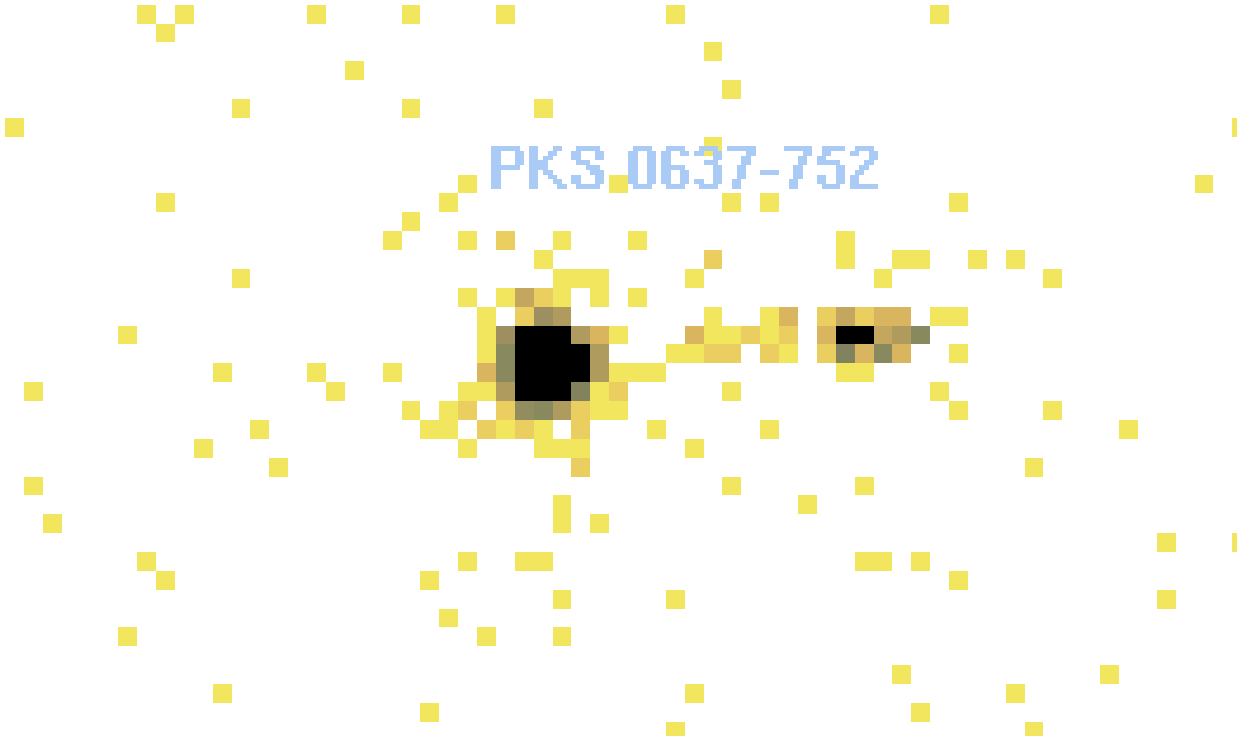
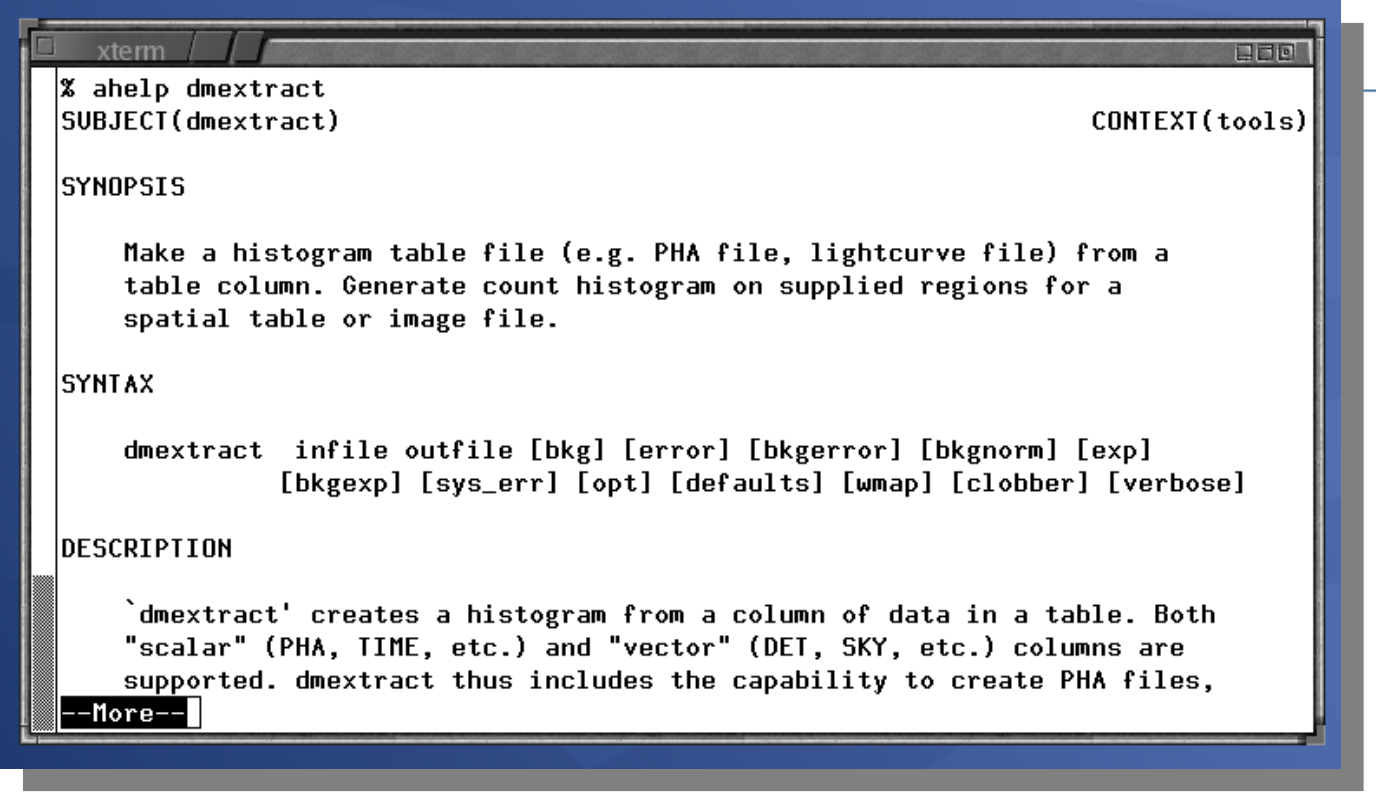
Analysis of Point-Like Sources

