

# CHANDRA AUTOMATED POINT SOURCE PROCESSING FOR CALIBRATION MONITORING

Bradley D. Spitzbart and Scott J. Wolk  
Chandra X-ray Center (CXC)

Harvard-Smithsonian Center for Astrophysics (CfA), Cambridge, MA, USA



We have developed a system to automatically analyze Chandra x-ray observations of point sources for use in monitoring telescope parameters such as point spread function, spectral resolution, and pointing accuracy, as well as for use in scientific studies. The Chandra archive currently contains at least 50 observations of stellar cluster-like objects, yielding 10,000+ sources of all spectral types well-suited for cataloging. The system incorporates CIAO tools, Acis\_extract (Penn State), and YAXX (SAO) pipelines. Our software contribution comes in compiling the final results, merging in data from other catalogs, formatting text and XML output for web display, and developing back-end tools for analysis. We will outline this processing pipeline design and challenges and focus on its role in monitoring on-orbit observatory performance.

The *Chandra X-ray Observatory* was launched in July 1999 and has performed reliably since. Typical nuances and judgement calls in data analysis lead to many difficulties in comparing published data from different observers or from different observation dates. The data reduction and analysis software itself changes over time which can affect the final results even on the same dataset. In most cases different spectral models, parameter settings, and classification criteria will be applied based on the observer's preferences and familiarity. The goal of our catalog is to provide a uniform (not necessarily optimal) database for the comparison of data from different stellar clusters. This type of catalog provides added science return as well as convenient observatory health and performance metrics. The catalog will make it possible to treat science quantities in similar ways to how spacecraft temperatures and voltages are treated for monitoring and trending. This assessment takes into account instrumental, aspect reconstruction, and ground software factors.

## Observatory Performance Metrics

Using PSF and spectral line measurements from all the best point sources (greater than 200 counts) gives a much better baseline than could be available from a necessarily limited calibration campaign.

The figure at right shows the 90% encircled energy radius (EE) at 1.49 keV vs. off-axis angle,  $\theta$ , from the nominal airmass for sources combined from throughout the *Chandra* mission. Highly piled-up (bright) sources are apparent with EE radii less than 2.3 arcsec. The curve fits a polynomial of the form,  $EE = 8e^{-5}\theta^2 - 0.019 + 3.0$ . By filtering on time or energy we can detect shifts in this fit which indicate any mirror alignment problems.

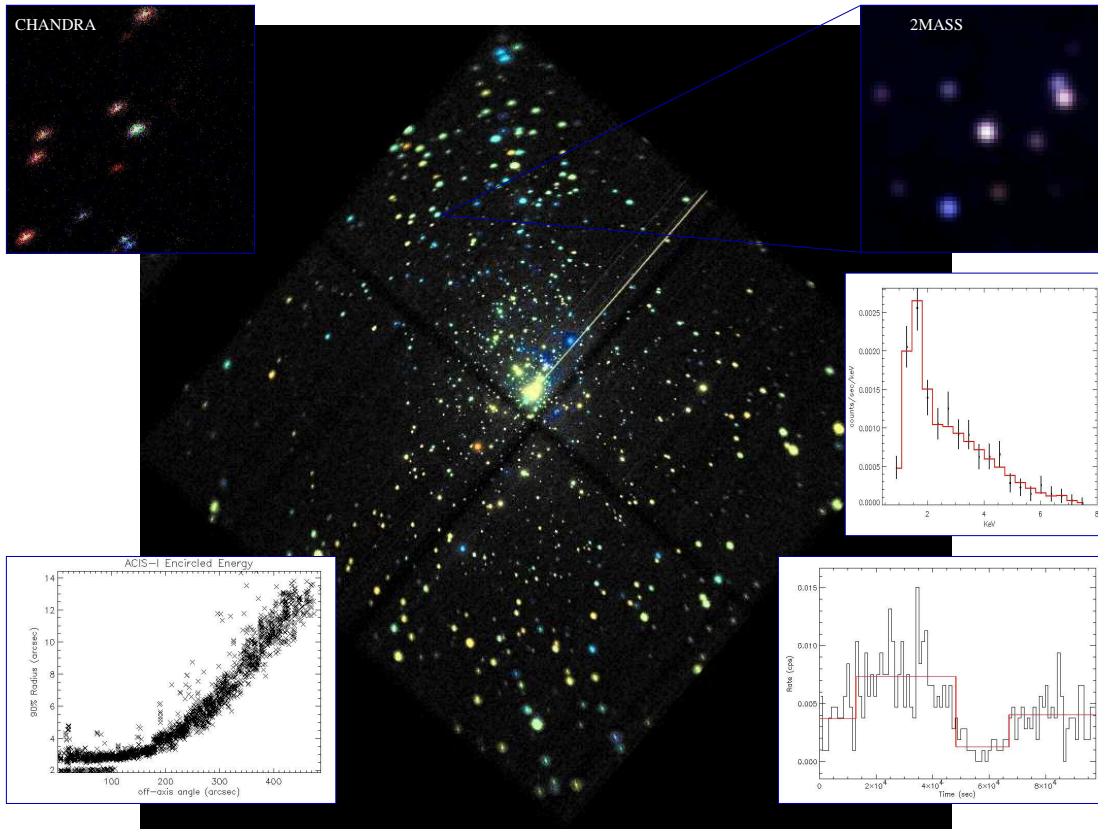
The Orion Nebula Cluster was observed for 1 million seconds in January 2003 and provides a good test of observatory performance applications with over 900 detected sources. This image gives an excellent view of the telescope focal plane. Note the elongation and rotation of sources far off-axis due to the cylindrical shape of *Chandra*'s mirrors. The elongation and rotation as a function of chip position is an important quantity to measure and track over time, as any shifts must be explained. Our catalog will enable a "mega image" of all point source photons that have fallen on the focal plane.

