CHANDRA X-RAY OBSERVATORY

CIAO Analysis

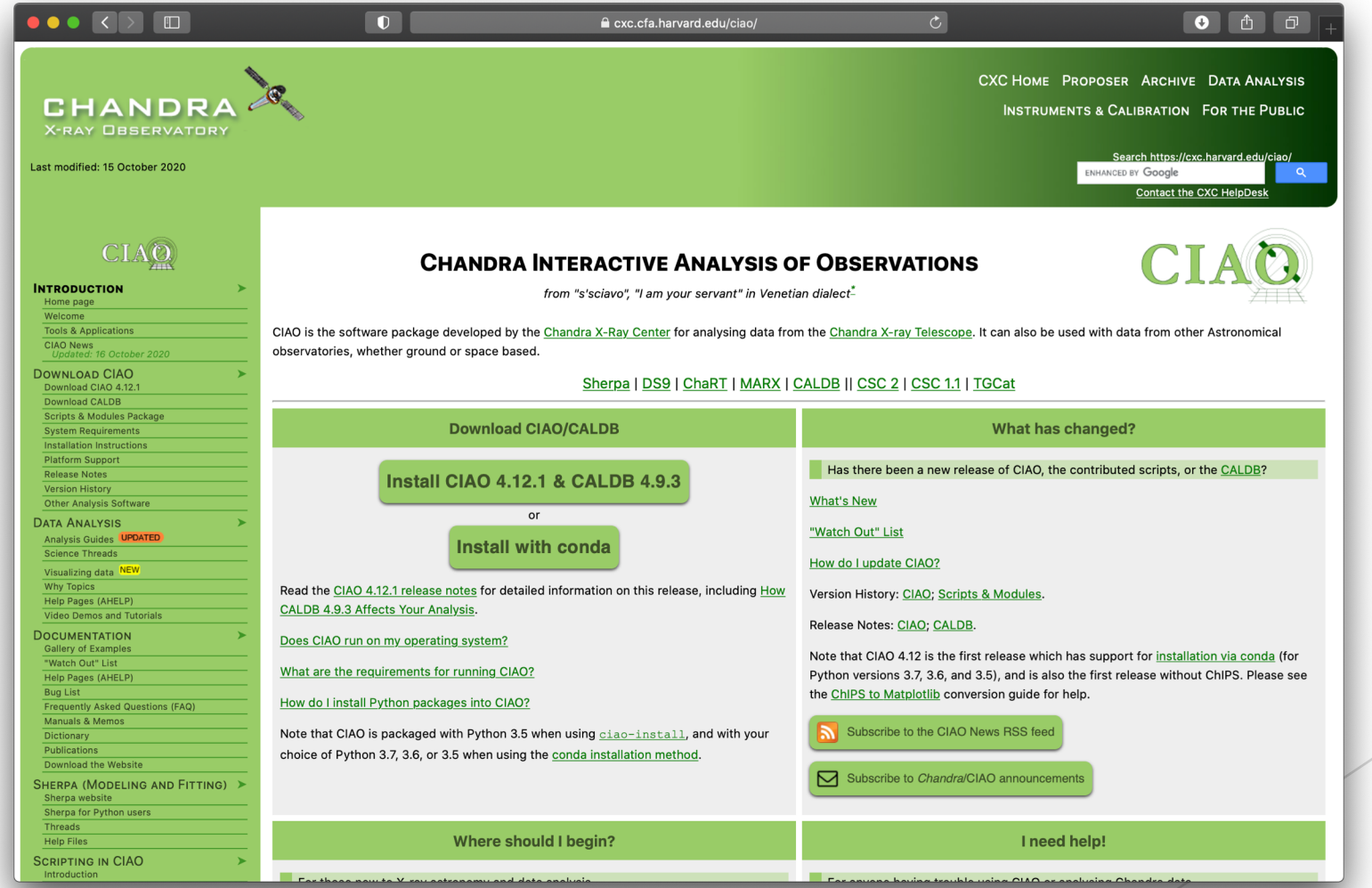
getting help, obtaining data, and data preparation basics

Nicholas Lee
Center for Astrophysics | Harvard & Smithsonian
Chandra X-ray Center—Science Data Systems

The Fifth ArAS School for Astrophysics—Chandra/CIAO Workshop, October 19-21, 2020

CENTER FOR ASTROPHYSICS HARVARD & SMITHSONIAN

First, a quick detour on documentation and getting 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.).

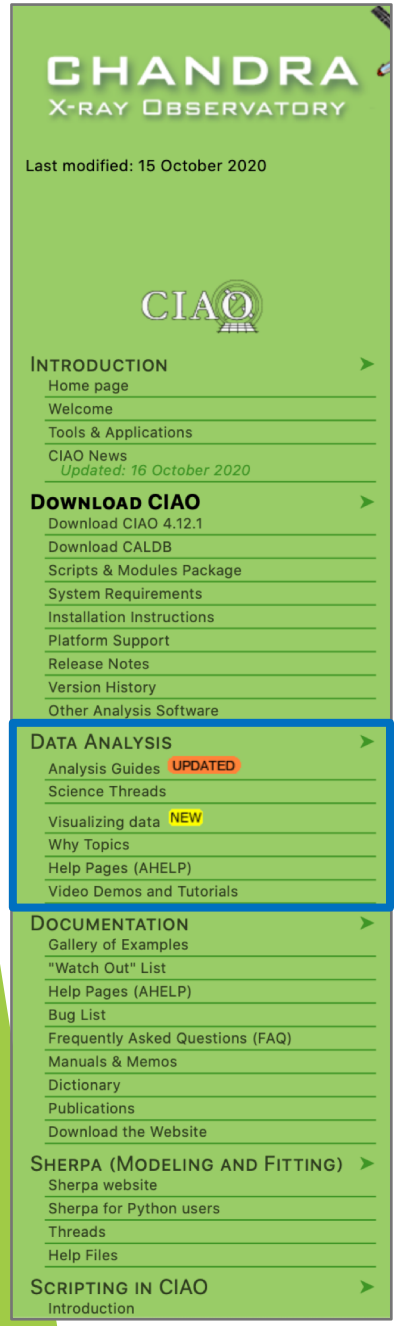
```
unix% ahelp <toolname>
unix% ahelp <context>
unix% ahelp -c
```

- 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.

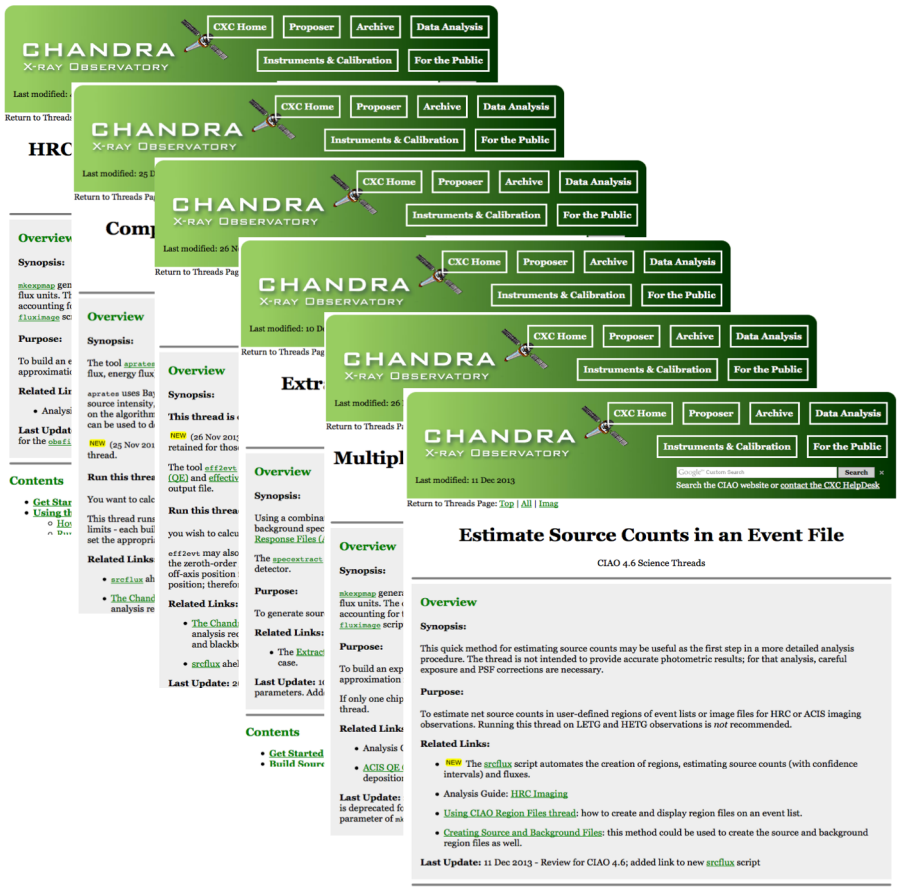
```
unix% dmextract
Input event file  (): ?
```



Science Analysis "Threads"

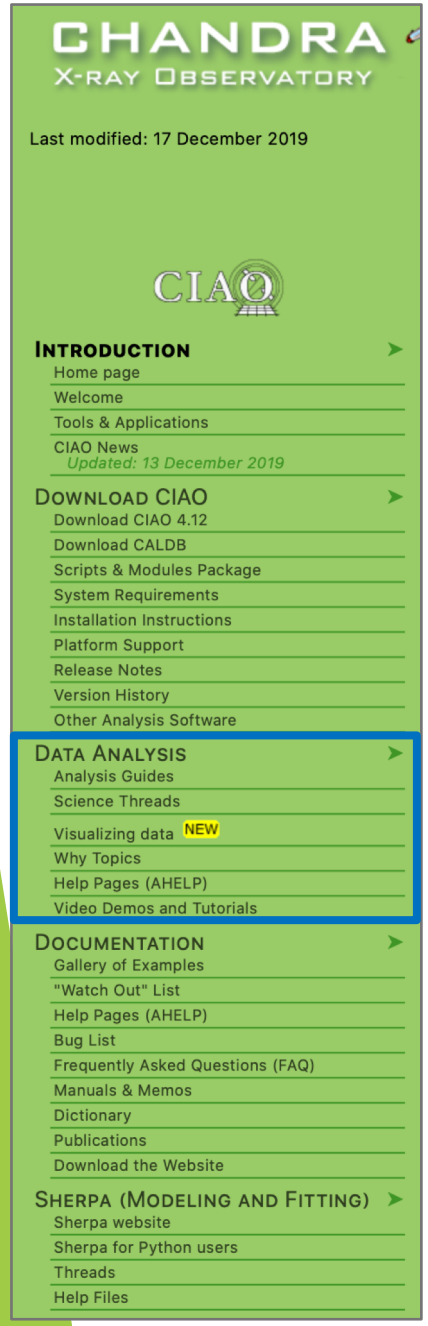
- Science Threads are the most important document type. Primarily organized based on science analysis categories.
  - over 150 CIAO and Sherpa threads, designed to teach users the approach and concerns that go along with analysis
  - all threads begin with a "quick overview" to provide a synopsis, purpose, 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; `ahelps` 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.