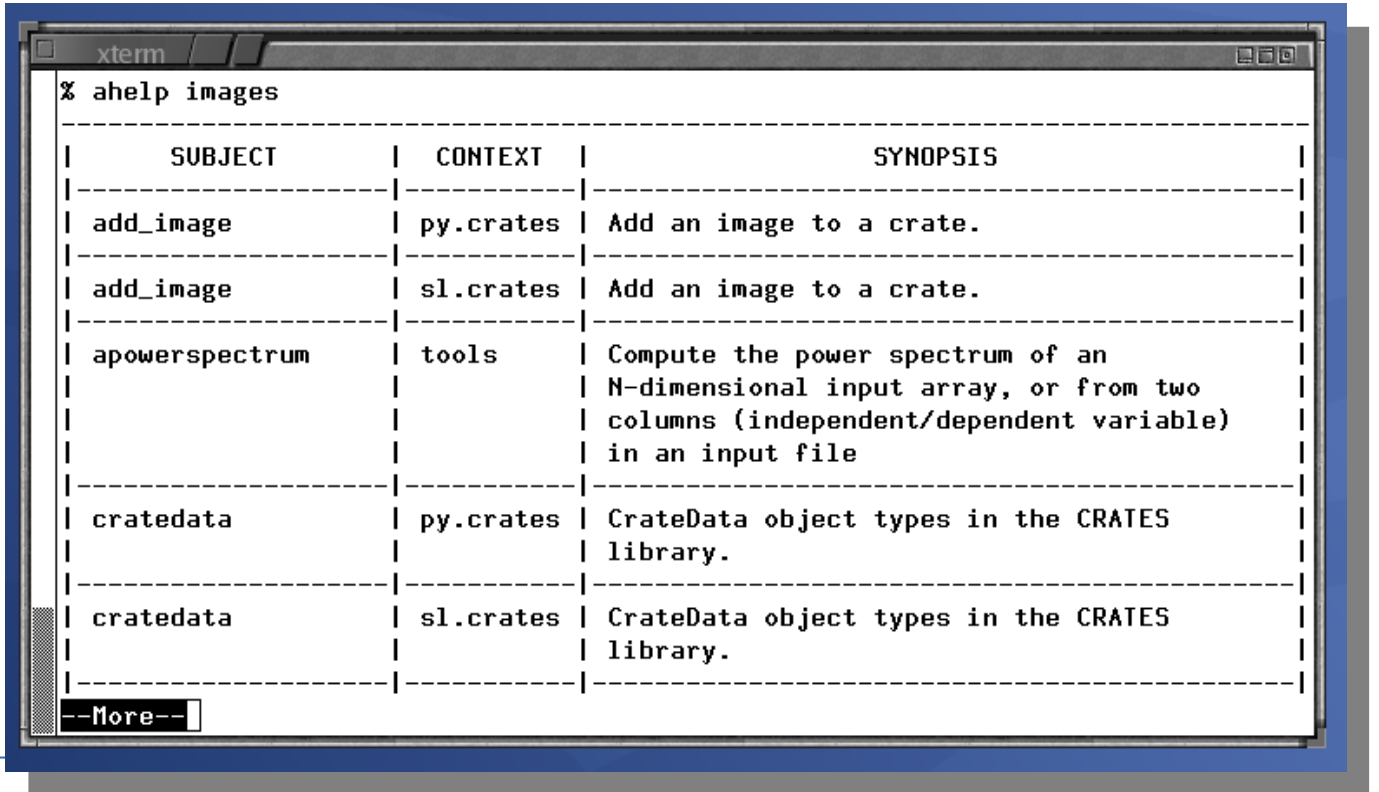


Kenny J. Glotfelty

Getting Started

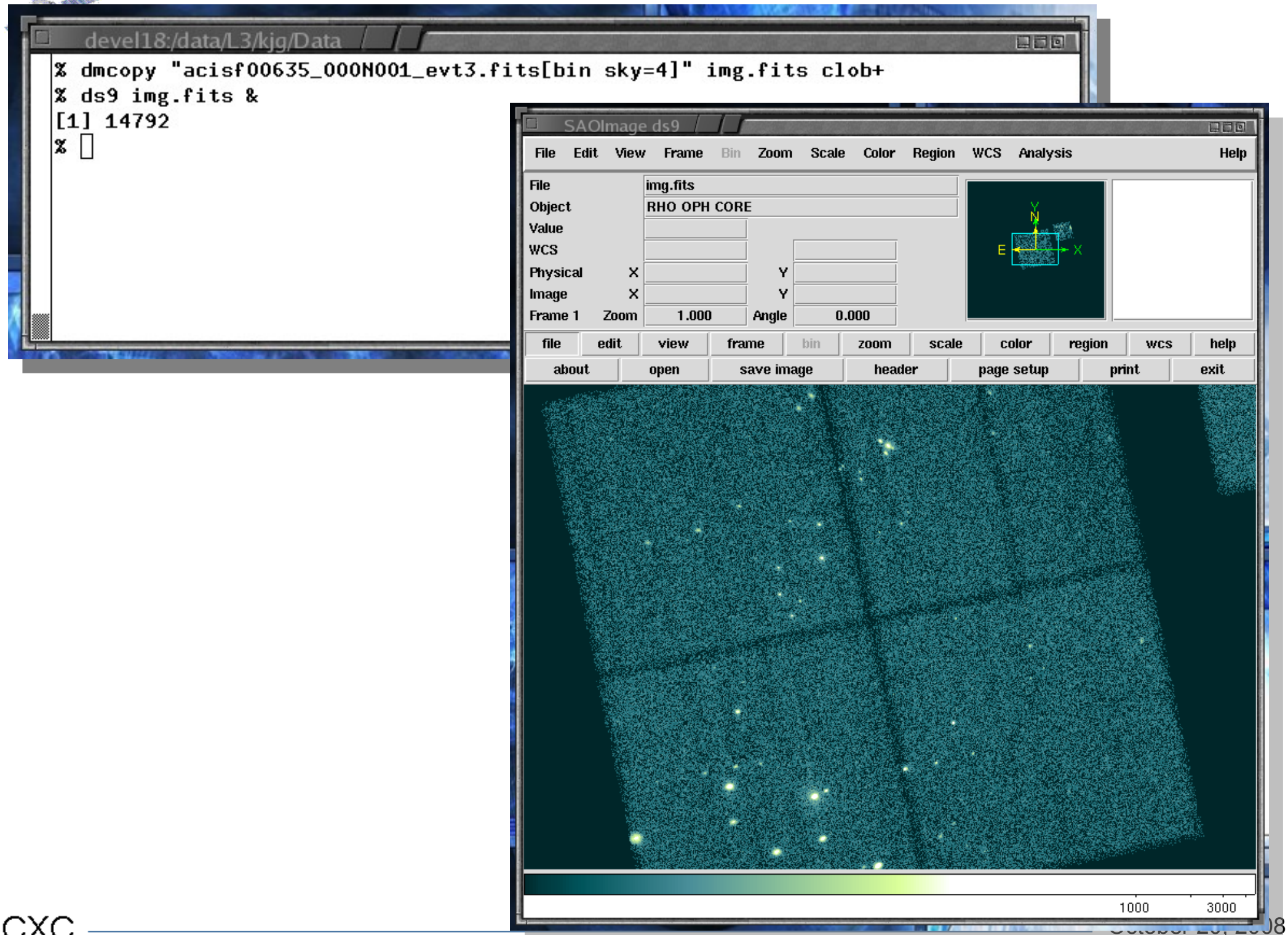
- Threads
  - http://cxc.harvard.edu/ciao/threads/
  - Usually more than one way to do things
  - Many common threads have been scripted
    - Be sure to get contrib .tar file
  - You do not have to walk on the red line!
- Help files
  - **ahelp** accesses each tasks help file from the command line
    % ahelp dmextract
    % ahelp images
  - online at http://cxc.harvard.edu/ciao/ahelp/
- Other
  - proposers guide, manuals, memos, publications, white papers, analysis guides, workshops, etc.

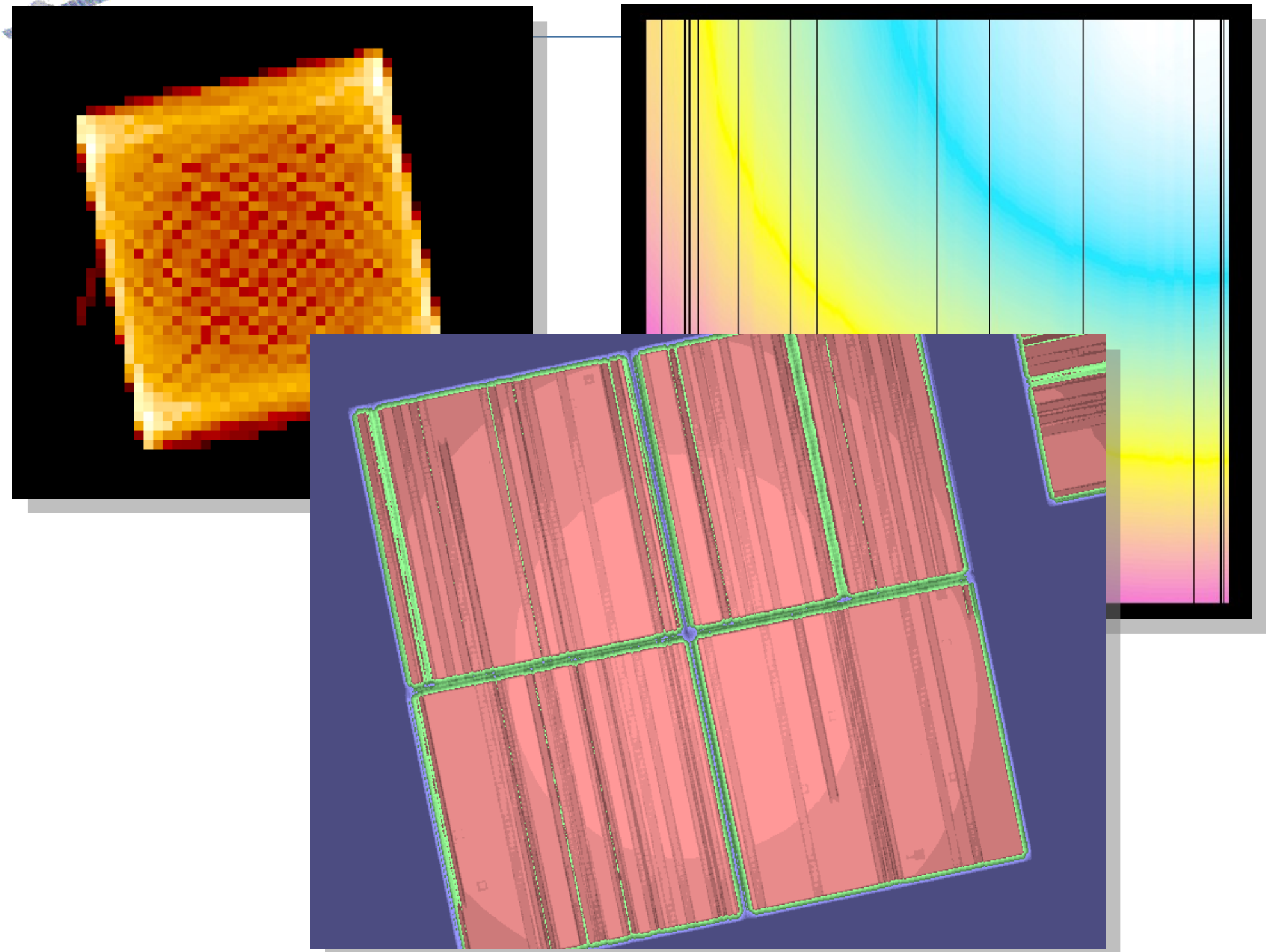

xterm
% ahelp dmextract
SUBJECT(dmextract) CONTEXT(tools)
SYNOPSIS
Make a histogram table file (e.g. PHA file, lightcurve file) from a table column. Generate count histogram on supplied regions for a spatial table or image file.
SYNTAX
dmextract infile outfile [bkg] [error] [bkgerror] [bkgnorm] [exp] [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,
--More--

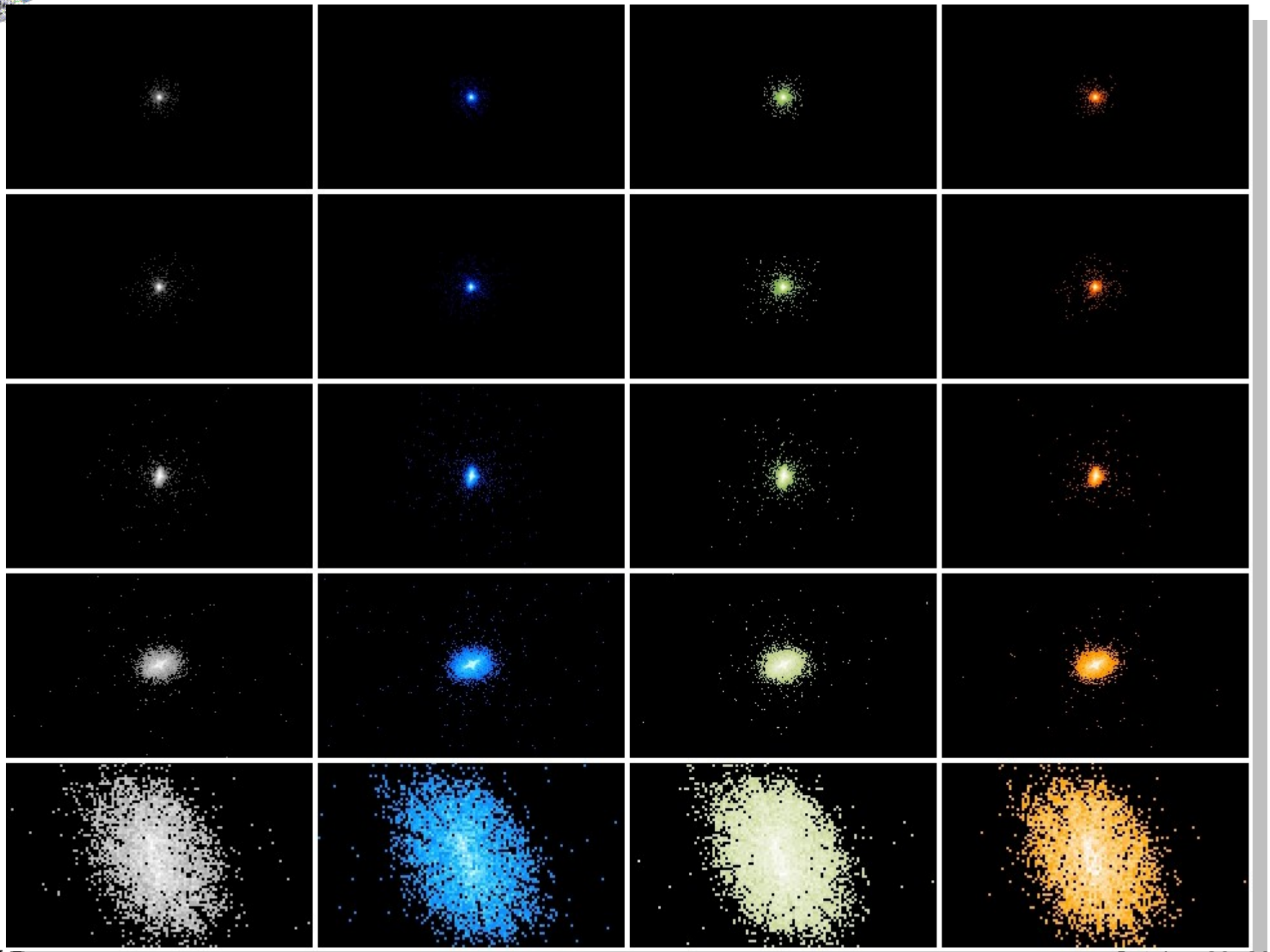

xterm
% ahelp images
SUBJECT | CONTEXT | SYNOPSIS
add_image | py.crates | Add an image to a crate.
add_image | sl.crates | Add an image to a crate.
apowerspectrum | tools | Compute the power spectrum of an N-dimensional input array, or from two columns (independent/dependent variable) in an input file
cratedata | py.crates | CrateData object types in the CRATES library.
cratedata | sl.crates | CrateData object types in the CRATES library.
--More--

