CENTER FOR ASTROPHYSICS
HARVARD & SMITHSONIAN

CXCDS/SW Overview

Access and Analysis of Chandra Data

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Celebrating ~24 Years

Chandra X-ray Observatory

Launched July 23, 1999

Overview

The Chandra X-ray Observatory is the NASA flagship mission for observing the sky in the X-ray band at the highest angular resolution and sensitivity

Chandra is one of NASA's "Great Observatories" – along with Hubble (visible, near-ultraviolet), Spitzer (infrared), & CGRO (gamma rays)

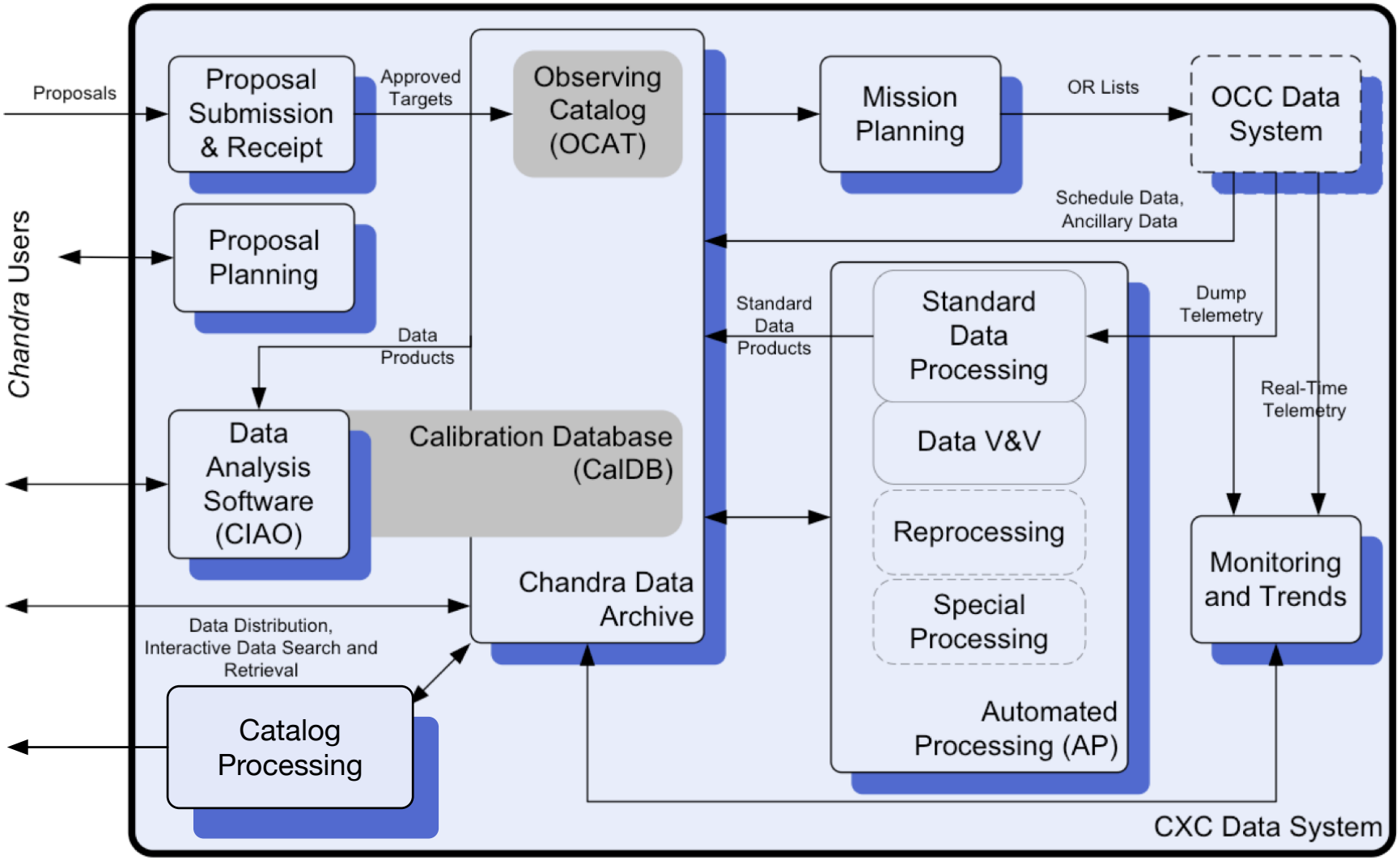
The Chandra X-ray Center Data System (CXCDS) software group provides end-to-end software support for Chandra mission operations

The CXCDS/SW consists of ~1.8 million lines of logical code

Our group consists of 16 developers, 5 team leads, 1 end-to-end scientist, a deputy end-to-end scientist, a software development manager and deputy sw mgr who also doubles as a team lead

> Our ability to maintain a large system with a group of this size is due to the experience and dedication of this team
>
> A number of team members have been here since before Chandra Launch – I recently counted 10

Forward and Return Thread



CXC Data System Threads

Return Thread

Standard Data Processing

Supports science and engineering pipeline processing of telemetry data from *Chandra*, pipeline and automated processing infrastructure, archive management and storage of science and engineering data, and operations support for pipeline processing

Monitoring and Trends Analysis

Supports monitoring of real-time and dump data for limit violations, long term trending of science, engineering, and derived data products

Data Distribution and Archive Access

Supports data archiving and distribution, management and maintenance of operational and public databases and data holdings, search and retrieval of data products

The *Chandra* Source Catalog (Level 3 Processing)

Supports development of the X-ray source catalog by reducing, analyzing, and merging data on a source-by-source basis, and provides tools to search and manipulate catalog data and interface to *CIAO*

CXC Data System Threads

Return Thread (continued)

Data Analysis Software (*CIAO*)

Supports user data analysis via a set of platform-portable software tools, libraries, and software applications

Configuration Management Tools

Supports configuration management and releases of software developed by the CXCDS software team, bug and enhancement request tracking, management of OTS, compiler and OS testing

