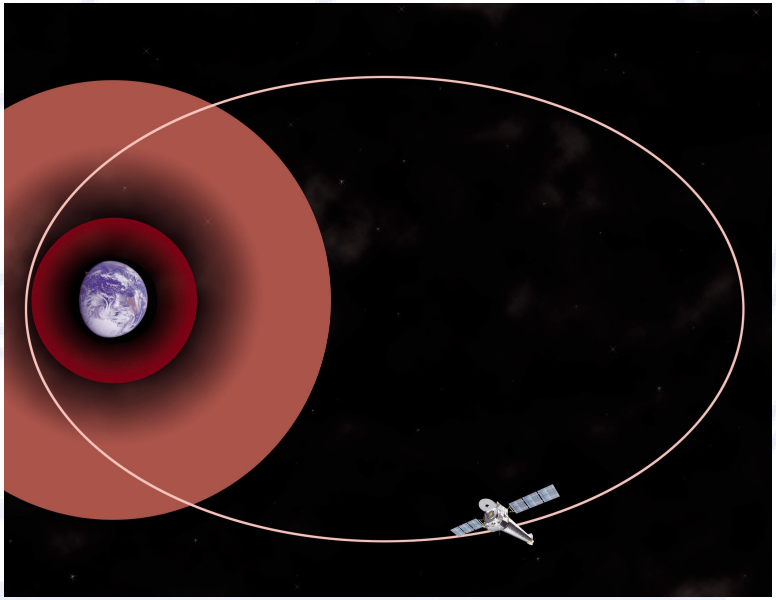
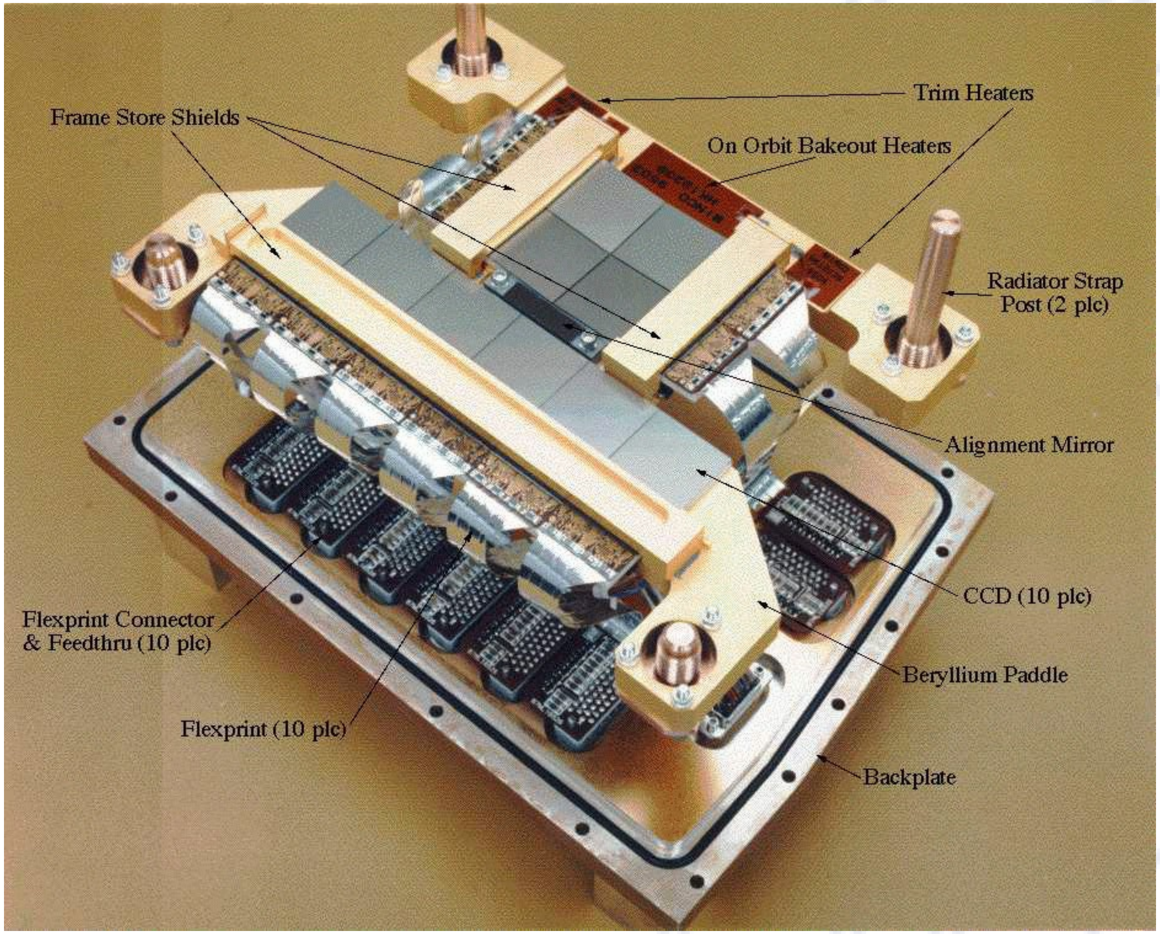
Did you know Chandra & CIAO do this?

Chandra X-ray Observatory

•Launched in 1999 on STS 93 (Columbia)
•Sensitive to energies from 0.1 to 10.0 keV
•Has a spatial resoltuion better than 0.5" thanks to the 4 pairs of nested grazing incident paraboloid/hyperboloid mirror pairs.
•Two science instruments: CCD imager and microchannel plate, either of which can be used with either of the transmission gratings.
•Orbits 200 times higher than HST, traveling 1/3 the way to the Moon.

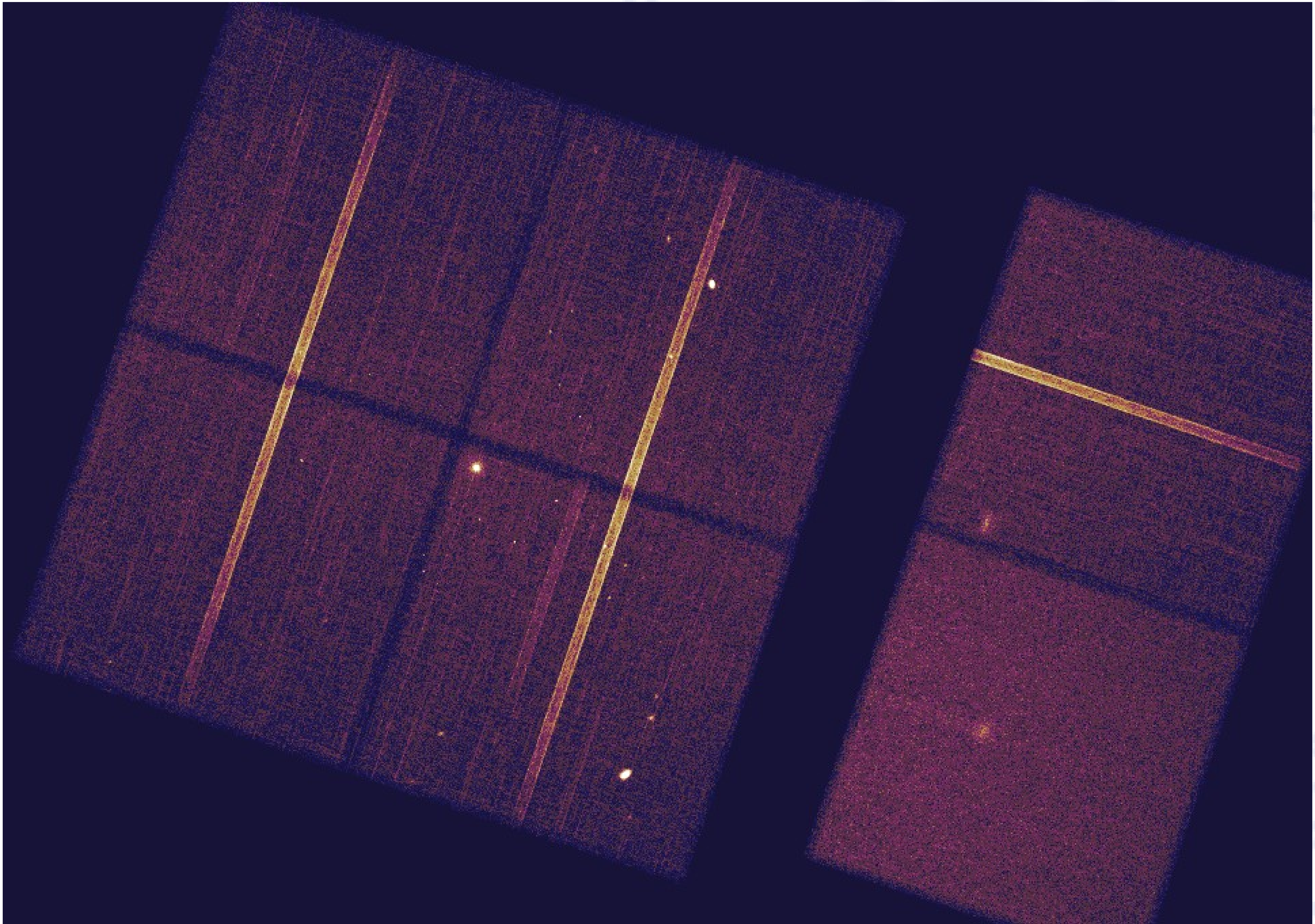


Detectors : ACIS

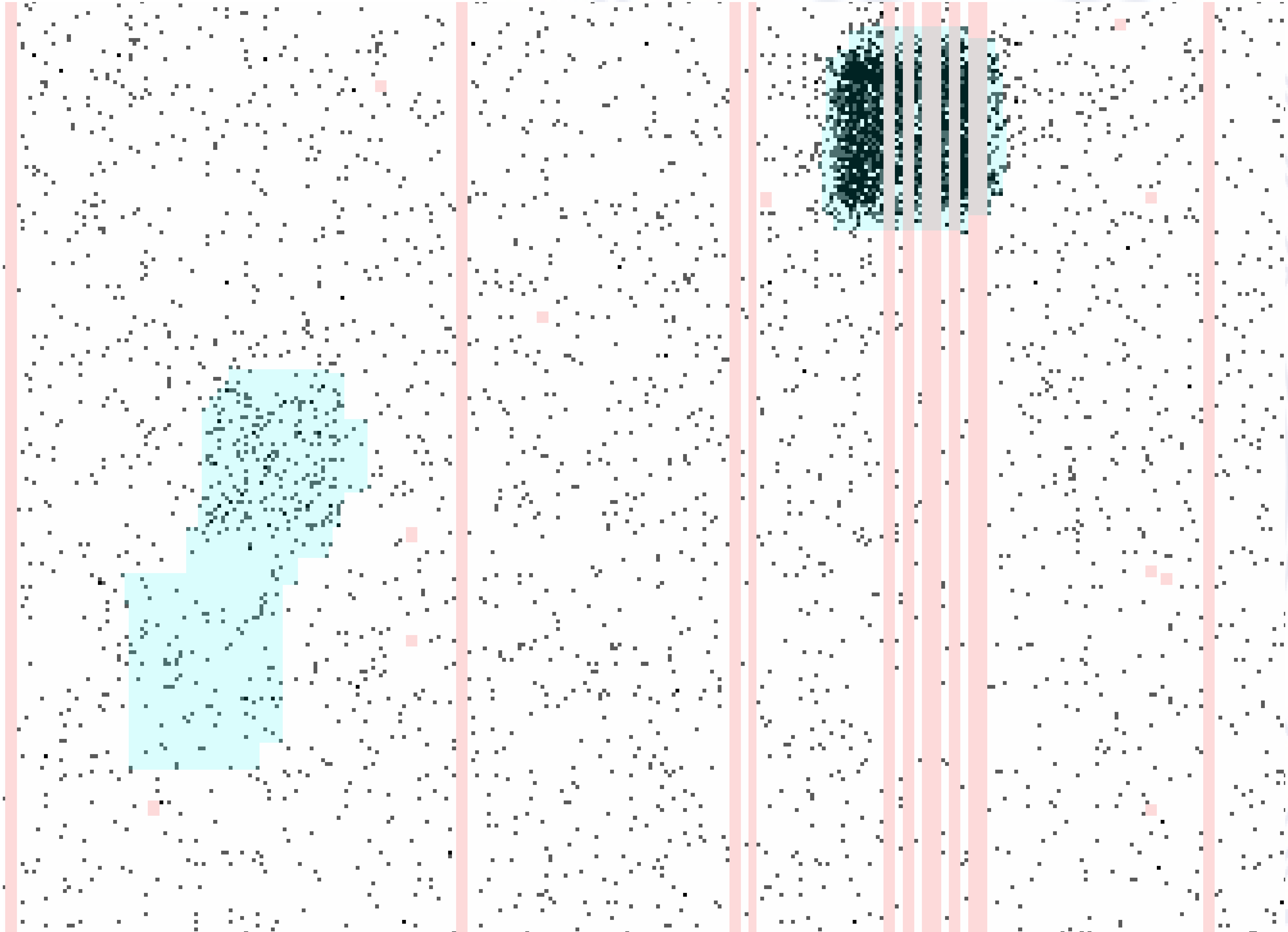


•Most popular instrument is the Advanced CCD Imaging Spectrometer, ACIS.
•Array of 10 CCDs, any 6 of which may be used together.
•Imaging array is tiled to follow the focal surface of the HRMA
•Spectrocopy array is tiled to follow the Rowland circle to optimize grating line spread.
•Intrinsic spectral resolution allows for joint spectral, spatial, and timing analysis.

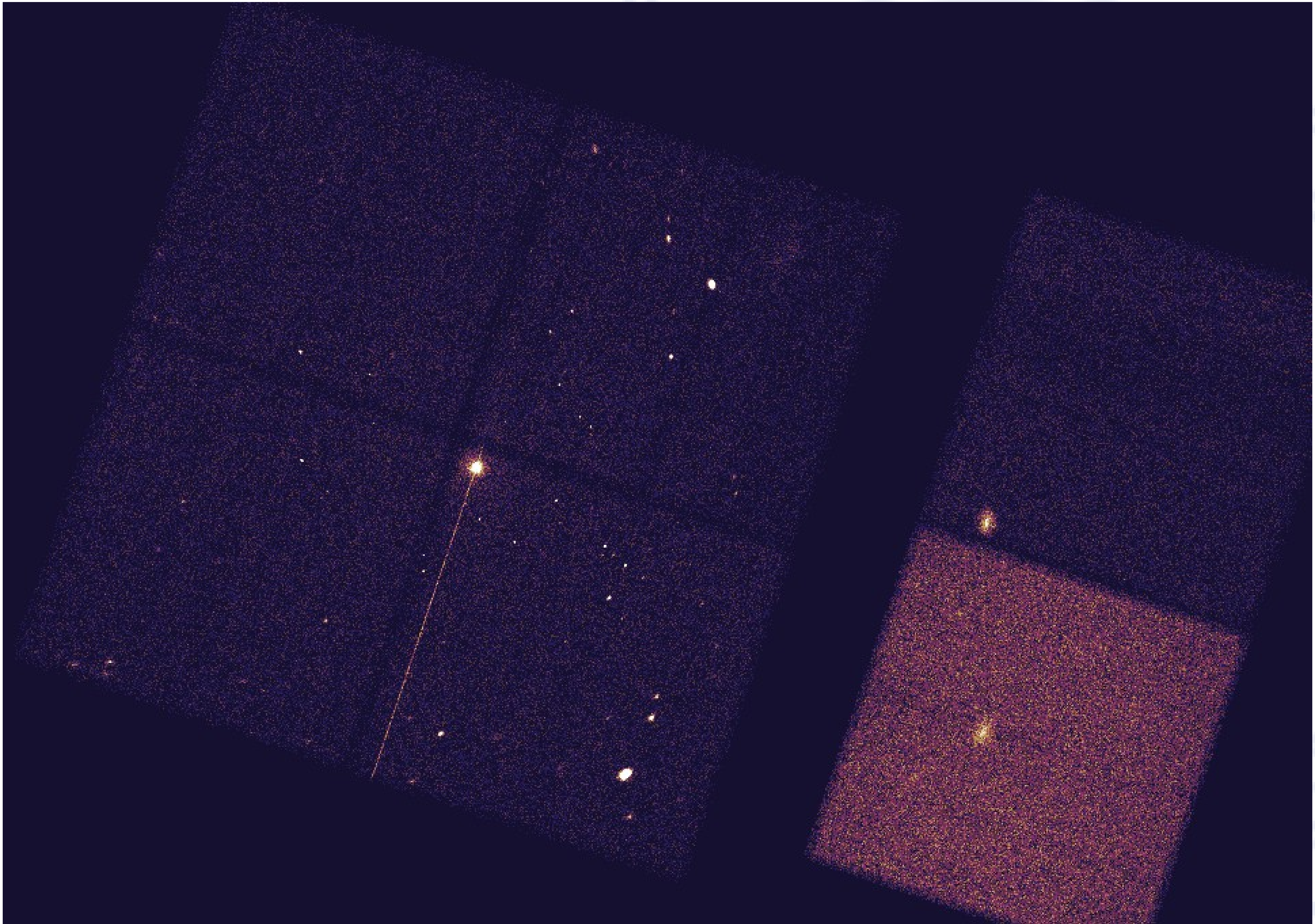
Level 1 Events – unfiltered



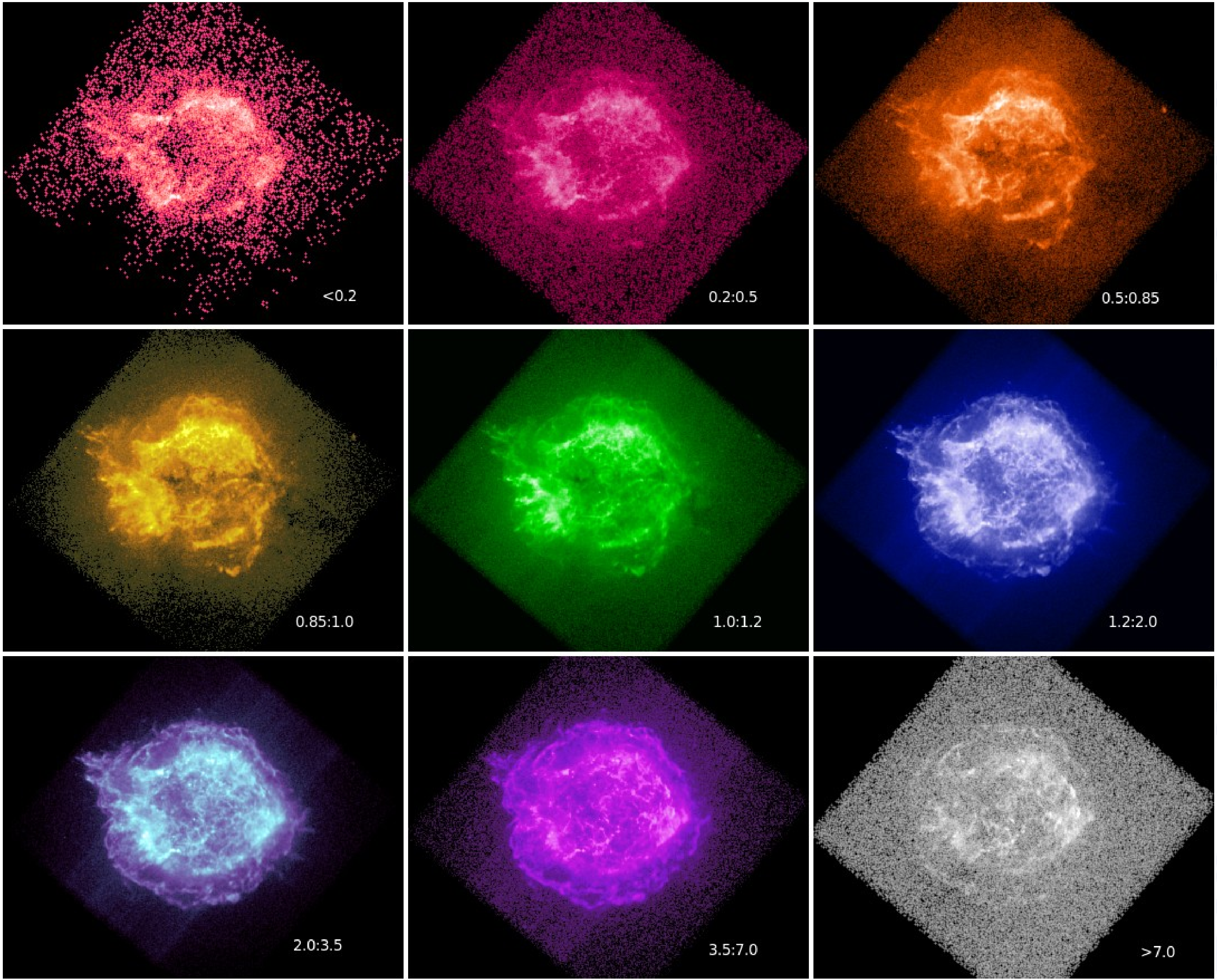
Chip Coordinates, Bad pixels



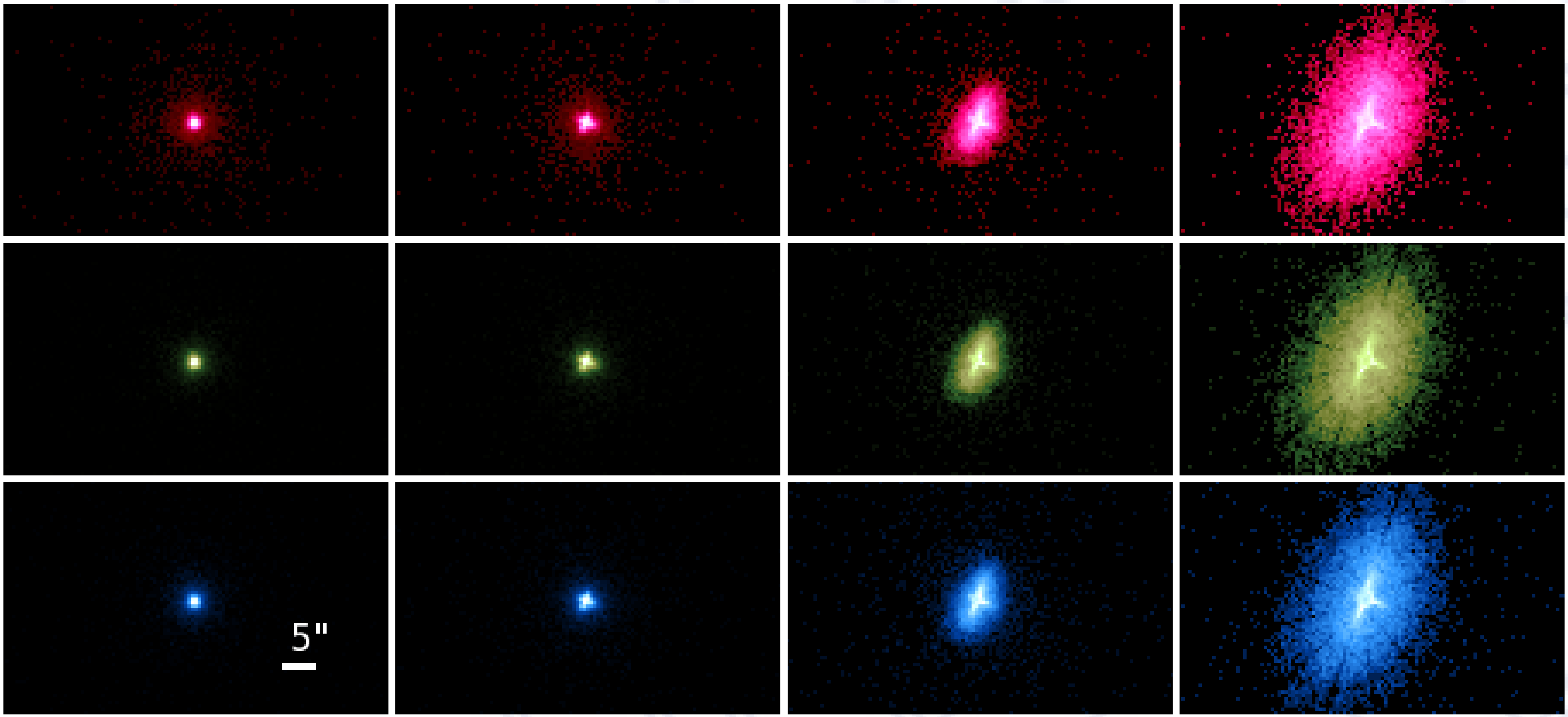
Level 2 Events



Cassiopeia A with ACIS

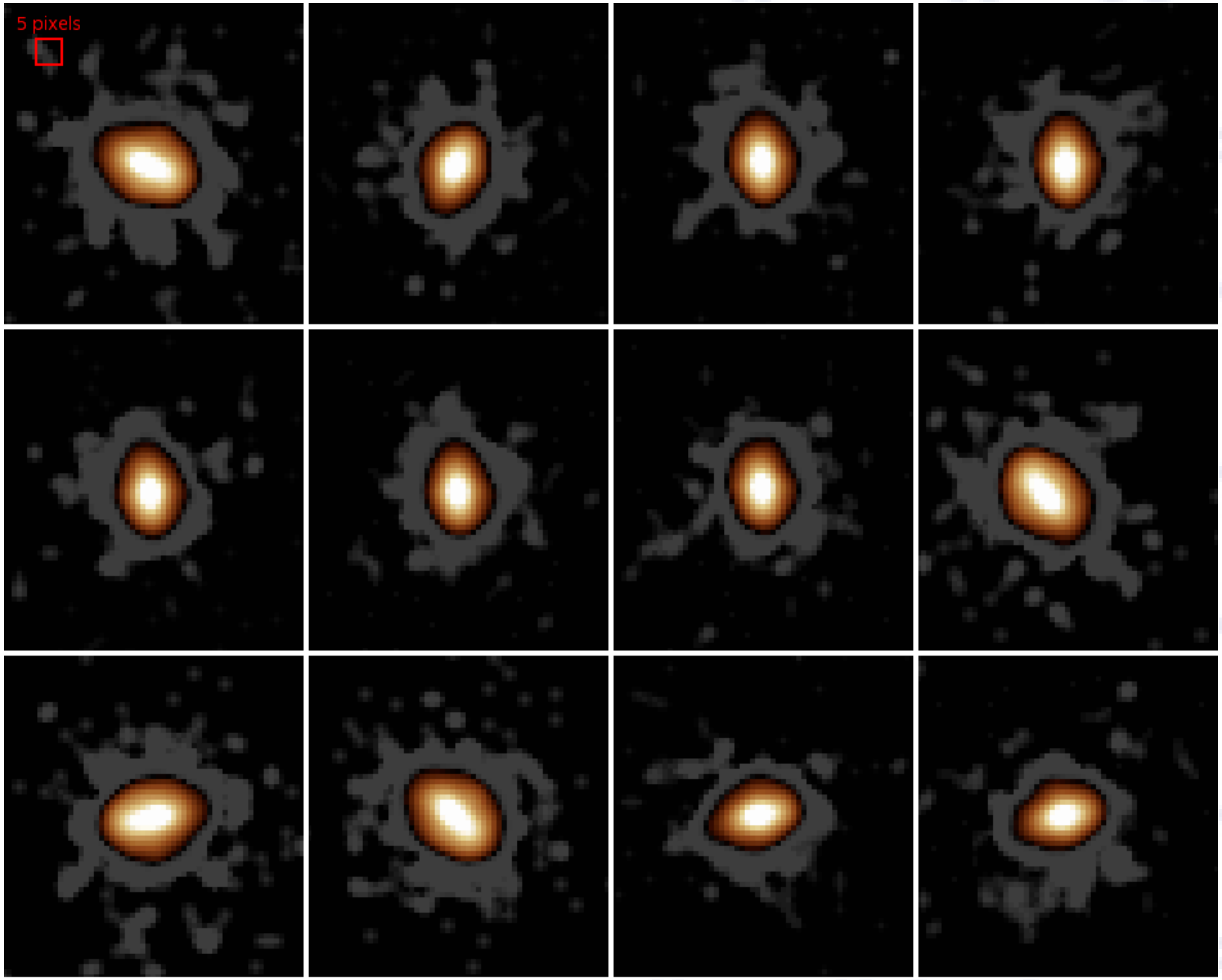


Chandra PSF



The Chandra PSF varies with energy and location relative to the optical axis. Shown are simulated PSFs at 0.92 keV (red, top row), 1.56 keV (green, center row), and 3.8 keV (bottom row). From left-to-right the PSF is simulated on-axis (left), 1', 2', and 5' (right) away from the optical axis.

