15 Years of CIAO

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It is now almost sixteen years since launch and *Chandra* continues to produce spectacular results! A portion of the success is to be attributed to the data analysis software CIAO (*Chandra* Interactive Analysis of Observations) that the *Chandra* X-ray Center (CXC) continues to improve and release year after year: forty eight software releases—the latest is CIAO 4.7 in December 2014—since the first CIAO 1.0 in 1999.

Chandra Users

While the first release enabled the initial *Chandra* guest observer science, we now continue to extend and improve the CIAO package, supporting the full range of expertise from advanced use by experienced X-ray astronomers to simple analysis by novice users.

CIAO is downloaded more than 1200 times a year (Fig. 1) and it is used by a wide variety of users around the world (we have recorded visits to CIAO web pages from almost every nation in the world, Fig. 2): from novice to experienced X-ray astronomers, high school, undergraduate and graduate students, archival users (many new to X-ray or *Chandra* data), users with a large amount of resources, and users from smaller countries and institutions. The scientific goals and kinds of datasets and analysis cover a wide range: observations spanning from days to years, different instrument configurations and different kinds of targets, from pointlike stars and quasars, to fuzzy galaxies and clusters, to moving solar objects. These different needs and goals require a wide variety of specialized software and careful and detailed documentation which is what the CIAO software is all about. In general, we strive to build a software system which is easy for beginners, yet powerful for advanced users.

CIAO Supports Users from Proposal to Publication

CIAO is comprised of a large collection of data analysis tools, complex scripts, and documentation which aims at supporting users from the moment they plan a *Chandra* observation to when they are ready to publish a paper (Fig. 3). In addition, except for a few instrument-specific tools, most tools can be used for the analysis of other X-ray and even non X-ray data.

At the proposal planning stage CIAO can be used to assess the feasibility of an observation and to examine the *Chandra* field-of-view (e.g., with tools like `colden` and `obsvis`), it can be used for batch archive and catalog searches (e.g., `find_chandra_obsid`, `download_chandra_obsid`, `search_csc`) and to inspect and explore data sets (What is this dataset? How many photons? What is the instrument configuration? Quick look visualization, e.g., with `ds9`, `prism`, `dmlist`, `dmstat`, `dmcopy`). When it is time for detailed data reduction, tools are available to apply the latest calibrations to an observation, to locate

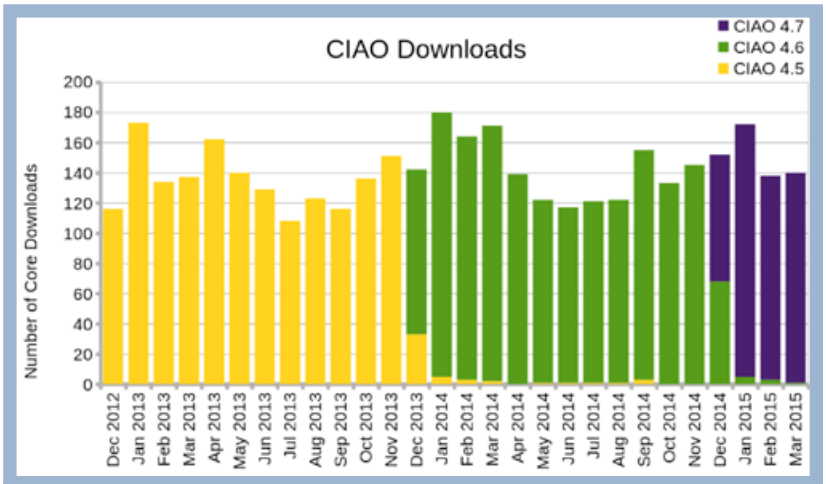


Fig. 1 — CIAO software downloads since December 2012 (CIAO 4.5 to CIAO 4.7).