Spatial Analysis

- Image
  - **dmcopy** can create images
    - apply various filters: energy, time, etc
    - doesn't have to be just 2D, can be N-D
    - since all CIAO tools share same I/O, binning syntax supported by all tools.
  - ds9 is powerful ~~analysis~~ visualization tool
    - load event files as well as images (and much more)
- Responses
  - Exposure maps (**mkexpmap**) [cm^2 sec]
    - Instrument Map (**mkinstmap**) convolved with Aspect Histogram (**asphist**)
  - PSF: Point Spread Functions (**ChaRT**)


devel18:/data/L3/kjg/Data
% dmcopy "acisf00635_000N001_evt3.fits[bin sky=4]" img.fits clob+
% ds9 img.fits &
[1] 14792
%
SAOImage ds9
File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help
File img.fits
Object RHO OPH CORE
Value
WCS
Physical X Y
Image X Y
Frame 1 Zoom 1.000 Angle 0.000
N
E
X
file edit view frame bin zoom scale color region wcs help
about open save image header page setup print exit
1000
3000



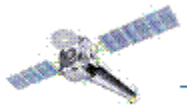


Spatial Analysis :: Photometry

- aperture photometry
  - **dmextract**
    - generic histogram
    - allows for src & bkg, corrects for aperture area
    - allows for input exposure map
  - **dmstat**
    - general statistics : mean, min, max, total, number, centroid, stdev
    - careful when counting image pixels vs. rows in a table
  - **dmlist** opt=counts
    - simple, counts = number of rows

aprates

- compute confidence limits, including upper limits



SAOImage ds9

File Edit View Frame Bin Zoom Scale Color Region WCS Analysis

File acisf00635_0
Object RHO OPH CC
Value
WCS
Physical
X
Y
Image
X
Y
Frame 1
Zoom 1.000
Angle 0.000

N E

devel18:/data/L3/kjg/Data

```
% dmextract "acisf00635_000N001_evt3.fits[bin sky=region(ds9.reg)]" \
? dme1.fits clob+ op=generic
% dmlist "dme1.fits[cols counts]" data,clean
#  COUNTS
              7459.0
% dmkeypar dme1.fits counts echo+
7459.0
%
```

devel18:/data/L3/kjg/Data

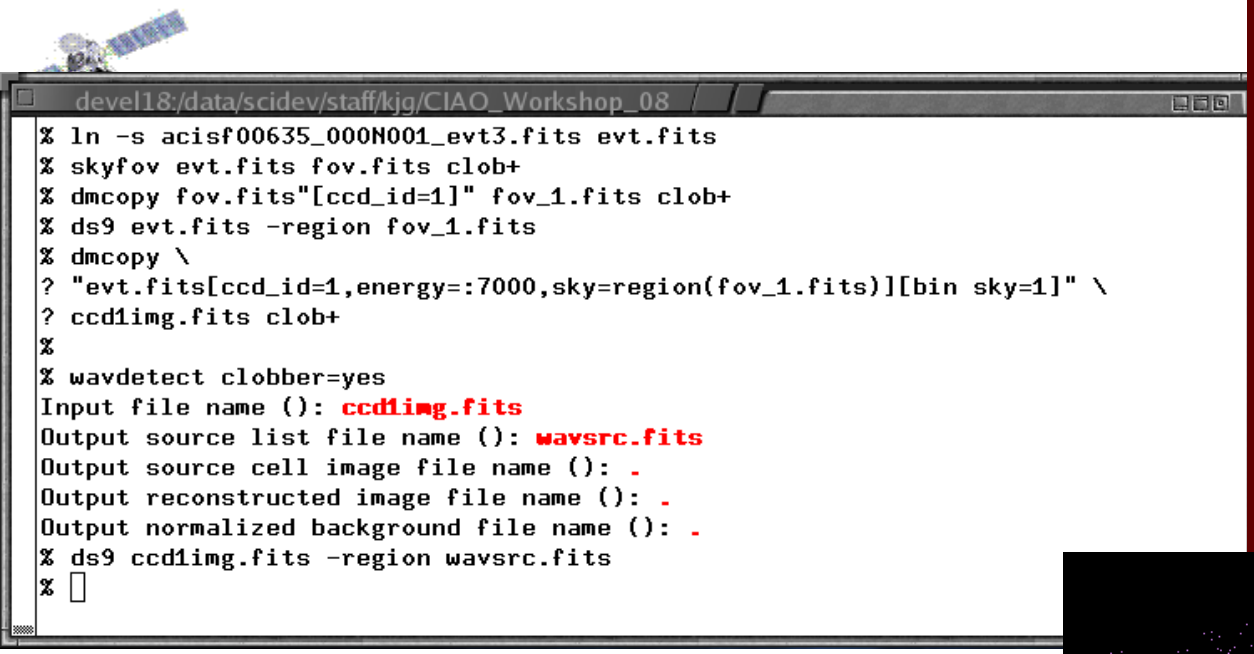
```
% dmstat "acisf00635_000N001_evt3.fits[sky=region(ds9.reg)][cols x,y]"
sky(x, y)[pixel]
    min:        ( 3462.0292969 3466.5251465 )        @:        ( 6072 5913 )
    max:        ( 3537.482666 3543.2092285 )         @:        ( 5068 6969 )
   mean:        ( 3500.9227245 3503.9806653 )
  sigma:        ( 7.0976260136 6.5894499522 )
    sum:        ( 26113382.602 26136191.783 )
   good:        ( 7459 7459 )
   null:        ( 0 0 )

%
```

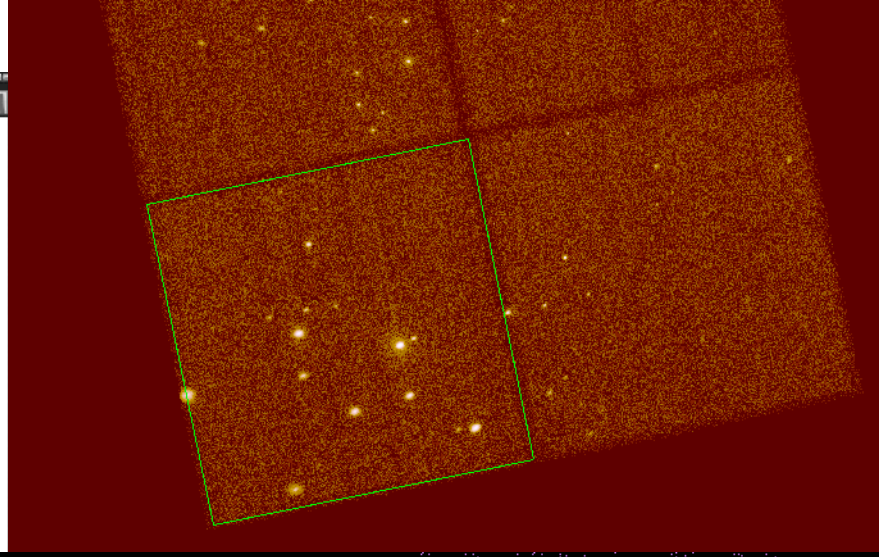
devel18:/data/L3/kjg/Data

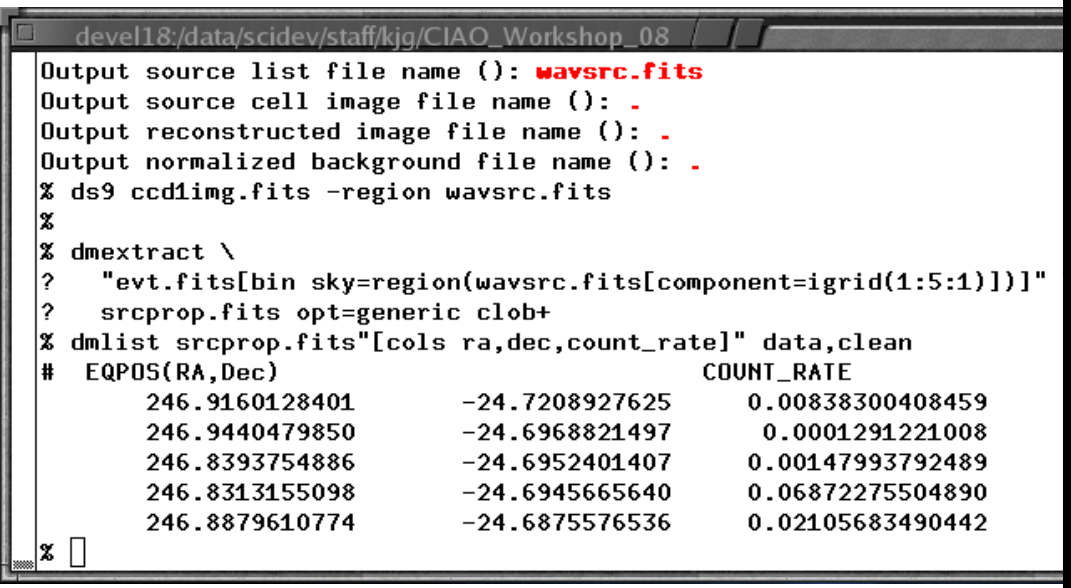
```
% dmstat "acisf00635_000N001_evt3.fits[sky=region(ds9.reg)][bin sky=1]" cen-
EVENTS_IMAGE
    min:        0            @:        ( 3495.118821 3466.118821 )
    max:        127          @:        ( 3503.118821 3505.118821 )
   mean:        1.5298461538
  sigma:        7.8695310828
    sum:        7458
   good:        4875
   null:        1366
%
```

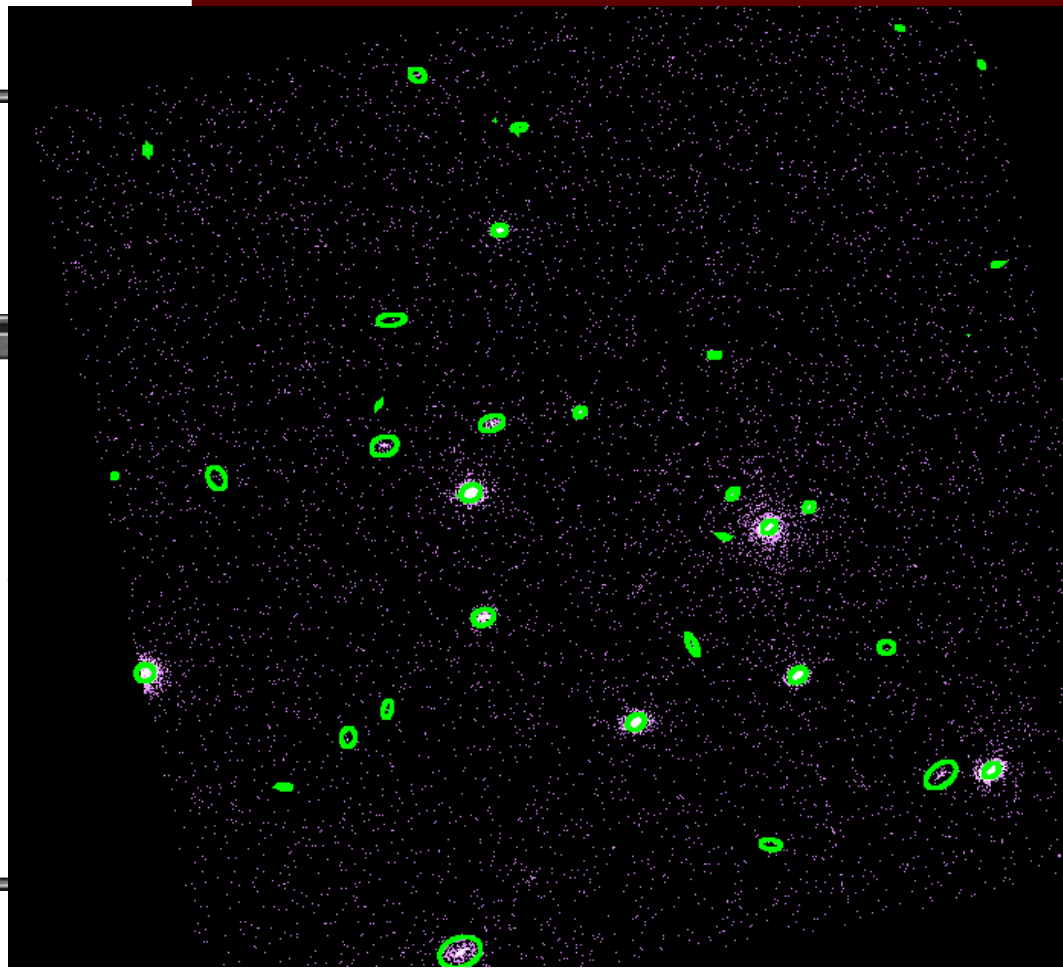
Spatial Analysis :: detection

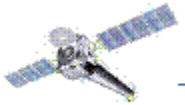
- Already had a presentation on various detect tools strengths and weaknesses
  - We'll try something fairly advanced
    - Make an image for just 1 CCD
    - Filter on energy band
    - Detect sources
    - Perform aperture photometry
  - The region output by wavdetect is never used by wavdetect!
    - Therefore quantities computed from detect regions shouldn't be expected to identically match detect outputs
- CIAO 4.1 will have tools to compute a limiting sensitivity for a particular exposure, aperture size, and background.