PSF observed by ACIS



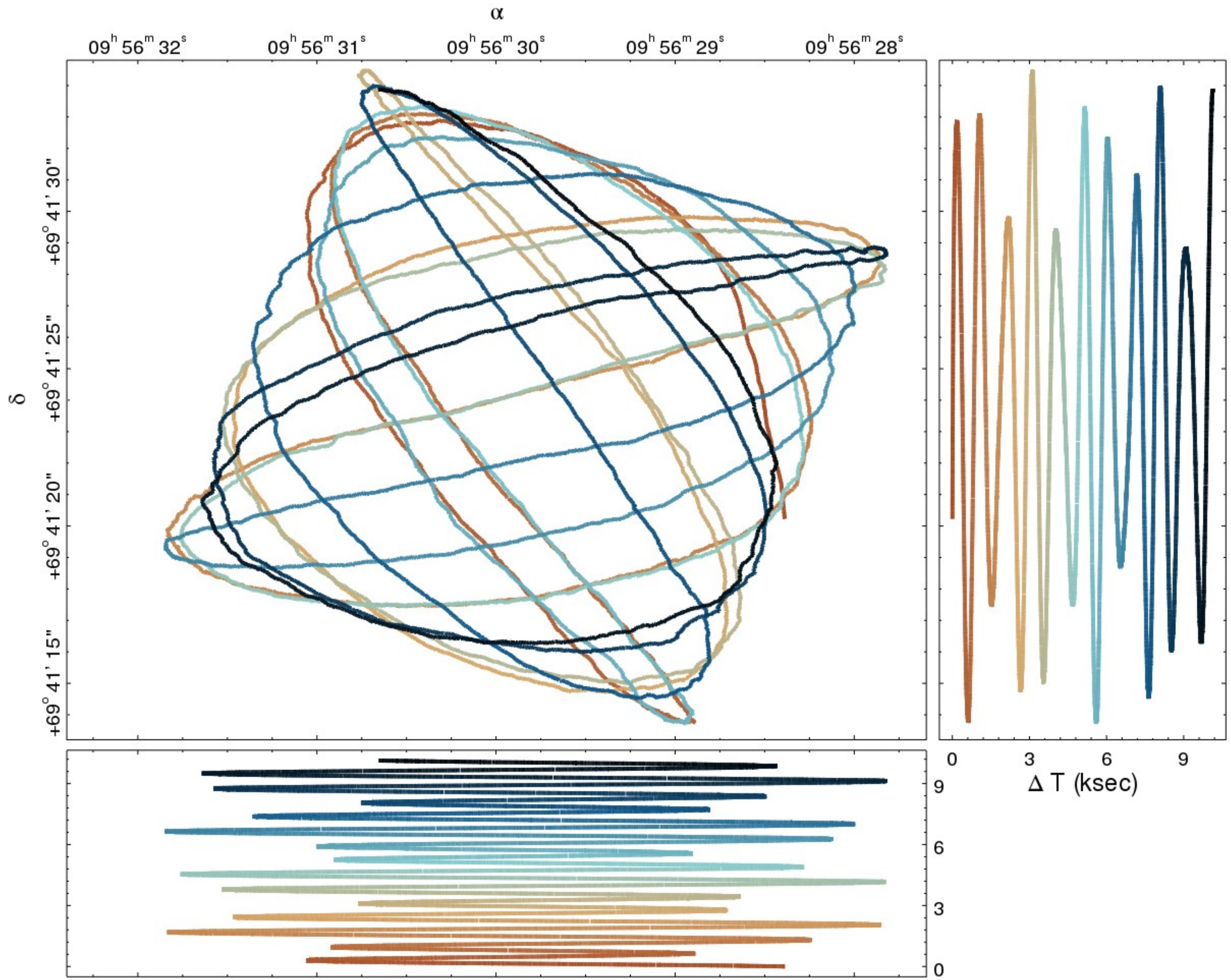
The PSF observed by the instrument varies.

Shown here are 12 examples of PSFs at 5' off-axis with various locations azimuthal around the optical axis, with different detector/SIM configuration, and with different spacecraft ROLL angle.

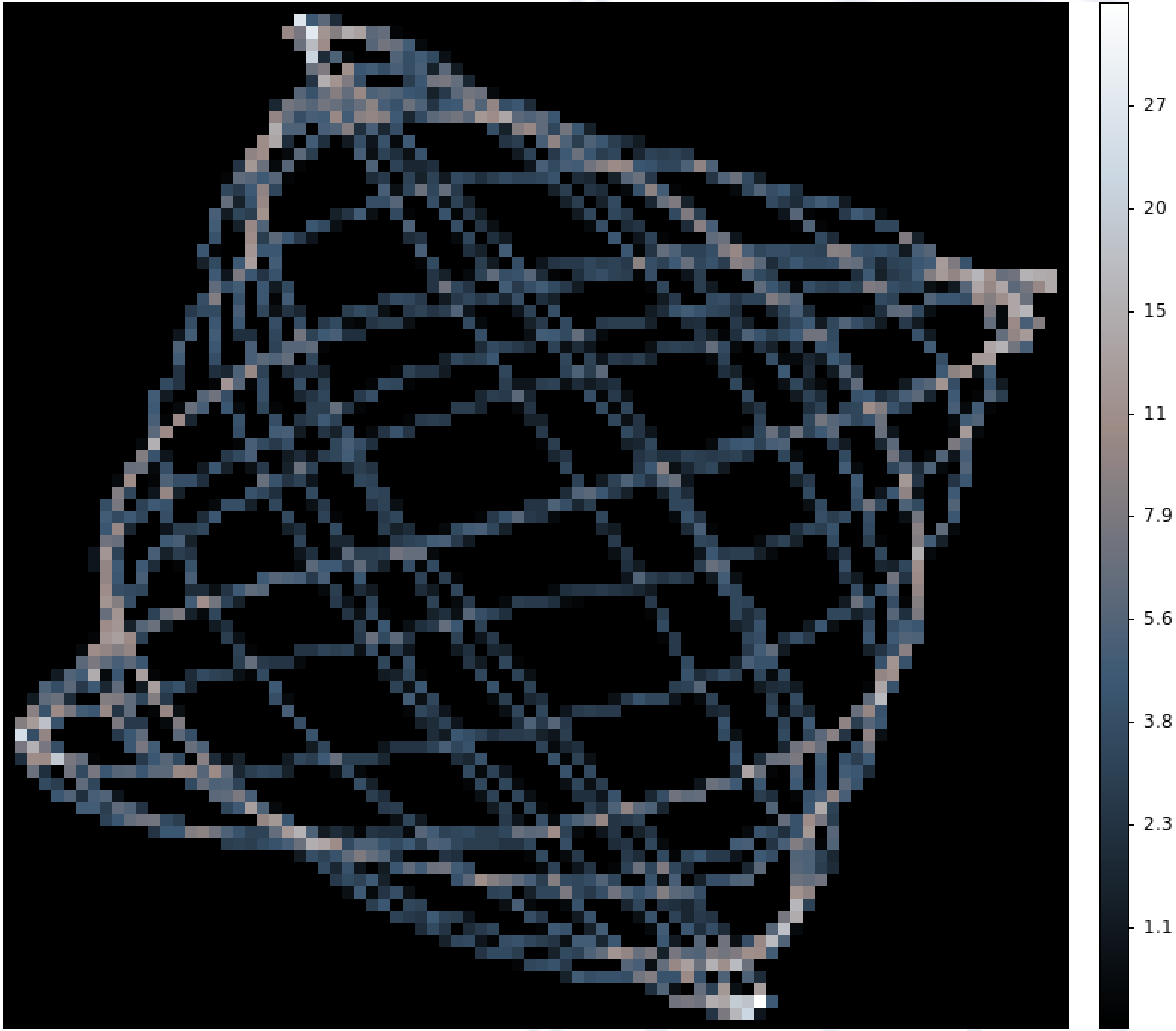
The ROLL of the spacecraft means that a point source observed in one observation may look different in another.

The shape of the PSF also varies due to the tilts of the ACIS CCDs and where the SIM is positioned.

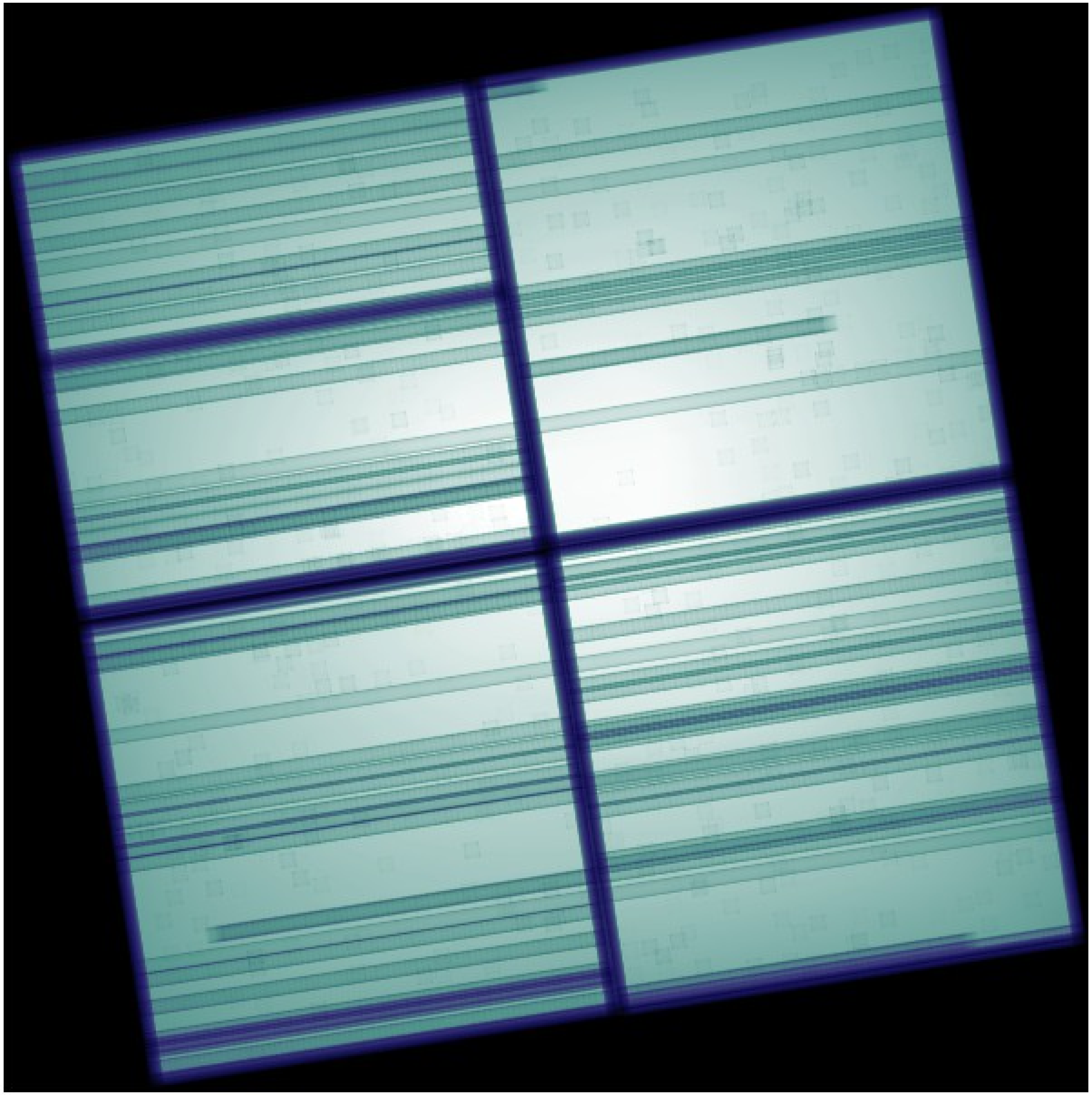
Aspect


α
09h 56m 32s
09h 56m 31s
09h 56m 30s
09h 56m 29s
09h 56m 28s
δ
+69° 41' 30"
+69° 41' 25"
+69° 41' 20"
+69° 41' 15"
0
3
6
9
Δ T (ksec)

Aspect Histogram



Exposure Time



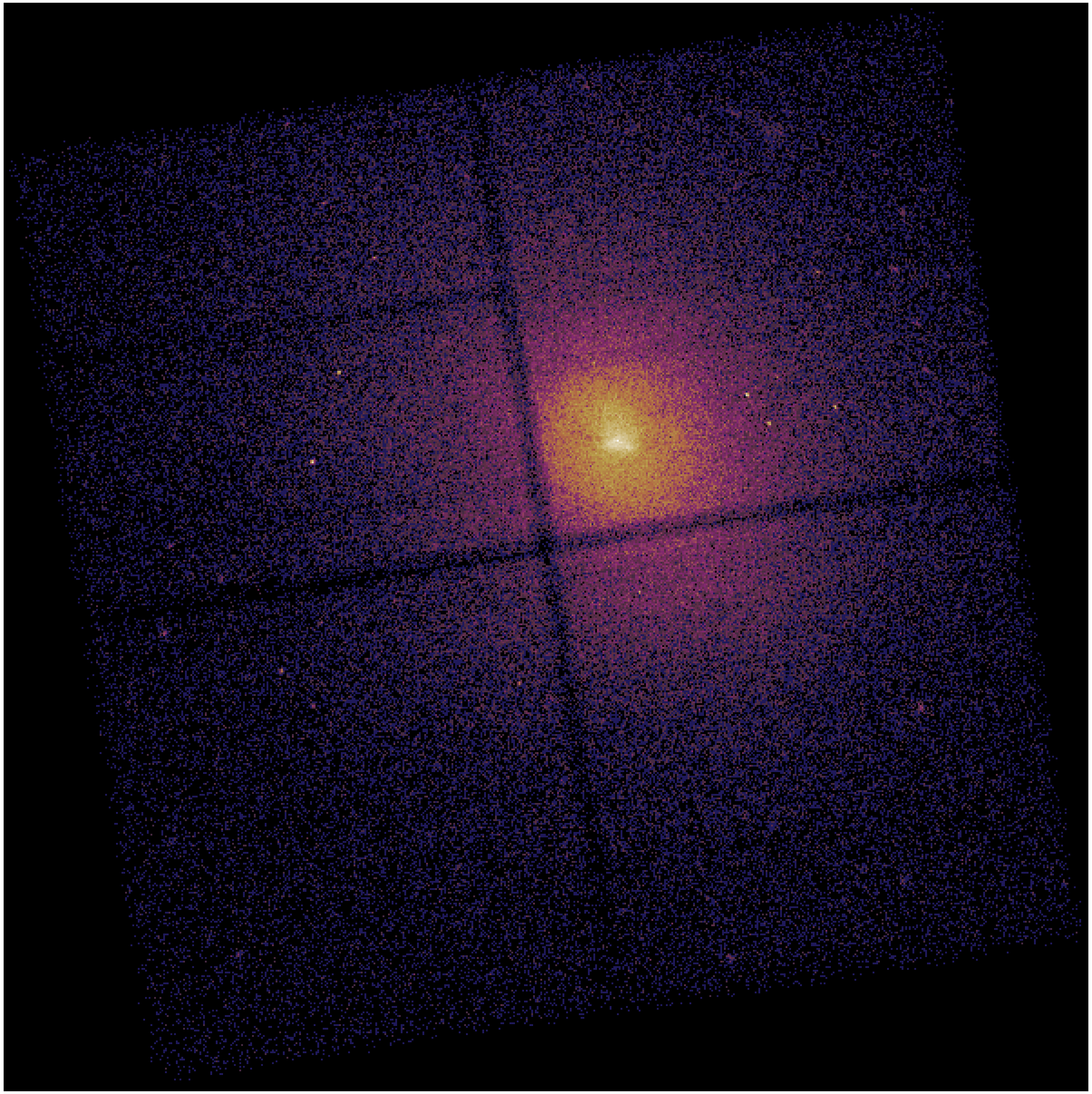
Chandra Exposure maps are the result of taking the product of the instrumental and mirror responses and convolving it with the pointing history (aspect histogram) and therefore have units of cm^2 sec.

Shown is the combined exposure map for the 4 ACIS-I chips.

The gaps between the chips are visible as are several bad columns and individual bad pixels.

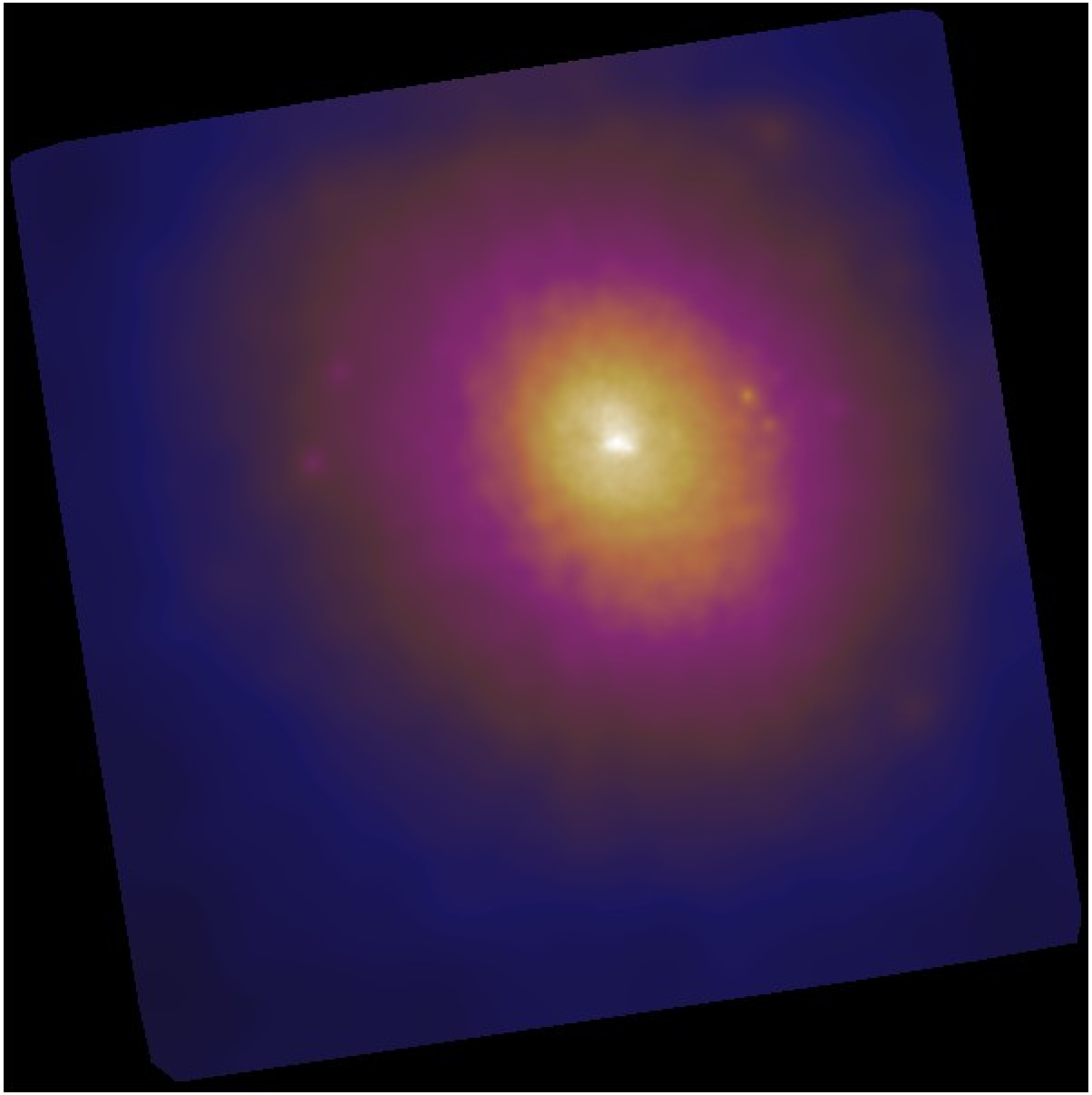
The size of the dither was chosen to fill-in the chip gaps with at least some exposure.

Observed Image



Counts image of 0.5 to 7.0 keV image of Abell 2199, ObsID 10805.

Exposure Corrected

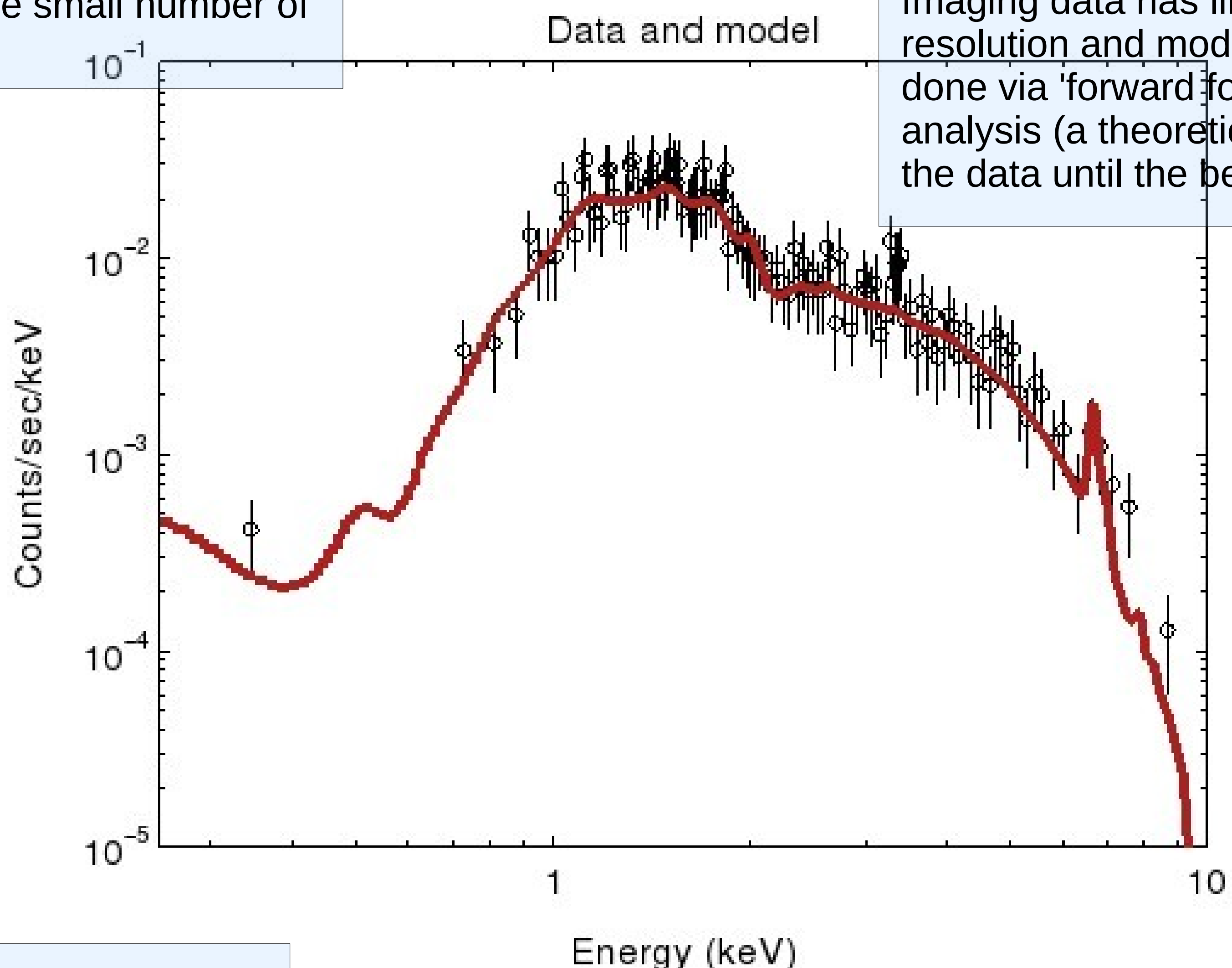


Data corrected for the exposure variation and slightly smoothed.

