# Introduction to the

CHANDRA
SOURCE CATALOG

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Introduction

- The *Chandra Source Catalog (CSC)* is intended to eventually be the definitive catalog of X-ray sources detected by Chandra
  - The catalog is being deployed using a phased approach
    - Each new release will add new capabilities and new functionality
    - New catalog releases will take place roughly every 18−24 months

- Current catalog version is Release 1.0 (March 2009)
  - Includes 135,914 source detections from 3,912 observations, totaling 94,676 apparently distinct X-ray sources on the sky

Release 1.0 sky coverage

Current Catalog Release
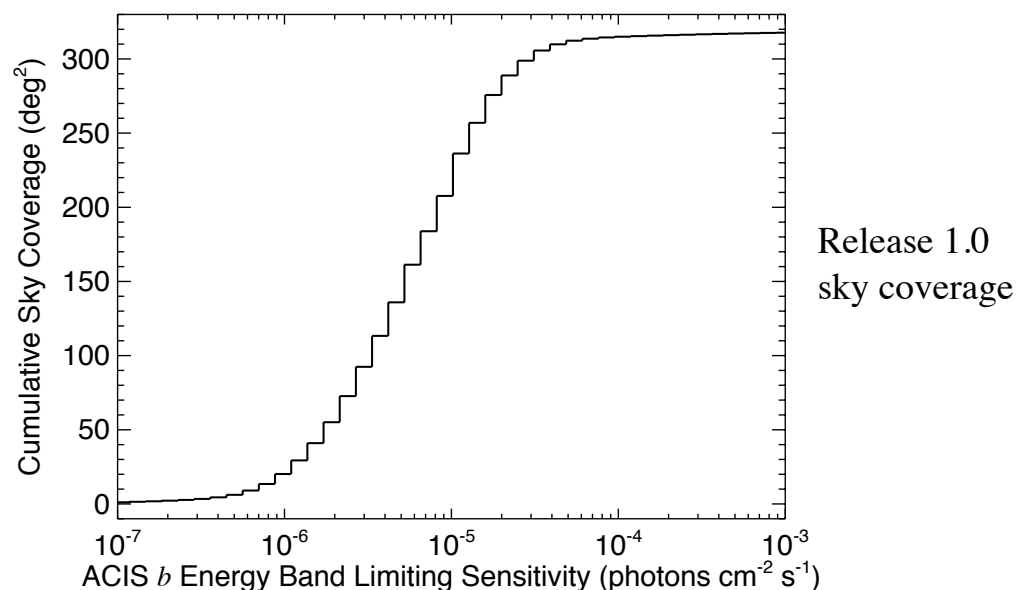
Release 1.0 Limitations

- The catalog is constructed from pointed observations
  - *It is not all-sky, and does not include sources detected to a uniform depth*
- Restricted to point and compact sources with observed spatial extents $< \sim 30$ arcsec detected in a *subset* of ACIS imaging observations released publicly prior to January 2009
- Some observations of fields containing extended sources are excluded from the catalog, or in some cases only a part of the field is included
  - Implies that release 1.0 does not include sources near some of the most famous Chandra targets
- Includes sources with flux estimates that are at least 3 times their estimated 1σ uncertainties in at least one energy band
  - Corresponds to ~10 counts on-axis, and ~30 counts far off-axis
- Source detections are performed on individual observations (no stacking)

Catalog users need to consider possible selection effects!

Future Catalog Releases

Release 1.1 (~ March, 2010)

- Add public HRC-I observations to Release 1.0
- "Catch-up" ACIS observations released publicly prior to the end of 2009
- Otherwise, Release 1.1 retains the same limitations as Release 1.0

Release 2 (~2011)

- Stack observations with same instrument configurations and similar pointings (within ~30 arcsec) prior to source detection
- Perform source detection down to a faint threshold (~5 counts?)
  - Use a maximum likelihood probability to evaluate the "reality" of detected sources to maintain an acceptable false source rate
- Updated algorithms, including
  - Improved aperture photometry solution for overlapping sources
  - Inclusion of upper limits from non-detections
  - Improved background modeling
- Improved handling of extended emission up to ~60 arcsec scale (?)