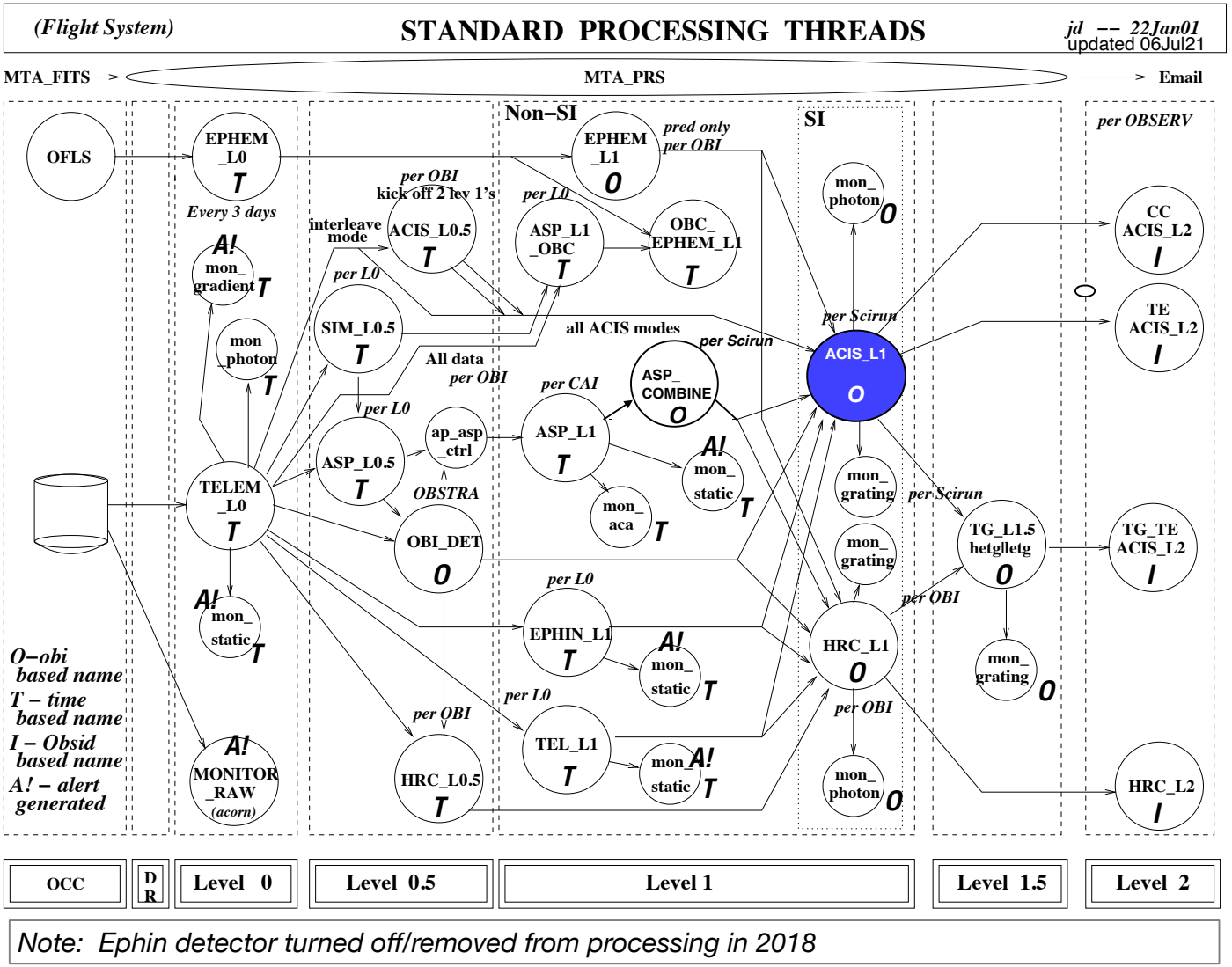
Pipeline Processing Levels

Split into several *levels* based on functionality

Data receipt, packet interface, strip file processing

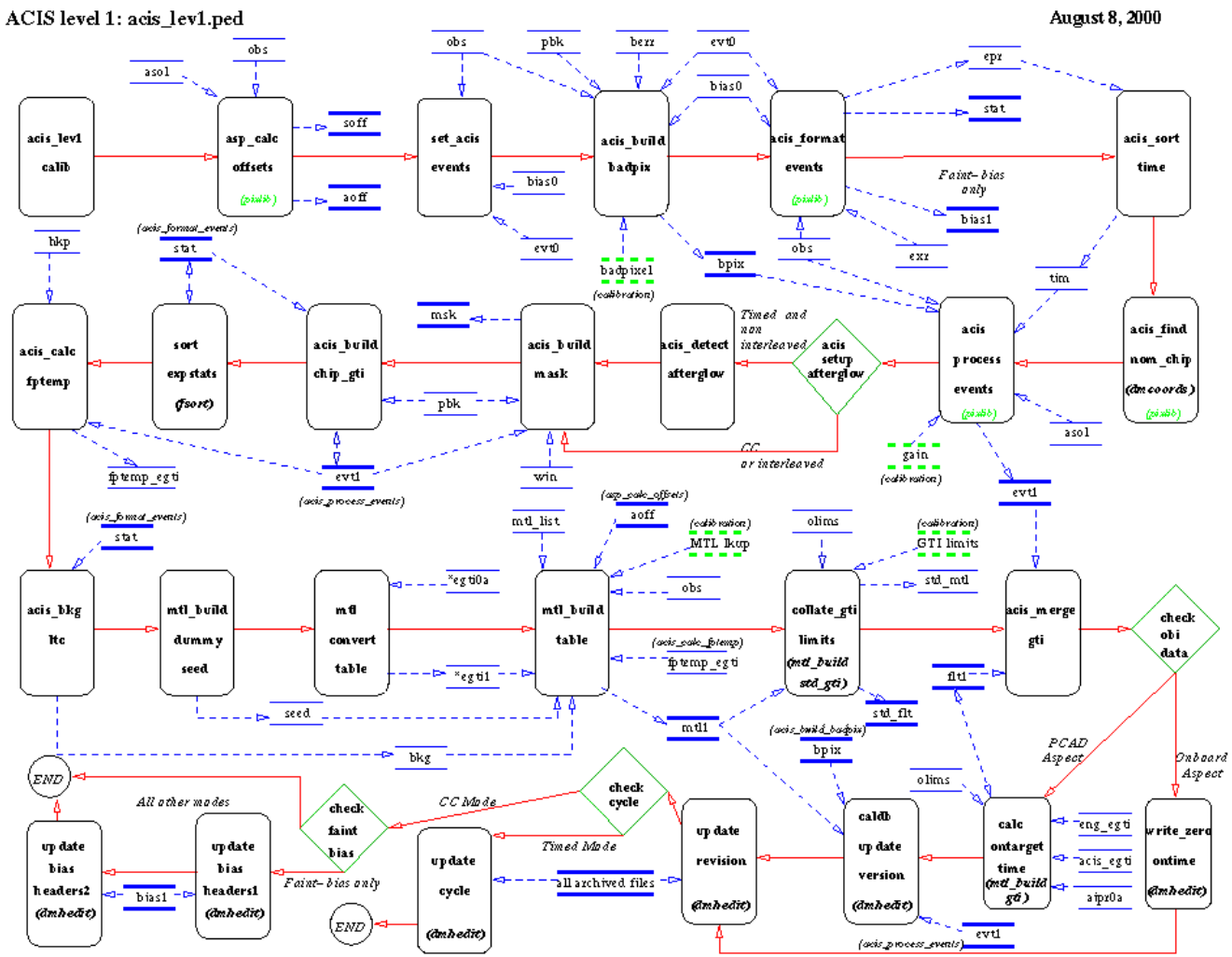
Level 0:	de-commutate telemetry
Level 0.5:	determine observation intervals, perform early SI special mode processing
Level 1:	perform main SI calibrations, apply Aspect solution, compute good time intervals
Level 1.5:	apply grating-specific calibrations
Level 2:	merge observation intervals and apply data filters
Level 3:	Chandra Source Catalog Processing
V&V/QA:	perform validation and verification (SDP); Quality assurance (L3)