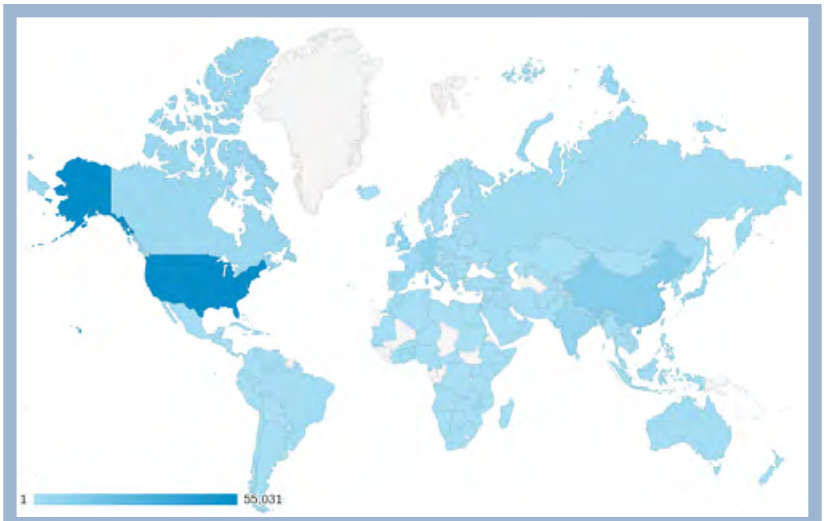


Fig. 2 — Access to CIAO webpages from all over the world over an approximately two year period.

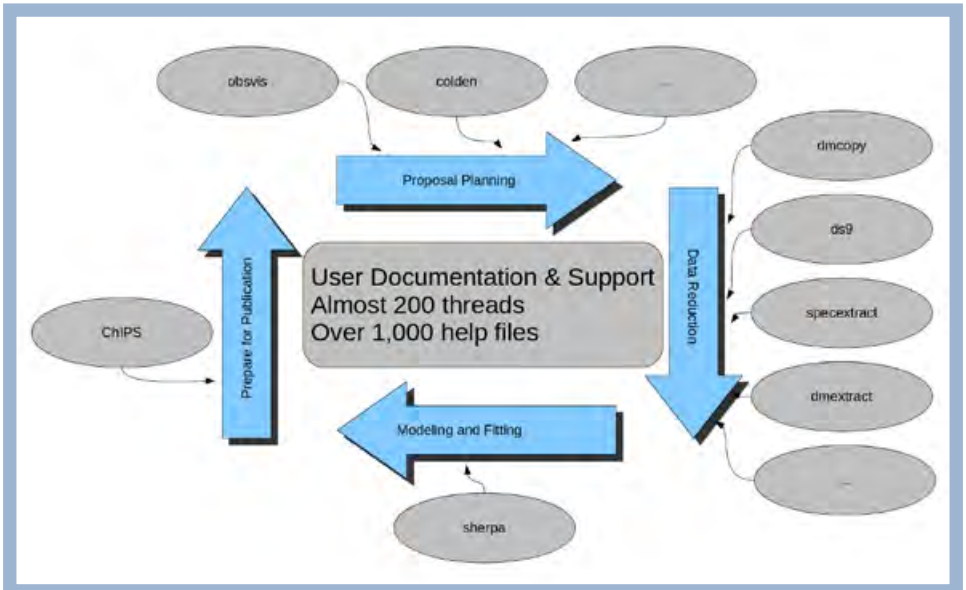


Fig. 3 — Flowchart with the CIAO tools that help users from proposal planning to publication.

sources and measure their properties (position, brightness, and variability), and for each source, to generate tailored calibration files (e.g., spectral calibration) via tools like `dmextract`, `wavdetect`, `specextract`, `srcflux`, and `fluximage`.

In the final stages of the analysis, the *Sherpa* application (the CIAO 1D and 2D modeling and fitting package) is invoked. *Sherpa* is built via a Python interface, which is familiar to the new generation of astronomers and widely used by other missions. Finally, the ChIPS application can be invoked to prepare publication quality graphics.