Release 3+

- Handle very extended sources
- "Simultaneous" arbitrary multi-observation detection

Where To Get Information
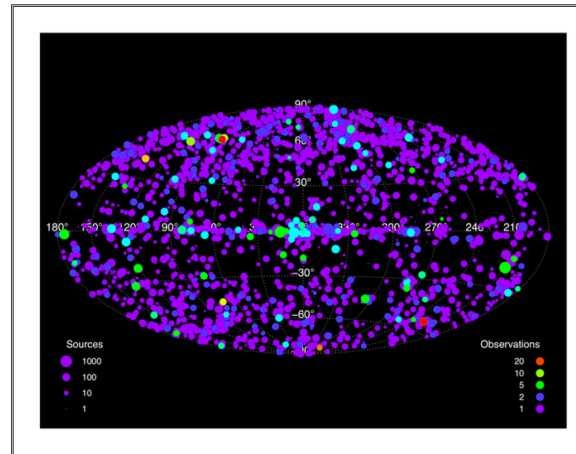
Catalog Website

http://cxc.cfa.harvard.edu/csc/

- Links to catalog interfaces for data access
- Detailed documentation
  - "About the Catalog" describes catalog organization, concepts, caveats and limitations, and a description of the catalog statistical properties
    - *Users should be familiar with these concepts in order to make best use of the catalog*
    - Users should review caveats and limitations prior to using the catalog
      » Current caveats include source position errors, variability measures, backgrounds
  - *Definitions of the tabulated source properties and the file-based data products*
  - Help on using the catalog interfaces, including examples
  - User threads, FAQs, "How and Why" topics
  - Links to memos that describe algorithms in more detail
- Request for acknowledgement of use and plea to include the appropriate catalog dataset identifier in publications

Catalog Website

The Chandra Source Catalog
Release 1.0.1: Point and compact source catalog

CSC Data Access:

CSCview
(Help)

Command-line Interface

CSC Sky in Google Earth
UPDATED

CSC-SDSS Cross-match Catalog

CSC Sensitivity Map Service

The locations of observations included in the CSC, in Galactic coordinates (click the image for equatorial coordinates). The size of each symbol is proportional to the logarithm of the number of sources detected in the field, while the color encodes the number of closely-located observations.

The Chandra Source Catalog (CSC) is ultimately intended to be the definitive catalog of X-ray sources detected by the Chandra X-ray Observatory. To achieve that goal, the catalog will be released to the user community in a series of increments with increasing capability. **The first official release of the CSC includes information about sources detected in public ACIS imaging observations from roughly the first eight years of the Chandra mission. Only point sources, and compact sources, with observed spatial extents <~30 arcseconds, are included. Highly extended sources, and sources located in selected fields containing bright, highly extended sources, are excluded from the first release.**

The CSC contains positions and multi-band count rates for the sources, as well as derived spatial, spectral, and temporal calibrated source properties that may be compared with data obtained by other telescopes. The CSC also includes associated data products for each source, including images, photon event lists, light curves, and spectra.

Each distinct source on the sky (i.e., object at a specific RA and Dec) is recorded in a single "master source" table entry and one or more "source observation" table entries. The individual source entries contain the properties of a single detection from a single observation. The master source entry is the best estimate of all the properties of a source, based on the data extracted from the individual source entries. The Catalog Organization page contains further details.

The current version of the catalog is release 1.0.1. This version fixes the var_flag error that was present in release 1.0 of the catalog.

The Schedule and Status page has the current processing status and release schedule.

Users are urged to review the catalog Caveats and Limitations prior to using the CSC for their scientific investigations.

Questions about the CSC may be submitted to the CXC Helpdesk; refer also to the FAQs section of the website for answers to frequently asked questions.

Request for Acknowledgment of Use of the Chandra Source Catalog

Users are kindly requested to acknowledge in the acknowledgment section of any resulting publications their use of the Chandra Source Catalog.

This will help us greatly to keep track of catalog usage, information that is essential for providing full accountability of our work and services, as well as for planning future services.

The following language is suggested:

This research has made use of data obtained from the Chandra Source Catalog, provided by the Chandra X-ray Center (CXC) as part of the Chandra Data Archive.

