

Ian N. Evans,¹ Francis A. Primini,¹ Kenny J. Glotfelty,¹ Craig S. Anderson,¹ Nina R. Bonaventura,¹ Judy C. Chen,¹ John E. Davis,² Stephen M. Doe,¹ Janet D. Evans,¹ Giuseppina Fabbiano,¹ Elizabeth C. Galle,¹ Daniel G. Gibbs II,¹ John D. Grier,¹ Roger M. Hain,¹ Diane M. Hall,³ Peter N. Harbo,¹ Xiangqun (Helen) He,¹ John C. Houck,² Margarita Karovska,¹ Vinay L. Kashyap,¹ Jennifer Lauer,¹ Michael L. McCollough,¹ Jonathan C. McDowell,¹ Joseph B. Miller,¹ Arik W. Mitschang,¹ Douglas L. Morgan,¹ Amy E. Mossman,¹ Joy S. Nichols,¹ Michael A. Nowak,² David A. Plummer,¹ Brian L. Refsdal,¹ Arnold H. Rots,¹ Aneta Siemiginowska,¹ Beth A. Sundheim,¹ Michael S. Tibbetts,¹ David W. Van Stone,¹ Sherry L. Winkelman,¹ and Panagoula Zografou¹

¹Smithsonian Astrophysical Observatory, ²Mit Kavli Institute for Astrophysics and Space Research, ³Northrop Grumman Information Systems

Abstract

The Chandra Source Catalog (CSC) is a general purpose virtual X-ray astrophysics facility that provides access to a carefully selected set of generally useful quantities for individual X-ray sources, and is designed to satisfy the needs of a broad-based group of scientists, including those who may be less familiar with astronomical data analysis in the X-ray regime. The first release of the CSC includes information about 94,676 distinct X-ray sources detected in a subset of public ACIS imaging observations from roughly the first eight years of the Chandra mission. This release of the catalog includes point and compact sources with observed spatial extents $\leq 30''$. The catalog (1) provides access to estimates of the X-ray source properties for detected sources with good scientific fidelity; (2) facilitates analysis of a wide range of statistical properties for classes of X-ray sources; and (3) provides efficient access to calibrated observational data and ancillary data products for individual X-ray sources. The catalog includes real X-ray sources detected with flux estimates that are at least 3 times their estimated 1σ uncertainties in at least one energy band, while maintaining the number of spurious sources at a level of ≤ 1 false source per field for a 100 ks observation. For each detected source, the CSC provides commonly tabulated quantities, including source position, extent, multi-band fluxes, hardness ratios, and variability statistics. In addition, for each X-ray source the CSC includes an extensive set of file-based data products that can be manipulated interactively, including source images, event lists, light curves, and spectra.

Introduction

The *Chandra Source Catalog (CSC)* is eventually intended to be a definitive catalog of X-ray sources detected by the *Chandra X-ray Observatory*. The catalog is being deployed using a phased approach:

- Each new release will add new capabilities and additional functionality
- New catalog release will take place roughly every 18–24 months

Release 1 (March 2009) includes 135,914 source detections from 3,912 observations, totaling 94,676 apparently distinct X-ray sources on the sky.

This release is restricted to point and compact sources with flux estimates that are at least $3\times$ their estimated 1σ uncertainties (~ 10 counts on-axis, and 20–30 counts off-axis) in at least one energy band, and observed spatial extents $\leq 30''$, detected in a subset of ACIS imaging observations released publicly prior to January 2009. Observations of fields containing extended sources are excluded from the catalog, or in some cases only a part of the field is included. Source detection is performed on each observation individually (multiple observations are not co-added).

For each source the catalog includes numerous tabulated properties, including:

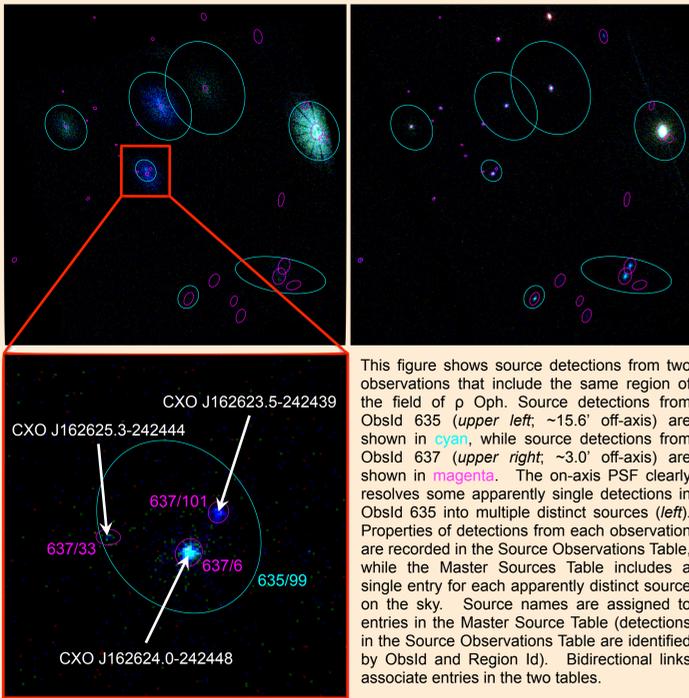
- Source positions and position errors,
- Aperture photometry fluxes and confidence limits in several energy bands, computed using several different methods
- Multi-band spectral hardness ratios,
- Power-law and thermal black-body spectral fits for bright sources,
- Intra- and inter-observation source variability measures,
- Estimates of the source extent compared to the local PSF.

