Introduction to

CIAO

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CIAO

CIAO 4.6 Homepage
Introduction
- Welcome
- Tools & Applications
- CIAO News
  - *Updated: 4 Nov 2014*

Data Analysis
- Analysis Guides
- Science Threads
- Why Topics
- Help Pages (AHELP)
- Video Demos and Tutorials

Documentation
- "Watch Out" List
- Bug List
- Frequently Asked Questions (FAQ)
- Manuals & Memos
- Dictionary
- Publications
- Download the Website

Download CIAO
- Download CIAO 4.6
- Download CALDB
- Scripts & Modules Package
- System Requirements
- Installation Instructions
- Platform Support
- Release Notes
- Version History
- Other Analysis Software

Sherpa (Modeling and Fitting)
- Sherpa website
- Threads
- Help Files

ChIPS (Plotting Package)
- ChIPS website
- Threads
- Help Files

Scripting in CIAO
- Introduction
- Modules
- Running Tools from Python

Data Products

CIAO

Chandra Interactive Analysis of Observations

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

WHAT'S NEW | WATCH OUT

Quick CIAO links: Download CIAO | Science Threads | Help Files | Scripts
Related CXC sites: ChIPS | Sherpa | PSFs with ChaRT | CALDB
Chandra Source Catalog | TGCat: Chandra Gratings Catalog

Install CIAO 4.6.1 & CALDB 4.6.3

Read the CIAO 4.6.1 release notes for detailed information on this release, including How CALDB 4.6.3 Affects Your Analysis.

Subscribe to the CIAO News RSS feed

Subscribe to *Chandra*/CIAO announcements

I've never used CIAO before. Where should I begin?

Welcome to CIAO
Introduction to the Tools & Applications

Download CIAO 4.6.1
Installing CIAO 4.6.1 thread

Introductory Science Threads

Analysis Guides

Has a new version of CIAO or CALDB been released?
What has changed in the site recently?

What's New

"Watch Out" List

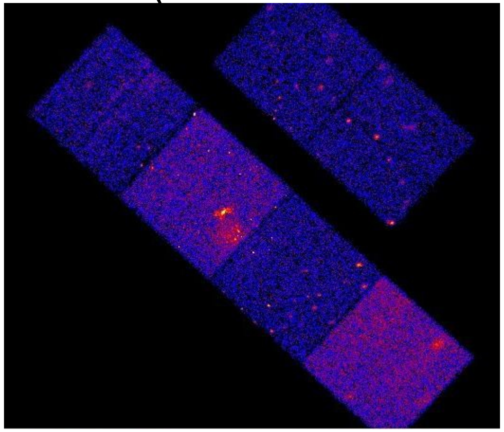
Version History

CIAO Release Notes

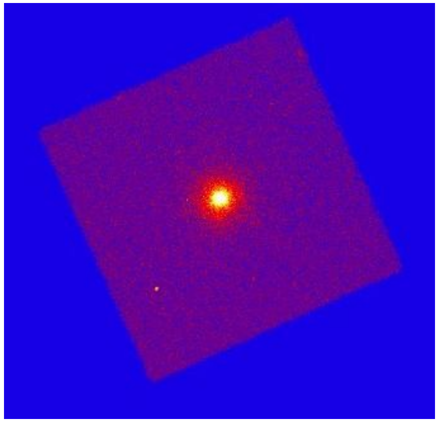
CALDB Release Notes

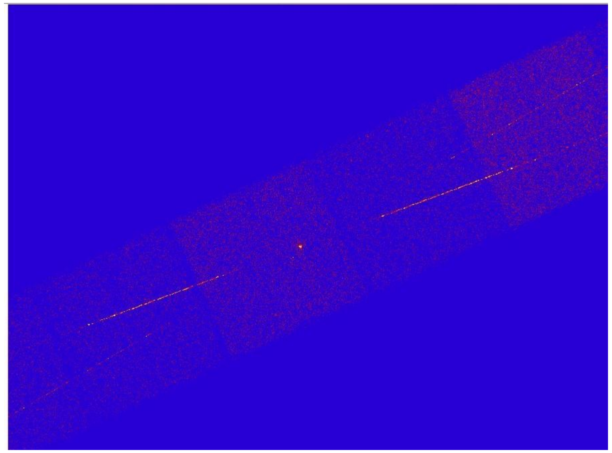
Scope

- Caveat: will cover ACIS imaging data only
  - (81% of recent observations)



- Basics the same for HRC and gratings, but with extra wrinkles





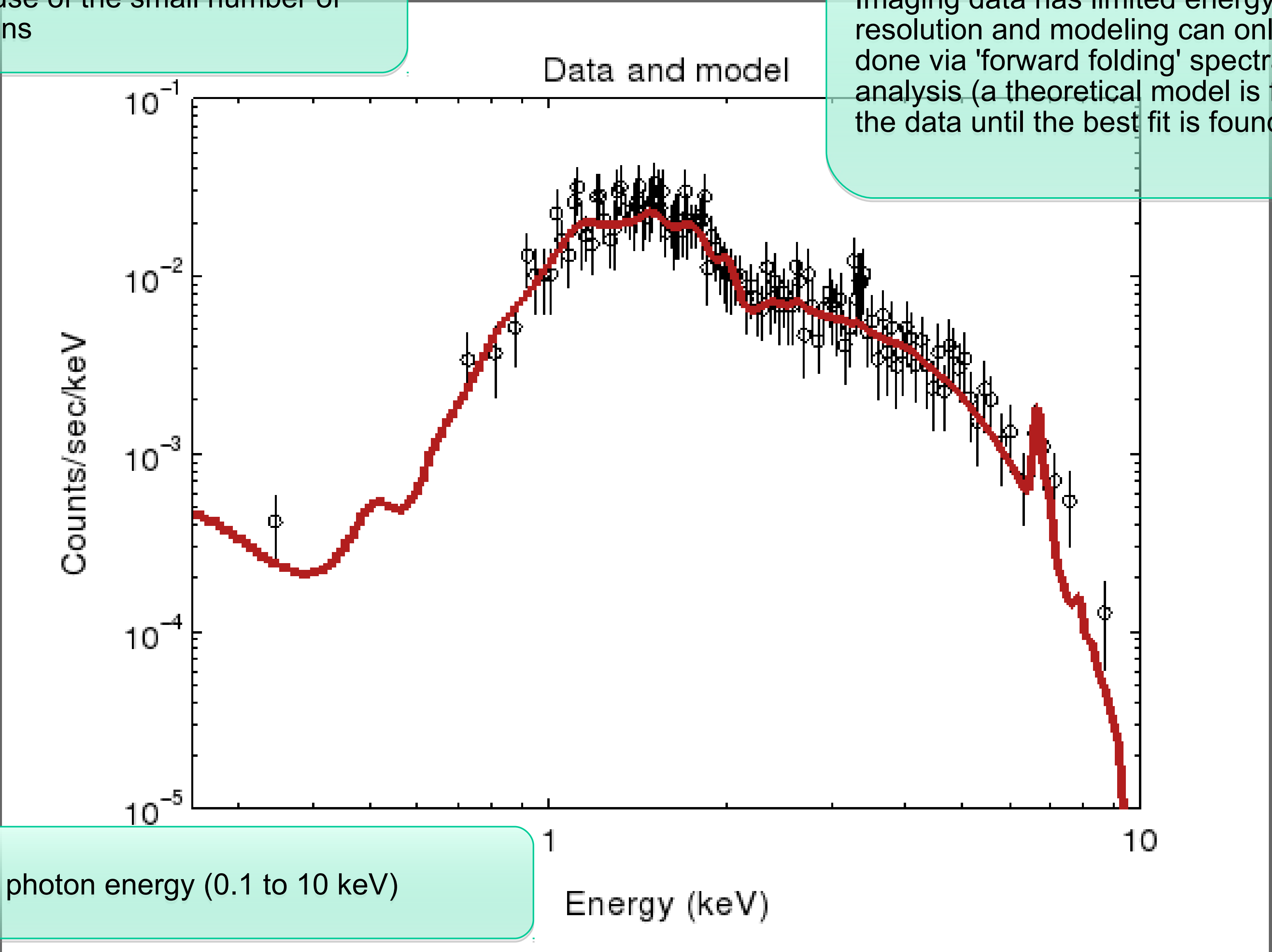
Introduction to X-ray Data Analysis

- X-ray astronomy is different .....
  - Problem 1: Photon counting with small number statistics
  - Problem 2: Spectral line spread function is often broad and messy - forced to foward-folding approach
  - Problem 3: Bands are very broad, so energy (wavelength) dependence more obvious (e.g. in PSF)
  - Problem 4: Different optics - PSF degrades rapidly off axis
  - Problem 5: The telescope is not pointing steadily like, say, HST - it's moving back and forth across the source.
  - But:
  - Advantage: We have more information on each photon (position, energy, arrival time)

Complexities in X-Ray and Chandra Data Analysis

In Poisson statistics regime because of the small number of photons

Imaging data has limited energy resolution and modeling can only be done via 'forward folding' spectral analysis (a theoretical model is fitted to the data until the best fit is found)



2 decades of photon energy (0.1 to 10 keV)

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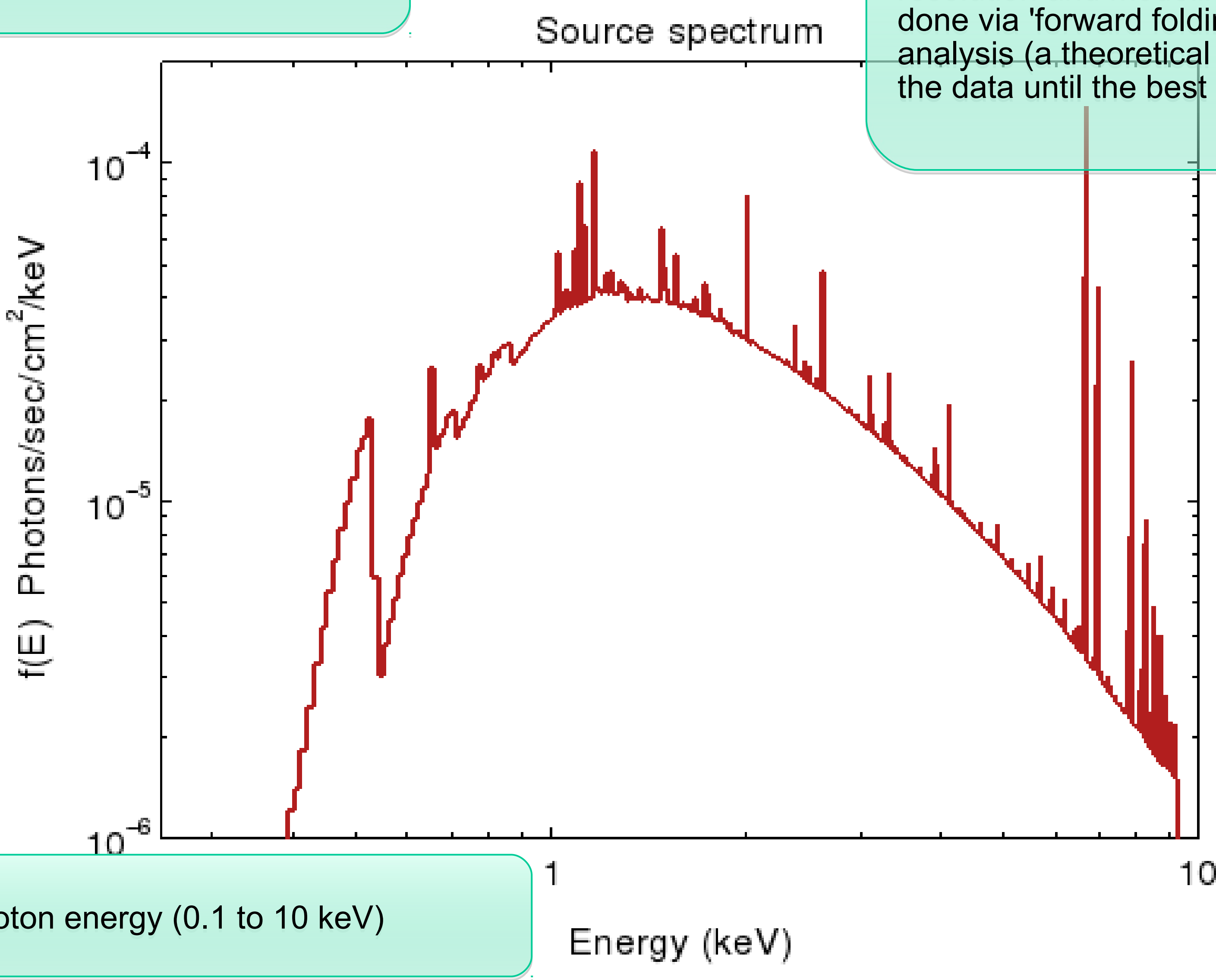


2 decades of photon energy (0.1 to 10 keV)

Complexities in X-Ray and Chandra Data Analysis

Every aspect of the observation varies with

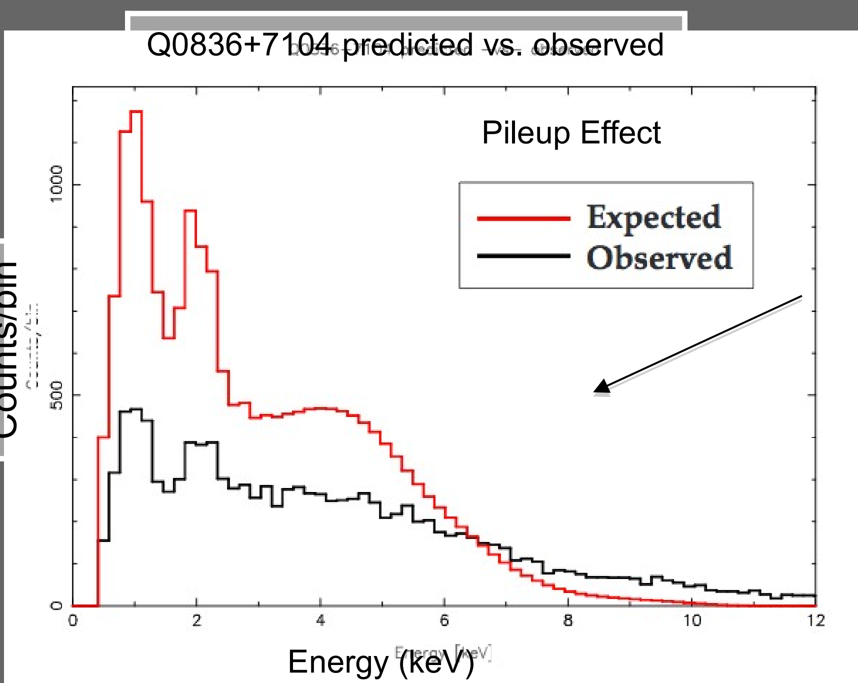
- **energy**
- **position**
- **time**

(e.g. image sharpness, sensitivity, instrumental energy scale)

The Chandra PSF

Energy

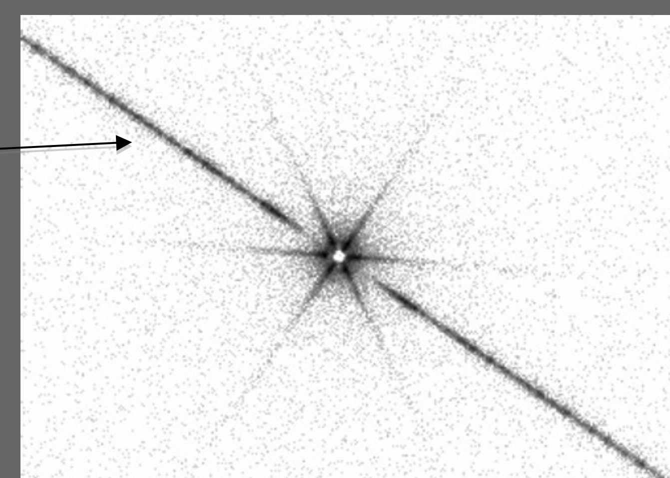
Off-axis angle



Specific instrumental effects eg.