→ `srcflux` script

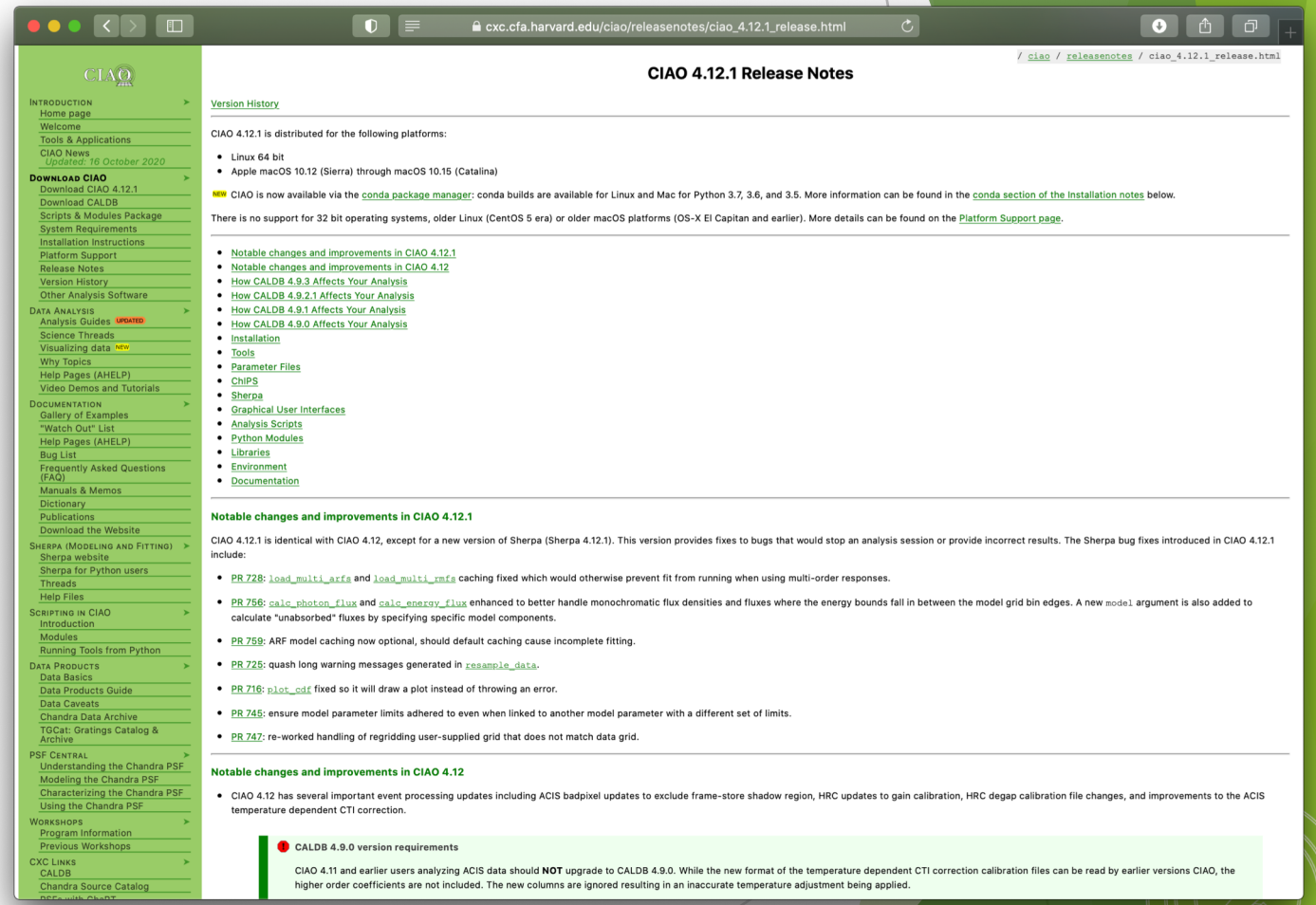


"Guides" and "Why" Pages

- 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

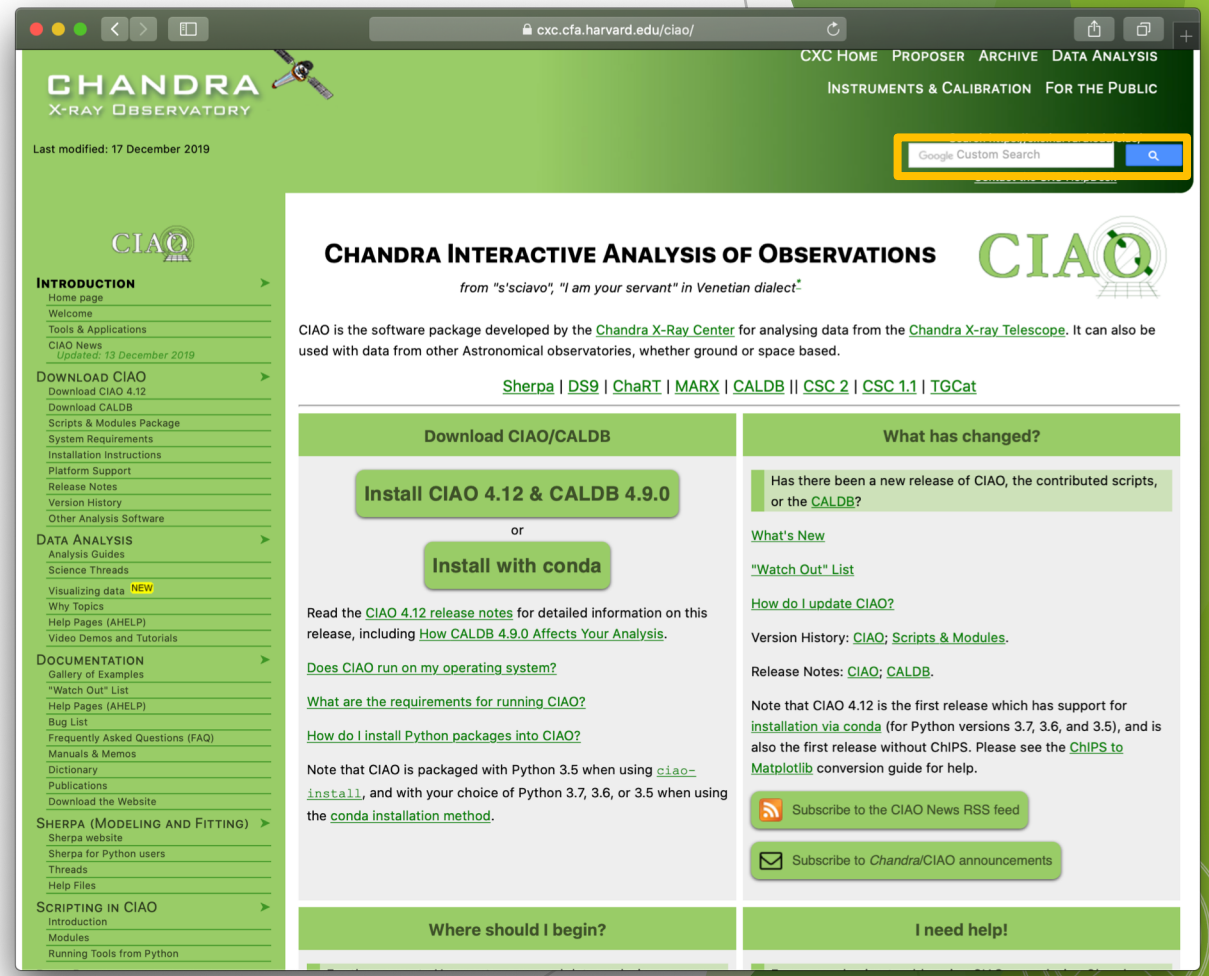
- CIAO release notes are revised whenever a new version or patch of a package is updated.
- CalDB components are updated periodically, but will vary from one release to the next.
  - categorized by detector and instrument configuration
  - describes files changed and affects on tools, analysis type, 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: `cxc.harvard.edu/caldb`
- Details of changes to contributed scripts can be seen at: `cxc.harvard.edu/ciao/download/scripts/history.html`



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 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



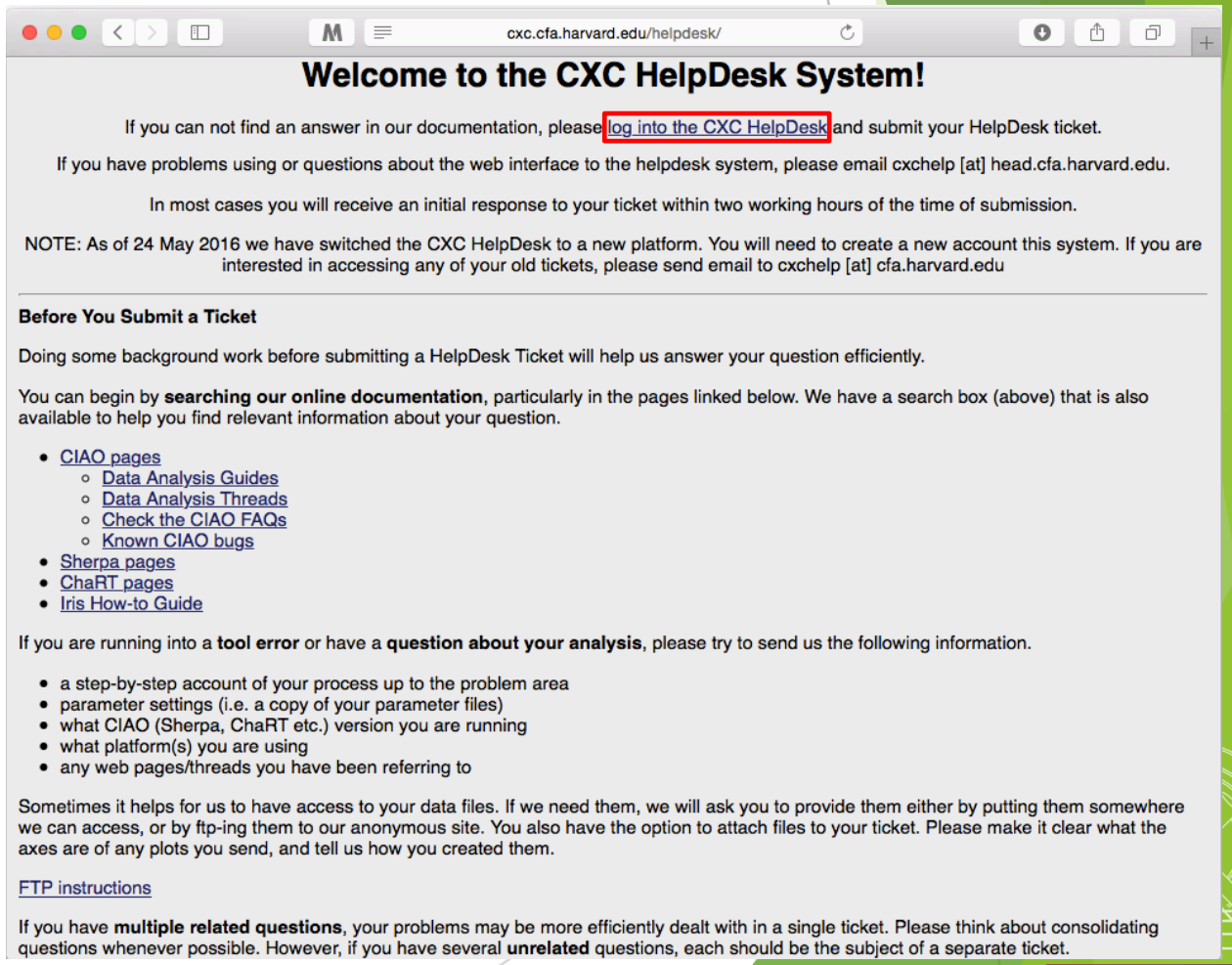
CHANDRA X-RAY OBSERVATORY

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
  - 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



