



Introduction to CIAO

(Chandra Interactive Analysis of Observations)



CIAO: Chandra's data analysis system
Fruscione et al. 2006, SPIE Proc. 6270, 62701V, D.R. Silvia & R.E. Doxsey, eds.



THE PEOPLE WHO DID IT!

CIAO: Chandra's data analysis system

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From "ahelp ciao"....

- A powerful data analysis system originally written for the needs of users of the Chandra X-ray Observatory.
- Built to handle *N-dimensional* data without concern about which particular axes are being analyzed: Chandra is the first mission with 4-dimensional data (2 spatial, time, energy) in which each dimension has many independent elements.
- Mission independent (a part from a few instrument specific tools). It is now used to analyze data at all wavelengths.



- Provides users with the ability to filter down and project the 4-D Chandra event data to manageable sizes and convenient array: all CIAO tools take a *‘filtering and binning’* specification on the command line, making use of a general purpose *‘regions’* syntax: “**ahelp dm**” for information on the Data Model that makes all this possible.
- To keep track of how the data had been filtered and binned CIAO relies on the *‘data subspace’*. Tools keep track of this subspace automatically and allow users to review previous data processing: see “**ahelp subspace**”.



- The CIAO design allows close interconnection of tools. For example, the output of any of source detection program can be fed into *dmextract* to create a summed spectrum which can then be fit in *Sherpa*.
- The modeling and fitting tool *Sherpa* is central to the CIAO system. *Sherpa* performs forward fitting of models to data in N-dimensions. *Sherpa* (and ChIPS!) includes the “**Python**” and “**S-Lang**” languages which can be used for scripting and data manipulation. See “**ahelp sherpa**.”



http://cxc.harvard.edu/ciao : it all begins here!

Chandra X-ray Center

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Last modified: 15 September 2008

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CIAO

from "s'sciavo", "I am your servant" in Venetian dialect*

WHAT'S NEW | WATCH OUT

Download CIAO | Science Threads | Scripts | Manuals | ChIPS | Sherpa | ChaRT | ObsVis | CALDB
For faster access: [Download CIAO from Leages](#) | [Leicester Mirror Site](#)

NEW The Chandra X-Ray Center released [version 4.0.2](#) of the Chandra Interactive Analysis of Observations (CIAO) software package on 16 April 2008.

The CIAO 4.0.2 patch enables CIAO to run on Mac OS X 10.5 (Leopard) Intel. The patch is optional for 10.4 (Tiger) Intel machines. The patch *should not* be applied to Linux, Solaris, or Mac PowerPC installations of CIAO.

[Download the 4.0.2 patch.](#)

NEW (15 Sep 2008) The Chandra Contributed Software page has been updated to include a variety of analysis packages and tools which are widely used in the community.

[Other Software for Chandra Data Analysis](#) (Note that this is a new URL as well.)

Contributions to the page should be submitted through the [Helpdesk](#).

NEW (8 Sep 2008) CALDB 3.5.0 has been released for use with CIAO 3.4 and CIAO 4.0.

Information on the patch is available from the [CALDB 3.5.0 Release Notes](#) and [How CALDB 3.5.0 Affects Your Analysis](#).

[Download CALDB 3.5.0](#)

CIAO 4.0 is a full installation of the CIAO software. It contains all the enhancements and bug fixes since CIAO 3.4, including those which were made available in the 4.0 Beta releases.

The most notable change to the CIAO tools in version 4.0 is that the ACIS dead area correction is turned on by default; refer to the [How CIAO 4.0 and CALDB 3.4.2 Affect Your Analysis section](#) of the release notes for details. There is a new version of textract - named `textract2` - which provides similar functionality, but allows large and asymmetric regions for better determination of background counts. Significant work has been done on the tool `wadetect`, which has two new parameters. The `aso_freeze` tool has been enhanced so that it can create object-centered aspect solutions which allows an object-centered exposure map to be generated. A number of bug fixes to the Data Model library and several CIAO tools are also included.

