CIAO 1.0 to CIAO 4.11: A World Apart

Antonella Fruscione, for the CIAO team

4 October 1999:

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The Chandra X-ray Center is pleased to announce the first release of
the data analysis software:
 CIAO (Chandra Interactive Analysis of Observations)
                    V1.0
How to get the software
The software may be obtained via the WWW:
   by clicking on "Data Analysis" on the main WWW page: asc.harvard.edu
or directly from the ftp area:
                    asc.harvard.edu
We will also distribute the software on CDROM or DAT tape on request.
Help/Comments
Please send requests for help and comments to the CXC helpdesk, click on
"Help Desk" on our main WWW page: asc.harvard.edu.
                Belinda Wilkes
          User Support Group, CXC
  on behalf of: Data Systems
                       Science Data Systems
                       User Support
```

This is the first email announcement[1] to all *Chandra* Cycle 1 Guest Observers and Guaranteed Time Observers about the new software to analyze data from the newly launched *Chandra* X-Ray Observatory. CIAO 1.0 contained ~30 tools, was available for 3 platforms (Solaris 2.6, Redhat Linux 5.2 and Slackware Linux 3.5) and had essentially no "WWW" documentation. The word "ciao" comes from an old expression in the Venetian language, "s'ciavo", that means "I am your servant" (Fruscione & Siemiginowska 2000) and CIAO has been the servant of users of *Chandra*—and later other observatories—since its inception.

Fast forward 20 years and more than 50 versions and we arrive to CIAO 4.11 which was released on 14 December 2018. This newest version is distributed for several Linux and Mac OS X operating systems, includes Python 3.5 and, for the first time, the *Jupyter notebook system*. The Sherpa application (the modeling and fitting application that has been part of CIAO since the beginning) is now also distributed as a standalone application on *GitHub*. Will Python, Jupyter notebook, and GitHub fall out of use and make us smile in 20 years time like the mention of Solaris and Slackware do now?

CIAO is comprised of a large and complex set of tools, applications, scripts and online documents, all of which have evolved incredibly during the last 20 years as the scientific needs, user and instrument demands and technology have changed. Here, we briefly highlight some of the historical changes that have occurred in a variety of aspects in the system.

From Expert X-ray Astronomers to All Astronomers

The first releases of the CIAO software were directly aimed at enabling users to do Guest Observer science. And while the design of the software was mission independent from the start, CIAO was almost exclusively used by expert X-ray astronomers to analyze *Chandra* data. While the support of *Chandra* science is still the main goal, the new versions of the software are striving to make it more accessible to a larger audience with a wide range of expertise and available resources: 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. Additionally, many users now utilize CIAO tools and applications for more than just *Chandra* data. With our goal to continue to teach about *Chandra* and CIAO to the new generations of astronomers, we have organized 15 CIAO workshops in the last 20 years, from Cambridge to India to Seattle (at the last AAS meeting). Students come ready to learn, with new questions and new challenges that we try to answer, and their feedback helps us improve the software and the documentation.

From Individual Tools to Complex Scripts

The first releases of CIAO included only individual tools aimed at performing specific and generally narrowly scoped analysis tasks. The CIAO documentation, and in particular the CIAO threads, were—and still are—helping users string together individual tools to perform more complex analysis procedures. In the early years of the mission scientists (from the CXC and elsewhere) immediately started writing scripts to automate some of the most common and repetitive tasks or to fulfill specific analysis needs that CIAO was not ready to satisfy at the time. These "contributed" scripts, which we were gathering and advertising for users, were a collection of software programs written in several scripting languages, without specific coding standards or global consistency. After the integration of Python into CIAO, we started a concerted effort to review the code of all these heterogeneous scripts and to rewrite and update

1. Note the signature by Belinda Wilkes, current CXC Director, and at the time Deputy Leader of the User Support Group

them making them uniform (both in terms of code and documentation) and easier to maintain (Galle et al. 2011, Burke 2011). The first versions of several new powerful scripts were also written to automate some of the most common and complex tasks. Scripts like `chandra_repro`, `specextract`, `fluximage`, and `srcflux` have now become essential items in the CIAO system and encode the crucial steps and actions of many individual tools and threads.

