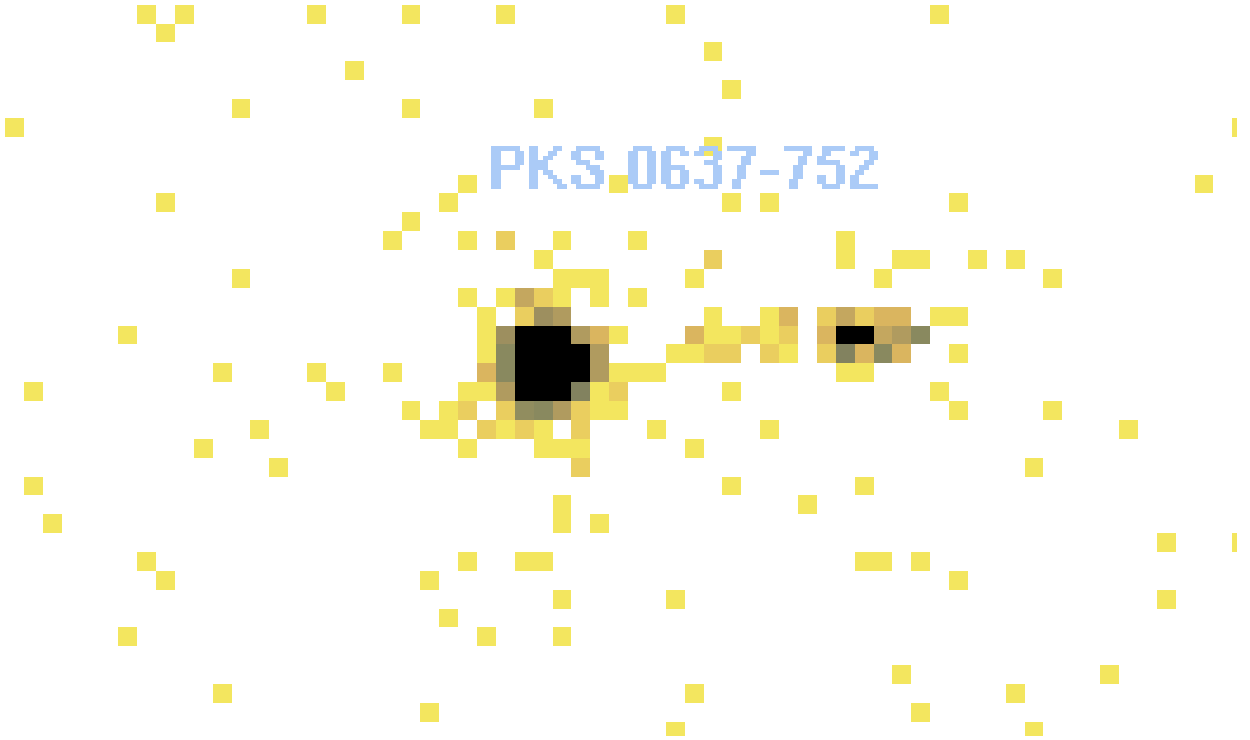
Analysis of Point-Like Sources



Kenny J. Glotfelty

Getting Started

- Threads
  - http://cxc.harvard.edu/ciao/threads
    - Usually more than 1 way to do things
  - Many common threads have been scripted; get the contrib tar file!
- Help files
  - **`ahelp`** accesses each tasks help file from the command line

```
% ahelp dmextract
% ahelp images
```

  - Available online: http://cxc.harvard.edu/ciao/ahelp/
- Additional documentation
  - Proposer's Guide, Workshop notes, Manuals, etc.
- Chandra Source Catalog
  - Roughly 100,000 sources with precomputed properties (fluxes,etc) and complete set of analysis data products

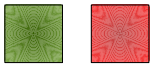
xterm

```
SUBJECT(dmextract)                                              CONTEXT(tools)

SYNOPSIS

    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.

SYNTAX

    dmextract  infile outfile [bkg] [error] [bkgerror] [bkgnorm] [exp]
               [bkgexp] [sys_err] [opt] [defaults] [wmap] [clobber] [verbose]

DESCRIPTION

    `dmextract' creates a histogram from a column of data in a table. Both
    "scalar" (PHA, TIME, etc.) and "vector" (DET, SKY, etc.) columns are
    supported. dmextract thus includes the capability to create PHA files,
    lightcurves, and spatial radial profiles.
:
```

xterm

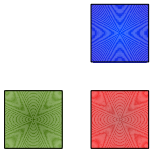
SUBJECT	CONTEXT	SYNOPSIS
aconvolve	tools	Convolve an N-dimensional image with a kernel
add_image	py.chips	Adds an image to the current window.
add_image	sl.chips	Adds an image to the current window.
add_piximg	py.crates	Add an image to a crate.
add_piximg	sl.crates	Add an image to a crate.
apowerspectrum	tools	Compute the power spectrum of an N-dimensional input array, or from two columns (independent/dependent variable) in an input file

:



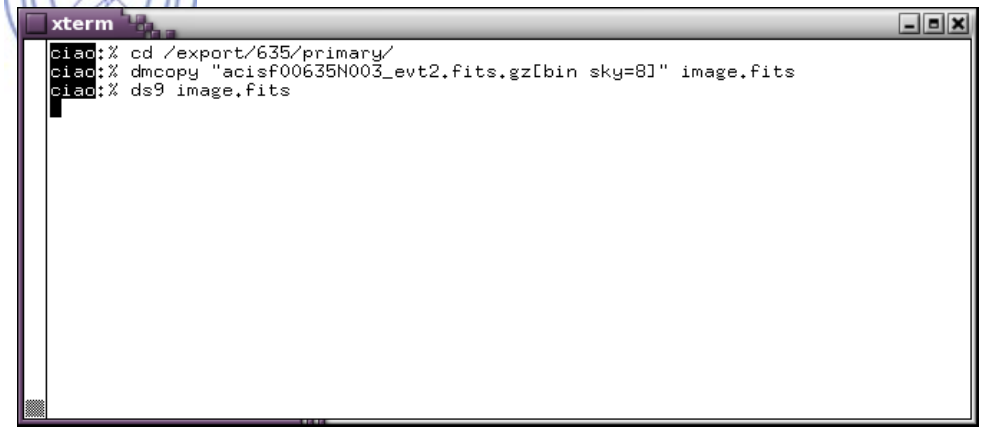
Axes of Analysis

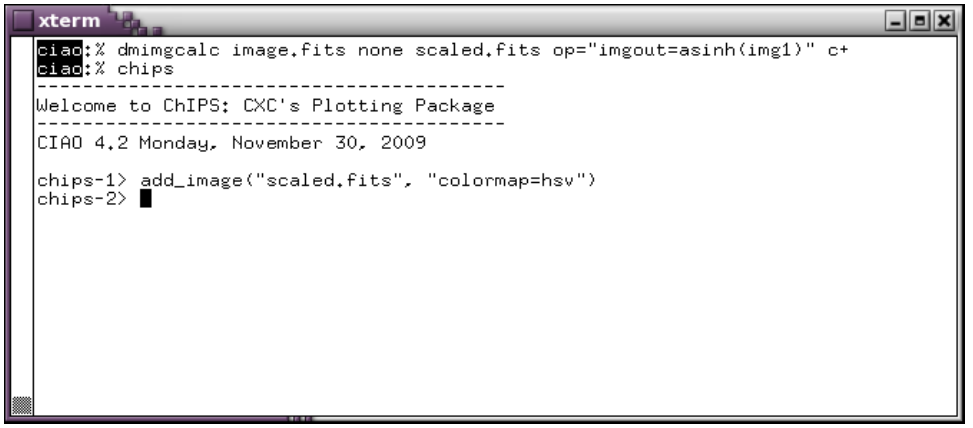
- Observation data
  - Spatial
    - *Is it a (point) source?*
  - Spectral
    - *What kind of source is it?*
  - Temporal
    - *Is it variable; and if so how?*
- Calibration
  - Efficiency
    - *I detected 10 events, how bright is my source?*
  - Uncertainty
    - *The event was detected at (x,y), what's the probability it came from a source at (x', y')?*

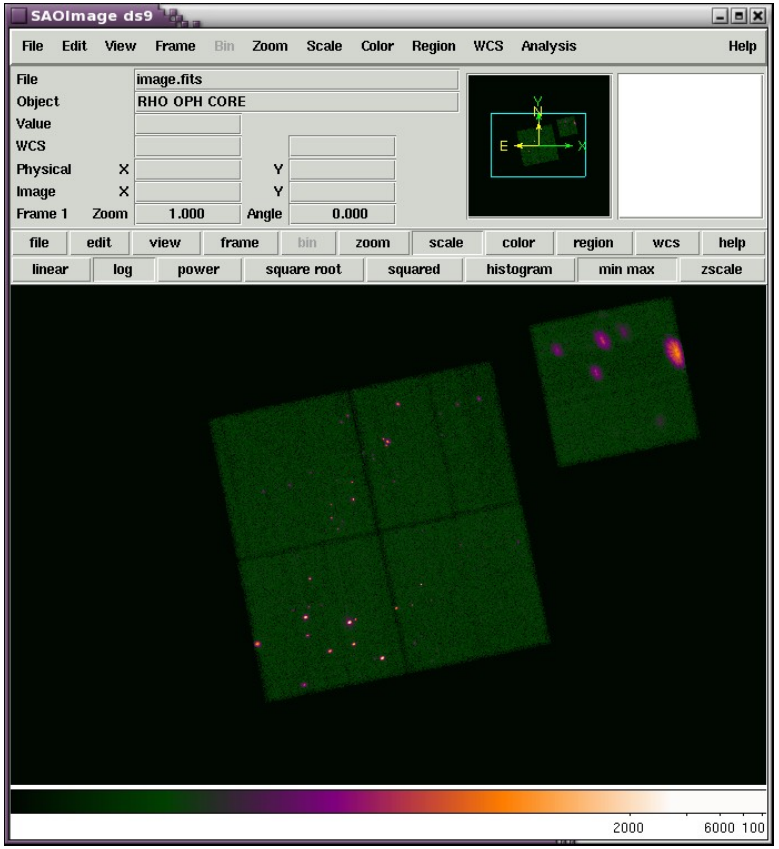


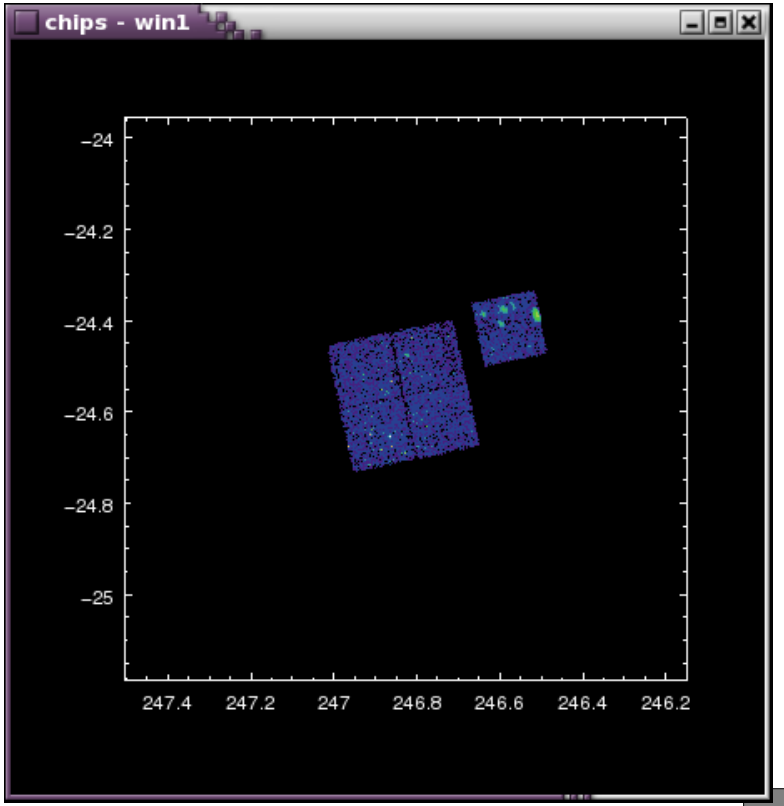
Spatial Analysis

- Images
  - **dmcopy** can create images while applying various other filters
    - Doesn't have to be just 2D
    - Since all CIAO tools share same I/O, binning supported by all tools
  - **ds9** is powerful, interactive visualization tool
    - Load event files as well as images
    - Open architecture allows customization
  - **chips** now supports images including overlaying plots
- Responses
  - Exposure maps: **mkexpmap** [cm^2 sec]
    - Convolve instrument map, **mkinstmap**, with aspect histogram, **asphist**.
  - Point Spread Function
    - **ChaRT**, **psf_project_ray**, and (or) **MARX**