Documentation and Community Support

One of the most praised characteristics of CIAO is the extent of the documentation that accompanies the data analysis system. CIAO documentation spans over 2000 web pages including FAQ, plot galleries, dictionaries, caveats, tips and tricks, bug notes, etc. There are about 200 science-task-oriented, step-by-

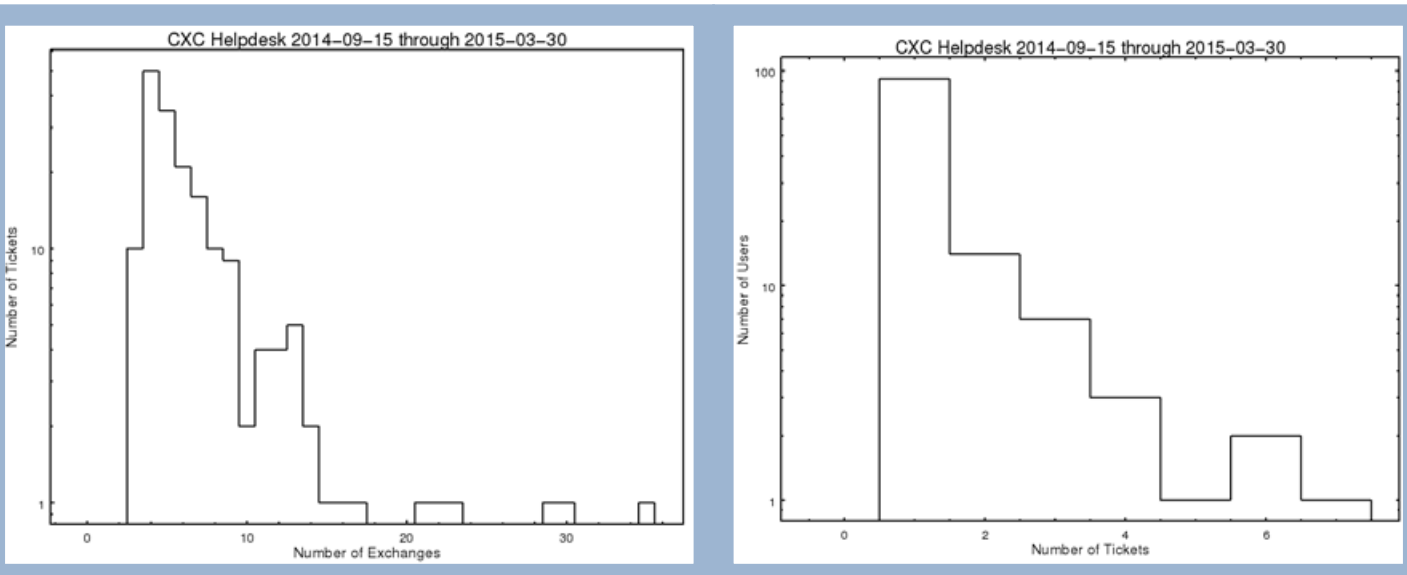


Fig. 4 — Left: Number of tickets vs. number of interactions per ticket. Most tickets have four user interactions: 1) User asks question 2) User get message saying ticket has been assigned 3) CXC contacts user with proposed answer 4) User confirms resolution. A few tickets are far more complex and require many interactions. Right: Number of users vs. number of tickets: a few users send many tickets.

Fig. 5 — Helping users during the hands-on session of the 10th CIAO workshop held at CfA in November 2014.

step, end-to-end, analysis "threads" and about 1000 help files for individual tools and concepts. The latest addition to our outreach effort are YouTube tutorials to walk users through the more interactive tasks.

Personal and prompt support to CIAO users is another aspect of which we are proud. The CXC Helpdesk receives hundreds of CIAO-related queries every year which are resolved, on average, within one day (Fig. 4).

Finally, the CIAO team strives to offer as much one-on-one community support as possible, via *Chandra*/CIAO Workshops hosted at the Center for Astrophysics in Cambridge, CIAO education and support at relevant meetings (e.g., X-ray schools, AAS), undergraduate training via NSF REU program at SAO and in person or email interaction with any astronomer who needs X-ray data analysis help. Most recently the 10th *Chandra* Calibration and CIAO workshop was held in Cambridge (Fig. 5) while a member of the CIAO team participated in the COSPAR Advanced School on X-ray Astrophysics in Mexico.

If you are planning your own workshop or astronomy school the CIAO team is ready to help plan content or can even come as presenters or support staff. Let us know via the CXC HelpDesk.

Always Improving While Responding to Changes

Both the *Chandra* observatory and the needs of users have changed since launch and in the past fifteen years the software has responded to these changes. Some updates are critical, for example updates to keep up with changes in spacecraft and/or instruments (eg., modify analysis tools to support temperature variation, combining shorter observations) or changes in users' hardware and operating systems (eg., Dec Alpha to Solaris to Linux to Mac).