Observed Spectrum

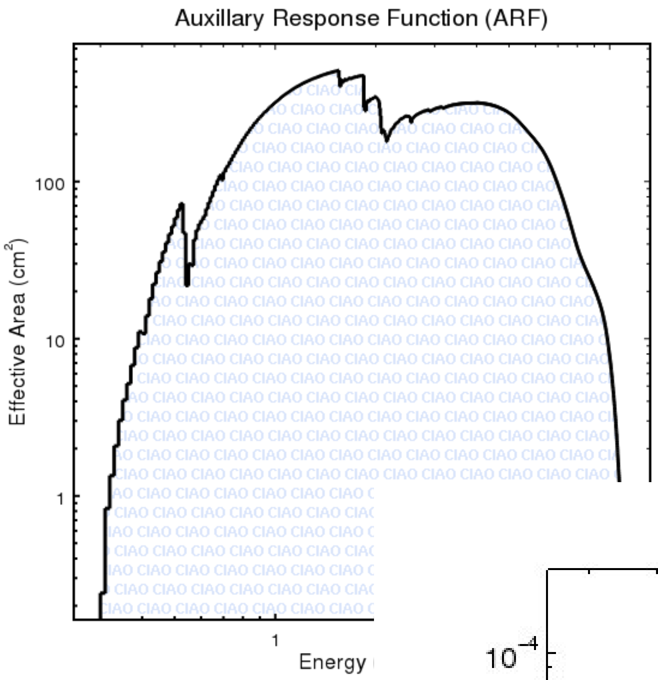
In Poisson statistics regime because of the small number of photons

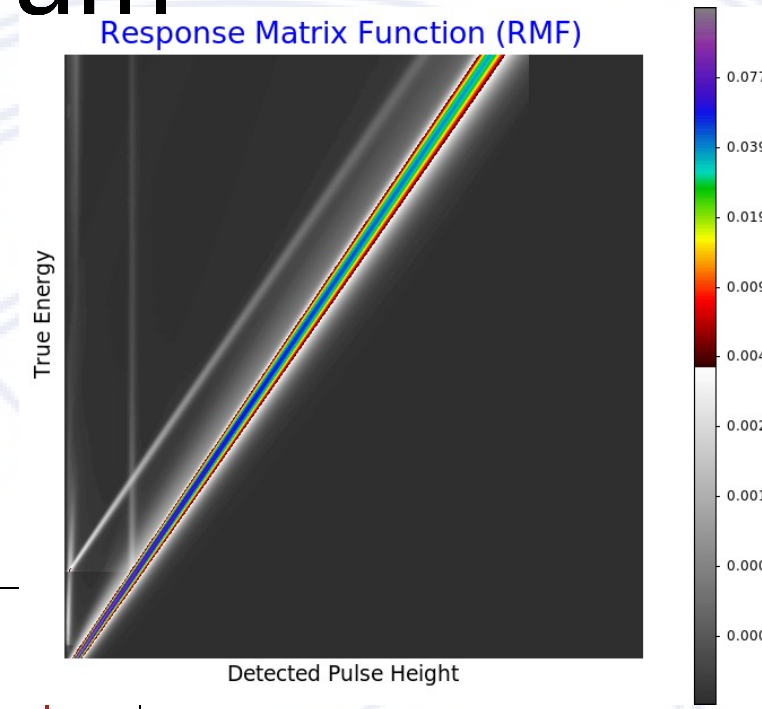
Imaging data has limited energy resolution and modeling can only be done via 'forward folding' spectral analysis (a theoretical model is fitted to the data until the best fit is found)

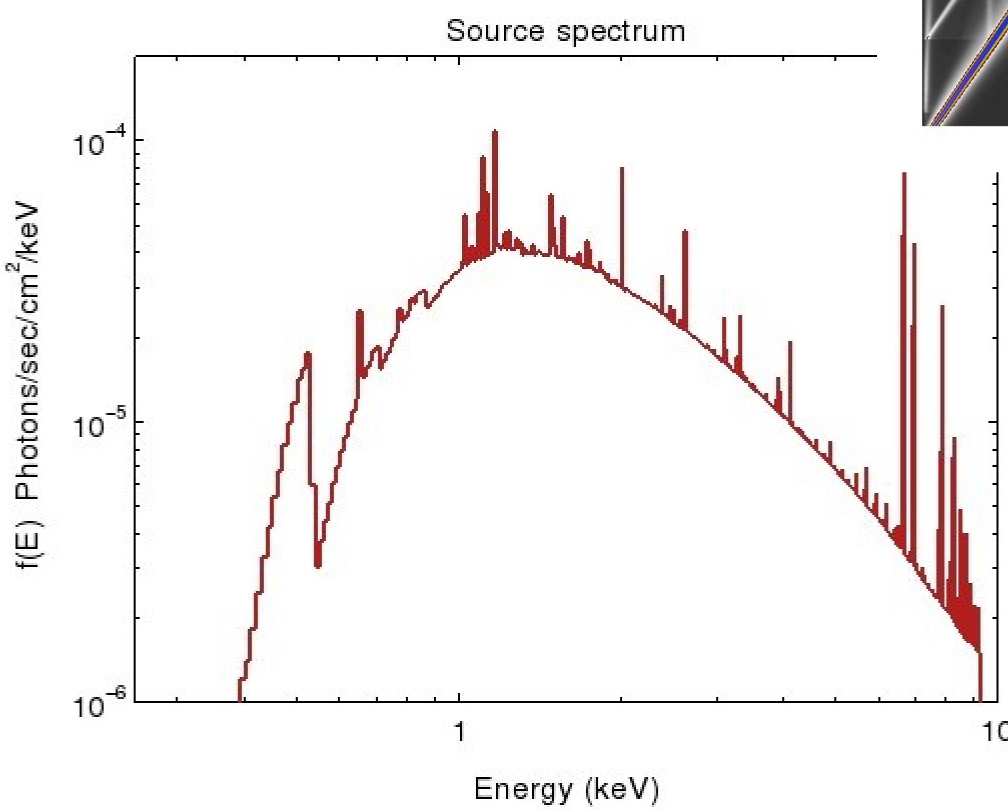


2 decades of photon energy

Model Spectrum







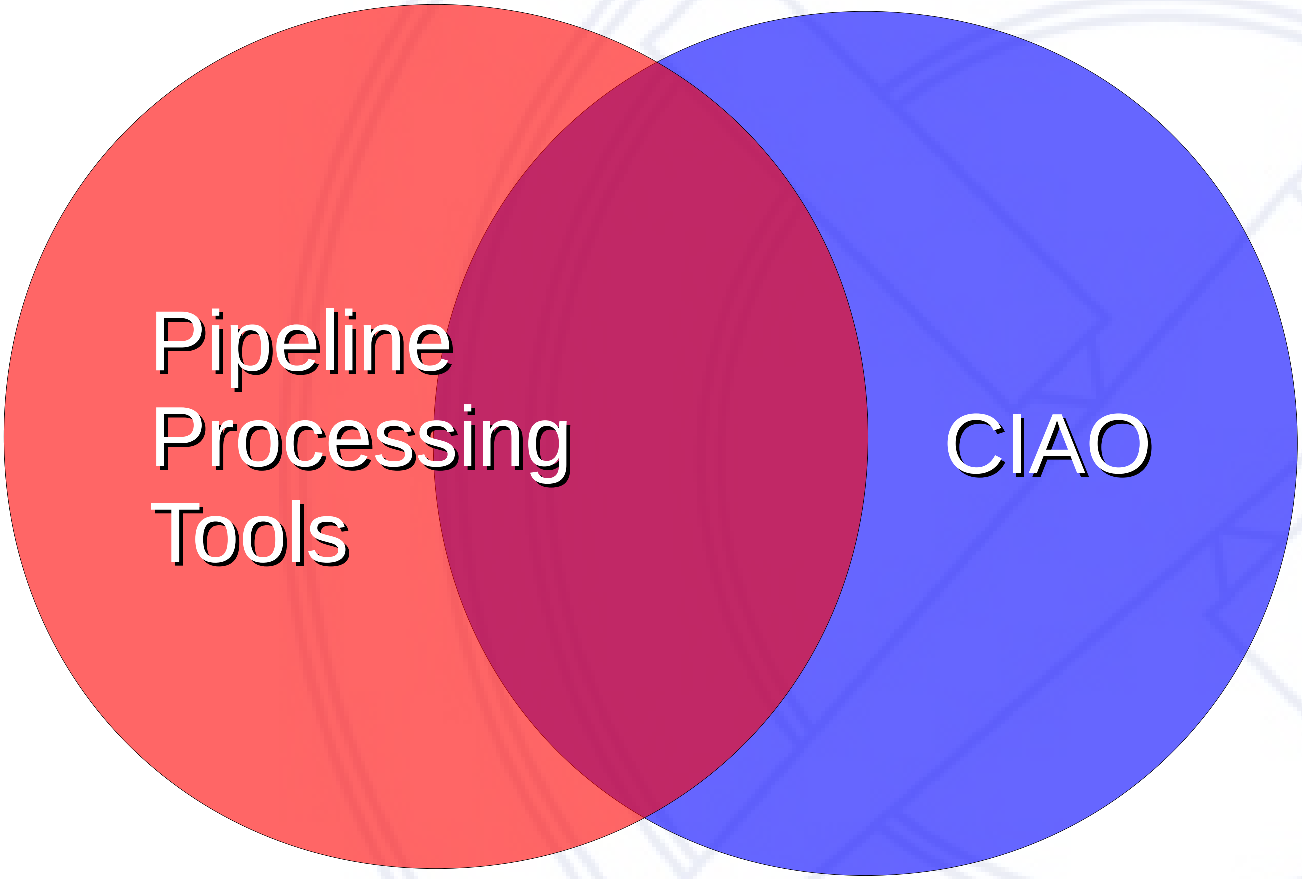
CIAO

Chandra Interactive Analysis of Observations

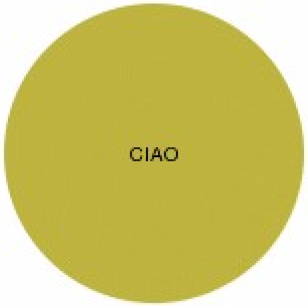
A set of tools and applications written to allow users to analyze the complex, heterogeneous Chandra datasets.

Many tools are generic and used with other programs.

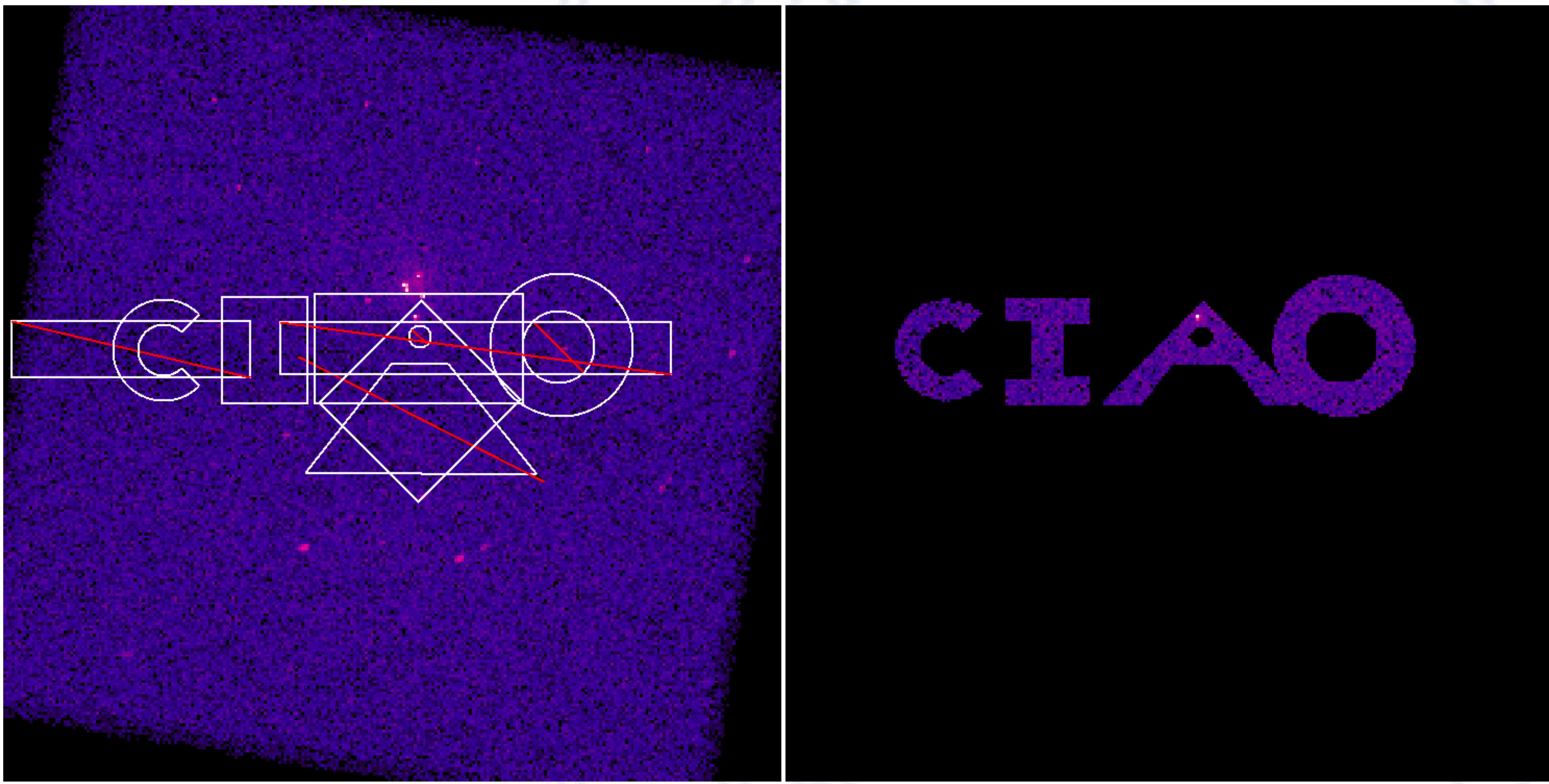
CIAO uses the same tools as Pipeline Processing



Tools and Scripts built on reusable core libraries

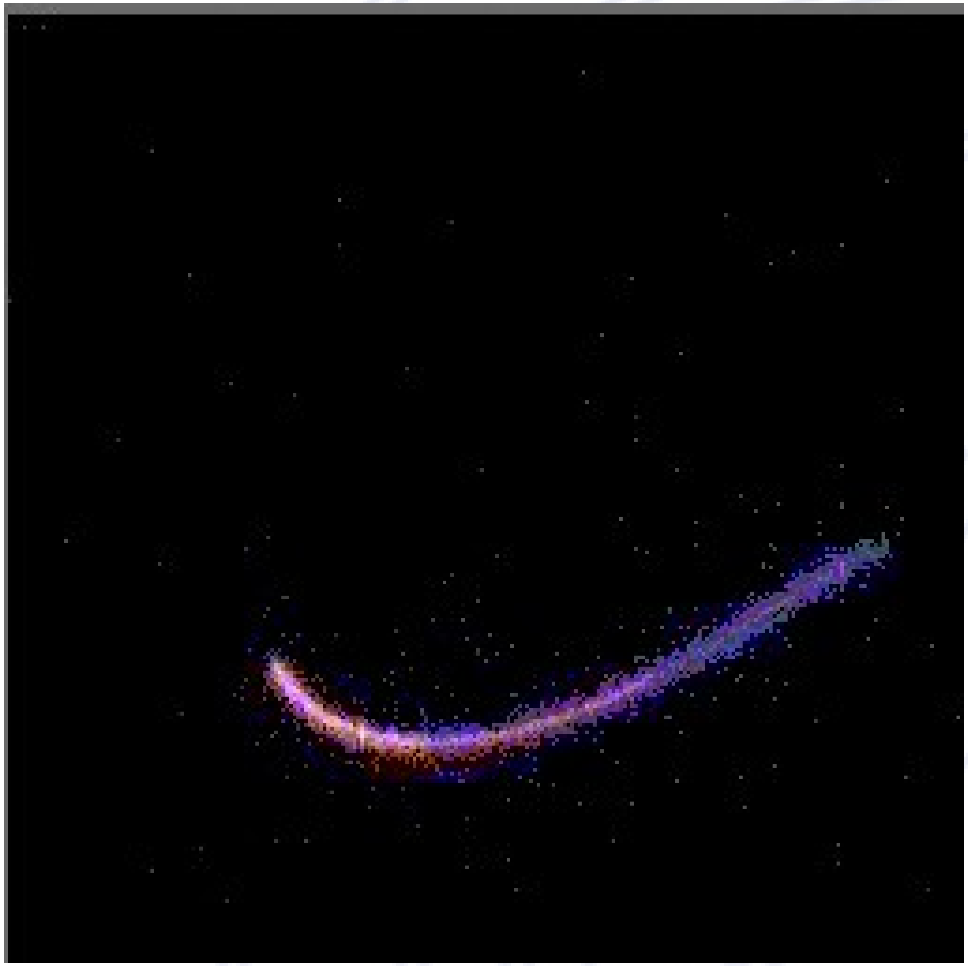


CIAO supports complex regions



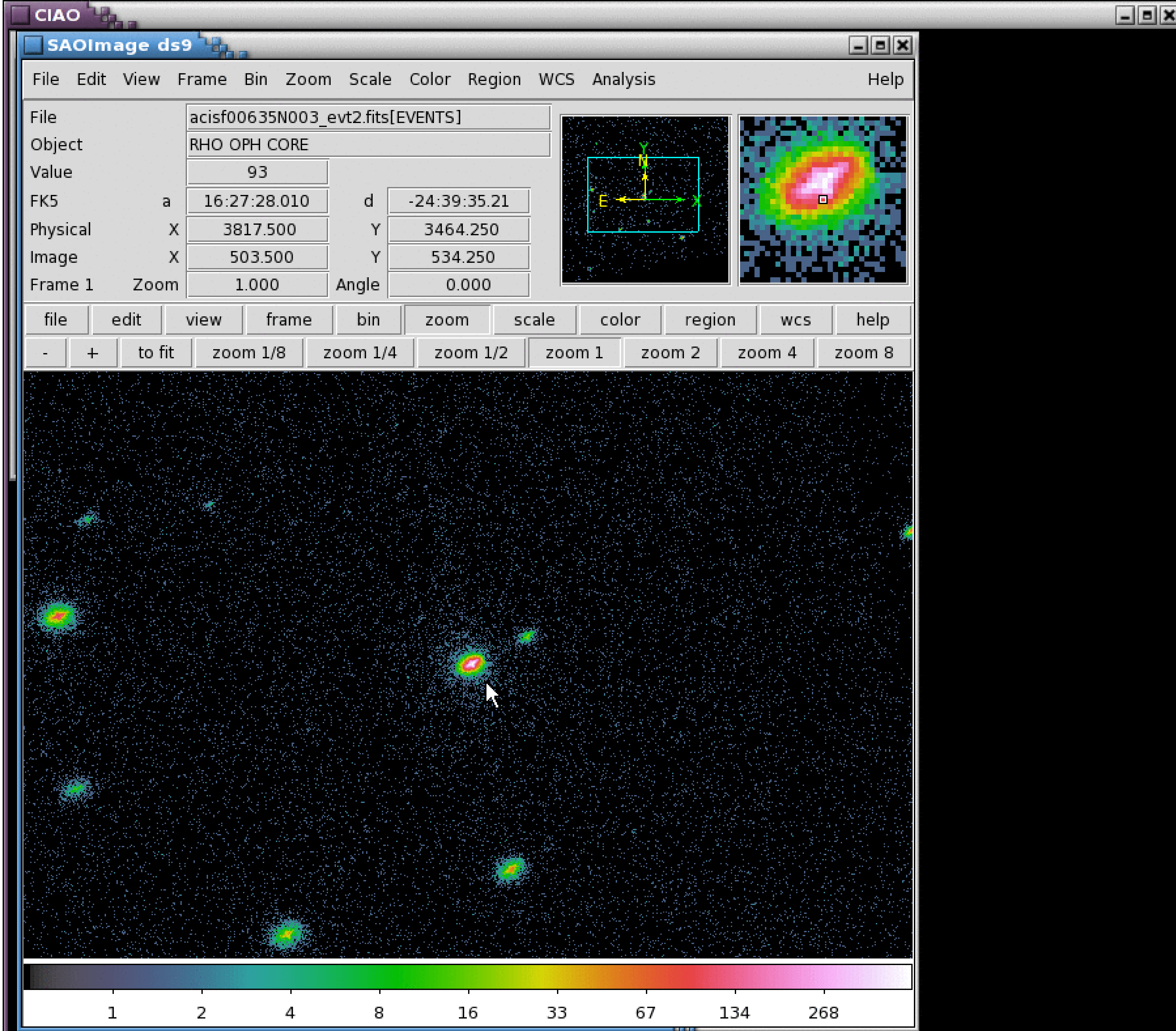
Uses logical AND, OR, and NOT operations to allow arbitrary control over overlaping regions.

CIAO supports higher dimension datasets



An HRC observation of Capella in CHIP coordinates. The 3D datacube has been smoothed with the ***aconvolve*** tool along the time axis.

CIAO can be run from within ds9.