Return Thread: SDP



Note: Ephin detector turned off/removed from processing in 2018

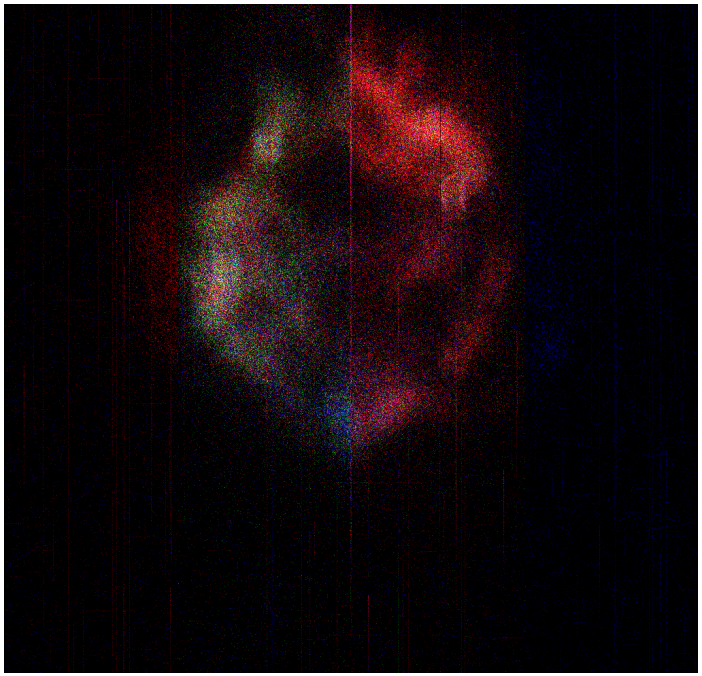
ACIS Level 1 Pipeline Diagram

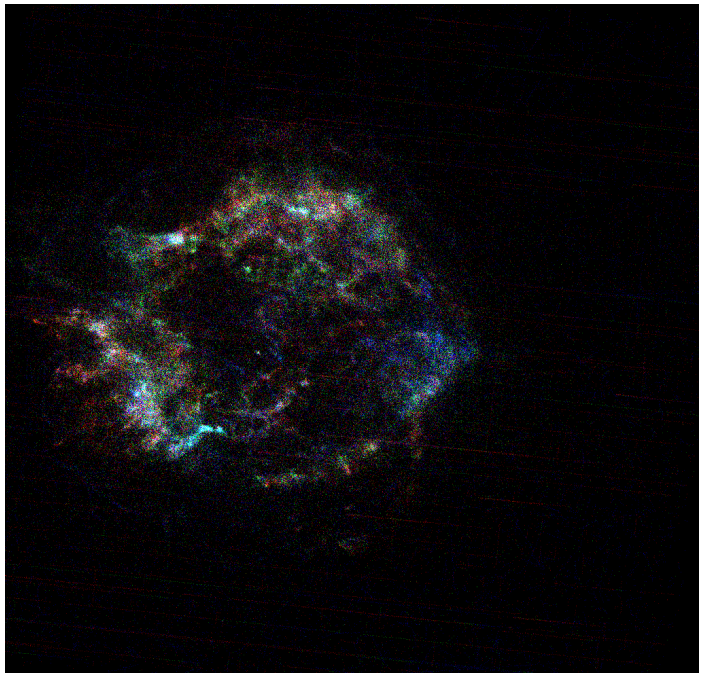


Ex. ACIS Level 1 Processing

ACIS Level 1 Example (ObsId 05162: SNR Cassiopeia A)

- Left figure shows photon event data input to the ACIS level 1 pipeline
  - Blurring is due to uncorrected spacecraft dither
  - Gross color variations occur because of variations of gain across the detector
- Right figure shows the result of ACIS level 1 processing
  - Aspect solution deblurs the image and correctly orients it on the sky
  - Gain correction allows actual photon energy dependence to be seen readily