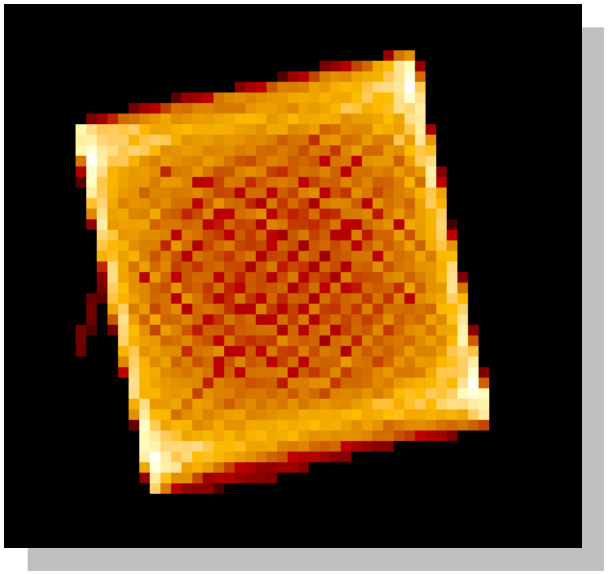

xterm
ciao:% cd /export/635/primary/
ciao:% dmcopy "acisf00635N003_evt2.fits.gz[bin sky=8]" image.fits
ciao:% ds9 image.fits


xterm
ciao:% dmimgcalc image.fits none scaled.fits op="imgout=asinh(img1)" c+
ciao:% chips
Welcome to ChIPS: CXC's Plotting Package
CIAO 4.2 Monday, November 30, 2009
chips-1> add_image("scaled.fits", "colormap=hsv")
chips-2>

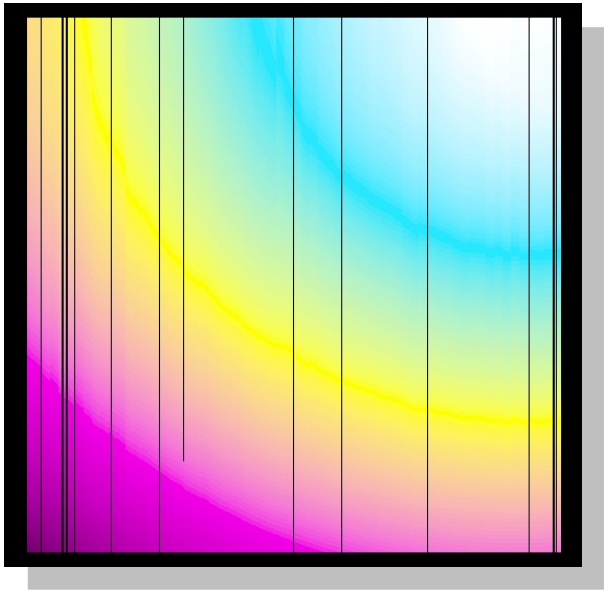

SAOImage ds9
File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help
File image.fits
Object RHO OPH CORE
Value
WCS
Physical X Y
Image X Y
Frame 1 Zoom 1.000 Angle 0.000
file edit view frame bin zoom scale color region wcs help
linear log power square root squared histogram min max zscale
2000 6000 100


chips - win1
-24
-24.2
-24.4
-24.6
-24.8
-25
247.4 247.2 247 246.8 246.6 246.4 246.2