Other improvements support changes in users' needs (2014 is not 1999!). These include changes in scientific approaches and computational approaches (eg., Bayesian methods, parallel processing); compatibility with newer missions; improved knowledge of best practices and special cases, to enhance science and minimize mistakes (eg., applying custom background region for grating spectra).

We identify and prioritize the research and development work on areas needing additional support, for example merging datasets split due to new thermal

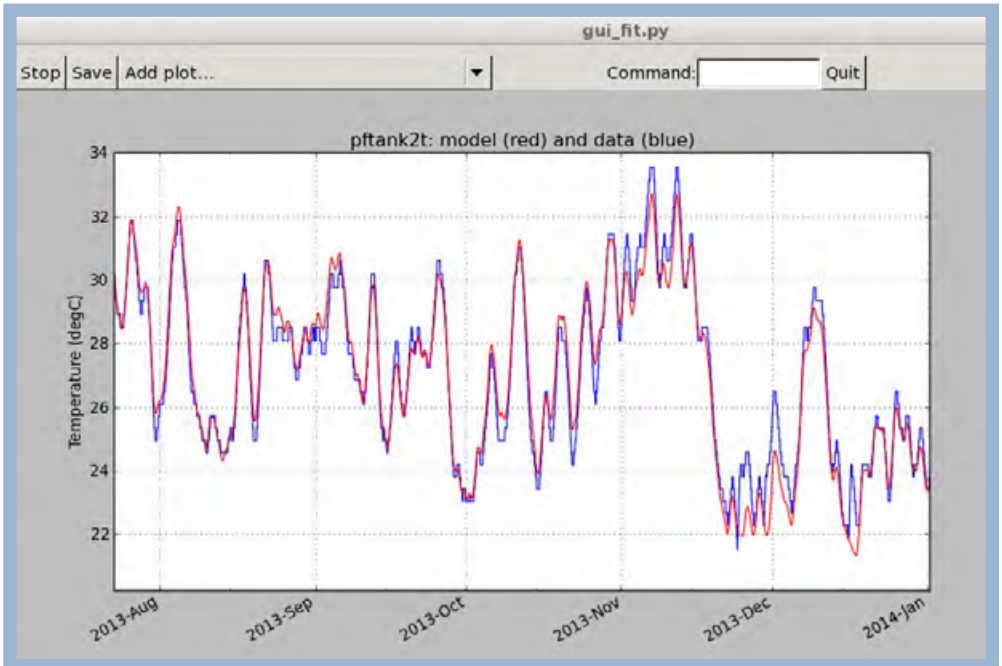


Fig. 6 — Graphical fitting tool using Sherpa to fit a 20-parameter model that predicts the temperature of the Chandra Integral Propulsion System tank. This is used within flight operations to ensure that critical thermal limits are not exceeded. The blue line shows the actual temperatures and the red line shows the model prediction.

