Maintaining Software for Active Missions: A Case Study of Chandra's Instrumentation Over Time

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Abstract

During eleven plus years of operation, ample knowledge has been gained regarding the Chandra X-ray Observatory's scientific instruments and how they are performing over time. In this paper we will summarize the significant software changes related to the performance and knowledge gained about the observatory's instrumentation specifically targeting the last five years of the mission. With this knowledge, numerous upgrades to the Chandra processing software have taken place to correct issues that have developed on orbit (ACIS CTI effects, LETG/ACIS rotation), to correct for hardware issues (HRC timing), and for our better understanding of the evolution of the instrumentation (temporal gain shifts in both instruments).

In addition, we will discuss the challenges in maintaining software when the calibrations for different operating modes are incrementally made available. This includes challenges in maintaining an archive with a mixture of data products with different calibrations applied. This paper roughly covers the era of the 3rd reprocessing of the Chandra archive (Repro-3).

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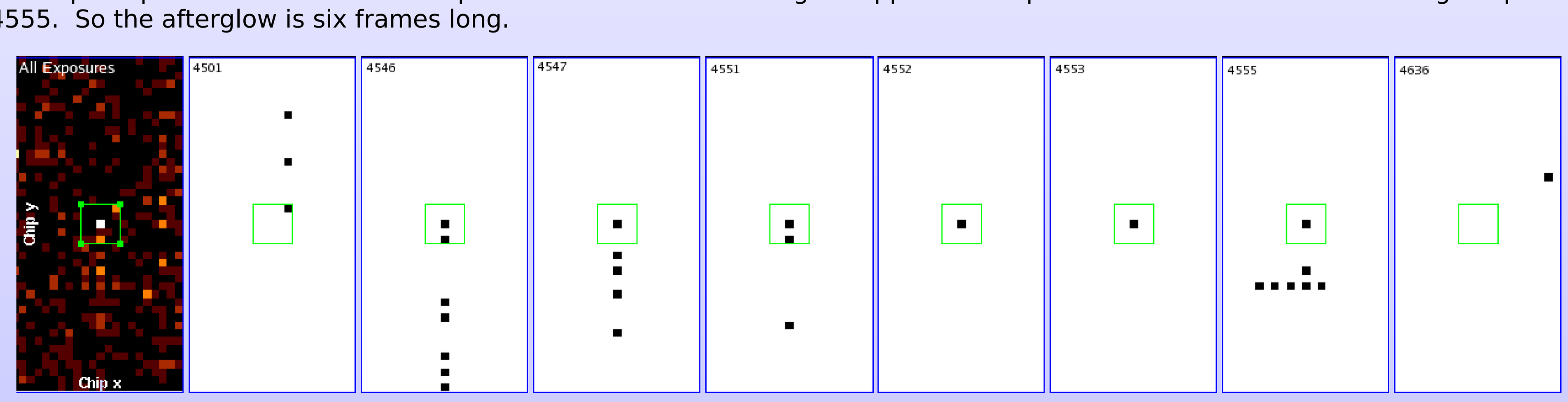
ACIS – Afterglow Detection

A cosmic-ray "afterglow" is produced when a large amount of charge is deposited on a CCD by a cosmic ray. Most of the charge is clocked off of the CCD in a single frame. However, a small amount can be captured in charge traps, which release the charge relatively slowly. As a result, a sequence of events can appear in a single detector pixel over a few frames as the trapped charge is released.

To date, two algorithms have been used by the CXC to identify cosmic-ray afterglows. The first algorithm was implemented in the CIAO tool *acis_detect_afterglow* and used for pipeline processing from the summer of 2000 to the fall of 2004. In an attempt to minimize the loss of source events, another algorithm was developed and implemented in the CIAO tool *acis_run_hotpix* , which is a wrapper around the tools *acis_find_hotpix*, *acis_classify_hotpix* and *acis_build_badpix*. This algorithm has been used for pipeline processing (and reprocessing) since the fall of 2004.