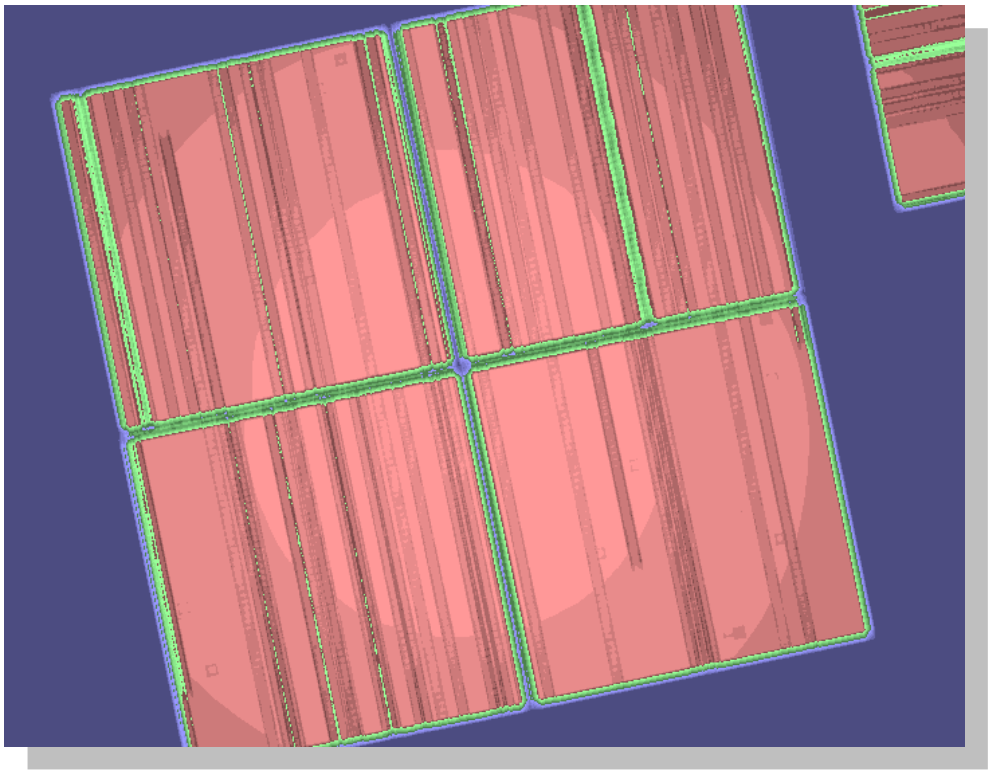
ObsId : 635



aspect histogram

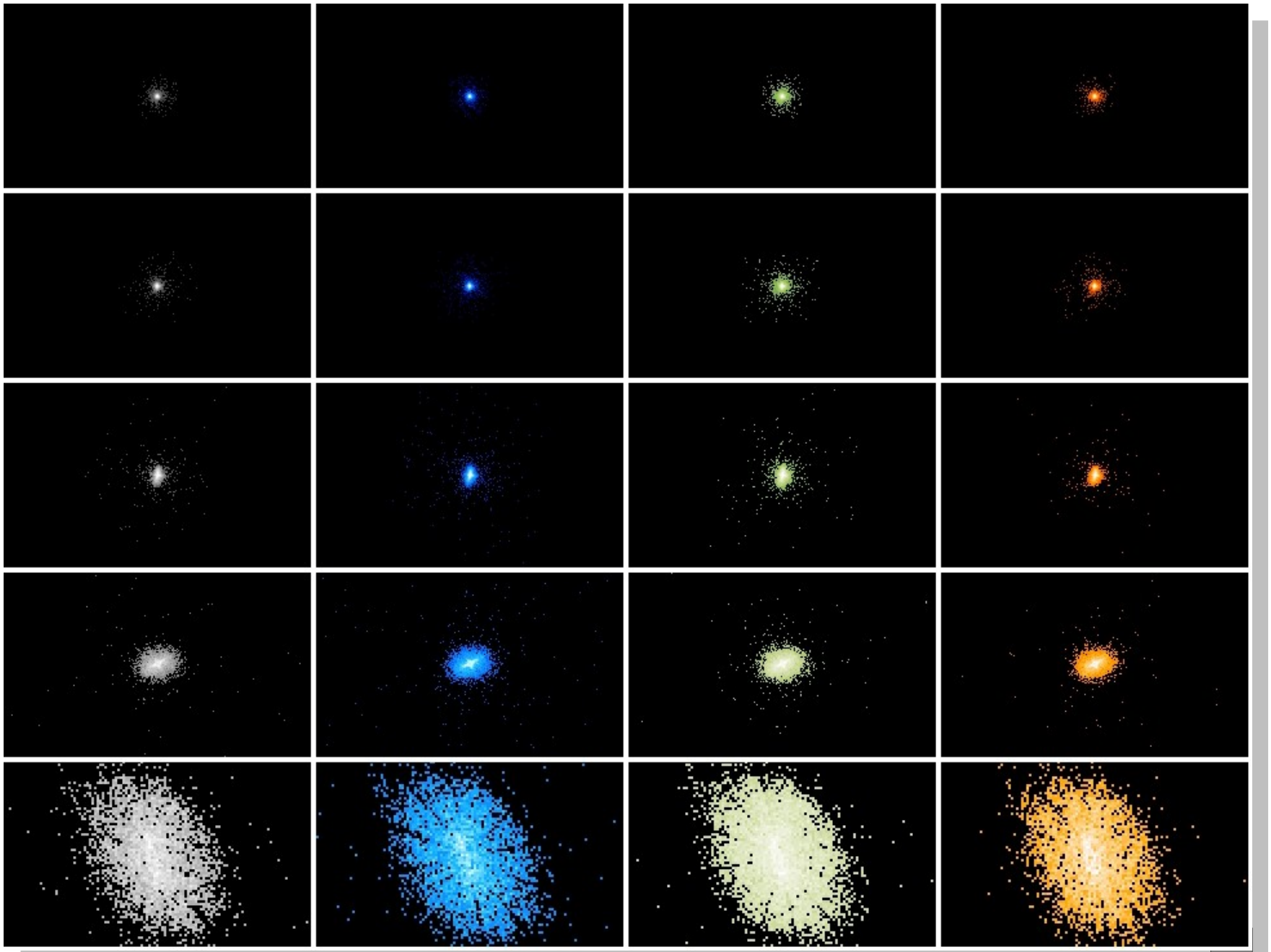


instrument map



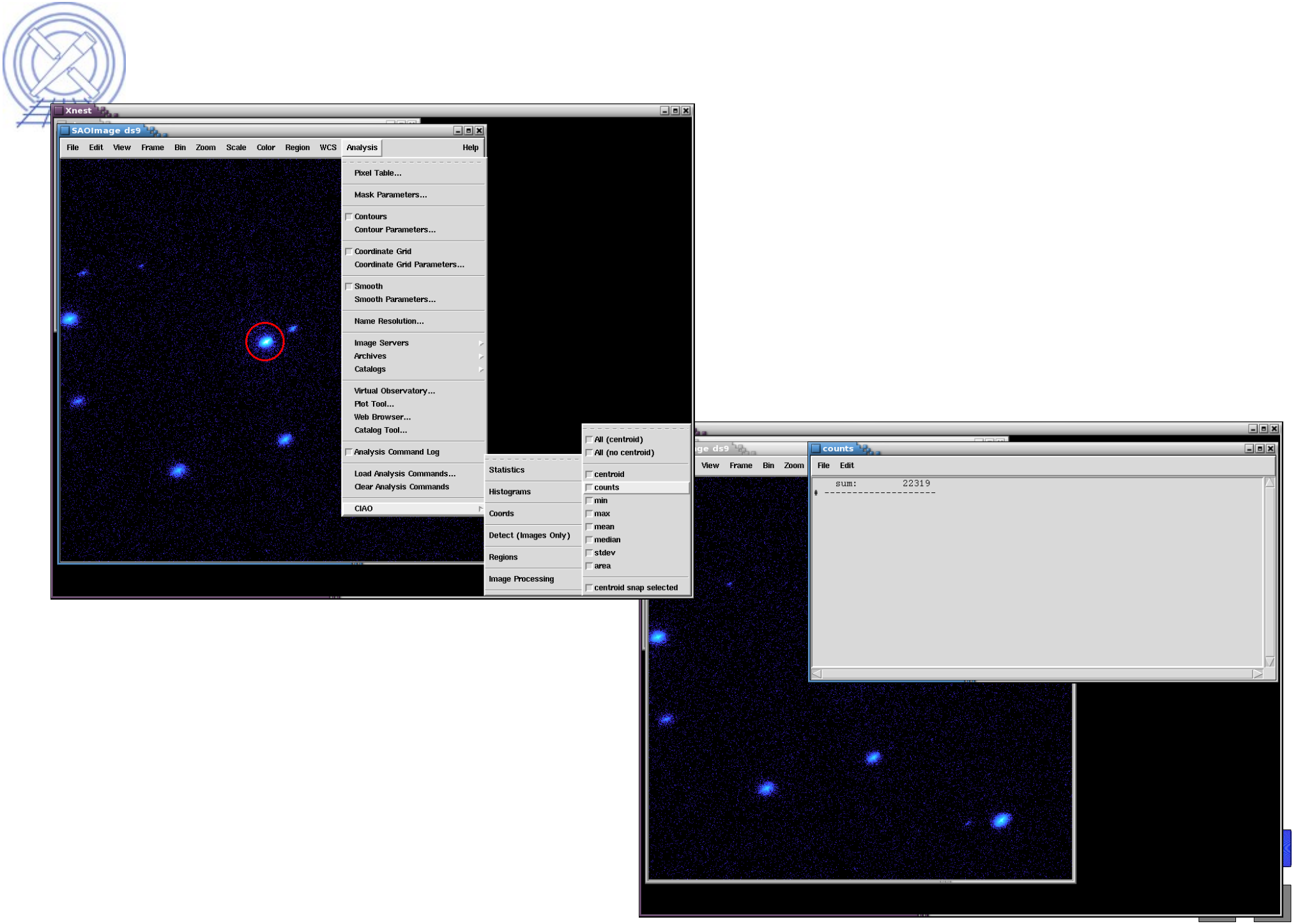
exposure map

Examples of PSF

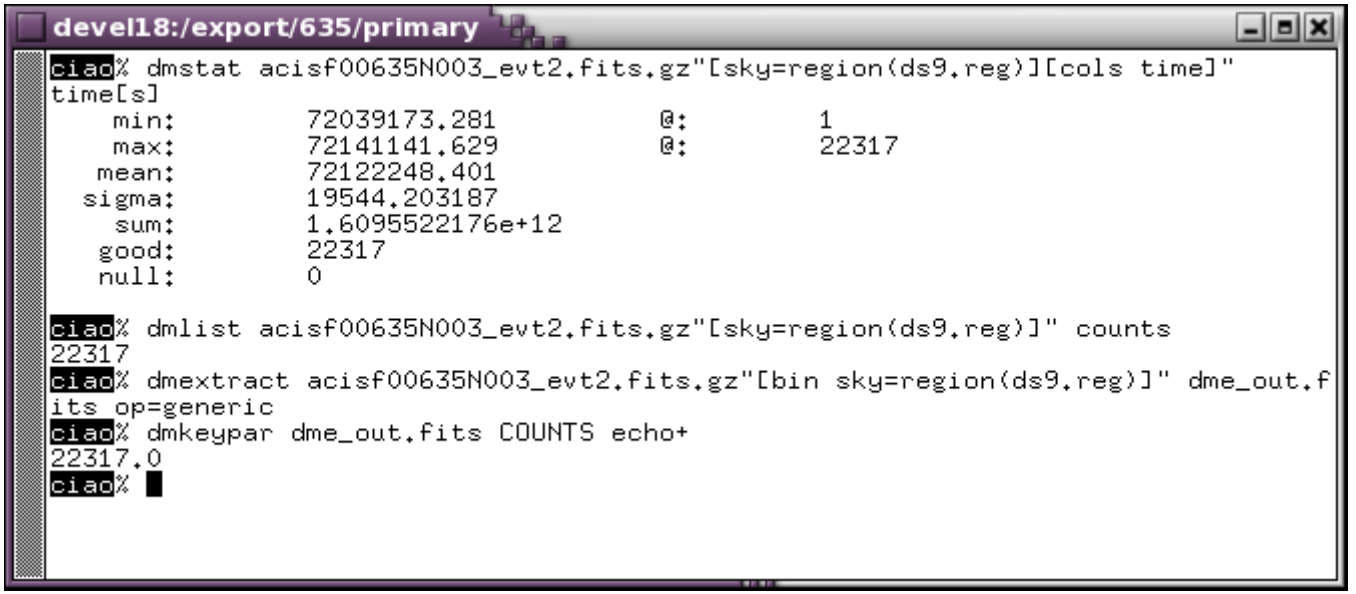


Aperture Photometry

- **`ds9`**
  - Common analysis tasks available in the Analysis menu
- **`dmstat`**
  - General statistics: mean, min, max, sum, etc.
    - Careful what you count: sum(pixels) vs. #rows in table.
- **`dmlist`**
  - opt=counts, simple
- **`dmextract`**
  - Counts, errors, rates, includes exposure corrections
- **`aprates`**
  - Given source and background counts it computes the Bayesian background-marginalized posterior probability distribution assuming Poisson and/or Gaussian statistics


Xnest
SAOImage ds9
File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help
Pixel Table...
Mask Parameters...
Contours
Contour Parameters...
Coordinate Grid
Coordinate Grid Parameters...
Smooth
Smooth Parameters...
Name Resolution...
Image Servers
Archives
Catalogs
Virtual Observatory...
Plot Tool...
Web Browser...
Catalog Tool...
Analysis Command Log
Load Analysis Commands...
Clear Analysis Commands
CIAO
Statistics
Histograms
Coords
Detect (Images Only)
Regions
Image Processing
All (centroid)
All (no centroid)
centroid
counts
min
max
mean
median
stdev
area
centroid snap selected
counts
File Edit
sum: 22319

View Frame Bin Zoom

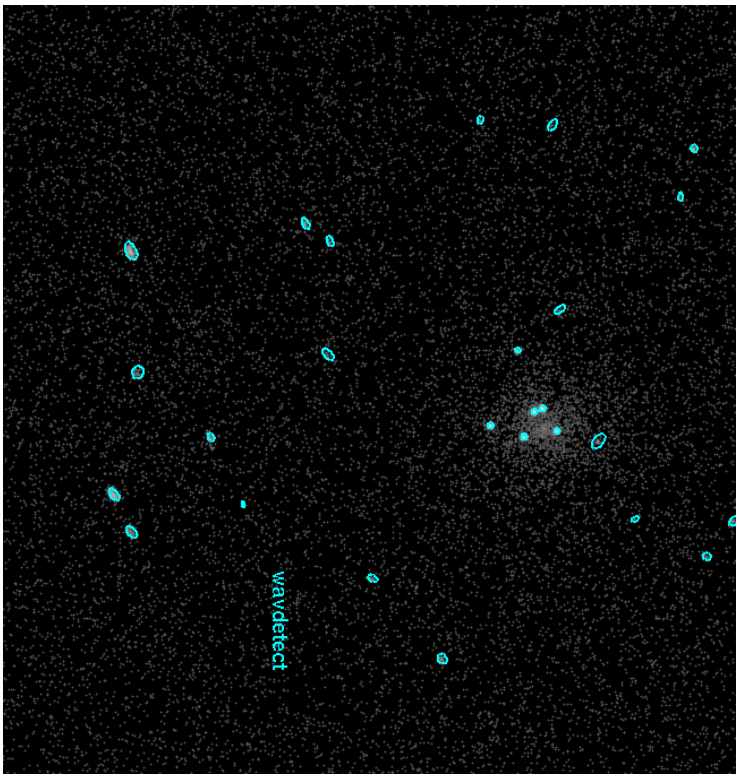

devel18:/export/635/primary
ciao% dmstat acisf00635N003_evt2.fits.gz"[sky=region(ds9.reg)][cols time]"
time[s]
min: 72039173.281 @: 1
max: 72141141.629 @: 22317
mean: 72122248.401
sigma: 19544.203187
sum: 1.6095522176e+12
good: 22317
null: 0
ciao% dmlist acisf00635N003_evt2.fits.gz"[sky=region(ds9.reg)]" counts
22317
ciao% dmextract acisf00635N003_evt2.fits.gz"[bin sky=region(ds9.reg)]" dme_out.f
its op=generic
ciao% dmkeypar dme_out.fits COUNTS echo+
22317.0
ciao%

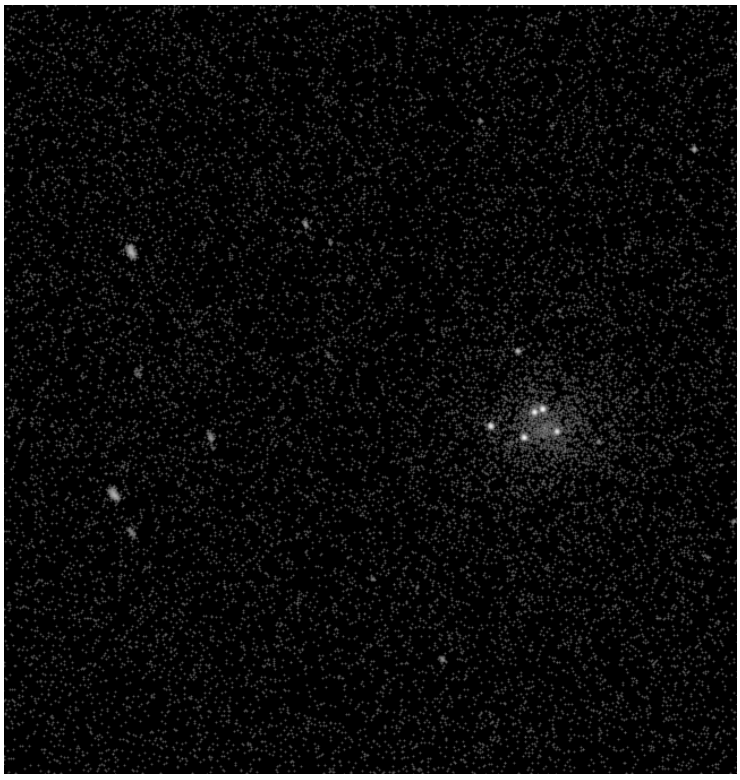
Source Detection

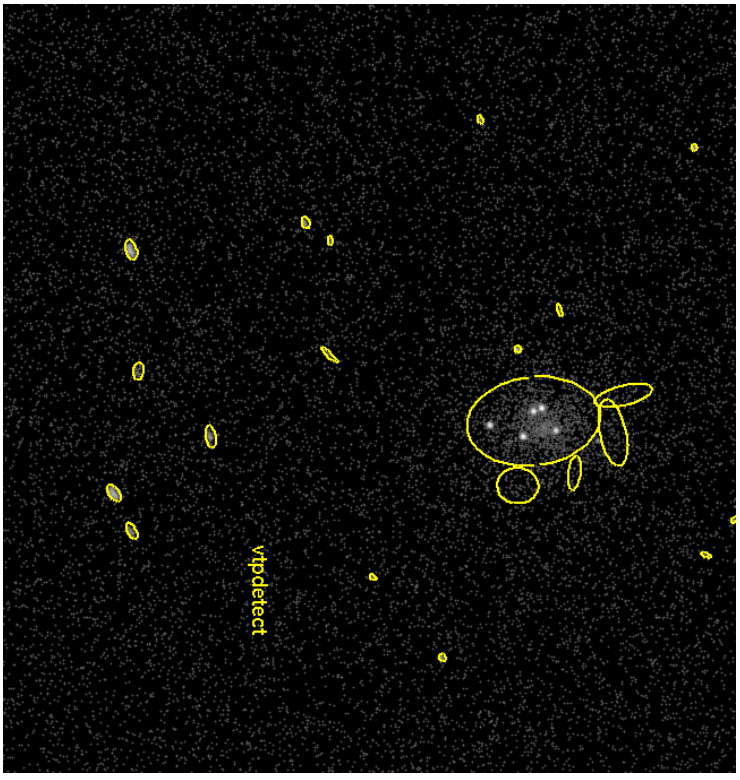
- Upcoming talk goes into detail of different algorithms
  - **`celldetect`** : simple, fast
  - **`wavdetect`** : sophisticated, slow, statistically well calibrated
  - **`vtpdetect`** : scale-free, irregular shape

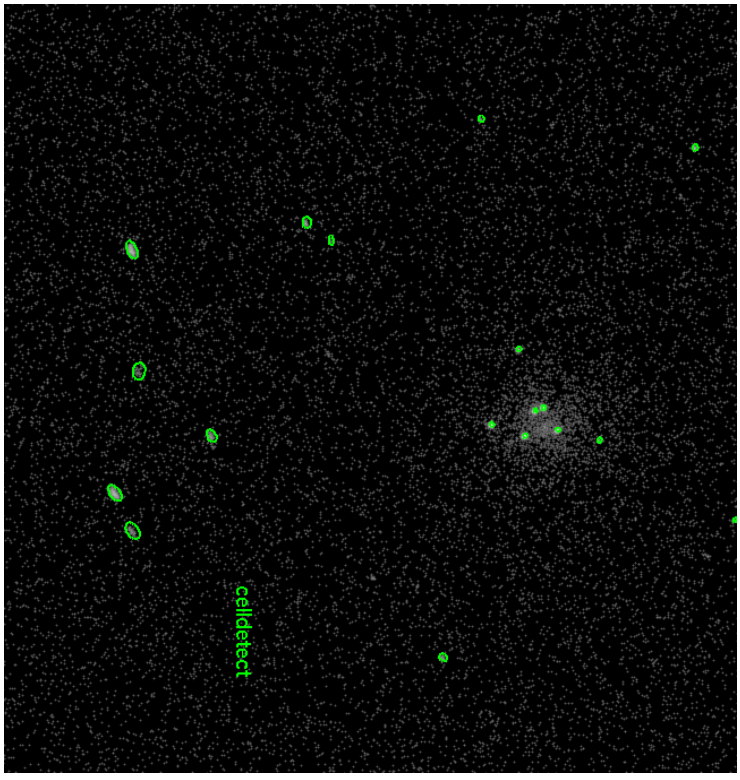
  Note: the output source lists from detect can be used as input to other analysis tasks
- Limiting sensitivity
  - **`aprates`** : specific location w/ custom region
  - **`lim_sens`** : whole field, region based on size of PSF.
- Word of warning
  - Beware of afterglows
    - Output from all of the detect tools are source *candidates*! Users need to do more detailed analysis to verify as real sources.