The Data Model library now supports an ASCII kernel. This kernel allows users to generate ASCII format files for use within Data Model enabled tools (e.g. `dmlist`, `dmcopy`), and apply the suite of Data Model capabilities to those files via its extended filename syntax. The ASCII kernel is considered beta for this release.

The CIAO 4.0 release includes a new, more powerful version of *ChIPS*, the CIAO plotting package. It can be used during data analysis - e.g. to plot histograms, and to create publication quality figures. Detailed documentation on the new system is available from the [ChIPS website](#).

[Download CIAO and CALDB](#)

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CIAO 3.4

from "s'sciavo", "I am your servant" in Venetian dialect?

WHAT'S NEW | WATCH OUT

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[Download CIAO and CALDB](#)



CIAO help!

AHELP

- CIAO comes with its own help system called **ahelp**.
- Every component of the CIAO system has its own help text: tools (e.g. `dmcopy`, `wavdetect`), applications and their components (e.g. `sherpa`, `fit`, `model`), scripting language and its functions (e.g. `slang`, `get_fit`, `get_data`) and numerous concepts (e.g. `regions`, `coords`, `dmsyntax`, etc.).
- The entire collection of `ahelp` files currently has more than 1000 pages!

The **ahelp** commands (see `ahelp ahelp` for details) access the CIAO on-line documentation. For example:

% **about <word>** (e.g. `about contour`) gives a list of subjects related to the query

% **ahelp <name>** (e.g. `ahelp tgextract`) provides by default the ASCII version of the help file.

% **sherpa/chips> ahelp("name")** (e.g. `ahelp("fit")`) provides the ASCII version of the `ahelp` file within the `sherpa` or `chips` environments.



DATA ANALYSIS GUIDES : *start from here!*

- A roadmap through the threads.
- Arranged by instrument (ACIS, HRC) or type of analysis (e.g. extended sources)

DATA ANALYSIS THREADS (*General, Sherpa, ChIPS, Chart*)

- About 100 CIAO processing recipes designed to teach users by leading step-by-step through a procedure.
- Added or updated as needed (look for the “**new**” or “**updated**” icons!).
- Several threads and groups of threads have been or will be made more automated in the form of scripts.
- PDF version available on-line, and threads are printer friendly.
- Quick “overview” at the beginning (synopsis, purpose, when to use etc.)



IMPORTANT CIAO WEB PAGES

Read especially the

What'sNew, "Watch out", Bugs, Caveats, Dictionary, FAQ pages, Platform support, Why topics, How does CIAOX.X and CALDBY.Y affects my analysis, Manuals and Memos, !

HELPDESK

When everything else fails....

<http://cxc.harvard.edu/helpdesk/>

with CIAO version, platform, data, purpose etc...

See Elizabeth Galle talk!



WHAT IS CIAO?

- Collection of programs (*tools, applications, scripts, S-Lang and Python modules*).
- Generally run from the shell; some part can be run from GUIs.
- Source code is available to users.
- Available on several platforms; currently (as of CIAO 4.0) supported:
 - Solaris 8
 - Fedora Core 4 and 7 (also for other linux platforms)
 - Mac OS X 10.4 and 10.5 Intel
 - Mac OS X 10.4 PPC

Has been successfully installed by users on other “unsupported”(= no regression testing done!) platforms: check the *Platform Support* page

The CIAO Environment

We recommend the use of an alias called “`ciao`” to start up the system: it sets up number of environment variables and path assignments.

`ciao -v` tell what version you are using (useful when reporting problems)



General Concepts

- File format
- Parameter Files
- Filters
- Regions
- Good Times Intervals (GTI)
- Scripting languages: Python and S-Lang



File Format

- Chandra data is stored in FITS format. As of CIAO4.0 ASCII (text) files can now be handled by many tools and applications through the new software library known as the “ASCII kernel” (`ahelp dmascii`)
- When CIAO operates on data it stores processing state/information along with data (keywords, subspace).
- A single file can contain multiple “datasets” (e.g. data, GTI, weight map, regions) stored in “blocks”.
- Blocks can contain image or table data. Table columns can be vectors.
- `dmlist` (a command line tool) or `prism` (a GUI) are available to view file contents.