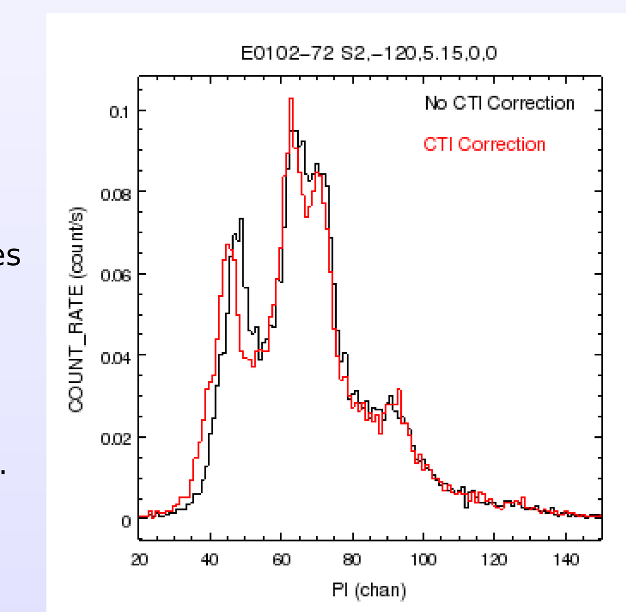
A third afterglow-detection algorithm is being implemented. The principal change being the algorithm searches for afterglows using the events in a short, sliding time window instead of using the events from the entire observation (i.e., the algorithm searches in three dimensions instead of two). Like the second algorithm, it is designed to avoid discarding events associated with real astrophysical sources. It is also designed to enhance the detection efficiency for afterglows that have as few as four events.

The figure below demonstrates the afterglow phenomenon. The first panel shows the data integrated from all exposures. The subsequent panels show individual exposure numbers. The afterglow appears in exposure 4546 and continues through exposure 4555. So the afterglow is six frames long.



ACIS – CTI Correction & Destreak

CTI Correction:
When X-rays (and cosmic rays) deposit charge in an ACIS CCD, the charge is read out using one of four sets of read- out electronics. Each read out is used for a specific 256 pixel x 1024 pixel subset (node) of the CCD. Since charge is read out at only one location on a node, the charge at all other locations must be moved to the read out. Charge is moved both vertically (i.e. in the negative CHIPY or "parallel" direction) and horizontally (i.e. in the positive or negative CHIPX or "serial" direction). The total number of pixels through which charge must be moved depends on the location at which charge is deposited on the CCD. As charge is moved, some may be lost to charge traps that are distributed across the detector. The mean fractional amount of charge lost per pixel transferred is called the charge transfer inefficiency (CTI). Due to the accumulated effects of cosmic radiation damage, the number of charge traps (and, hence, the CTI) on the CCDs is increasing with time.



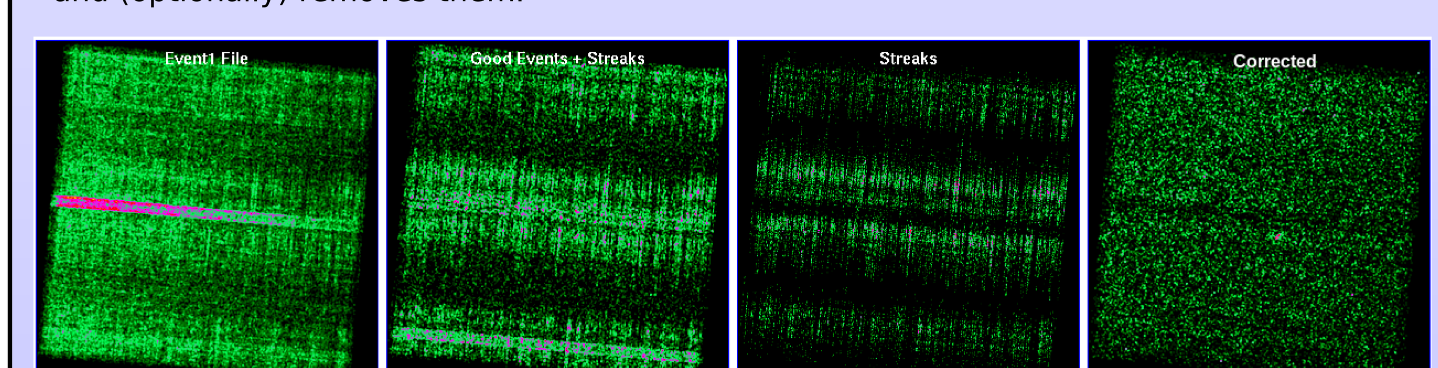
CTI affects the measured spectral distribution of astrophysical sources in two ways:

1. Since some of the charge is trapped, the amount of charge read out is less than the amount of charge deposited. This effect causes the measured pulse-height distribution for a source to be shifted to lower pulse heights (i.e. results in an apparent gain shift).

2. For a variety of reasons, CTI causes a degradation in the energy resolution of a CCD. The measured pulse-height distribution of a monoenergetic source (or a line feature) is Broadened.

As of CALDB v3.1.0 (23 June 2005), parallel CTI calibration products are available for the ACIS-I0, I1, I2, I3, S0, S2, S4, and S5 CCDs. Parallel and serial calibration for the back-illuminated chips (ACIS-S1, S3) were released in CALDB v3.3.0 (18 December 2006).

Destreak:
There is a flaw in the serial readout of the ACIS chips, causing a significant amount of charge to be randomly deposited along pixel rows as they are read out. ACIS-S4 (ccd_id=8) is significantly affected by this problem. The *destreak* tool detects coincidence of events in adjacent pixels along a row (i.e. the serial read), flags probable streak events, and (optionally) removes them.

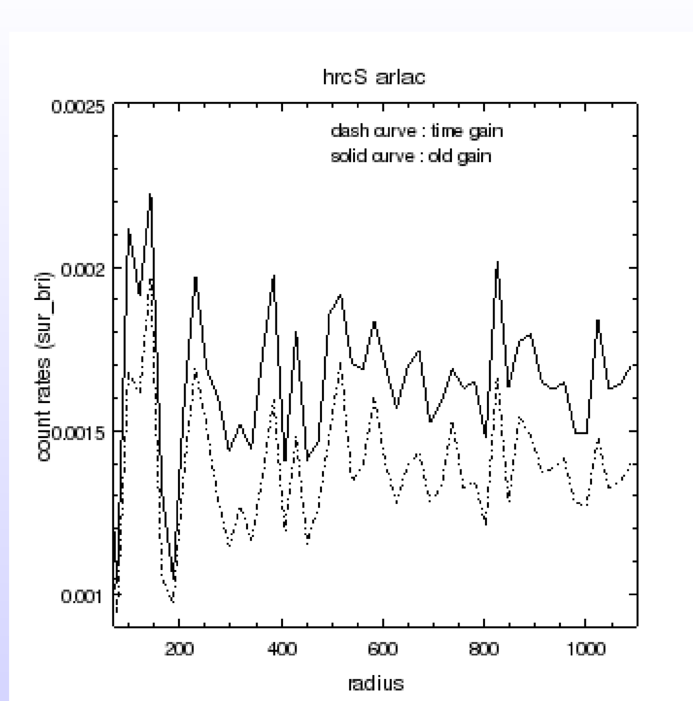


HRC

The new time varying gain correction algorithms for HRC-I and HRC-S have been implemented in the tool *hrc_process_events* to support the new calibration files.

The new gain files for both instruments are based on the sum of amplitudes (SAMP) metric rather than the pha because SAMP is more spatially uniform for the HRC plates than is the pha.

For the HRC-S instrument, the primary purpose of the new gain map application is to reduce background.

