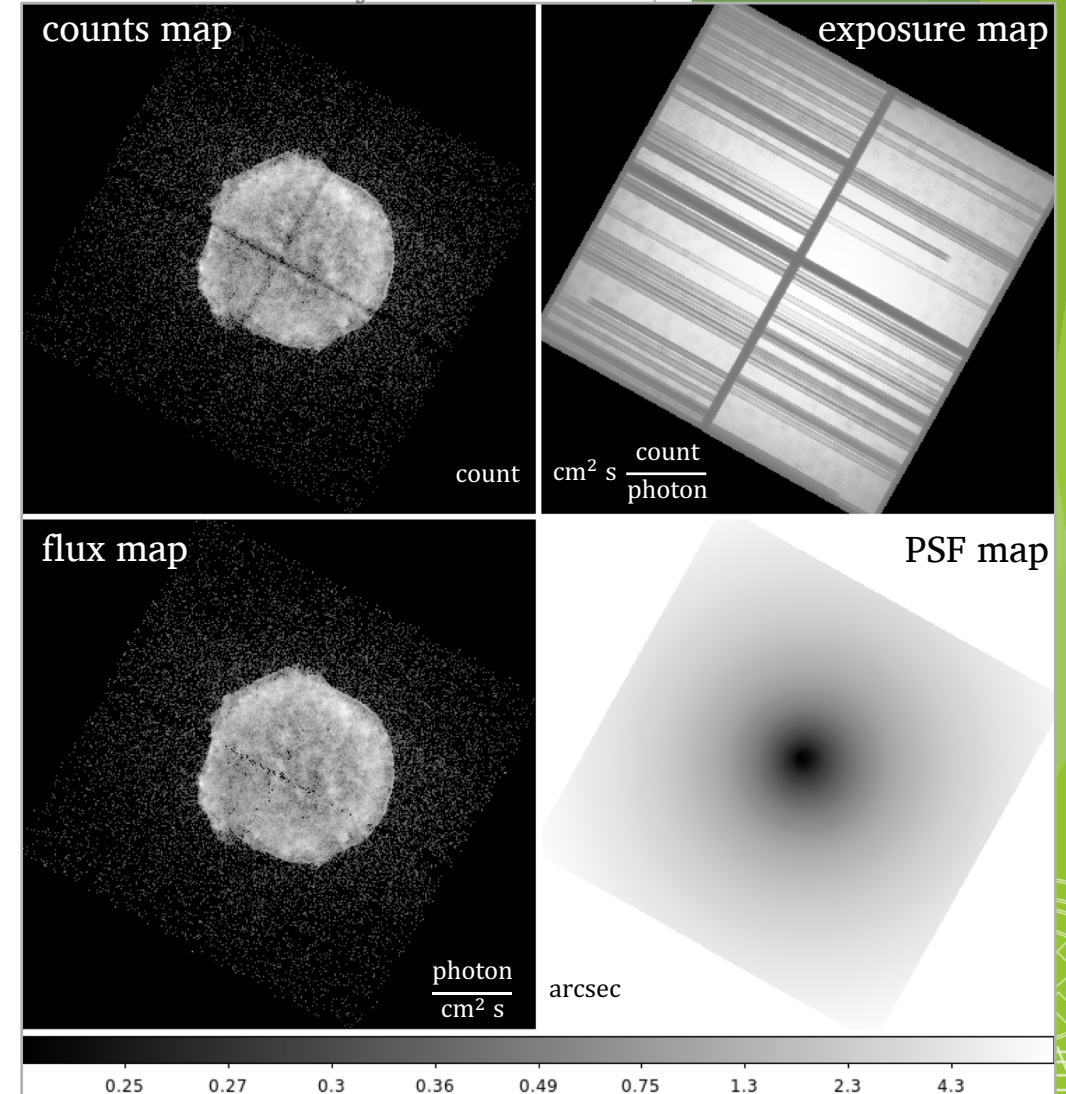
# Source Detection Inputs

## fluximage Data Products

- ▶ Binned counts map with clipping.
- ▶ Exposure maps are observation-specific maps of the instrument sensitivity, incorporating mirror area and detector QE, convolved with the telescope's aspect solution.
  - ▶ 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.
  - ▶ the mkpsfmap size is the radius of a circular region enclosing a given fraction of the counts from a point source (the "ECF" or "encircled counts fraction")
  - ▶ sizes are for a PSF of a given monochromatic energy or photon distribution