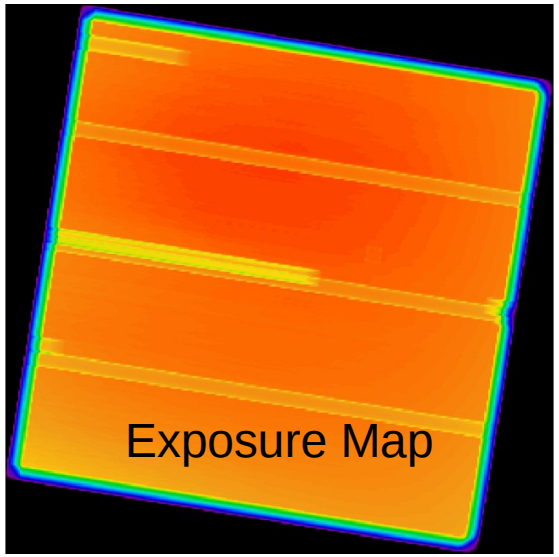
Obsid: 5794

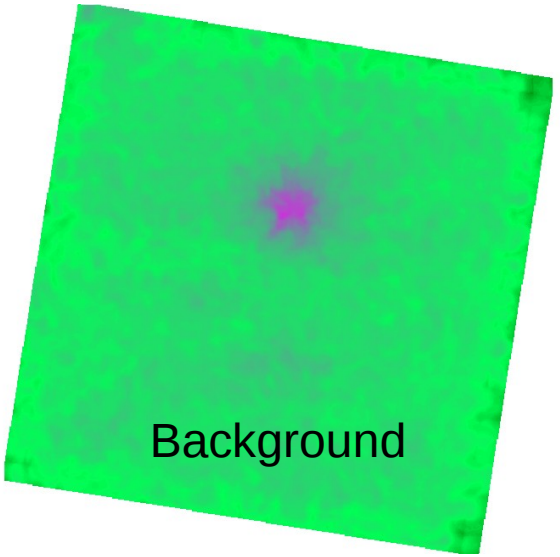


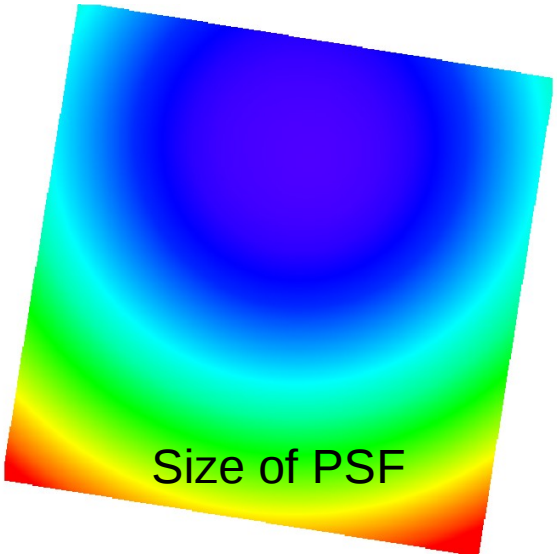


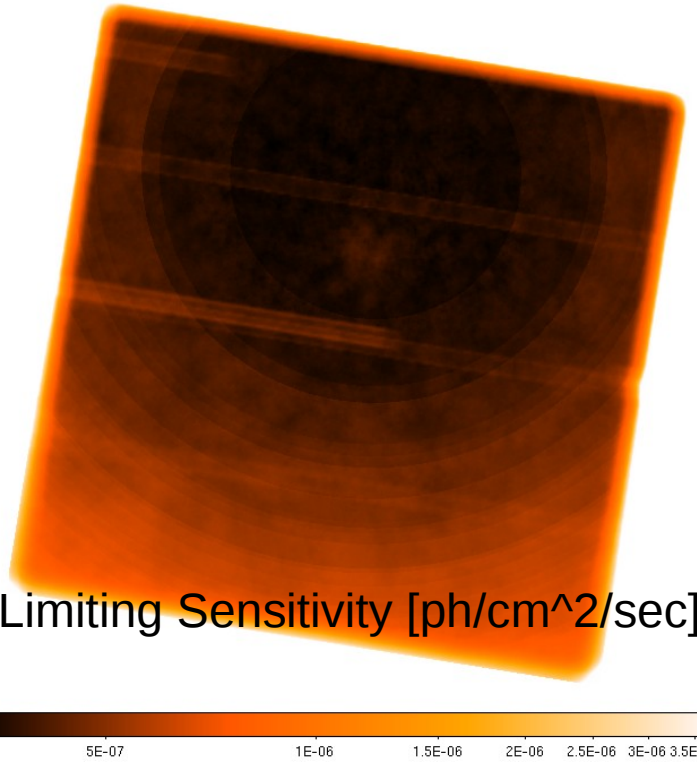





Exposure Map

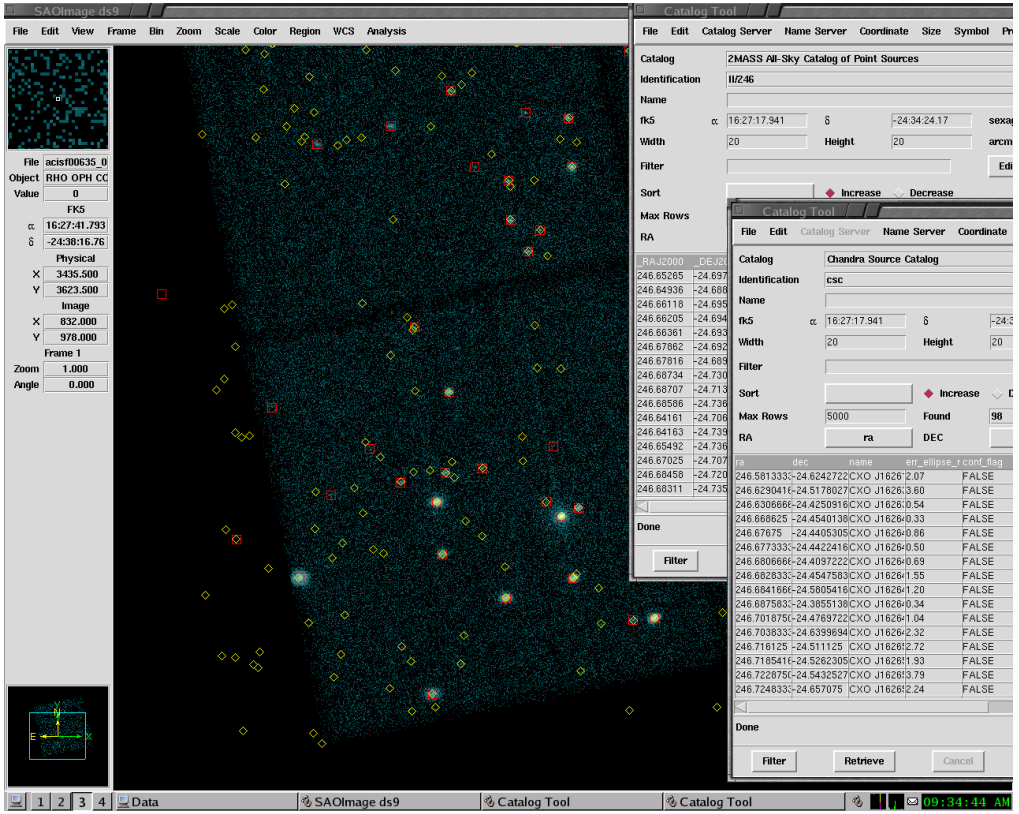

Background


Size of PSF


Limiting Sensitivity [ph/cm^2/sec]
5E-07
1E-06
1.5E-06
2E-06
2.5E-06
3E-06
3.5E-06

WCS Alignment

- **`reproject_aspect`** used to match source lists and update World Coordinate System (WCS)
  - Can update WCS in tables, images, or aspect solution.
    - If going to reprocess event data, may want to do asol and then all derived products (images, exposure maps, etc.) will already be corrected
  - Wrapper around **`wcs_match`** and **`wcs_update`**
    - May want to run individually if match step is complicated (ie require several iterations to optimize parameters)
    - Can run **`wcs_update`** alone if already know offsets to be applied.
- **`reproject_image`** and **`reproject_image_grid`** match image pixels between images (including from different missions)



devel18:/data/scidev/staff/kjg/CIAO_Workshop_08

```
% wcs_match chandra.dat "2mass.dat[cols ra=raj2000,dec=dej2000]" \
?   match_out.fits wcsfile=acisf00635_000N001_evt3.fits \
?   radius=2 clob+ verbose=3
```

devel18:/data/scidev/staff/kjg/CIAO_Workshop_08

```
***Ref Src 294 matched dup Src 97
Examining source 295 in ref src file.
36 common sources found between:
2mass.dat[cols ra=raj2000,dec=dej2000]
chandra.dat
After deleting poor matches, 36 sources remain
Transform elements are:
        delta_x(sky pix):  0.061756
        delta_y(sky pix):  0.491405
        rotation(deg.):    0.014014
        scale factor:      1.000378

Source Residuals
----------------
 Ref#  Dup#    Ref RA      Ref Dec.    Prior  Transfm  Resid Incl
                                       Resid  Resid    Ratio
 125    30    246.77748   -24.69690    0.74    0.61     0.62    Y
```

devel18:/data/scidev/staff/kjg/CIAO_Workshop_08

```
 263    78    246.90968   -24.61627    0.13    0.08     0.09    Y
 275    95    247.01936   -24.58225    0.08    0.16     0.16    Y
 285    61    246.86279   -24.53820    0.40    0.12     0.13    Y
 286    68    246.87485   -24.56016    0.25    0.09     0.09    Y
 289    73    246.88688   -24.54301    0.44    0.15     0.16    Y
 291    72    246.88615   -24.55665    0.47    0.22     0.22    Y
 294    97    247.05747   -24.54706    0.04    0.18     0.19    Y

Source Residuals, before/after transform (arcsec), and percentage improvement:

   Average Residuals:          0.364059   0.313694   13.83%
   Maximum Residuals:          1.075055   0.979588    8.88%

Source Residual Ratios, before/after transform, and percentage improvement:

   Average Residual Ratios:    0.369978   0.318795   13.83%
   Maximum Residual Ratios:    1.092535   0.995517    8.88%
```

devel18:/data/scidev/staff/kjg/CIAO_Workshop_08

```
% wcs_update acisf00635_000N001_evt3.fits none match_out.fits
%
```

Morphology

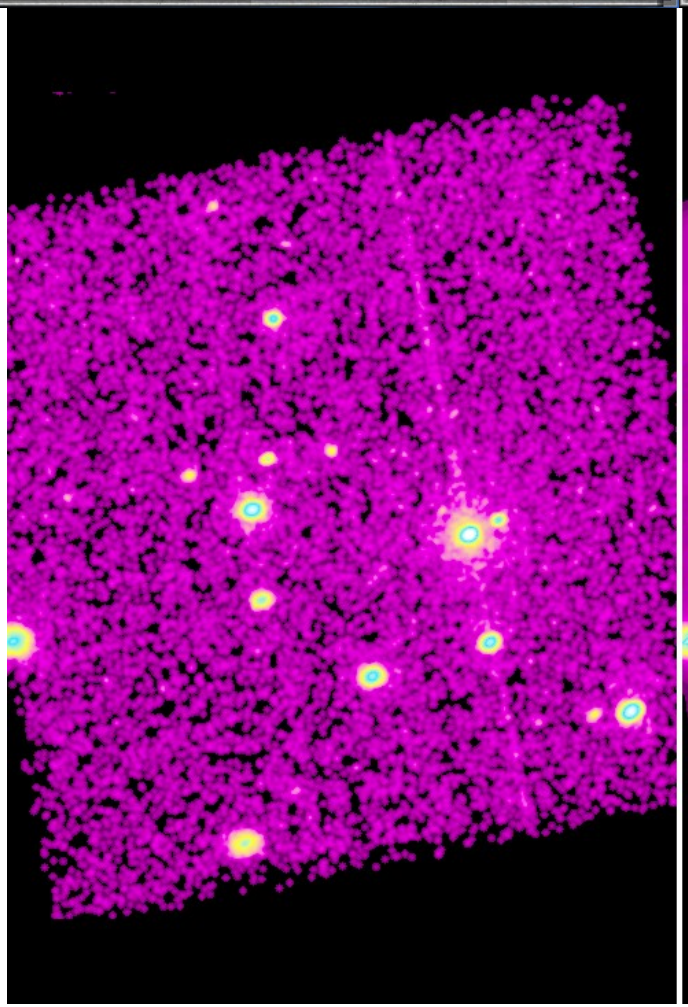
- Smoothing
  - **`csmooth`** : adaptively smooths image. Note: not flux preserving!
  - **`aconvolve`** : normal fixed-kernel smoothing
- Radial profiles
  - **`dmextract`** : binning on sky(); use **`sherpa`** to fit radial profile with radial profile of PSF.
- Extent & deconvolution
  - **`srcextent`** measure the detected source size, size of PSF and deconvolved extent.
  - Can do full 2D modeling and fitting in **`sherpa`** including PSF and Exposure map
  - **`arestore`** runs simple Lucy-Richardson deconvolution algorithm.
- Other
  - Tired of those point sources? Get rid of them with **`dmfilth`**