ACIS offers the capability to simultaneously acquire high resolution images and moderate resolution spectra. Therefore, we have intrinsic energy information for each photon collected. We will build up a list of absorption and emission lines for comparison against time and detector location and not be limited to the energies tracked now from the external calibration source. Spectral characteristics can be used to monitor CTI and to monitor for a systematic appearance of any new absorption features indicating contamination on the mirror or focal plane surfaces.

Thermal control has become a topic of concern on-orbit. Due to radiation interactions the spacecraft's silver teflon insulation has darkened at a faster rate than expected, leading to higher temperatures. Although mirror and optical bench components can peak several degrees above established norms, no image distortions are reported to date. The point source catalog will confirm this result and provide a method of continued monitoring. Distortions introduced by the aspect reconstruction system, either hardware or software, will be readily apparent.

## Science Applications

The archive is designed to aid both the X-ray astronomer with a desire to compare X-ray datasets and the star formation astronomer wishing to compare stars across the spectrum. It brings together *Chandra* data on open clusters and other bright, variable, young stars for the study of the various physical mechanisms indicated by the x-ray emission. *Chandra*'s superb spatial resolution allows the resolution of stars in crowded regions 2-3 kpc away. With good sensitivity between 2 and 8 keV, *Chandra* can penetrate star forming clouds to levels rivaling near-IR telescopes. These features allow novel investigations of star formation which is more massive, more embedded and more distant than previously possible. Using the point source database, one could follow the progression of luminosity and variability for various mass stars from the birthline to the present day without having to weigh the impact of the different analysis assumptions made by each team.



A one million second Orion Nebula Cluster observation. We measure and track the elongation and rotation of sources as a function of off-axis angle and chip position. Spectral fits and lightcurve analysis is performed for each field source.

## Processing

To accomplish automated analysis we employ several independent software packages. This allows for much code-reuse and minimal buy-in costs or new development.

### Data Preparation

Standard CXC data products and CIAO software tools are used to download data from the archive, to create exposure maps (`merge_all`), and to detect point sources (`PWDetect`). Appropriate source and background regions are constructed based on the Chandra PSF library and desired encircled energy using the parameterization by Kester Allen (2003).

### Standard Analysis

The `Yaxx` package by Tom Aldcroft (CfA) completes the analysis steps..

1. Extract source events.
2. Extract source and background spectra.
3. Fit spectra using `Sherpa`. This step can be repeated any number of times for different models and different initial guesses.

### Add-on Analysis

**Quantile Spectral Analysis** (JaeSub Hong, CfA, 2004) augments spectral fitting and traditional hardness ratios. Quantile analysis determines the energy values that divide the detected photons into fractions of the total counts. This is especially useful for faint sources where low statistics preclude meaningful spectral fitting.

**Bayesian Block lightcurves** (Jeffrey Scargle, MIT, 1998) yield a segmentation of time intervals during which the photon arrival rate is statistically constant. The resulting locations, amplitudes, and rise and decay times provide another metric for identifying flaring and variable candidates. The code is written in `s-lang`.

### Data Compilation/Output

The `Yaxx` output data files in FITS and ASCII are compiled and converted to XML by `Perl` scripts. Available information from other sources is included when possible. Some of this is generated automatically. For example, DSS and 2MASS images are downloaded using `SkyView` and a link to query `SIMBAD` for basic data and name cross-references can be easily created given any source position. Other facts must be gathered manually. Here, a query of the Astronomical Data System (`ADS`) and scan of the returned articles can turn up mass, distance, and multi-band magnitude values.

### Performance

A typical observation with 400 point sources processes completely in about 24 clock hours on a 4 processor sunFire.

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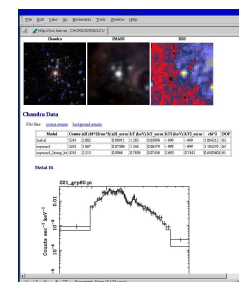
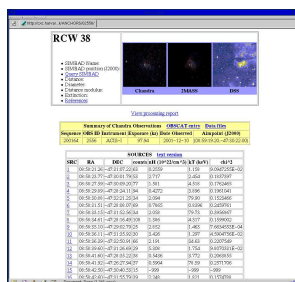
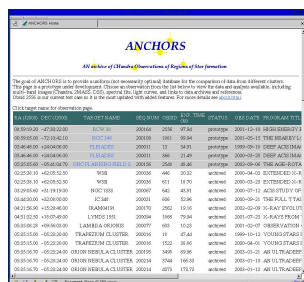
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Prototype website: <http://hec-www.harvard.edu/~swolk/ANCHORS>



The catalog's three main page types. Links and information about all available observations are listed on the top page (left). Each observation has its own sub-page (middle). And each source has its own page, showing multi-band images and plots, spectral fit parameters and plots, and light curve plots and statistics (right).