Chandra Source Catalog

Ian Evans, for the *Chandra* Source Catalog team

The current release of the *Chandra* Source Catalog (CSC) continues to be well utilized by the astronomical community. Usage over the past year has averaged more than 10,000 searches per month, summed across the various user and virtual observatory catalog interfaces supported by the CXC. Version 1.1 of the CSC, released in late 2010, includes properties and data for 158,071 detections from 5,110 *Chandra* observations, comprising 106,586 distinct sources on the sky.

When we released version 1.1 of the CSC, our plan was to provide an updated version of the catalog once sufficient new data had been accumulated. However, during the period since release 1.1, the CSC team at the CXC has received numerous suggestions from the community for improvements to be included in release 2.0 of the catalog, and we have carefully considered how to best respond to those requests. The most common request for release 2.0 was to "go deeper", and that is where our efforts have been concentrated. Release 2.0 will not only go deeper, but will also include 5 more years of data (observations released publicly during 2010–2014) than the previous release.

A two-fold approach has been used to improve the depth of the catalog, by (a) stacking multiple observations of the same field prior to source detection, and (b) using an improved source detection method that allows us to reliably detect point sources down to roughly 5 net counts on-axis, for exposures shorter than the median *Chandra* observation duration. To minimize the impact of the variation of the *Chandra* point spread function (PSF) across the field, source detection in release 2.0 is constrained to run on stacks of observations that have pointings co-located within 60 arcsec, and that use the same instrument. Source