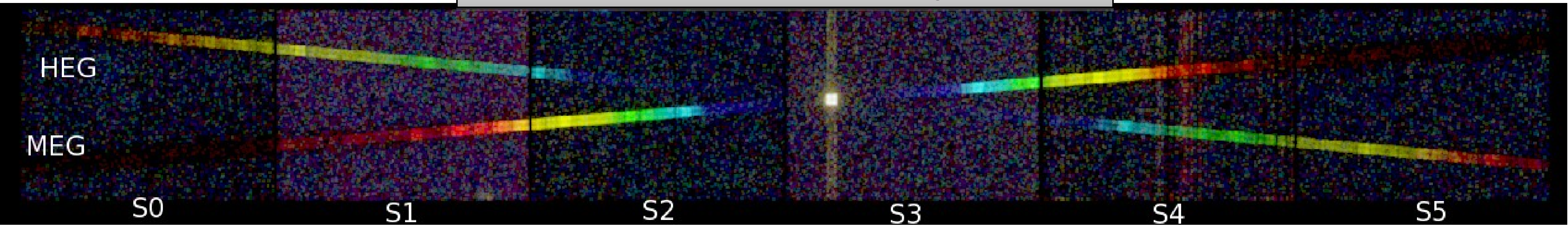
readout streak

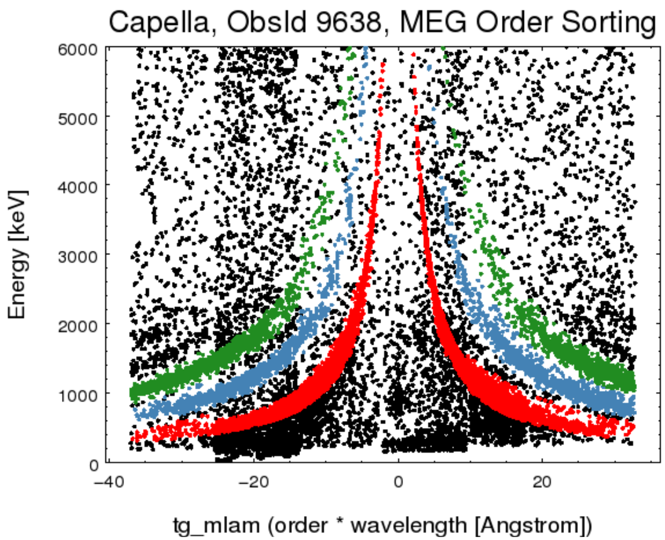
pileup - two or more photons detected as single event

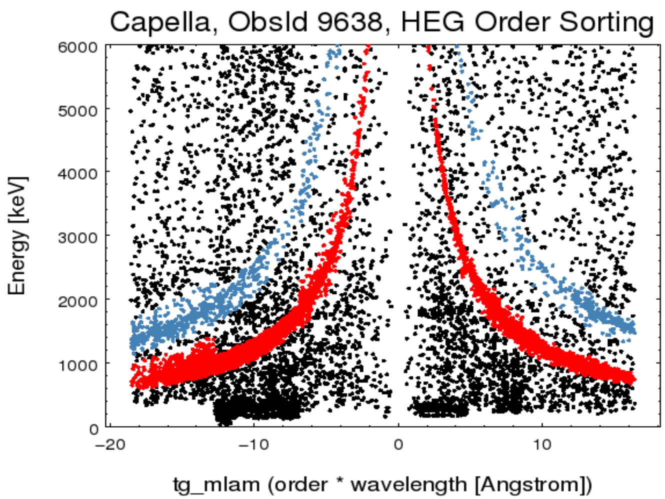


Complexities in X-Ray and Chandra Data Analysis

Capella: ACIS-S + HETG Raw Detector Image Color Coded





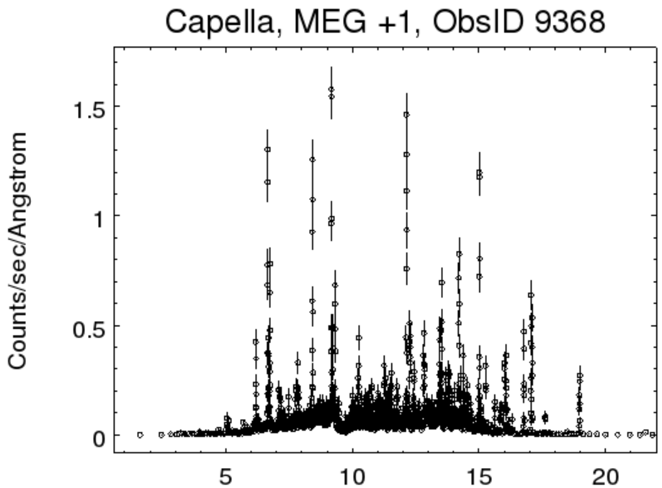


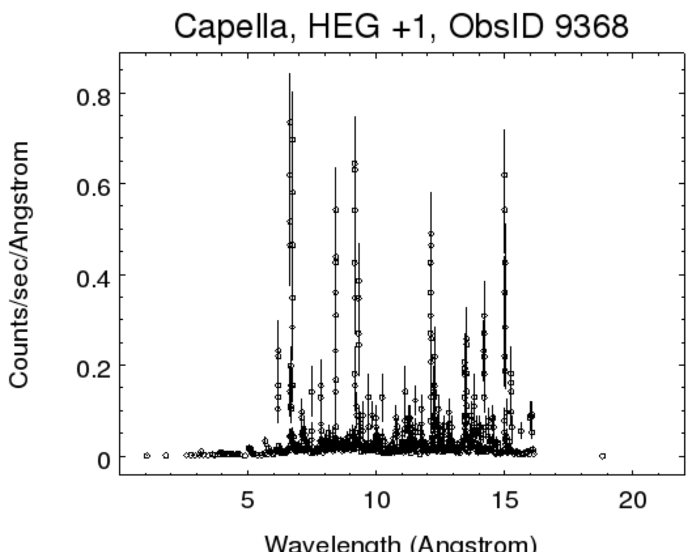
overlapping spectral orders separation

complicated geometry – need precise zero order location

wavelength scale sensitive to details of chip geometry

background different on each chip





Chandra Users

We support users of Chandra data from around the world

•Both experienced and novice X-ray astronomers

•their graduate and undergraduate students

•archival users, many new to X-ray/Chandra data

•users with a large amount of resources and users from smaller countries and institutions

users with different science goals …

•estimate the X-ray flux of my favorite object

•model fitting to spectrum to get velocity (line width) of material

•model fitting spectrum to find gas temperature, pressure in 100 different galaxies

•assess reality of a marginal detection (3 photons at the position of a gamma-ray burst)

…. and with widely varying datasets

•20 minutes to 2 days (or even 1 month for coadded data)

•different configurations (chips, subarrays, gratings, special instrument settings)

•different targets (pointlike stars and quasars, fuzzy galaxies and clusters, moving solar system objects)

All this requires a wide variety of specialized software AND careful documentation

CIAO: supports users from proposal to publication

Tools for proposal planning
Assessing feasibility and examining Chandra field-of-view

e.g. *obsvis, colden*

Tools for data discovery and access
Command line programs to complement the Archive and Catalog searches

e.g. *find_chandra_obsid, download_chandra_obsid, search_csc*

Tools for data inspection and exploration
What is this dataset? How many photons? What instrument configuration? Quick look visualization...

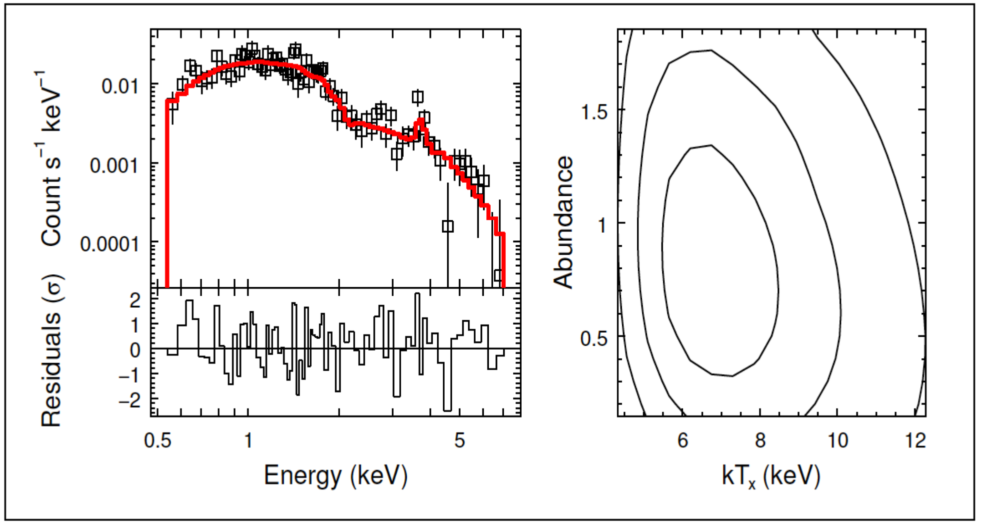
e.g. *ds9, prism, dmlist, dmstat, dmcopy*

Tools for data reduction
Apply latest calibrations to observation
Locate sources and measure their properties (position, brightness)
For each source, generate tailored calibration files (e.g. spectral calibration)

e.g. *dmextract, wavedetect, specextract, srcflux, fluximage*

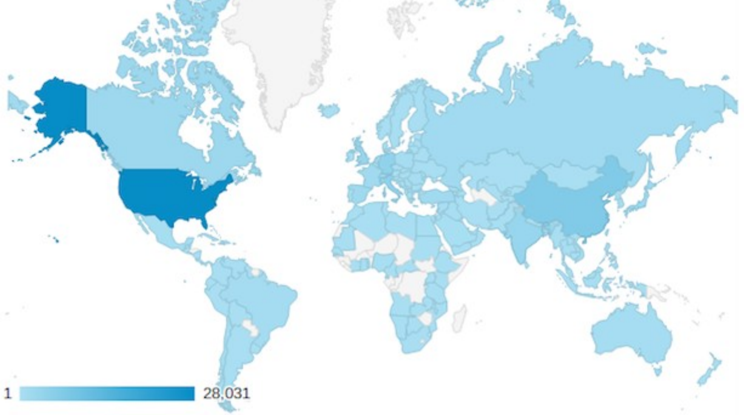
Tools for interactive data analysis
'sherpa' – 1D and 2D modeling and fitting
Python environment – familiar to the new generation of astronomers and used in other missions

Tools to prepare for publication
'ChIPS' – publication quality graphics integrated with the analysis system



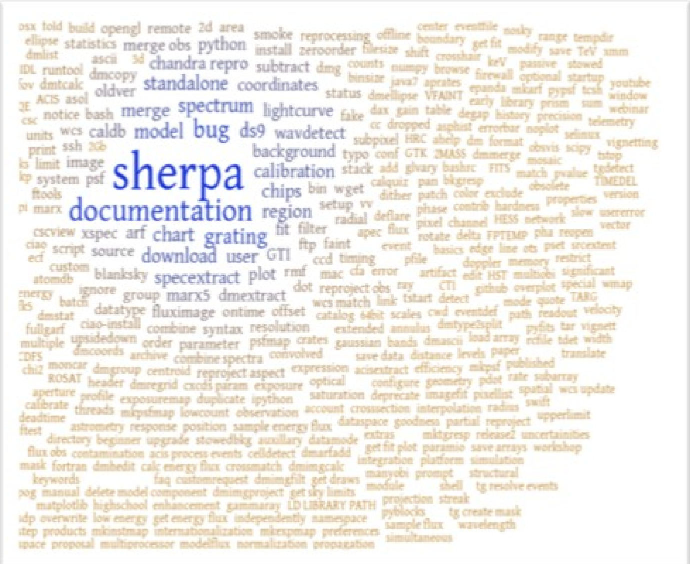
Documentation and Community Support

number of CIAO web visits in the past year



Documentation

•Science-task-oriented step-by-step, end-to-end analysis 'threads' (170+)
•1000 help files for individual tools, concepts
•Over 2000 web pages including FAQ, plot galleries, dictionaries, caveats and bug notes etc.
•You Tube tutorials



Helpdesk

•About 450 CIAO tickets last year from all over the world
•Median time to respond 1 hour, to resolve 1 day
•Experienced help desk staff backed up by SDS scientists and other CXC staff when needed

One-on-One Community Support

•Chandra/CIAO Workshops hosted at CFA
•CIAO education and support at relevant meetings (e.g. X-ray schools, AAS)
•Undergraduate training via NSF REU program at SAO

Maintenance and Responding to Change

Critical maintenance

updates to keep up with changes in spacecraft and/or instruments

eg. modify analysis tools to support temperature variation, combining shorter observations

support changes in users' hardware and operating systems

eg. Dec Alpha to Solaris to Linux to Mac

Address users' needs if/as resources allow…

support changes in users' needs (2014 is not 1999), incorporate changes in scientific approaches and computational approaches; compatibility with newer missions

eg. Bayesian methods, parallel processing

incorporate improved knowledge of best practices and special cases – enhance science, minimize mistakes

eg. applying custom background region for grating spectra

identify and prioritize areas needing additional support

eg. merging datasets split due to new thermal constraints

analysis tools for extended sources

support for alternate instrument configurations (e.g. continuous clocking readout mode)

CIAO – *Chandra Interactive Analysis of Observations*

- → A set of Unix command line tools and Python applications
- → Shares code with standard processing pipeline
- → Allows Chandra instrument specific data reduction
- → Tailored to specialized X-ray astronomy data analysis, but not specific to Chandra
- → Coded with attention to standards and interoperability so that generic tools can be (and are!) used for XMM, Nustar, and even optical and radio data (e.g. multiwavelength analysis)
- → Easy for beginners, yet powerful for advanced users
- → Linux and Mac, annual releases
- → Installed 1200+ times per year (single users to large institutions)

Basics of CIAO

- Data files are in FITS format (usually binary tables, not just images)
- CIAO can also operate on ASCII file in many cases
- All (well, almost all) CIAO tool that want an input file can accept a CIAO Data Model “virtual file”

   e.g instead of   evt.fits
   take   “evt.fits[energy=300:1000,sky=circle(4096,4096,20)]”

Each file (dataset) is made up of sections called 'blocks' (HDUs for FITS fans)
Blocks can be tables or images

Key tools:
   dmcopy infile outfile
   dmlist infile opt=blocks,cols,data

   ahelp dmlist   → help for tool dmlist
   plist dmlist   → list parameters for dmlist

Key applications:
   Sherpa   - fitting
   ChIPS – plotting
   ds9 – imaging and analysis