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

CHANDRA X-RAY OBSERVATORY

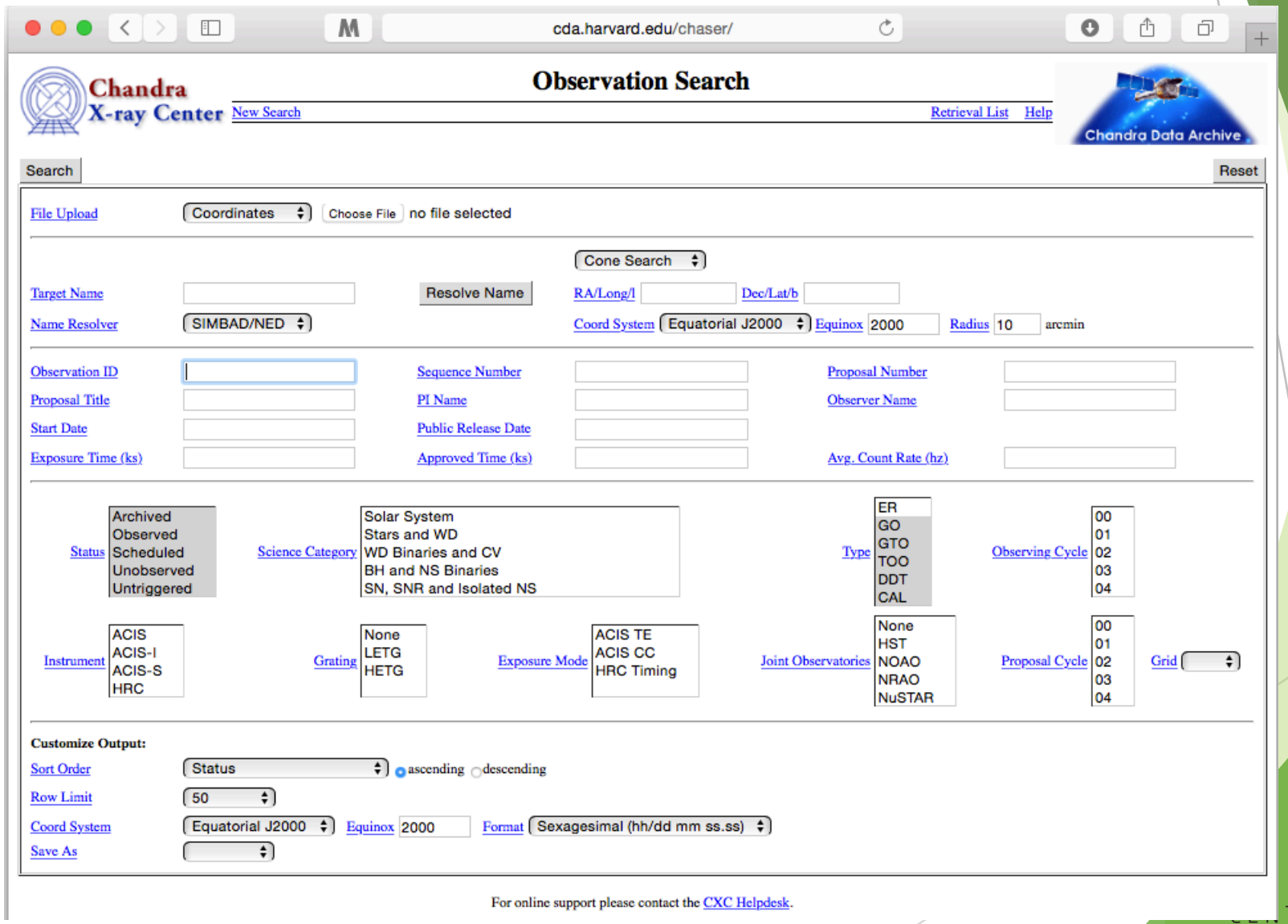
The *Chandra* Data Archive

cxc.harvard.edu/cda

CENTER FOR ASTROPHYSICS HARVARD & SMITHSONIAN

ChaSeR: *Chandra* Search and Retrieval System

cda.harvard.edu/chaser



ChaSeR: *Chandra* Search and Retrieval System

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 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

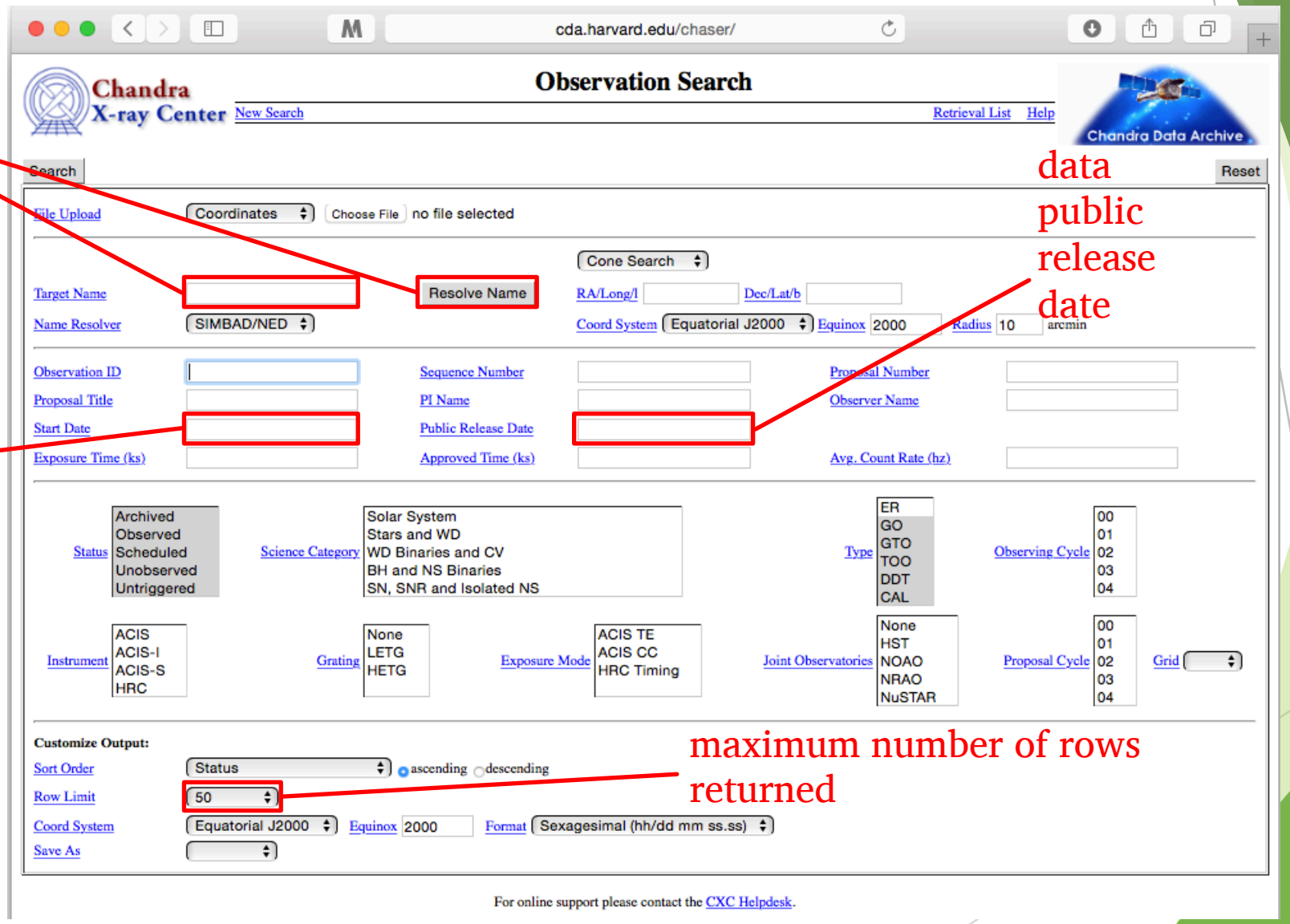
ChaSeR (continued)

source name and name resolver

observation start date

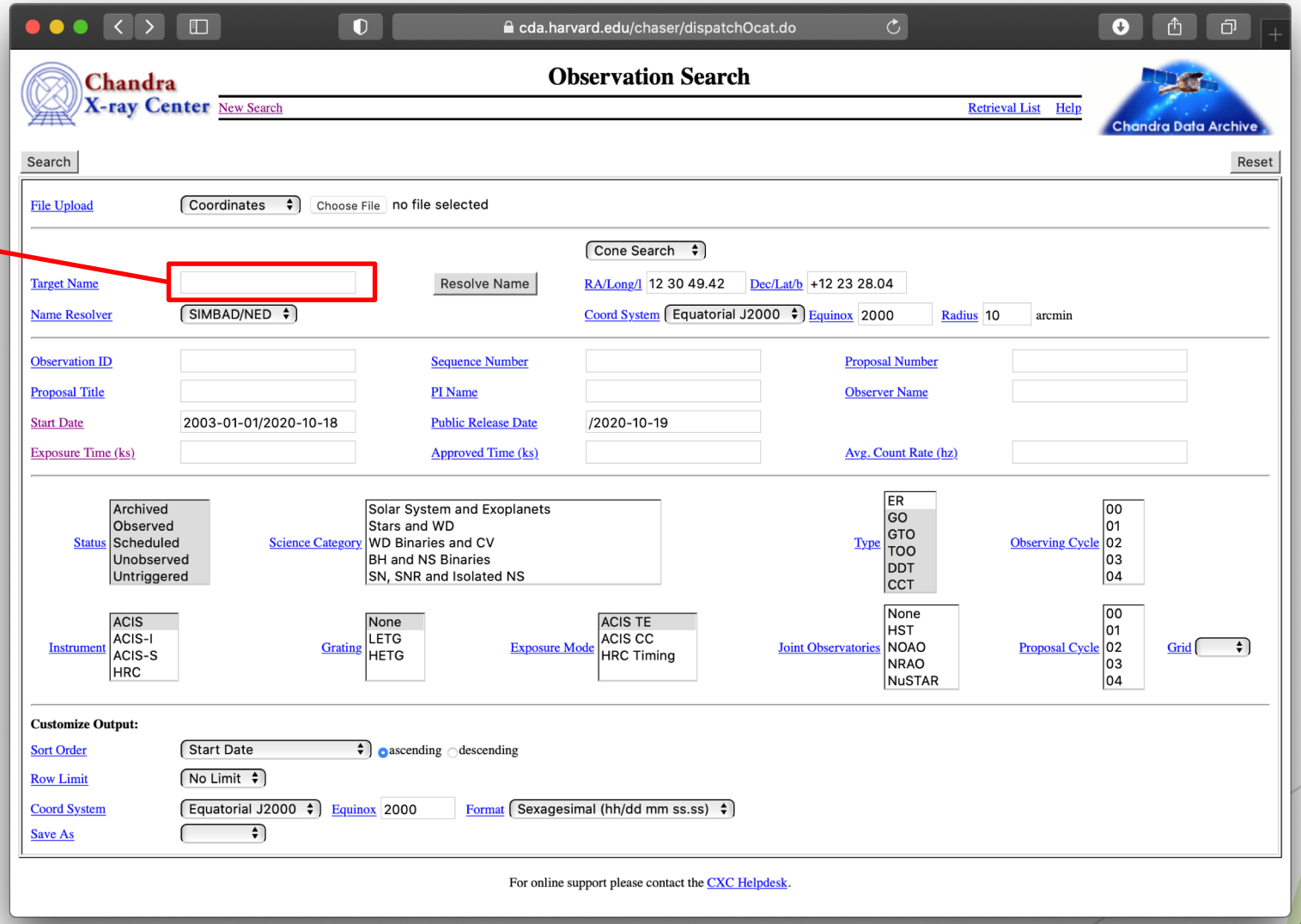
data public release date

maximum number of rows returned

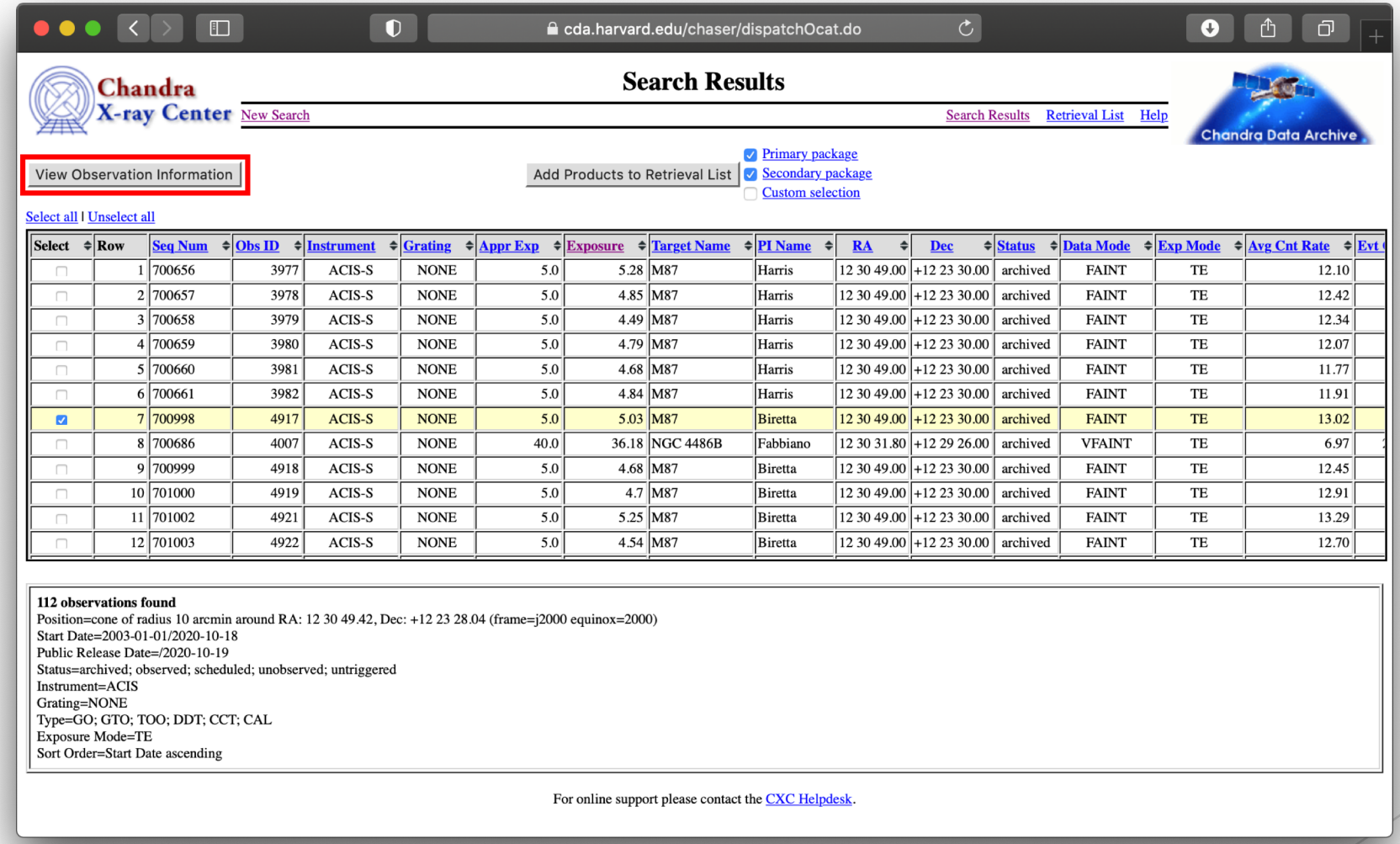


ChaSeR (continued)

M87



ChaSeR Query Results



cda.harvard.edu/chaser/dispatchOcat.do

Chandra X-ray Center

Search Results

New Search | Search Results | Retrieval List | Help

Chandra Data Archive

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
☐	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	
☐	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	
☐	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	
☐	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	
☐	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	
☐	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	
☑	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	
☐	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	
☐	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	
☐	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	
☐	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	
☐	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	

112 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=2003-01-01/2020-10-18
Public Release Date=/2020-10-19
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.