CIAO
SAOImage ds9
File Edit View Frame Bin Zoom Scale Color Region WCS Analysis Help
File acisf00635N003_evt2.fits[EVENTS]
Object RHO OPH CORE
Value 93
FK5 a 16:27:28.010 d -24:39:35.21
Physical X 3817.500 Y 3464.250
Image X 503.500 Y 534.250
Frame 1 Zoom 1.000 Angle 0.000
file edit view frame bin zoom scale color region wcs help
- + to fit zoom 1/8 zoom 1/4 zoom 1/2 zoom 1 zoom 2 zoom 4 zoom 8
1 2 4 8 16 33 67 134 268

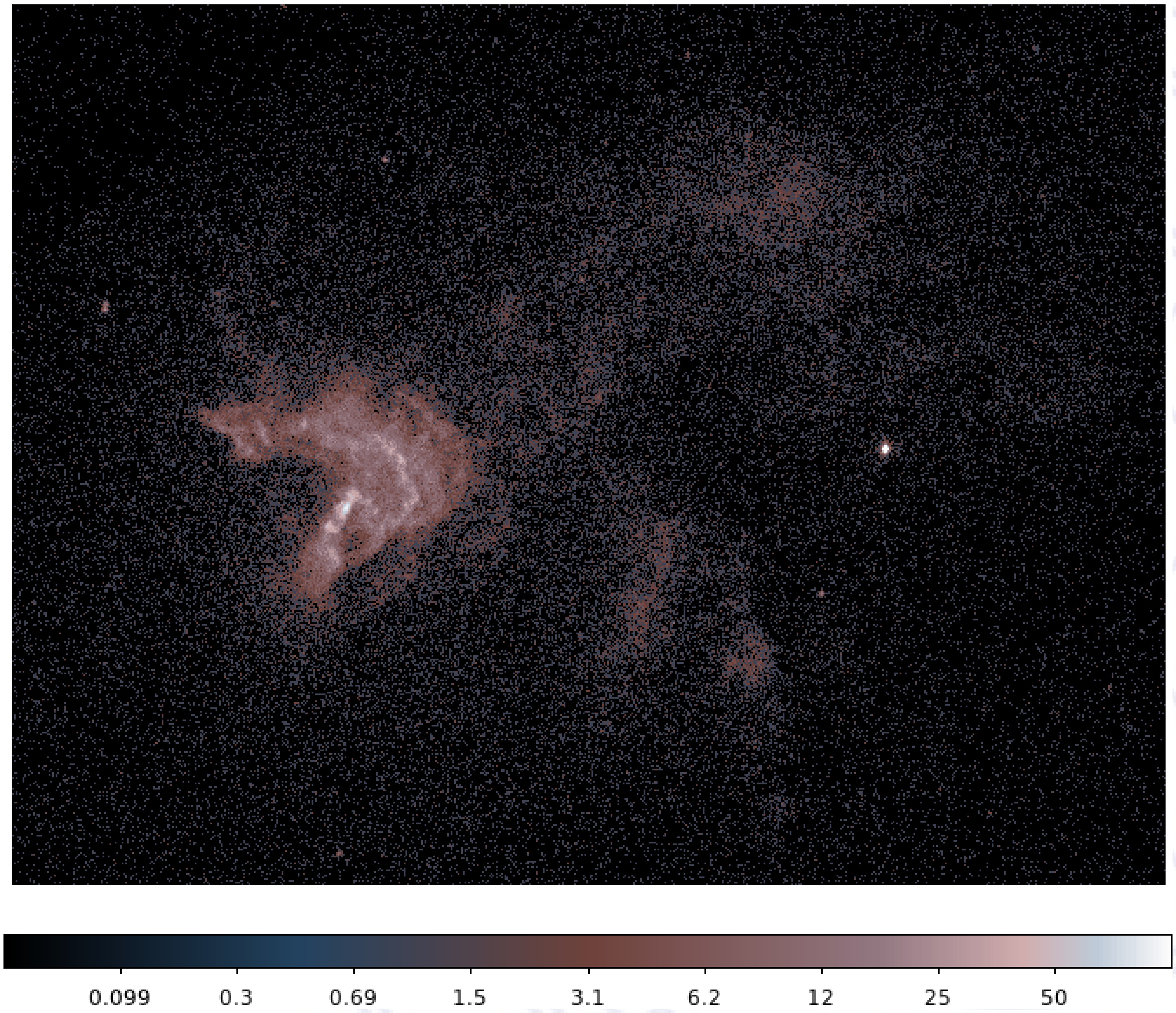
Help is available when prompted

File Edit View Terminal Tabs Help

```
% dmcoords
Input dataset/block specification (): ?
SUBJECT(dmcoords)                                                    CONTEXT(tools)


PARAM infile


    type=file
    filetype=input
    reqd=yes

    Input file, or dm defined virtual file

    dmcoords uses the file header to initialize the configuration. You
    can enter 'none' and set up the configuration from the parameters.
Input dataset/block specification (?): 
```

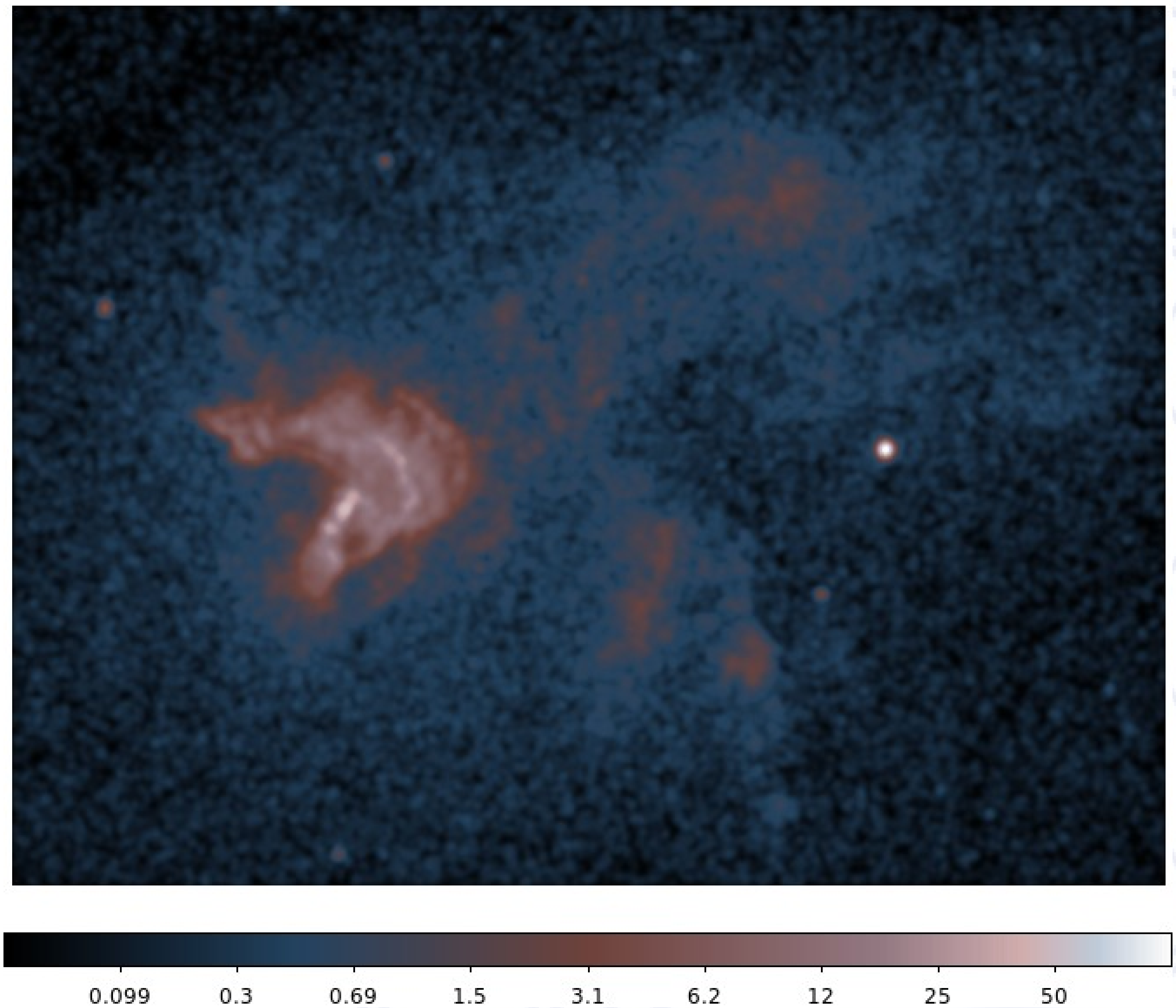
Gallery: Image Processing

Broad band counts image



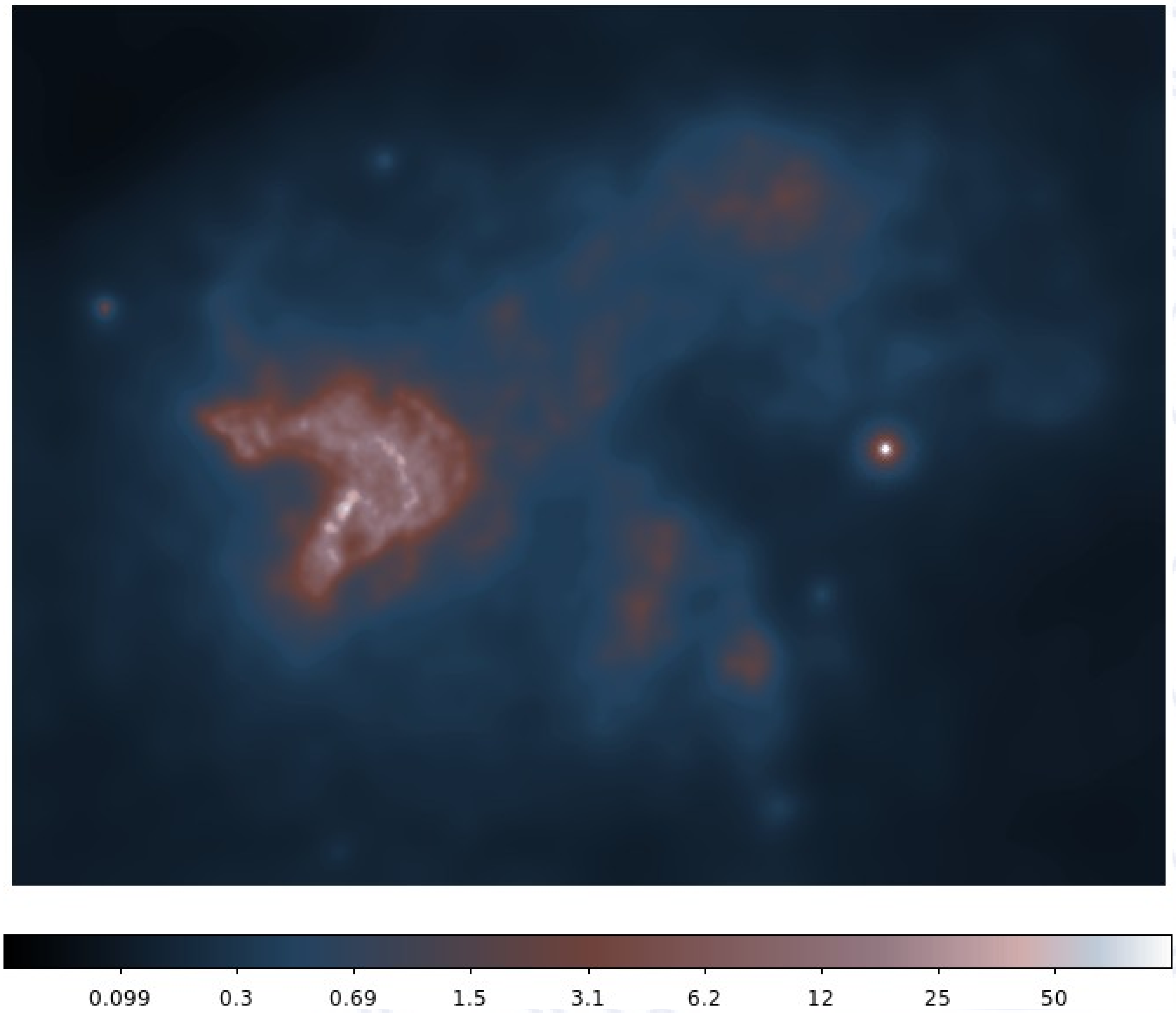
Broad band counts image for SNR G350.1-0.3, OBS_ID 10102

aconvolve: linear smoothing



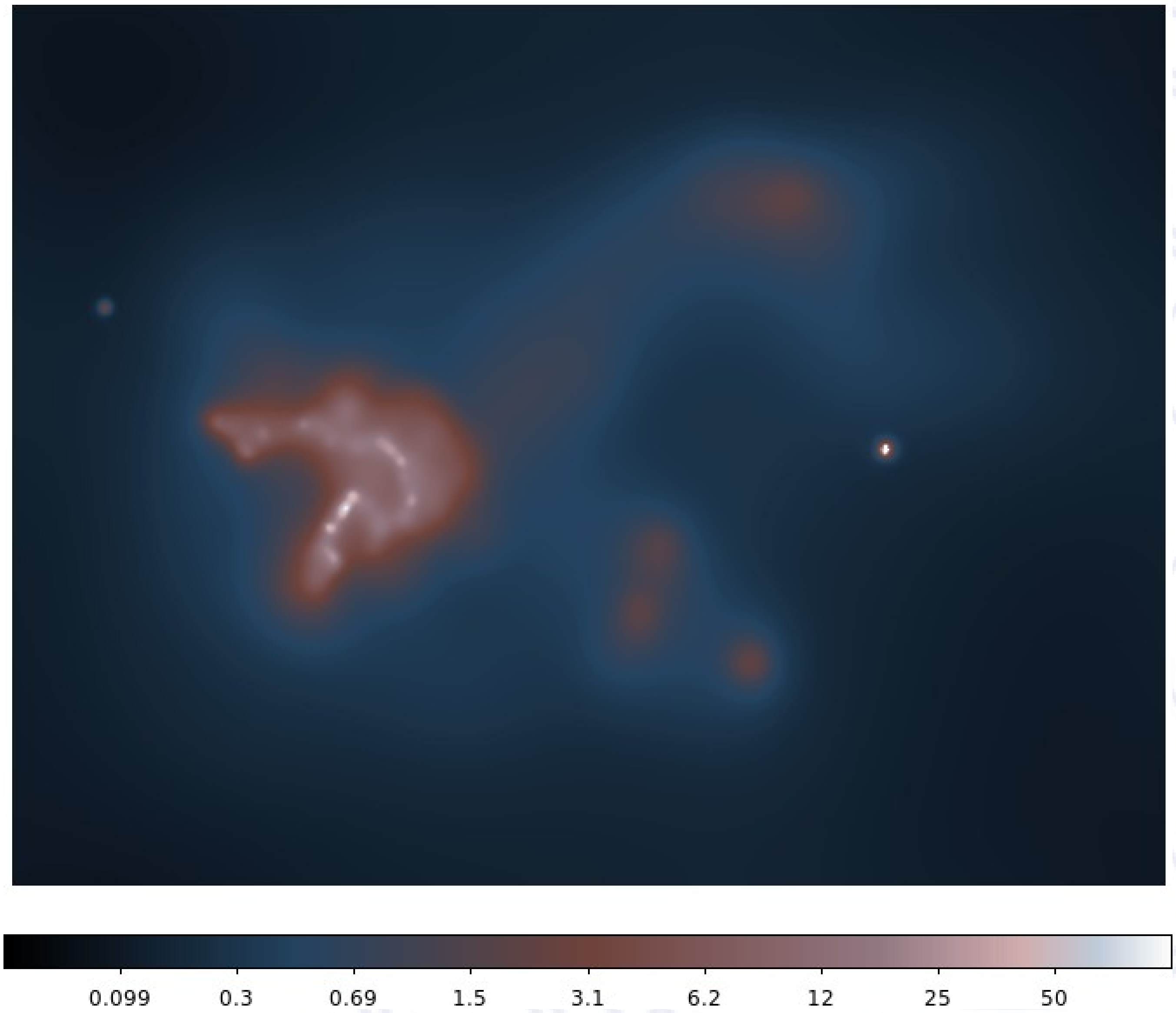
aconvolve provides N-dimensional smoothing with various built-in convolution kernels or user supplied file.

dmimgadapt: adaptive smoothing



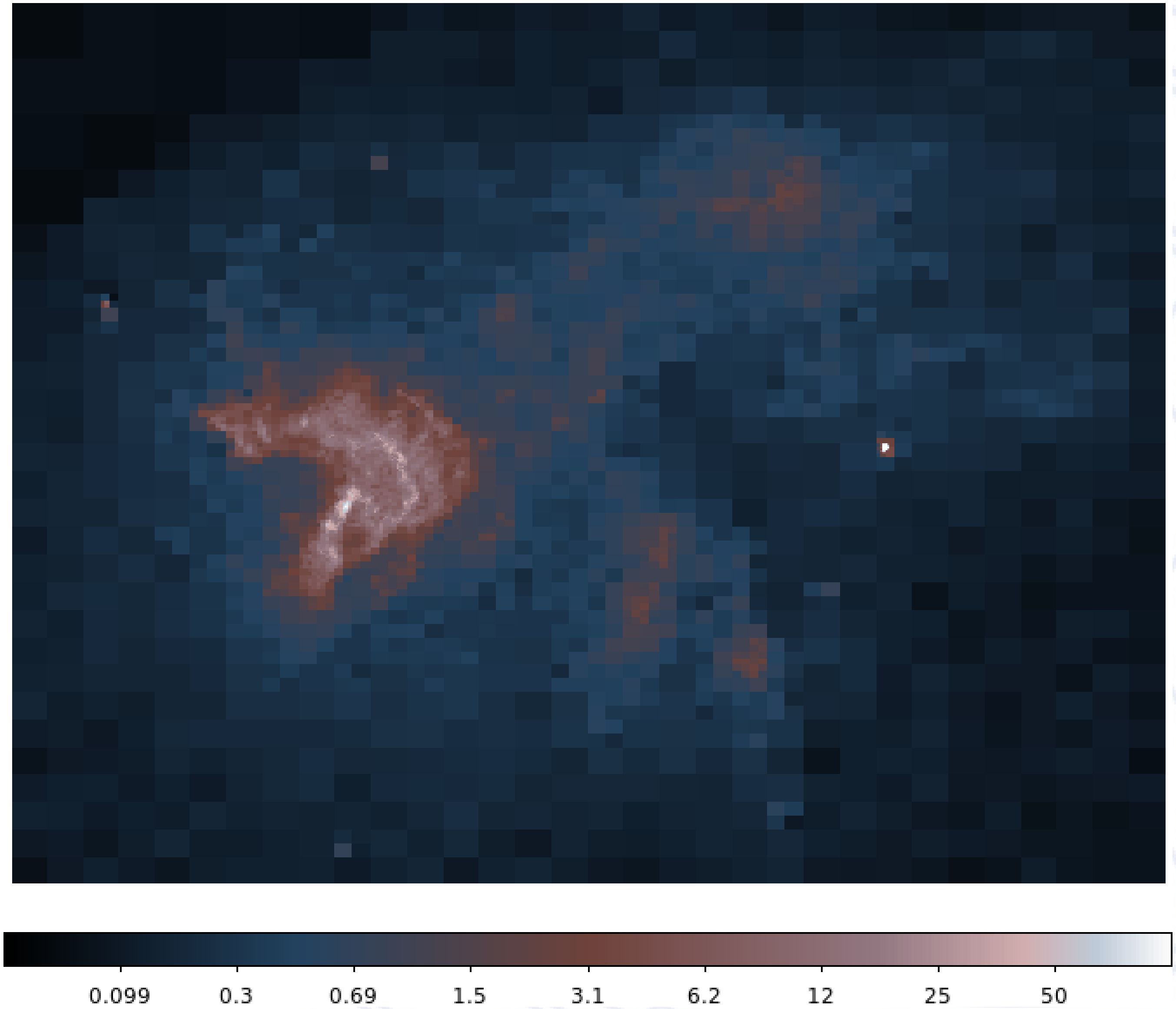
dmimgadapt provides a simple, quick way to adaptive smooth an image with a variety of filter functions: Gaussian, Cone, Pyramid, Tophat, Boxcar, Quadratic, etc

csmooth: adaptive smoothing



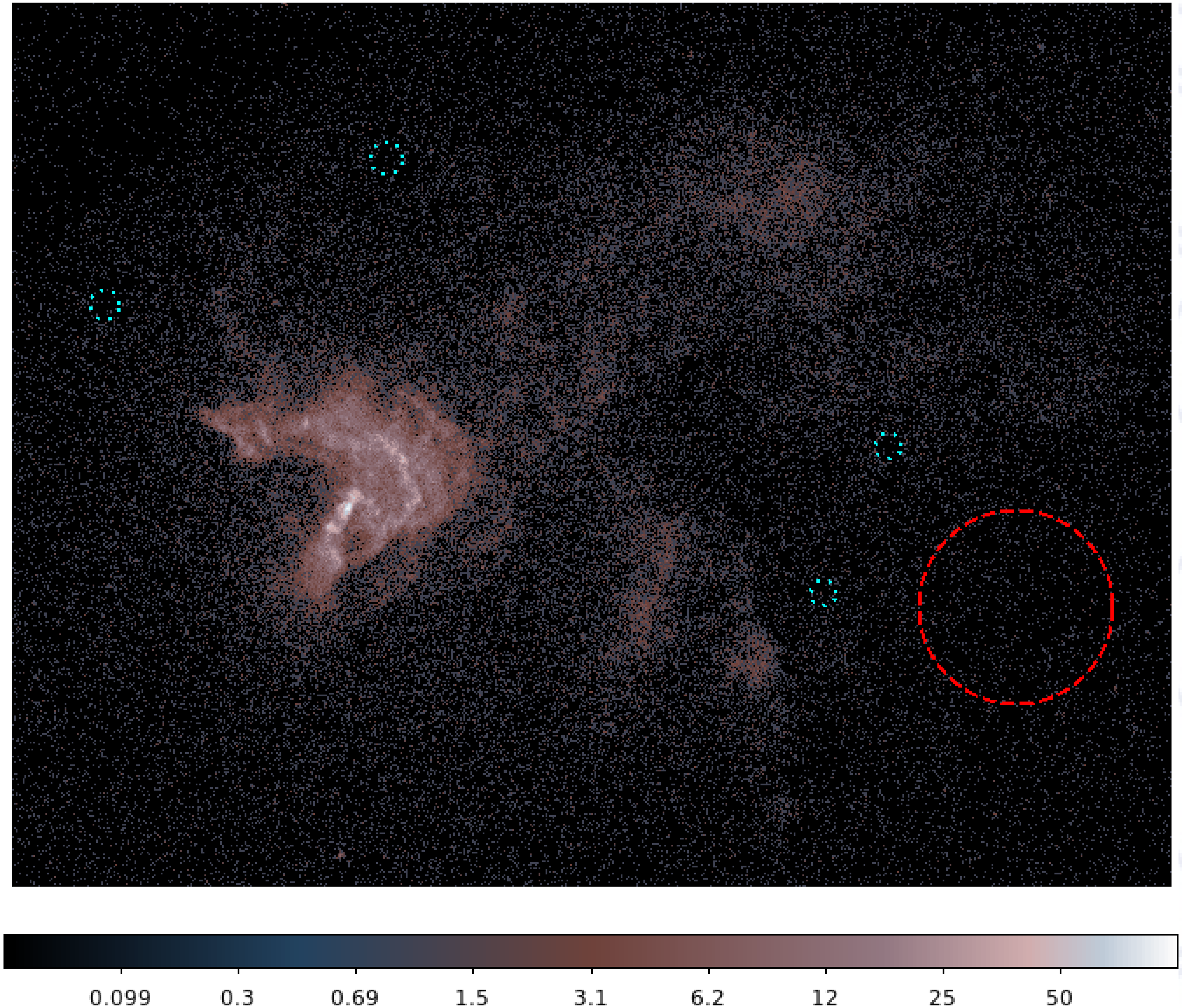
csmooth is the defacto standard for adaptively smoothing Chandra data. It has support for backgrounds and user supplied smoothing scale maps.

dmnautilus: adaptive binning



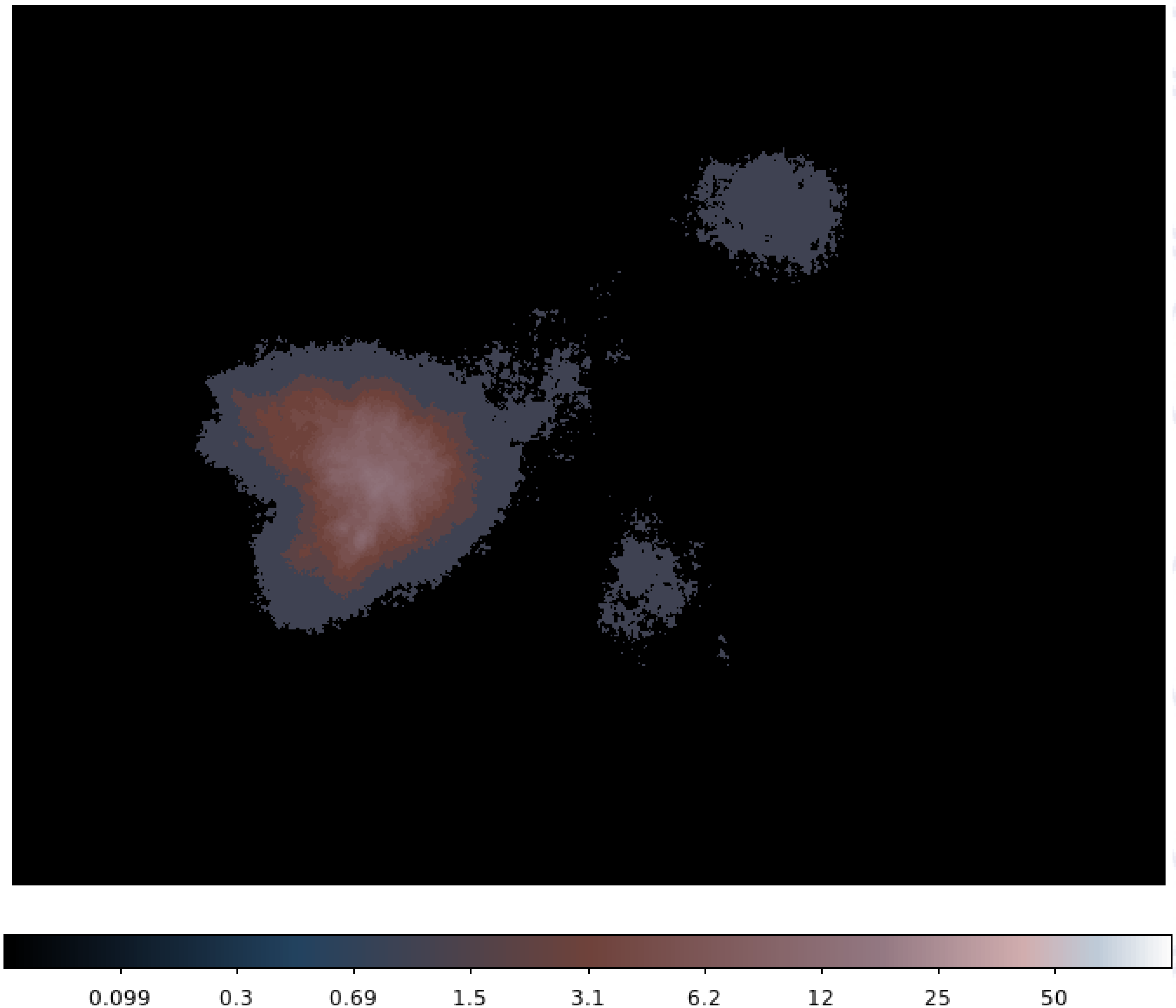
dmnautilus provides an adaptively binned image: each pixel satisfying the input SNR threshold.