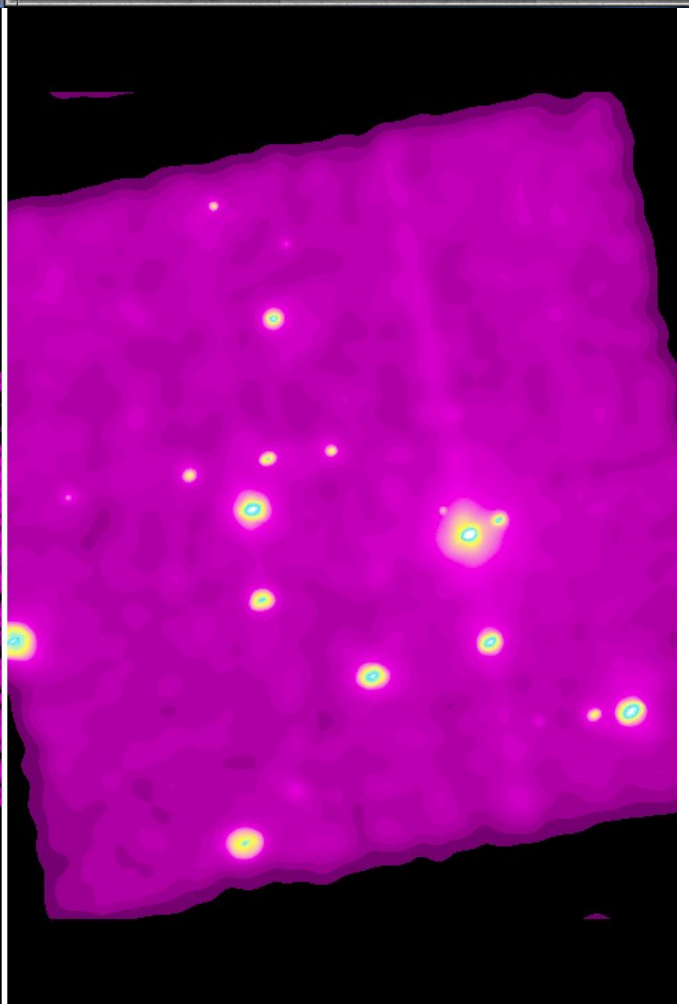
devel18:/data/scidev/staff/kjg/CIAO_Workshop_08

```
% aconvolve
Input file name (): ccd1img.fits
Kernel specification (): lib:gaus(2,5,1,3,3)
Output file name (): gsm.fits
```

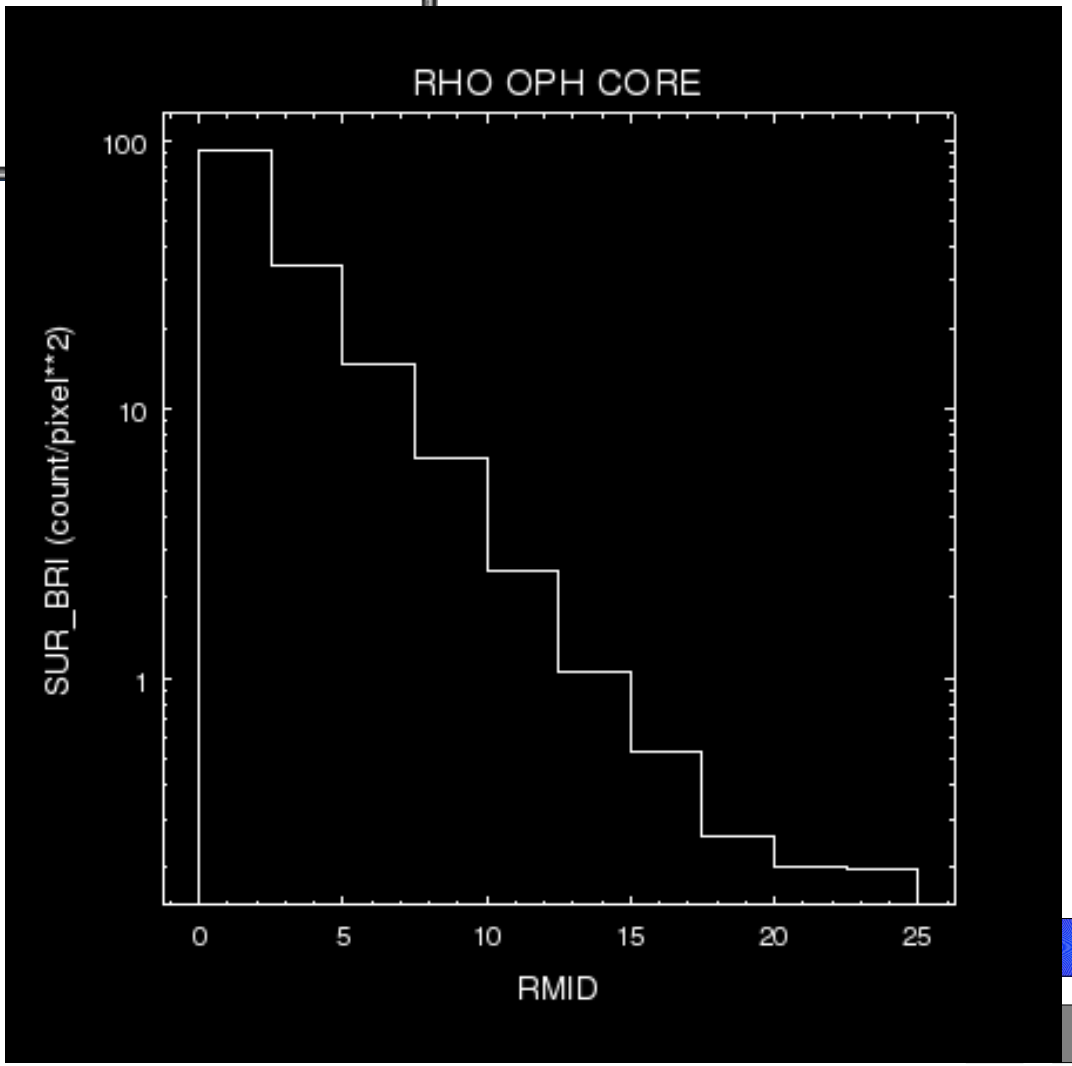
devel18:/data/scidev/staff/kjg/CIAO_Workshop_08

```
% csmooth verb=3
input file name (): ccd1img.fits
image of user-supplied map of smoothing scales ():
output file name (): csm.fits
output significance image (.): csm_sig.fits
output scales [kernel sizes] image (.): csm_scl.fits
Convolution method. (slide|fft) (fft):
Convolution kernel type. (gauss|tophat) (gauss):
initial (minimal) smoothing scale [pixel] (INDEF):
maximal smoothing scale [pixel] ()sclmin:) (INDEF): 15
minimal significance, S/N ratio (4): 3
maximal significance, S/N ratio ()sigmin:) (5):
compute smoothing scales or user user-supplied map (compute|user) (compute):
```





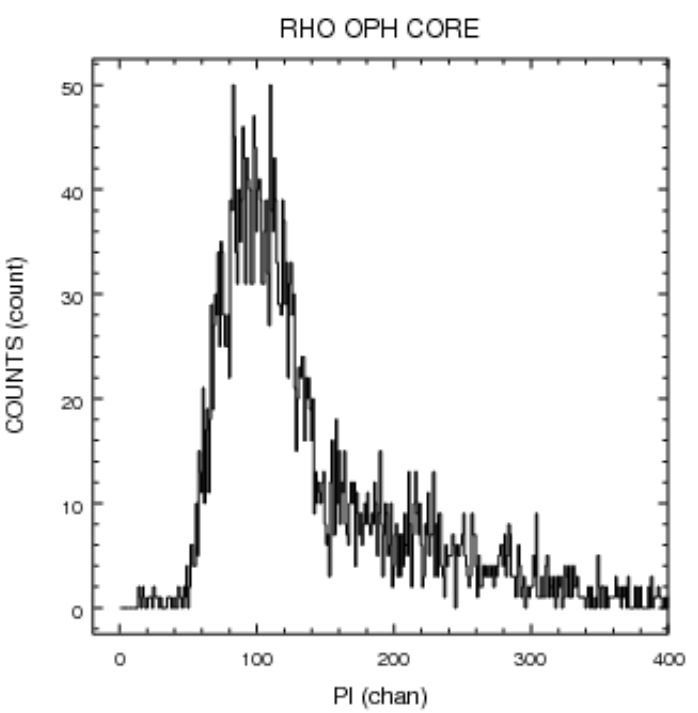
```
devel18:/data/scidev/staff/kjg/CIAO_Workshop_08
% dmextract \
? "acisf00635_000N001_evt3.fits[bin sky=pgrid(3501,3504,0:25:2.5,0:360:360)]" \
? radial.fits clob+ op=generic
% dmtcalc radial.fits rmid.fits expr="rmid=((r[0]+r[1])/2.0)" clob+
% chips
chips-1> make_figure("rmid.fits[cols rmid,sur_bri]")
chips-2> clear;
-------> clear();
chips-3> make_figure("rmid.fits[cols rmid,sur_bri]","histogram")
chips-4> log_scale(Y_AXIS)
chips-5>
```



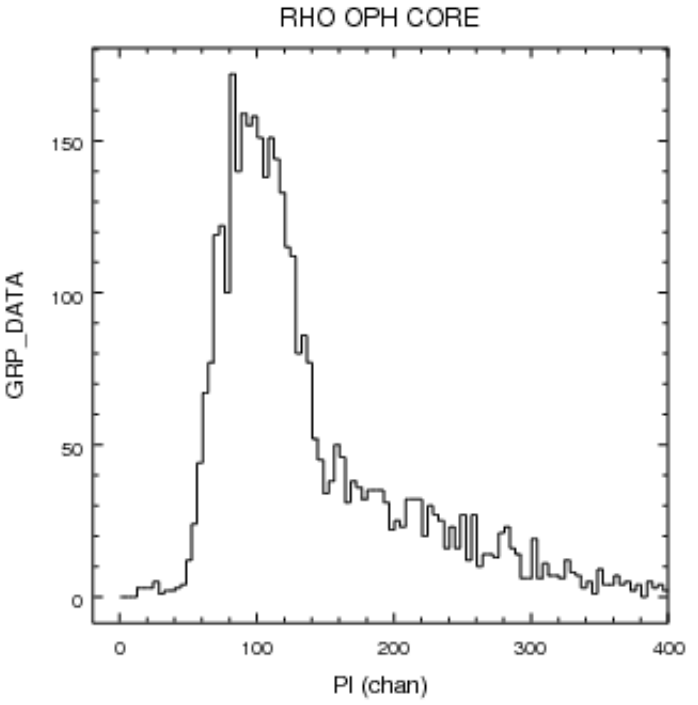
Spectral Analysis

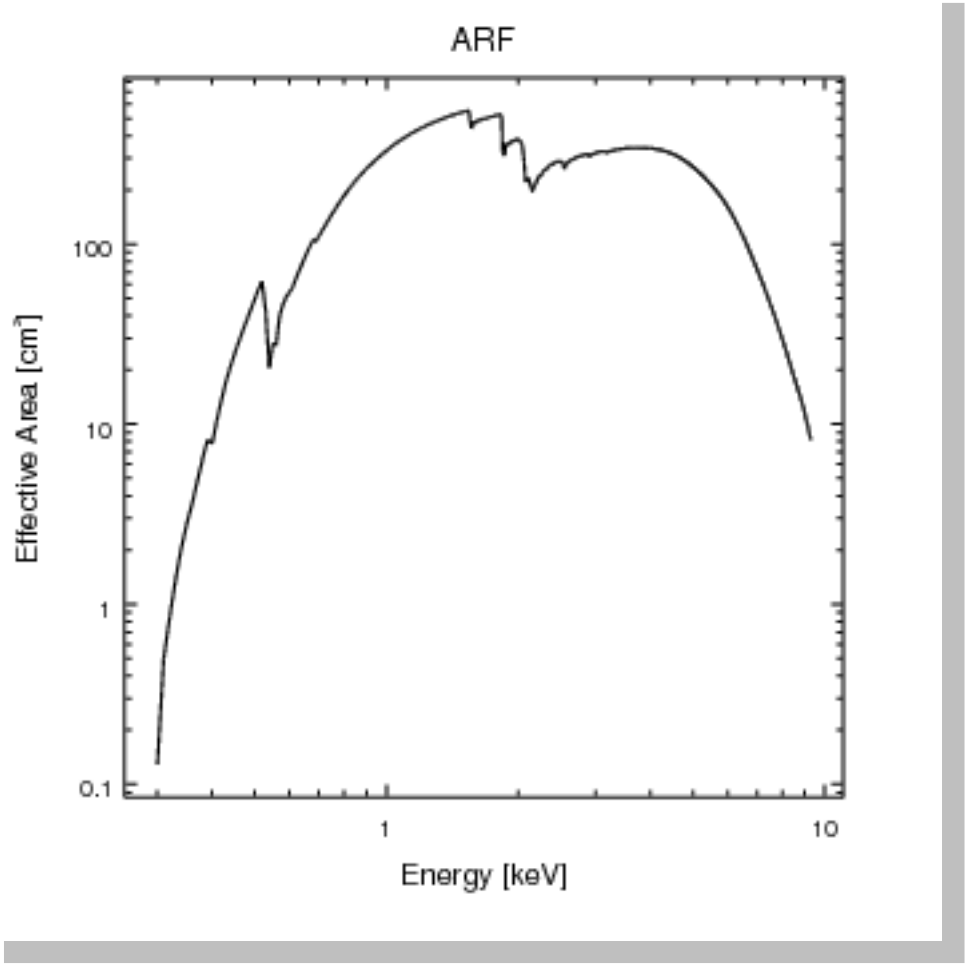
- Energy spectrum
  - **`dmextract`** bin on energy column(s)
    - always bin on PI
  - Can group spectrum directly in **`sherpa`** or with **`dmgroup`**
- Responses
  - ARF: Auxiliary Response Function (cm^2)
    - **`mkarf`** and **`mkwarf`**
  - RMF: Response Matrix File (or Function)
    - **`mkrmf`** and **`mkacisrmf`**; depending on calibration data available
- Scripts
  - **`specextract`**, **`psextract`**, etc. automate the extraction of source and background spectra, make responses, and set meta-data to allow easy input to **`sherpa`**

```
devel18:/data/scidev/staff/kjg/CIAO_Workshop_08
% dmextract \
? "acisf00635_000N001_evt3.fits[sky=circle(3150,3310,30)][bin pi=1]" \
? spectrum.fits clob+ op=pha1
% chips
chips-1> make_figure("spectrum.fits[cols pi,counts]","histogram")
chips-2> limits(X_AXIS, AUTO, 400 )
chips-3> print_window("pi", "export.format=png export.clobber=yes");
chips-4>
%
%
```




```
devel18:/data/scidev/staff/kjg/CIAO_Workshop_08
% dmgroup spectrum.fits spectrum_grp.fits BIN_WIDTH 4 \
? xcol=channel ycol=counts clob+ mode=h
% chips
chips-1> make_figure("spectrum_grp.fits[cols pi,grp_data]", "histogram")
chips-2> limits(X_AXIS, AUTO, 400 )
chips-3>
```