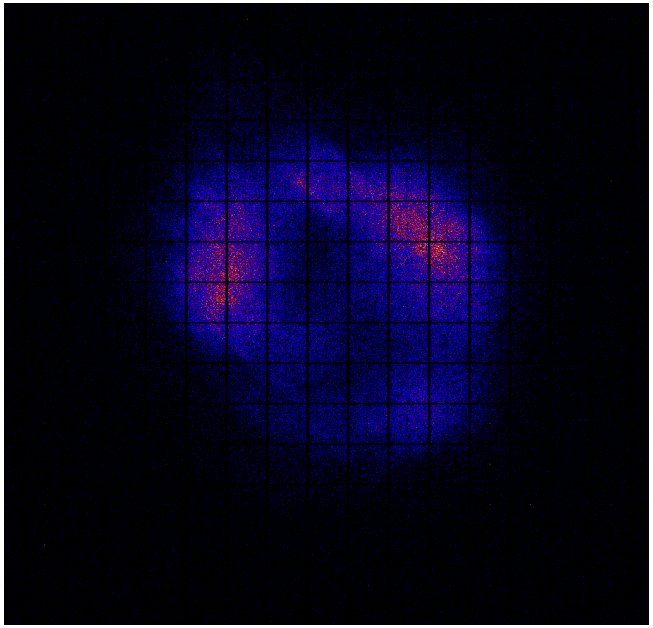


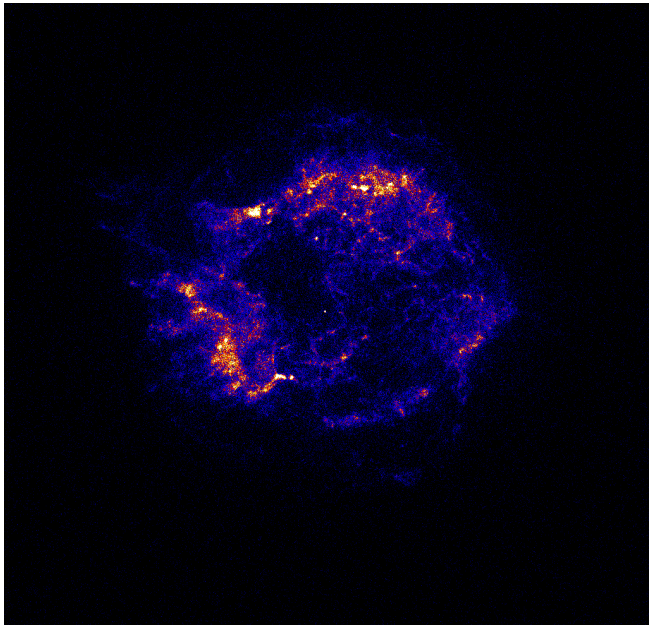


Ex. HRC Level 1 Processing

HRC Level 1 Pipeline and Example (ObsId 05164: SNR Cassiopeia A)

- Very similar in overall layout to ACIS level 1 pipeline, with main calibration steps performed by the *hrc_process_events* tool
- Left figure shows photon event data input to the HRC level 1 pipeline
  - Regular pattern of gaps is present because degap correction has not been applied
- Right figure shows the result of HRC level 1 processing
  - Aspect solution deblurs the image and correctly orients it on the sky
  - Degap correction locates photon events correctly in image space





The Chandra Data Archive

Archive Overview

- The archive provides storage and management for the CXC data holdings, including both static data and dynamic information
  - Static data do not change once ingested
    - Examples include submitted proposals and standard data products
    - Static data are typically stored in files with the metadata in databases
  - Dynamic information may be updated frequently, and are typically related to CXC operations
    - Examples include the observing catalog (*ocat*), user information, peer review data, mission planning schedules, and data processing status
    - Dynamic data are typically stored in databases

Proprietary Data Access

- The archive protects the rights of the data owners for the proprietary period of each observation
  - All relational data and file metadata are publicly available
  - Data files are restricted to the owners or specific CXC operations
  - Checking happens in the archive servers on a per-client request basis

Archive Search & Retrieval

Search and Retrieval

General purpose access to the archive for search and retrieval is provided by *ChaSeR* & CSCview graphical interfaces

ChaSeR

*A*pplication on the web

- Search by observation attributes stored in the ocat
- Browse list of observations found
- Browse list of associated data products
- Browse observation details, images, and V&V reports
- Login for proprietary data retrieval

CSCview

*A*pplication downloaded and auto-installed at the users desktop

- Interface to Chandra Source Catalog
- Data download to disk capability
- Query catalog with filters in form or following ADQL protocol

CDA VO Services

VO interfaces provide standards-based access to Chandra data through simple positional queries or more complex queries using the Astronomical Data Query Language (ADQL).

We have generalized VO services that are a suite of services that can be configured to provide VO interfaces to any dataset.

Our approach uses a thin web service layer for the individual VO interfaces, a middle-tier query component which is shared among the VO interfaces for parsing, scheduling, and executing queries, and existing web services for file and data access.

The CXC VO services provide:

- Simple Cone Search (SCS),
- Simple Image Access (SIA), and
- Table Access Protocol (TAP) implementations

for both the Chandra proposal and observation catalogs within the existing archive architecture.

CIAO

Chandra Interactive Analysis of Observations (*CIAO*)

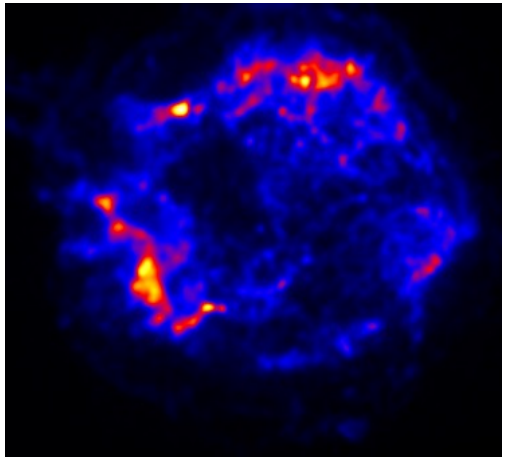
Software package is a powerful data-analysis system written to support the users of the *Chandra* X-ray Observatory

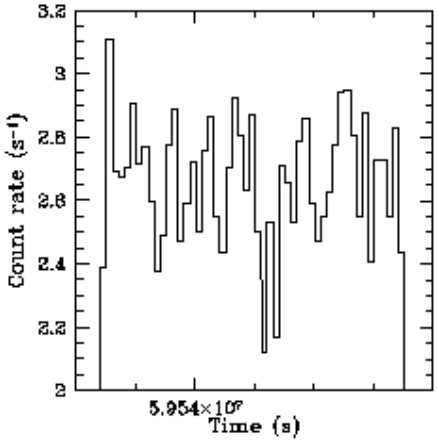
Consists of a large number (~80) of programs, ancillary data files for these programs, and an on-line help system

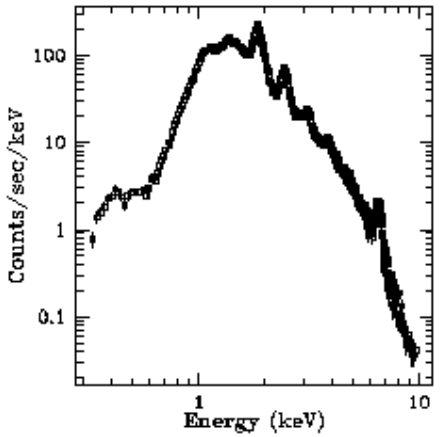
Supported on the platforms that the community uses most, currently several flavors of Linux and Mac OS-X