CHANDRA X-RAY OBSERVATORY

CENTER FOR ASTROPHYSICS HARVARD & SMITHSONIAN

ChaSeR ObsID Entry

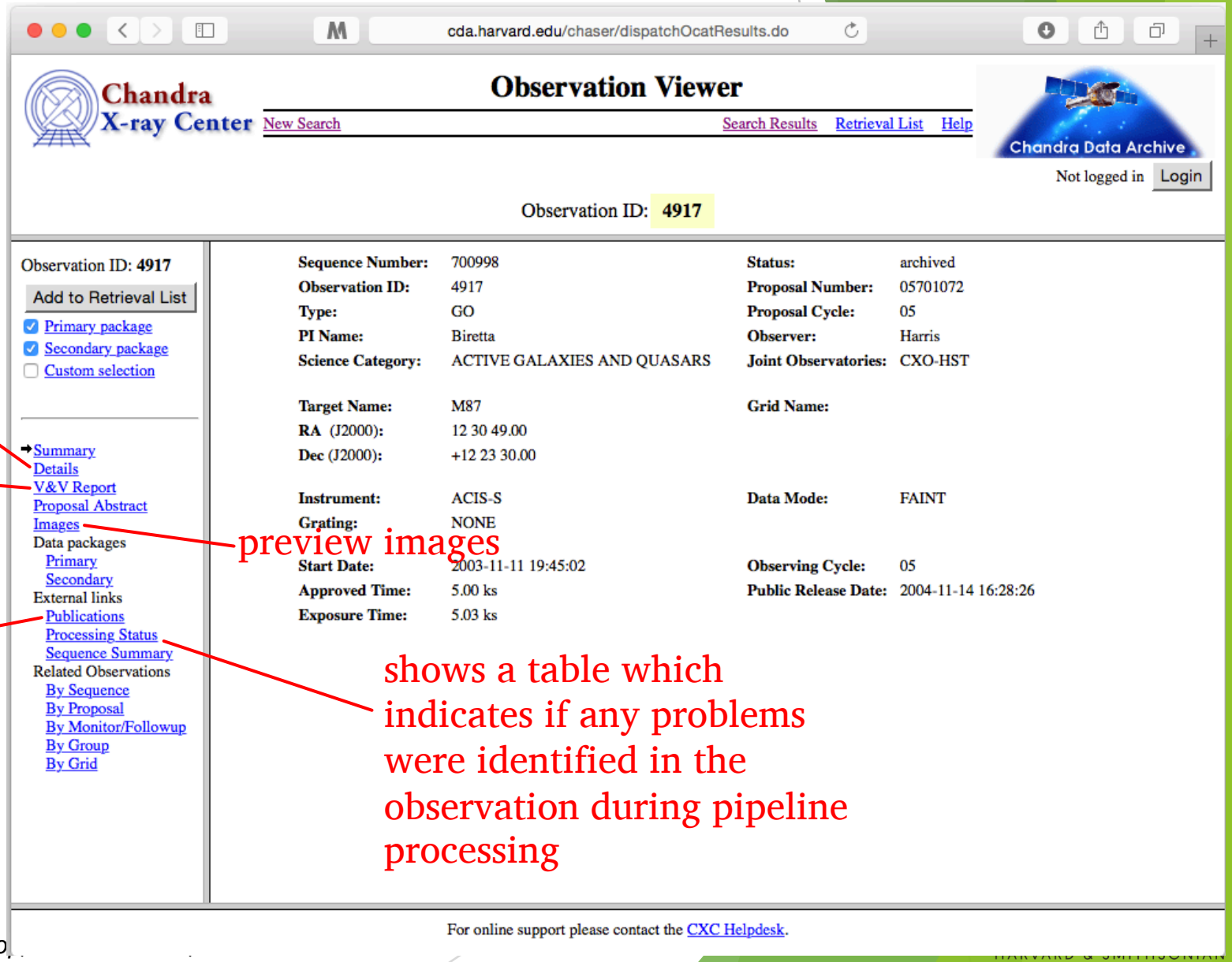
details of the instrument configuration for the observation