The Event File

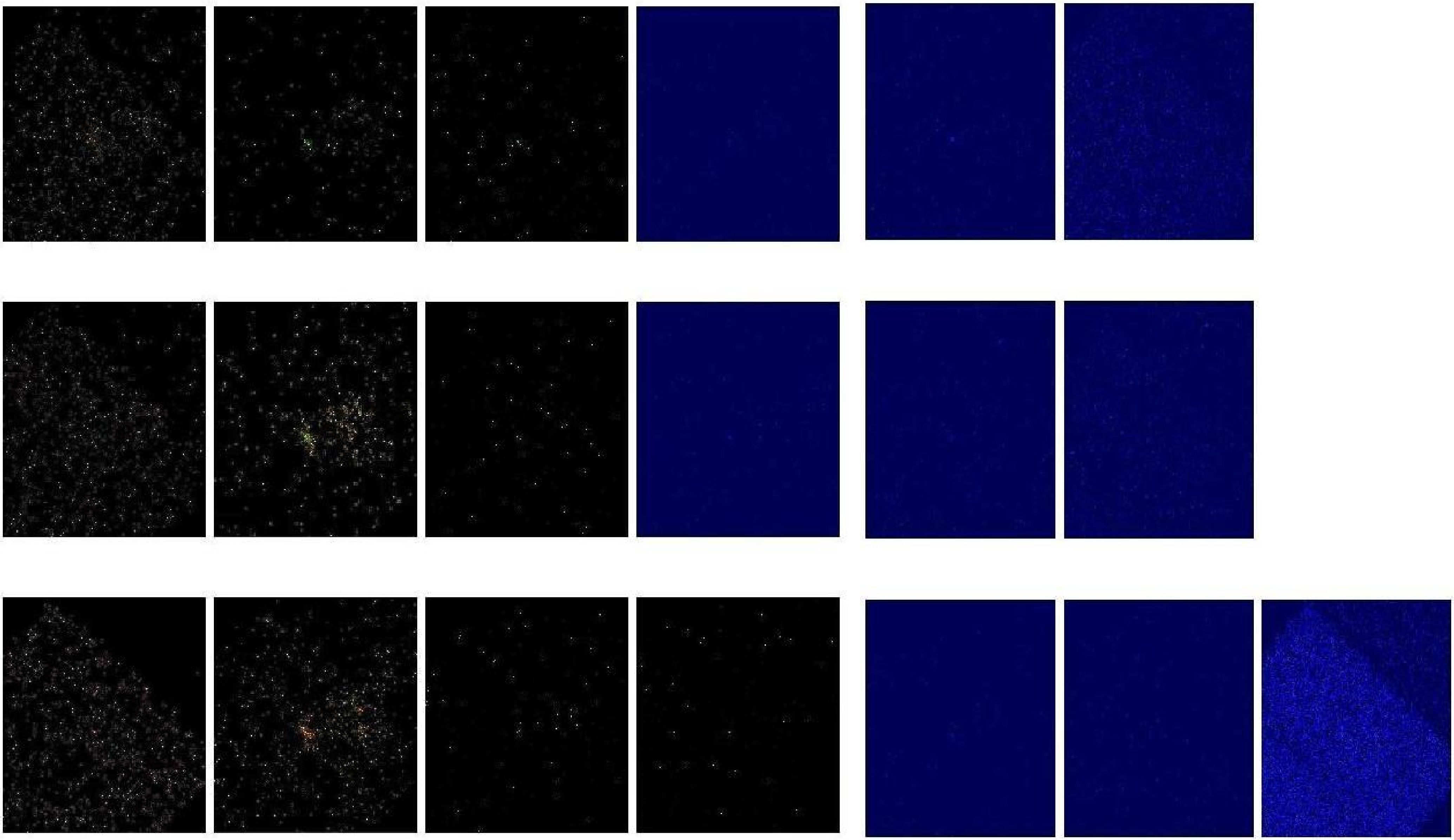
- In optical astronomy, the primary data set is an image. In radio interferometry, it's a visibility array.
- In X-ray astronomy, the primary data set is an event list - a table of (putative) photons
  - Our software makes it easy to generate an image from the event list, so it's easy to forget that's what you have. But making the image loses information.
  - First cut way of thinking about the event list: it's a 4-dimensional array of x, y, time, energy. But most pixels are empty (we don't have many photons!) so it's more compact to just list the non-empty ones.
  - Complication: we actually have many more parameters for each photon, not just 4.

Inside the event list

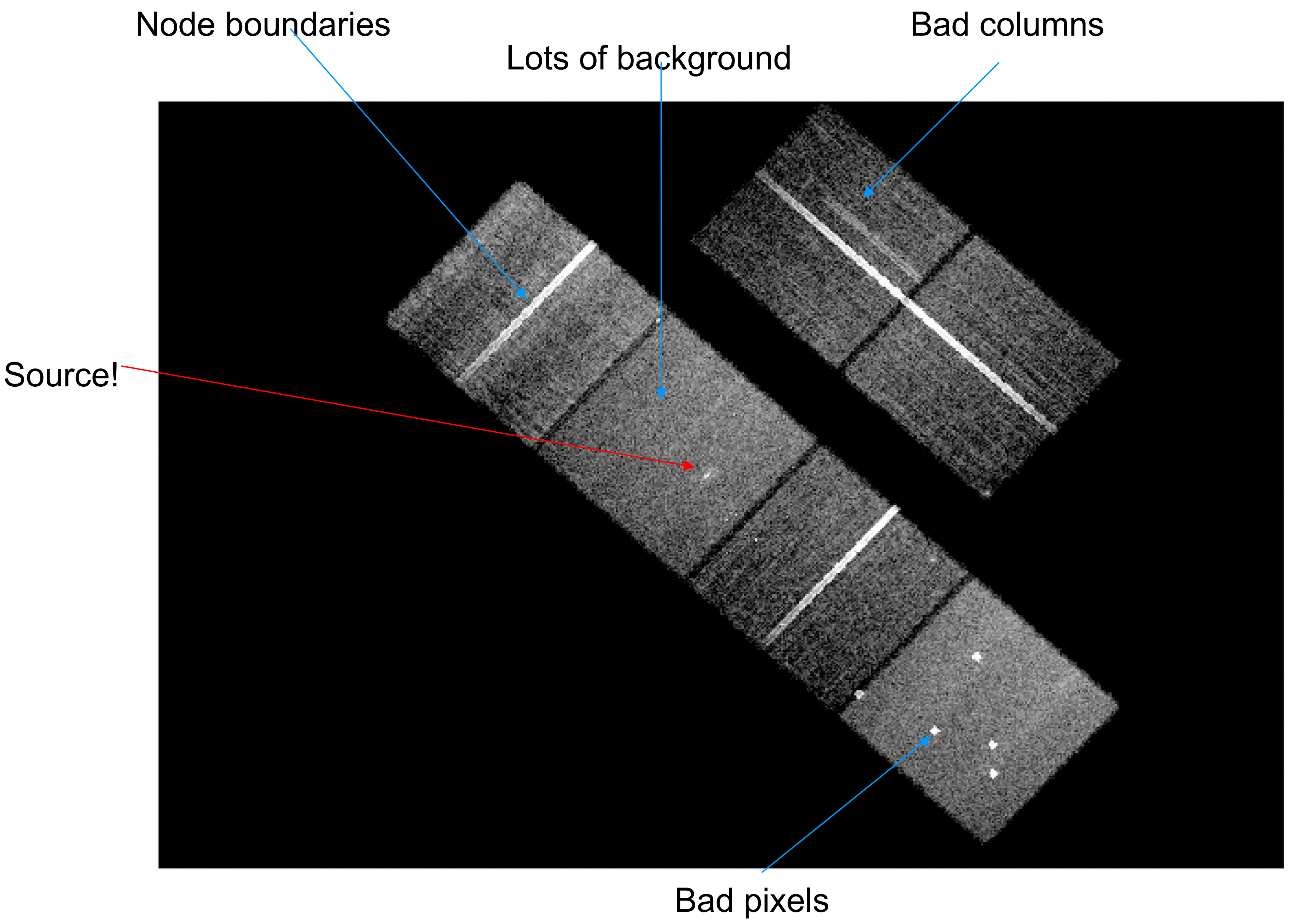
```
jupiter> dmlist acisf03041_001N001_evt3.fits cols

--------------------------------------------------------------------------------
Columns for Table Block EVENTS
--------------------------------------------------------------------------------

ColNo  Name                 Unit        Type         Range
   1   time                 s            Real8        154361559.6127299964:154436827.4158599973 S/C TT corresponding to mid-exposure
   2   ccd_id                            Int2         0:9                    CCD reporting event
   3   node_id                           Int2         0:3                    CCD serial readout amplifier node
   4   expno                             Int4         0:2147483647           Exposure number of CCD frame containing event
   5   chip(chipx,chipy)    pixel        Int2         1:1024                 Chip coords
   6   tdet(tdetx,tdety)    pixel        Int2         1:8192                 ACIS tiled detector coordinates
   7   det(detx,dety)       pixel        Real4        0.50:      8192.50     ACIS detector coordinates
   8   sky(x,y)             pixel        Real4        0.50:      8192.50     sky coordinates
   9   pha                  adu          Int4         0:36855                total pulse height of event
  10   pha_ro               adu          Int4         0:36855                total read-out pulse height of event
  11   energy               eV           Real4        0:  1000000.0          nominal energy of event (eV)
  12   pi                   chan         Int4         1:1024                 pulse invariant energy of event
  13   fltgrade                          Int2         0:255                  event grade, flight system
  14   grade                             Int2         0:7                    binned event grade
  15   status[4]                         Bit(4)                              event status bits
```

```
jupiter> dmlist acisf03041_001N001_evt3.fits"[cols -status]" data,raw,clean rows=1:20
#  time              ccd_id node_id expno    chip(chipx,chipy) tdet(tdetx,tdety) det(detx,dety)                     sky(x,y)                               pha      pha_ro   energy                    pi  fltgrade grade
 154362662.7665936351  0   1   107   369 513   3574 4763   3540.2504882812   1556.8157958984   1473.2664794922   4129.1977539062   3868   3680   15358.6318359375   1024   16   4
 154362662.7665936351  0   2   107   562 589   3650 4570   3615.2900390625   1748.9260253906   1676.4797363281   4093.9599609375   3977   3750   15254.2246093750   1024   64   2
 154362662.7665936351  0   0   107   247 876   3937 4885   3902.1516113281   1435.5321044922   1426.5589599609   3750.3830566406   3765   3514   14473.1611328125    992    0   0
 154362662.8076336384  7   0   107   189 301   4106 2003   4069.4038085938   4313.6518554688   4280.3339843750   4160.218750   3568   3503   15899.1279296875   1024   11   6
 154362662.8076336384  7   1   107   264 388   4181 2090   4144.4223632812   4225.7763671875   4209.175781250   4069.1887207031   128   109   632.9125366211   44   72   6
 154362662.8076336384  7   2   107   555 410   4472 2112   4435.0400390625   4204.0610351562   4245.8291015625   3780.0749511719   1717   1702   7969.5327148438   546    8   3
 154362662.8076336384  7   2   107   676 441   4593 2143   4556.0268554688   4172.6386718750   4239.1547851562   3655.2526855469   1908   1853   8829.906250   605   16   4
 154362662.8076336384  7   1   107   483 465   4400 2167   4363.3208007812   4149.5029296875   4178.0693359375   3839.4790039062   1011    994   4767.4877929688   327    2   2
 154362662.8076336384  7   3   107   881 613   4798 2315   4760.8256835938   4001.3994140625   4112.1772460938   3420.4289550781   1348   1310   6024.1176757812   413    0   0
 154362662.8076336384  7   2   107   690 834   4607 2536   4569.7802734375   3780.8713378906   3857.9919433594   3563.6794433594   2011   1942   9294.6806640625   637   72   6
 154362662.8076336384  7   1   107   348 925   4265 2627   4228.7290039062   3689.4941406250   3700.4628906250   3879.6706542969   1722   1664   8069.8139648438   553    2   2
 154362662.8076336384  7   1   107   502 954   4419 2656   4381.6430664062   3660.5825195312   3702.6135253906   3724.0622558594   3011   2957   14100.3310546875   966  208   6
 154362662.8486736417  6   3   107   803 548   3678 2250   3639.6469726562   4066.6665039062   3952.636718750   4532.1162109375   2258   2095   8640.0263671875   592    2   2
 154362662.8897136450  3   0   107    40 717   4415 3101   4376.0224609375   3215.3222656250   3265.1691894531   3640.8110351562   3146   2950   12326.56250   845    0   0
 154362662.8897136450  3   0   107    78 901   4231 3139   4192.5224609375   3177.2634277344   3191.2951660156   3813.0412597656   2252   2077   8826.3281250   605   64   2
 154362662.9307536483  2   0   107   208 240   3301 3878   3266.0554199219   2440.0964355469   2284.2392578125   4573.9658203125   3451   3423   13226.7988281250   906   16   4
 154362662.9307536483  2   2   107   517 719   3780 3569   3744.8583984375   2748.1215820312   2681.5275878906   4166.1748046875   3816   3544   14376.746093750   985   64   2
 154362662.9717936218  1   0   107   101 567   4565 4208   4527.886718750   2109.5788574219   2211.8908691406   3271.5732421875   1644   1543   6498.9438476562   446   64   2
 154362662.9717936218  1   3   107   996 952   4180 5103   4141.839843750   1216.6264648438   1259.9039306641   3471.8693847656   2406   2170   9509.4218750   652   16   4
 154362666.0075938106  0   2   108   683 156   3217 4449   3183.1049804688   1869.4627685547   1709.3774414062   4541.6933593750   3466   3429   13290.0634765625   911    0   0
```

Energy slices through an event list, 0.1 - 10 keV



Level 1 Event List - Calibrated but Dirty

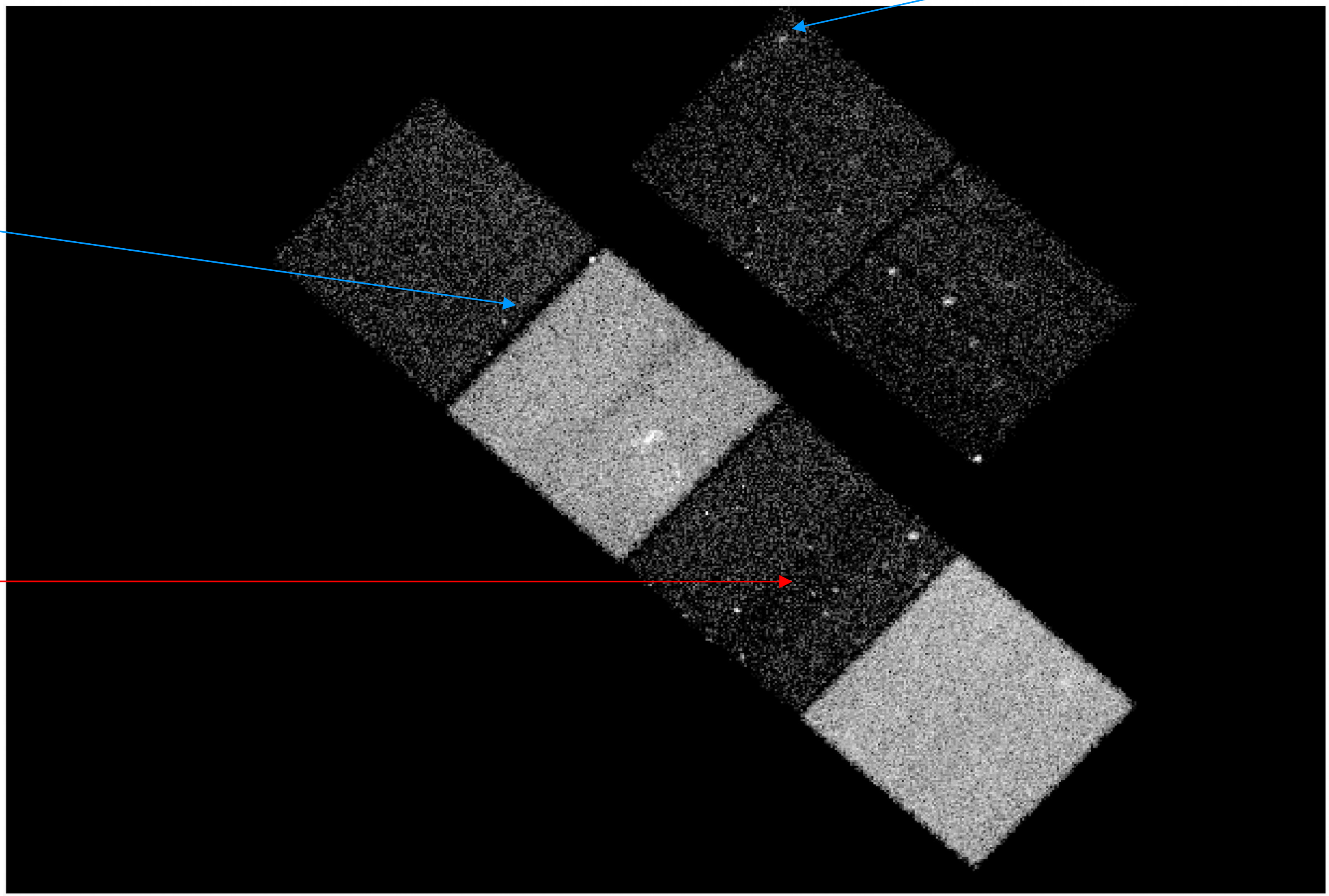


Level 2 event list - cleaned and filtered

Energy filter 300-7000 eV removes background but not signal
Grade filter removes cosmic ray events etc
Good time filter removes times of high background, poor data quality