Prism: file viewer, editor, tool launcher

blocks

header

prism : dstrk_evt2low.fits

| TABLE | NAME | COLS | ROWS |
|-------|---------|----------------------|------|
| IMAGE | PRIMARY | NULL | |
| TABLE | EVENTS | 21 cols, 174012 rows | |
| TABLE | GT17 | 2 cols, 1 rows | |
| TABLE | GT14 | 2 cols, 1 rows | |
| TABLE | GT15 | 2 cols, 1 rows | |
| TABLE | GT16 | 2 cols, 1 rows | |
| TABLE | GT18 | 2 cols, 1 rows | |
| TABLE | GT19 | 2 cols, 1 rows | |
| TABLE | REGION | 9 cols, 3 rows | |

COMMENT This FITS file may contain long string keyword values that are continued over multiple keywords. The HEASARC convention uses the & character at the end of each substring which is then continued on the next keyword which has the name CONTINUE.
 ORIGIN ASC / Source of FITS file
 CREATOR tg_resolve_events - Version CIAO / String tool that created this
 REVISION 2 /
 ASCDSVER CIAO 2.2 Tuesday, October 16, 2001 / ASCDS version number
 CHECKSUM W6YR24Y0M4Y0M4Y0 / HDU checksum updated 2003-10-27T03:00:15
 DATASUM 3474871056 / data unit checksum updated 2002-05-31T19:14:
 DATE 2002-05-24T21:14:44 / Date and time of file creation

prism : dstrk_evt2low.fits

| TABLE | NAME | COLS | ROWS |
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| TABLE | GT16 | 2 cols, 1 rows | |
| TABLE | GT18 | 2 cols, 1 rows | |
| TABLE | GT19 | 2 cols, 1 rows | |
| TABLE | REGION | 9 cols, 3 rows | |

| time | expno | rd | chip | tdet | det | sky |
|-------------------|-------|---------------|---------------|---------------|---------------|---------------|
| 70330662.76835759 | 19829 | (float,float) | (short,short) | (short,short) | (float,float) | (float,float) |
| 70330662.76835759 | 19829 | (float,float) | (short,short) | (short,short) | (float,float) | (float,float) |
| 70330662.80939759 | 19829 | (float,float) | (short,short) | (short,short) | (float,float) | (float,float) |

View Mode: Read/Write Displaying rows 1 - 20 (174012 total rows)

Sun 26-Oct 22:46:45 Loading file dstrk_evt2low.fits
 Sun 26-Oct 22:46:45 Configuring Analysis Menu from file: /soft/ciao/bin/ciao.ans

Quick Help:
 [Left Mouse Button] - Select Column
 [Middle Mouse Button] - Select Row
 [Right Mouse Button] - Menu Options
 <control>[Left Mouse Button] - Edit Cell

data

quick help

Expanded float vector column: sky

| | (x) | (y) |
|---|-------------|-------------|
| 1 | 6669.506348 | 3639.539551 |
| 2 | 6751.366699 | 3993.511963 |
| 3 | 4014.948730 | 3752.250488 |
| 4 | 3497.506104 | 3910.956055 |
| 5 | 4115.995605 | 4011.445557 |

Displaying rows 1 - 20 (174012 total rows)

OK Help



Prism: a preview of what is coming in CIAO 4.1!