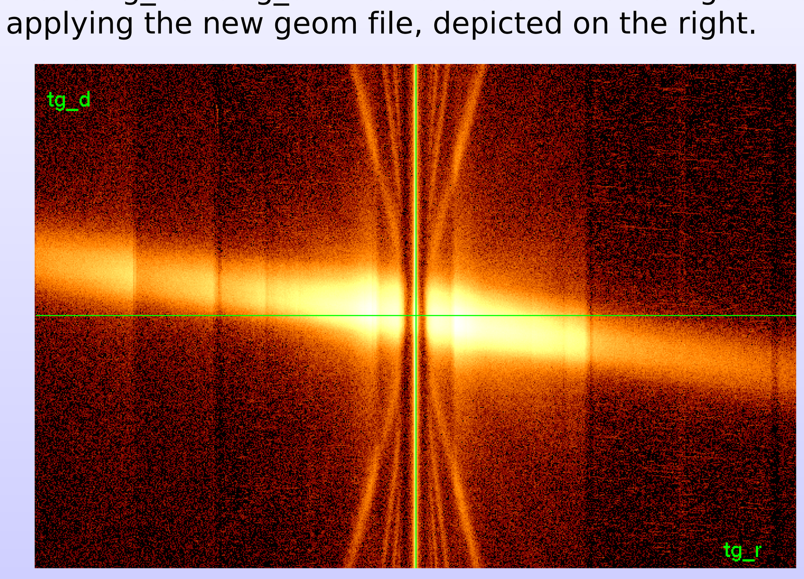


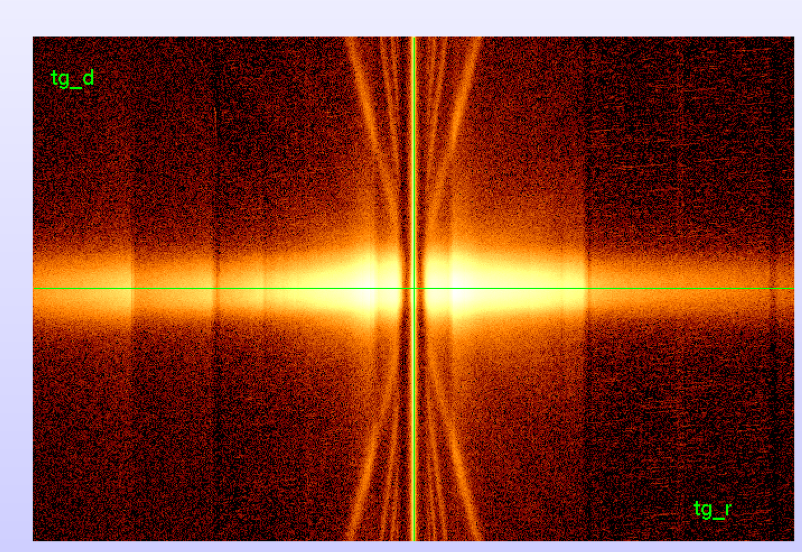
The figure has two plots for HRC-S arlac in the observation ID 11930. The plots were created from processing the events with the old gain file (solid) and with the new time gain map (dash). The background count rates are dropped as desired after applying the new gain file.