ObsID 10095: Tycho's SNR





# Source Detection

## by way of wavdetect

```

unix% punlearn ardlb
unix% acis_set_ardlib 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
  
```

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

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

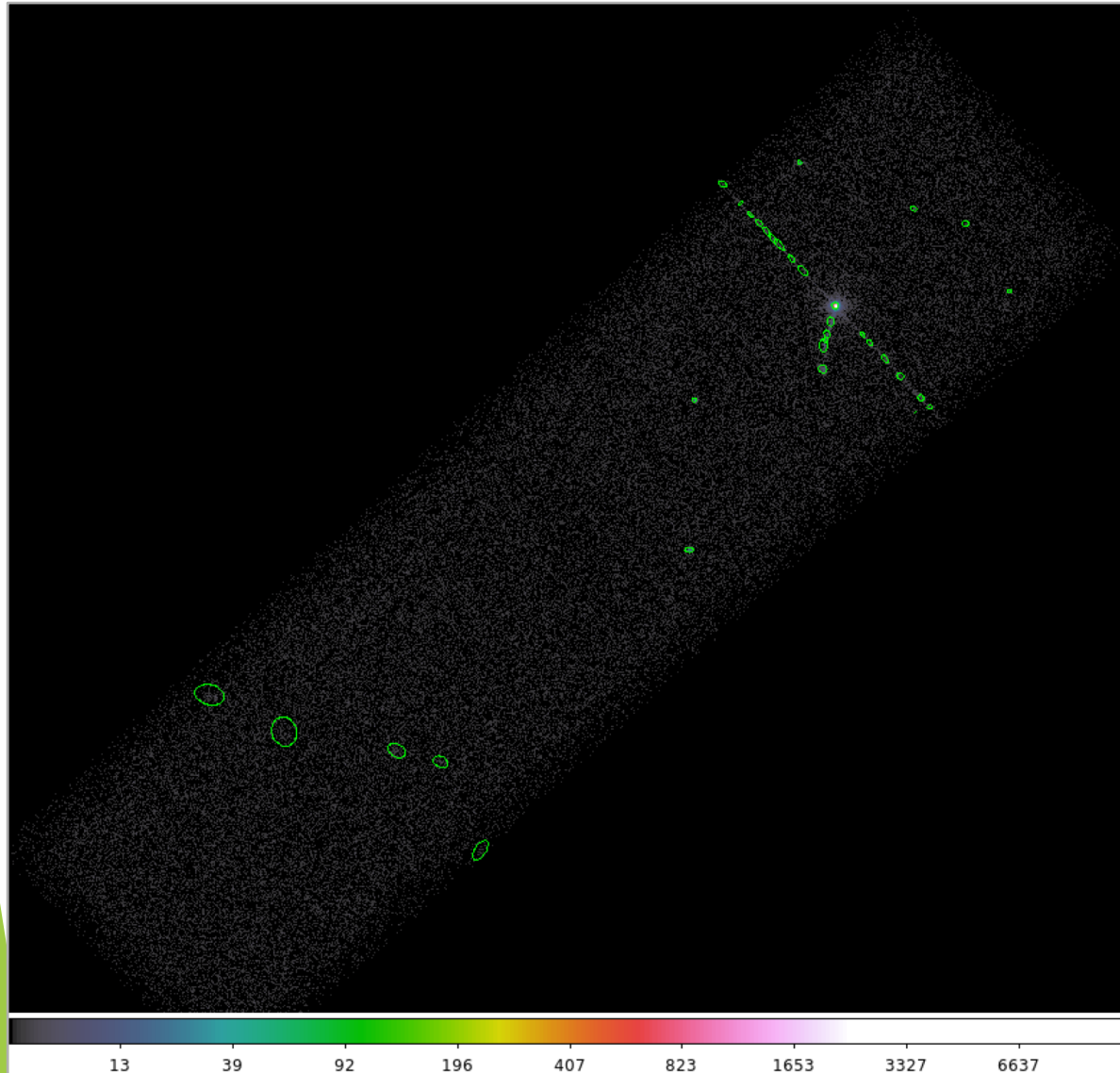
set of wavelet scales

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





# 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% dmlist 7302_src.fits cols
```

```
-----  
Columns for Table Block SRCLIST
```

ColNo	Name	Unit	Type	Range	
1	RA	deg	Real8	0: 360.0	Source Right Ascension
2	DEC	deg	Real8	-90.0: 90.0	Source Declination
3	RA_ERR	deg	Real8	-Inf:+Inf	Source Right Ascension Err
4	DEC_ERR	deg	Real8	-Inf:+Inf	Source Declination Error
5	POS(X,Y)	pixel	Real8	3386.50: 4354.50	Physical coordinates
6	X_ERR	pixel	Real8	-Inf:+Inf	Source X position error
7	Y_ERR	pixel	Real8	-Inf:+Inf	Source Y position error
8	NPIXSOU	pixel	Int4	-	pixels in source region
9	NET_COUNTS	count	Real4	-Inf:+Inf	Net source counts
10	NET_COUNTS_ERR	count	Real4	-Inf:+Inf	Error in net source counts
11	BKG_COUNTS	count	Real4	-Inf:+Inf	Background counts
12	BKG_COUNTS_ERR	count	Real4	-Inf:+Inf	Error in BKG_COUNTS

```
. . . MORE INFO . . .
```