The screenshot displays the CIAO Prism software interface. The main window shows a FITS file named 'rprofile_exclmore_DTCOR.fits' with various extension headers. A 'Plot Dialog' window is open, showing settings for a plot of AREA vs NET_COUNTS. A 'win4' window shows a plot of NET_COUNTS vs AREA with data points and error bars. A table below the main window displays the data for the first 9 rows of the histogram.

| | BG_ERR | BG_COUNTS | BG_RATE | BG_SUR_BRI | BC_SUR_BRI_ERR | NET_COUNTS | NET_ERR | NET_RATE | ERR_RA |
|-------|------------|-----------|------------|--------------|----------------|-------------|-------------|------------|---------|
| units | count | count | count/s | count/pixel* | count/pixel**2 | count | count | count/s | count/s |
| 1 | 98.3412426 | 9671 | 0.99624788 | 8.30223735 | 8.4422742045 | 1208.45677 | 35.05771866 | 0.12448790 | 0.00361 |
| 2 | 98.3412426 | 9671 | 0.99624788 | 8.30223735 | 8.4422742045 | 714.823688 | 27.4803003 | 0.07363680 | 0.00283 |
| 3 | 98.3412426 | 9671 | 0.99624788 | 8.30223735 | 8.4422742045 | 518.1918651 | 24.0493216 | 0.05338098 | 0.00247 |
| 4 | 98.3412426 | 9671 | 0.99624788 | 8.30223735 | 8.4422742045 | 430.602307 | 22.3264349 | 0.04435804 | 0.00229 |
| 5 | 98.3412426 | 9671 | 0.99624788 | 8.30223735 | 8.4422742045 | 372.266993 | 21.2757458 | 0.03834869 | 0.00219 |
| 6 | 98.3412426 | 9671 | 0.99624788 | 8.30223735 | 8.4422742045 | 426.790666 | 22.9790851 | 0.04396539 | 0.00236 |
| 7 | 98.3412426 | 9671 | 0.99624788 | 8.30223735 | 8.4422742045 | 442.968532 | 23.6726029 | 0.04563193 | 0.00243 |
| 8 | 98.3412426 | 9671 | 0.99624788 | 8.30223735 | 8.4422742045 | 437.087766 | 23.9772820 | 0.04502613 | 0.00246 |
| 9 | 98.3412426 | 9671 | 0.99624788 | 8.30223735 | 8.4422742045 | 489.695614 | 25.4661779 | 0.05044547 | 0.00262 |



Parameter Files (`ahelp parameter`)

- Processing parameters for CIAO tools can be set on the command line or, as with IRAF and FTOOLS, using parameter files.
- Parameters files are
 - ✓ stored in `$HOME/cxcds_param4/`
 - ✓ are called `<tool>.par` (e.g. `dmcopy.par`)
 - ✓ are ASCII files.

CAVEAT: Always delete or rename the `cxcds_param` when upgrading operating system or CIAO version

- A “Parameter Editor GUI” (`peg`) and a number of routines (e.g. `plist`, `pset`, `punlearn`) are provided to read and write to these files. A S-Lang interface to the CXC parameter library is also available (see `ahelp paramio`).



Parameter Editor GUI (PEG)

unix% peg dmlist

(slightly different look in CIAO4.1 but same functionality)

| ColNo | Name | Unit | Type | Range | Null |
|-------|-----------|-----------------|-------|-------------------------------------|-----------|
| 1 | TIME | s | Real8 | 105562662.5093476325:105574773.4882 | |
| 2 | RAWX | PIXELS | Int2 | -4.605 | - |
| 3 | RAWY | PIXELS | Int2 | 1.602 | - |
| 4 | DETX | 0.05 ARCSECONDS | Int2 | -19768.19910 | - |
| 5 | DETY | 0.05 ARCSECONDS | Int2 | -20305.19820 | - |
| 6 | POS(X, Y) | 0.05 ARCSECONDS | Int4 | 1.51840 | -99999999 |
| 7 | PHA | CHAN | Int2 | 0:32767 | - |
| 8 | PI | CHAN | Int2 | 0:15000 | - |
| 9 | FLAG | | Int4 | - | - |
| 10 | PATTERN | | Byte | - | - |
| 11 | CCDNR | | Byte | - | - |