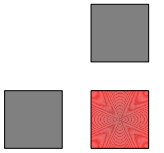



ARF
Effective Area [cm²]
100
10
1
0.1
1
10
Energy [keV]


Energy
FWHM=125eV @ 3.3keV
Pulse Height

Fluxes

- **`sherpa`** talk will go into details of modeling & fitting spectra.
- **`modelflux`**
  - Computes conversion from observed counts to integrated flux for arbitrary **`sherpa`** models
  - Similar to **`PIMMS`** but with arbitrary models and custom ARF.
- **`eff2evt`**
  - Computes a 'flux' for each events based on detected energy and location.
  - Sum to get approximate, model independent, source fluxes.
- Watch out!
  - If source is near the edge of detector or dithers across multiple chips.
  - Even a point source, far off axis, needs to be treated like an extended source.



```
devel18:/home/kjg/Desktop/modelflux
ciao:% dmextract 'evt.fits[energy=500:7000][bin sky=region(ds9.reg)]' \
?   - opt=generic | dmkeypar - COUNT_RATE echo+
0.0858363996433866
ciao:%
ciao:% modelflux \
?   arf='arf.fits' \
?   rmf='rmf.fits' \
?   model='xsphabs.abs1*powlaw1d.p1' \
?   paramvals='abs1.nh=3;p1.gamma=1.7;p1.ampl=1' \
?   emin='0.5' \
?   emax='7' \
?   oemin=')emin' \
?   oemax=')emax' \
?   rate=')dmkeypar.value' \
?   verbose='3'
Model fluxes:
Rate (0.5,7)= 0.085836 count s^-1
Photon Flux (0.5,7)= 0.00027934 photon cm^-2 s^-1
Energy Flux (0.5,7)= 1.717e-12 erg cm^-2 s^-1
ciao:%
```

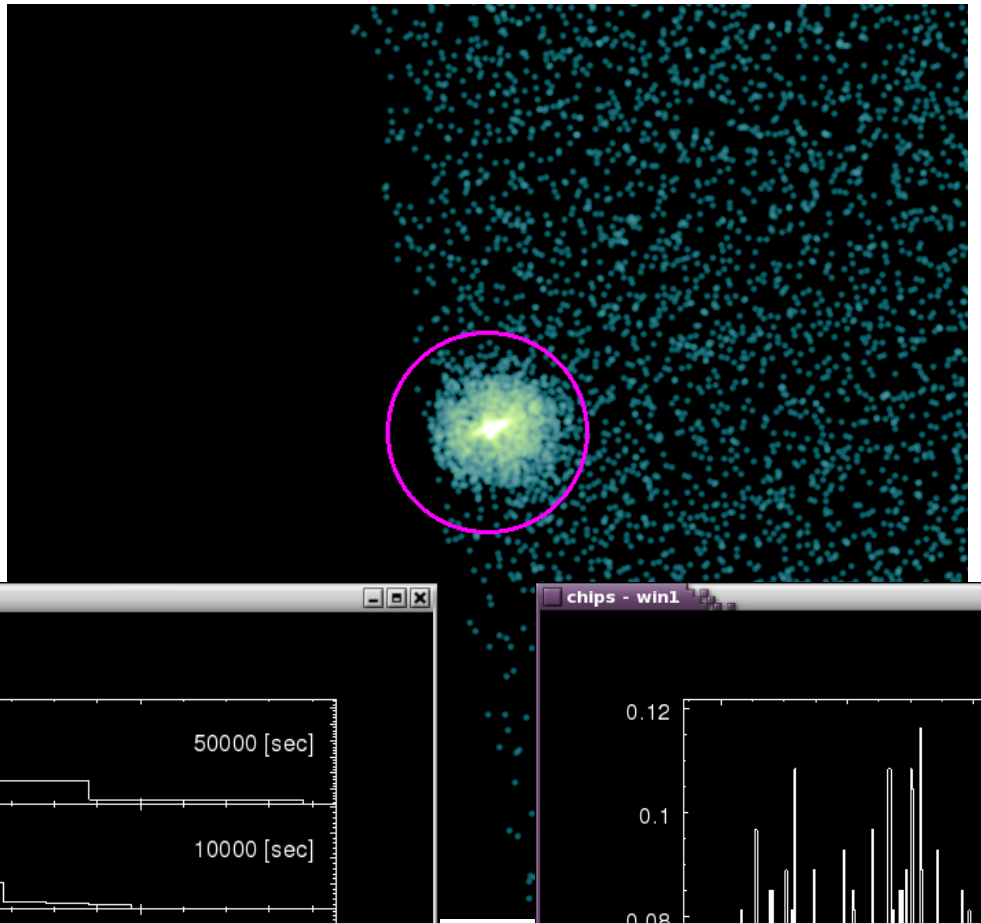
```
devel18:/home/kjg/Desktop/modelflux
ciao:% eff2evt evt.fits - | \
? dmstat '-[energy=500:7000][sky=region(ds9.reg)][cols flux]'
FLUX[ergs/cm**2/s]
    min:        4.1858621248e-17            @:        5872
    max:        1.1998206875e-15            @:        3137
   mean:        7.2267648951e-17
  sigma:        6.826720916e-17
    sum:        6.2453702223e-13
   good:        8642
   null:        0

ciao:%
```

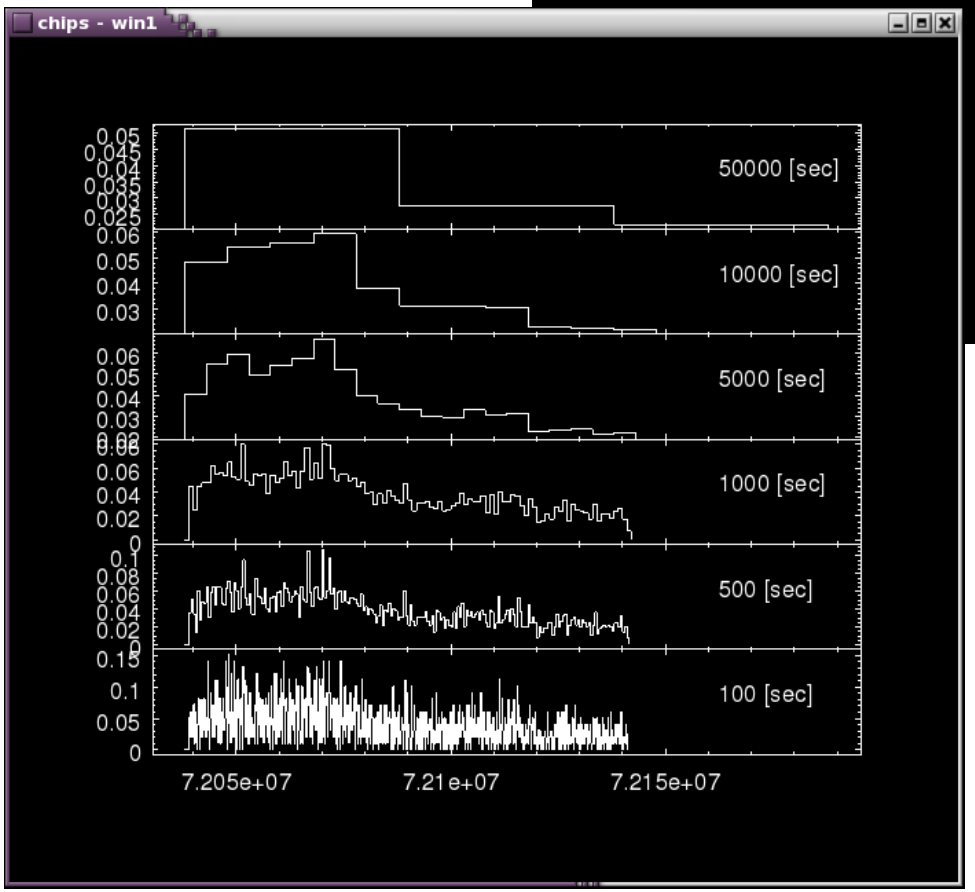
Colors

- Hardness ratios, multiple definitions:
  - H/S
    - sig_r = (a/b) sqrt(sig_a^2 / a^2 + sig_b^2 / b^2)
  - (H-S)/(H+S)
    - sig_hr = 2 sqrt(b^2 sig_a^2 + a^2 sig_b^2) / (b+a)^2
  - (H-S)/B
- Counts vs. Rates vs. Fluxes
- Net vs. Total
- Energy bands
  - No standard definitions
- User contributed package **BEHR** can be used to get hardness ratios with confidence limits.

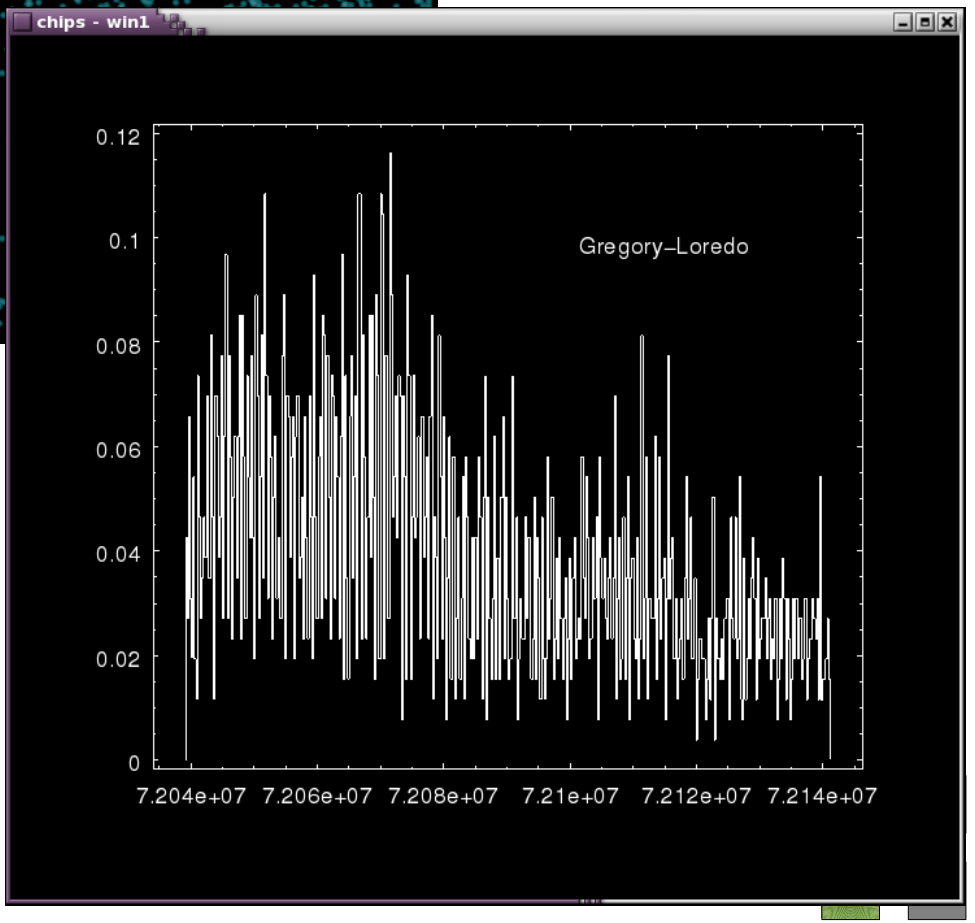
Temporal Analysis

- Lightcurve
  - **`dmextract`** using opt=ltc1 or ltc2 properly accounts for good time intervals
    - Careful binning on times approximately equal to instrumental times
  - **`glvary`** computes an 'optimally' binned lightcurve
- Responses
  - Efficiency
    - Good time intervals and dead-time factor
    - **`dither_region`** can be used to include changes in aperture due to s/c dither (eg off chip).
    - HRC includes a time-resolved dead-time factors file.
  - Times are considered absolute
    - Not really true (eg normal ACIS integrates for 3.2 sec per exposure)