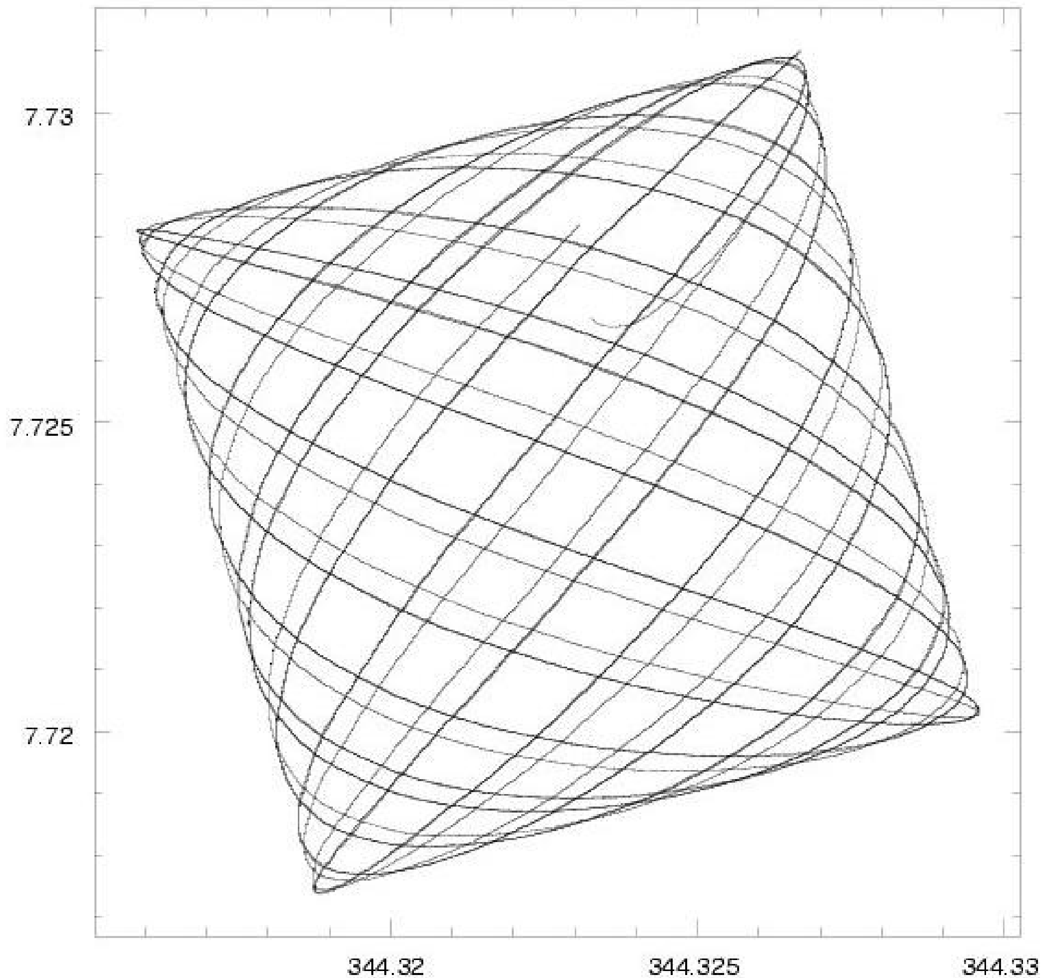
Sources fuzzy far off axis (PSF big)

Beware chip gaps!



More sources!

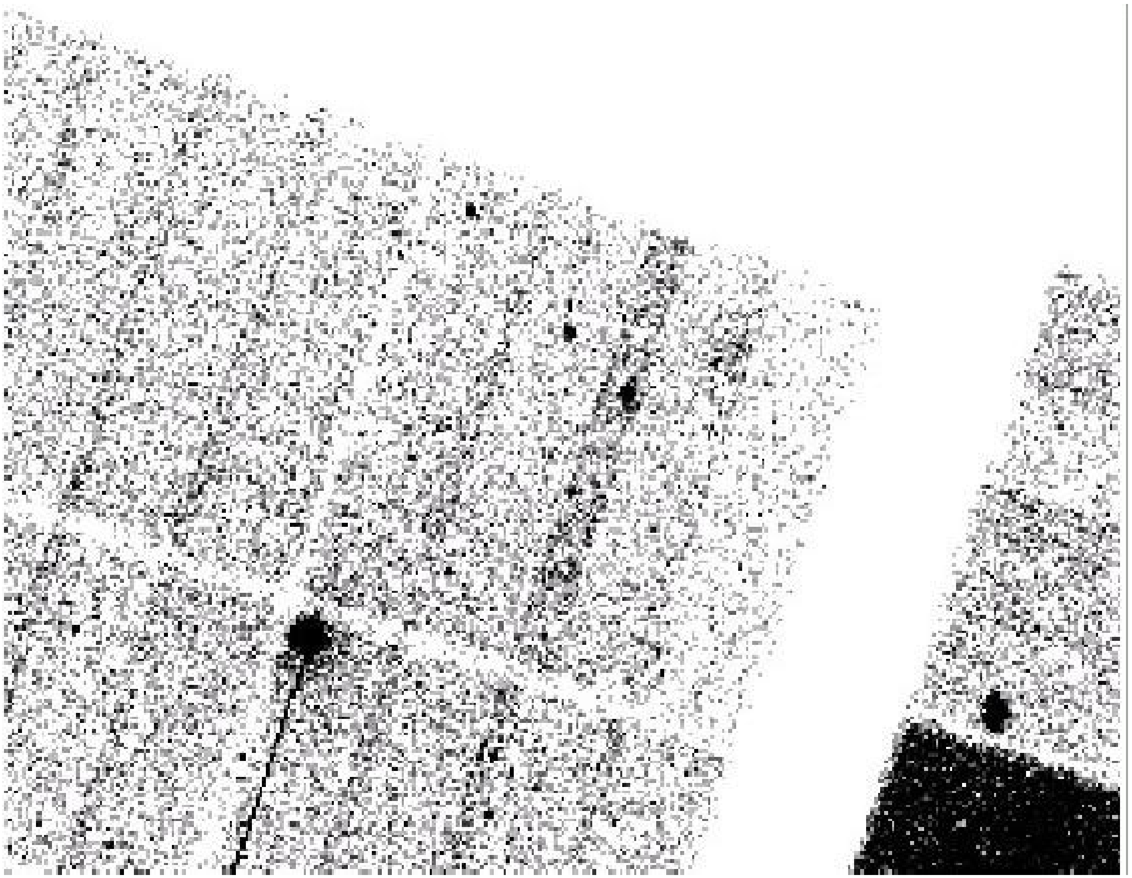
The aspect solution



During an observation, Chandra's optical axis describes this 'dither pattern' on the sky, (Problem 5), smearing the image of a point source. The RA, Dec, roll angle of the telescope versus time is called the 'aspect solution'; the asol1.fits file provides this for each observation.

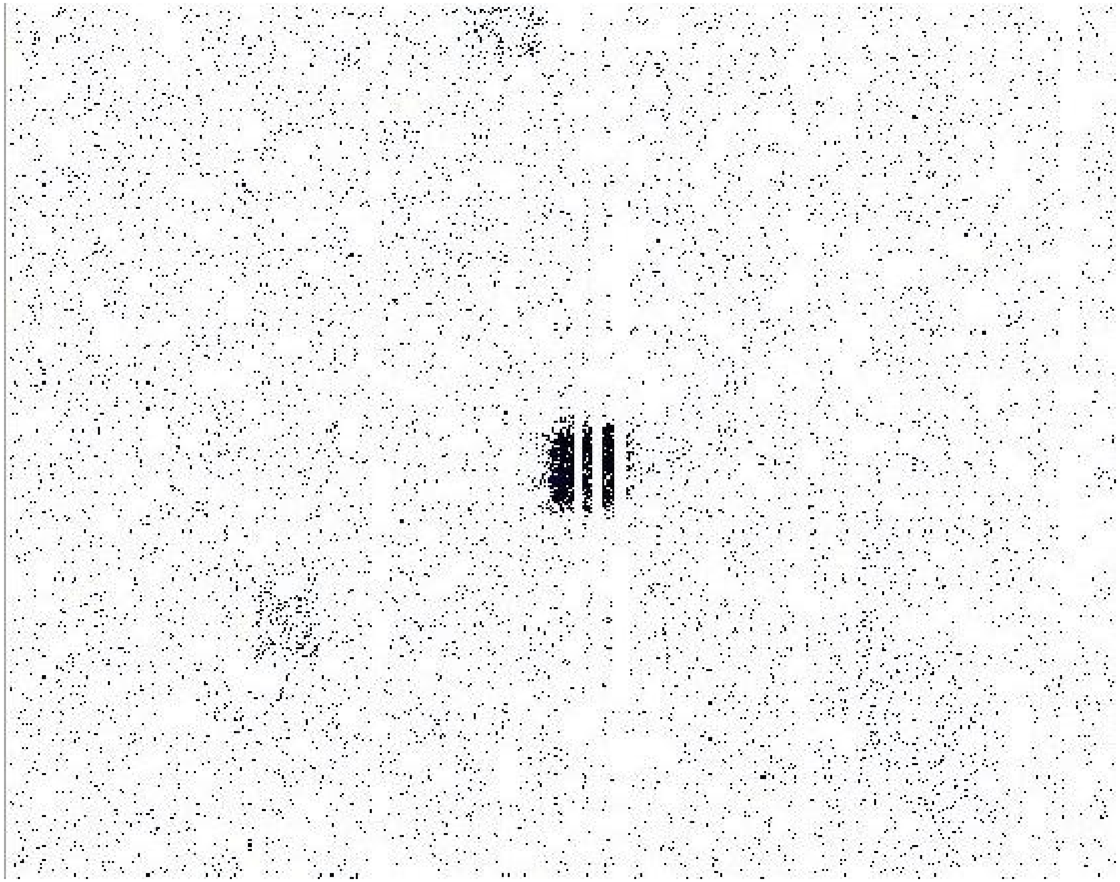
We record the motion of the guide stars in the star tracker so that we can calculate RA and Dec for EACH PHOTON and so reconstruct the image.

Chandra aspect-corrected data



This is what you get after calibration but before cleaning the data. Note the sharp point sources near the center.

Chandra raw (chip) data



In instrument space, the photons are spread out over 20 arcsec and have bad columns going through them - so be careful of the effective exposure time. If you didn't dither, you could lose the source entirely if it landed on a bad pixel

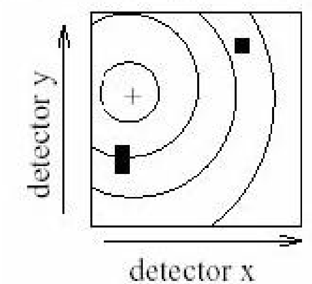
Spatial Response: EXPOSURE MAP

The *Exposure Map*, $E(\Delta h, \lambda, \hat{p})$ retains spatial information at the expense of spectral. It has units of [cm^2 counts $photons^{-1}$] .

$$\int d\lambda\, S(\lambda, \hat{p}) \approx \frac{C(\Delta h, \hat{p})}{E(\Delta h, \lambda, \hat{p})}$$

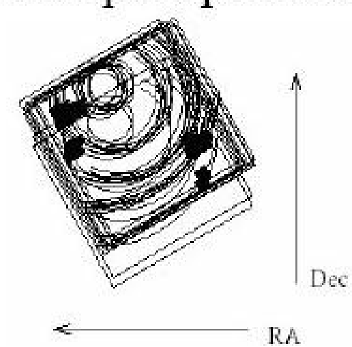
C is the observed counts per spatial bin in a pulse-height bin. *S* is the source flux, with units of [phot $cm^{-2}s^{-1}Å^{-1}$].

Instrument Map – efficiency calibration information, band integrated. (create with `mkinstmap`)



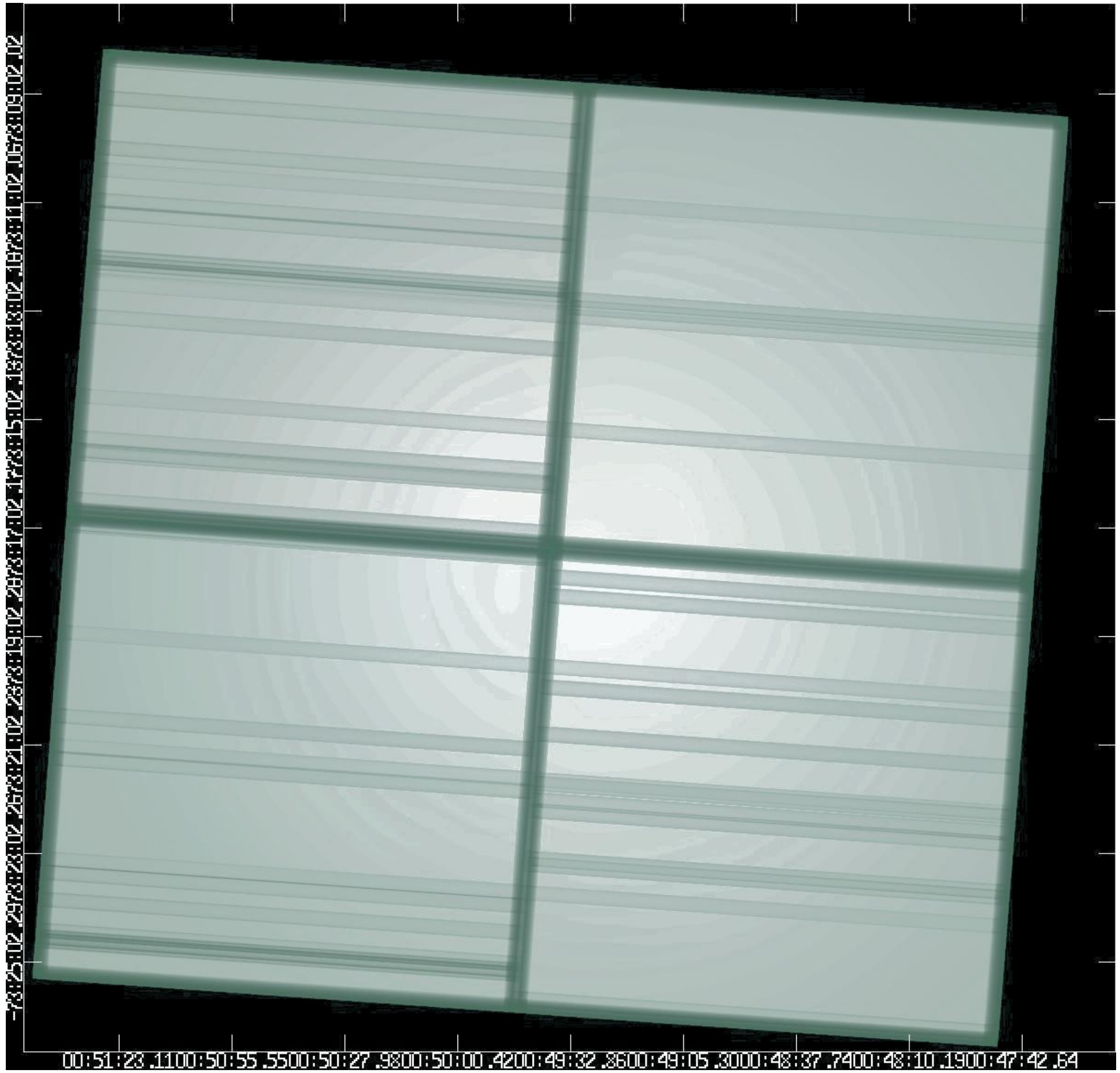
= mirror area x detector QE

Exposure Map – applies telescope aspect history and coordinate transformations (= area x time). (create with `mkexpmap`).