Filters, Regions, and GTIs

- filtering (removal of unwanted events) is an essential part of X-ray analysis - e.g. to remove periods of high background or poor aspect solution, exclude uninteresting sources from an image etc.
- the DataModel (DM) provides great filtering flexibility: e.g. `dmstat` “`evt2.fits[EVENTS][energy>300][cols -grade]`” (see [ahelp filtering](#), [ahelp dmimgfiltering](#))
- GTIs (Good Time Intervals) are used to define what times periods of the observation can be used (i.e. contain valid data). They are generally stored as a block in the event list (see [ahelp chandra times](#))
- Regions are used to define the source and background areas of an image. They are text files that can be created manually or within ds9, and are used as a filter (e.g. “[`sky=region(source.reg)`]”). (see [ahelp dmregions](#))
- Subspace records the filters applied to a file; `dmlist` can read this history using `opt=subspace` (see [ahelp subspace](#))



Scripting Languages

- Two scripting (or interpreted = no compilation is necessary) languages are supported in CIAO via Sherpa and ChIPS: Python (as of CIAO4.0) and S-Lang
- Sherpa and ChIPS are infact importable modules for Python and S-Lang.
- More info in Douglas Burke talk tomorrow



CIAO overview

Data manipulation: copy, filter, extraction, stats, etc.

Data preparation (or Chandra-specific instrument tools): update calibration, correct for instrumental effects, find & extract grating data, create aspect histograms

Response tools: exposure map, PSF, RMF and ARF

Source Detection: celldetect, wavdetect, vtpdetect

Timing & Background tools: lighcurve, power spectrum, barycenter correction

Convolutions, Transforms, & Smoothing: csmooth, aconvolve, acrosscorr, apowerspectrum

Plotting: ChIPS (*)

Modeling/Fitting: Sherpa (*)

S-Lang & Python: ChIPS and Sherpa modules; slsh/ipthon shells

GUIs: DS9, prism,peg



The “Data Model” and the Data Manipulation Tools

- The CXC analysis and processing software is built on a common versatile interface library called the CXC Data Model (or just DM).
- The DM provides users with a powerful built-in data filtering and binning capability.
- The name “Data Model” reflects the fact that the interface can be used on data files of different format (all described by a single abstract description - the same “model”) in a transparent way.
- The latest addition to the DM in CIAO4.0 is the “ASCII kernel” which gives the ability to operate on ASCII (text) file the same way as on FITS files (eg for filtering, plotting etc.)



- An important characteristic of the DM is that ANY program that asks for a data file name as input accepts a “*virtual file*” string which causes the program to see a filtered version of the file in question.
- The “virtual file” syntax is also commonly used to create on disk a filtered version of the input file.
- Another important characteristic of the DM is that all columns of event lists are treated “equally”: for example binning is allowed not only in spatial coordinates but also in e.g. time, or energy coordinate, giving the ability of creating multidimensional images in space-energy, or space-time, etc.



Data Manipulation Tools

The four DM “core” tools are:

dmlist: list contents or structure of a file

dmcopy: filter and bin tables and images

dmextract: make a histogram table file (e.g. PHA file, lightcurve file) from a table column. Generate count histogram on supplied regions for a spatial table or image file.

dmgti: create custom Good Time Intervals (GTIs) from a constraint expression

30+ data manipulation tools are included in CIAO4.0



DATA MODEL SYNTAX (`ahelp dmsyntax`)

- All CIAO tools use the DM library and therefore accept as input “virtual files” described using the DM syntax.
- In the DM context a “virtual file” is represented by a filename followed by a series of optional qualifiers in square brackets []:

“filename[block][filter][columns/binning][options][rename]”

where:

block - is the “section” of the file to use

filter- is the filter to be applied

columns/binning - specifies either the columns from a table to be included in an output table or the binning. When binning the data to generate an n- dimensional image, the range and binsize (min:max:bin) must be specified.

options - a sequence describing special options for the DM library

rename - specifies a name for the new block

Note that:

- the order of the qualifiers generally matters, however...
- not all qualifiers need to be present always



Simple examples of “virtual files”:

- Select the first three columns of the EVENTS block by number:
`acisf01843N001_evt2.fits [EVENTS] [time=84245787:84247000] [cols #1,#2,#3]`

or by name:

```
acisf01843N001_evt2.fits [EVENTS] [grade=0,2,3] [cols  
time,ccd_id,node_id]
```

after filtering in time or grade

- Bin an events file to create a PI spectrum for a specified region (input of dmextract):
`acisf01843N001_evt2.fits [EVENTS] [sky=region(mysrc.reg)] [bin pi=1:1024:1]`

or an image (input of dmcop):

```
acisf01843N001_evt2.fits [EVENTS] [pha<100] [bin  
x=320:480:4,y=320:480:4]
```



In the examples above:

block: [EVENTS]

filter: [time=84245787:84247000]

[grade=0,2,3]

[sky=region(mysource.reg)]

[pha<1000]

columns/binning:

[cols time,ccd_id,node_id]

[cols #1,#2,#3]

[bin pi=1:1024:1]

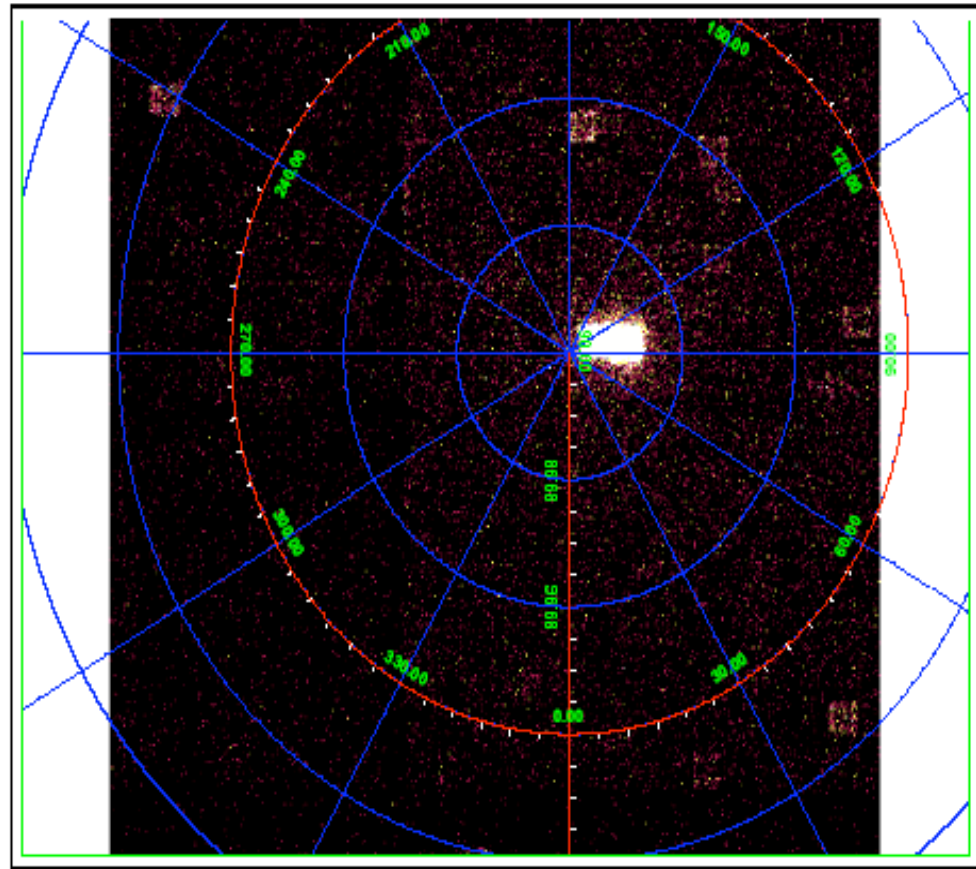
[bin x=320:480:4,y=320:480:4]