# Source Detection (cont.)

## by way of wavdetect

- ▶ Wavelets are correlated with data image at each scale size.

- ▶ scales are the radii of the Ricker (aka “Mexican Hat”) 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  $\sqrt{2}$

- ▶ `sigthresh` parameter is the threshold that a pixel belongs to a source.

- ▶ 
$$\text{sigthresh} \approx \frac{1}{\text{number of image pixels}}$$

- ▶ `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

```
unix% dmlist flux/7302_broad_thresh.img blocks
```

```
-----  
Dataset: flux/7302_broad_thresh.img  
-----
```

	Block Name	Type	Dimensions
Block	1: EVENTS_IMAGE	Image	Int4(968x926)

```
unix% python -c 'print(1/(968*926))'  
1.1156132302804205e-06
```

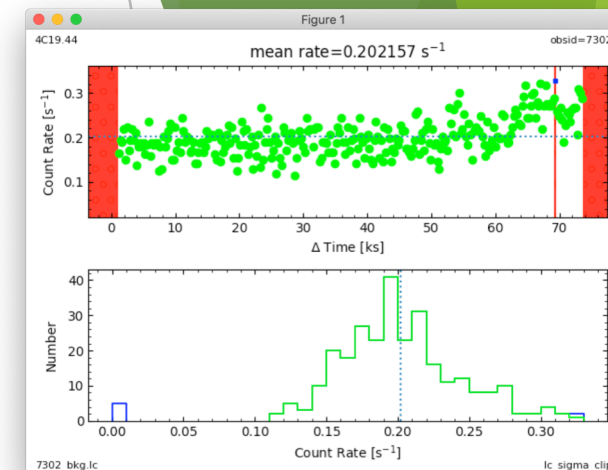






# Finding background flares

- ▶ The `deflare` script is a command-line interface to the `lightcurves` Python module to apply the `lc_clean` and `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% dmcopu 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
```

- ▶ run `deflare`

```
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

```
unix% dmcopu "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  $\Rightarrow$  less source counts
  - ▶ longer exposure time  $\Rightarrow$  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?