= Instmap $\otimes$ Aspect

Typical exposure map



Problem 3: Exposure map is energy dependent; must assume a spectrum if using a broad band

Event analysis or binned analysis?

- Don't make an image too quickly. If you can get an answer directly from the event list, that's better - binning the data loses information, and collapsing the axes loses information.
- Spatial analysis: make an image (using dmcopy)
  - lose energy and time information
- Spectral analysis: make a 'PHA file' using dmextract (or a grating spectrum using tgextract)
  - lose spatial and time information
- Temporal analysis: make a light curve using dmextract

The fundamental equation of astronomy

$$N(E) = A(E)F(E)\Delta T$$

Our instrument makes a spectrophotometric measurement; the sensitivity ("effective area") A(E) tells us how to convert from flux to instrumental counts for a given exposure time ΔT

But, a real instrument doesn't measure the true energy, it measures instrumental energy E'. The line spread function ("response matrix" in X-rays) R(E,E') describes how a monochromatic input spectrum is broadened by the instrument (Problem 2)

Let us further assume that the instrumental energy E' is measured in discrete channels (bins) E'i. Then

$$N(E'_i) = \int A(E)R(E,E'_i)F(E)dE\Delta T$$

Of course, you may not be measuring all of the light from the source. Even if it's a point source, there may be an aperture correction. We need the PSF P(x-x',y-y') and the spatial dependence of the QE, q(x,y). Then at a given instrument position x',y'

$$\boxed{N(E'_i, x'_i, y'_i) = \int\int A(E)R(E,Ei)F(E,x,y)P(x-x'_i, y-y'_i)q(E,x'_i,y'_i)dEdxdy\Delta T}$$

The source may also be variable in time - we'll ignore this for the purposes of this talk.
The detector sensitivity is time-variable on long timescales, but for a single observation you just have to worry about times when the data is filtered - the Good Time Intervals (GTIs)

$$N(E'_i, x'_i, y'_i) = \int\int\int A(E)R(E,Ei)F(E,x,y,t)P(x-x'_i, y-y'_i)q(E,x'_i,y'_i)dEdxdydt$$

Pulse height

When you plot an optical spectrum, the wavelength (or energy) axis is really an instrumental quantity. A spectral line is broadened by instrumental effects, so the energies plotted are not the true energies of the photon. However, the instrument is calibrated (i.e. the definition of instrumental energy is rescaled) such that the peak of a line is at the correct energy.

In X-ray astronomy, instead of using the instrumental energy E', we work with the energy bin number. For historical reasons to do with long-forgotten instruments, this bin number is know as the PI channel (for 'pulse invariant' channel) - we'll denote it by P. So, for fixed energy bin widths dE,

$$E' = P\, dE =[\text{on average}]\ E$$

The instrument actually measures a raw energy bin number p, called the PHA channel, or 'pulse height analyser channel'. The scaling of the instrumental energy to real energy depends on position and time:

$$E'(\text{raw}) = p\, dE = g(x,y,t)P\, dE$$

This function g (the gain) is usually assumed to obey

$$g(x,y,t) = g\_spatial(x,y)\ g\_t(t)$$

and we provide calibrations of both the spatial gain and the temporal gain.

Spectra in Poissonland

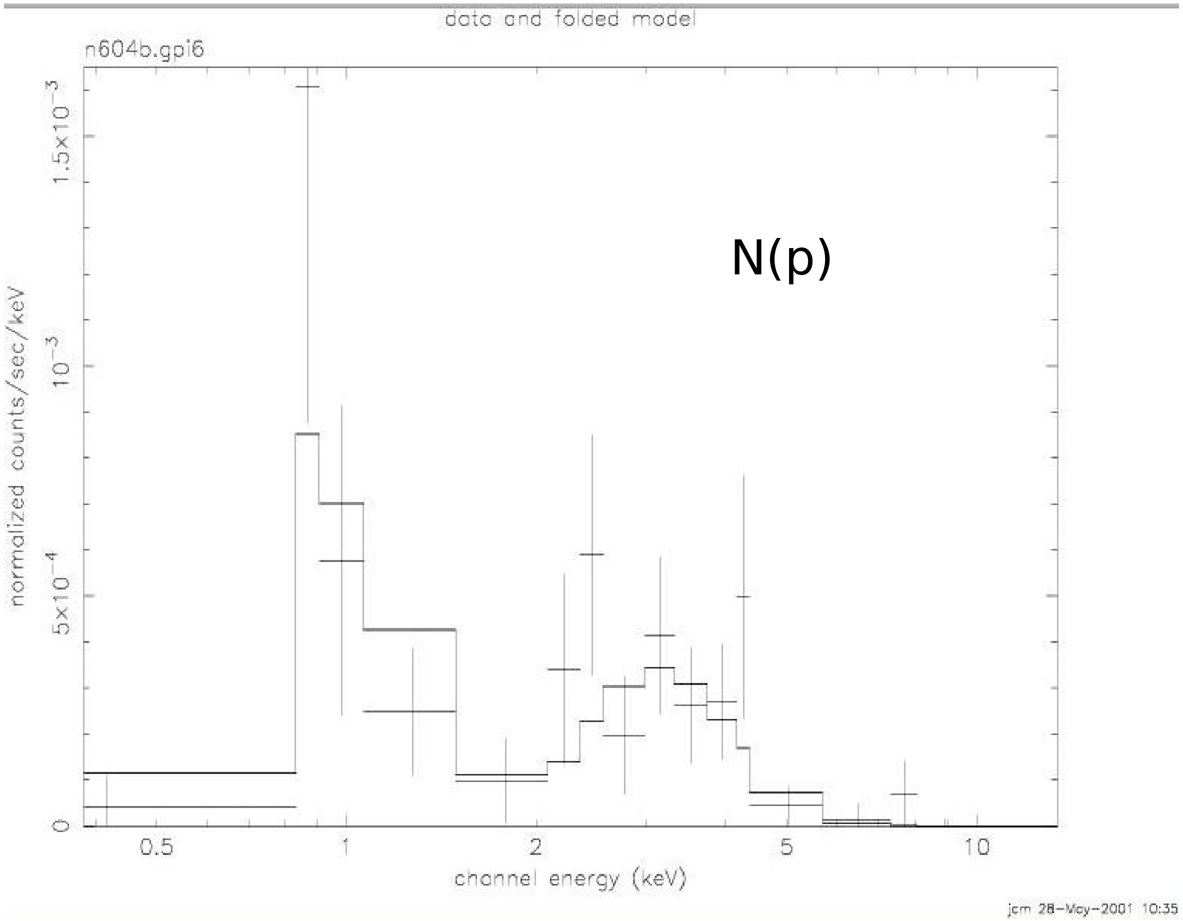
We pick a parameterized F(E) such as warm absorber models, lines, thermal plasma codes. Which F(E)? You must pick one based on expected physics, but match number of free parameters with quality of data.

With less than 100 counts, we usually just use count ratios (X-ray colors) for spectral analysis.

Does one model fit significantly better than another? Be careful that two physically different models may look quite similar in F(E) space.

Incompletely calibrated instrumental features may show up in residuals, limiting factor in high S/N spectra – these features may include edges. Beware apparent science in regions where A(E) is changing rapidly.

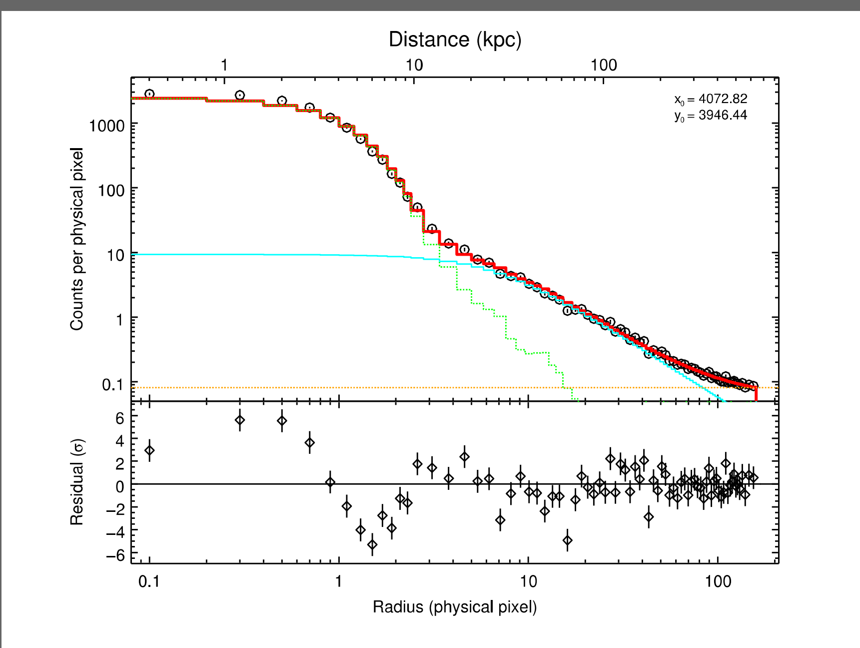
$$N(p) = \int R(E,p)A(E)F(E)dE$$

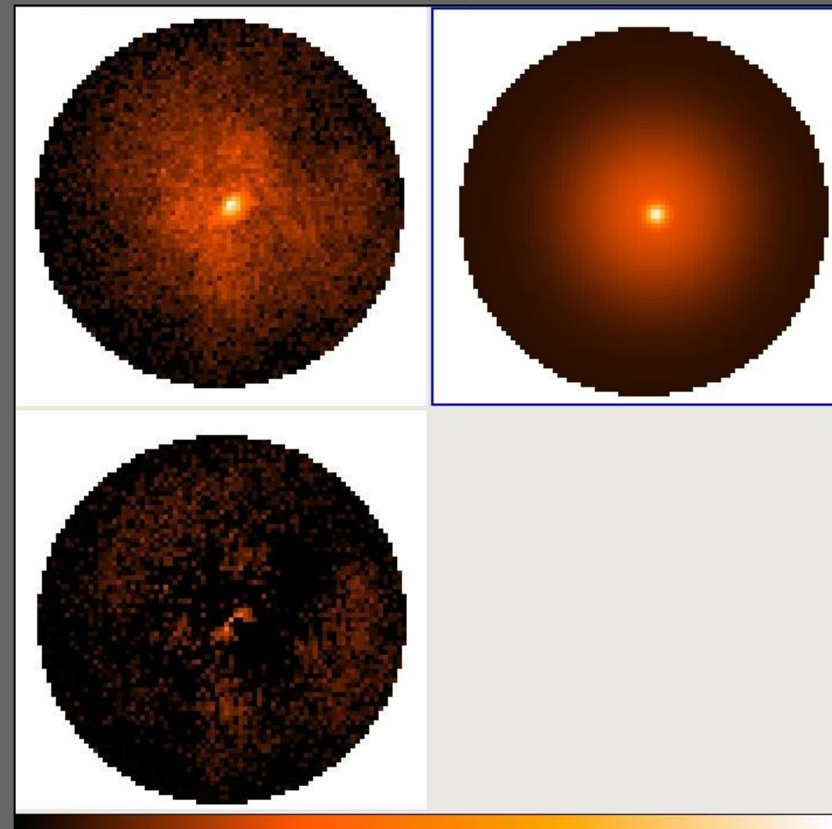


Sherpa: Modeling and Fitting in Python

Sherpa

Modeling and fitting for 1-D and 2-D datasets **in any waveband** including: spectra, images, surface brightness profiles, light curves, general ASCII data.

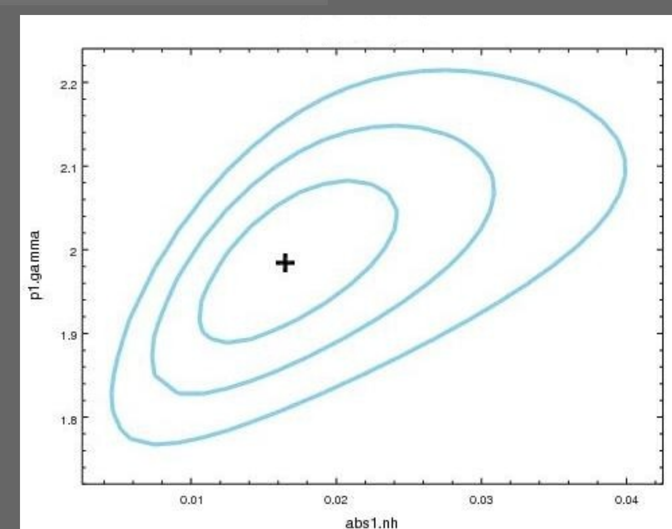




Coded in a Python environment – familiar to the new generation of astronomers and used in other missions

Model Poisson and Gaussian data

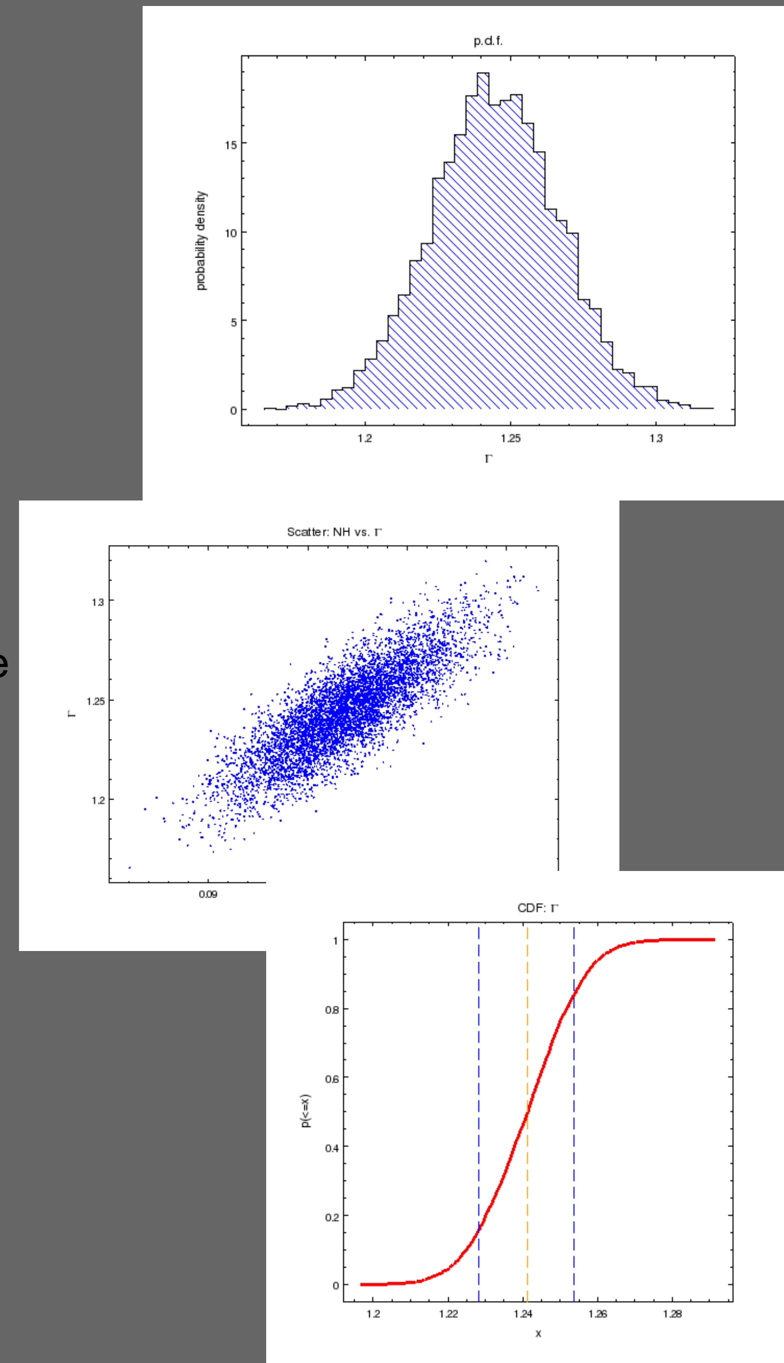
Calculate confidence levels on the best-fit model parameters