DM Examples 1: Detector Image

Imaging on multiple coordinate systems: first, let's look at a region in detector coordinates, filtered on energy and time.

```
dmcopy "merge3e.fits[energy=500:2000, time=:63940080, 63940180:][bin  
detx=3500:4500:2, dety=3500:4500:2]" det.img
```

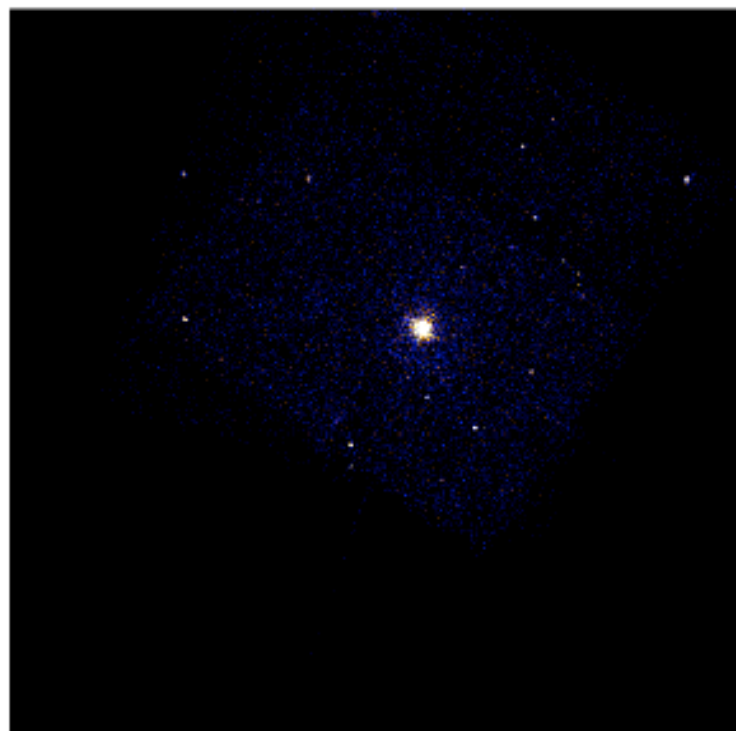




DM Examples 2: Sky Image

Now look at the same photons but in sky coordinates

```
dmcopy "merge3e.fits[energy=500:2000,  
time=:63940080,63940180:,detx=3500:4500,dety=3500:4500][bin x=3200:4800:2,  
y=3200:4800:2]" sky.img
```