dmfilth: fill-in-the-holes



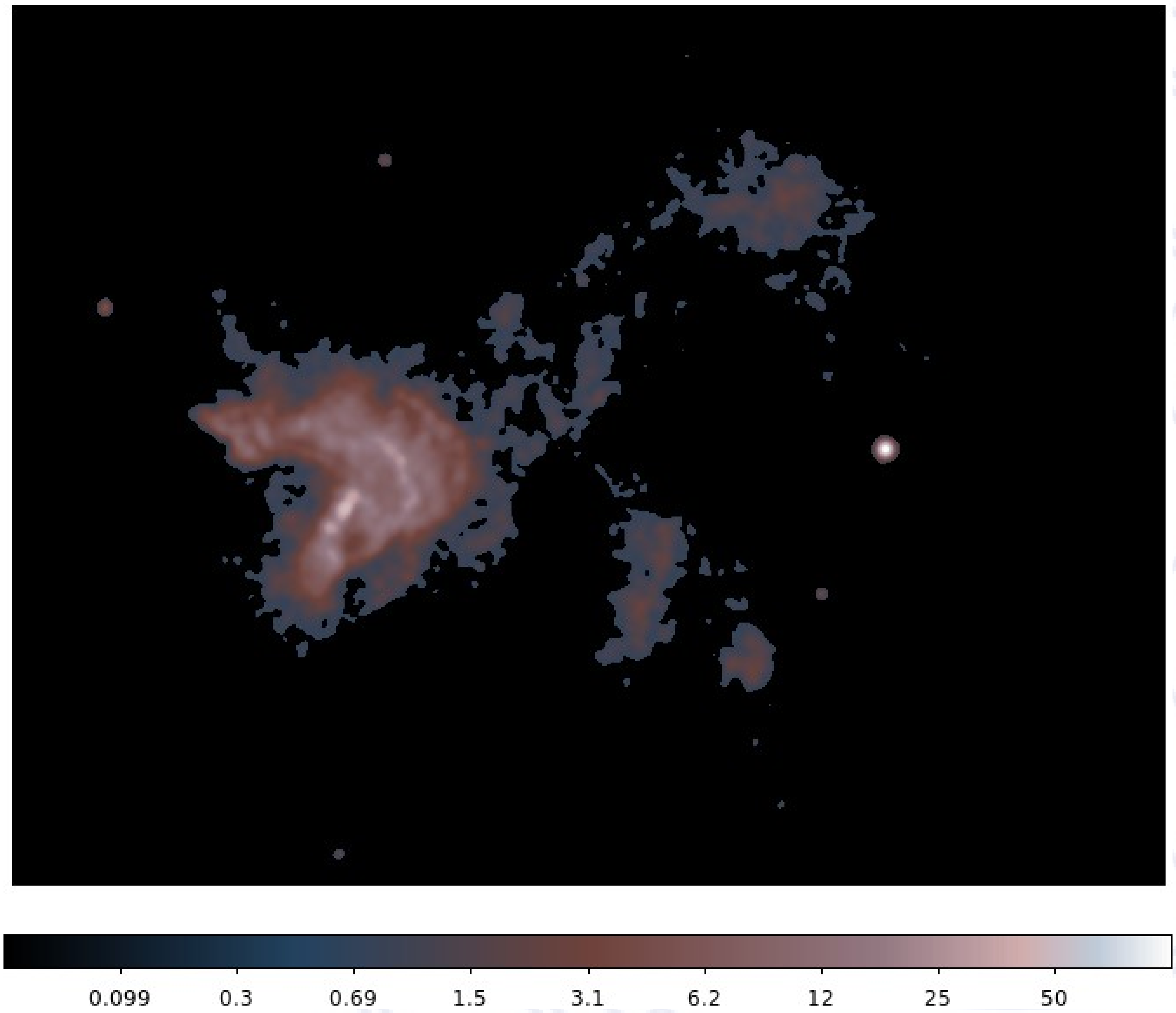
When those point sources get in the way, remove them with dmfilth.

dmimgfilt: non-linear filtering



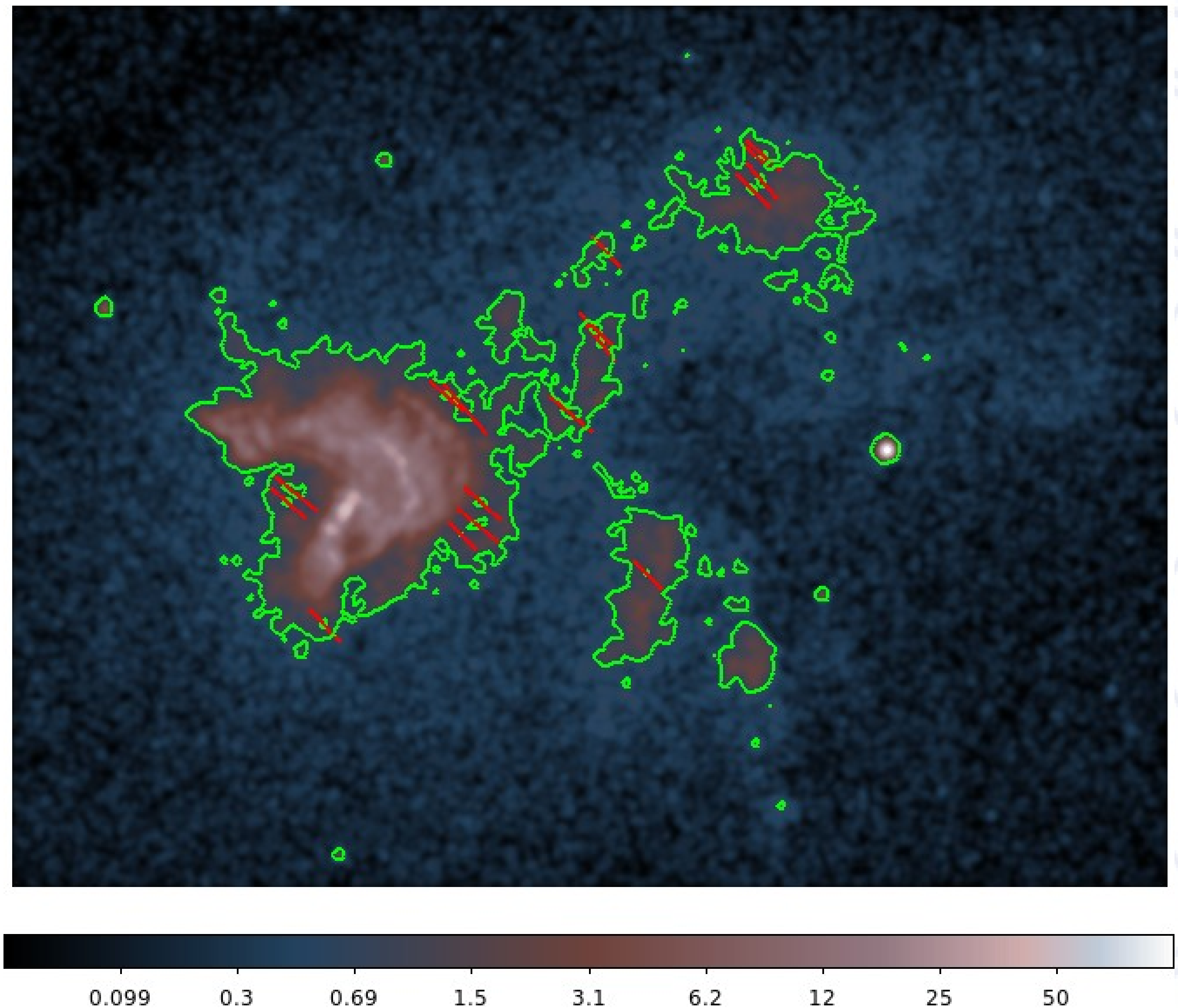
Looking to apply a non-linear filter to an image such as the median pixel value in some annulus? Chances are dmimgfilt has the nonlinear filter function you are looking for.

dmimgthresh: clip pixel values



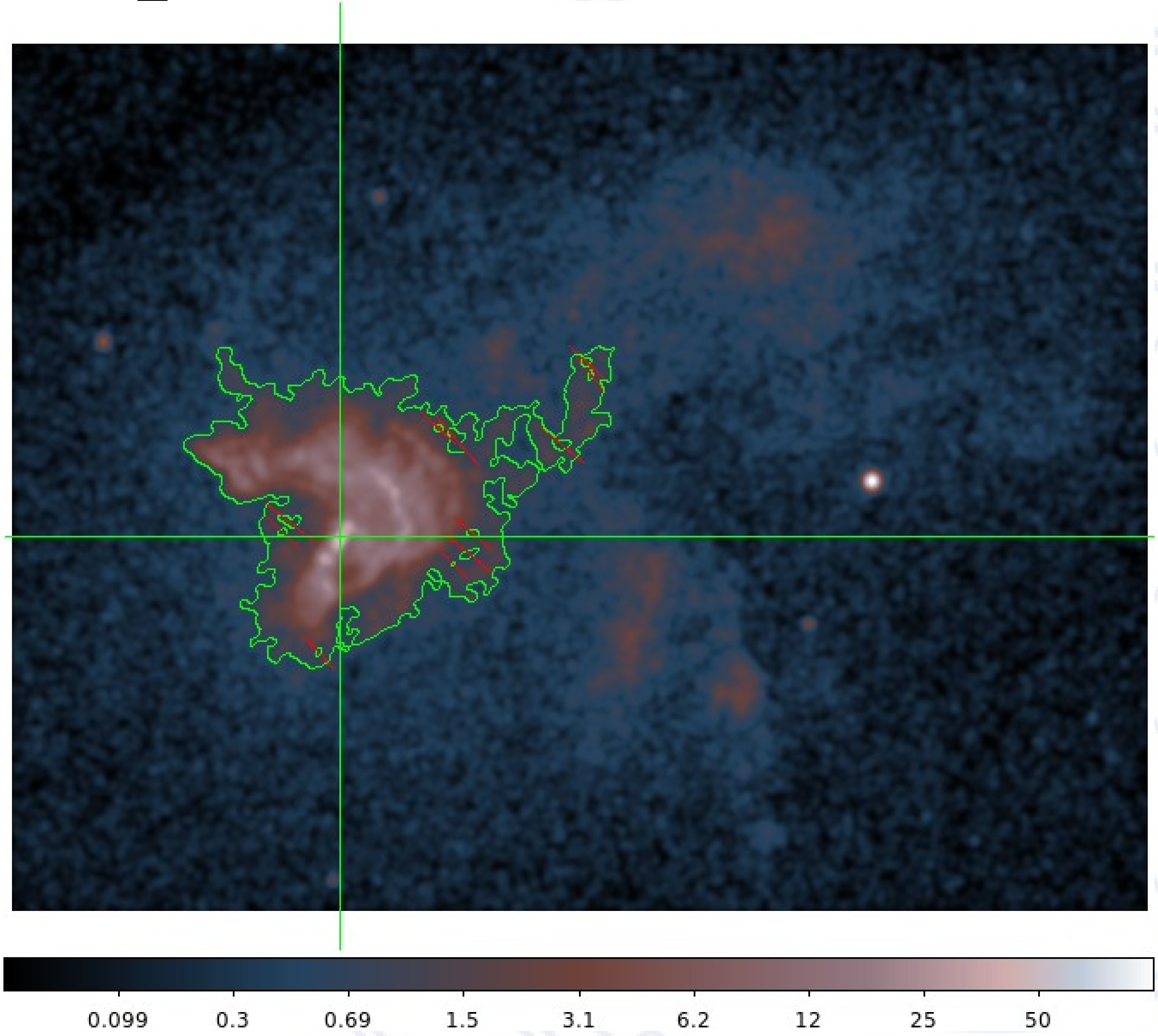
dmimgthresh is used to replace pixel values above or below the input threshold. Typically with the value 0, but any value, including NaN can be set.

dmcontour: make global contours



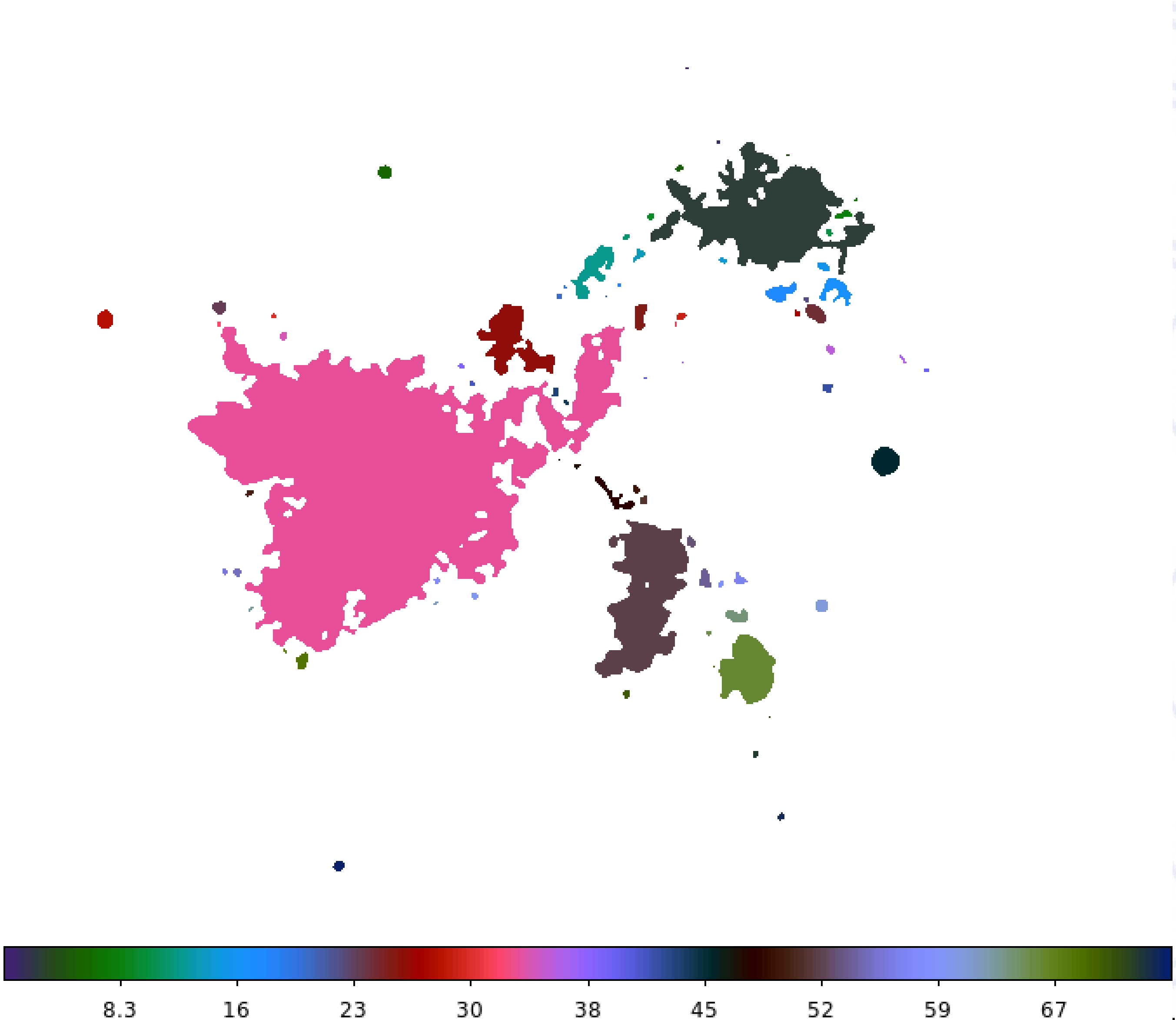
Need to make a region that follows some contour level? dmcontour may be what you are looking for.

dmimglasso: localized contours



Only want to select a specific, single object? Then try the “magic-wand” style tool: dmimglasso.

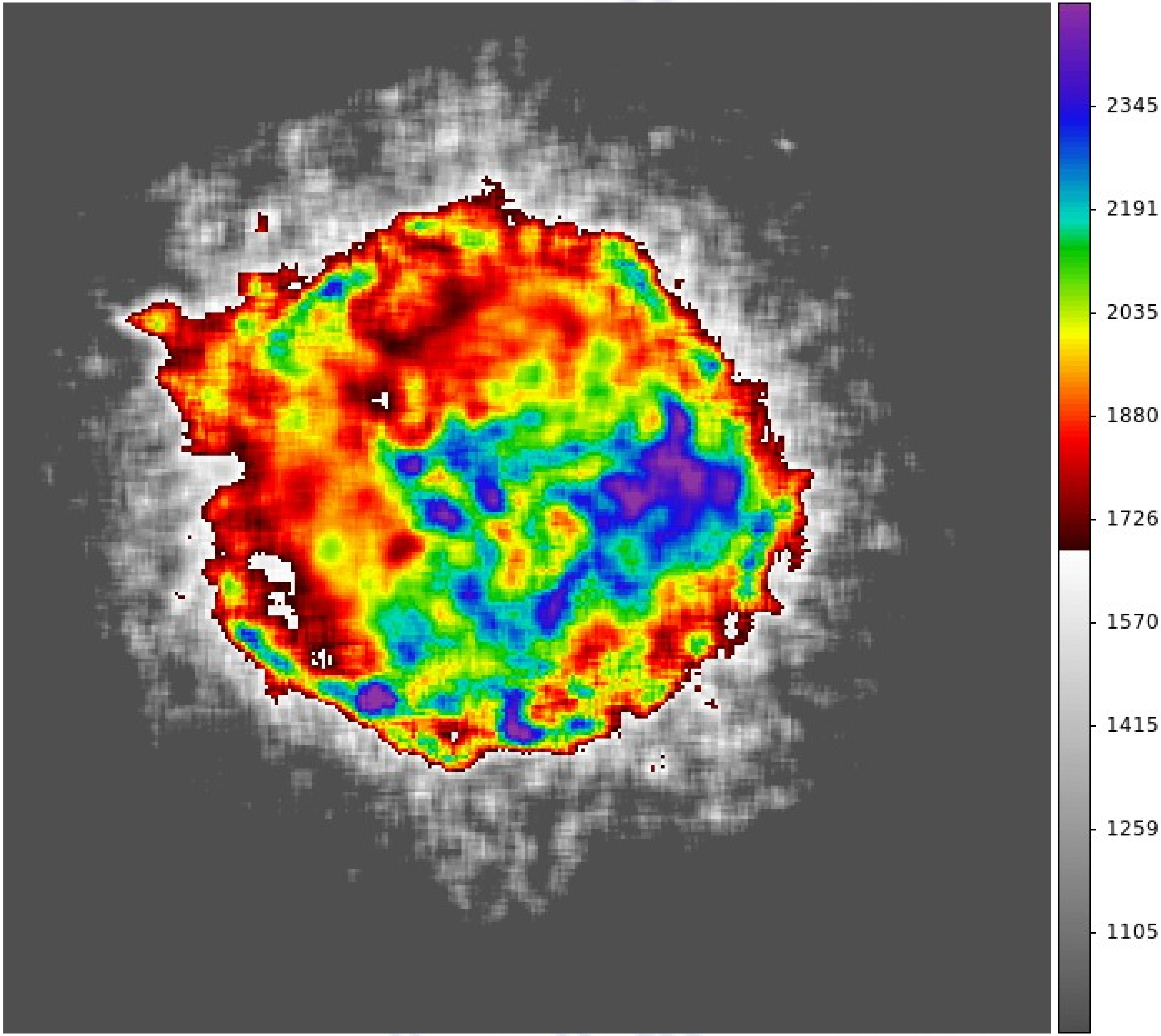
dmimgblob: connected pixels



Tools like dmimgblob can be used as part of a custom source detection workflow. It provides a map of connected pixels above threshold.

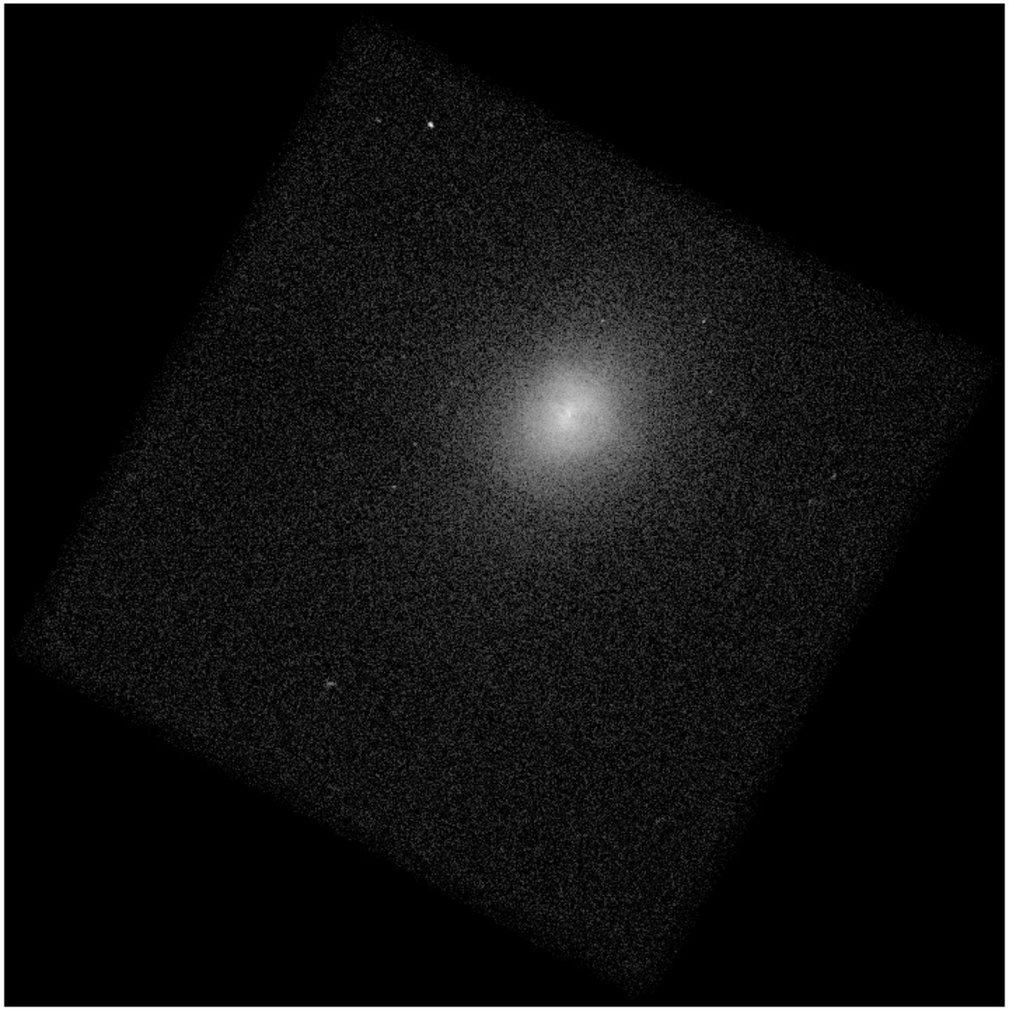
But wait! There's More!

mean_energy_map

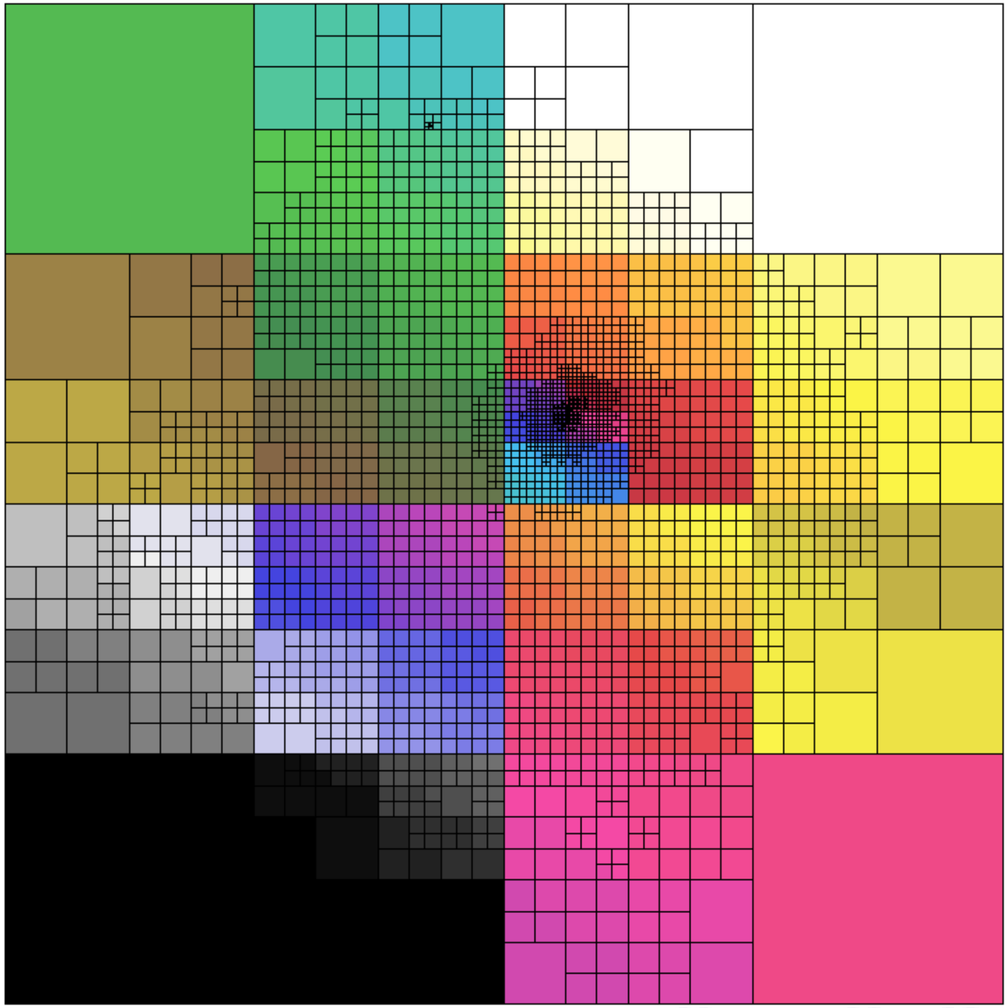


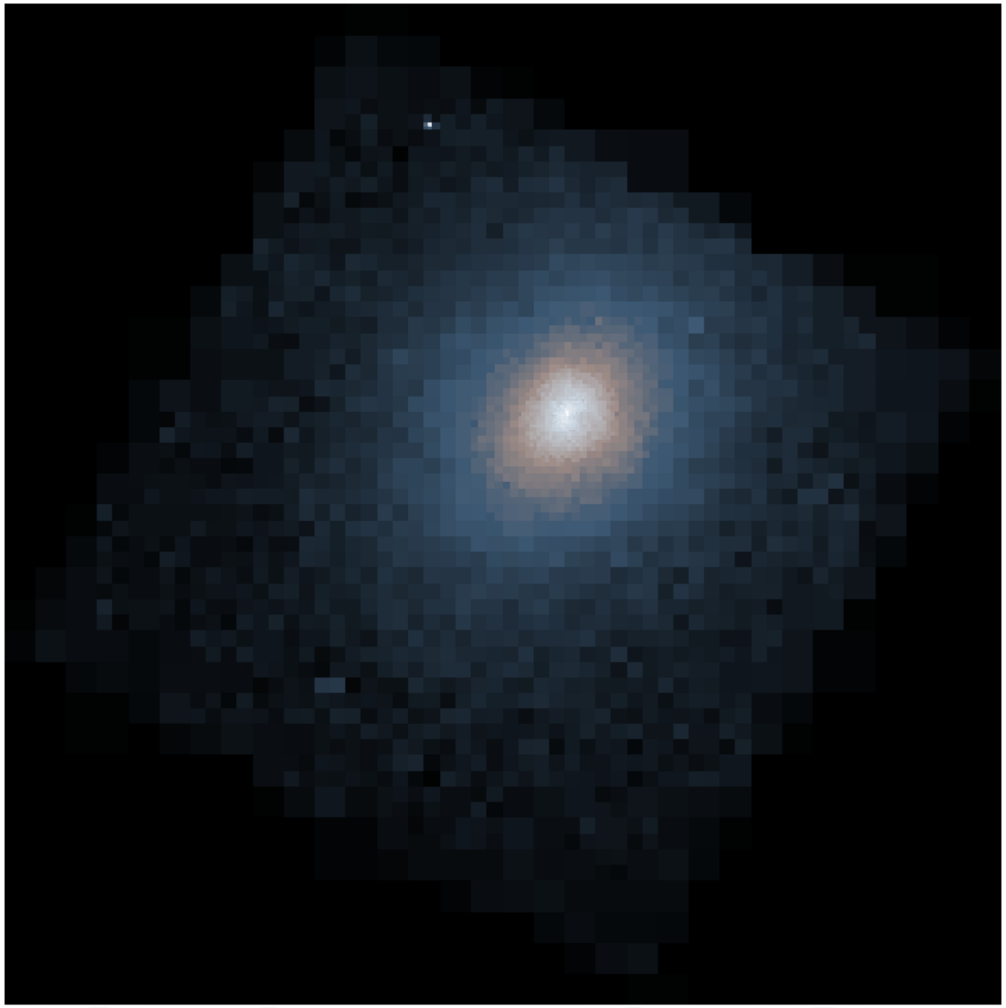
mean_energy_map is not a temperature map, but can be used to quickly look for spatially varying spectral features as in the above mean_energy_map of CasA.