Analyzing X-ray Photon Event Files

From the event file you can create many data products, such as images, light curves, imaging spectra, and grating spectra







Key Features of CIAO

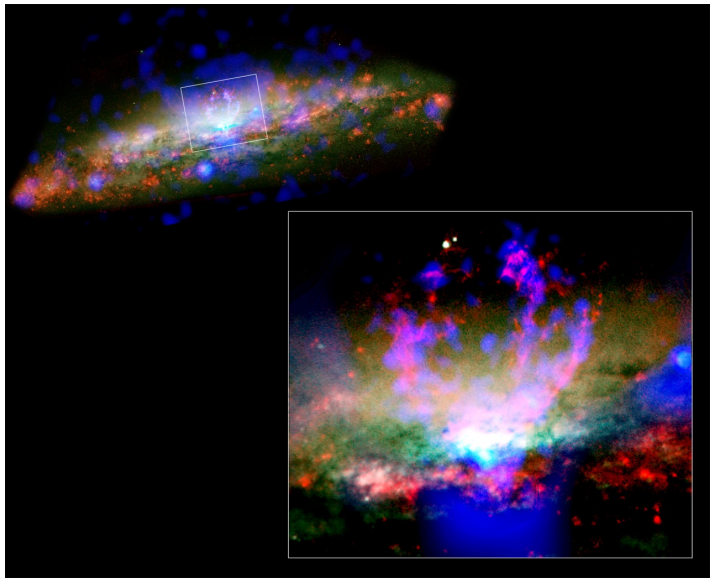
Support for *Chandra* Data and Data Standards

Designed to handle easily *N*-dimensional data

Chandra is the first mission with 4-d data (2 spatial, 1 time, and 1 energy) *in which each dimension has many independent elements*

By following standards, *CIAO* aims at being instrument- and mission-independent

Allows users to combine their analysis of *Chandra* data with data from other telescopes (e.g. *HST*, *Spitzer, XMM*)



NGC 3079

- *Chandra* data in blue
- *HST* emission in red and green

The red (~10,000 °C gas) and blue (~10,000,000 °C gas) filaments are formed as a “super-wind” of gas escapes from the center of the galaxy

Key Features of CIAO

The *Sherpa N*-d Modeling and Fitting Engine

The modeling and fitting tool *Sherpa* is a major component of *CIAO*

Sherpa performs forward fitting of models to *N*-dimensional data, and allows scientists to analyze spectra, light curves, and images

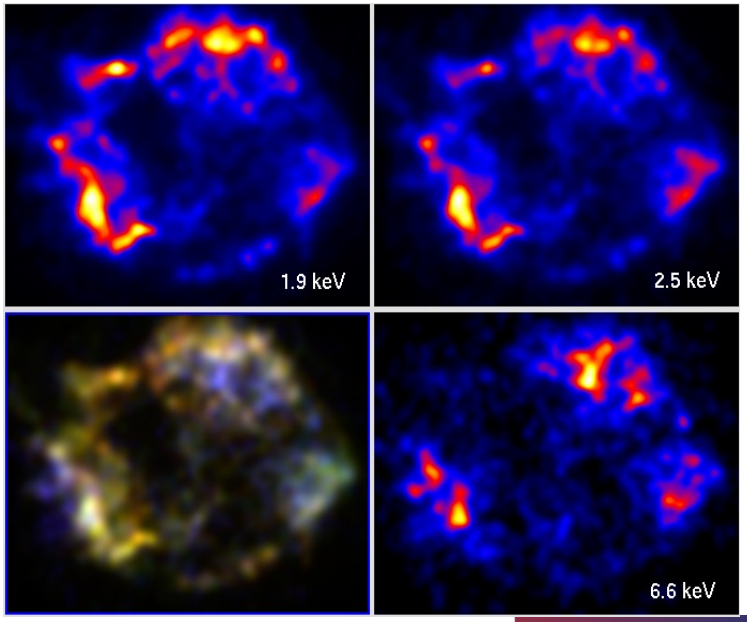
DataModel Filtering and Binning

All *CIAO* tools understand a common and powerful syntax, provided by the *DataModel* library, for filtering and binning files

This syntax allows users to easily extract subsets of data from files (filtering) and convert the data into different representations (binning)

Cassiopeia A

- The *Chandra* "first light" data has been filtered, binned, and smoothed to create images of the emission from the nebula at different energies
- By combining the images into a "false-color" image we can see how the properties of the nebula vary with position, which tells us how the ejecta from the supernova propagated through its surroundings.



Key Features of CIAO

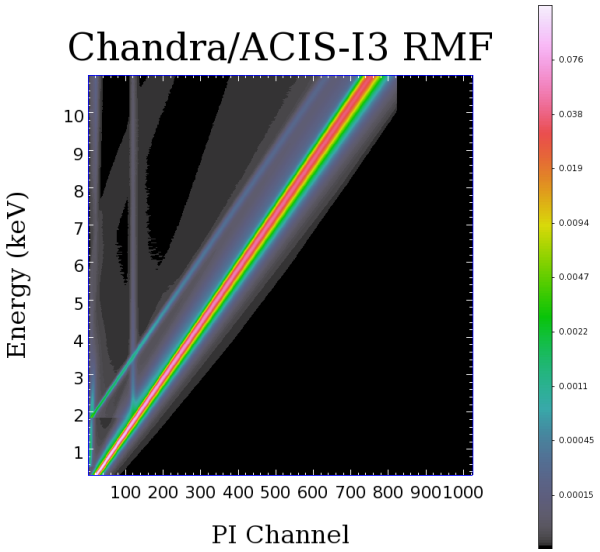
Chandra ACIS spectra

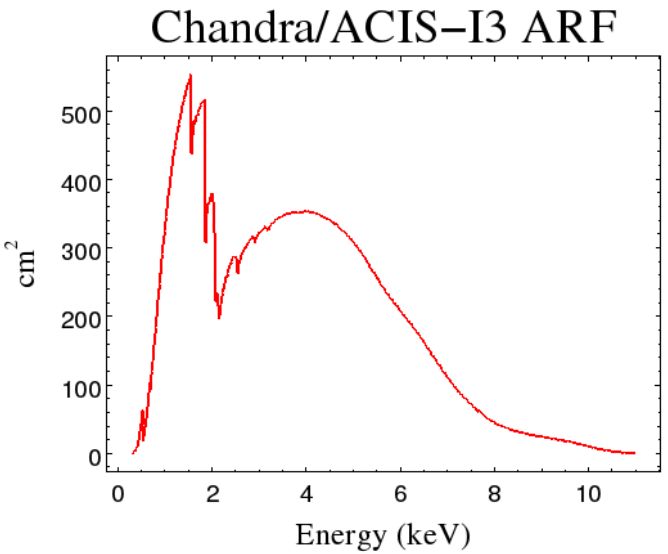
ACIS spectral resolution depends on X-ray energy and location on the detector