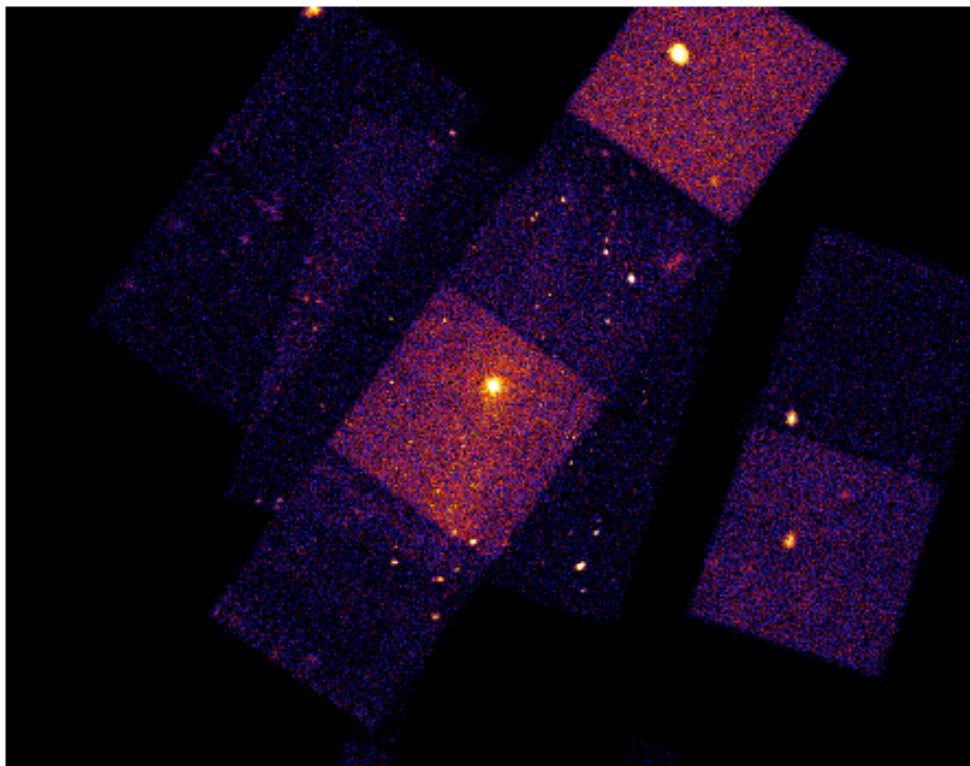




DM Examples 3: Merged sky image

The whole field was created by merging three separate observations.

```
dmmerge "786.fits, 787.fits, 1730.fits" outfile=merge3e.fits
```

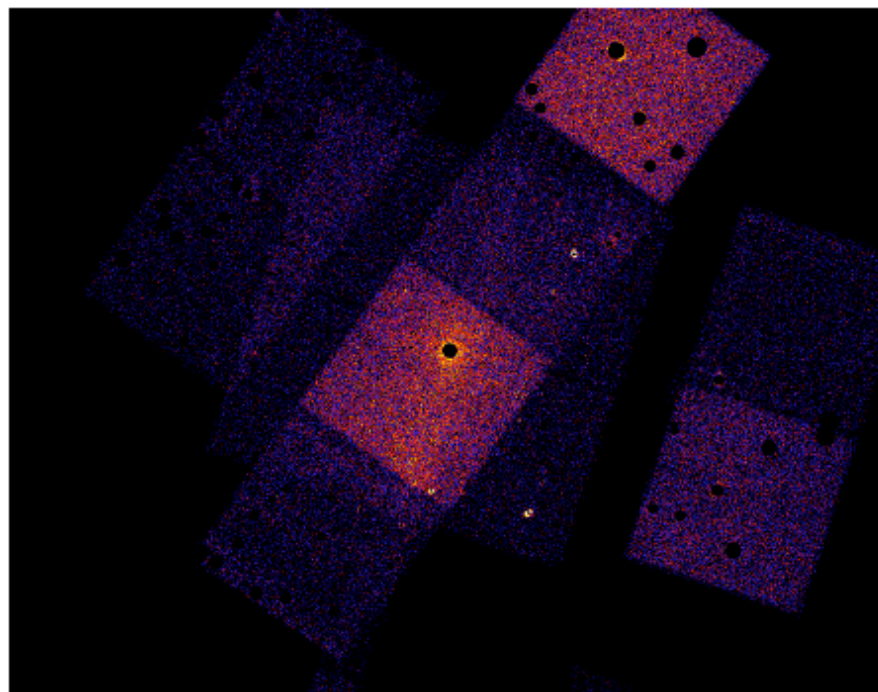




DM Examples 4: Removing sources

We can generate a background image by removing sources found by the automatic source detection program.

```
dmcopy "merge3e.fits[exclude sky=region (gg.reg)]" exclude.fits
```





DM Examples 5: Infrared spectroscopy data

ISO data: LWS LSAN file. This is a very simple file by wavelength and flux for the different detectors and scans are mixed together. We can use the DM tools to isolate a single scan and dump wavelength versus flux for it.

```
dmcopy "lsan59901083.fits[lsancnt=4][cols lsanwav, lsanflx]"  
subset.fits  
dmlist "lsan59901083.fits[lsanscnt=4][cols lsanwav, lsanflx]"  
data,raw outfile=lis.asc
```