From Zero to S-Lang to Python

CIAO tools are mostly written in the C or C++ language but in the early 2000s the need to introduce a scripting language in CIAO became compelling. A document of required features from the time stated:

> *On top of the usual benefits one expects from the use of a scripting language (e.g., extensibility, rapid prototyping, dynamic/loose typing, no compilation, etc.), there were several additional requirements: (a) powerful mathematical capability (with transparent support for multi-dimensional arrays) that would serve as a basis for rapid scientific algorithmic development (b) concise syntax that will be as natural as possible for scientists to adopt (c) embeddability into existing applications (d) as small a footprint as possible (CIAO is already fairly large)*

Several scripting languages were considered and ultimately the S-Lang scripting language was deemed as the best choice—but Python was a strong contender. As explained in Primini et al. (2005):

> *S-Lang is an open-source interpreted language, bundled with Linux and installed on millions of machines world-wide. It provides most of the usual benefits one expects from a scripting language [...] and is especially well-suited to scientific and engineering tasks due to its powerful, native multi-dimensional numerical capabilities. For example, it supports complex numbers [...] achieving performance and capability on a par with compiled code and commercial analysis packages. These features are built in to S-Lang and distinguish it from more widely known languages like Perl, Python, or Tcl, which lack native high-performance multi-dimensional numerical capability.*

The capabilities of Sherpa and Chips applications were immediately improved by the introduction of the scripting language (Burke et al. 2005, Doe et al. 2005) and S-Lang remained the scripting language in CIAO for several years.

But the usage of computing languages evolved and the trend in the astronomical community changed. By 2010 the use of Python in astronomy had reached critical levels and many astronomy-related packages were being developed in the Python language. The widespread use of Python and the vast amount of documentation (probably one of the weakest point for S-Lang) convinced us to gradually move our own project toward Python. For a while the two scripting environments coexisted within CIAO, though eventually the use of S-Lang in CIAO was finally deprecated in 2010. Python was adopted as the primary scripting language in CIAO 4.0 (in December 2007) and in the following years the entire collection of contributed scripts (a mix of shell, Perl, S-Lang and slsh scripts) was reviewed and rewritten in Python.

Also in CIAO 4.0 the original design of Sherpa was completely modified and a new version was implemented in Python (Doe et al. 2007, Refsdal et al. 2009). Currently Sherpa is also available as a stand-alone (i.e., independent of CIAO) modeling and fitting application for Python that is actively developed via GitHub and that users can use in their own Python scripts.

From Chips to Matplotlib

ChIPS (the *Chandra* Imaging and Plotting System) has been the plotting package of CIAO since the early versions of the software, but was completely redesigned in CIAO 4.0 (in 2007) to make it a powerful plotting system that

Figure 1: Students at the last in the series of Chandra/CIAO workshops: #15 at the AAS 233 in Seattle, WA

could be used to prepare high quality plots for scientific publications (Germain et al. 2006). ChIPS was designed so that "figures" (which include not only curves and histograms, but also contours and images) could be generated and changed interactively and could be easily saved, printed, restored and exchanged with collaborators. ChIPS is the underlying plotting system for all CIAO applications (in particular Sherpa and Prism) but in the past few years upgrades to the underlying technology and compatibility with newer operating systems (particularly the Mac OS) made it too difficult and time consuming to maintain the system as it was originally designed. As of the latest version (CIAO 4.11), we made the difficult decision to stop any further development of the ChIPS application. As the announcement of the ChIPS webpage says:

As of the CIAO 4.11 release, the development of ChIPS has stopped and the CXC's plan is to retire ChIPS in the next year or so. CIAO 4.11 includes version 2.2.3 of Matplotlib alongside ChIPS, and a ChIPS to Matplotlib conversion guide is provided to help CIAO users convert. Please contact the CXC Helpdesk if you need help or have questions about this conversion.

In CIAO 4.11, ChIPS is still the default plotting package for Sherpa (although it is possible to switch to using Matplotlib), and ChIPS is also used by prism and the ds9 analysis extension (dax) for DS9.

ChIPS is powerful and produces very nice figures for scientists, but it is time to move on. In the Python world the majority of users have adopted Matplotlib and we are following in the same footsteps, vowing to help ChIPS users to learn the new system. Citing the matplotlib documentation "*Matplotlib tries to make easy things easy and hard things possible*." It is a good promise for ChIPS users who will need to switch!