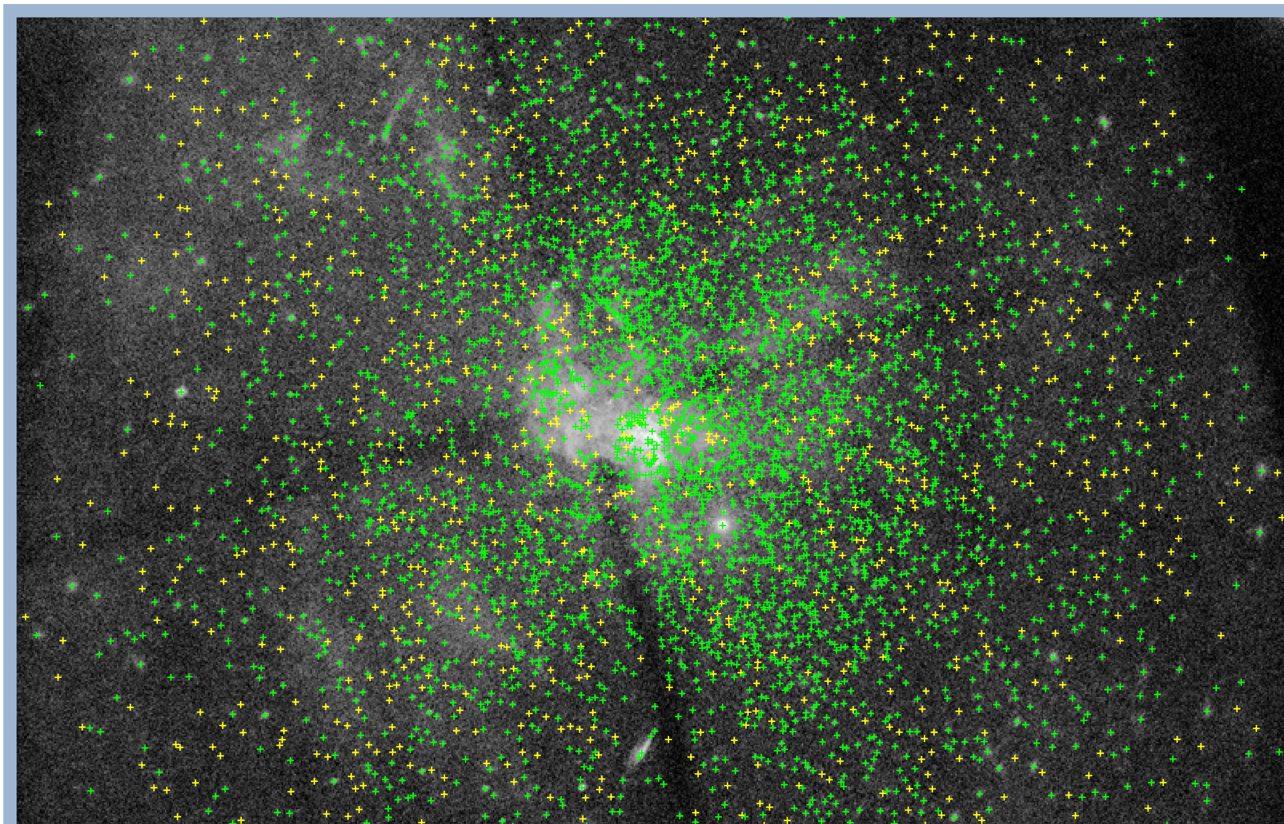

Fig. 1 — This image consists of a stack of 44 ACIS observations of the region surrounding Sgr A, with source detections from a pre-release version of the CSC 2.0 processing system. Although the source likelihoods were not yet calibrated in detail at the time of this preproduction test run, all of the detections shown have preliminary classifications as "true" (green crosses) or "marginal" (yellow crosses). There are roughly 20% more detections identified than in the well-known Muno et al. (2009) catalog in the same area. The size of the image is roughly 17 × 11 arcmin.*

detection is performed primarily using the CIAO wavelet detection tool (`wavdetect`) that was used for release 1.1, but with the tool parameters updated to detect fainter candidate sources, albeit with an unacceptably large false detection rate. A new maximum likelihood estimator, `mle`, uses *Sherpa* to fit the local PSF model (and with the local PSF model convolved with an elliptical Gaussian, to simulate sources with inherent extent) to each candidate source, in order to evaluate the likelihood that the candidate source is real. Candidate source detections will be classified as either "true" or "marginal" in the catalog, depending on their likelihood. However, catalog users will be able to access the lists of all candidate source detections regardless of these thresholds. Fitting with the local PSF should also improve source astrometry, particularly for larger off-axis angles where PSF asymmetries can bias the `wavdetect` position determinations.

Release 2.0 uses a new Voronoi-tessellation background tool, `mkvtbkg`, to create improved background maps prior to source detection. In many cases, these background maps perform better than the release 1.1 maps in regions where the background intensity is changing rapidly, for example near galaxy cores, and at large off-axis angles. As a side effect, `mkvtbkg` can identify regions containing extended emission, and this capability will be used to include bright, extended sources in the CSC for the first time. Such sources will include a bounding convex hull polygon in the catalog. Sets of polygons with multiple intensity thresholds will be available to end users who wish to perform more detailed analyses of detected extended sources. The impact of better backgrounds, stacking observations, and deeper detections using the `wavdetect`/`mle` combination is demonstrated spectacularly in Figs. 1 and 2, from a preproduction test run of the catalog pipeline on the Sgr A* field.