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

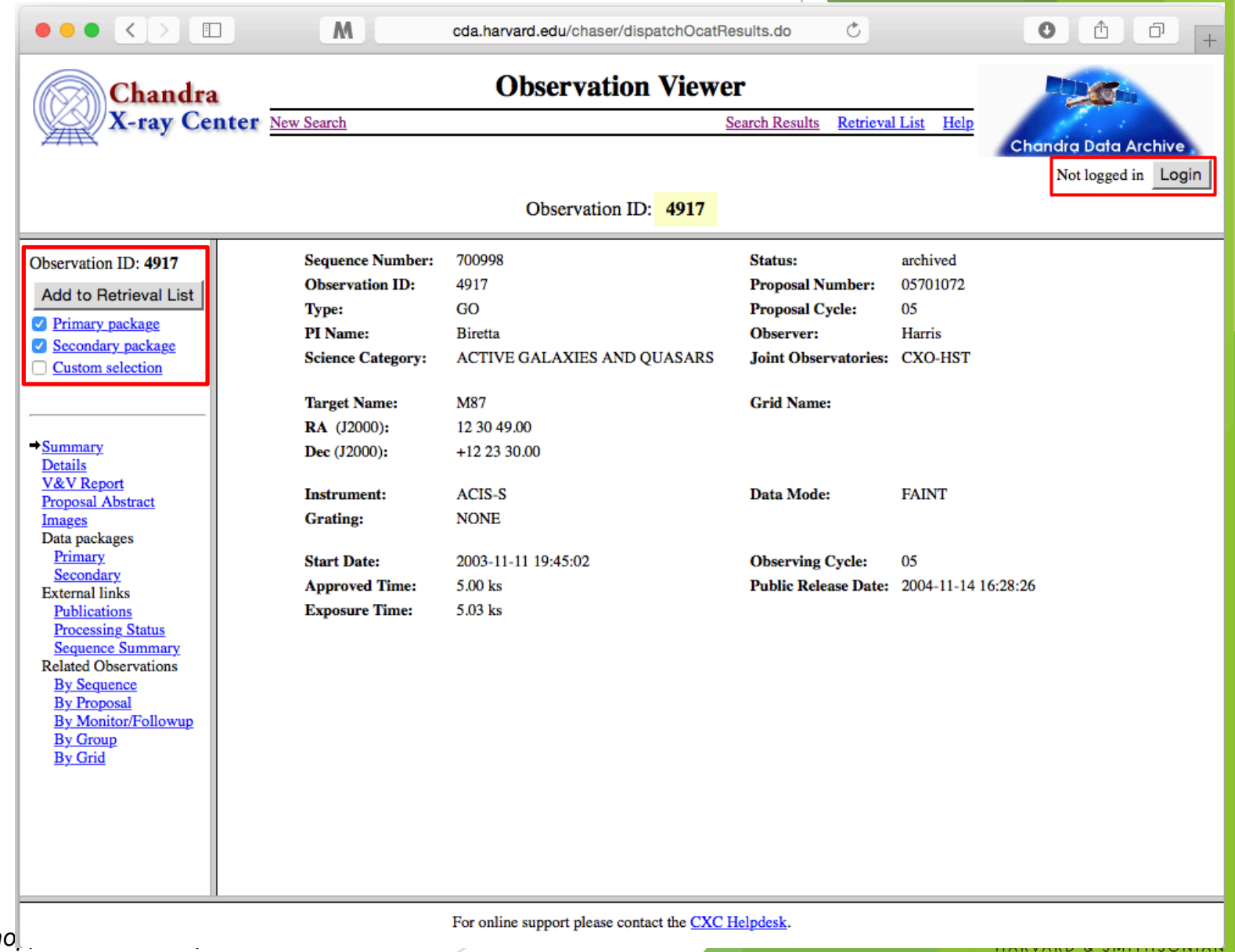
preview images

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`



Beyond ChaSeR:
find_chandra_obsid

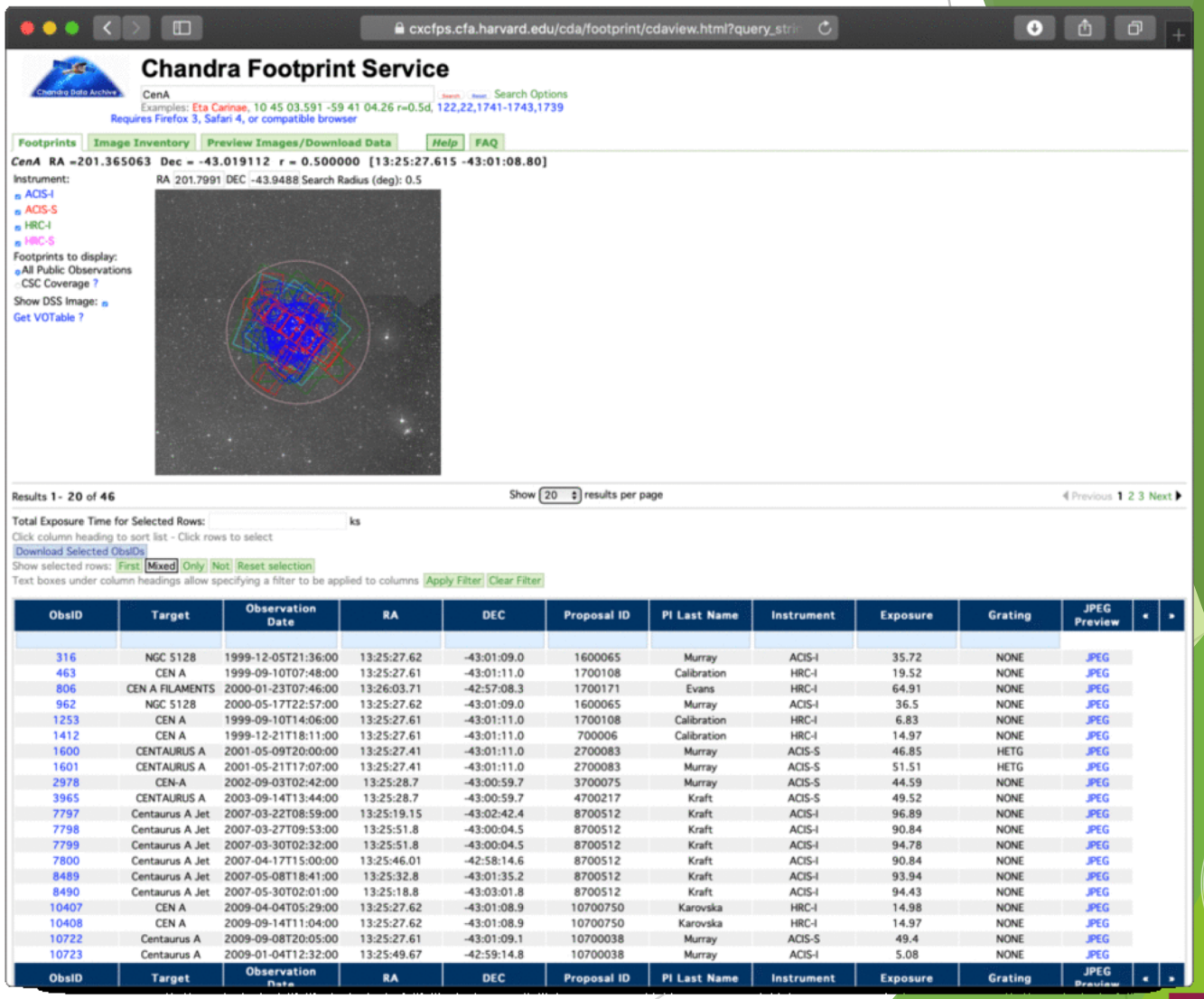
```
unix% find_chandra_obsid 4C19.44
# obsid  sepn   inst grat   time    obsdate   piname   target
2140       0.0 ACIS-S NONE    9.1 2001-01-08 Sambruna 1354+195
6903       0.1 ACIS-S NONE   43.7 2006-04-01   Harris  4C19.44
6904       0.1 ACIS-S NONE   34.8 2006-03-20   Harris  4C19.44
7302       0.1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

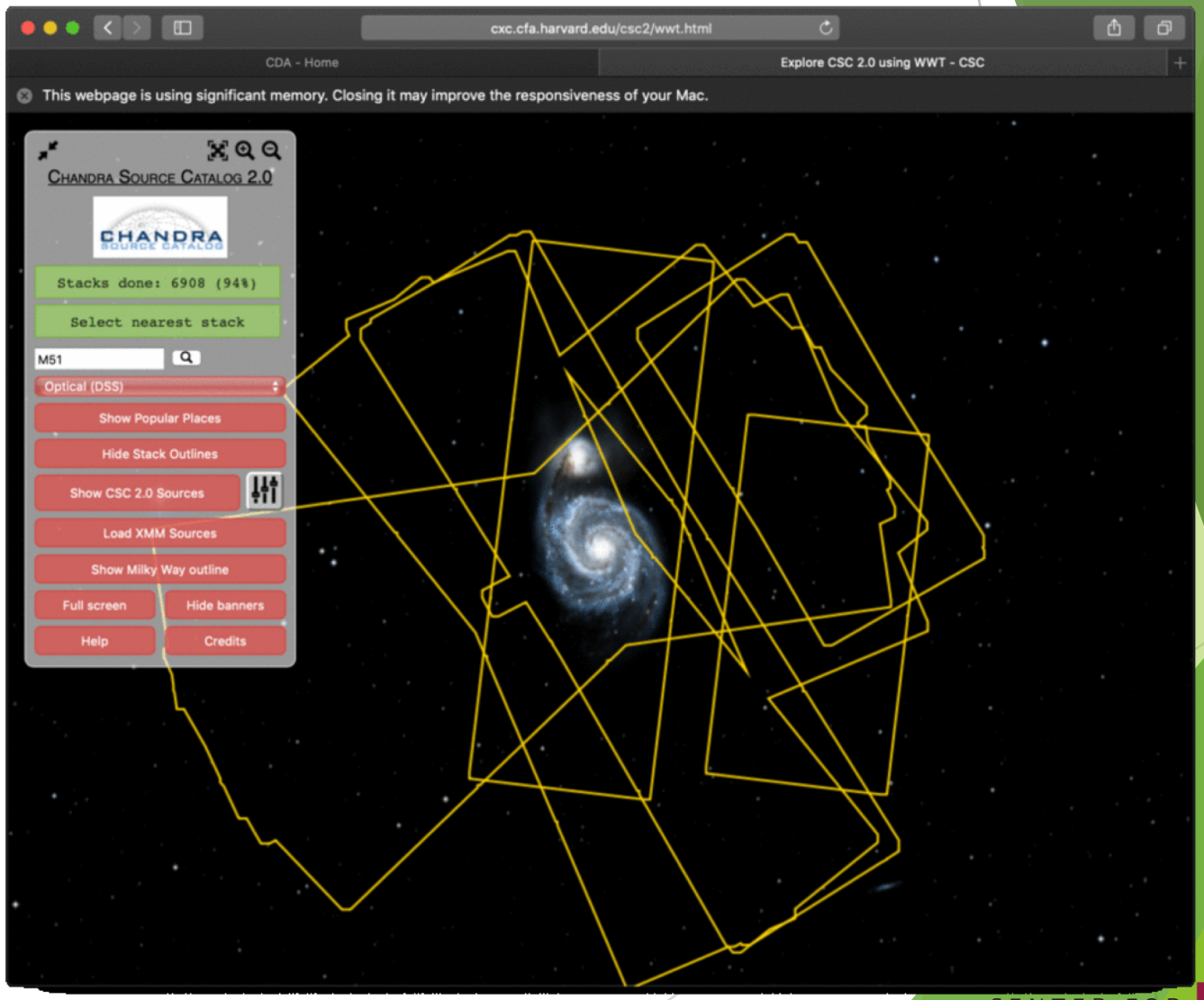
- A search by position or object name overlays the footprints of *Chandra* Observations on Digitized Sky Survey images, allowing further selection and retrieval of observations.



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	Karovska	HRC-I	14.98	NONE	JPEG
10408	CEN A	2009-09-14T11:04:00	13:25:27.62	-43:01:08.9	10700750	Karovska	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
ObsID	Target	Observation Date	RA	DEC	Proposal ID	PI Last Name	Instrument	Exposure	Grating	JPEG Preview

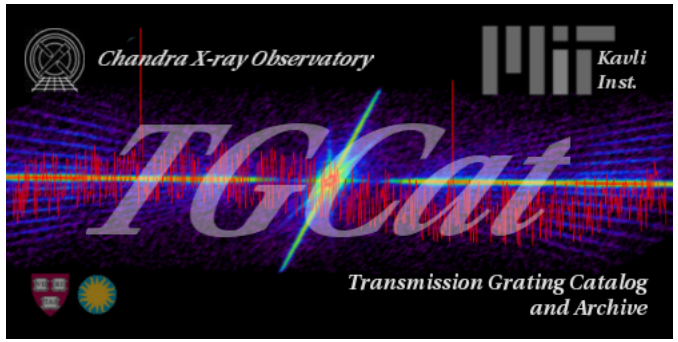
Beyond ChaSeR:
Chandra Source Catalog-Worldwide Telescope
cxc.harvard.edu/csc2/wwt.html

- 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.

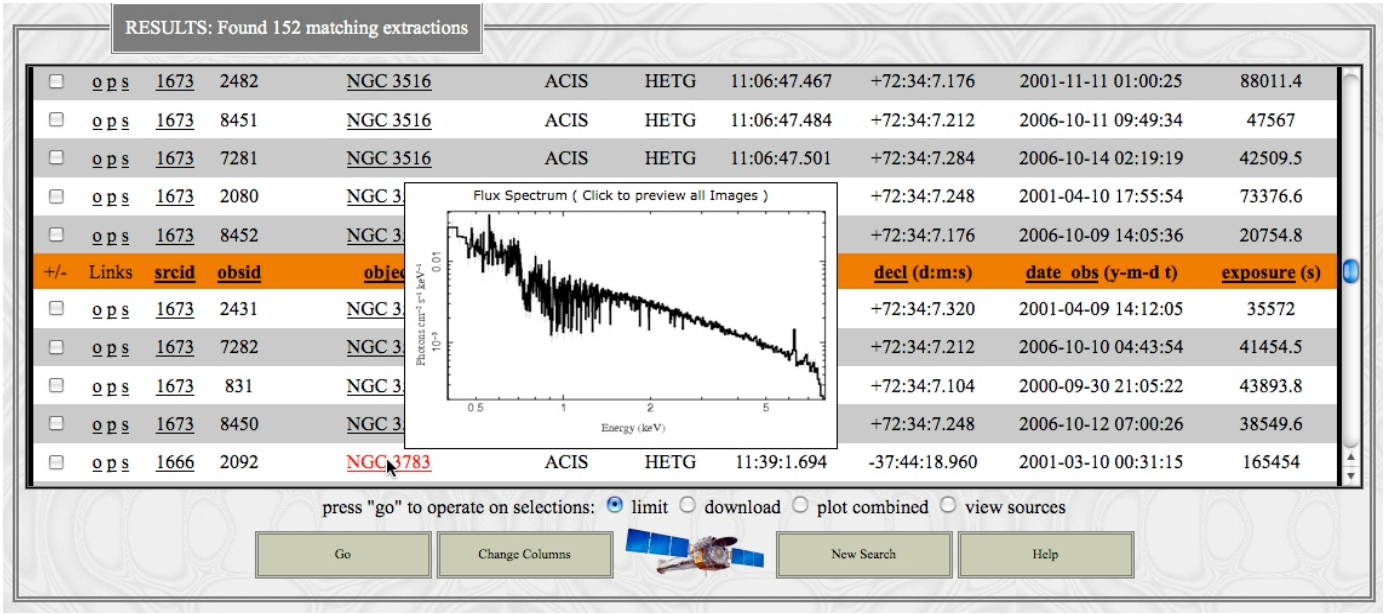


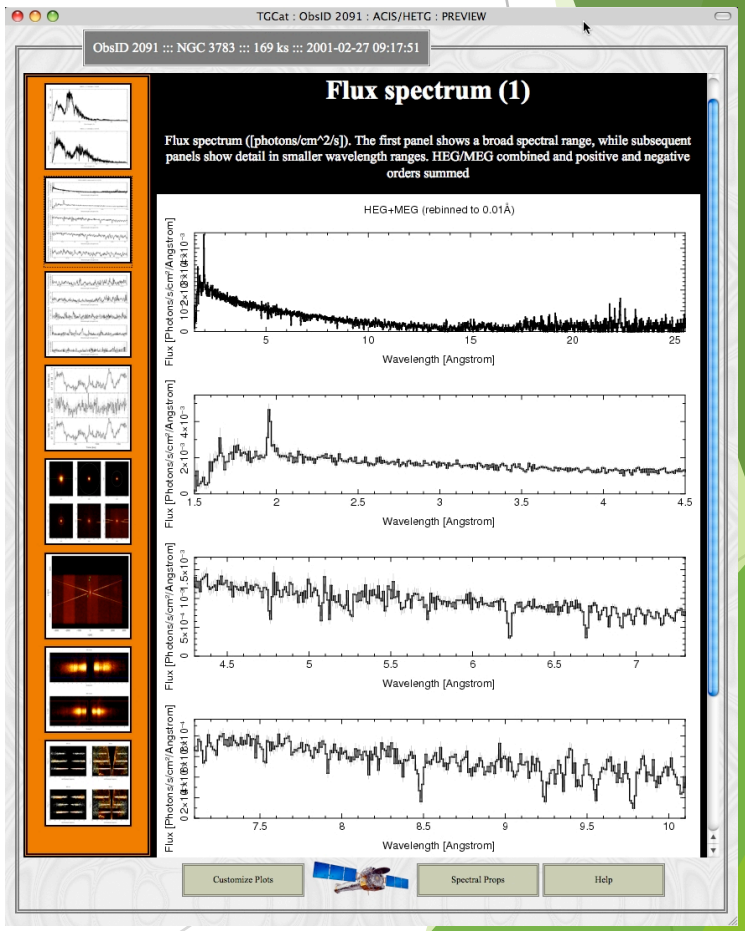
Beyond ChaSeR: TGCat

tgcat.mit.edu



- 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 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.

CHANDRA X-RAY OBSERVATORY

Threads of Analyses

cxc.harvard.edu/ciao/threads

cxc.harvard.edu/sherpa/threads

CENTER FOR ASTROPHYSICS HARVARD & SMITHSONIAN

Analyses:

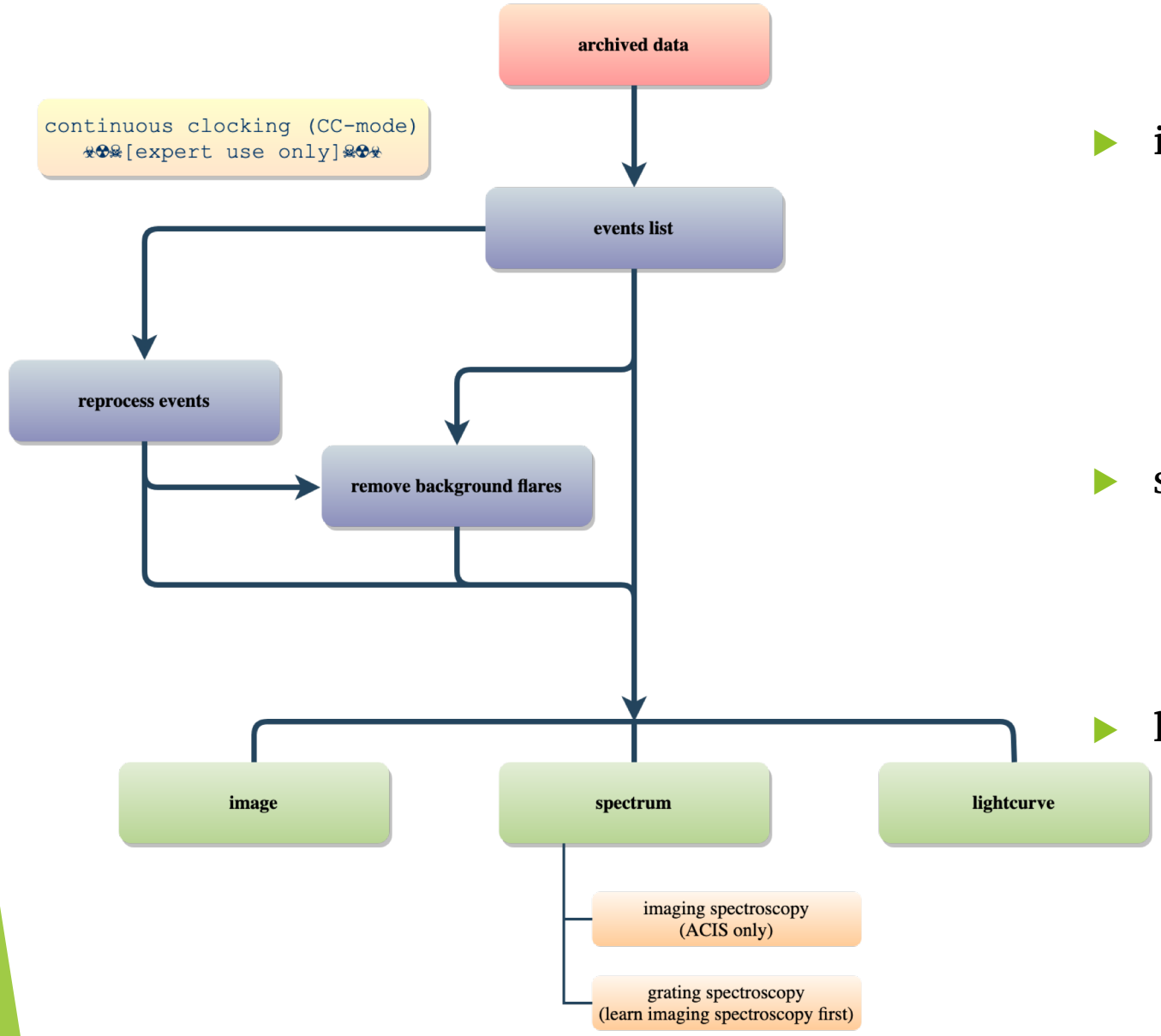
- The data contained in the events list informs us of the types of data products we can generate.
  - Image—bin on spatial-axes, lose energy and temporal information
  - Spectra—bin on spectral-axis, lose spatial and temporal information
  - Lightcurves—bin on time-axis, lose spatial and energy information
  - 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
```