devel18:/data/scidev/staff/kjg/CIAO_Workshop_08
% ln -s acisf00635_000N001_evt3.fits evt.fits
% skyfov evt.fits fov.fits clob+
% dmcopy fov.fits"[ccd_id=1]" fov_1.fits clob+
% ds9 evt.fits -region fov_1.fits
% dmcopy \
? "evt.fits[ccd_id=1,energy=:7000,sky=region(fov_1.fits)][bin sky=1]" \
? ccd1img.fits clob+
%
% wavdetect clobber=yes
Input file name (): ccd1img.fits
Output source list file name (): wavsrc.fits
Output source cell image file name (): .
Output reconstructed image file name (): .
Output normalized background file name (): .
% ds9 ccd1img.fits -region wavsrc.fits
%



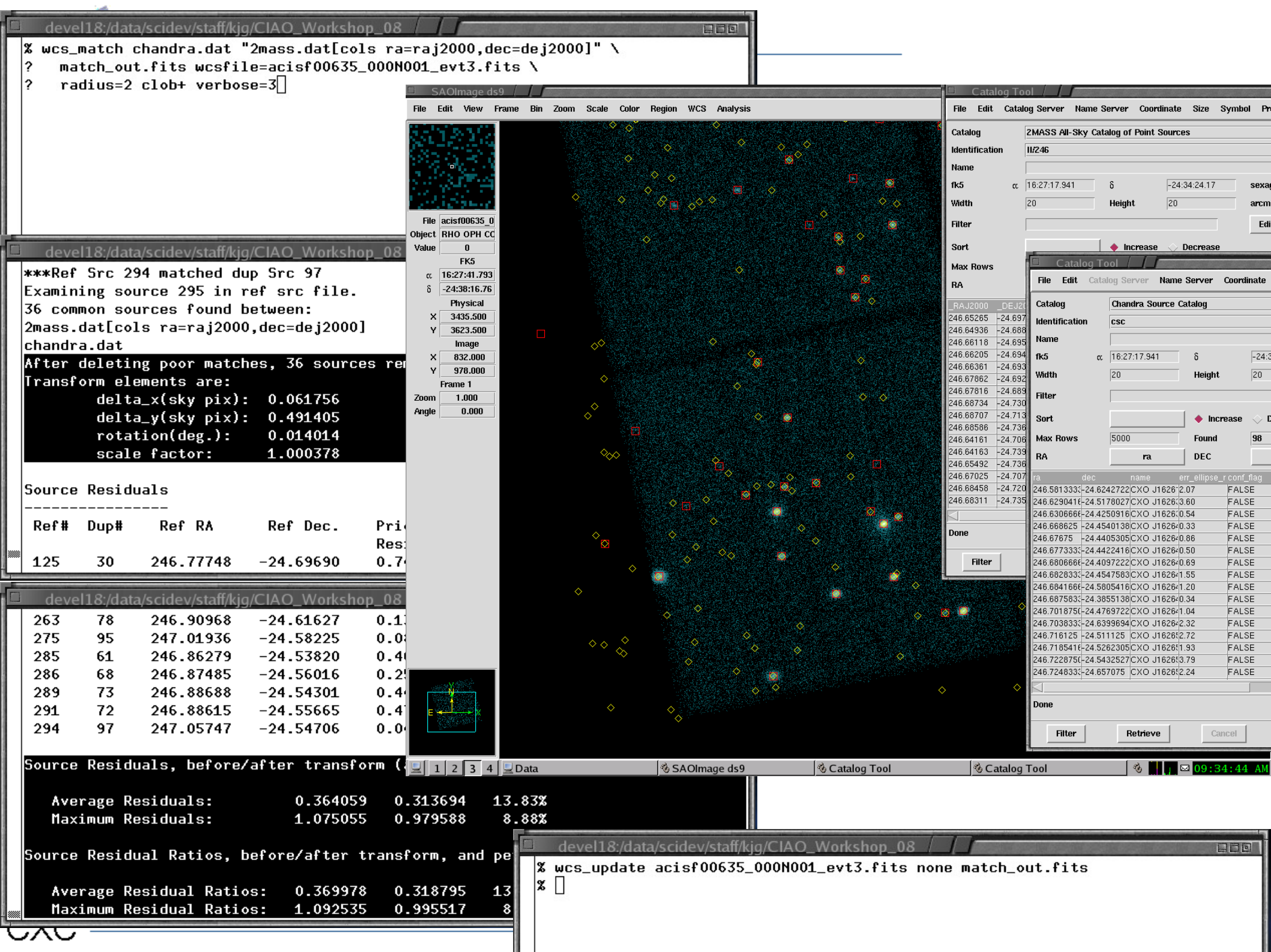

devel18:/data/scidev/staff/kjg/CIAO_Workshop_08
Output source list file name (): wavsrc.fits
Output source cell image file name (): .
Output reconstructed image file name (): .
Output normalized background file name (): .
% ds9 ccd1img.fits -region wavsrc.fits
%
% dmextract \
? "evt.fits[bin sky=region(wavsrc.fits[component=igrid(1:5:1)])]"
? srcprop.fits opt=generic clob+
% dmlist srcprop.fits"[cols ra,dec,count_rate]" data,clean
# EQPOS(RA,Dec)   COUNT_RATE
      246.9160128401   -24.7208927625   0.00838300408459
      246.9440479850   -24.6968821497   0.0001291221008
      246.8393754886   -24.6952401407   0.00147993792489
      246.8313155098   -24.6945665640   0.06872275504890
      246.8879610774   -24.6875576536   0.02105683490442
%





Spatial Analysis :: alignment

- **reproject_aspect** is used to match source lists and update WCS
  - Can update WCS in tables (event files, source lists), images, or Chandra aspect solution (asol) files.
- Wrapper around **wcs_match** and **wcs_update**
  - May be useful to run individually especially if source matching could be tricky (large numbers of sources, poor correlation)
  - Can tweak matching parameters of **wcs_match** and then run **wcs_update** once satisfied that matches are optimal.
- **reproject_image** and **reproject_image_grid** match image pixels between images (including from different telescopes)


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
***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 re
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. Pri
Res
125 30 246.77748 -24.69690 0.7
263 78 246.90968 -24.61627 0.1
275 95 247.01936 -24.58225 0.0
285 61 246.86279 -24.53820 0.4
286 68 246.87485 -24.56016 0.2
289 73 246.88688 -24.54301 0.4
291 72 246.88615 -24.55665 0.4
294 97 247.05747 -24.54706 0.0
Source Residuals, before/after transform (
Average Residuals: 0.364059 0.313694 13.83%
Maximum Residuals: 1.075055 0.979588 8.88%
Source Residual Ratios, before/after transform, and pe
Average Residual Ratios: 0.369978 0.318795 13
Maximum Residual Ratios: 1.092535 0.995517 8
SAOImage ds9
File Edit View Frame Bin Zoom Scale Color Region WCS Analysis
File acisf00635_0
Object RHO OPH CC
Value 0
FK5
α 16:27:41.793
δ -24:38:16.76
Physical
X 3435.500
Y 3623.500
Image
X 832.000
Y 978.000
Frame 1
Zoom 1.000
Angle 0.000
Catalog Tool
File Edit Catalog Server Name Server Coordinate Size Symbol
Catalog 2MASS All-Sky Catalog of Point Sources
Identification II/246
Name
fk5 α 16:27:17.941 δ -24:34:24.17
Width 20 Height 20
Filter
Sort Increase Decrease
Max Rows
RA
_RAJ2000 _DEJ2
246.65265 -24.697
246.64936 -24.686
246.66118 -24.695
246.66205 -24.694
246.66361 -24.693
246.67862 -24.692
246.67816 -24.689
246.68734 -24.730
246.68707 -24.713
246.68586 -24.736
246.64161 -24.706
246.64163 -24.739
246.65492 -24.736
246.67025 -24.707
246.68458 -24.720
246.68311 -24.735
Done
Filter
Catalog Tool
File Edit Catalog Server Name Server Coordinate
Catalog Chandra Source Catalog
Identification csc
Name
fk5 α 16:27:17.941 δ -24:3
Width 20 Height 20
Filter
Sort Increase
Max Rows 5000 Found 98
RA ra DEC
ra dec name err_ellipse_r conf_flag
246.581333 -24.6242722 CXO J1626 2.07 FALSE
246.629041 -24.5178027 CXO J1626 3.60 FALSE
246.630666 -24.4250916 CXO J1626 0.54 FALSE
246.668625 -24.4540138 CXO J1626 0.33 FALSE
246.67675 -24.4405305 CXO J1626 0.86 FALSE
246.677333 -24.4422416 CXO J1626 0.50 FALSE
246.680666 -24.4097222 CXO J1626 0.69 FALSE
246.682833 -24.4547583 CXO J1626 1.55 FALSE
246.684166 -24.5805416 CXO J1626 1.20 FALSE
246.687583 -24.3855138 CXO J1626 0.34 FALSE
246.701875 -24.4769722 CXO J1626 1.04 FALSE
246.703833 -24.6399694 CXO J1626 2.32 FALSE
246.716125 -24.511125 CXO J1626 2.72 FALSE
246.718541 -24.5262305 CXO J1626 1.93 FALSE
246.722875 -24.5432527 CXO J1626 3.79 FALSE
246.724833 -24.657075 CXO J1626 2.24 FALSE
Done
Filter Retrieve Cancel
1 2 3 4 Data SAOImage ds9 Catalog Tool Catalog Tool 09:34:44 AM
devel18:/data/scidev/staff/kjg/CIAO_Workshop_08
% wcs_update acisf00635_000N001_evt3.fits none match_out.fits
%

Spatial Analysis :: morphology

- smoothing:
  - **aconvolve**: simple Gaussian (& other kernel) smoothing
  - **csmooth**: adaptive smoothing, Ebling et.al
    - **WARNING**: csmooth does not preserve photometry

- radial profile
  - **dmextract** using input ***stack***
  - **dmellipse** will allow users to find ellipses aligned with moments enclosing fraction of flux (eg PSF fraction)

- remove
  - Tired of those annoying sources? Remove 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