We would like to remind you that it is also very helpful for us if you could include Dataset Identifiers in the manuscript. The Dataset Identifier for the Chandra Source Catalog is:

ADS/Sa.CXO#CSC

Catalog Organization

- The catalog is split into two principal tables of source properties
  - The "**Master Sources Table**" contains an entry for each *apparently distinct detected X-ray* **source** on the sky
  - The "**Source Observations Table**" contains an entry for each *source* **detection** extracted from an observation
- Distinguishing **sources** from **detections** effectively addresses the strong dependence of the Chandra PSF on off-axis angle

Comparison of a region of the sky included in ObsId 635 (left) with the same region included in ObsId 637 (right)

The on-axis PSF in ObsId 637 clearly resolves some apparently single source detections in ObsId 635 into multiple distinct sources
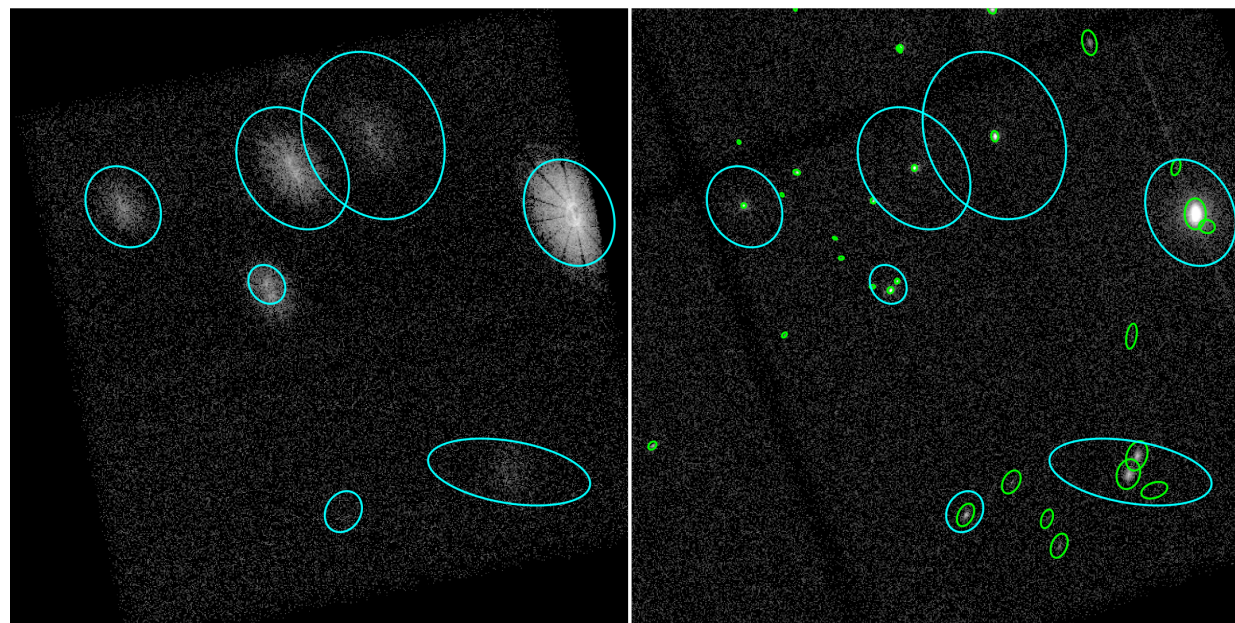
Master Sources Table

- Includes estimates of "mean" source properties derived from observations in which the source is detected (and is not confused)
  - Master sources have *names* (*e.g.*, CXO J162624.0-242448) because they correspond to apparently distinct X-ray sources on the sky
- Roughly 60 source properties are tabulated for each master source
  - Total of 287 table columns (including measured values and associated confidence limits across all energy bands)

You will typically use the Master Sources Table when you are interested in the properties of X-ray sources detected by Chandra

Notes:

1) Wherever possible, measured and derived sources properties have associated confidence limits or other defined errors

2) For observations obtained using ACIS, many source properties are evaluated in multiple *energy bands*

| Band Name	ACIS broad (**b**)	ACIS ultrasoft (**u**)	ACIS soft (**s**)	ACIS medium (**m**)	ACIS hard (**h**)	HRC wide (**w**)
Energy Range	0.5–7.0 keV	0.2–0.5	0.5–1.2	1.2–2.0	2.0–7.0	~0.1–10

Source Observations Table

- Includes properties derived from a detection in a *single* observation
  - Source observations do *not* have names, since a single detection may be associated with multiple X-ray sources
- Roughly 120 source properties are tabulated for each source observation
  - Total of 599 table columns (including measured values and associated confidence limits across all energy bands)

You will typically use the Source Observations Table when you are interested in individual observations of X-ray sources detected by Chandra

Master Sources/Source Observations Associations

- Entries in the master sources table and entries in the source observations table are associated via either *unique* or *ambiguous* links
  - A *unique* link means that the **detection** in the source observations table is associated with a *single* X-ray **source** in the master sources table
  - An *ambiguous* link means that the **detection** in the source observations table is associated with *multiple* X-ray **sources** in the master sources table (i.e., the detection must be resolved into multiple sources by another observation)