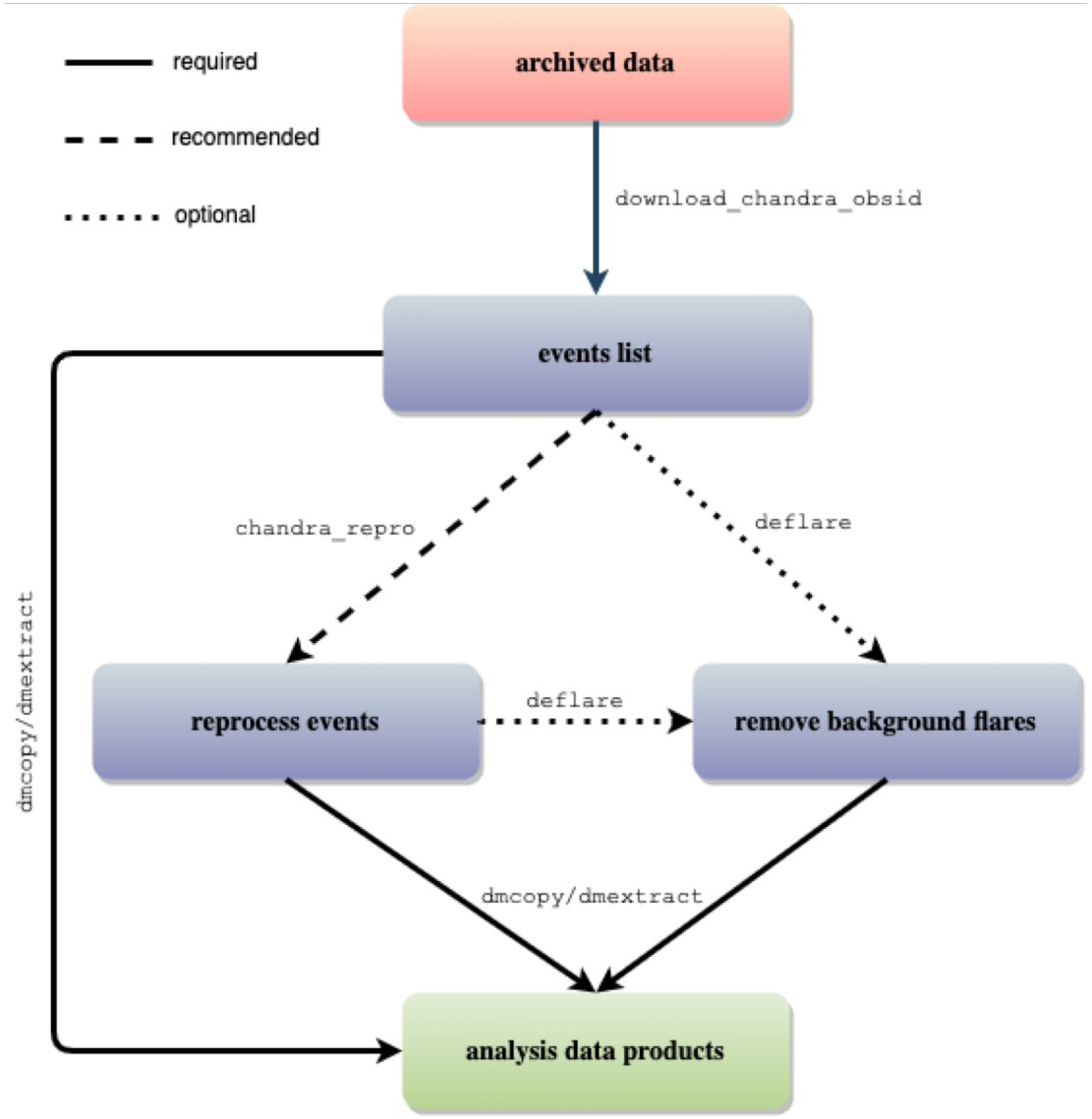
- Example Overview: extract and fit a spectrum
  - download data
  - exclude serendipitous field sources and find periods of flaring background
  - define extraction regions
  - extract spectra and generate response files
  - spectral fitting and source flux