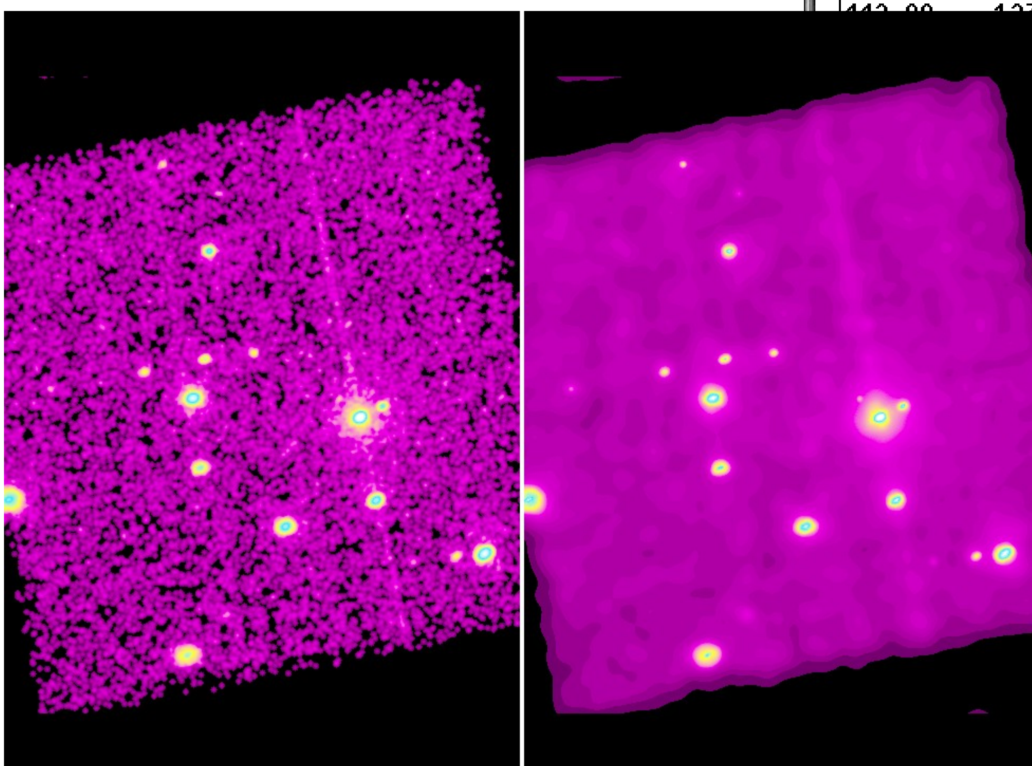
```
% csmooth verb=3
input file name (): ccd1img.fits
image of user-supplied map of smoothing scales ():
output file name (): csm.fits
output significance image (.): csm_sig.fits
output scales [kernel sizes] image (.): csm_scl.fits
Convolution method. (slide|fft) (fft):
Convolution kernel type. (gauss|tophat) (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

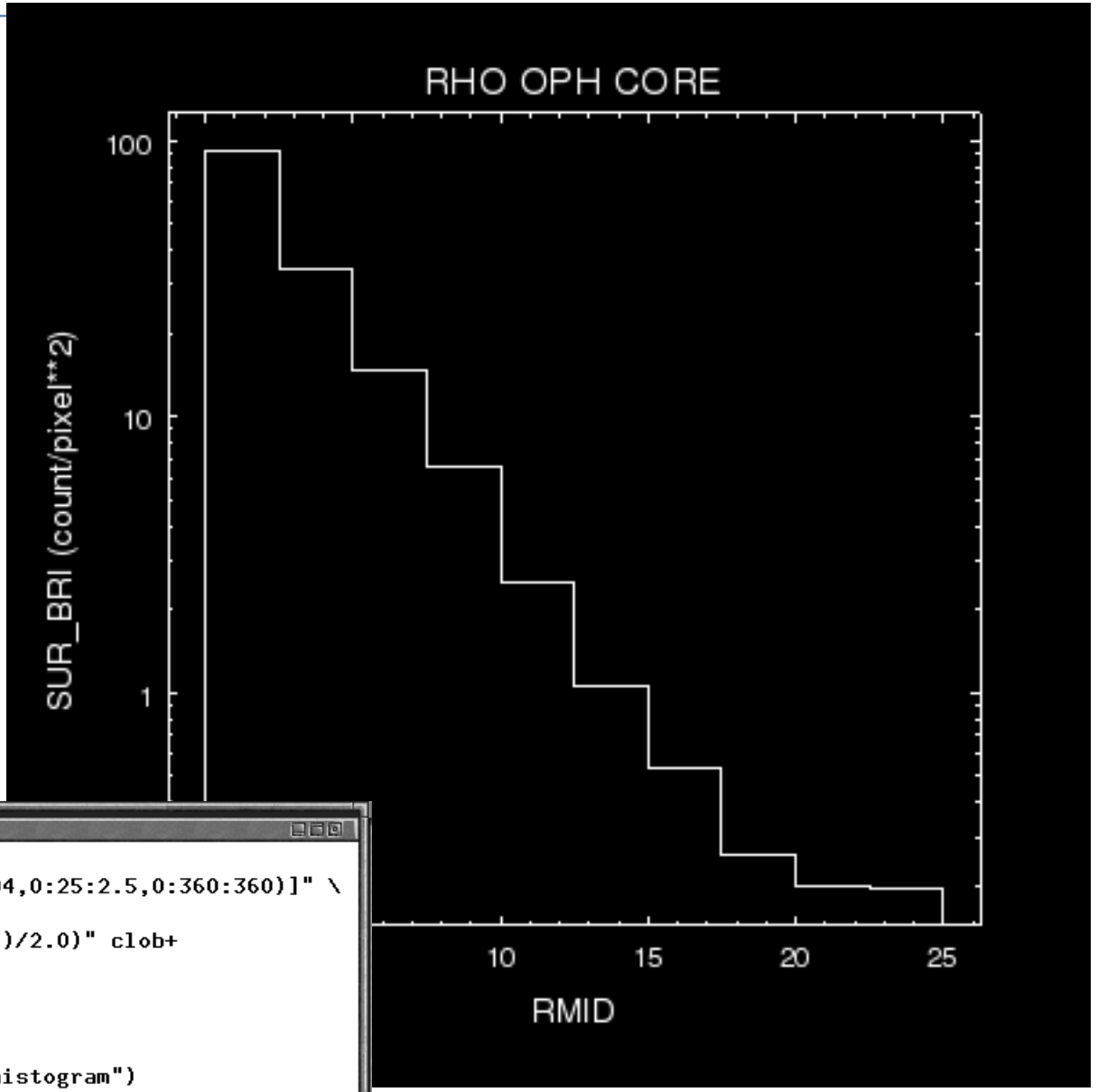
```
minimal significance, S/N ratio (4): 3
maximal significance, S/N ratio ()sigmin:) (5):
compute smoothing scales or user user-supplied map (compute|user) (compute):
                       smoothing    out/in       pixels     counts     significance
 n_max   m_krnl_min    radius     diffl  cumul  done (%)   done (%)       range
                                                                      min    med    max

--------------------------------------------------------------------------------------
-
                 .68    0.188     1.000  1.000    0.00       4.77     3.10   4.20   7.29
                 .86    0.198     1.000  1.000    0.00       9.33     3.05   4.70   5.55
                 .20    0.208     1.000  1.000    0.00      11.99     3.10   3.73   4.98
                 .95    0.223     1.000  1.000    0.00      12.82     3.65   4.62   5.36
                 .16    0.238     1.000  1.000    0.00      13.25     4.27   2.32   4.64
                 .08    0.252     1.000  1.000    0.00      13.82     3.05   3.13   3.48
                 .14    0.267     1.000  1.000    0.00      14.30     3.15   3.24   3.91
                 .98    0.312     1.000  1.000    0.00      14.38     3.01   3.01   3.01
```

/scidev/staff/kjg/CIAO_Workshop_08

```
                 .36    3.756     1.000  1.000    0.35      66.37     3.00   3.38   5.28
                 .17    4.447     1.000  1.000    0.42      67.39     3.00   3.30   4.92
                 .83    5.396     1.000  1.000    0.51      68.14     3.00   3.31   4.50
                 .86    6.526     1.000  1.000    0.61      68.81     3.00   3.29   4.66
                 .35    7.925     1.000  1.000    0.73      69.52     3.00   3.23   4.17
                 .20    9.802     1.000  1.000    0.89      70.08     3.00   3.24   4.25
                 .63   12.111     1.000  1.000    1.13      70.78     3.00   3.28   4.55
                 .39   14.788     1.000  1.000    1.45      71.34     3.00   3.30   4.87
                mainder will be smoothed on scale of 15.000000
                 .00   15.000     1.000  1.000  100.00     100.00    -5.79  -0.11   4.08
                g data
                riting data
                g data
                riting data
                g data
                riting data
%
```



CXC

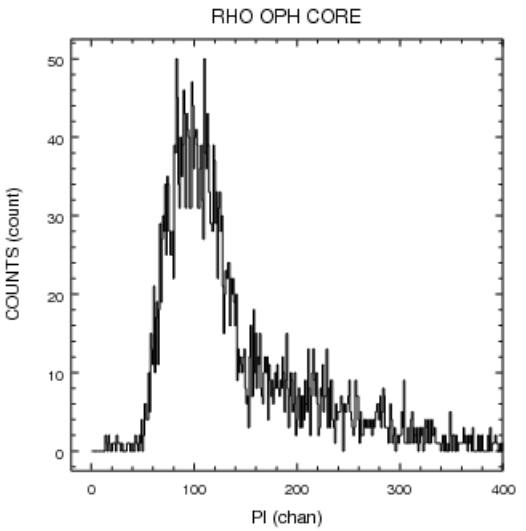



```
devel18:/data/scidev/staff/kjg/CIAO_Workshop_08
% dmextract \
? "acisf00635_000N001_evt3.fits[bin sky=pgrid(3501,3504,0:25:2.5,0:360:360)]" \
? radial.fits clob+ op=generic
% dmtcalc radial.fits rmid.fits expr="rmid=((r[0]+r[1])/2.0)" clob+
% chips
chips-1> make_figure("rmid.fits[cols rmid,sur_bri]")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