Forward folding is used to fit the observed counts per channel using a spectral model

This requires a *redistribution matrix (RMF)* that maps the relationship between the incident photon energy and the output signal's distribution over channels and an ancillary response file (ARF) that contains the effective area as a function of energy

The ARF for a source depends on the location of the source on the detector and the dither history of the observation (via the aspect solution)





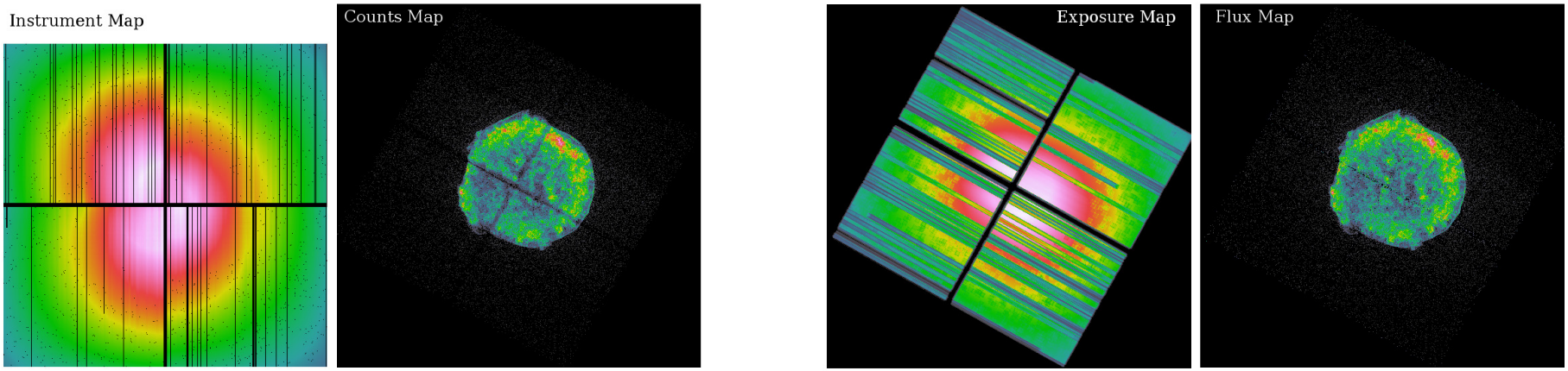
Key Features of CIAO

Converting counts to flux units

The instrument map is an image in detector coordinates of instrument sensitivity, including effective area and detector QE

The exposure map is an instrument map convolved with the aspect solution to account for dither

For Chandra, instrument and exposure maps typically have units of cm^2 s counts/photon and produce exposure-corrected images in flux units of photon/cm^2/s



Chandra Source Catalog

A Work in Progress

The *Chandra* Source Catalog (*CSC*) 2.0 was completed in October 2019 and includes data from the 1st 15 years of the Chandra mission (through the end of 2014)

CSC 2.0 includes 317K X-ray sources and ~1700 data values recorded for each source

- Includes ~35 types of user-accessible FITS data products (~22 TB)

CSC 2.1 will complete processing in the next few months and add public Chandra data through the end of 2021 to the catalog

- ~410K X-ray sources, ~1.2M detections, ~1.8M detections + upper limits

Chandra Source Catalog

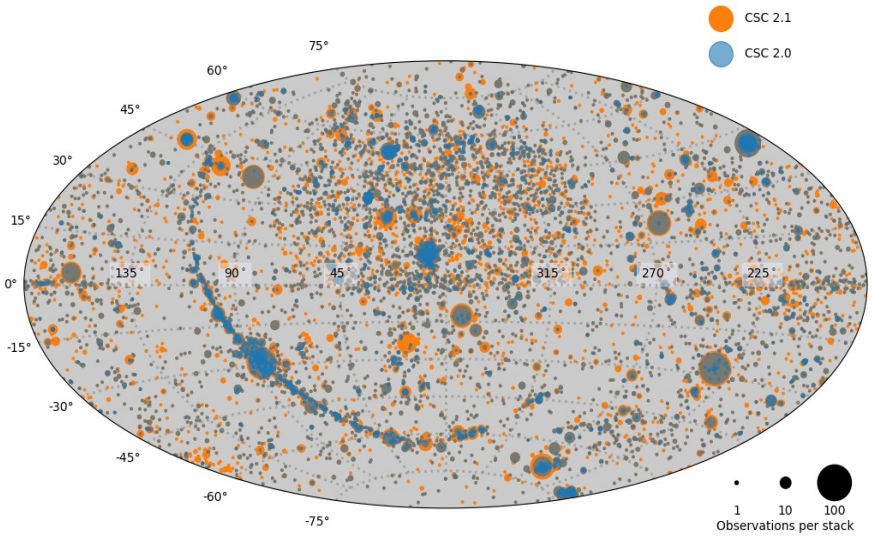
The definitive catalog of serendipitous sources observed by Chandra

Uniform catalog and data products
- Uniformly processed with consistent calibrations and state-of-the-art Bayesian algorithms

Stacked (co-added) imaging observations
- Co-added exposure times up to ~6.7 Ms (~77 days)

Tabulated properties
- Position, extent, photometry, variability, hardness ratio, spectral parameters in multiple energy bands
- For sources and detections

Science-ready data products
- Per source / detection / field / stacked field event files, images, backgrounds, calibrations, regions, local PSFs, spectra, light curves, photometry probability density functions, sensitivity, extended source polygons