Master Source/Source Observation Associations
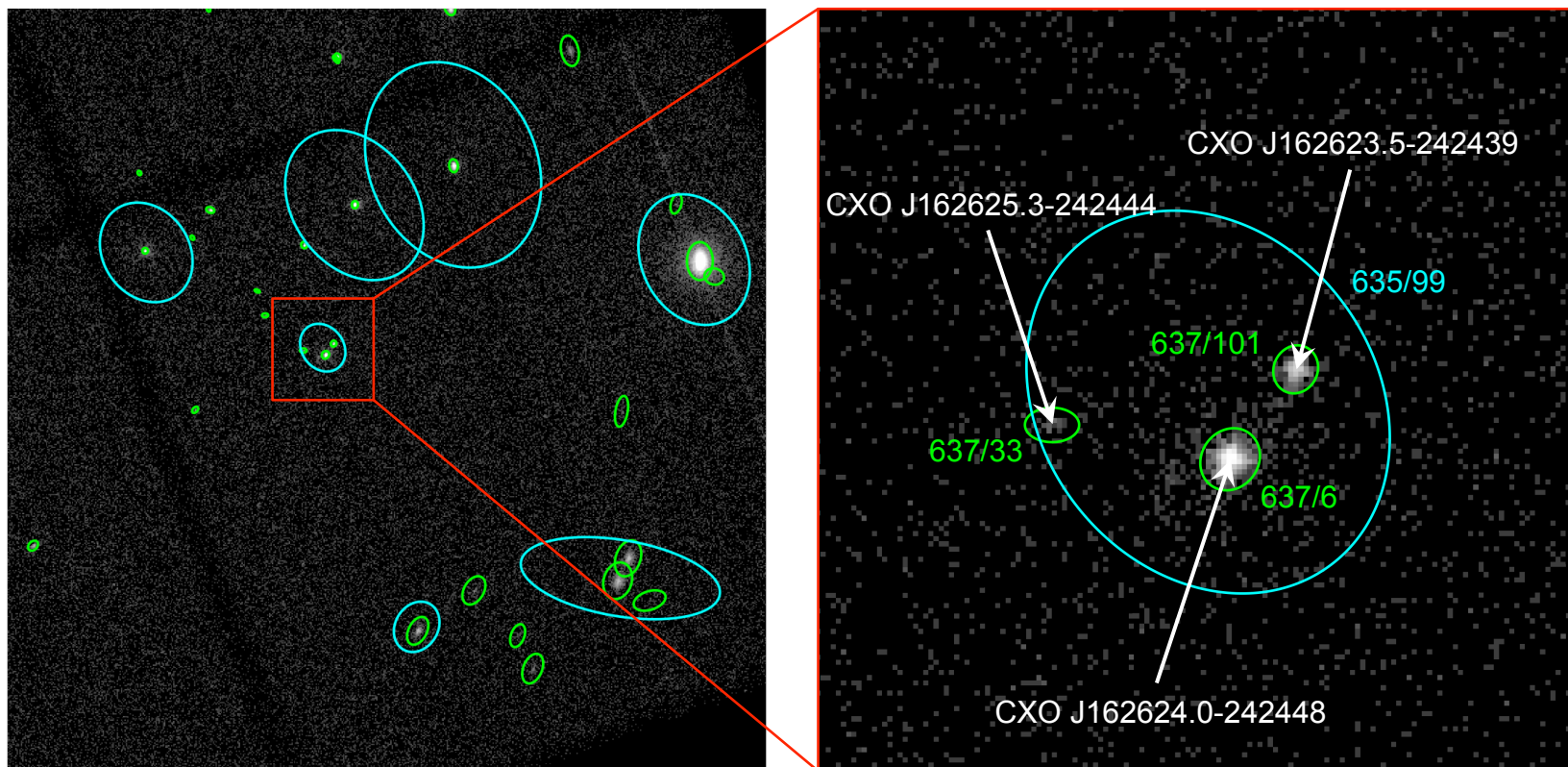
Master Source	635/99	637/6	637/33	637/101
CXO J162623.5-242439	*ambiguous*	—	—	*unique*
CXO J162624.0-242448	*ambiguous*	*unique*	—	—
CXO J162625.3-242444	*ambiguous*	—	*unique*	—

Source Observations Table Contents

Source Observations Table

- Observation-specific information
    - Identifies the *observation* in which the source was detected
        - Includes the observation identification, observation target and spacecraft pointing, observation timing, instrument configuration, and data processing information