From Plain Text to Threads to Jupyter Notebooks

The analysis of *Chandra* data is still not "easy" but certainly it was not easy at the beginning of the mission. A lot of individual tools existed but were not necessarily linked together and limited documentation was available on how to run the tools sequentially. Support to early users was mostly in the form of ad hoc emails (or answers to HelpDesk tickets!) delineating all the steps needed with some additional explanations.

A major milestone happened with CIAO 2.0 (in 2000) when concurrently with the release of the software an entirely new set of webpages was introduced to help and guide users during their data analysis (Fruscione 2002, Galle & Fruscione 2003). In particular a strong emphasis was put into the "data analysis threads" "processing recipes designed to teach users by leading them, step-by-step, through a procedure".

Fun Facts about CIAO

There are ~150 downloads of CIAO every month.

CIAO users are almost evenly split between Linux (55%) and Mac (45%) based on downloads.

CIAO originally included tools required for Chandra proposal planning (PIMMS), which is why it is released annually in December with the Chandra Call For Proposals.

CIAO now includes over 160 individual command line tools; almost 80 contributed scripts, and 1245 individual help files.

Combined (CIAO+Chips+Sherpa) there are over 2,300 web pages.

The CXC HelpDesk on average answers at least one CIAO related question every day of the year. The median response time is less than an hour and most are resolved within a day.

The tools in CIAO are a subset of the same tools used in standard Chandra pipeline processing, as well as in the production of the Chandra Source Catalog.

The data analysis threads became a signature documentation within CIAO and cover many of the tasks that scientists are trying to perform: from the most basic ones to the more complicated.

"*Threads are "living" documents and are being updated and improved continuously and great care has been taken in making sure that they faithfully reproduce the behavior of each tool, especially when new software patches or releases are distributed.*" (Fruscione 2001)

The format and the underlying technology used to generate the documentation webpages changed over the years but the threads are still the most used components of the CIAO documentation and now number in the hundreds.