CSC 2.1 sky coverage ~800 deg^2

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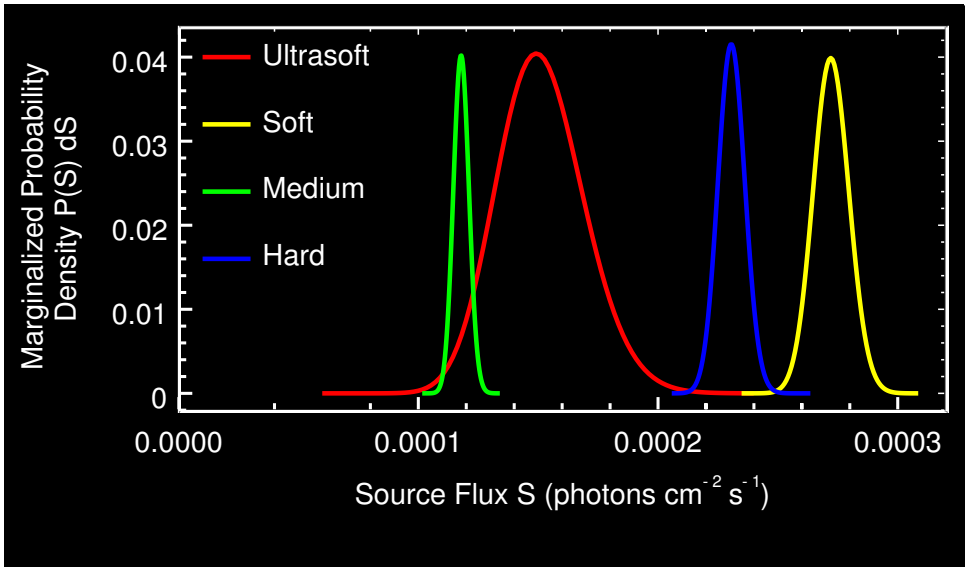
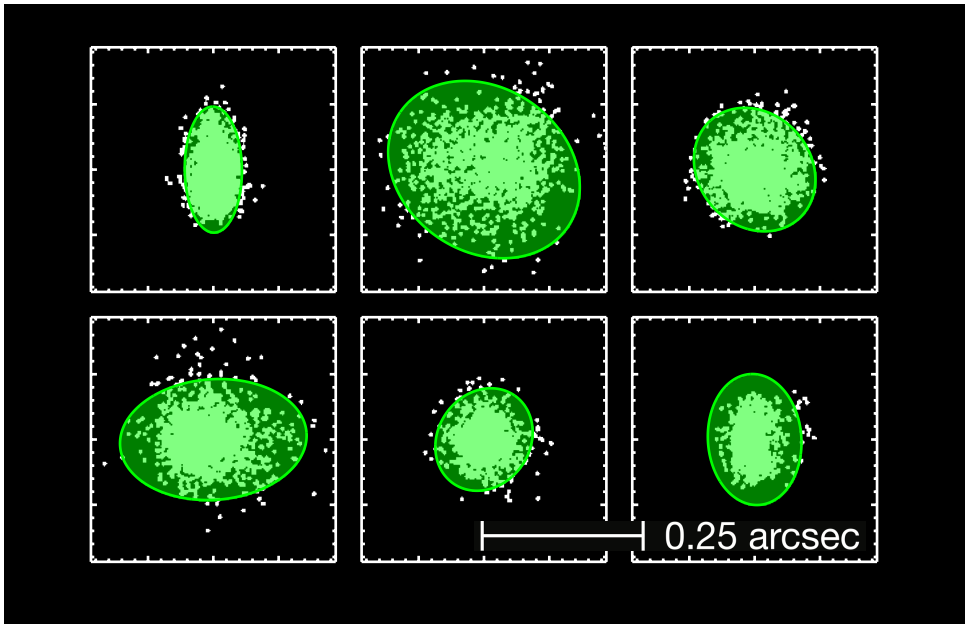
Chandra Source Catalog





Catalog properties

- Most properties calculated in 5 energy bands for ACIS, and 1 energy band for HRC
- All numeric properties have associated *independent* lower and upper confidence limits
- Aperture photometry properties have associated marginalized probability density functions computed using Bayesian analysis
- Some properties have associated MCMC draws
- Aperture-photometry derived properties are computed for a set of Bayesian Blocks for each source; the number of Bayesian Blocks depends on the source variability