- Detected source properties
    - Provides the extracted data for each *source detection*
        - Includes the observation-specific source identification, source position (celestial, msc, chip) and position errors, source significance (S/N), measured source and local PSF extents, estimated deconvolved source extent, source and background region apertures, PSF 90% ECF aperture, multi-band aperture photometry fluxes, cross-band spectral hardness ratios, power-law and black-body spectral fits (for 150+ net source counts only), time variability probabilities and statistics, and a set of flags and codes that indicate circumstances that may be relevant to the user (*e.g.*, source is: confused, extended, variable, dithers across chip edges, piled-up, saturated, …)

See the website for detailed descriptions of tabulated properties

Master Sources Table Contents

Master Sources Table

- Master sources
  - Provides estimates of properties for each *apparently distinct source* on the sky
    - Includes the source name, source position and position errors, source significance (S/N), estimated deconvolved source extent, multi-band aperture photometry fluxes, cross-band spectral hardness ratios, power-law and black-body spectral fits, intra- and inter-observation variability probabilities and statistics, observation summary, and a set of flags
    - Source *name* is CXO J*hhmmss.s±ddmmss*, where coordinates are ICRS

  - Master source properties are typically computed by *combining measurements* from each individual source detection
    - *e.g.*, merged source positions and position errors; aperture photometry fluxes, spectral hardness ratios, inter-observation variability
    - Merged source properties are only computed using data from individual source observations that have *unique associations* to the master source
  - In some cases, the sources properties from the observation with *highest S/N* are used instead of combining measurements from multiple observations (*e.g.*, power-law and black-body spectral fit properties)

Catalog Data Products

File-Based Data Products

- Each observation has an associated set of *full-field* (per-observation) and *source-specific* (per-source-detection) data products
  - Full-field data products include the "Level 3" event file, fluxed images (several bands and blocking factors), background images, exposure map, limiting sensitivity map, aspect histogram, bad pixel, and field of view files
  - Source-specific data products include the source region event file, fluxed images, PSF images, exposure map, low resolution PI spectrum, ARF, RMF, adaptively binned light curve, and source and background region definitions
  - These data products can be analyzed further using *CIAO* tools

CXO J162624.0-242448
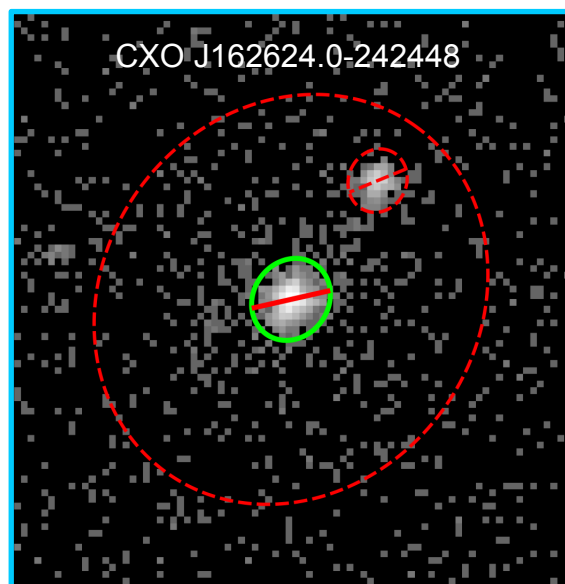
The source region event file contains events within a rectangular bounding box on the tangent plane that encloses the background region; to extract only the events included in the source region the source region filter must be applied

The background region has cut-outs that exclude the source region and any overlapping source regions