What about adaptive binning?



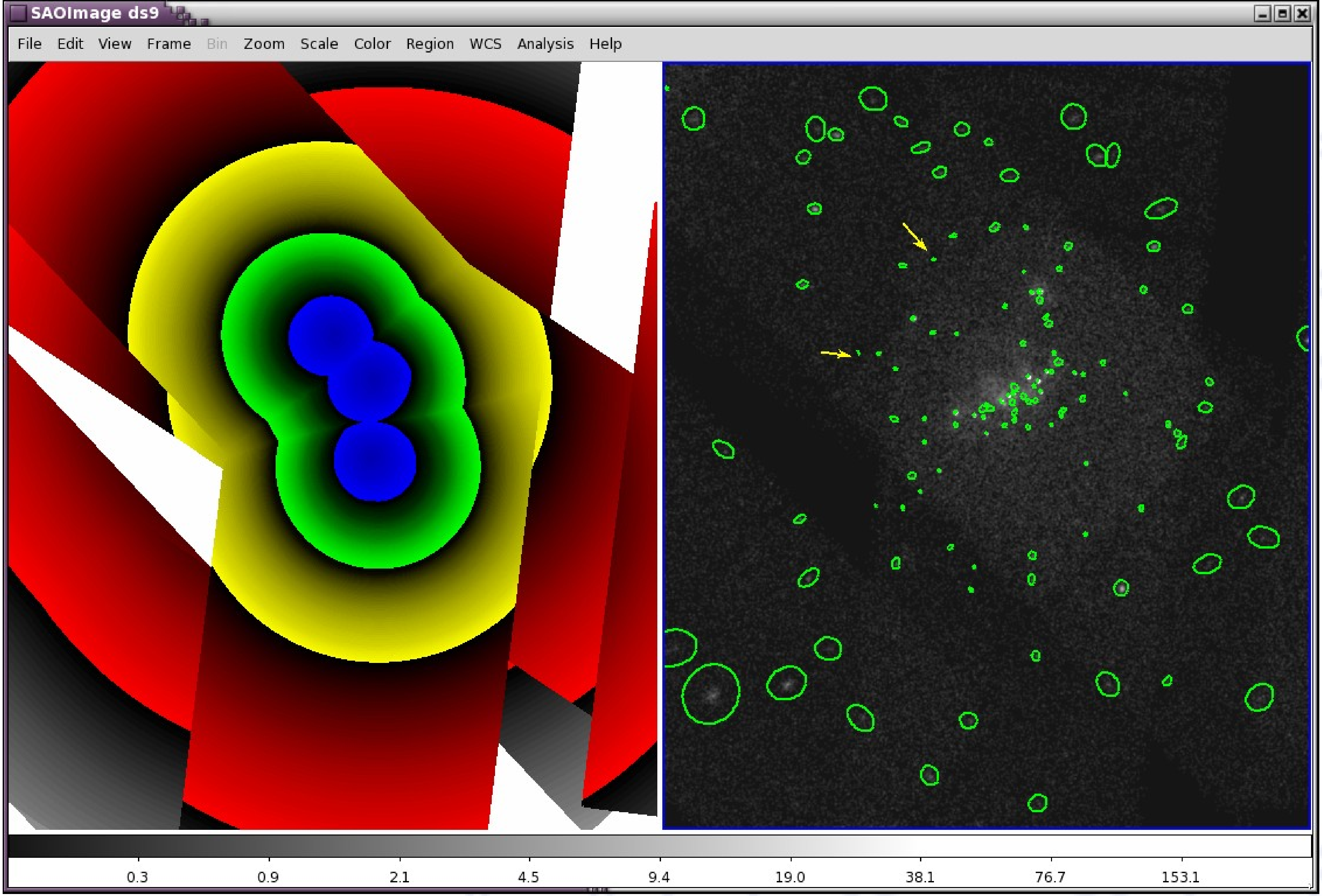
Abell 2579 (OBS_ID=6934) imaged on ACIS-7, 0.5 to 7.0 keV.





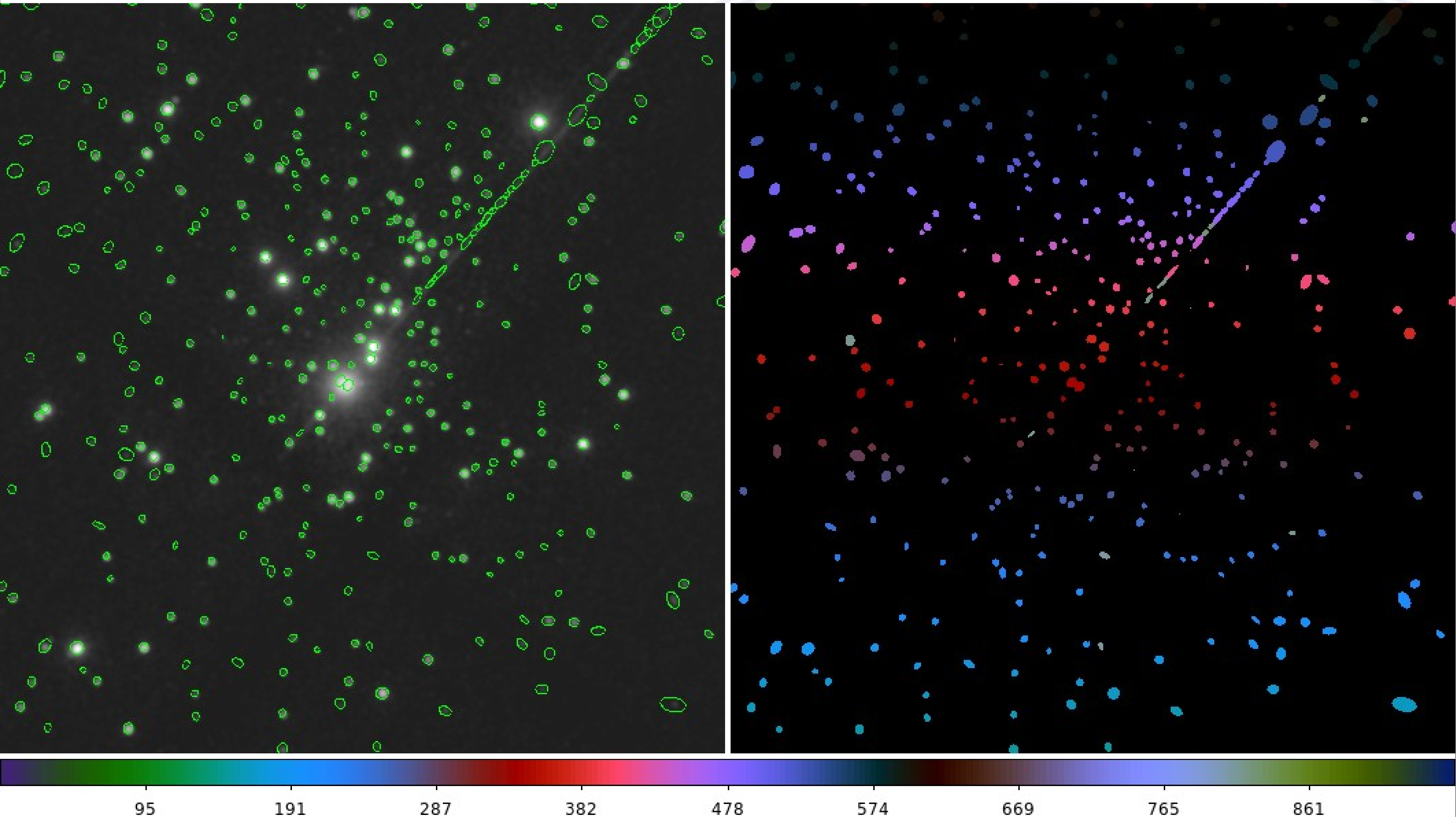
dmnautilus provides a simple, quick quad-tree adaptive binning algorithm. On the left is the output mask file showing the pixels grouped together. On the right is the binned image.

Need to run wavdetect on a merged dataset?



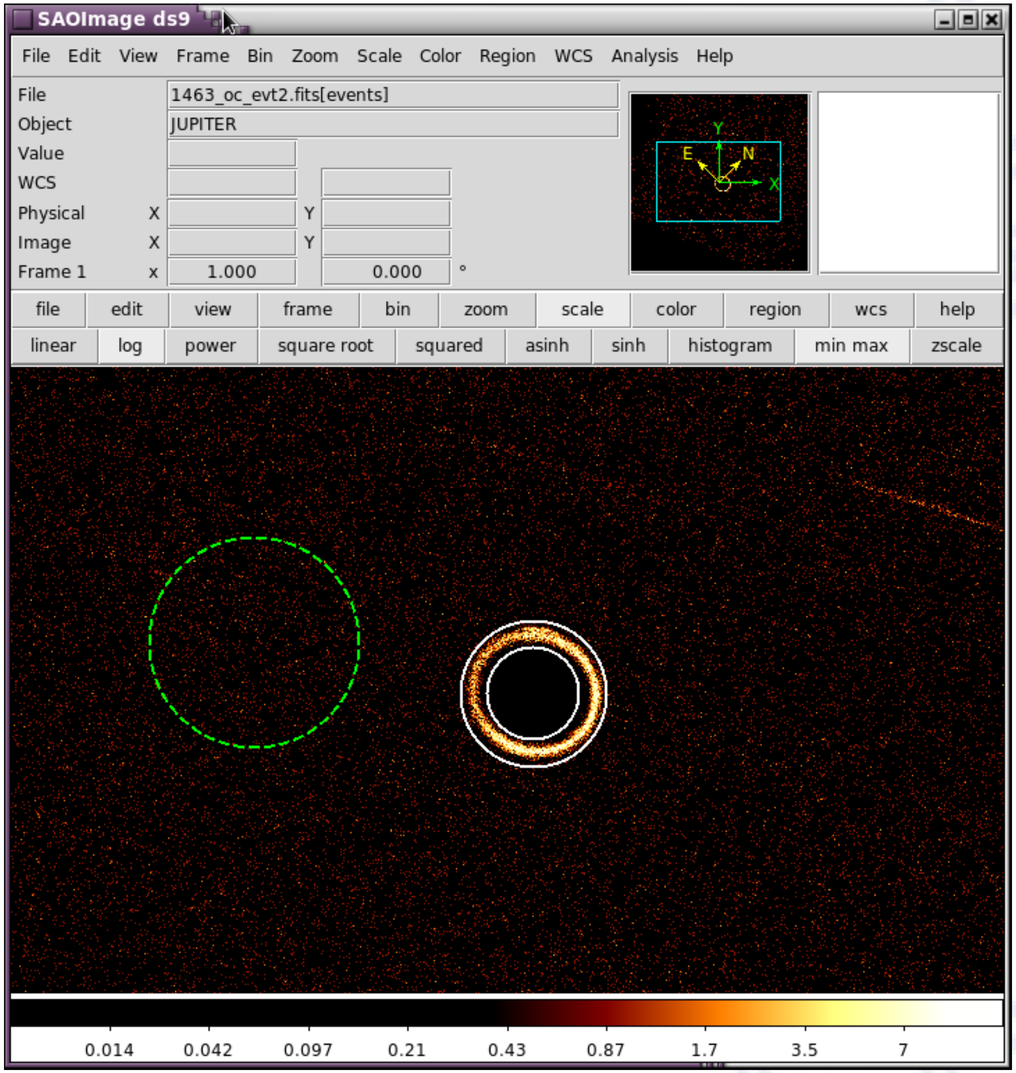
(Left) Shows a merged PSFMAP created with dmimgfilt, taking the minimum exposed pixel value from each of the 3 input images. (Right) The merged dataset, NGC4485 OBS_ID's 1579, 4725, and 4726, with sources shown.

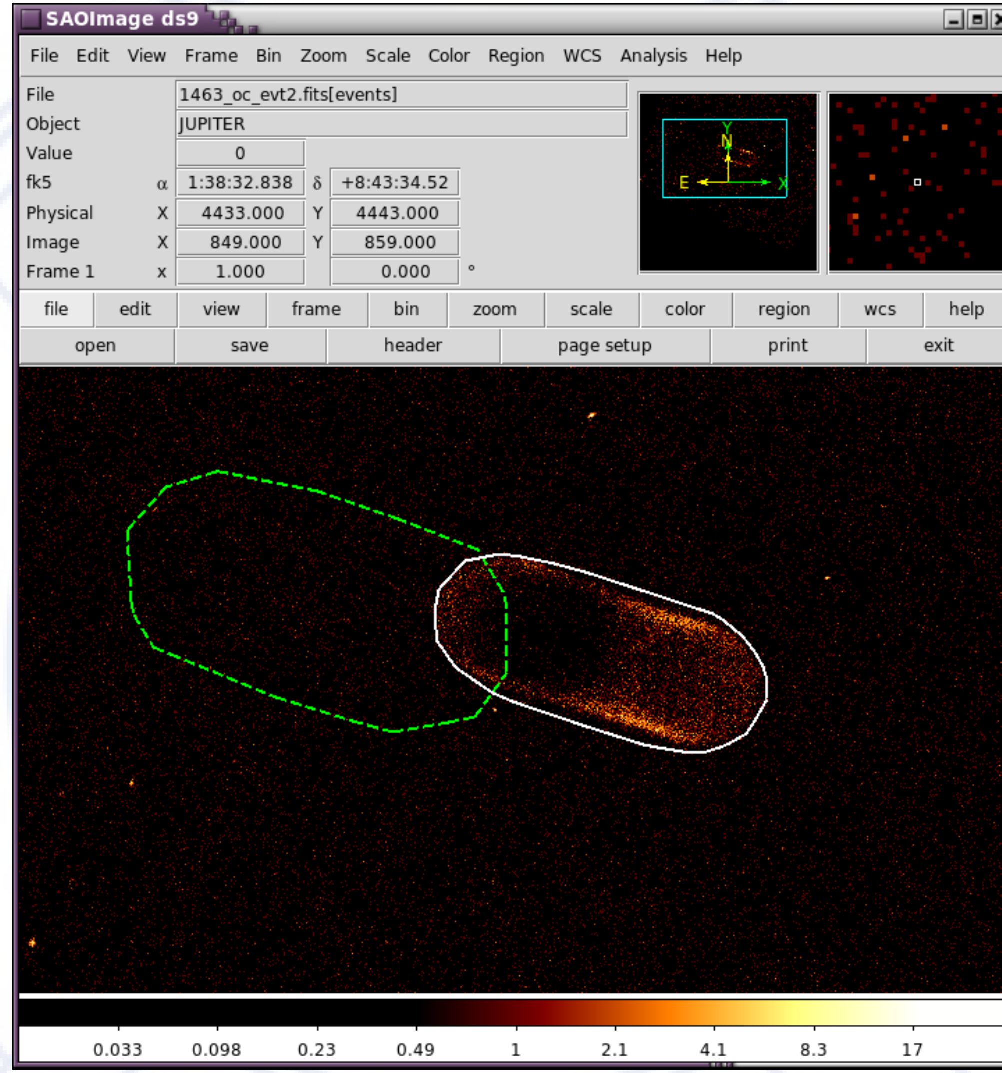
Where every source has a name ...



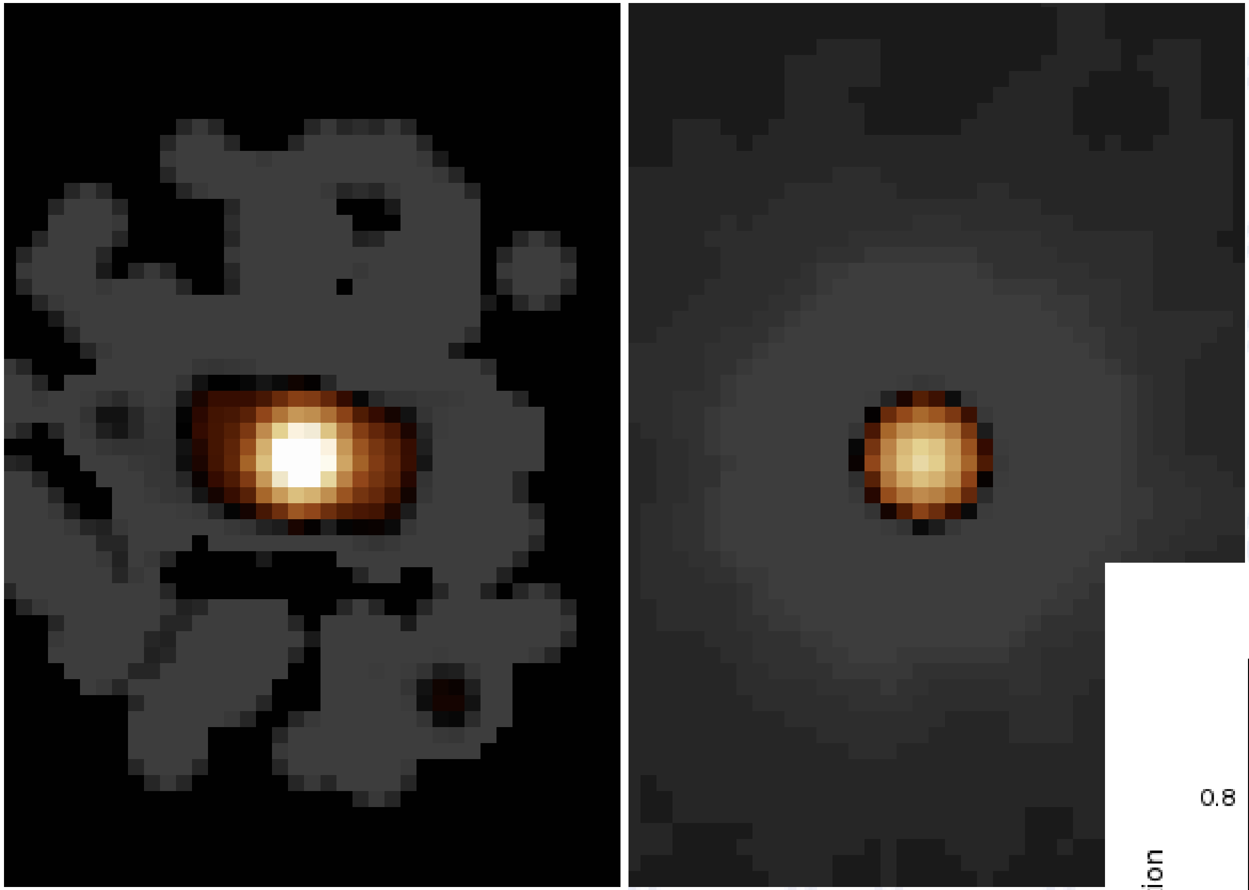
wavdetect sources of the Orion field (ObsID 4396) on the left are assigned a unique integer ID and are mapped into pixels on the right.

Something closer to home ...



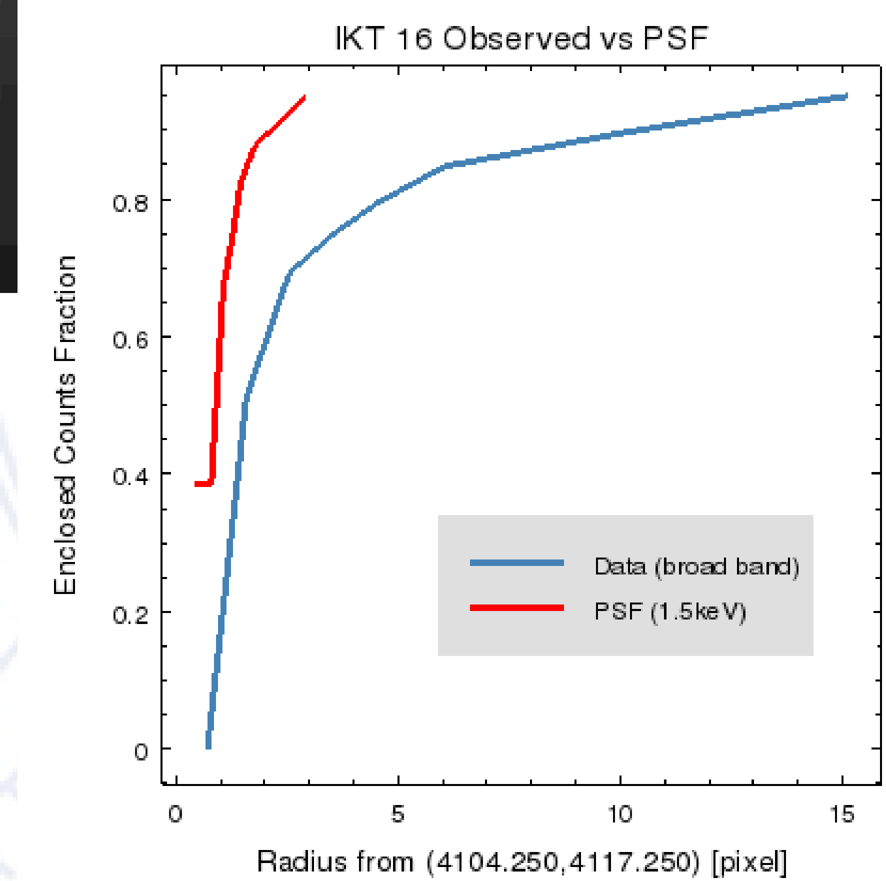


(Left) Shows an observation of Jupiter, OBS_ID 1463, that has been centered on the moving planet using sso_freeze. The center is devoid of events due to optical light saturation. (Right) shows the image in celestial coordinates as the planet moves across the field of view. The source and background regions have been created with dmimghull

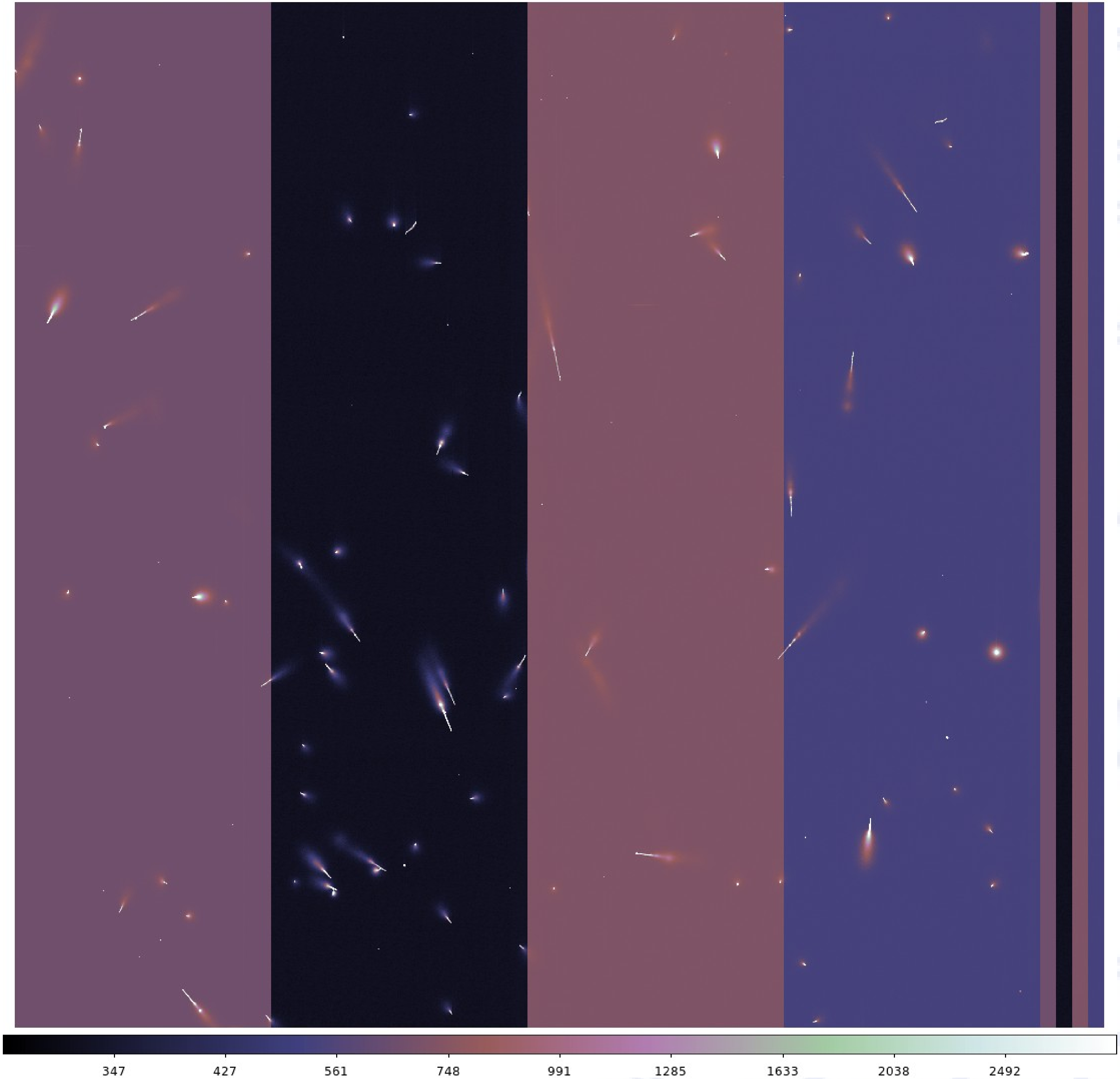


“There are no more point sources.” was a joke started in the Chandra community referring to the unmatched spatial resolution of the HRMA.