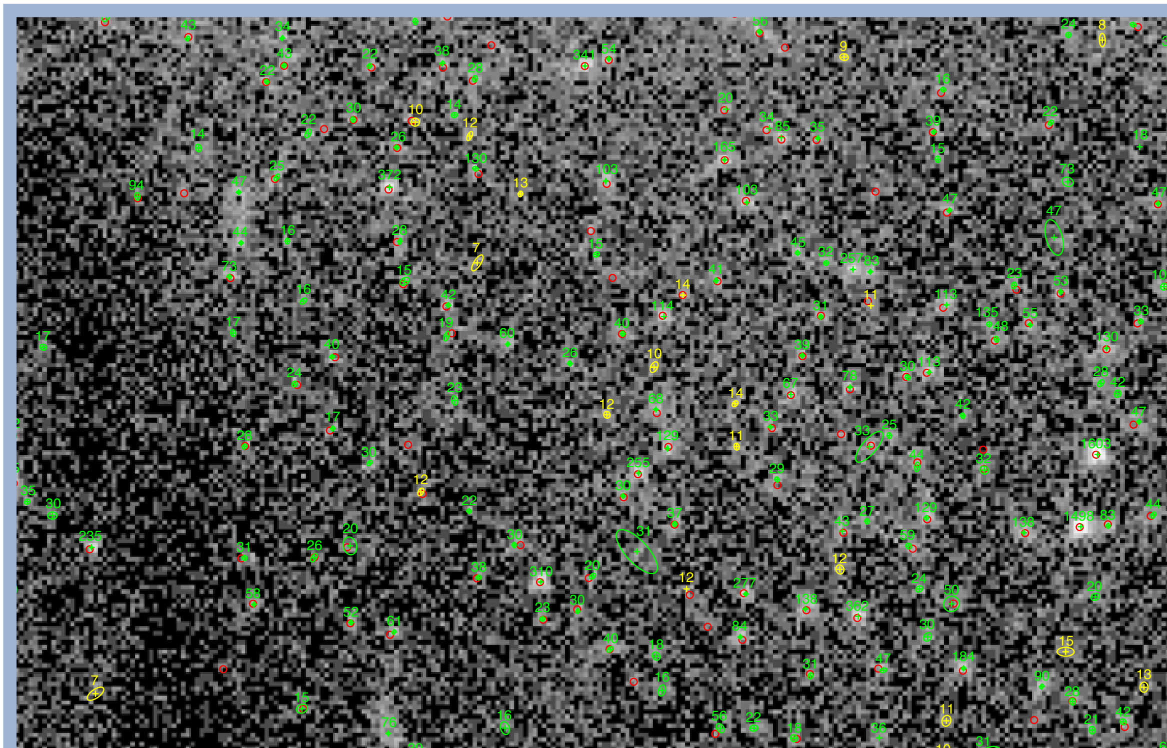

Fig. 2 — This image zooms in on a region of the field to the South of the core of Sgr A. The green and yellow crosses indicate the fitted source positions for "true" and "marginal" sources respectively, with error ellipses shown in most cases (error ellipses were not generated in all cases in this preproduction test run). The numbers listed with the detections are the raw (i.e., uncalibrated) source likelihood values. The red circles show the source positions from the Muno et al. (2009) catalog. A number of sources not present in the Muno et al. catalog are visible in the stacked images, and are detected in the CSC 2.0 preproduction test run. Conversely, a small number of sources reported in the Muno et al. catalog are not detected (or are below threshold) in the test run. Some differences in detections are to be expected at the faint limit, since the dataset used herein includes ~ 1/3 more exposure than the dataset of Muno et al. The size of the image is roughly 128 × 80 arcsec.*

Enhancements to the Bayesian aperture photometry code are included in release 2.0 of the CSC, and the photometric probability density functions are used directly for computing such quantities as hardness ratios and temporal variability measures, to avoid some inconsistencies present in release 1.1 of the catalog where these properties were computed independently.

Sources detected at the edges of the field of view, in the gaps between ACIS back-illuminated and front-illuminated chips (on the ACIS-S array), and on readout streaks associated with saturated, bright sources, are excluded from the CSC 2.0. In release 1.1, a significant fraction of sources in these regions were determined to be false. Release 2.0 will include limiting sensitivity maps computed on a fine-grained (4 × 4 arcsec) scale so that users can identify regions that are included in/excluded from the catalog.

As in release 1.1, CSC 2.0 will include numerous raw measurements for each detected source, as well as scientifically useful properties (and associated errors) derived from the observations in which a source is located. These properties include estimates of the source position, extent, and aperture photometry fluxes in several energy bands. Cross-band spectral hardness ratios will be reported for all detected sources, together with absorbed power-law, bremsstrahlung, and black-body spectral fits for brighter sources. Several source variability measures will be computed, both within a single observation of a source and between multiple observations that include the same source.

In addition to the tabulated properties, CSC 2.0 will provide FITS (and in some cases, JPEG) format data products that include full field event lists, multi-band images, exposure maps, limiting sensitivity maps, merged source lists, and extended source polygons. Source region data products include per-source-region event lists, multi-band images, photometry probability density functions, exposure maps, pulse-invariant spectra, spectral response matrices, and optimally binned light curves.

Production of release 2.0 of the CSC will require many months to run, even using a dedicated 320-core compute-cluster. When complete, the catalog should include information for of order 400,000 source detections from roughly 10,000 *Chandra* ACIS and HRC-I imaging observations. The total volume of archived data products available to the user is expected to exceed 20 TB.

To facilitate user access to the catalog as quickly as possible, production is being split into two major phases. The first phase recalibrates all of the *Chandra* data sets that are included in release 2.0, generates backgrounds, performs source detection, and then evaluates the candidate detections' likelihoods using the `mle` tool. This phase is expected to be complete in (Northern) autumn 2015. During this phase, a subset of the information contained in the resulting merged source lists will be combined into a "Preliminary Detections List" that will be incrementally updated on the catalog website. This list will include positions, likelihoods, extents, and associated errors. True aperture photometry will not be available, although a fitted intensity that is a reasonably good proxy (except in the Poisson regime) will be included. Properties derived from true aperture photometry, such as hardness ratios, spectral information, and variability measures, will not be available. Some error estimates will be preliminary. The remaining steps to complete release 2.0 of the CSC, including merging detections across multiple overlapping fields, extracting source properties, constructing the final catalog, and completing quality assurance processing, will take perhaps an additional 6 months. At that time CSC 2.0 will be made the official catalog release accessible by default through our standard catalog interfaces.

The CSC website (http://cxc.cfa.harvard.edu/csc/) provides access to the current version of the catalog, as well as a large bank of user documentation. The latter describes in detail the content and organization of the catalog, and lists important caveats and limitations that should be reviewed by prospective users. The various user interfaces are described, and there are several examples and user threads that demonstrate the use of these tools to access the catalog. The user documentation on the catalog website is continually improved as new features and capabilities are added. News updates about release 2.0 of the catalog will be added as processing progresses!

References

Muno, M. P., et al. 2009, ApJS, 181, 110.