Sample Source-Specific Data Products
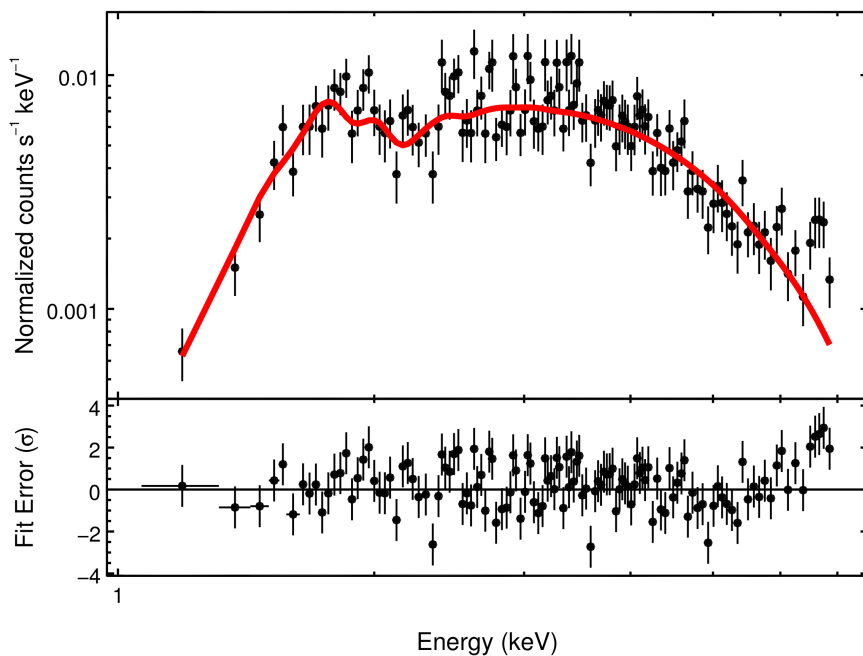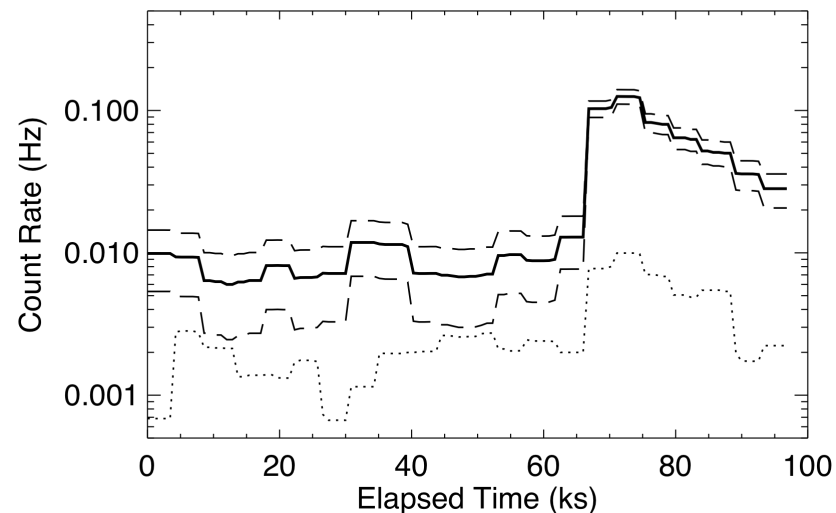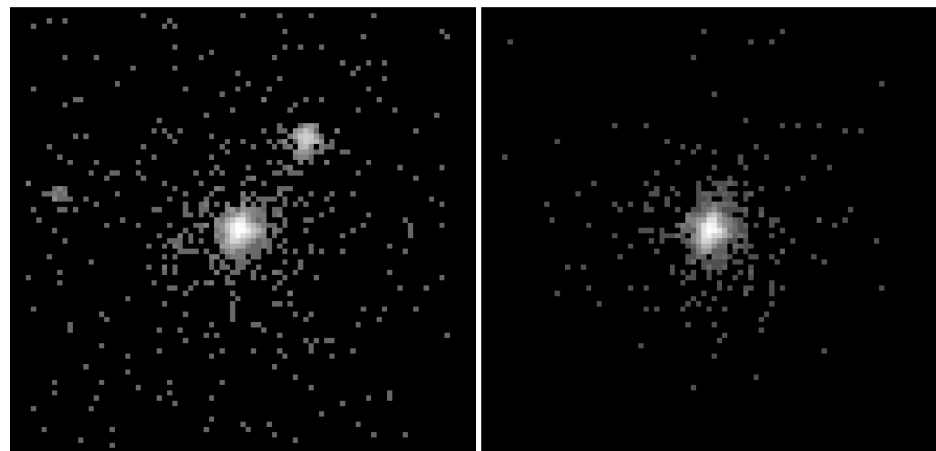
Sample data products for CXO J162624.0-242448

Upper left: ACIS **b** band source region image (photon flux units, background-subtracted) and the local **b** band PSF

Above: **b** band light curve (solid line) ±3σ errors (dashed lines), and background light curve (dotted line)

Left: ACIS PI spectrum, with best-fitting absorbed power-law shown (spectral fit parameters can be obtained by querying the source observations table entries associated with the source name)