(Top) an image of IKT16 compared with a SAOTrace simulation of the PSF created with ChaRT. (Right) Shows the enclosed counts fraction created with the ecf_calc tool showing the extended nature of the object.



Just events?

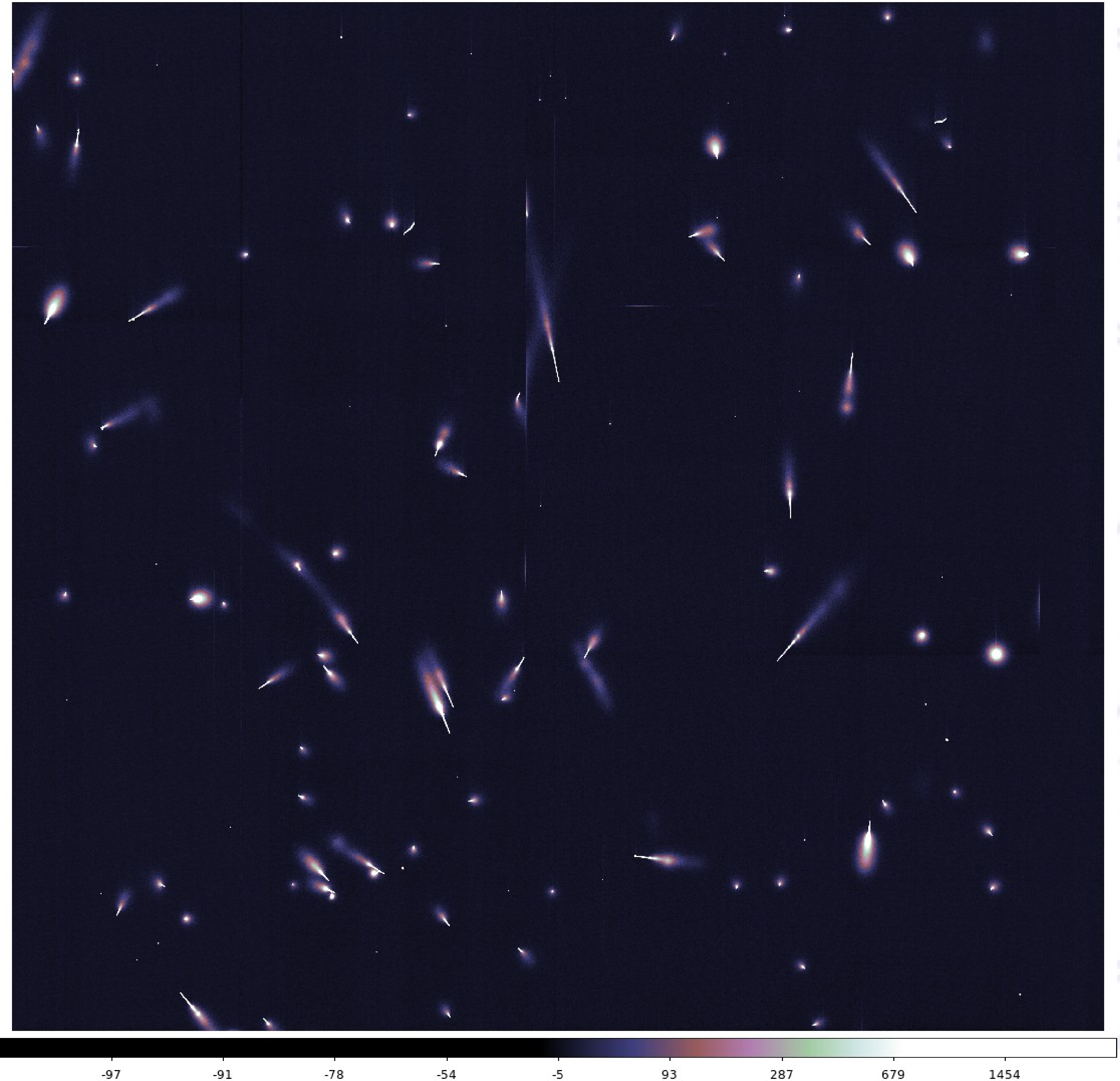


A raw ACIS-6 image (2009-08-26).

The vertical stripes are due to the DC offsets between the 4 readout nodes.

The other features are charged particles interacting with a stowed detector.

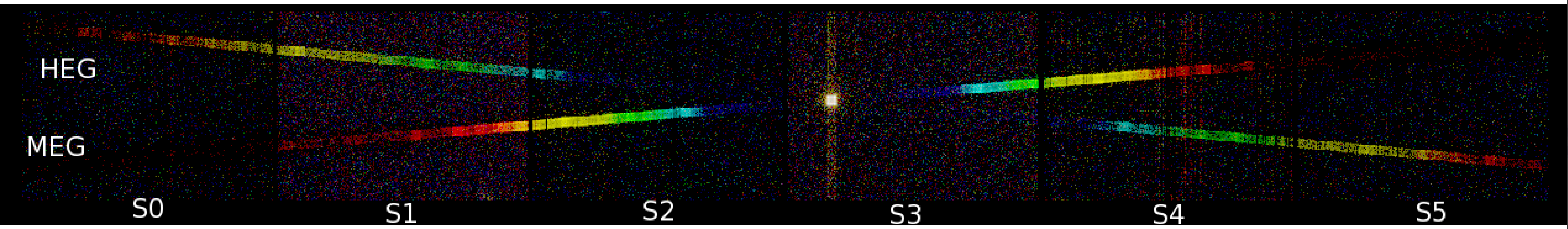
Raw frames are only available via WebChaSeR for special Calibration observations.

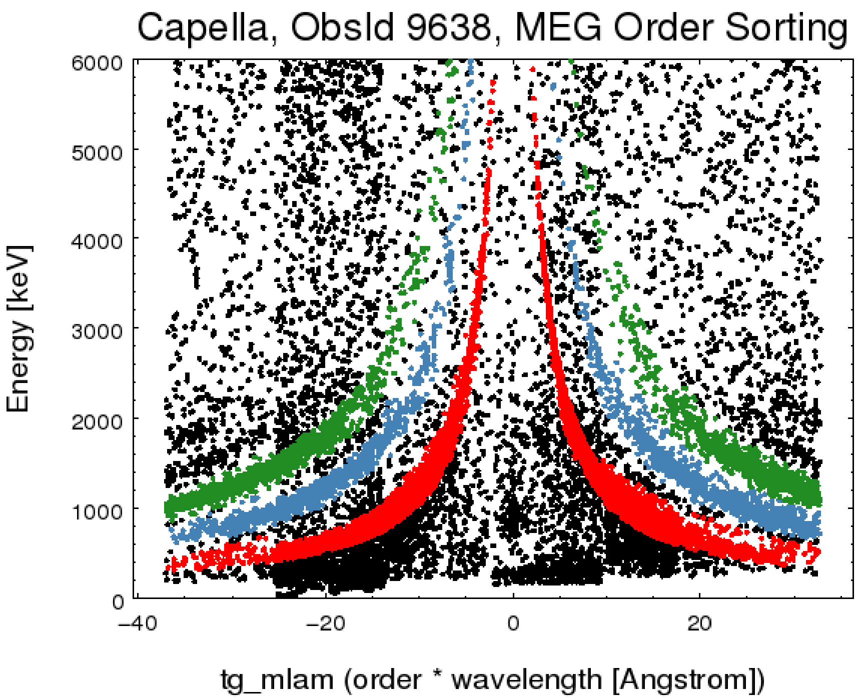


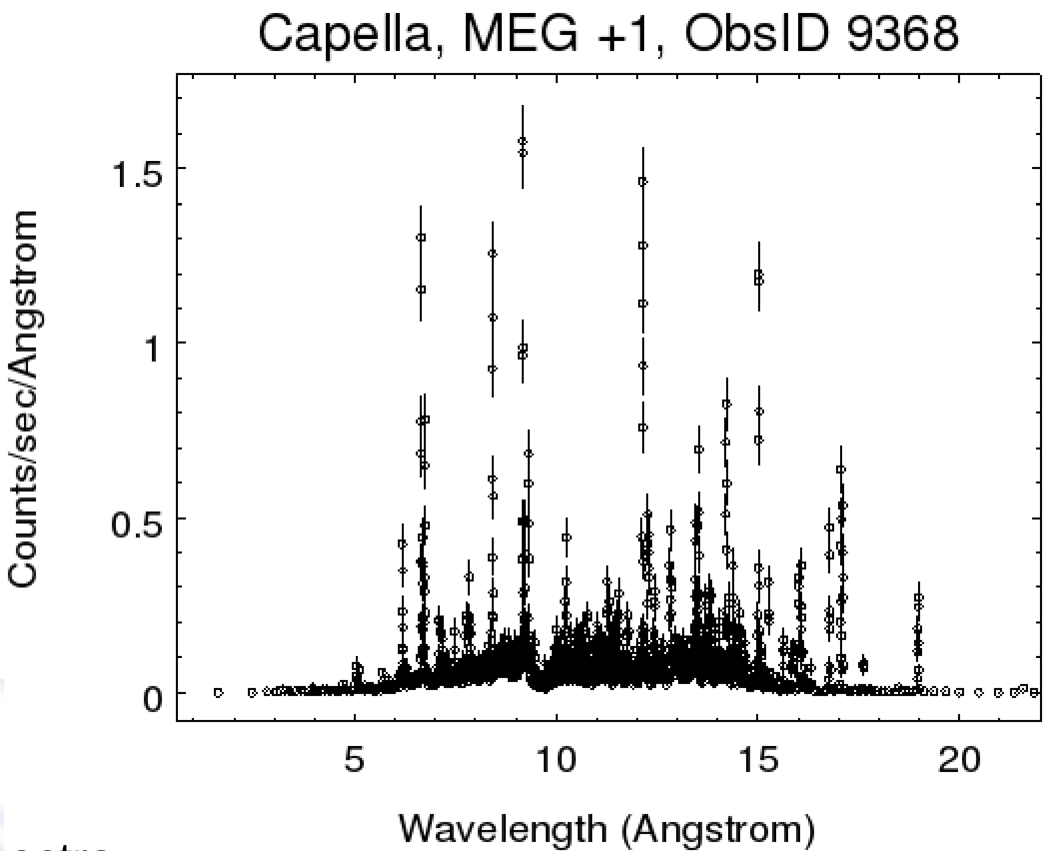
Finally dmimgcalc is used to subtract the node-to-node offset from the image.

Technically the image is not yet “flat” as there are still pixel-to-pixel gain variations.

What about gratings data?



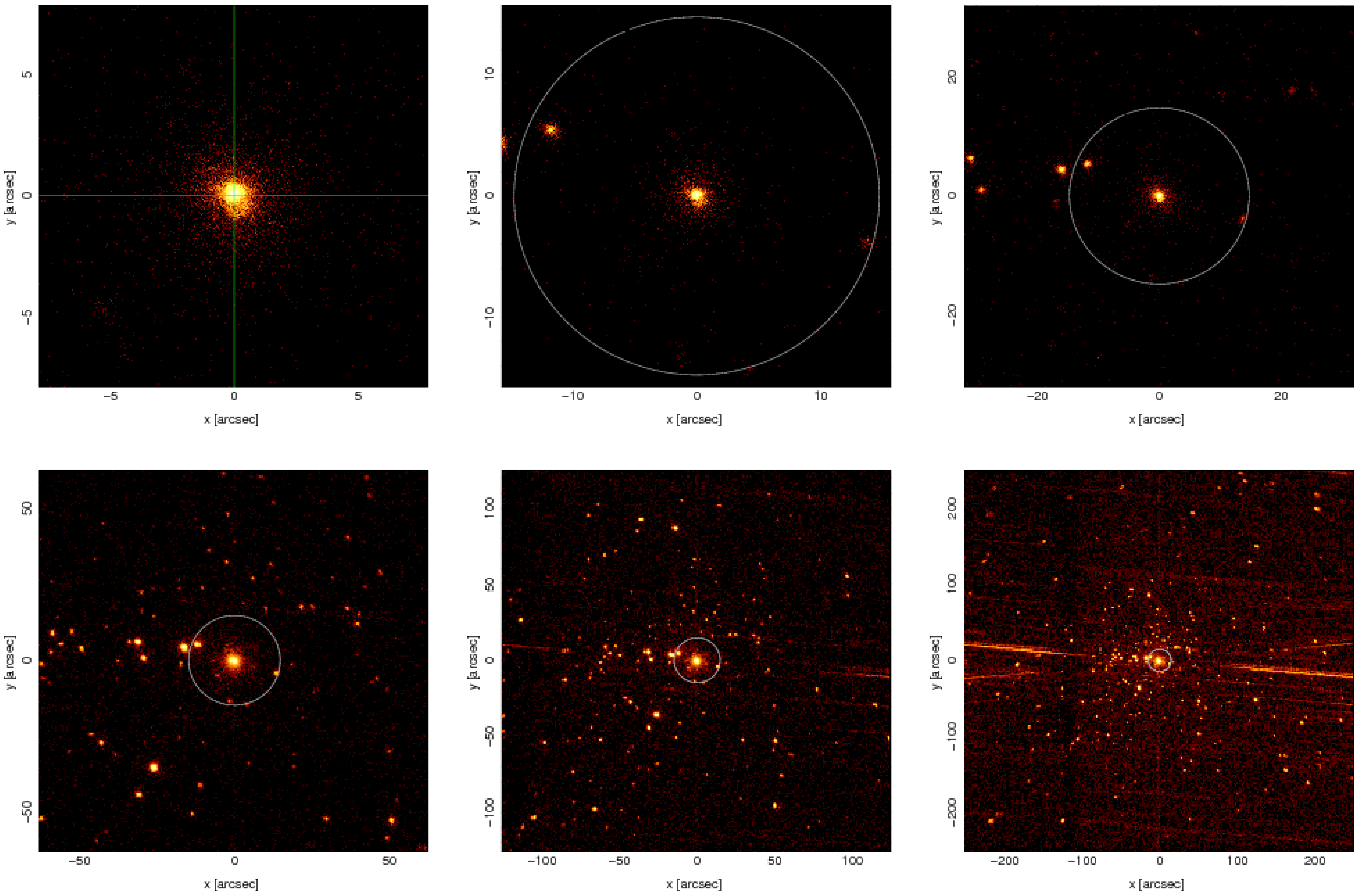




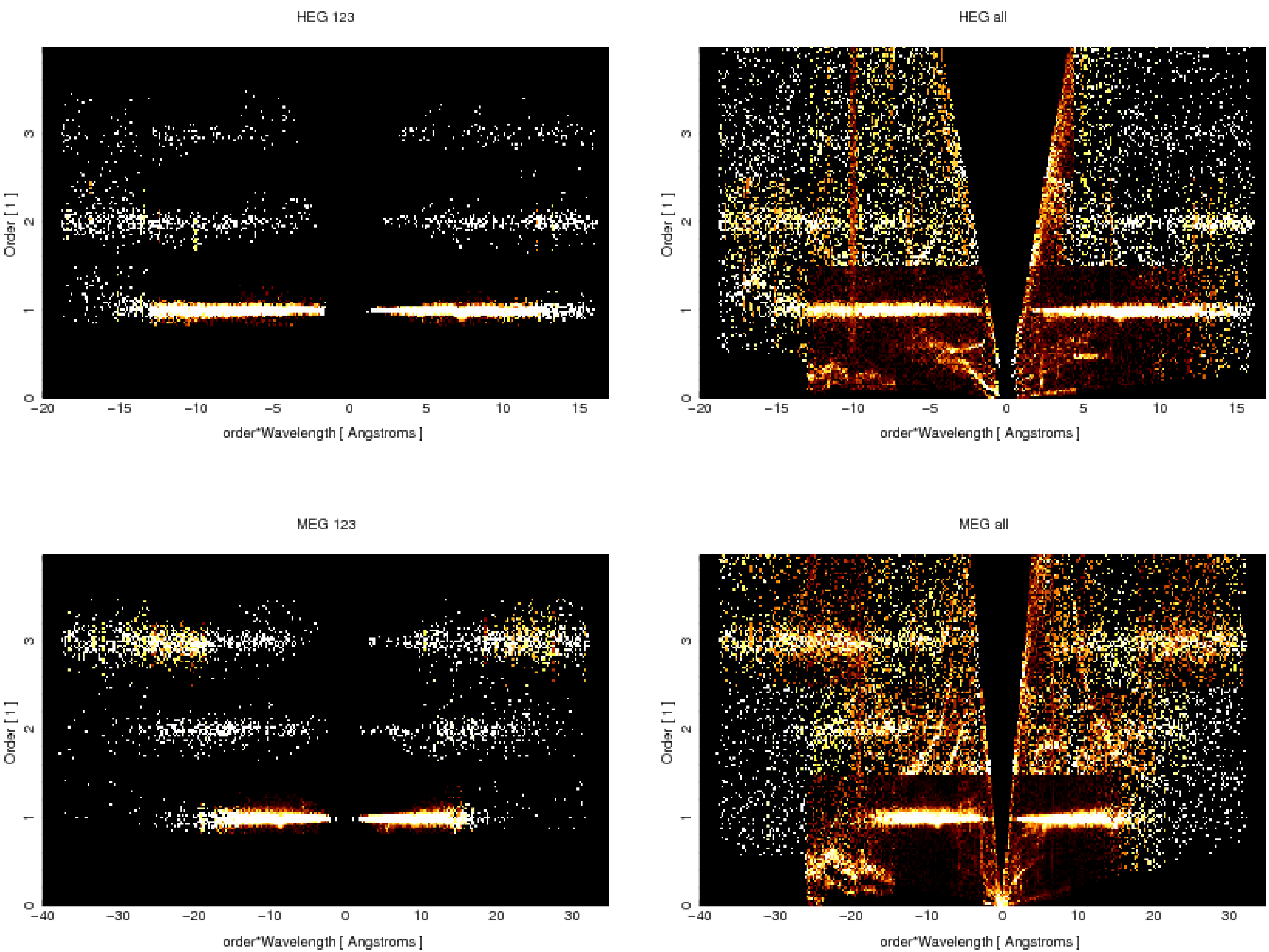
Gratings data provides high resolution spectra collected in multiple orders and with multiple grating arms.

TGCat

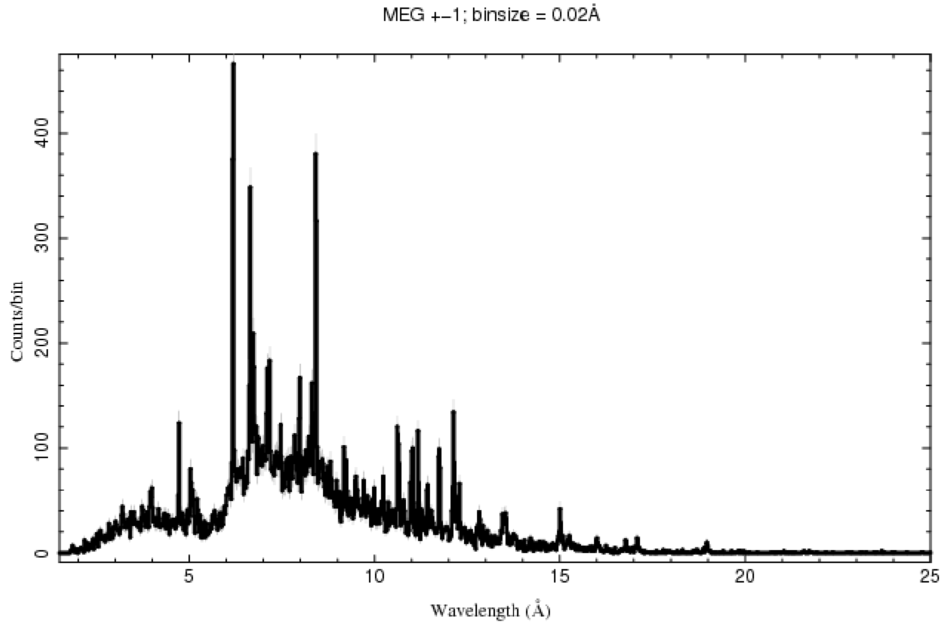
The Transmission Gratings Catalog produced by the MIT/CXC team includes reduced grating spectra and response files for public Chandra grating observations.