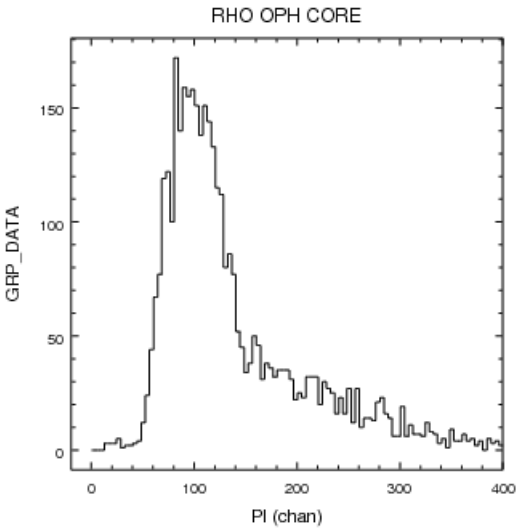
Spectral Analysis

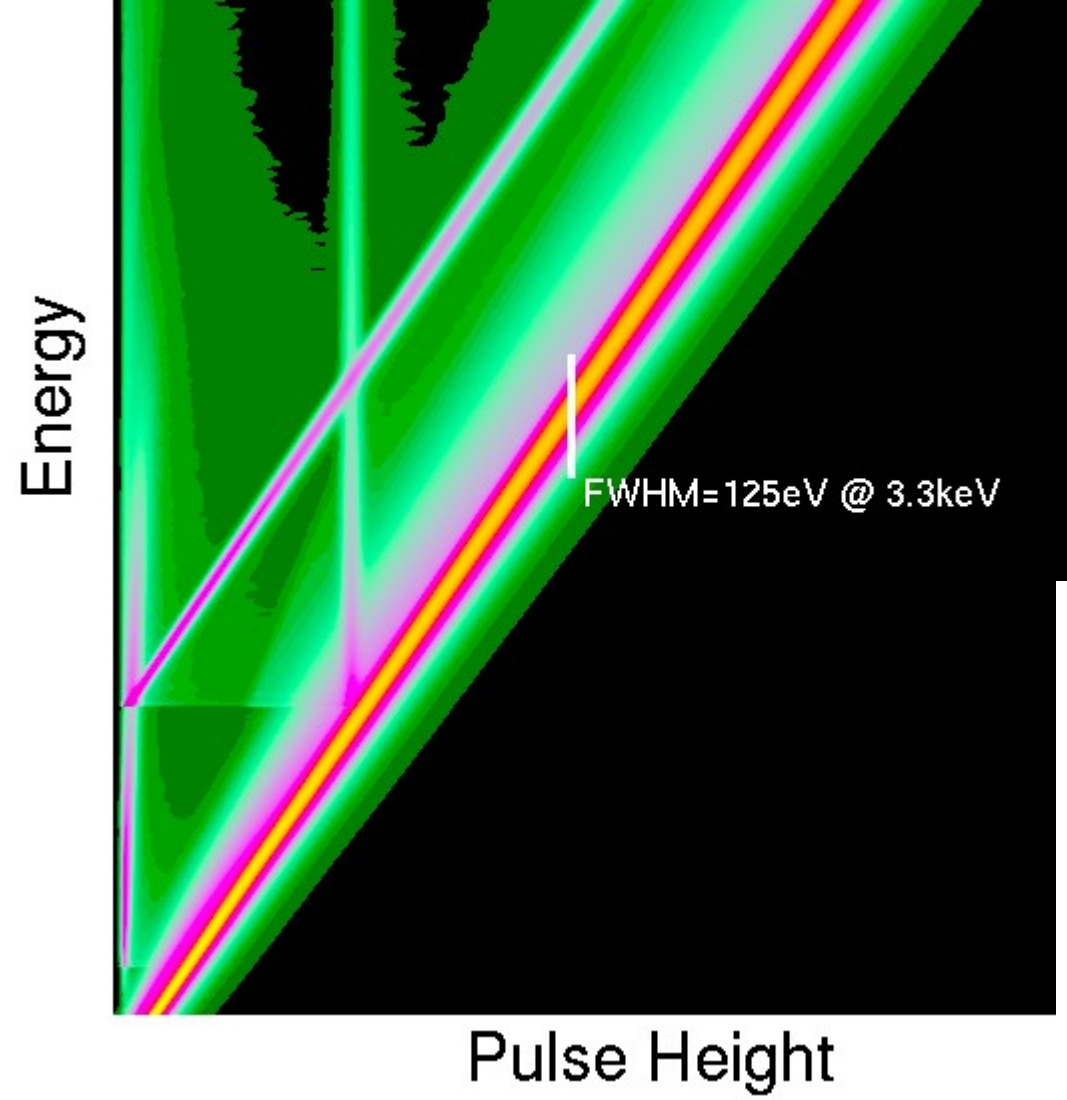
- Spectrum
  - **dmextract,** now bin on energy column(s)
- Responses
  - ARF: Auxiliary Response Function (File) [cm^2]
    - **mkarf** and **mkwarf** used to make ARFs for point-like sources
  - RMF: Response Matrix File
    - **mkrmf** and **mkacisrmf** used to make RMFs depending on gain calibrations
- Others
  - **specextract** makes all and adds necessary keywords
  - Contrib. software like **acis_extract**
  - CSC have pre-canned spectra & responses!

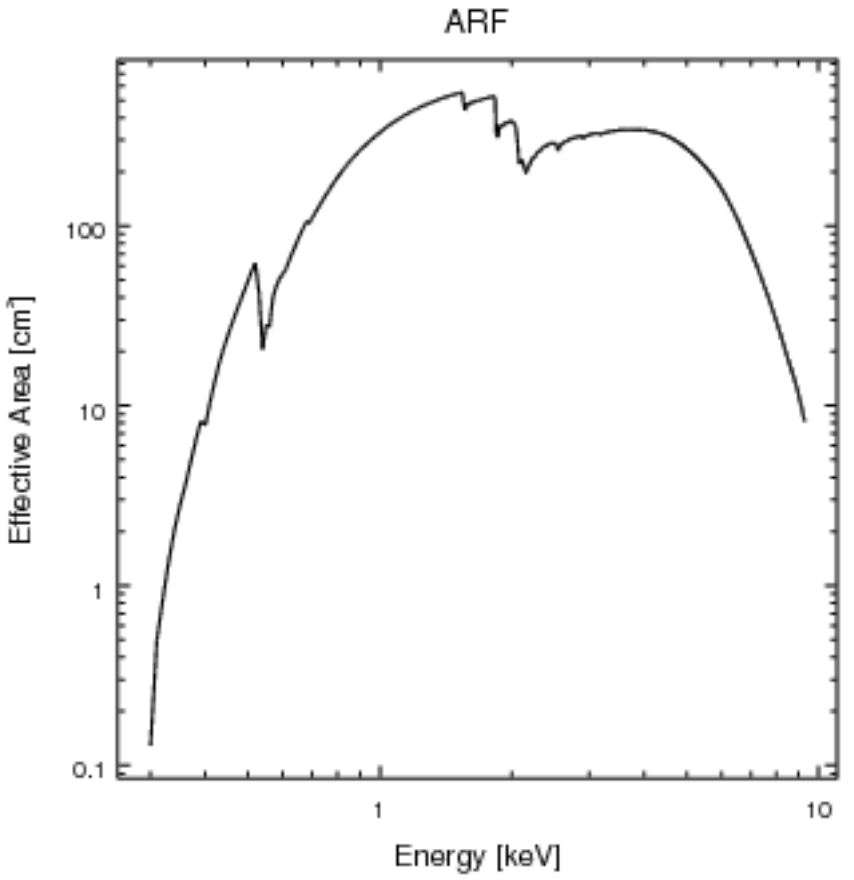
```
devel18:/data/scidev/staff/kjg/CIAO_Workshop_08
% dmextract \
? "acisf00635_000N001_evt3.fits[sky=circle(3150,3310,30)][bin pi=1]" \
? spectrum.fits clob+ op=pha1
% chips
chips-1> make_figure("spectrum.fits[cols pi,counts]","histogram")
chips-2> limits(X_AXIS, AUTO, 400 )
chips-3> print_window("pi",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




Energy
FWHM=125eV @ 3.3keV
Pulse Height


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

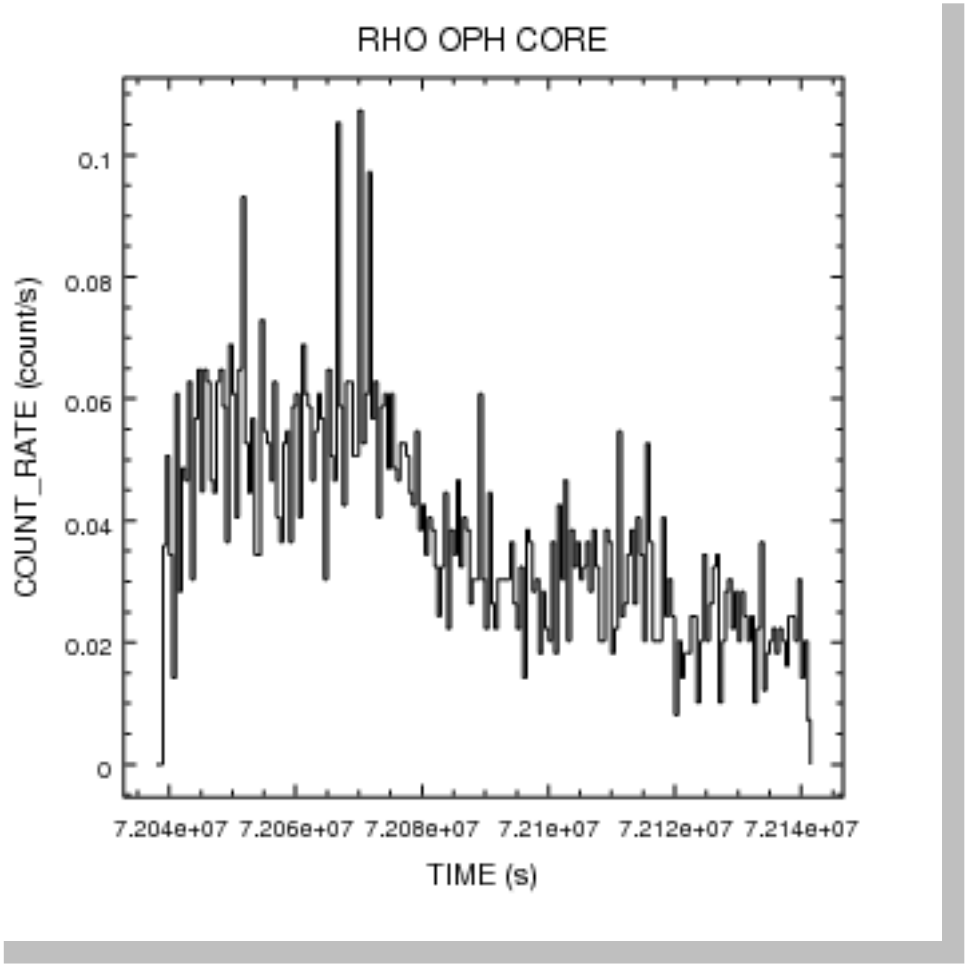
Spectral Analysis :: fluxes

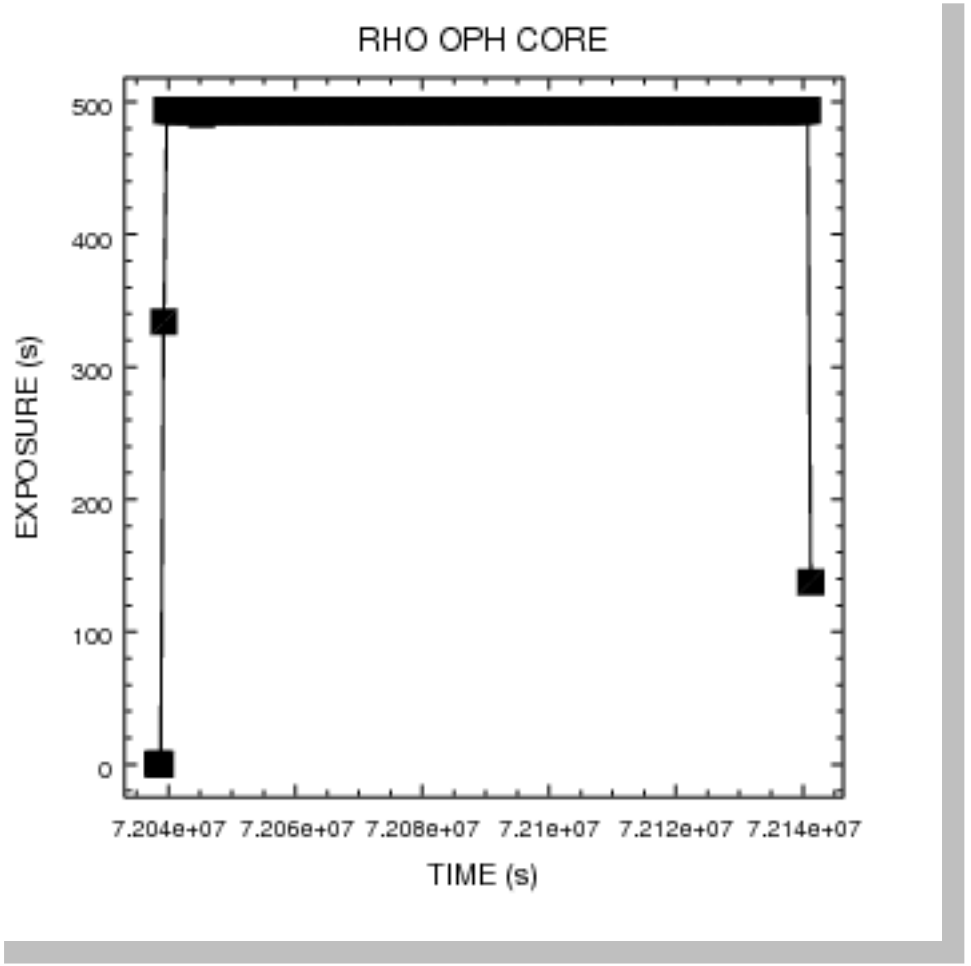
- Next talk is all about Sherpa & Statistics
- Watch out!
  - If source is near the edge or dithers across multiple chips
  - Even point like sources far off axis need to be treated like extended sources due to size of PSF