Transmission Gratings

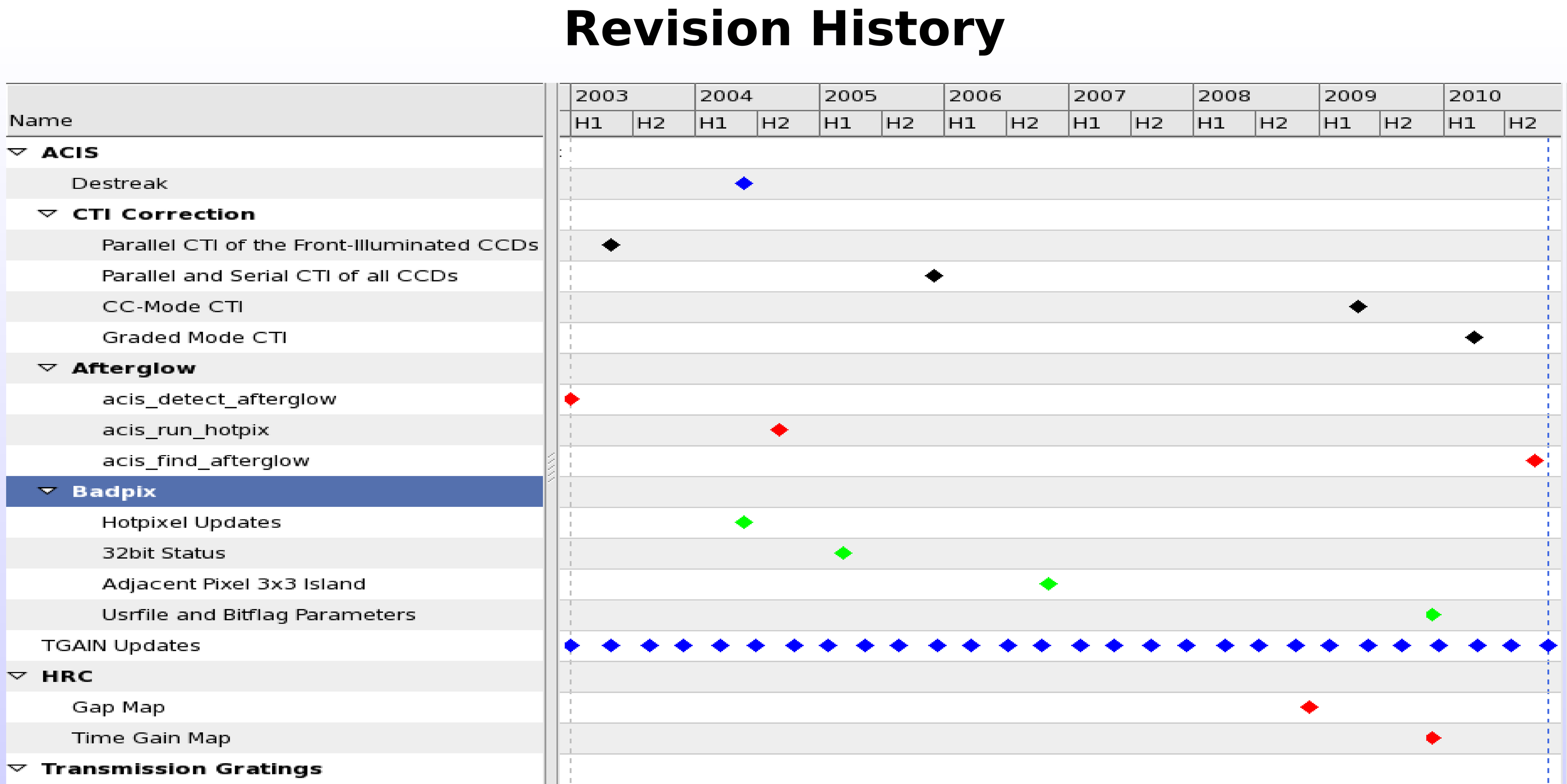
Pixlib, the Chandra coordinate library, has been updated to support a new format geom file which allows independent grating angles for each grating arm as seen by each instrument (ACIS, HRC-I, and HRC-S). Calibration data are different for ACIS LETG compared to HRC LETG.

The images below show the before and after of the ACIS LETG for observation ID 4148. Both images are in the diffraction coordinates tg_r and tg_d with the old and the new geom calibration files. The spectrum on the left become horizontal, as desired, after applying the new geom file, depicted on the right.





Revision History



Conclusions

During the eleven plus years of operation, Chandra has enabled many cosmological discoveries. In addition to these scientific discoveries, ample knowledge has been gained regarding the instruments themselves and how they are performing over time. With this knowledge, numerous upgrades to the Chandra processing software have taken place to correct issues that have developed on orbit (ACIS CTI effects), to correct for hardware issues (HRC timing), and for our better understanding of the evolution of the instrumentation (temporal gain shifts in both instruments). Priority for upgrades is given to the most popular instrumental configurations. In addition to learning about the evolution of the instrumentation, we have learned from our own software and algorithms. As an example the algorithm to detect afterglows is currently in its third iteration. With each step we learn better and more efficient ways to enhance and upgrade one of the most complex scientific instruments ever to fly.

Together with knowledge regarding instrumentation, there were several keys to success which made upgrades and enhancements possible. These include:

* Implementation of flexible, multi-dimensional software
* A consistent style of programming
  -> multiple programmers/developers
* Robust testing for incremental changes
* A single code base for operations and user analysis tools (CIAO)
  -> allows users to re-calibrate data
  -> saves money
* CIAO design based on mission independence