Sherpa: Modeling and Fitting in Python

Sherpa

- comes with well-tested, robust optimization methods - e.g. Levenberg-Marquardt, Nelder-Mead Simplex or Monte Carlo/Differential Evolution
- comes with statistics for modeling Poisson or Gaussian data
- can perform Bayesian analysis with Poisson Likelihood and priors, using Metropolis or Metropolis-Hastings algorithm in the MCMC (Markov-Chain Monte Carlo); allows to include non-linear systematic errors (calibration uncertainties) in the analysis
- is extensible (with python and compiled code):
  - is used in CIAO tools and scripts
  - in the Xija Chandra thermal modeling code
  - is used in the TeV HESS data analysis software
  - is used in the IRIS spectral energy distribution program

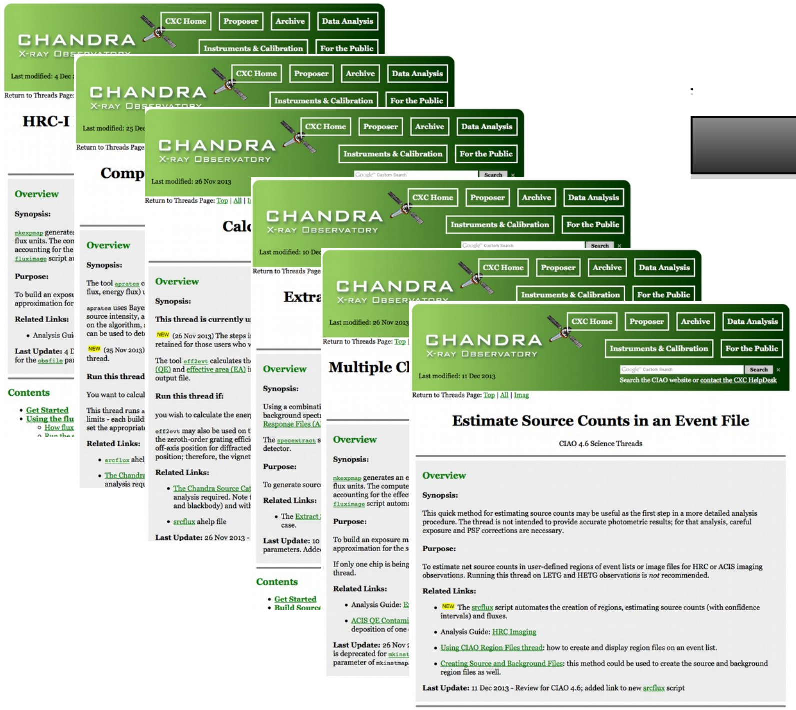


CALDB

- The CALDB (Calibration Database) contains everything you need that's not part of your specific observation.
- It's designed as a multimission directory structure. The Chandra files are in $CALDB/data/chandra
- Within that, they are arranged by instrument and kind of calibration. But, with luck, the software will find the CALDB files you need automatically.
- Just make sure that you keep the CALDB up to date! But, be careful - if you start off processing with a given version of the CALDB and CIAO, then upgrade to a new CALDB and CIAO, things are sometimes incompatible. Check the release notes.

CIAO scripts: analysis simplified

Recent emphasis on high level programs with easy interfaces – particularly helpful for users who are not X-ray astronomy specialists.



one script

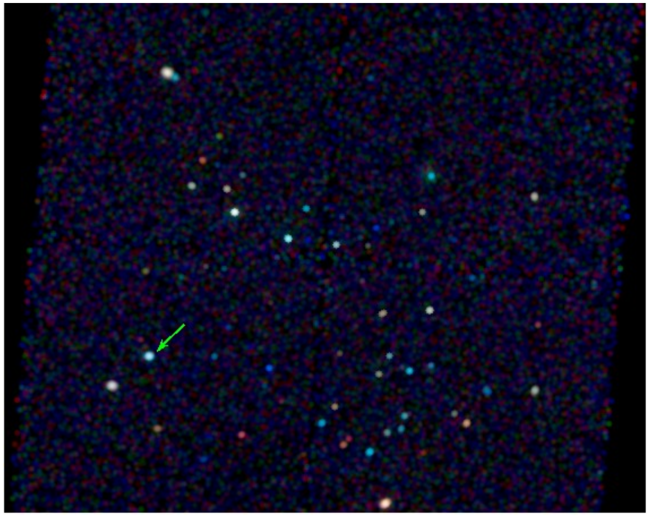
Wrap laborious thread analysis steps with a single command line script

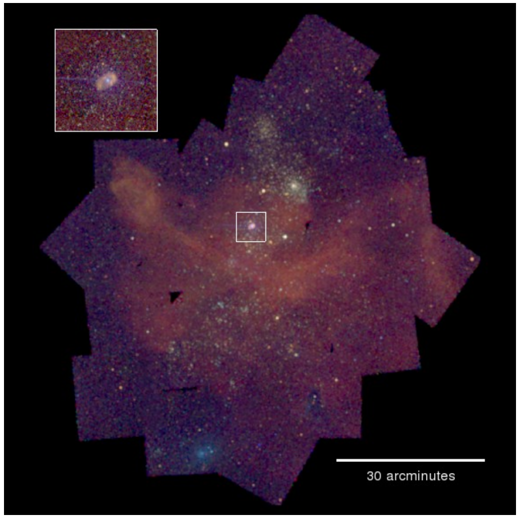
Handle the various special cases by inspecting the metadata in the data files

Scripts have parameters which allow the expert user to tune them

This new suite of scripts makes analysis quicker

Two examples: srcflux and merge_obs





MAKING X-RAY ANALYSIS EASIER

ciao_install - automated installation process
- tunable, also supports source builds

What data is there? WebChaser is still great, but sometimes find_chandra_obsid is handy for CL use or scripting::

```
neptune>
neptune> find_chandra_obsid "NGC 2403"
# obsid  sepn   inst grat   time    obsdate piname       target
2014      0.2 ACIS-S NONE   36.0 2001-04-17  CAPPI      NGC2403
2937      2.6  HRC-I NONE    2.8 2002-01-27 SUGIHO "NGC2403 S3"
4628      2.7 ACIS-S NONE   47.1 2004-08-23  Lewin  "SN 2004dj"
4629      2.7 ACIS-S NONE   45.1 2004-10-03  Lewin  "SN 2004dj"
4630      2.7 ACIS-S NONE   50.6 2004-12-22  Lewin  "SN 2004dj"
neptune>
```

There's also the footprint service cxc.harvard.edu/cda/footprint

find_chandra_obsid can also download the data, or you can use...

File Edit View Search Terminal Help

```
neptune>
neptune>
neptune> download_chandra_obsid 4628,4629
Downloading files for ObsId 4628, total size is 204 Mb.

  Type     Format      Size  0........H.........1  Download Time Average Rate
  ---------------------------------------------------------------------------
  oif      fits       25 Kb  ####################          < 1 s  179.5 kb/s
  vv       pdf        40 Kb  ####################          < 1 s  224.1 kb/s
  full_img jpg        60 Kb  ####################          < 1 s  422.4 kb/s
  cntr_img fits      175 Kb  ####################          < 1 s  933.2 kb/s
  full_img fits       92 Kb  ####################          < 1 s  603.0 kb/s
  evt2     fits       21 Mb  ####################            7 s  2882.5 kb/s
  asol     fits       12 Mb  ####################            4 s  2715.4 kb/s
  bpix     fits       44 Kb  ####################          < 1 s  385.3 kb/s
  fov      fits        6 Kb  ####################          < 1 s  68.0 kb/s
  eph1     fits      282 Kb  ####################          < 1 s  1150.0 kb/s
  cntr_img jpg       573 Kb  ####################          < 1 s  1604.3 kb/s
  stat     fits        2 Mb  ####################          < 1 s  2201.2 kb/s
  flt      fits        6 Kb  ####################          < 1 s  67.6 kb/s
  msk      fits        5 Kb  ####################          < 1 s  65.2 kb/s
  mtl      fits        2 Mb  ####################          < 1 s  2504.2 kb/s
  evt1     fits      125 Mb  ####################           53 s  2440.5 kb/s
  bias     fits      443 Kb  ####################          < 1 s  1198.8 kb/s
  bias     fits      493 Kb  ####################          < 1 s  1394.2 kb/s
  bias     fits      448 Kb  ####################          < 1 s  1495.9 kb/s
  bias     fits      431 Kb  ####################          < 1 s  1373.8 kb/s
  bias     fits      431 Kb  ####################          < 1 s  1313.7 kb/s
  bias     fits      441 Kb  ####################          < 1 s  1300.8 kb/s
  pbk      fits        4 Kb  ####################          < 1 s  45.1 kb/s
  vv       pdf        35 Mb  ####################           16 s  2255.8 kb/s
```

download_chandra_obsid gets the data for you
This one makes subdirs 4628/ and 4629/ each with the usual primary/, secondary/ subdirs that you are used to

Next we update the archive processing with the latest calibrations using chandra_repro

```
neptune> ls 4628
axaff04628N002_VV001_vv2.pdf  oif.fits  primary/  secondary/
neptune> chandra_repro
Input directory (./): 4628
Output directory (default = $indir/repro) ():
```

Now we have a new repro/ subdirectory with (hopefully) all the files you'll need for further analysis, including "repro_evt2.fits"

```
neptune> ls 4628
axaff04628N002_VV001_vv2.pdf  oif.fits  primary/  repro/  secondary/
neptune> ls 4628/repro
acisf04628_000N003_bpix1.fits  acisf04628_000N003_stat1.fits  acisf209642202N003_pbk0.fits
acisf04628_000N003_fov1.fits   acisf04628_asol1.lis           pcadf209643885N003_asol1.fits
acisf04628_000N003_msk1.fits   acisf04628_repro_bpix1.fits
acisf04628_000N003_mtl1.fits   acisf04628_repro_evt2.fits
neptune>
```

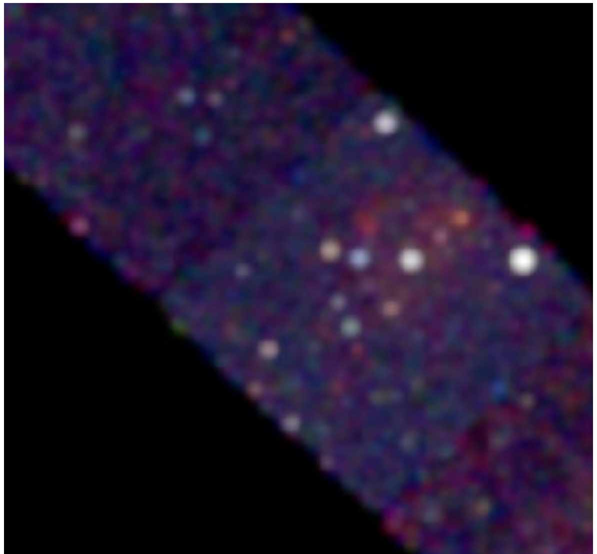
chandra_repro also works on grating data

Now you have calibrated data and are ready to do science.
You may want to take a look at the data by making a three color fluxed image using 'fluximage'; cd into the repro directory and run as shown here.

- knows about CSC bands soft, med, hard, broad

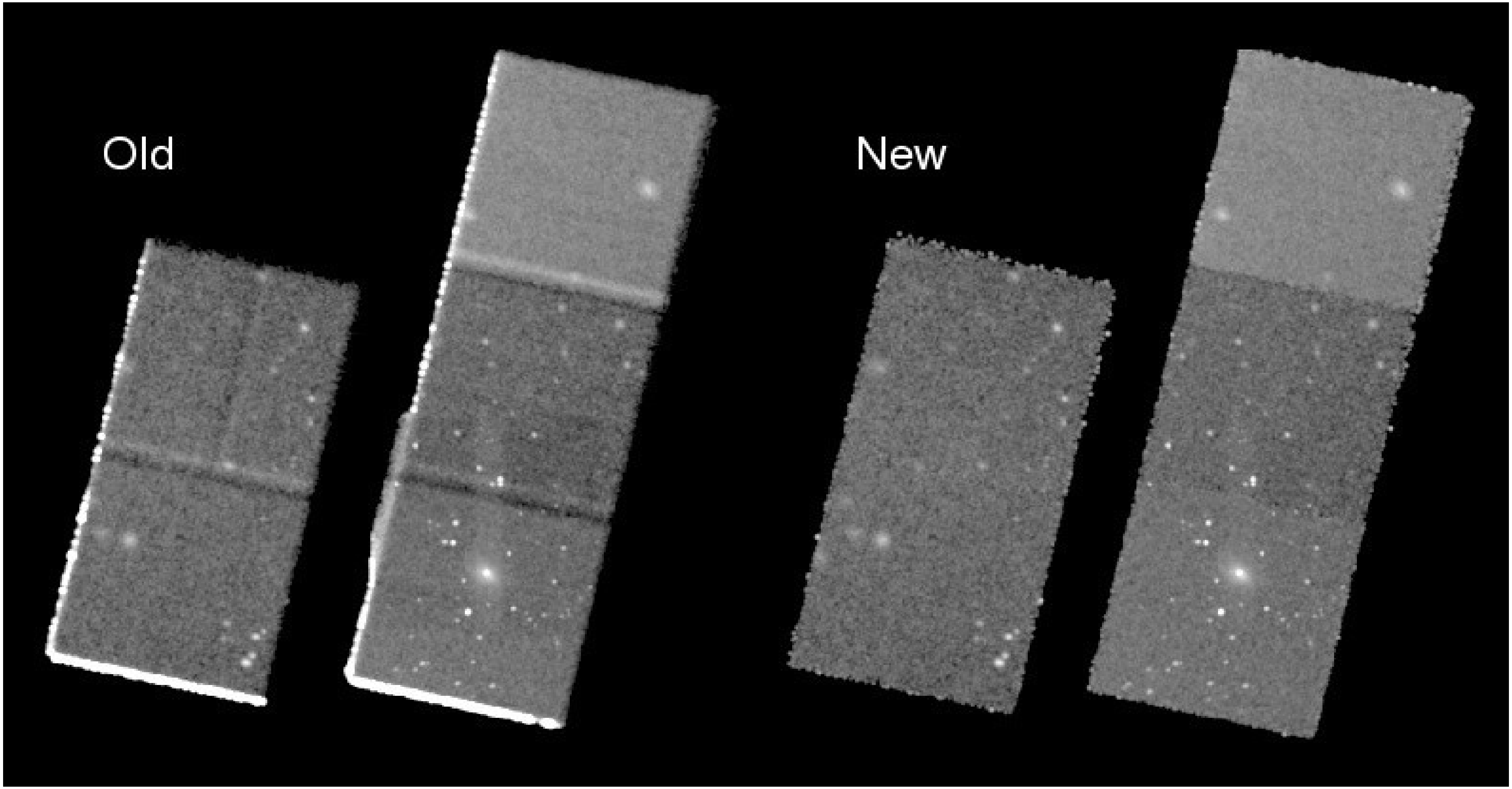
- finds the asol, badpix, mask etc. on its own

- makes exposure maps etc.:



```
neptune> fluximage *repro_evt2.fits out=fimg bin=4 bands=CSC
Running fluximage
Version: 08 November 2012

Using CSC ACIS soft science energy band.
Using CSC ACIS medium science energy band.
Using CSC ACIS hard science energy band.
Aspect solution pcadf209643885N003_asol1.fits found.
Bad pixel file acisf04628_repro_bpix1.fits found.
Mask file acisf04628_000N003_msk1.fits found.
PBK file acisf209642202N003_pbk0.fits found.

The output images will have 1301 by 1286 pixels, pixel size of 1.968 arcsec,
    and cover x=1336.5:6540.5:4,y=1672.5:6816.5:4.

Running tasks in parallel with 8 processors.
Creating aspect histograms for obsid 4628
Creating 18 instrument maps for obsid 4628
Creating 18 exposure maps for obsid 4628
Combining 6 exposure maps for 3 bands (obsid 4628)
Thresholding data for obsid 4628
Exposure-correcting 3 images for obsid

The following files were created:

 The clipped counts images are:
     fimg_soft_thresh.img
     fimg_medium_thresh.img
     fimg_hard_thresh.img

 The clipped exposure maps are:
     fimg_soft_thresh.expmap
     fimg_medium_thresh.expmap
     fimg_hard_thresh.expmap

 The exposure-corrected images are:
     fimg_soft_flux.img
     fimg_medium_flux.img
     fimg_hard_flux.img
```

Combining Observations – Example 1



Adding four observations shows limitations of old script: obsid no 3 has a different SIM position and obsid 4 is a subarray; the new script handles the exposure maps and reprojection correctly in these cases. Avoid bad pixels at edge with thresholding

merge_obs – Summary.