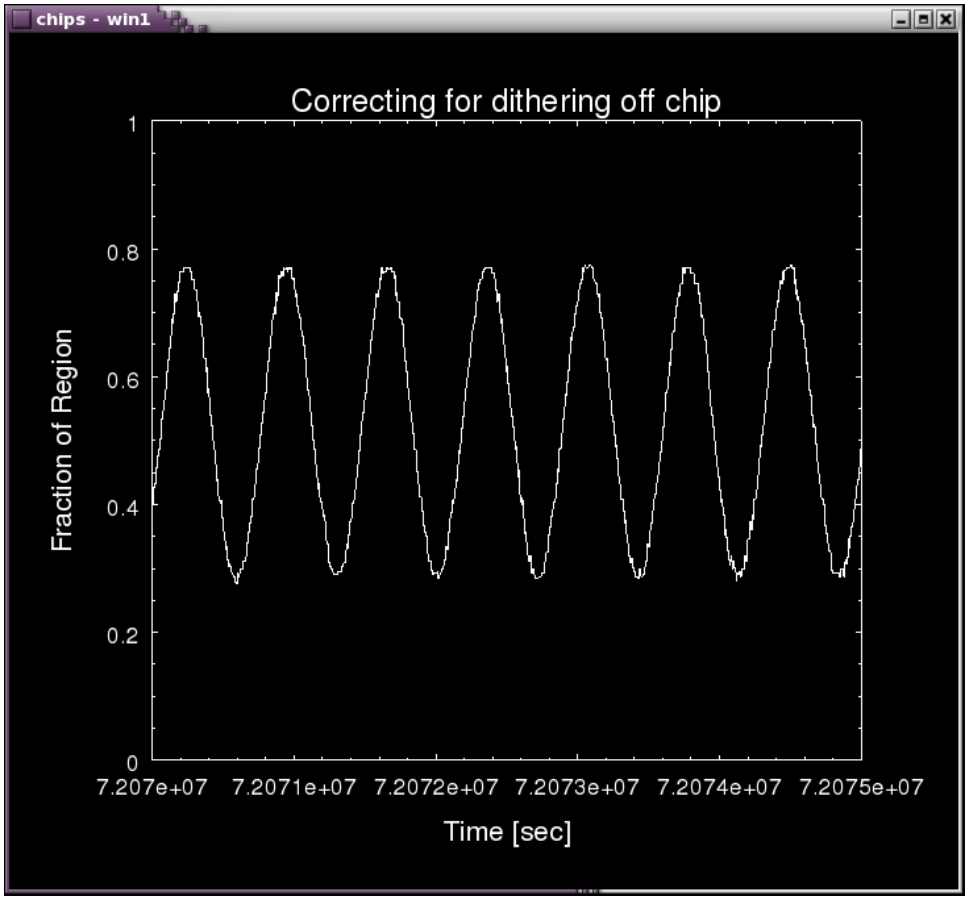




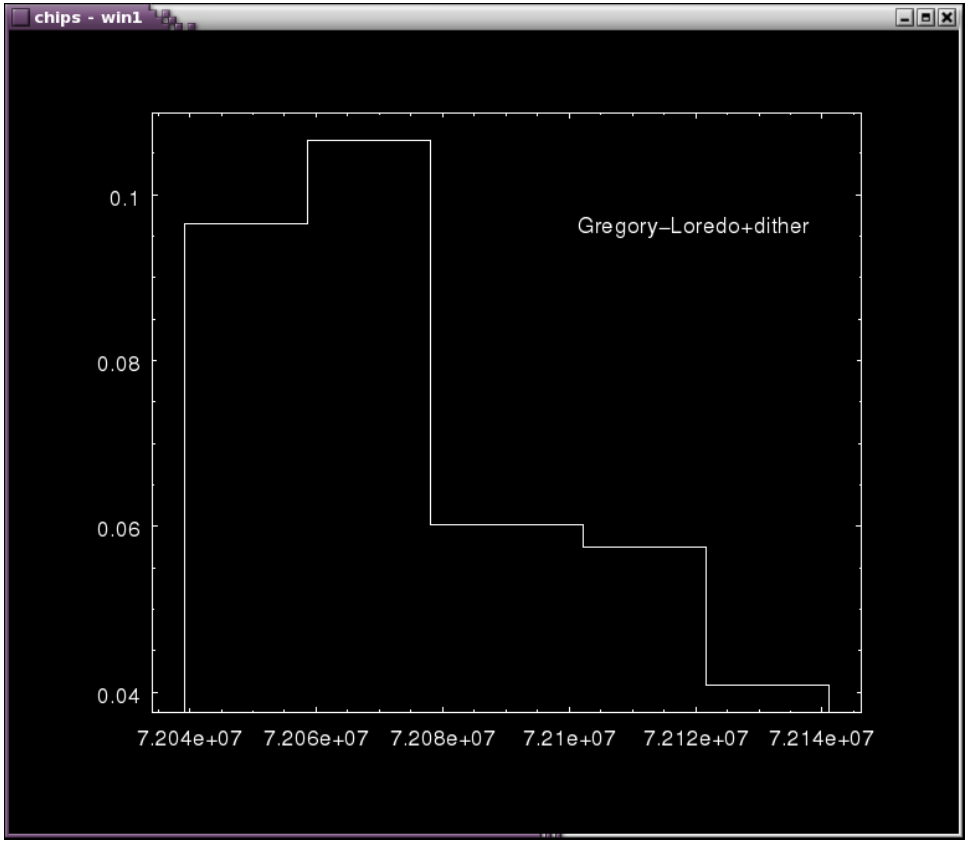
dmextract



glvary



dither_region area correction

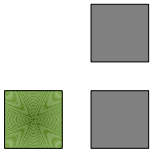


glvary with dither correction

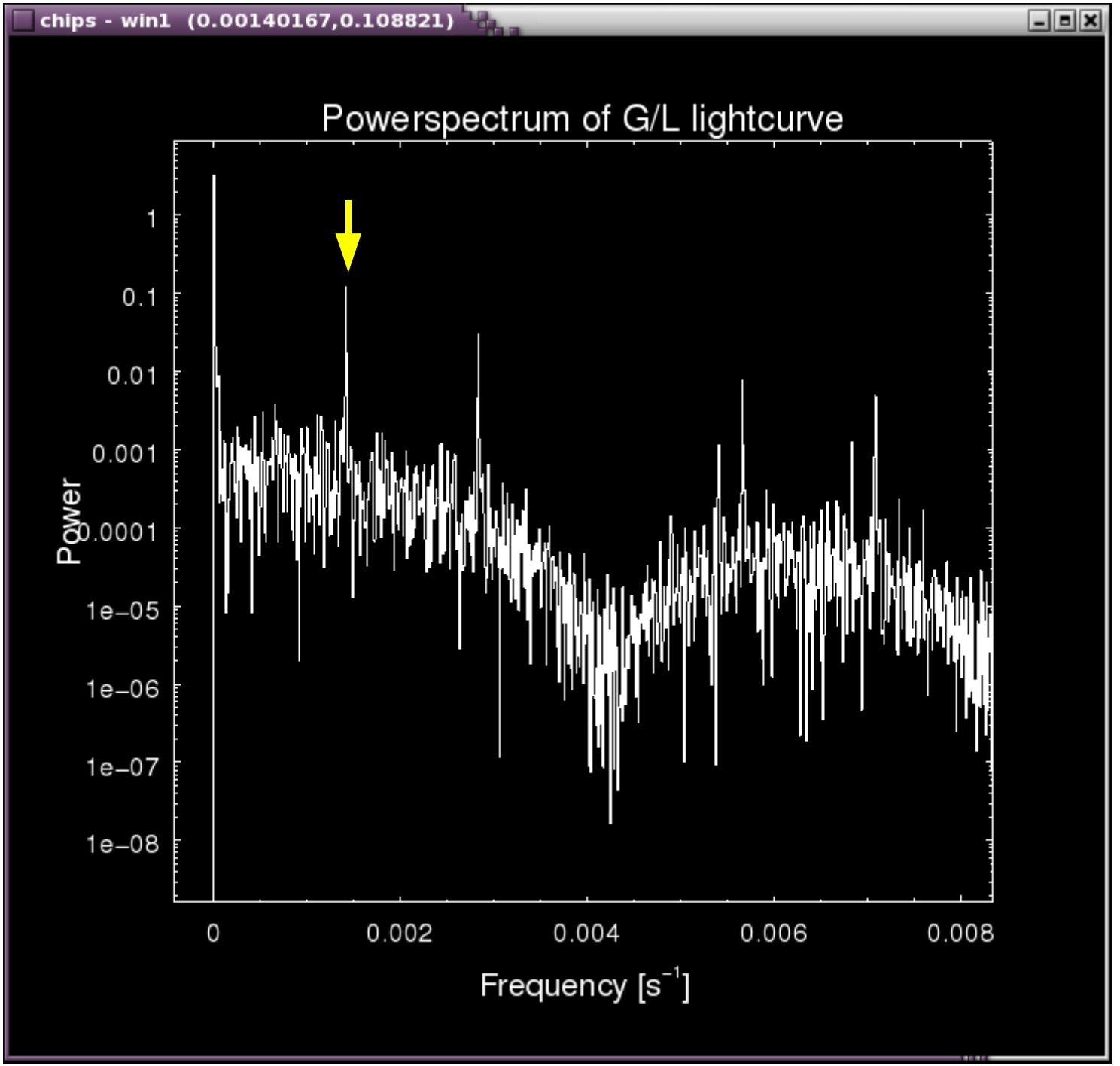
Variability

- **`glvary`**
  - Gives measures of variability, both a probability and a quantized "variability index"
    - varidex <= 1 → not variable
    - varindex >= 6 → definitely variable

    Previous example has VARINDEX=10
- **`apowerspectrum`**
  - Gives |FFT| of lightcurve; look for peaks
  - Not robust for faint sources
- **`sherpa`** can fit lightcurves
  - Fit to determine period and phase
  - Determine exponential decay



powerspectrum of un-correct glvary lightcurve
yellow arrow indicates period of aspect



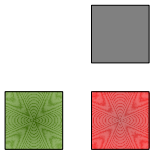
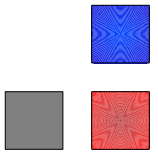
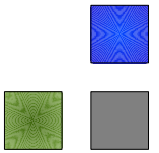
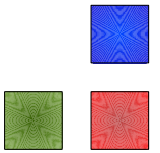
Timing

- Upcoming talk gives detailed treatment of Timing analysis especially in the Poisson regime.
  - Contrib software package **`sitar`**, includes some specialized tasks such as period and epoch folding.
- **`axbary`** performs barycenter time corrections
- **`dmextract`** can also bin to an arbitrary grid
  - Eg, fixed number of counts per variable time-bin.