As cited above, threads are living documents and they are updated frequently but they are not interactive. They are documents which include code, figures, links, and equations... sounds familiar? This is the definition of a Jupyter notebook! "Notebook documents" are not only readable documents which contain the description of the analysis steps and the results (output, figures, tables, etc.) but are also executable documents that can be run to perform data analysis. This is an expansion that could make the current CIAO threads even more useful. Presently, we are prototyping some CIAO threads as Jupyter notebooks, but none are publically available to users, yet. However, students at the most recent CIAO workshop (Jan 2019) were able to run the CIAO workshop exercises as Jupyter notebooks for the first time! Stay tuned for even more expanded and interactive CIAO documentation over the next 20 years.

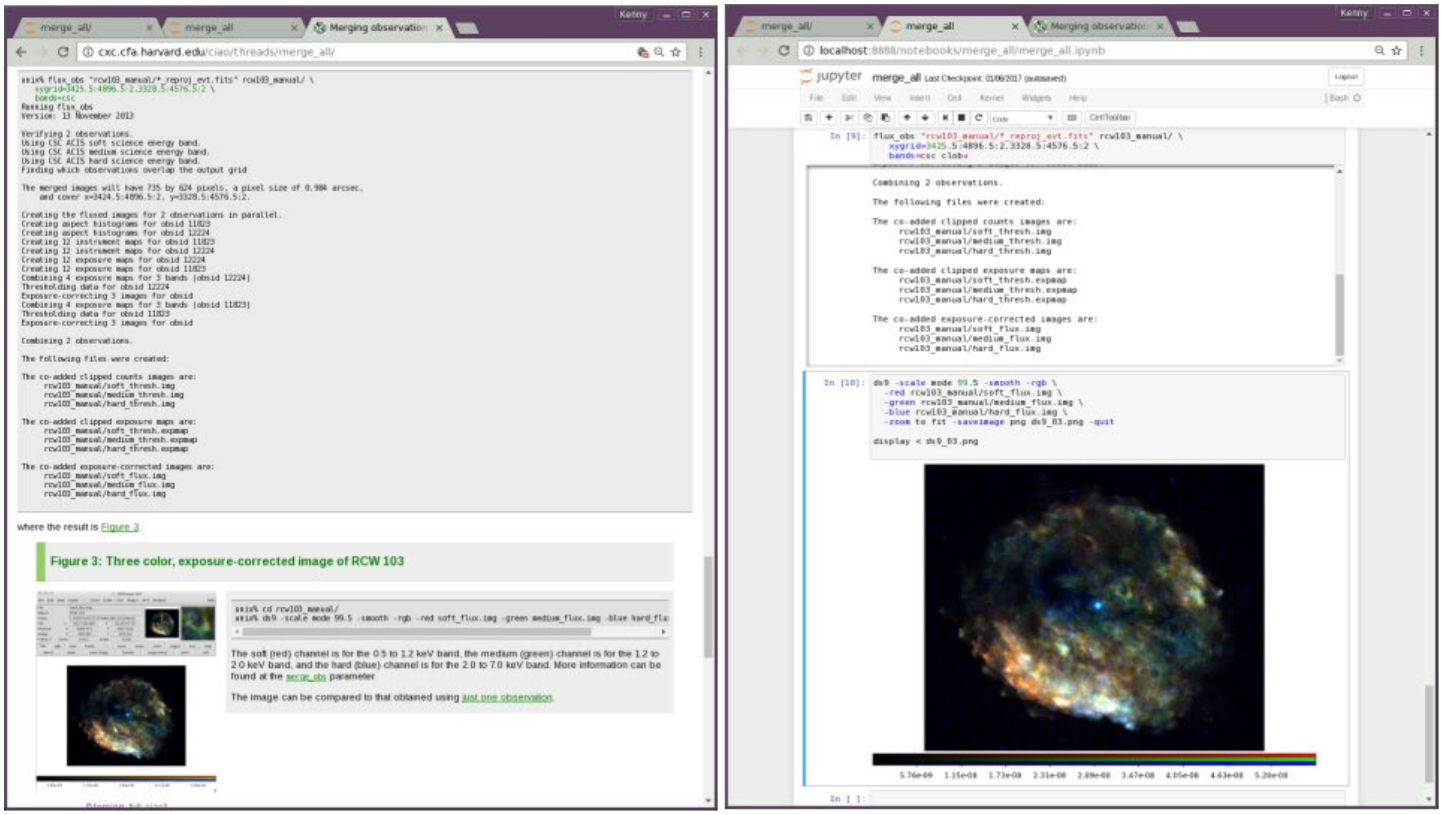

Figure 2: Prototype Jupyter notebook version of for the "Using merge_obs to combine observations and create exposure-corrected images" thread.

From RSS Feed to Social Media

"*The small orange button (the RSS feed button) that became so familiar to website visitors in the early 2000's was as dominant as a Twitter button on any of today's websites*." cites an online page reflecting about RSS. CIAO News has had *its own RSS feed* since 2010 and users embracing this way of getting new information can still subscribe to it to get updates regarding CIAO releases. It is, in fact, a very streamlined and simple way to get new content and updates. But if you belong to the social media generation, CIAO is on Twitter (@*Chandra*CIAO) and Facebook (*Chandra*CIAO) since 2015 and has even its own YouTube channel (4ciaodemos). Announcements of new software or calibration releases, important updates to documentation and various other items of interest to the CIAO community are all posted on these social media platforms! Follow and like us… but don't forget to check your RSS reader too.

Hidden Gems

Chandra is 20 years old and the software used to analyze its data is mature, well tested and well documented. It has evolved over time and has been used to perform analysis tasks that were not even thought of when we started.

CIAO is still "at the service" of very beginner users (some of whom were not even born when *Chandra* was launched!) and very experienced users (some of whom were students at launch!). The former group should check out the new http://cxc.cfa.harvard.edu/cdo/xray_primer.pdf

For the latter group: do you know that CIAO can even skeletonize? http://cxc.harvard.edu/ciao/gallery/thumbnail.html

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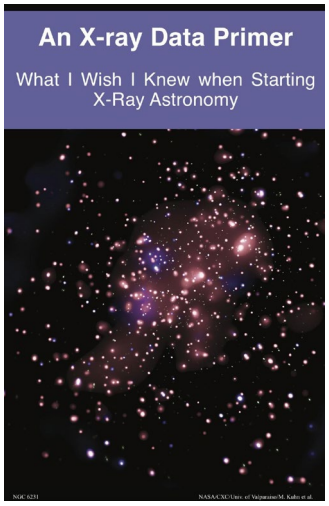

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