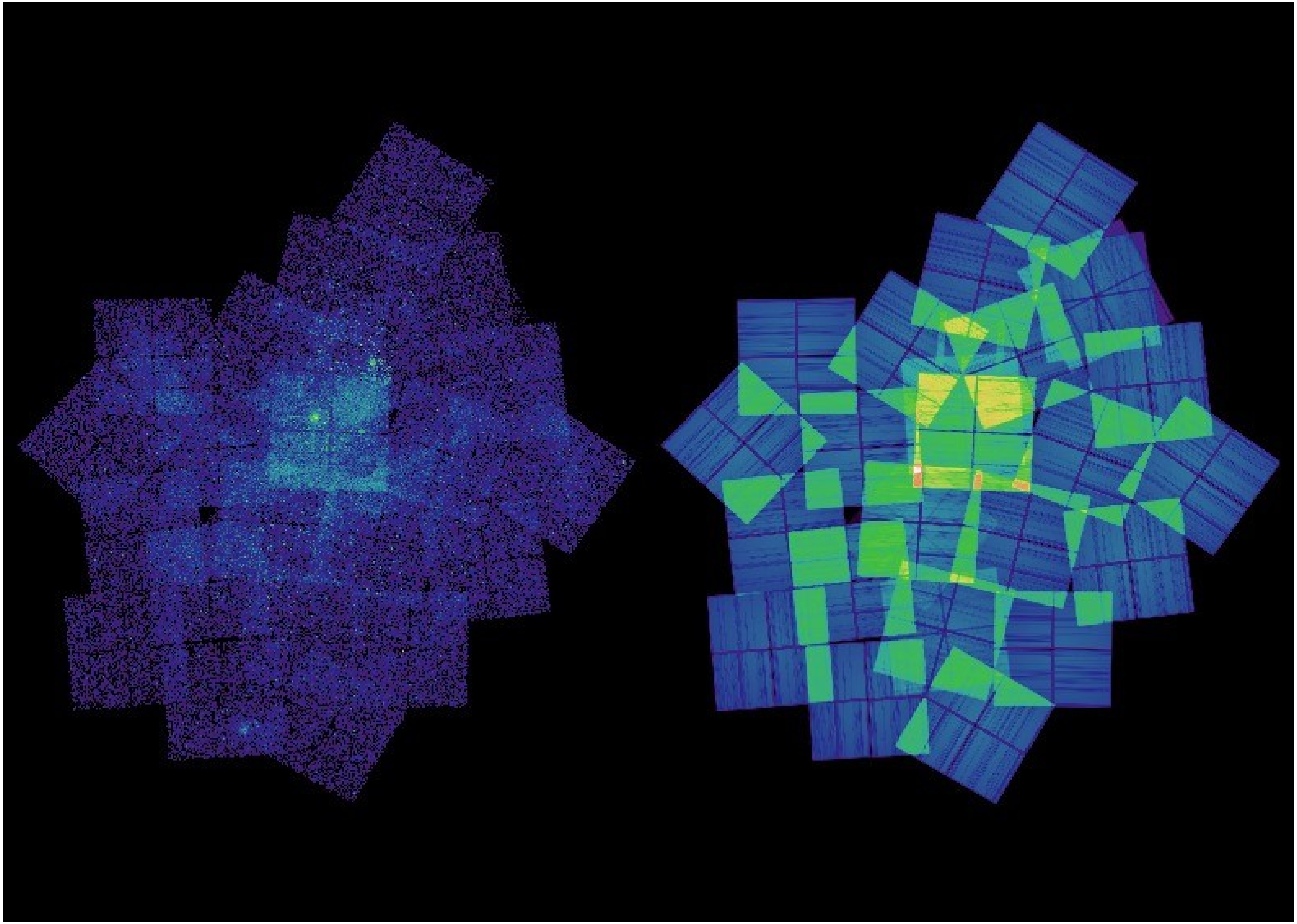
The new script

- parallelizes the computation across multiple processors on the host machine
- automatically determines the center and size of the mosaic (if the user doesn't specify) by averaging the unit vectors of the pointing directions and taking the union of the reprojected field-of-view polygons
- modifies headers to account for the fact that the 'sky' pixel coords go beyond their normal range (which can cause ds9 not to display part of the image)
- automatically handles different event input formats by trimming columns as needed
- automatic location and use of mask, aspect, bad pixel, parameter block files using values seeded in event file header
- sorts input files in time order
- for HRC-I, subtract particle background model
- thresholds final image using exposure map (default 1.5% of max exposure)
- cleans up intermediate files on exit
- supports standard catalog energy bands e.g. 'CSC', 'soft' as well as user-specified ones; can use spectral weight files for exposure maps if supplied

Limitations:

Cannot combine ACIS with HRC-I/S, or HRC-I with HRC-S
No ACIS background subtraction
No support yet for improving astrometry before merging

Combining Observations – Example 2

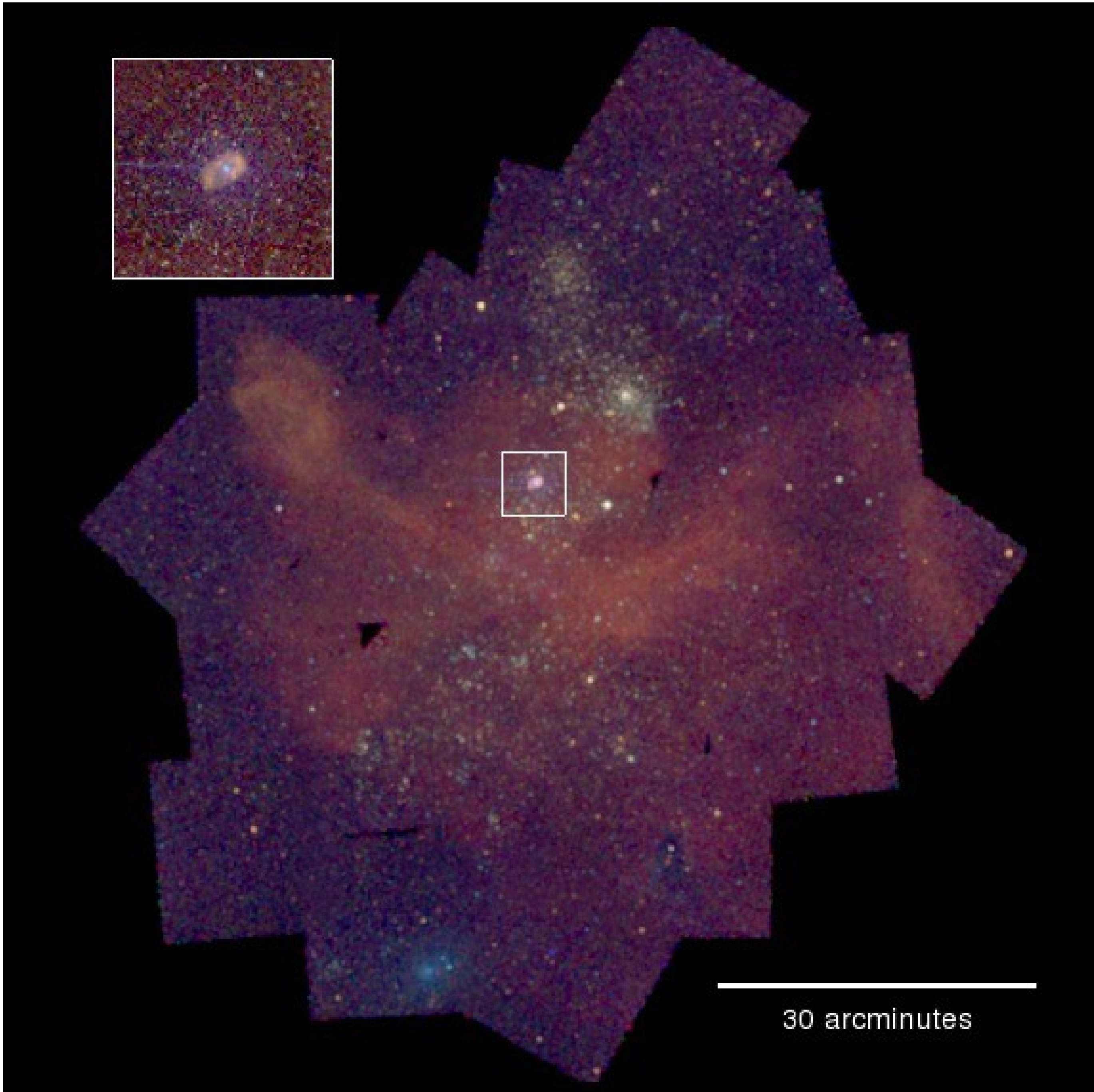


Eta Carina

Raw counts (left)

Exposure map (right)

Combining Observations – Example 2 cont



Eta Carina

40 ACIS-I datasets 1999-2008

Mix of FAINT and VFAINT

Exposure times from 10 to 90 ks

Input was simple list of event files:

ls */*evt2* > lis

merge_obs @lis"[ccd_id=:3]" out

Result is a set of 1363 x 1537 pixel images (size autocalculated to cover the field)

Grating data

chandra_repro:
- extracts PHA2 file
- recent mod to retain manal V&V extraction region rather than overwrite
- plan to enhance to include responses for each arm and order

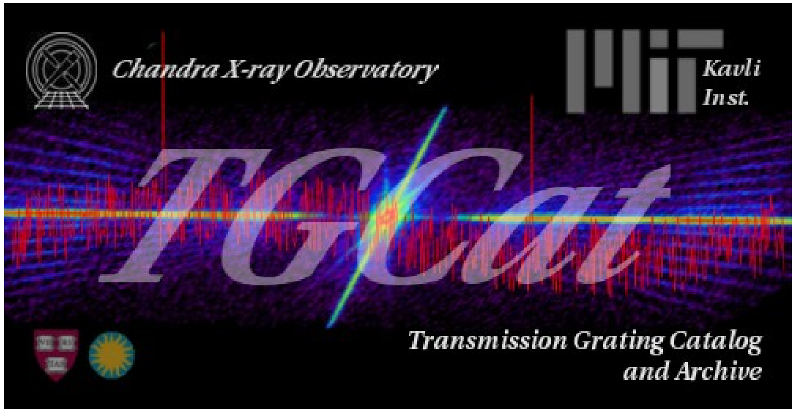
tgextract2
- extract spectra with customized source, bkg extraction regions
- useful for multiple source case

combine_grating_spectra
- coming soon, will coadd spectra and weight responses for
  - multiple orders
  - multiple exposures

tg_findzo:
- methods to find zero order pos even when center is blanked or piled

TGCAT (Huenemorder et al)
- tgcat.mit.edu

Processed grating archive -
manually optimized extraction regions
extractions for almost all grating observations
high level extracted properties



Fluxes

specextract -

Source and background ACIS spectra for point and extended cases

- Weighted or unweighted ARF and RMF, grouped spectra
- BUT: still sometimes awkward to use

will improve to automatically locate auxiliary files if chandra_repro has been used

combine_spectra

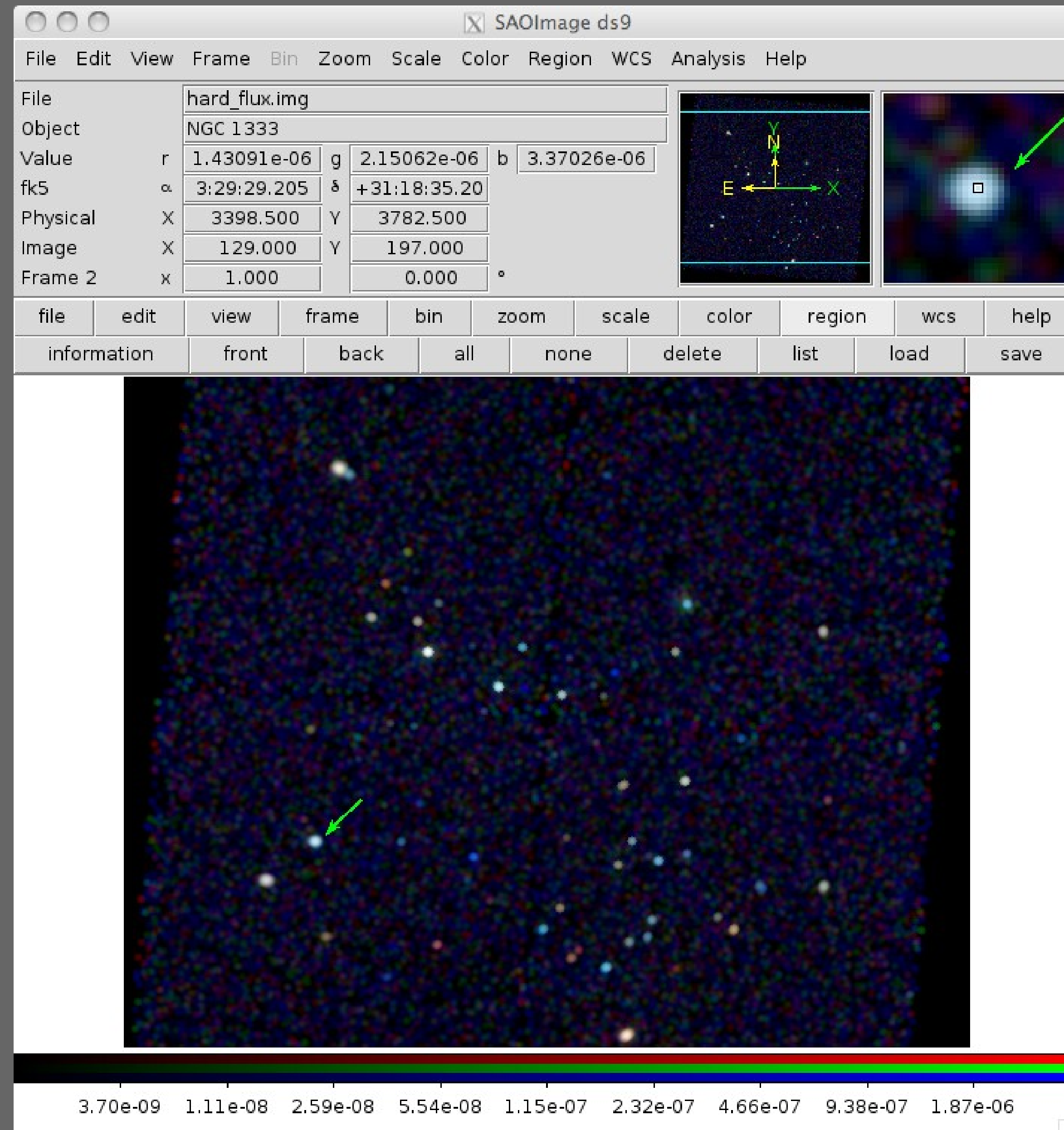
- sum multiple imaging PHA spectra, responses
  (better to do independent fits but more covenient at low S/N)

new higher level script srcflux which wraps use of several existing CIAO tools and scripts

srcflux evt2.fits ra,dec src.out

- generate regions using typical psf size
- use aprates to determine count rates and confidence intervals (or upper limits)
- run specextract to generate responses
- use eff2evt to estimate fluxes
- use modelflux to estimate fluxes given spectral model

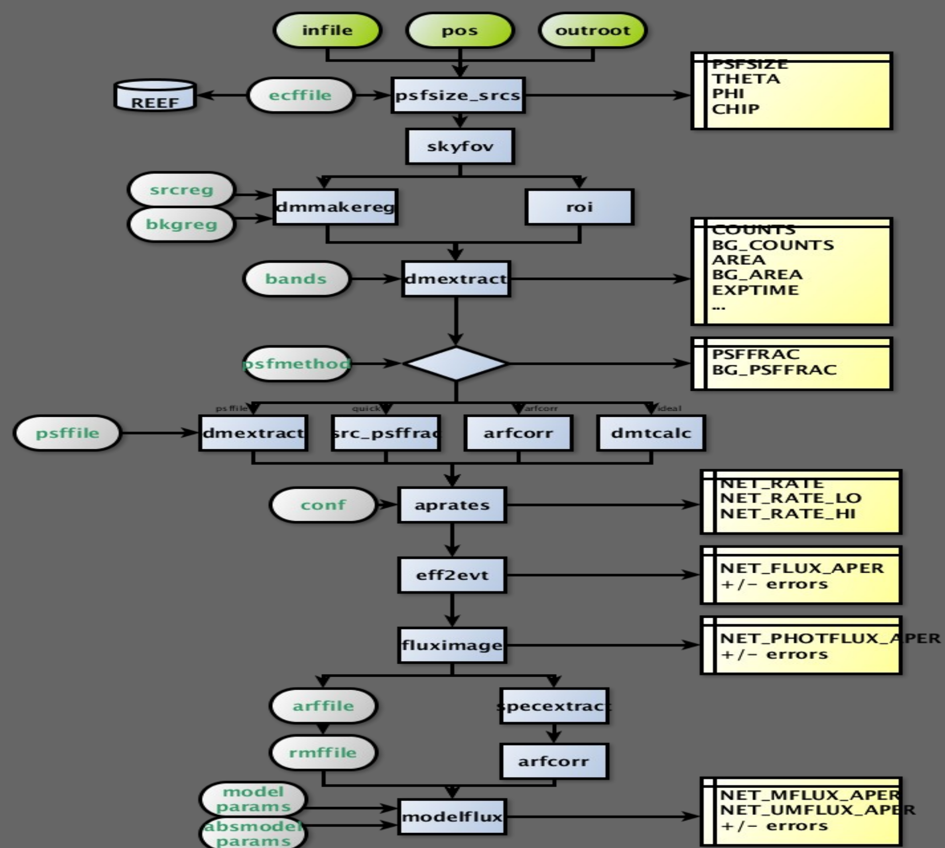
Calculating Source Flux



What is the X-ray flux of this source?