Catalog Data Access: CSCview

CSCview

- CSCview allows the user to query the tabulated catalog properties and identify sources that satisfy a set of user-supplied constraints
  - CSCview is a Java applet that runs in the user's web browser
  - The results of the query can be viewed on the screen or saved to a file
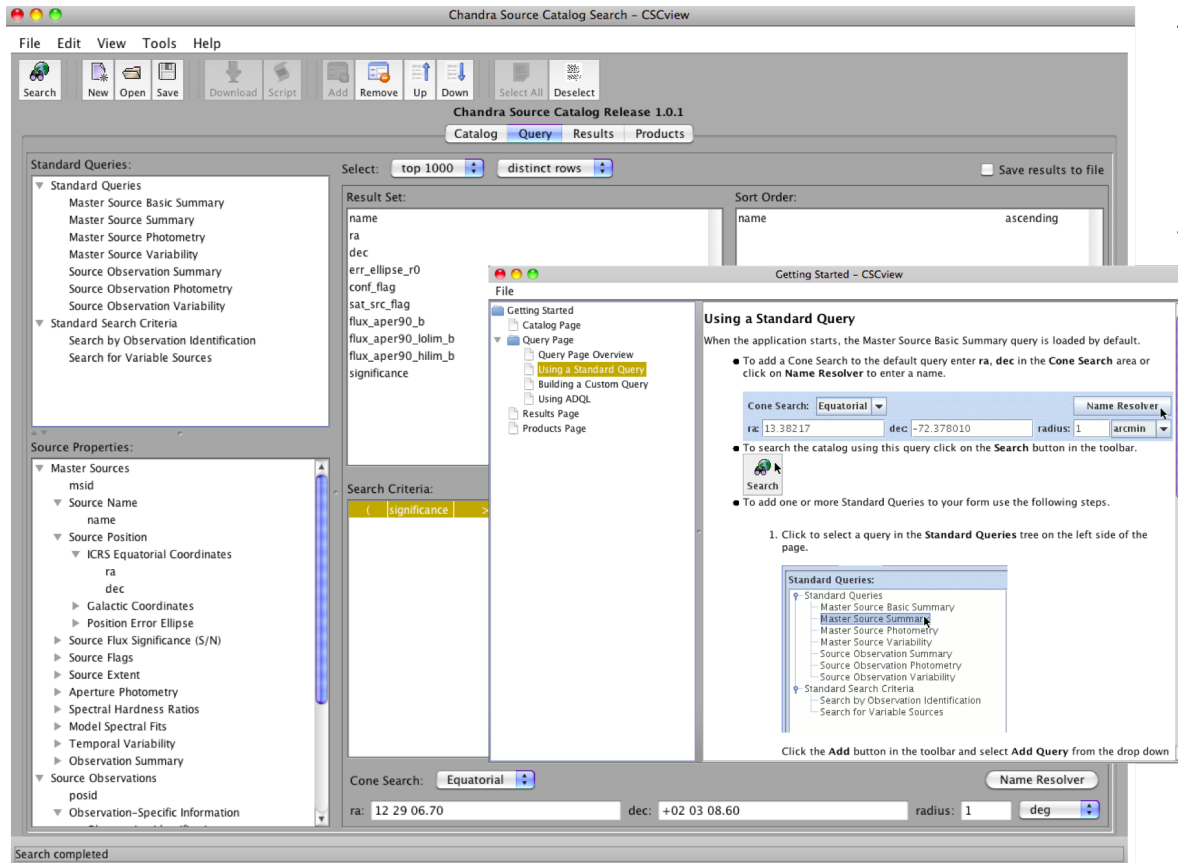
- Full-field or source-specific data products for matching sources can be selected and downloaded
- CSCview is forms-based, but converts the query to ADQL (Astronomical Data Query Language) for execution
  - The user can choose to write the query directly in ADQL