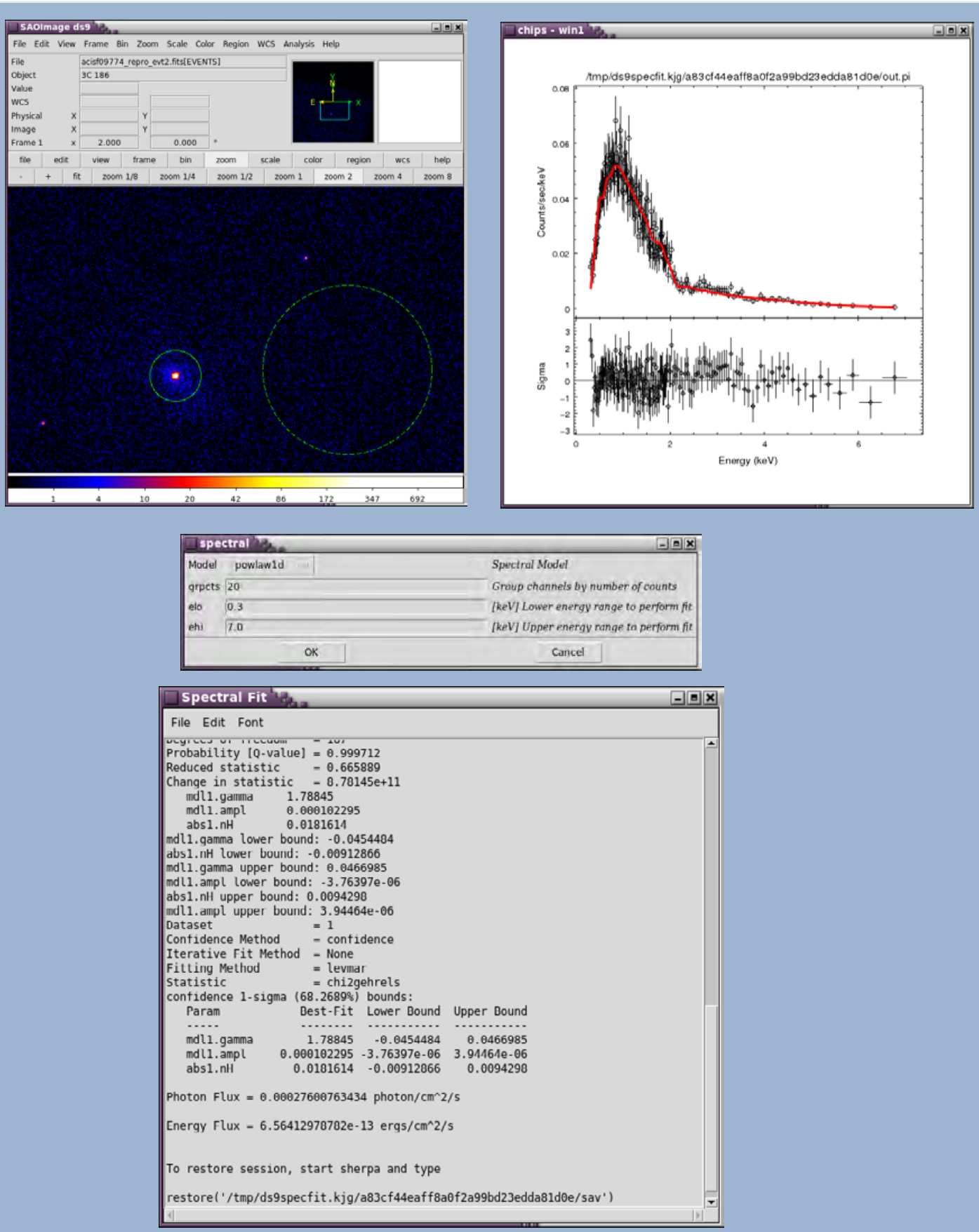
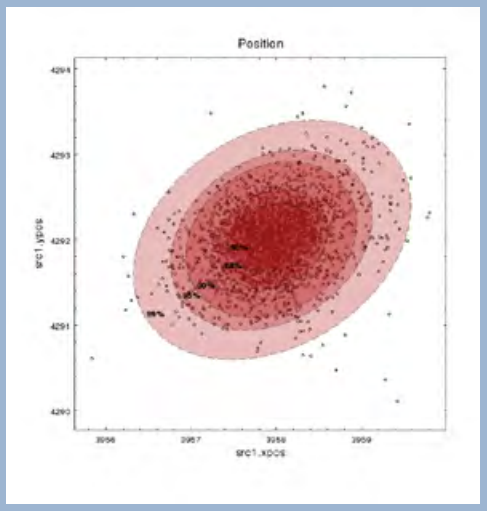
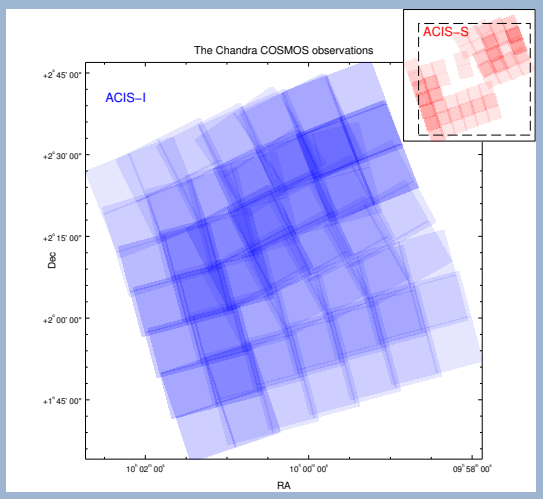
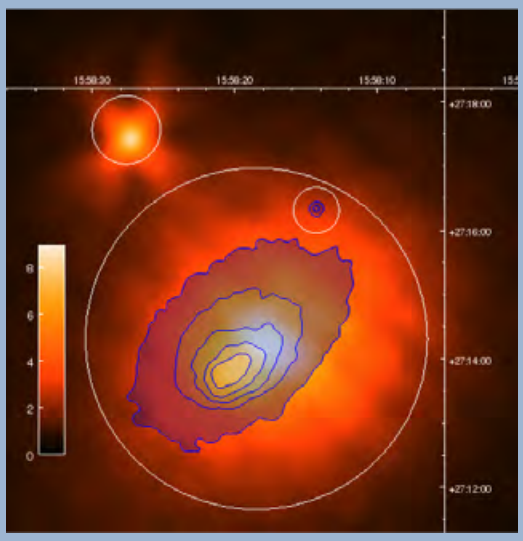
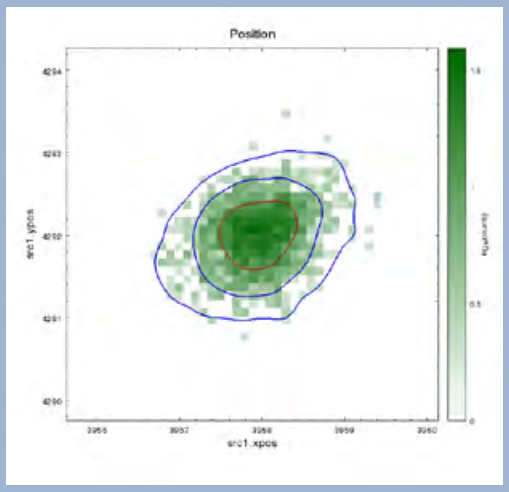