Calculating Source Flux

$ **srcflux** myevt2.fits “03:29:29.250 +31:18:34.73” myflux



Encodes the logic described in six different CIAO threads.

Return count rates and fluxes and errors with all appropriate corrections.

Uses many tools written for the Chandra Source Catalog.

Complementary to it for special cases and fields not covered by the catalog.

Summary of source fluxes

Position	0.5 - 7.0 keV
	Value 90% Conf Interval
3 29 29.25 +31 18 34.7	Rate 0.0398 c/s (0.0381,0.0415)
	Flux 5.17E-13 erg/cm2/s (4.94E-13,5.39E-13)
	Mod.Flux 4.38E-13 erg/cm2/s (4.2E-13,4.57E-13)

```
% srcflux repro/acisf06436_repro_evt2.fits "03:29:17.653 +31:22:44.97" mysrc
srcflux
           infile = repro/acisf06436_repro_evt2.fits
              pos = 03:29:17.653 +31:22:44.97
          outroot = mysrc
            bands = broad
           srcreg =
           bkgreg =
          bkgresp = yes
        psfmethod = ideal
          psffile =
             conf = 0.9
          rmffile =
          arffile =
            model = xsphabs.abs1*xspowerlaw.pow1
        paramvals = abs1.nH=0.0;pow1.PhoIndex=2.0
         absmodel =
        absparams =
            abund = angr
          fovfile =
         asolfile =
          pbkfile =
          mskfile =
         bpixfile =
          ecffile = CALDB
         parallel = yes
            nproc = INDEF
           tmpdir = /tmp
          clobber = no
          verbose = 1
             mode = ql
```

- echoes param choices

```
Extracting counts
Setting Ideal PSF : alpha=1 , beta=0
Getting net rate and confidence limits
Getting model independent fluxes
Getting model fluxes
Getting photon fluxes
Running tasks in parallel with 4 processors.
Running eff2evt for mysrc_broad_0001_src.dat
Running aprates for mysrc_broad0001_rates.par
Running eff2evt for mysrc_broad_0001_bkg.dat
Making response files for mysrc_0001
Running modeflux for region 1
Adding net rates to output
Appending flux results onto output
Appending photflux results onto output
Computing Net fluxes
Adding model fluxes to output
Scaling model flux confidence limits


Summary of source fluxes

Position                              0.5 - 7.0 keV
                                      Value        90% Conf Interval
3 29 17.65 +31 22 44.9  Rate          0.0609 c/s (0.0587,0.063)
                        Flux          5.43E-13 erg/cm2/s (5.24E-13,5.62E-13)
                        Mod.Flux      5.88E-13 erg/cm2/s (5.67E-13,6.08E-13)

~~~
```

reports progress and results
creates FITS output table for
each energy band
file has fluxes and many
additional cols with supporting
data

srcflux capabilities

- finds auxiliary files automatically, like specextract

- automatically determines PSF-appropriate extraction region size for source and background, or accepts user choice

- uses one of four methods to apply aperture correction

- runs on multiple energy bands including named CSC bands

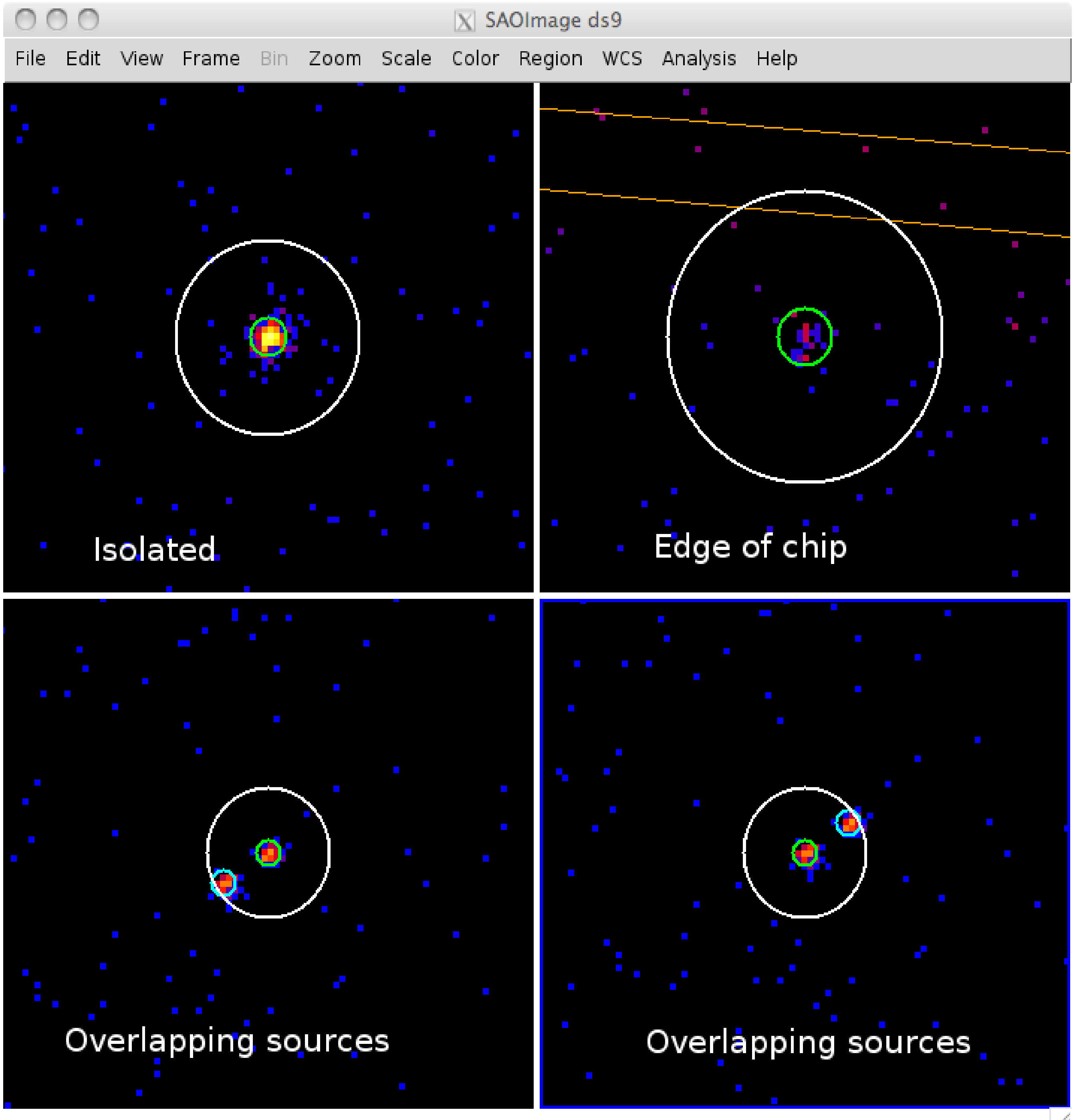
- accepts one position or a list (catalog of sources)

- calculates count rates using aprates method

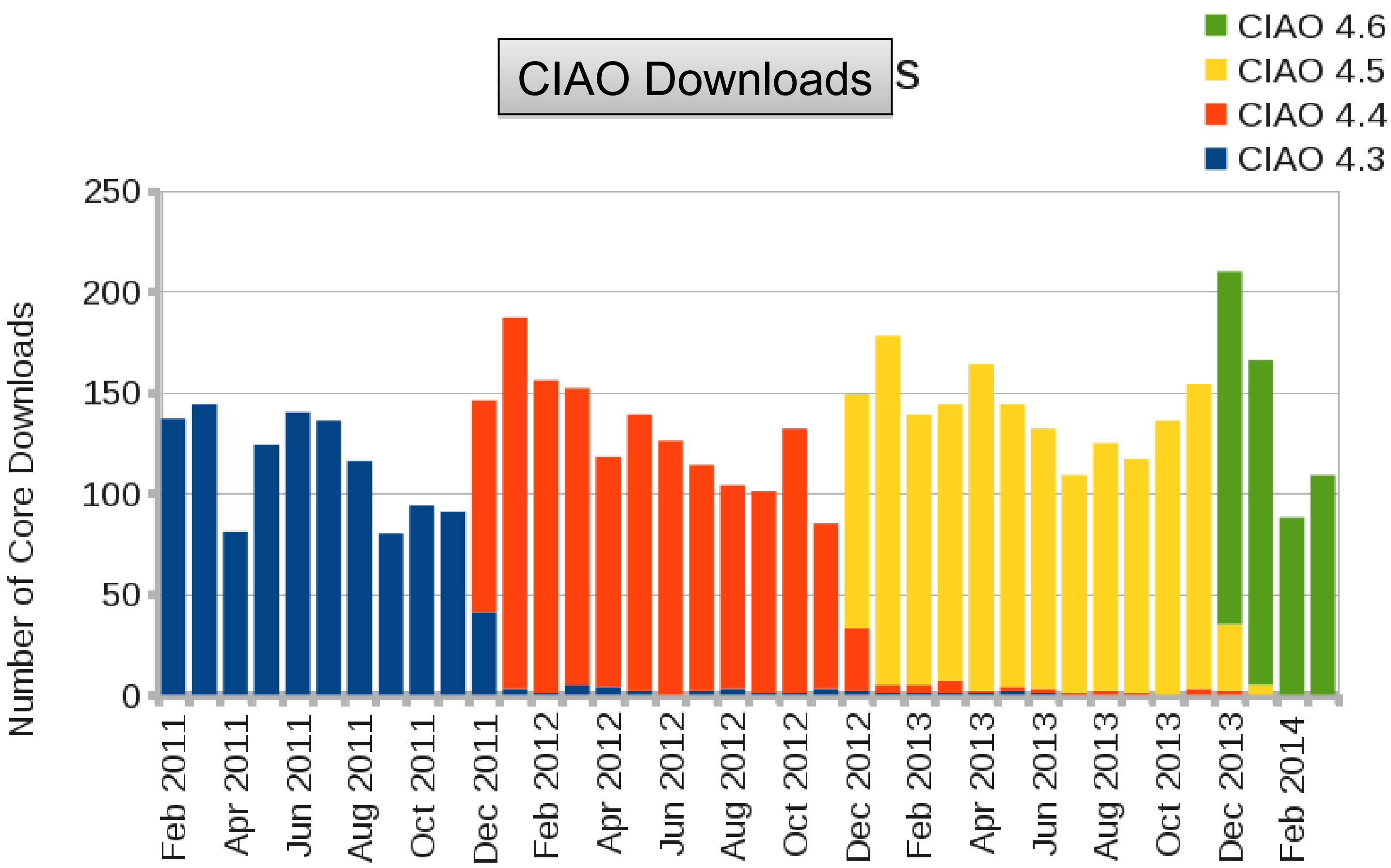
- calculates fluxes two different ways (specified spectral model and eff2evt method; however, no spectral fit is performed)

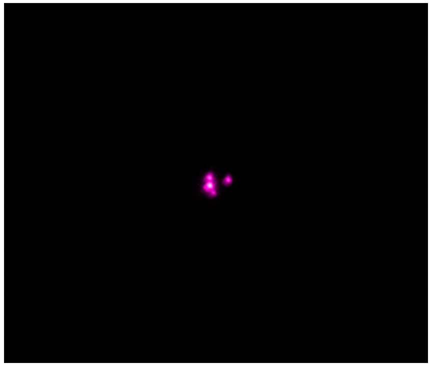
- generates spectral reponses for further analysis

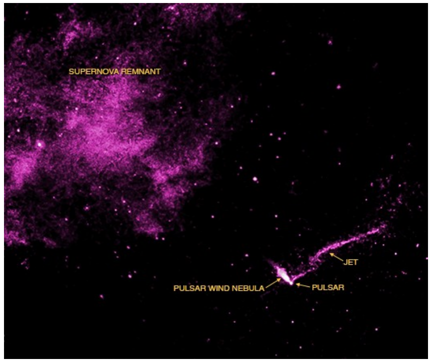
Ongoing work: handling of warning flags for hard cases, e.g. chip edge

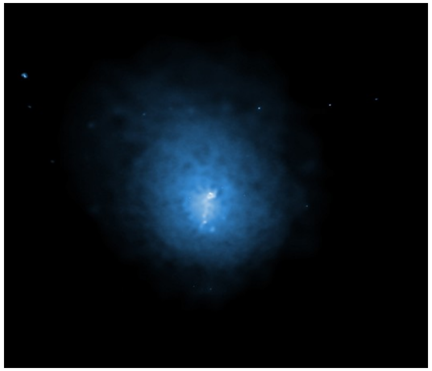

SAOImage ds9
File
Edit
View
Frame
Bin
Zoom
Scale
Color
Region
WCS
Analysis
Help
Isolated
Edge of chip
Overlapping sources
Overlapping sources

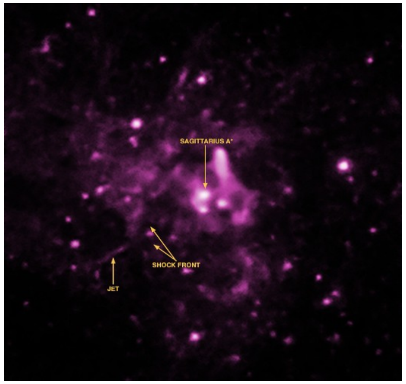
CIAO continues to support Chandra science

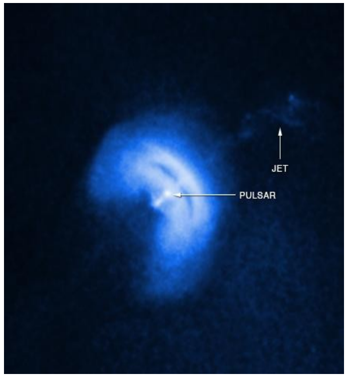












2013-14 Press Release Images