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
```

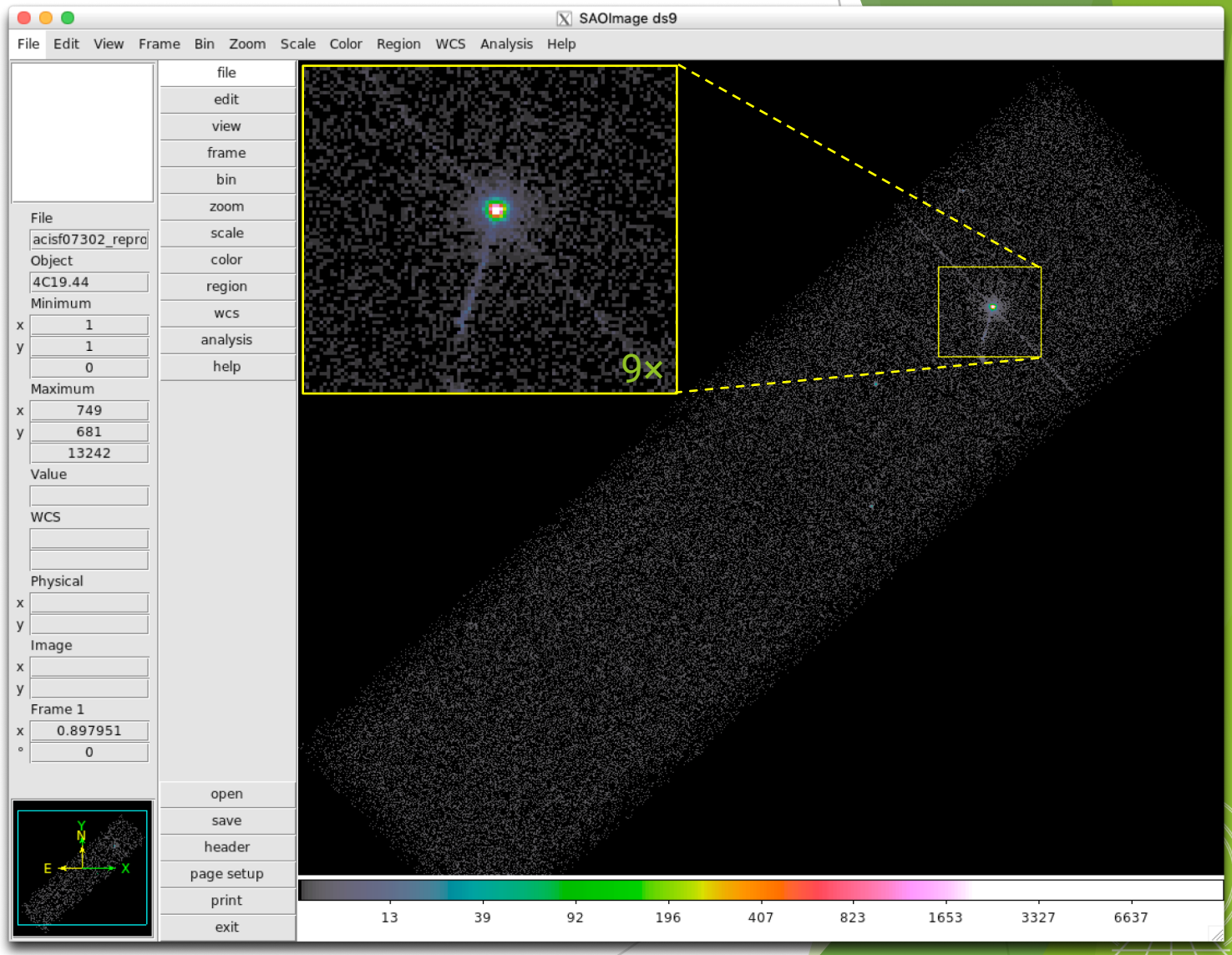
- Latest version of time-dependent gain applied.
- Latest temperature-dependent CTI correction applied.
- Ensures common set of calibration files used.

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

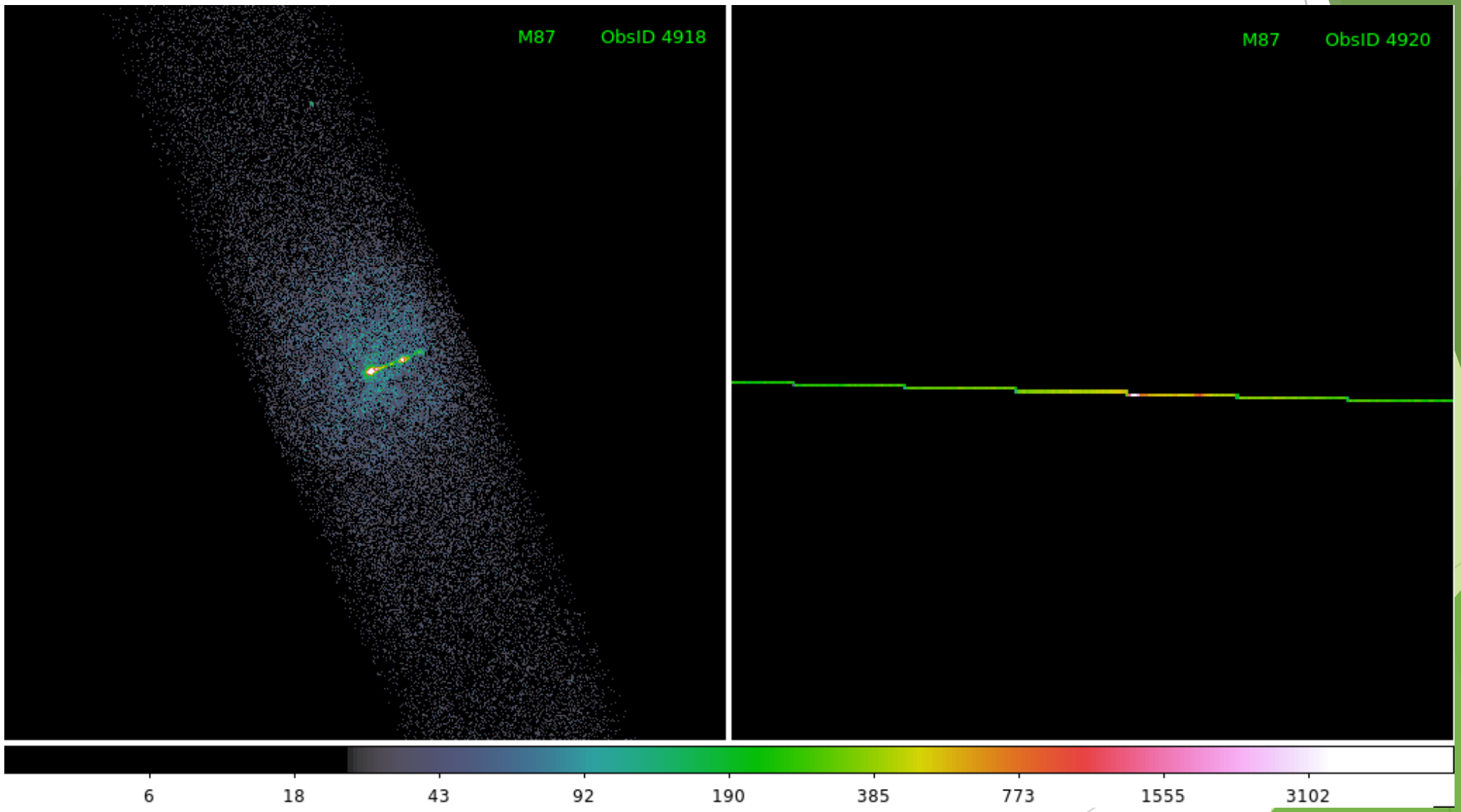
- Can download multiple datasets using a comma-separated string of ObsIDs and specify file types.
- `check_vf_pha` controls whether `acis_process_events` flags potential events near the event island as cosmic rays that are filtered out by the tool.

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

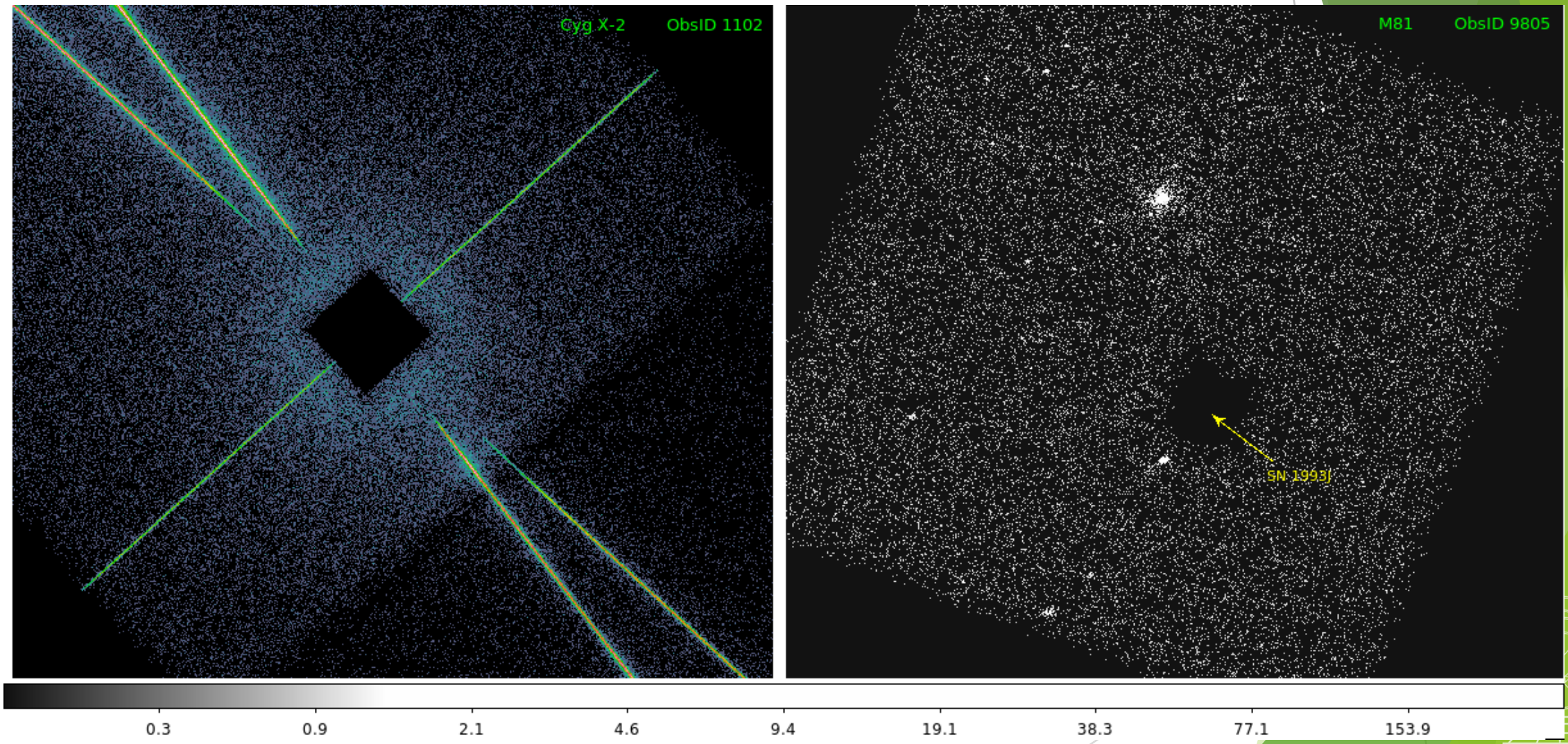


ACIS Continuous-Clocking Mode



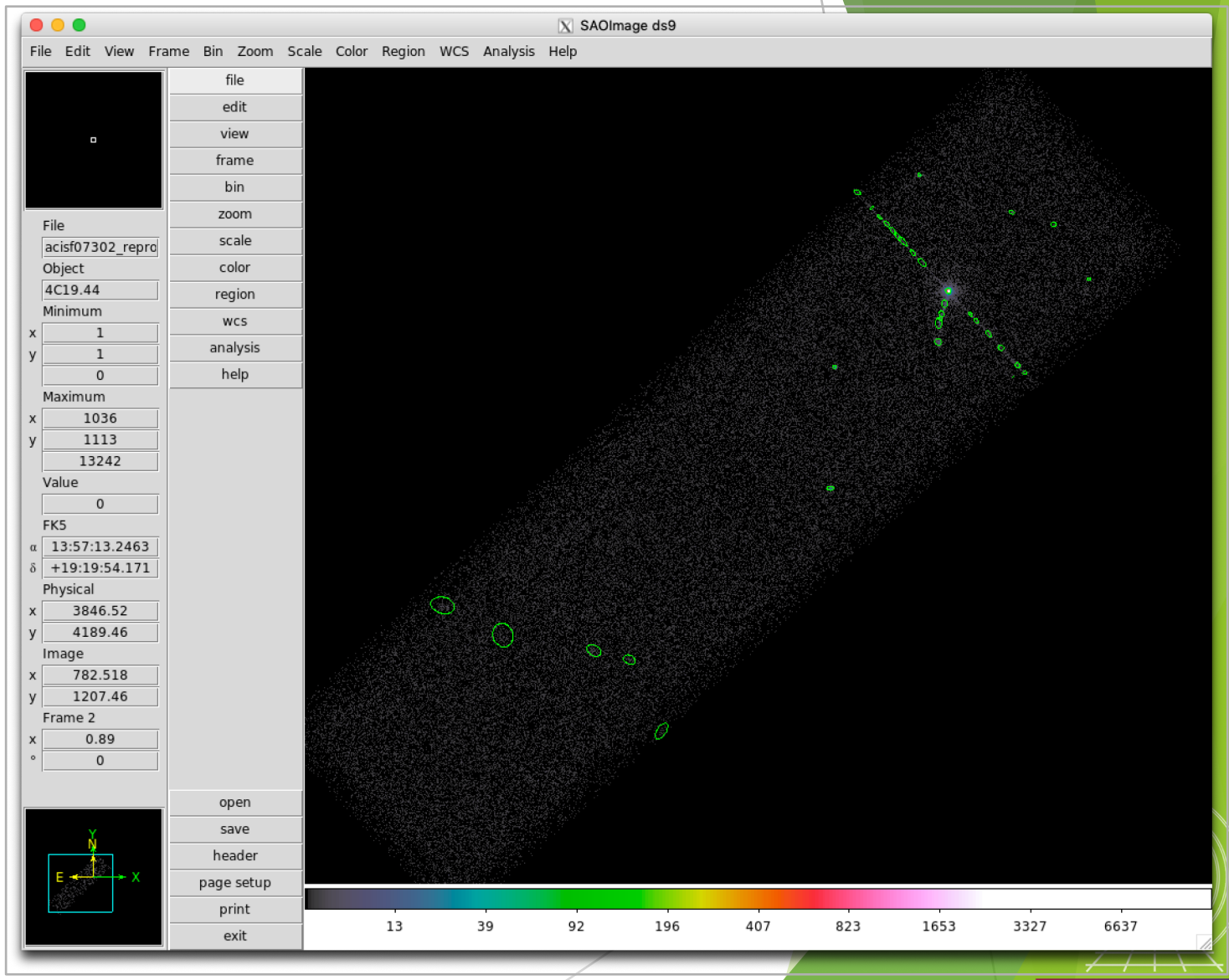
CHANDRA X-RAY OBSERVATORY

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, 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

- 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

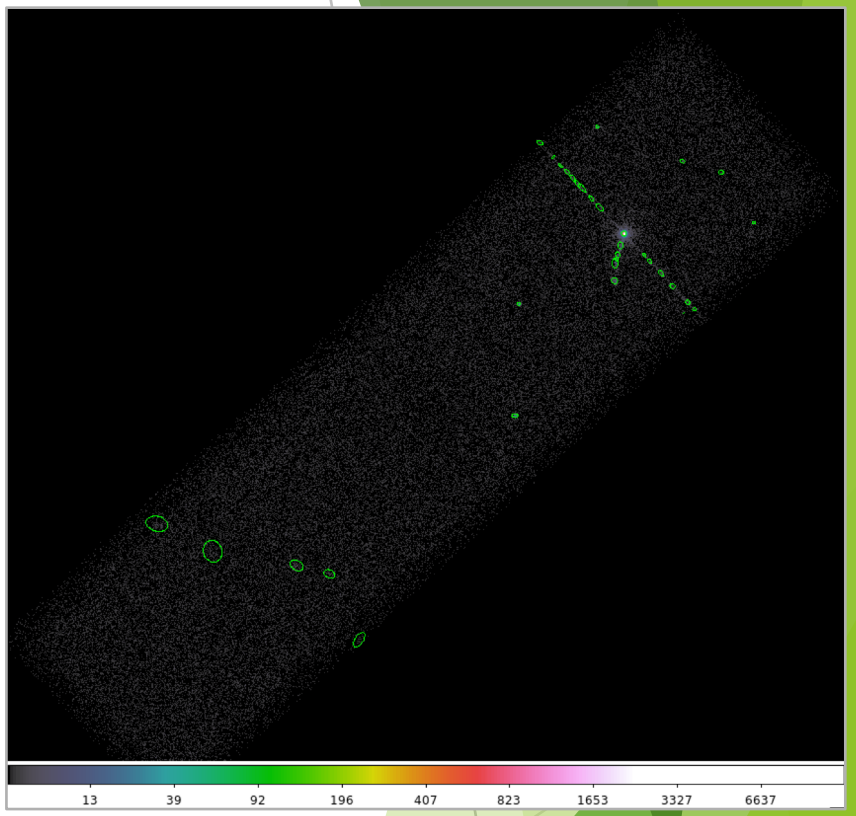
    Pros
    - fast and robust
    - works well for point sources
    - only requires an approximate PSF shape
    - can handle very large images easily

    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.

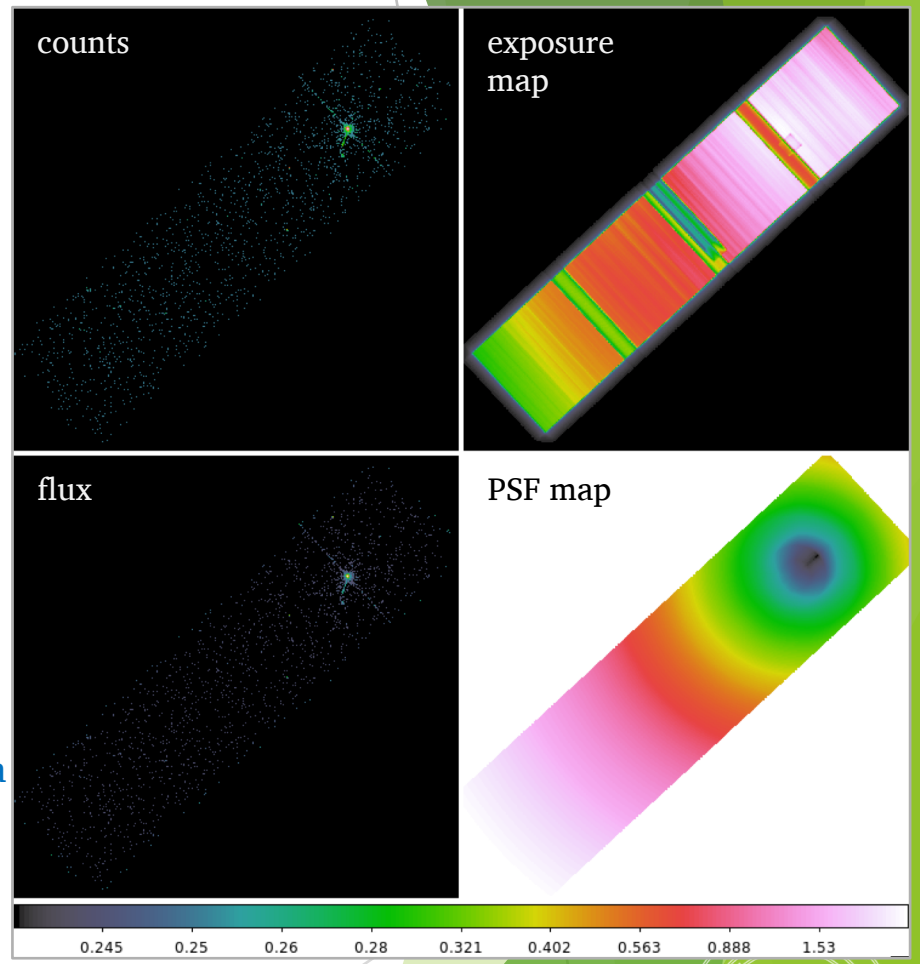
reduces false source detections from detector effects