In addition, a number of file-based data products are produced for each observation and source individually, suitable for analysis in the CIAO data analysis environment. They include full field images, exposure maps, and limiting sensitivity maps; together with source region and PSF images, source region exposure map, source light-curve, source region photon event list, ARF, and (for ACIS) source PI spectrum, and RMF.

Each release of the CSC includes a complete characterization of the statistical properties of the catalog, determined using a combination of simulations and real data sets reported in other published *Chandra* catalogs.

Catalog Organization

The catalog is split into two principal tables of source properties. The *Master Sources Table* contains one entry for each apparently distinct detected X-ray source on the sky, while the *Source Observations Table* contains one 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.



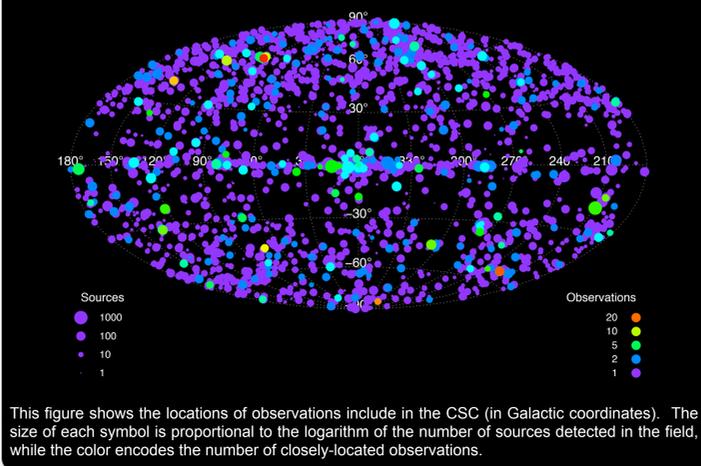
Future Releases

Release 1.1 (Spring 2010) includes public HRC-I imaging observations, and newly public ACIS observations, but otherwise retains the same limitations as Release 1.

Release 2 (~ 2011) co-adds multiple observations with the same instrument configuration and similar pointings (within $\sim 30''$) prior to source detection, and includes sources down to a faint threshold (~ 5 counts). This release also provides improved handling of extended emission (up to $\sim 60''$ spatial scale), and numerous algorithm improvements.

Catalog Sources

The first release of the CSC includes sources detected in public ACIS imaging observations from roughly the first 8 years of the *Chandra* mission.



This figure shows the locations of observations included in the CSC (in Galactic 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.

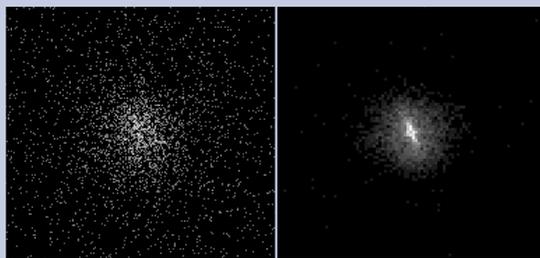
Tabulated Source Properties

The Source Observations Table includes entries tabulating raw and derived properties from each detection in each single observation. Roughly 120 distinct properties are tabulated (total of 599 table columns including measured values and associated confidence limits across all energy bands).

The Master Sources Table contains estimates of "mean" source properties for each apparently distinct source on the sky, derived from observations in which the source is detected and is not confused. Roughly 60 distinct properties are tabulated (total of 287 table columns).

Bidirectional links within the catalog database connect each entry in the Master Sources Table with associated entries in the Source Observations Table. These links uniquely associate matching detections across multiple observations of the same X-ray source, and also identify any associated confused off-axis source detections that have been resolved into multiple distinct X-ray sources by additional observations.

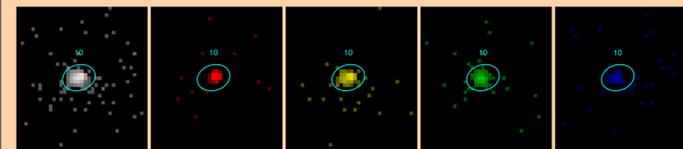
Tabulated source properties include source position and position uncertainties, significance (S/N), measured source and model local PSF extent, estimated deconvolved source extent, source and background region apertures, PSF 90% ECF aperture, multi-band aperture photometry fluxes, cross-band spectral hardness ratios, absorbed power-law and black-body spectral fits (for 150+ net source counts only), K-S, Kuiper, and Gregory-Loredo 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, is piled-up, saturated, etc.).



This figure shows the broad band image of the mildly extended ($\sim 1.2''$ deconvolved size) source CXO J140037.1+622132, observed at an off-axis angle $\theta \sim 9.2'$, on the left, with the associated model PSF on the right.