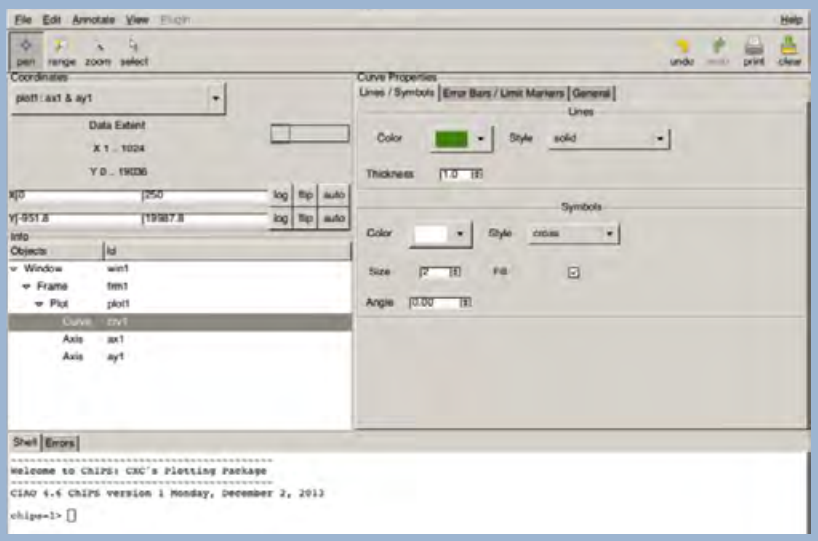
Fig. 7 – Using CIAO `dax` *in* `ds9`*. The menu dialog allows the user to select a model and parameters.* `Dax` *runs* `specextract` *on interactively selected regions and invokes Sherpa to determine the best fix spectrum.*