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 1σ integrated volume of a 2D Gaussian




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

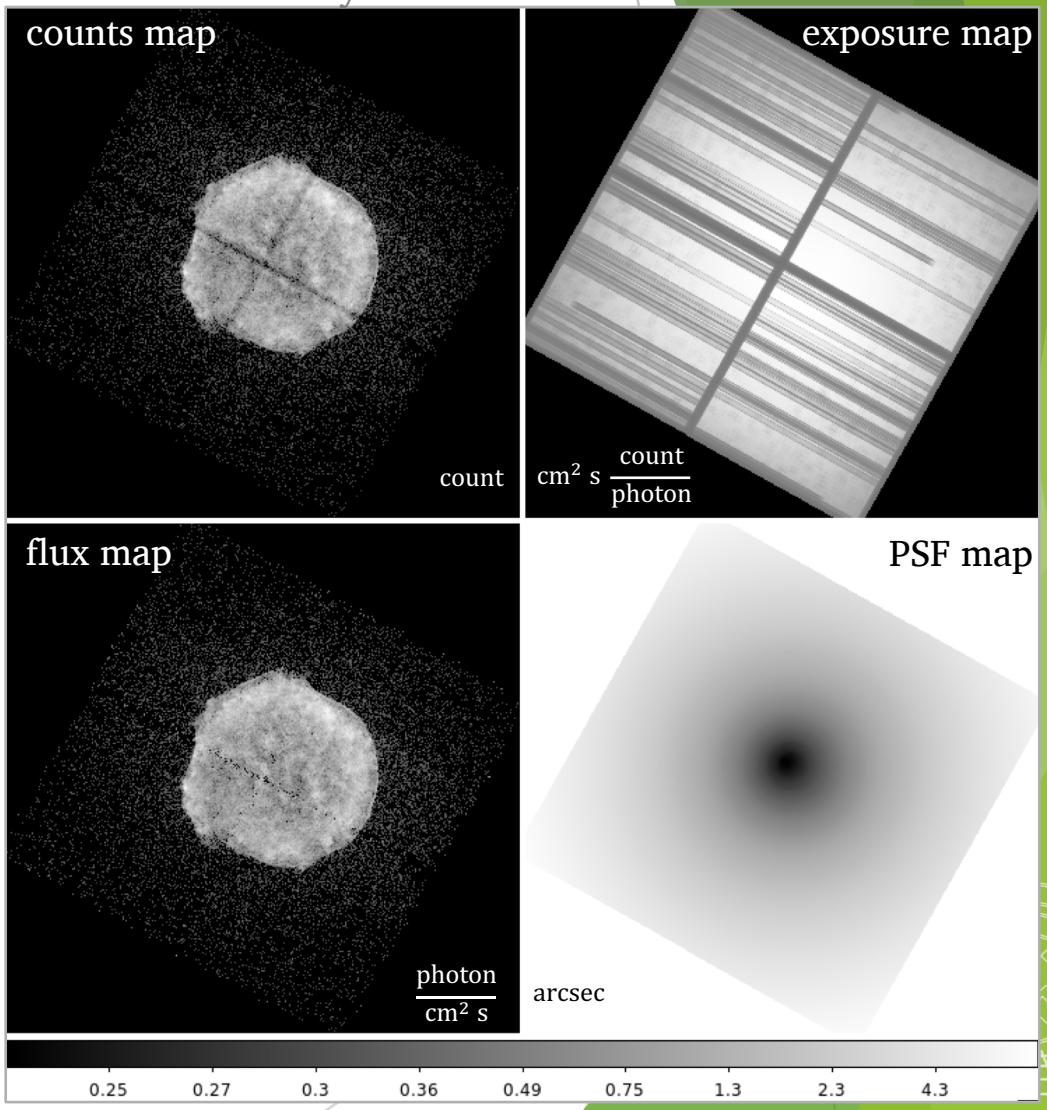
effective energy used for exposure map (2.3 keV for CSC broad band)

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 ardlib
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 $\mathbb{Z}$-valued pixels for valid results

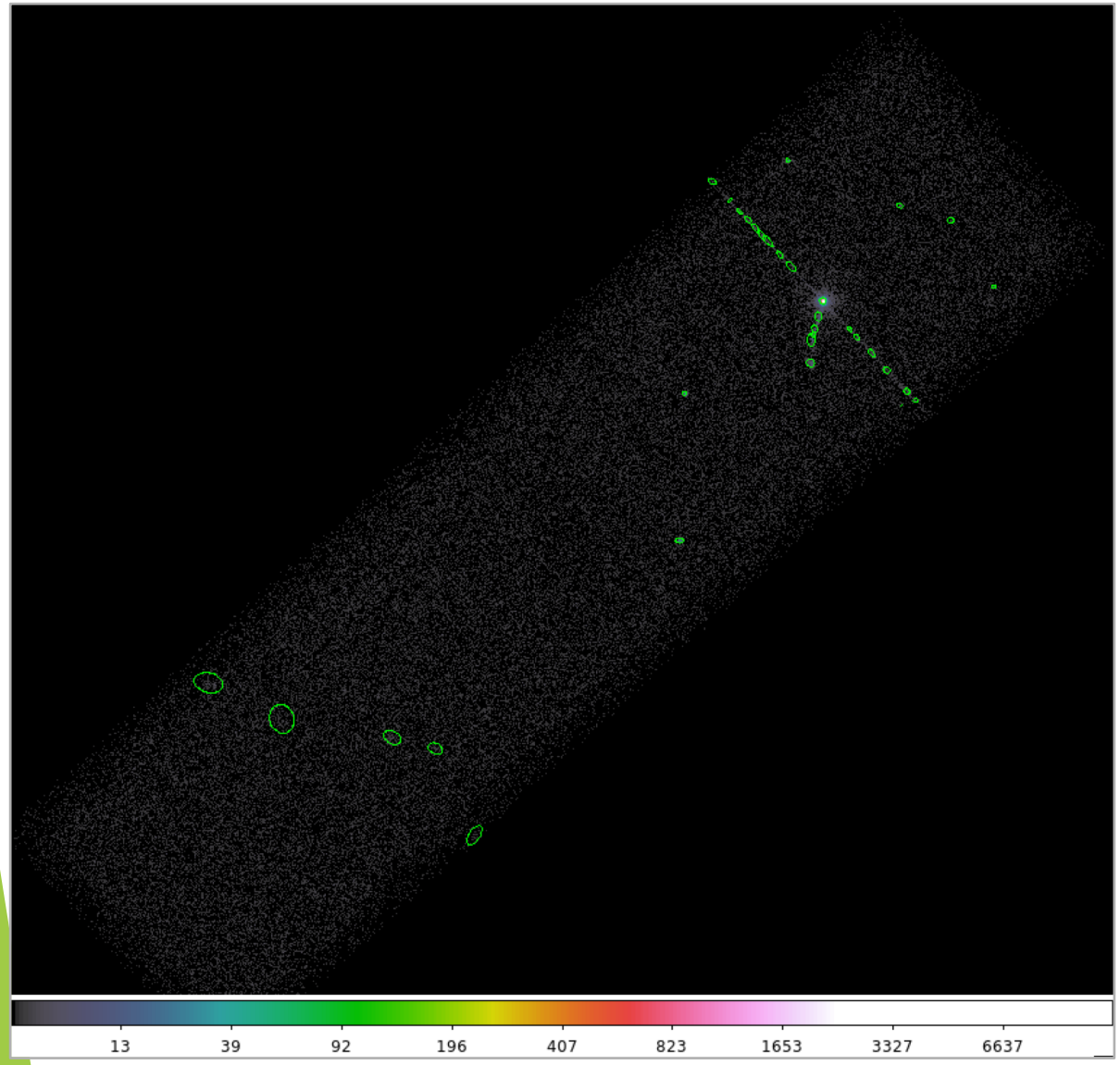
`fluximage` results

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`

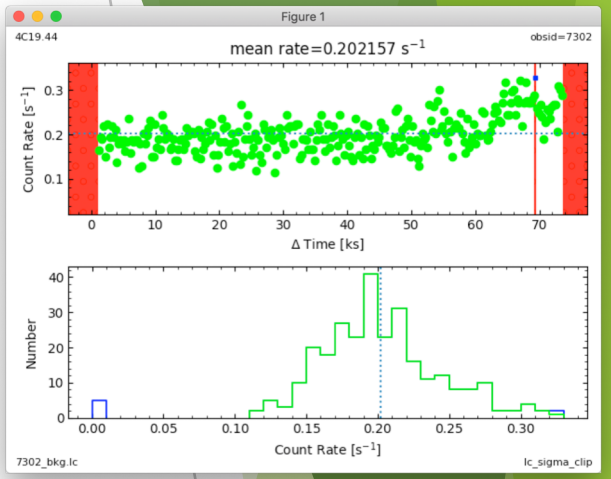
- Wavelets are correlated with data image at each scale size.
  - scales are the radii of the Ricker (aka "Mexican Hat") wavelet function
  - scales in units of image pixels
  - minimum and maximum scales chosen w.r.t. instrumental PSF sizes
    - smaller scales tend to detect small features and larger 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.
  - $sigthresh \approx \frac{1}{number\ of\ image\ pixels}$
- `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
```

CHANDRA X-RAY OBSERVATORY

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% 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
```

- 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% 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?