Energy Bands

The CSC computes source properties in 5 ACIS energy bands — broad (0.5–7.0 keV), ultra-soft (0.2–0.5 keV), soft (0.5–1.2 keV), medium (1.2–2.0 keV), and hard (2.0–7.0 keV) — and 1 HRC energy band — wide (~ 0.1 –10.0 keV). Band images and exposure maps are provided for each source, together with full-field limiting sensitivity maps.

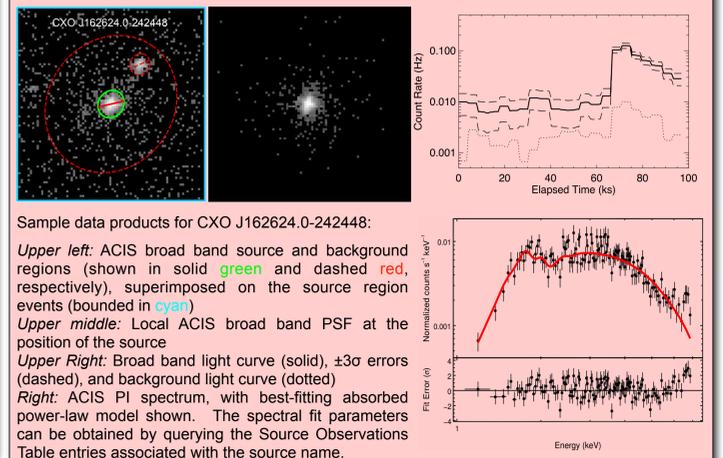


This figure shows the broad, ultra-soft, soft, medium, and hard band event images of the source CXO J021920.8-025840. The source region aperture is superimposed in cyan.

Acknowledgements. Support for the development of the *Chandra* Source Catalog is provided by the National Aeronautics and Space Administration through the *Chandra* X-ray Center, which is operated by the Smithsonian Astrophysical Observatory for and on behalf of the National Aeronautics and Space Administration under contract NAS8-03060.

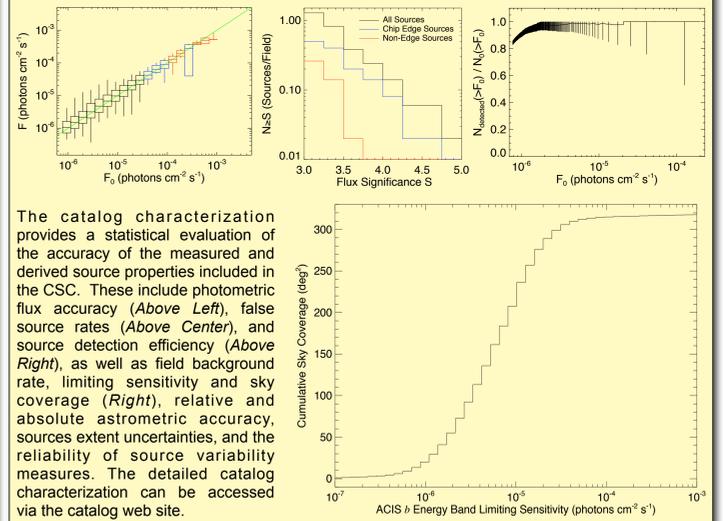
Catalog Data Products

The CSC includes a set of full-field (per-observation) and source-specific (per-source-detection) data products that can be manipulated using CIAO tools.



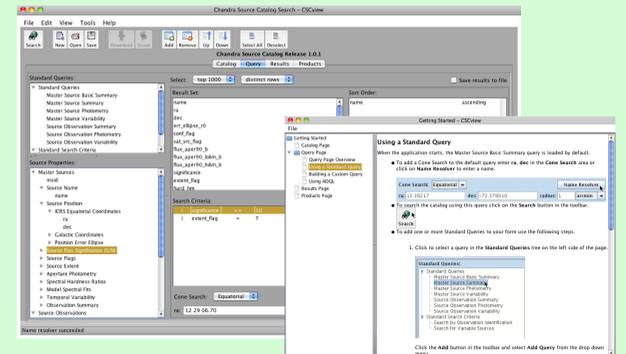
Statistical Properties

Each release of the CSC is accompanied by a detailed statistical characterization of the tabulated source properties. The characterization is developed primarily through the use of simulated datasets, including both empty fields (blank-sky) and simulated sources. These simulated datasets are processed by the catalog pipelines in the same fashion as real datasets.



Data Access

Several interfaces support access to CSC data. Poster 40.12 *Chandra Source Catalog: User Interfaces* (Bonaventura et al.) provides a description of the various interfaces that are available. The primary interface for accessing the catalog is *CSCview*, which provides query and data mining capabilities and data product retrieval.



Additional interfaces include *CSC Sky in Google Earth*, which allows the user to visualize the catalog directly using the Google Earth, as well as a command-line interface, sensitivity map service, IVOA-compliant Simple Cone Search, and the CSC-SDSS Cross-match Catalog.