Catalog Visualization: CSC Sky in Google Earth

CSC Sky in Google Earth

- Visualize the catalog in Google Earth running on your workstation
  - The top-level catalog KML file must be downloaded for use in Google Earth
  - Displays 3-color images of all catalog fields
  - Markers identify catalog sources; clicking on a marker pops-up a balloon listing key source properties
  - Displays field-of-view outlines for catalog fields and/or all Chandra observations
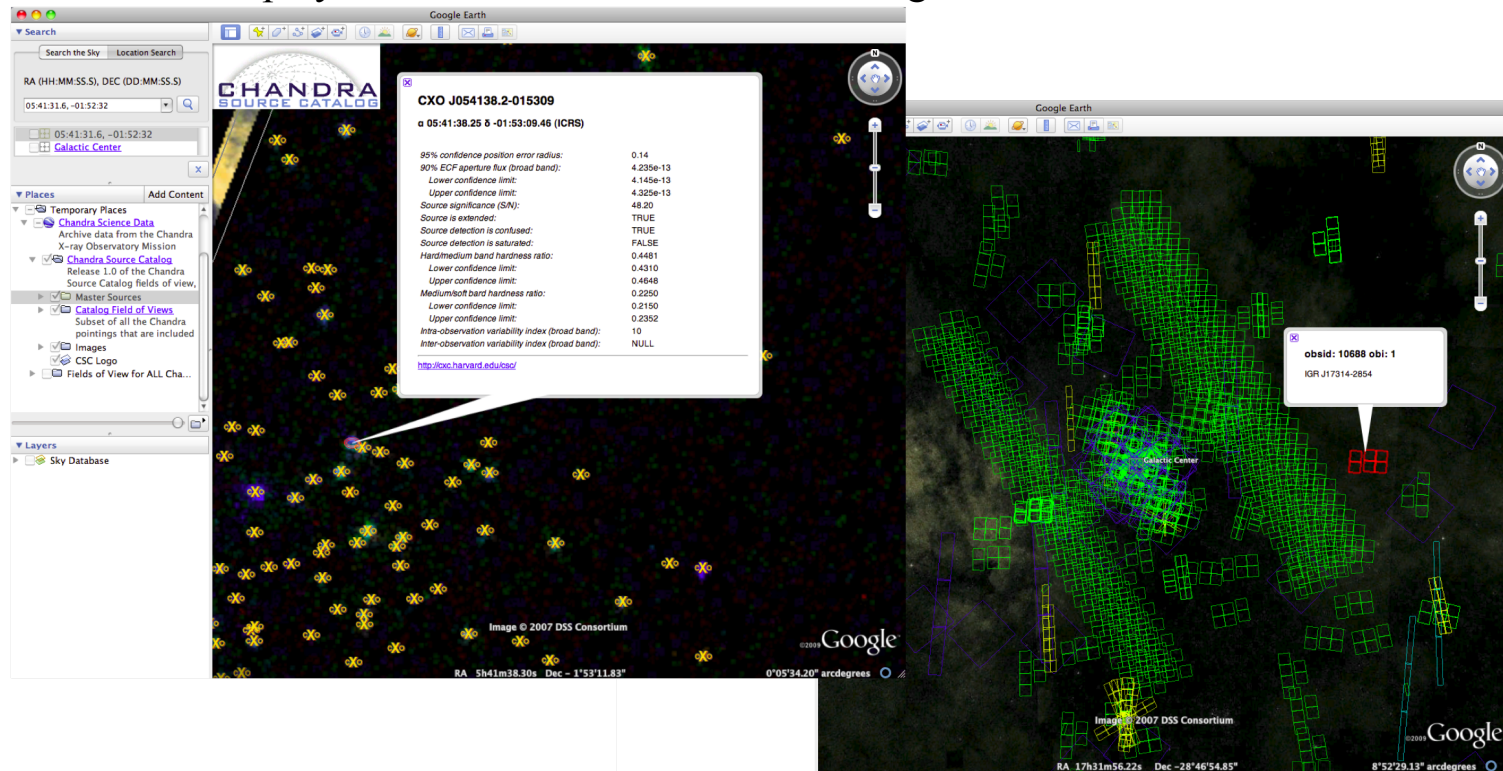
Additional Catalog User Interfaces

Command Line Interface (CLI)

- The ADQL query interface is also accessible directly via a URL
  - Users can query the catalog directly from the UNIX command line using (*e.g.*) `cURL` or `wget`

CSC Sensitivity Map Service

- Returns limiting sensitivity of the CSC at arbitrary user-specified locations
  - photons cm^{-2} s^{-1} in the ACIS broad energy band needed for a point source to be included in the catalog
  - As this service is a prototype, the user is advised to review the associated caveats

IVOA-compliant Simple Cone Search Interface

- Allows VO portals (*e.g.*, *DataScope*) and VO-aware tools (*e.g.*, *TOPCAT*) to directly search for catalog sources near a user-specified position

CSC-SDSS Cross-match Catalog Service

- Tabulates the list of sources common to both Release 1 of the CSC and Data Release 7 of the SDSS
  - Contains about 17,000 CSC-SDSS source pairs, about 8,000 of which are classified by SDSS as stars, and ~9,000 as galaxies
  - The Cross-match Catalog Service can return either all matching sources, or the subset of sources that satisfy optional user-specified search criteria