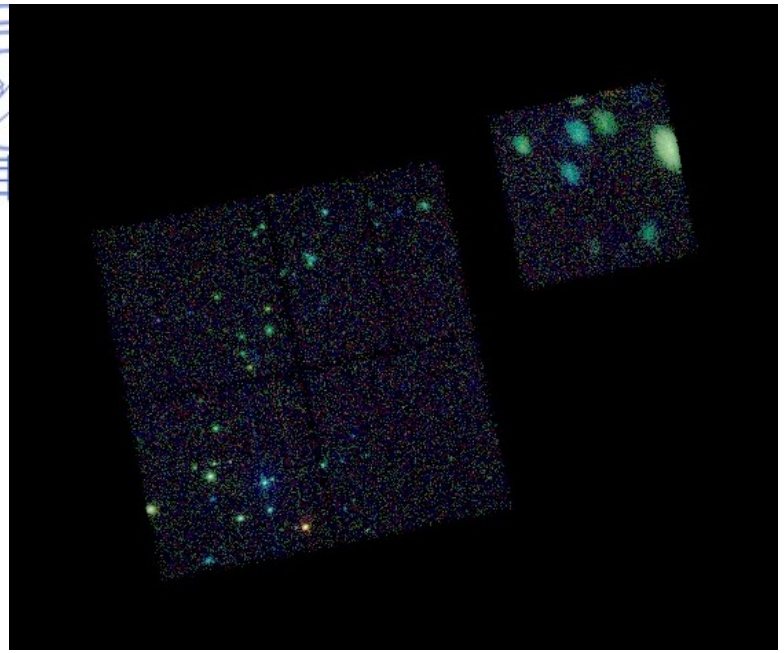
```
% dmextract “evt.fits[bin time=grid(filename)]”
```

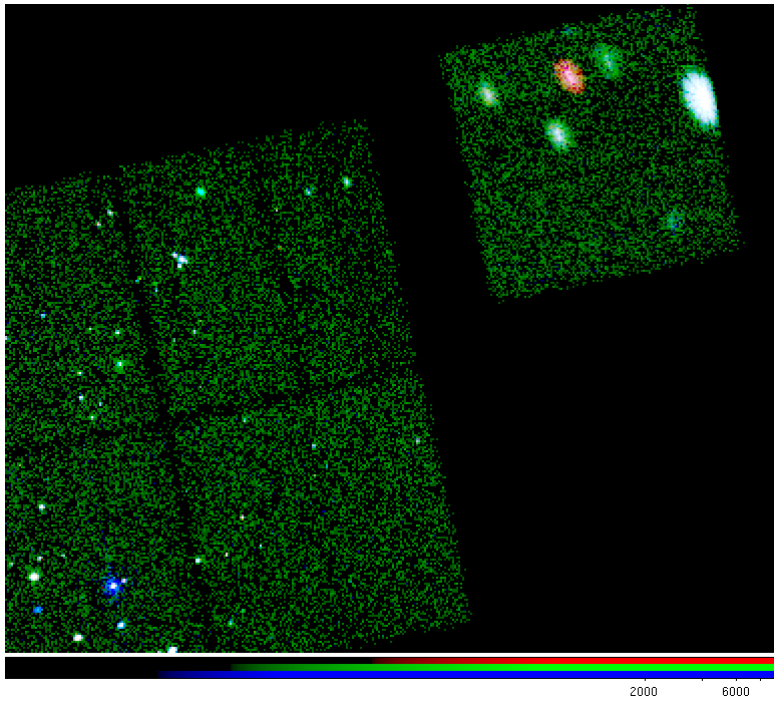
Mixed Axes

- Examples
  - 3-color coded image
    - Usually see spectral coding: red = low energy, green = medium energy, blue = high energy
    - But can also do as time-slices: red = beginning of observation, green = middle, blue = end
- Mixed Axes → Mixed Responses
  - When you mix axes you need to create responses to help interpret the results.

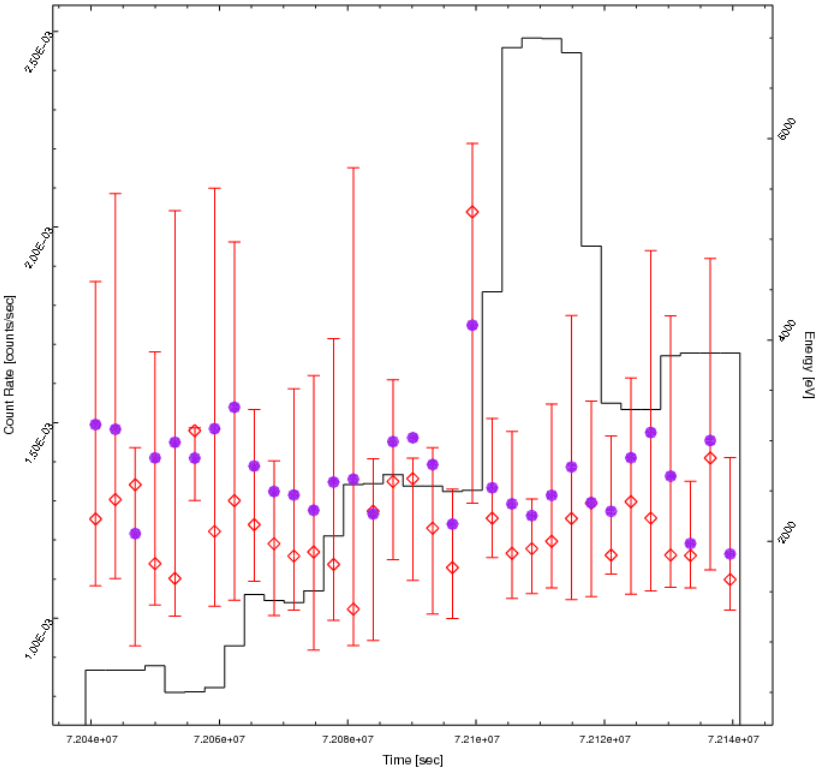





3 Color: Energy





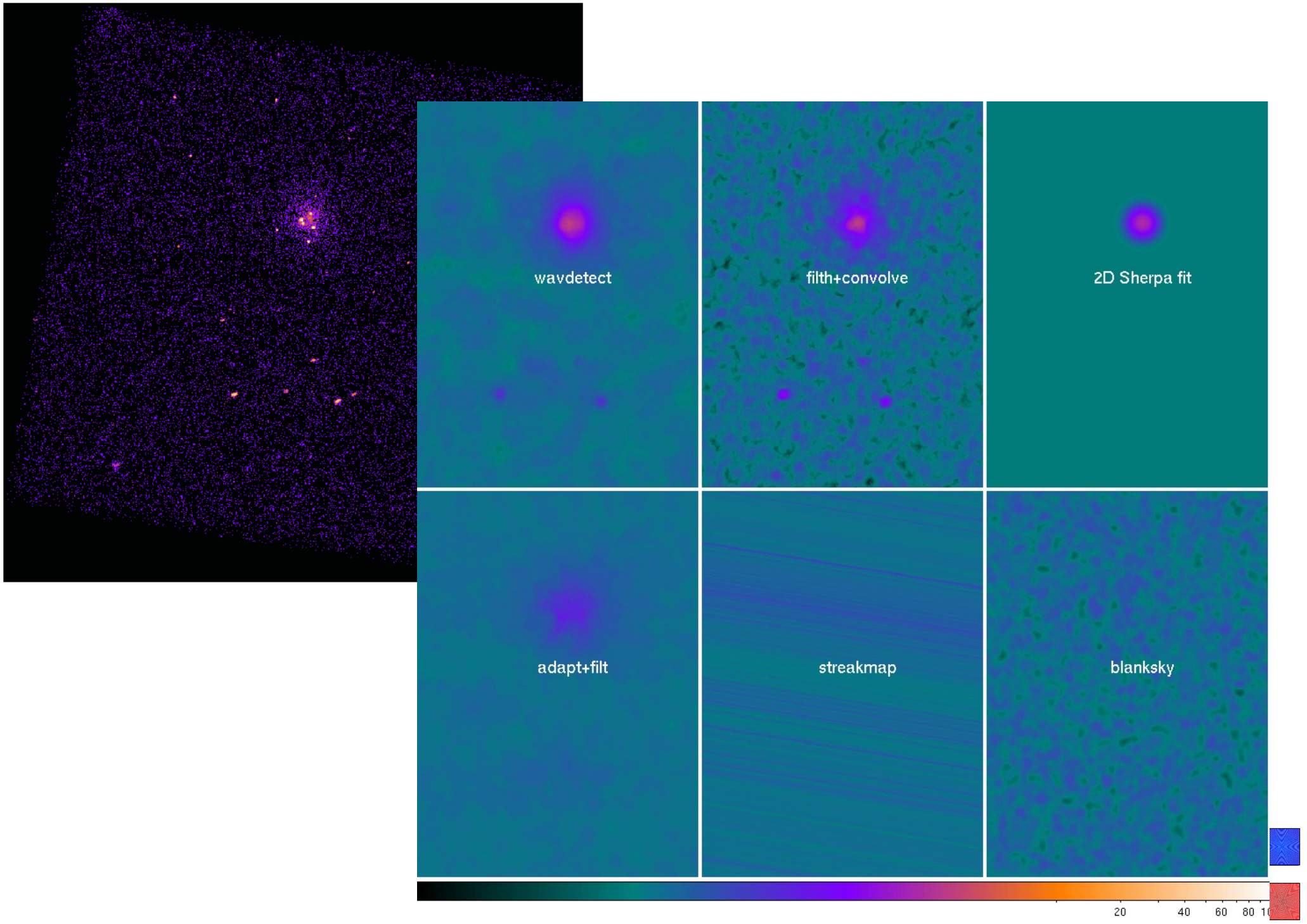
3 Color: Time

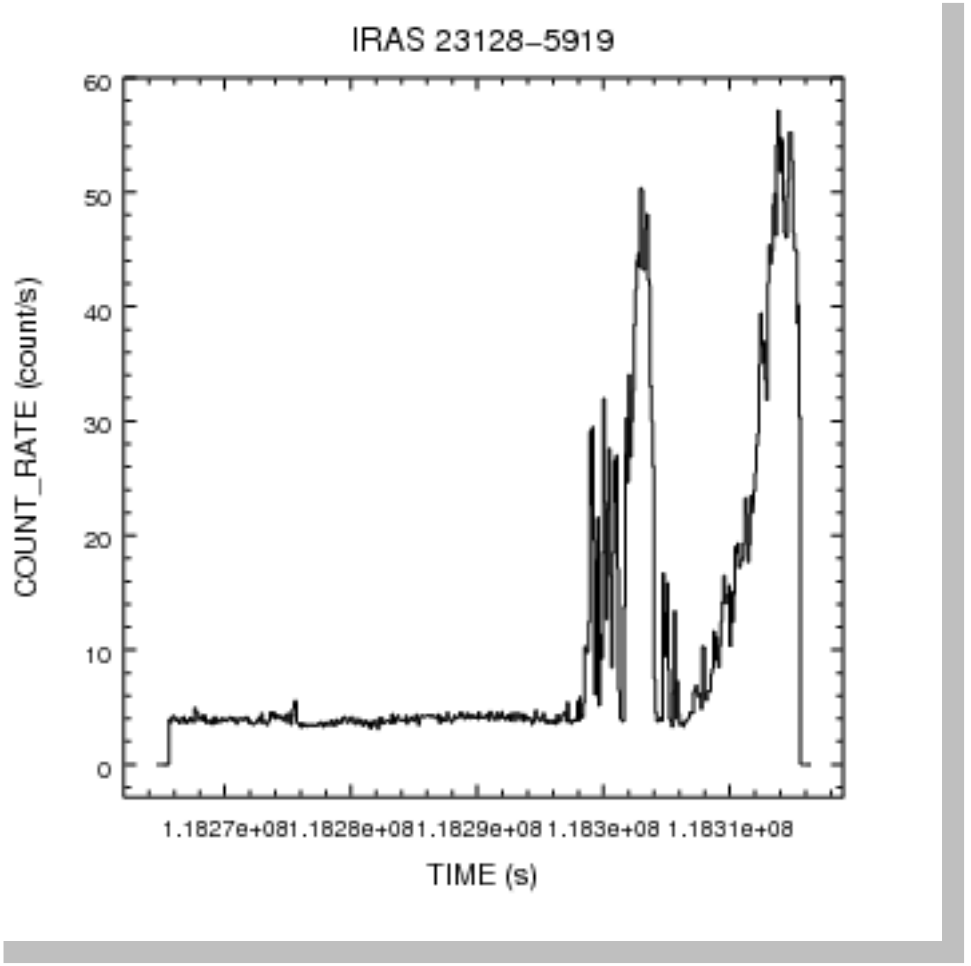


Lightcurve (solid line).
Energy: mean (purple),
median (open diamond),
25-75% quantile

Background

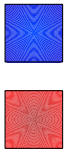
- Spatial
  - Various ways to make spatial background map including **`create_bkg_map`**, **`sherpa`**, **`dmfilth`**, **`dmimgfilt`**, **`wavdetect`** or using the *blank-sky* files in the CALDB
- Spectral
  - Use close by, source free region (often annulus around source) to extract background spectrum same as source. Depending on size could potentially use same RMF for both.
- Temporal
  - Can you **`dmextract`** to make background subtracted lightcurve; however it is binned at same time resolution as source. May want to instead extract background separately with larger time bins and then regrid background to match source with **`dmjoin`**
  - Background flares? Can use the **`deflare`** contrib script but for small regions may want to skip.


wavdetect
filth+convolve
2D Sherpa fit
adapt+filt
streakmap
blanksky
20
40
60
80


IRAS 23128−5919
COUNT_RATE (count/s)
60
50
40
30
20
10
0
1.1827e+08
1.1828e+08
1.1829e+08
1.183e+08
1.1831e+08
TIME (s)

Concluding Remarks

- **A**sk
  - Help-desk is there to assist with analysis questions.
- **A**ssess
  - Provide feedback via help-desk, user surveys, or you can submit comments to the Chandra Users Committee.
- **A**cknowledge
  - Did you know that most Chandra papers make no acknowledgment of CIAO, the CXC, or ds9?



About the Title Page

PKS 0637-752 was selected as the calibration source to focus the telescope based on previous observations from other X-ray missions that showed it to be an isolated point source. When the object was first imaged by Chandra during its Orbital Activation and Checkout phase, the nearby extended emission came as a surprise. Everyone was rushed to ensure that the data were real and not a problem with the mirrors or a bug in the aspect reconstruction software. All systems checked out okay; it was Chandra's first scientific discovery. Soon thereafter we adopted the phrase:

There are no point sources with Chandra.