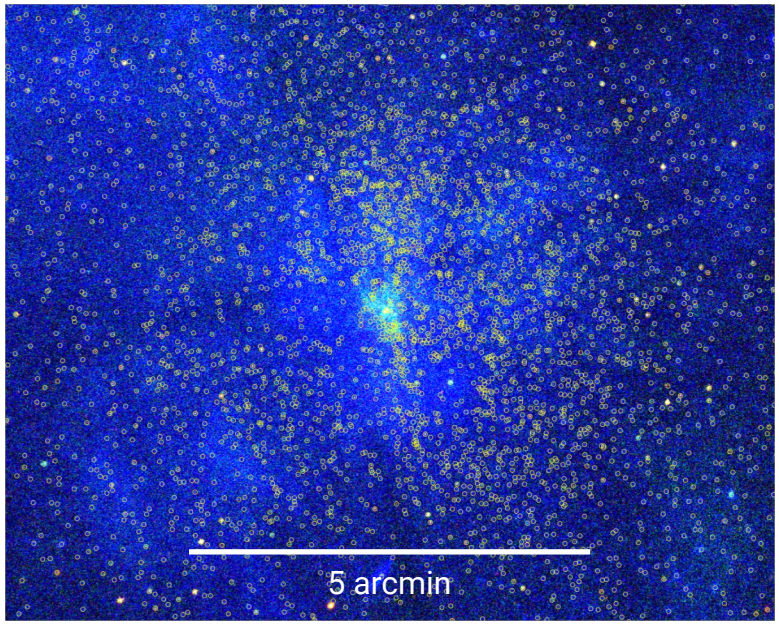
Spatial Resolution and Depth

Chandra has arcsecond spatial resolution on-axis

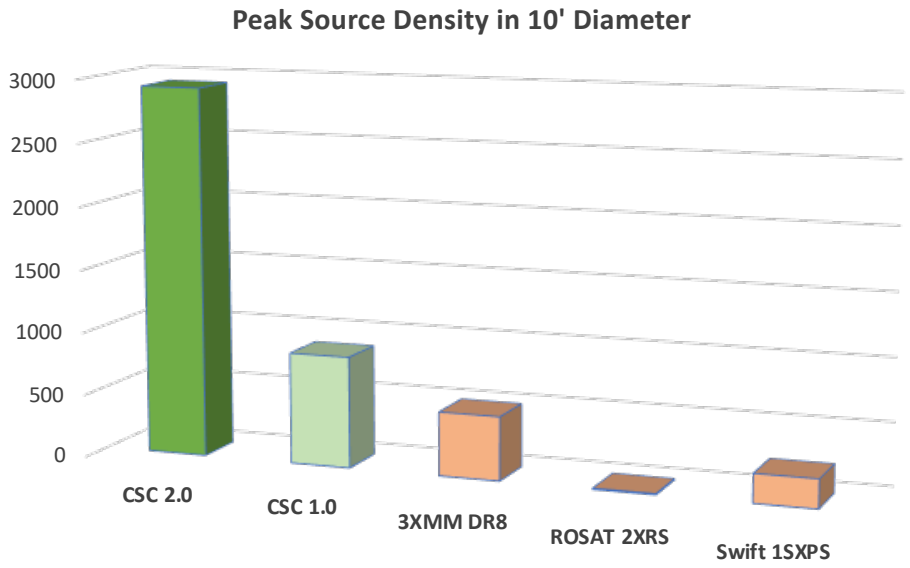
Chandra instruments have very low instrumental background

Outstanding sensitivity in heavily crowded fields

- Point source detection limit ~4–5 X-ray photons

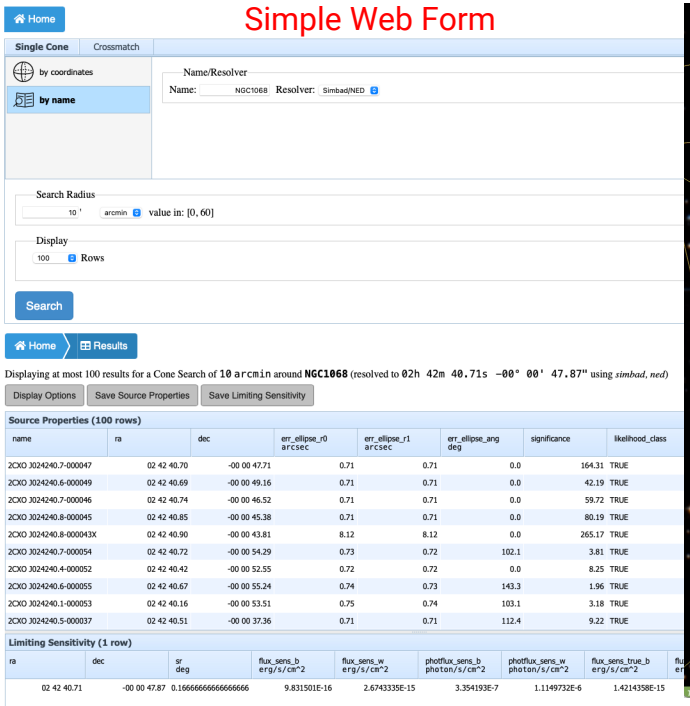


CSC sources in the core of Sgr A*

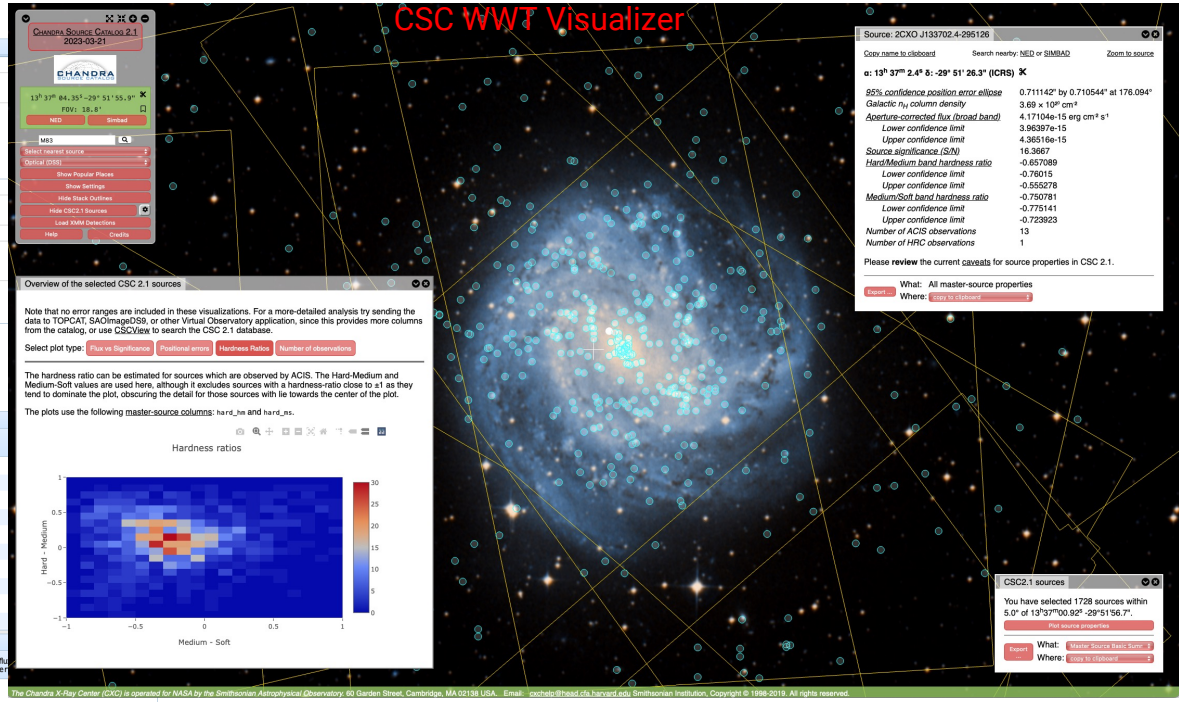


Multiple CSC User Interfaces

Simple Web Form



CSC WWT Visualizer



- *IVOA standard interfaces (TAP, SCS, SIAP) provide access to Jupyter notebooks using PyVO*
- *Simple web form*
- *CSC WWT visualizer*
- *Downloadable CSCview data-mining interface*
- *Web command line*
- *CIAO scripting & ds9*

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