- Looking ahead to CIAO 4.1 & beyond
  - **eff2evt** will generate a simple flux-per-event which can be summed. Hard part is getting good error bars!
  - A simple **PIMMS** like script is being developed based on catalog requirements

Temporal Analysis

- Lightcurve
  - **dmextract** using opt=lct1|ltc2 properly accounts for good time intervals
  - Careful binning on times approximately equal to instrumental time, eg ACIS full frame ~3.2 sec

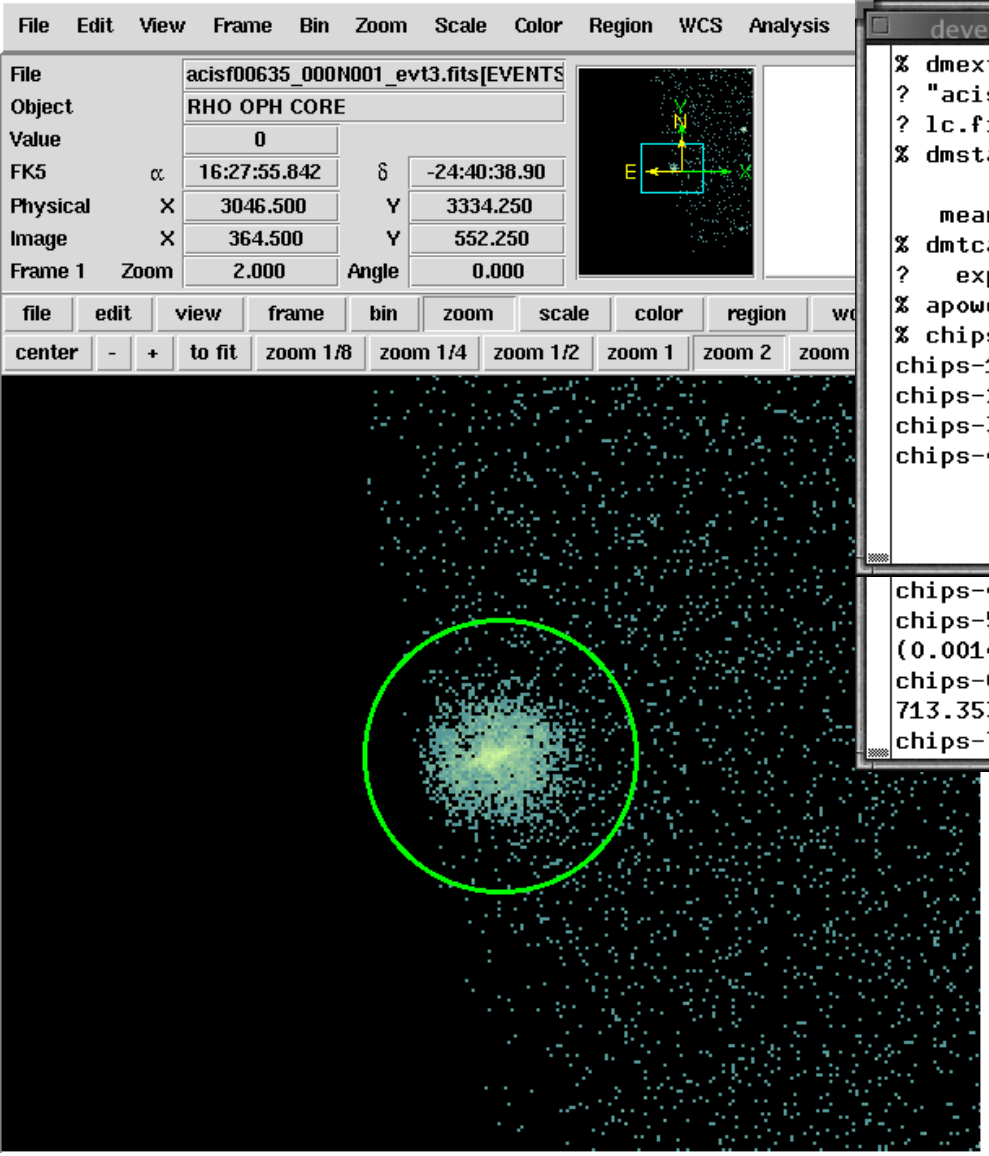
- Responses
  - Good Time Intervals [sec]
  - Times are considered absolute
    - not really true since frames are integrated for 3.2 sec
  - Fraction of aperture and/or PSF will be included in future release via **dither_region**


RHO OPH CORE
COUNT_RATE (count/s)
0.1
0.08
0.06
0.04
0.02
0
7.204e+07
7.206e+07
7.208e+07
7.21e+07
7.212e+07
7.214e+07
TIME (s)


RHO OPH CORE
EXPOSURE (s)
500
400
300
200
100
0
7.204e+07
7.206e+07
7.208e+07
7.21e+07
7.212e+07
7.214e+07
TIME (s)

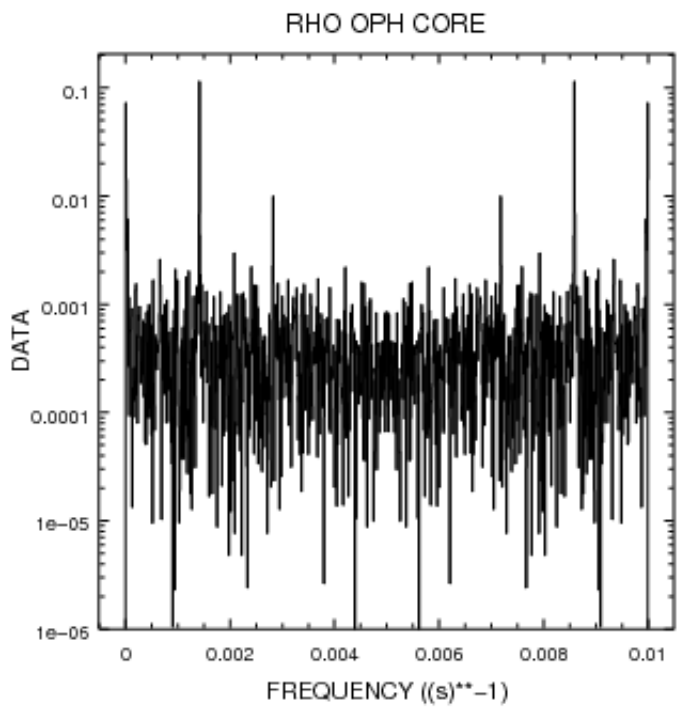
Temporal Analysis :: powerspectrum

- Is my (bright) source variable because of the telescope dithering?
  - create lightcurve
  - subtract off mean count-rate
  - generate powerspectrum
  - plot
  - identify lines and convert to period
- Yes, this source has a periodicity of ~700 sec which is period of dither.