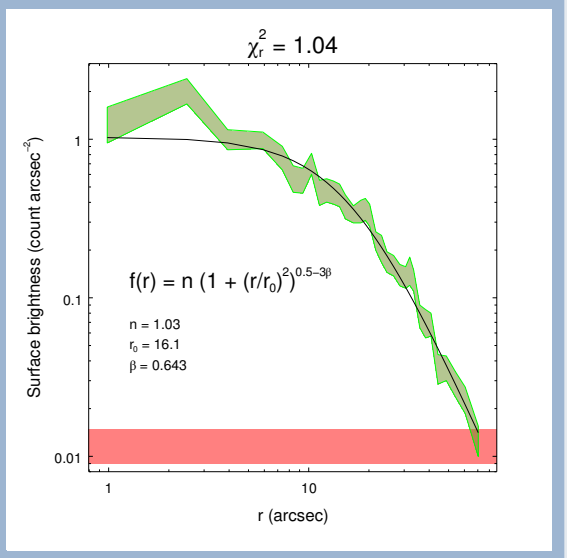


Fig. 8 – ChIPS (The Chandra Imaging and Plotting System) is a user interactive application which includes a GUI. ChIPS can be run in batch mode and is an importable module for Python. As shown above, ChIPS can mix plots, images, and contours to produce publication-quality figures.

constraints, developing analysis tools for extended sources, or supporting analysis of alternate instrument configurations (eg., continuous clocking readout mode).

CIAO Scripts: Analysis Simplified

The most recent "new" emphasis has been on high level programs (called "scripts") with easy interfaces—particularly helpful for users who are not X-ray astronomy specialists. These programs, all written in Python (Burke 2011), wrap laborious analysis steps described in the "threads" with simple command line scripts. They can also handle various special cases by inspecting the metadata in the data files. The scripts, by design, are simple to use for beginners, but also have parameters which allow fine tuning by the expert users. In general, the goal of the new suite of scripts is to make analysis quicker and accessible to all.

Two major scripts, `merge_obs` (designed to easily reproject and merge split observations) and `srcflux` (to calculate count rates and fluxes of a source given an event file and a location), have been illustrated in Fruscione et al. (2013, 2014) and Glotfelty et al (2014). In the same vein of simplifying analysis, `dax` (a `ds9` analysis extension) has been developed and extended over the past few years (Fig. 7). `Dax` provides access to common CIAO tasks and scripts from the `ds9` analysis menu and makes it very easy to choose source and background regions directly from the image.

While the first scripts tackled the most common data analysis threads, our goal is to simplify the analysis and maximize the science return for all users of *Chandra* and therefore lately we have concentrated our effort in covering many of the special "corner" analysis cases (e.g., how to combine grating spectra, how to process the Aspect Camera Assembly (ACA) optical monitor data, or how to properly deal with data taken in continuous clocking or interleaved mode).

The CIAO scripts package continues to grow and more high-level scripts are added at each release. The most recent (package 4.7.2, April 2015) contains three new scripts to deal with split observations and *Chandra* Good Time Intervals (GTIs) in addition to improvements and bug fixes for older scripts.

Sherpa and ChIPS

Sherpa and ChIPS are two large interconnected applications included in the CIAO package. *Sherpa* is the modeling and fitting application while ChIPS is the imaging and plotting platform (Fig. 8). Their development has substantially evolved from their first versions to today and they are now both available via the Python scripting language or as C/C++ libraries.

In response to the demand of the Python community—who actively contribute to *Sherpa*—and following the idea of open source and community contribution to the source code, *Sherpa* development was recently moved under `git` version control. Since April, *Sherpa* is an open source project with the source code repository on GitHub, the widely used repository for open-source software projects.

Currently, the *Sherpa* code can be installed in a Python environment independent of CIAO (standalone) and in particular it has been tested in the "Anaconda" Python distribution which provides many science and astronomy specific packages. The *Sherpa* standalone package is routinely used by the *Chandra* operations group who fit complex models to the data to forecast the thermal evolution of the spacecraft (Fig. 6).

CIAO on Social Media

Finally, to unmistakably project CIAO on the 21st century, we had to leap into the social scene! Since January, users can follow CIAO on Twitter (@ChandraCIAO), Facebook (ChandraCIAO), and Google+ (+ChandraCIAO). Posted topics include announcements of new software or calibration releases, important updates to documentation, and various other items of interest to the CIAO community. Follow us, like us, or add us to your circle.

More information and updates on CIAO can always be found at http://cxc.harvard.edu/ciao/ or subscribe to the CIAO News RSS feed at http://cxc.harvard.edu/ciao/feed.xml. To keep up-to-date with *Chandra* news, send any email message to the address: chandra-announce+subscribe@cfa.harvard.edu.

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