```
devel18:/data/scidev/staff/kjg/CIAO_Workshop_08
% dmextract \
? "acisf00635_000N001_evt3.fits[sky=circle(3155,3310,30)][bin time=::100]" \
? lc.fits op=ltc1 clob+
% dmstat lc.fits"[cols count_rate]" sig- med- |& grep mean

   mean:        0.038080718151
% dmtcalc lc.fits lc_zero.fits \
?   expr="count_rate=(count_rate-0.038080718151)" clob+
% apowerspectrum lc_zero.fits"[cols time,count_rate]" none power.fits clob+
% chips
chips-1> make_figure("power.fits", "histogram")
chips-2> limits(Y_AXIS, 1e-6, AUTO )
chips-3> log_scale(Y_AXIS)
chips-4>
```

```
chips-4> print_window("powerspectrum", "export.format=png export.clobber=yes")
chips-5> pick()
(0.00140183,0.0834193)
chips-6> 1/0.00140183
713.35325966772007
chips-7>
```



Temporal Analysis :: other

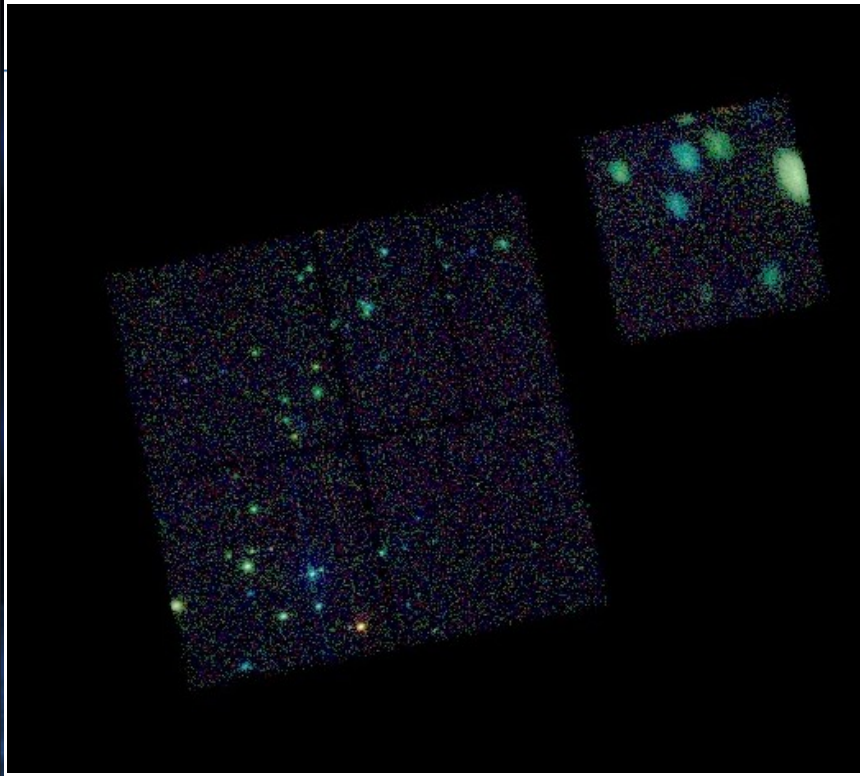
- **axbary** performs barycenter time corrections
- Timing talk will have more examples
  - Contrib. software **sitar** includes specialized timing tasks including period folding & Bayesian blocks decomposition
- Looking ahead
  - **glvary** provides an implementation of the Gregory-Loraedo algorithm to optimally bin lightcurves

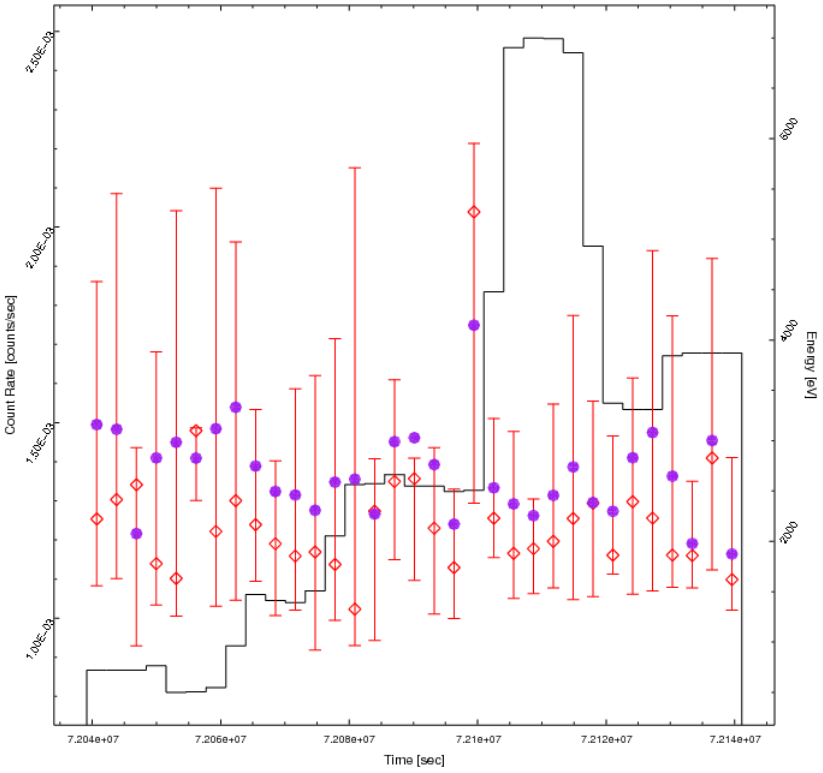
Mixing Axes

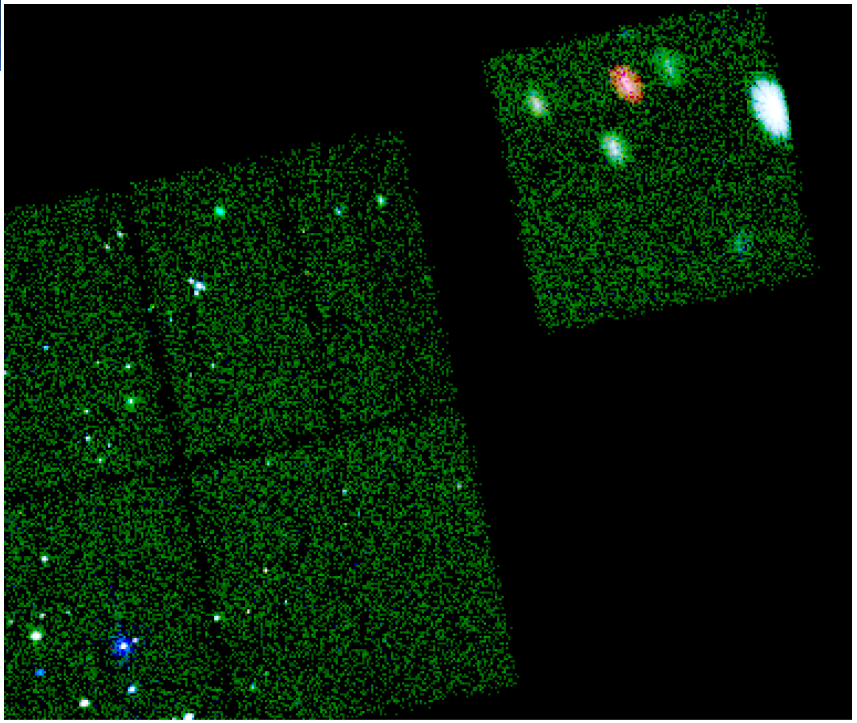
- Examples
  - 3-color coded images
    - Usually see spectrally coded :Soft (red), Medium (green), Hard (blue)
    - But can pick any property, like TIME.
  - Time resolved spectra (including phase resolved spectra)
- Mixed Axes -> Mixed Response
  - When you start to combine axes, you need to be careful about getting correct responses to correctly interpret data.

```
devel18:/data/scidev/staff/kjg/CIAO_Workshop_08
% dmcopy "acisf00635_000N001_evt3.fits[energy=500:1200][bin sky=8]" red.fits
% dmcopy "acisf00635_000N001_evt3.fits[energy=1200:2000][bin sky=8]" grn.fits
% dmcopy "acisf00635_000N001_evt3.fits[energy=2000:7000][bin sky=8]" blu.fits
%
% dmimg2jpg red.fits grn.fits blu.fits out=tricolor1.jpg scalef=log \
?   scalep=5 clob+ showaim- showgrid-
%
```

```
devel18:/data/scidev/staff/kjg/CIAO_Workshop_08
% dmcopy "acisf00635_000N001_evt3.fits[energy=500:1200][bin sky=8]" red.fits
% dmcopy "acisf00635_000N001_evt3.fits[energy=1200:2000][bin sky=8]" grn.fits
% dmcopy "acisf00635_000N001_evt3.fits[energy=2000:7000][bin sky=8]" blu.fits
%
% dmimg2jpg red.fits grn.fits blu.fits out=tricolor1.jpg scalef=log \
?   scalep=5 clob+ showaim- showgrid-
%
%
%
% dmcopy "acisf00635_000N001_evt3.fits[bin sky=8,time=::#3]" vary.fits
%
% ds9 -rgbcube vary.fits
```

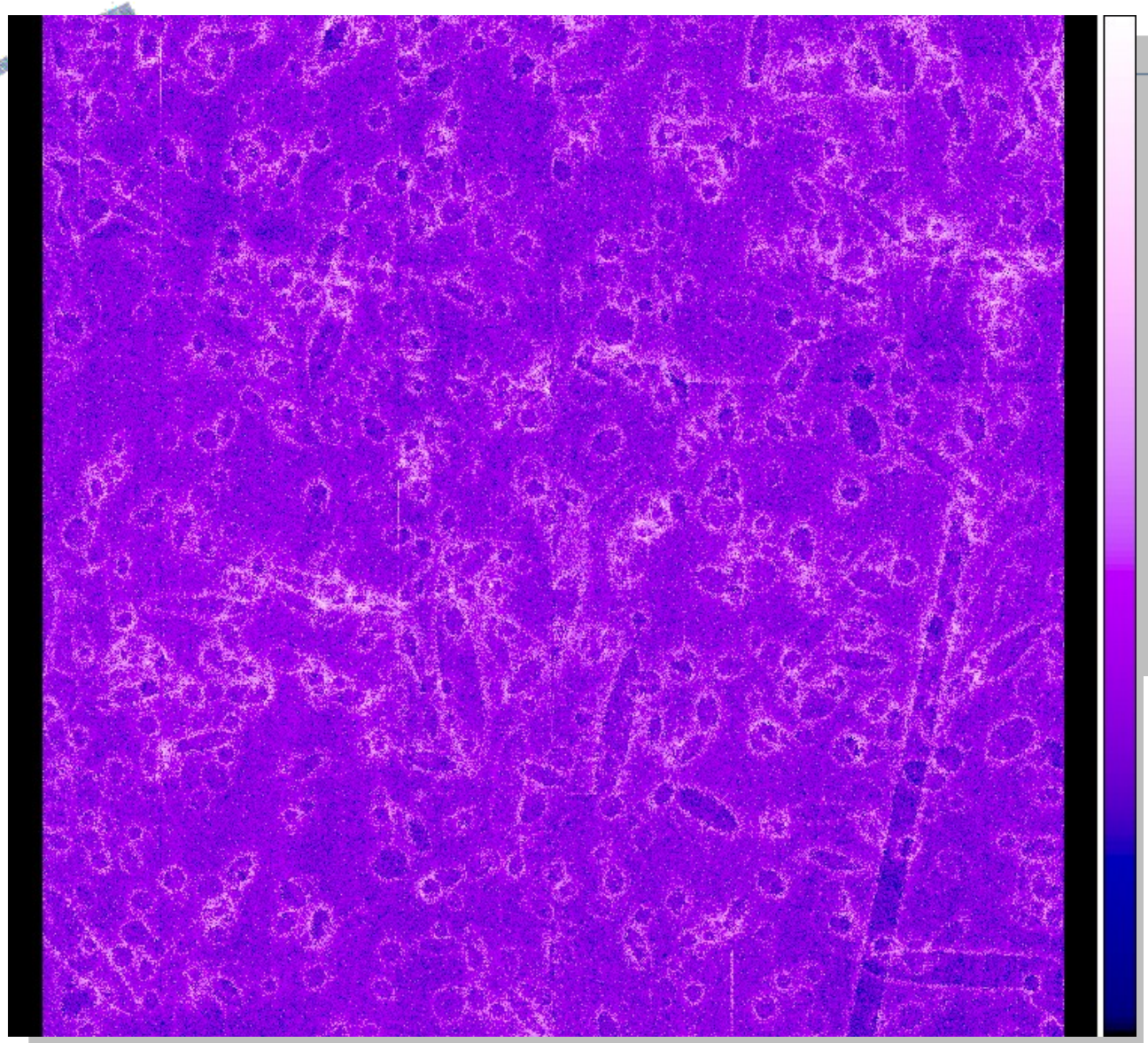


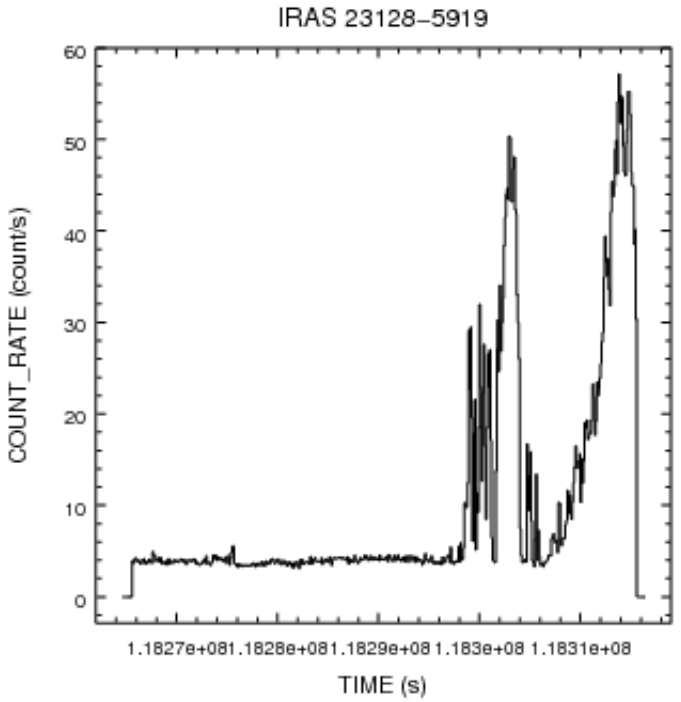


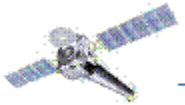


Background

- Spatial
  - Cosmic has vignetting effects
  - Instrumental is 'flat'; though not so due to CTI
  - Typically pick co-located annulus around point src
- Spectral
  - quiescent well calibrated in background files
  - during flares may be hard or soft and affect FI/BI chips differently.
  - Be sure to filter observation same as background files
- Temporal
  - many early observations near solar max have some enhanced periods
  - **lc_clean** script (contrib tar file) can be used to remove flares.




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



Shameless Self Promotion

- Help us to help you!
  - Report problems
  - Give us feedback, +/-
  - More later, be sure to provide as much info, not just "*it doesn't work*"
- Acknowledgment
  - Most Chandra papers don't acknowledge CIAO, CDA, etc.
  - Many don't reference any software package at all.

Questions?