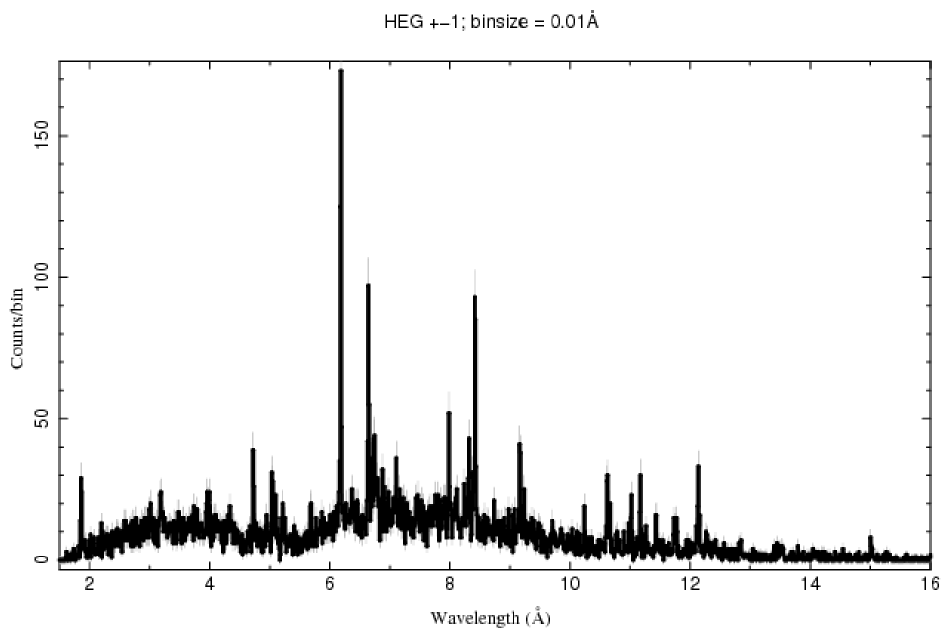


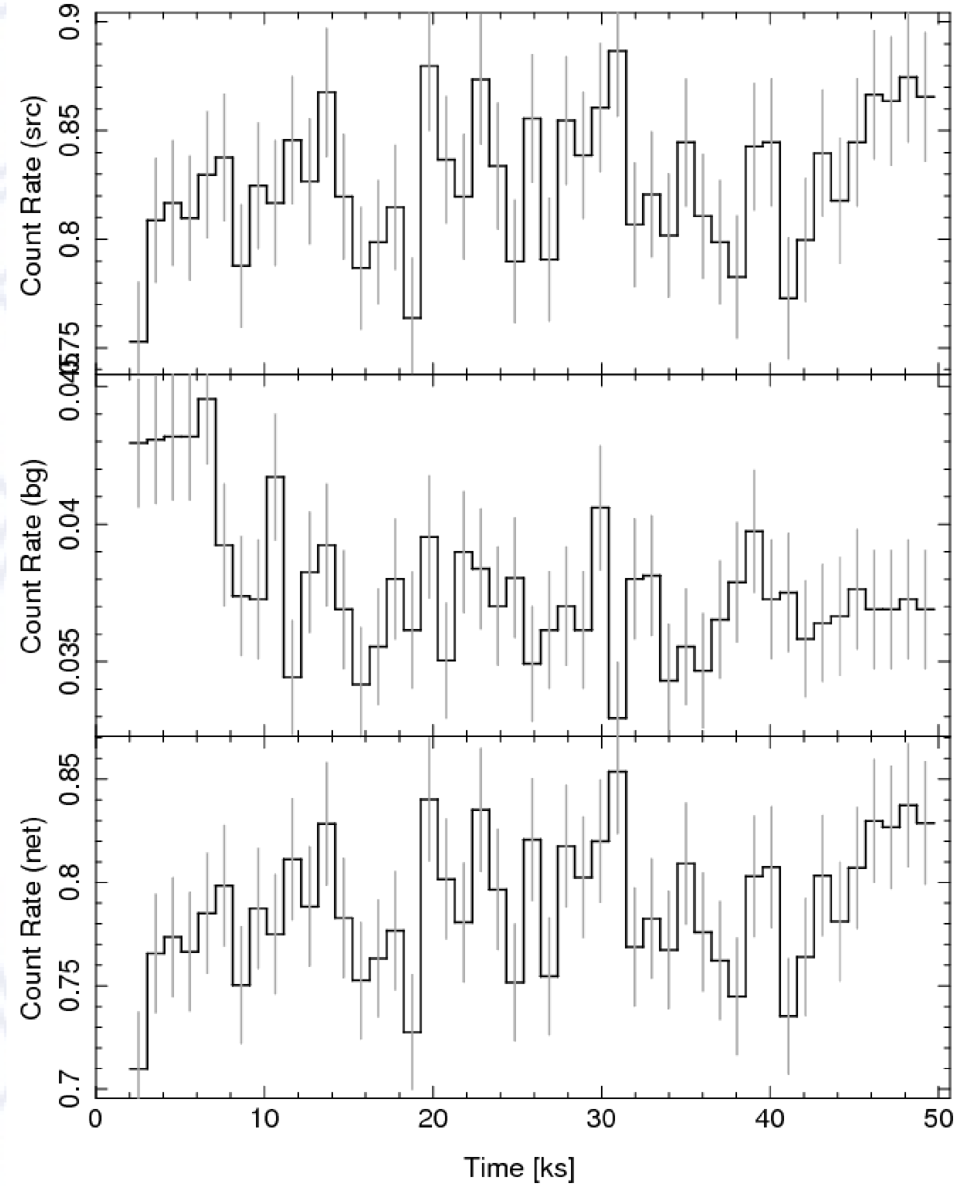
Grating data from the Orion cluster



TGCat includes diagnostic plots to show the quality of the spectral extractions





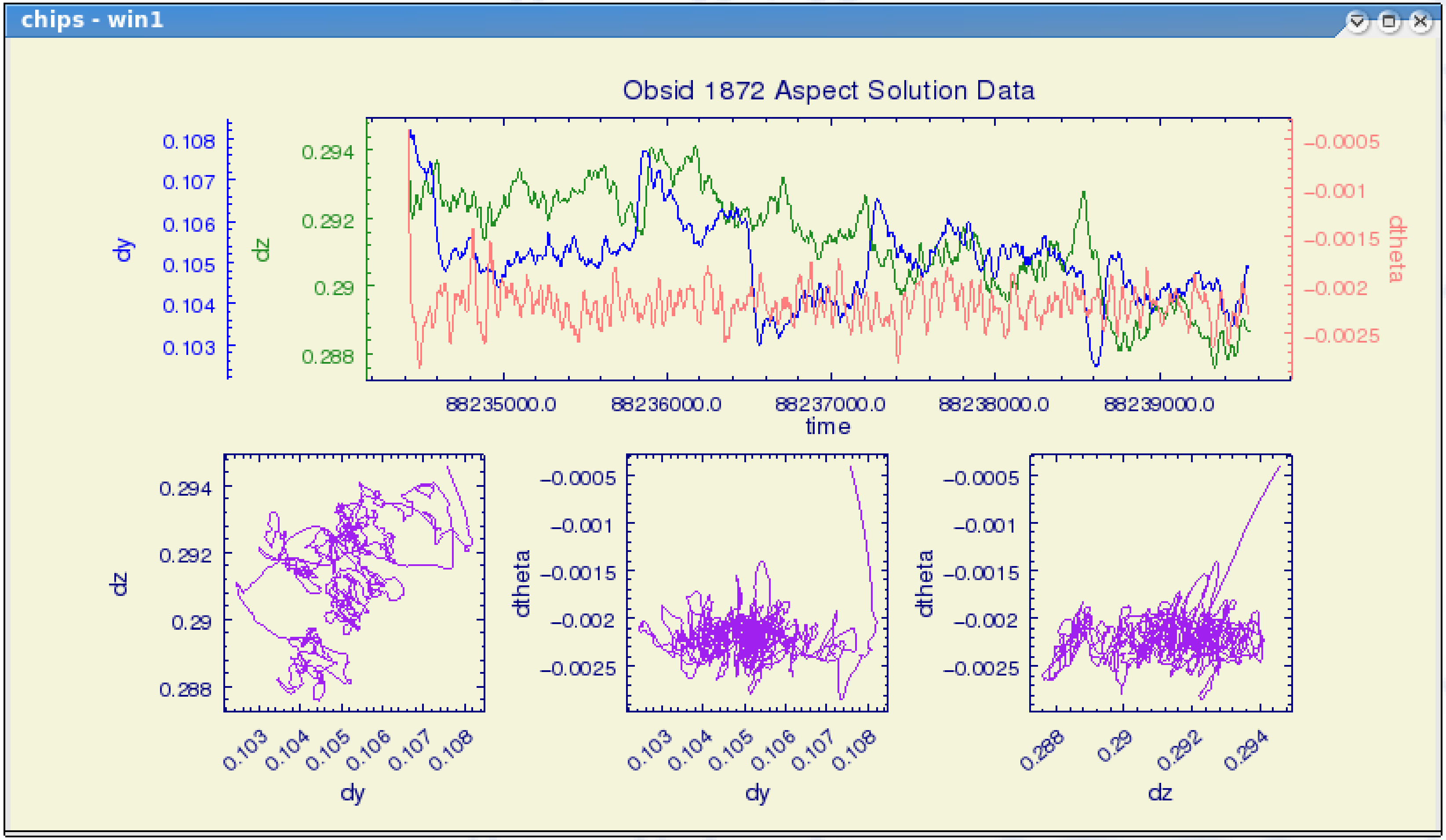


Spectra and Lightcurves are available for all sources.

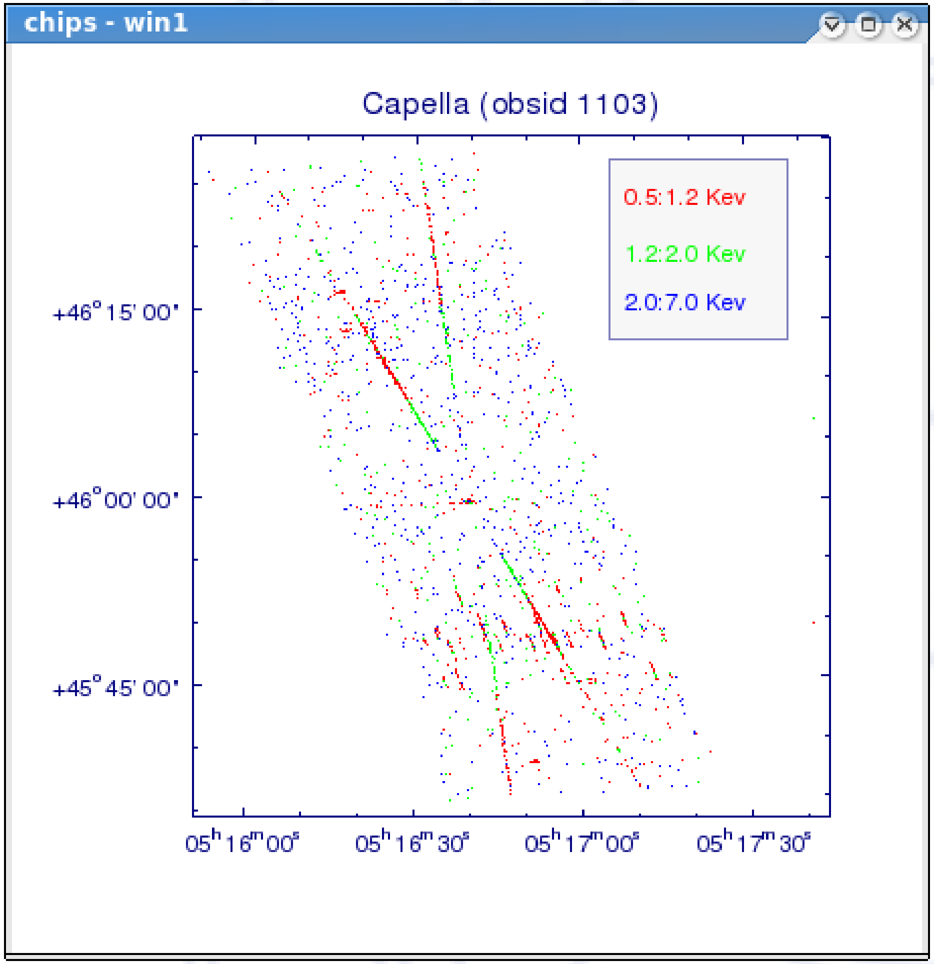
ChIPS

Chandra Image and Plotting System

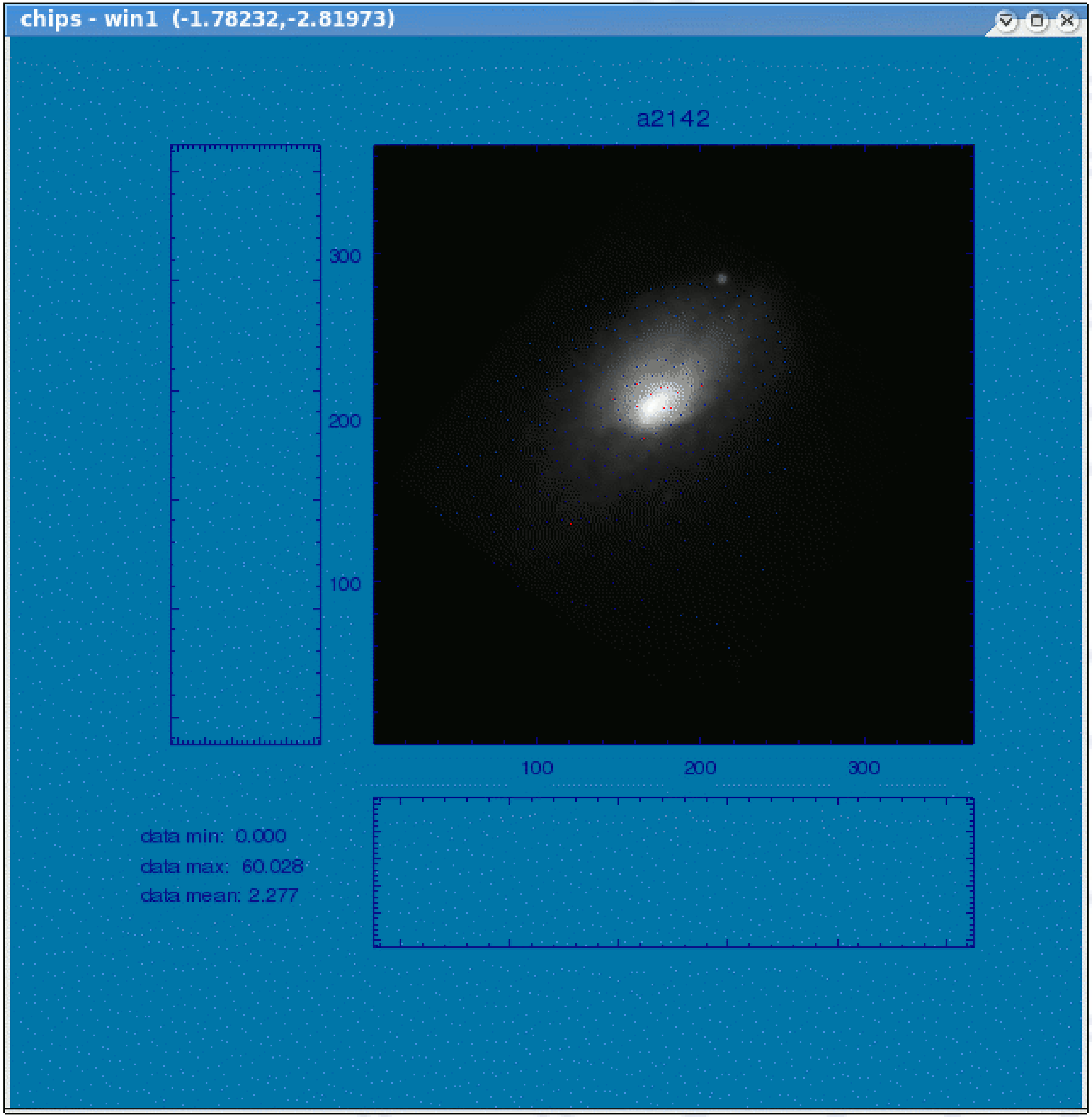
Multiple plots, multiple axes!

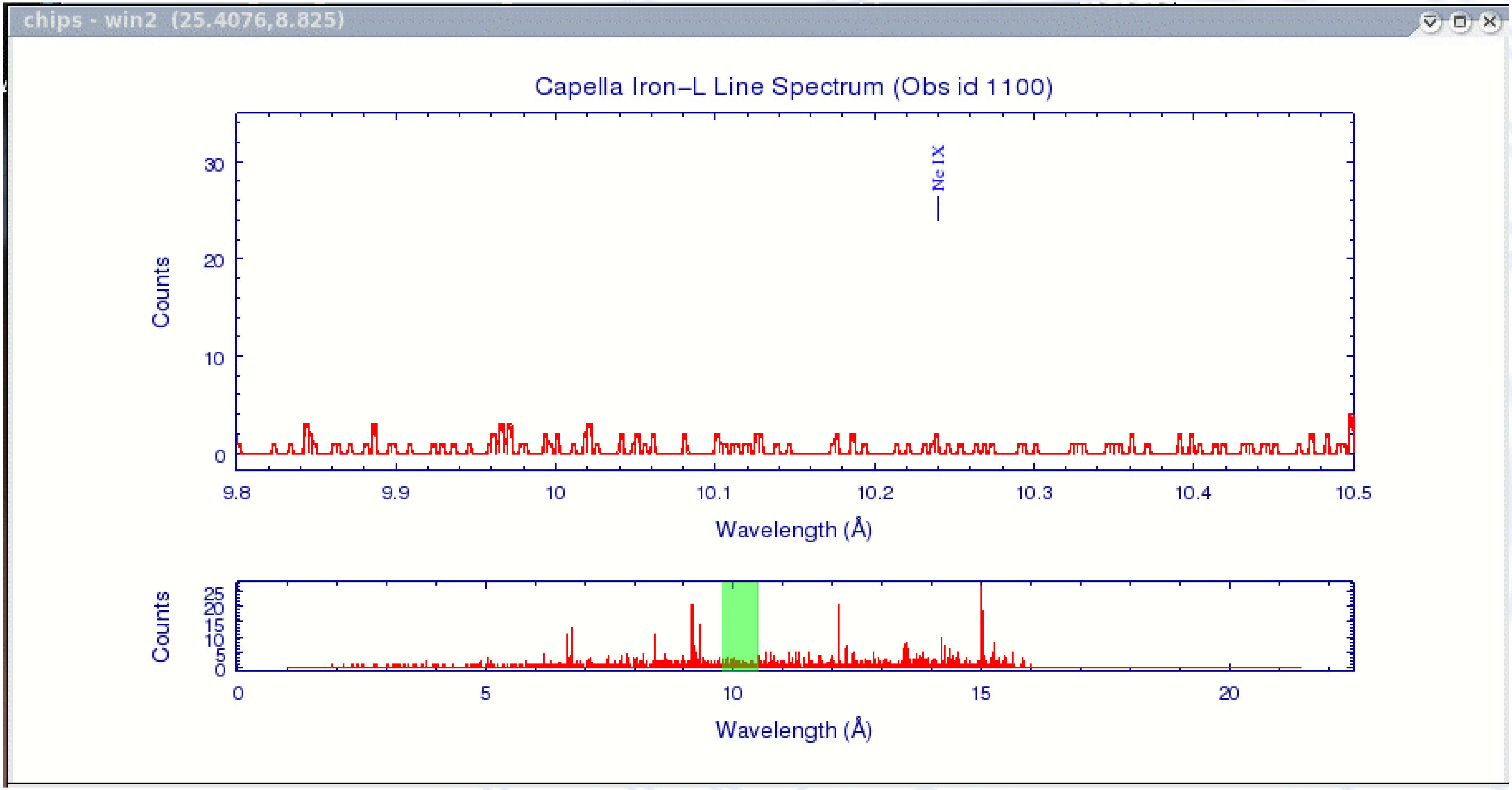


Plotting events from an event list, in multiple energy bands, using WCS



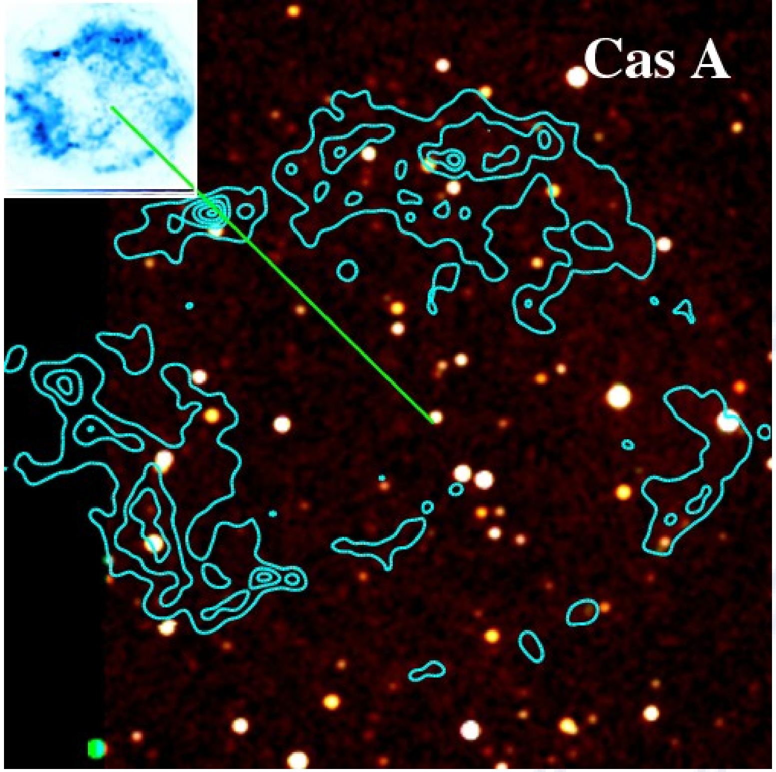
ChIPS is interactive!

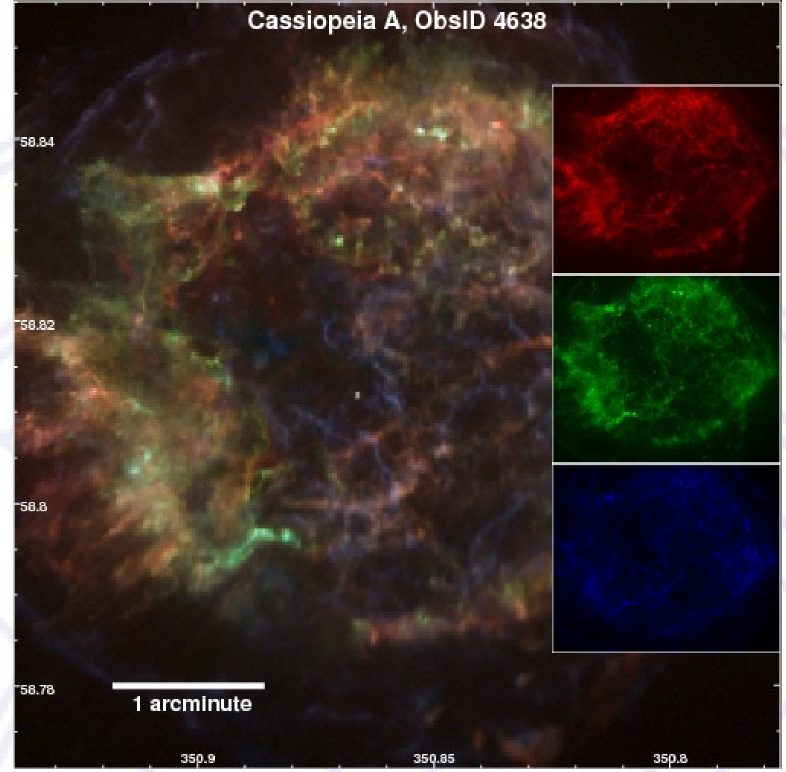

chips - win1 (-1.78232,-2.81973)
a2142
300
200
100
100
200
300
data min: 0.000
data max: 60.028
data mean: 2.277

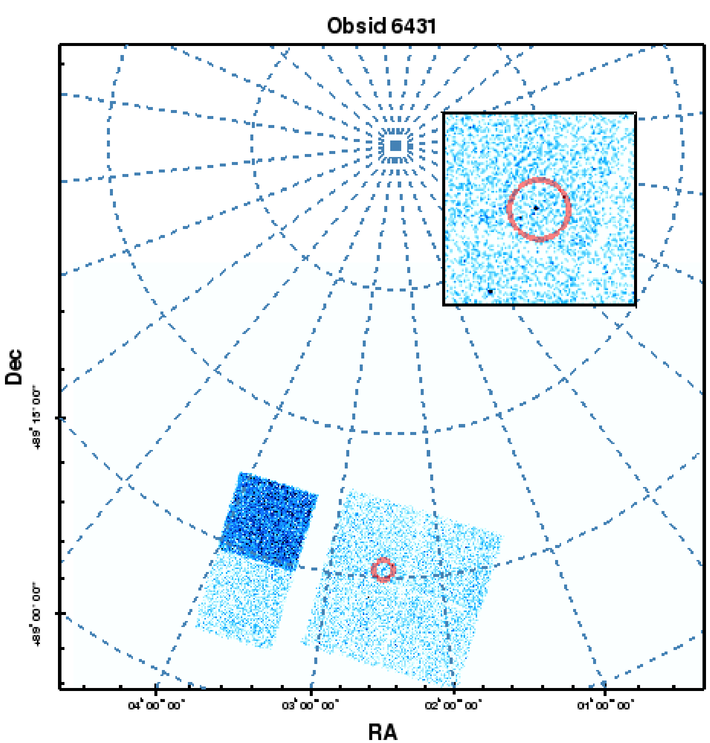


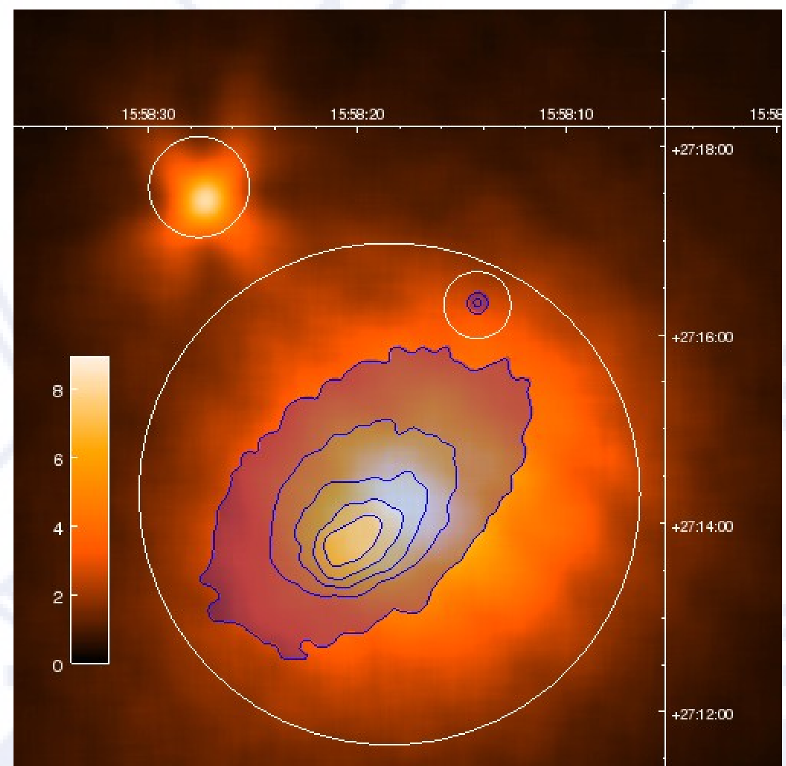
A little scripting is all that is necessary to interactively browse the line-rich Capella spectra.
(Lines were pre-selected)

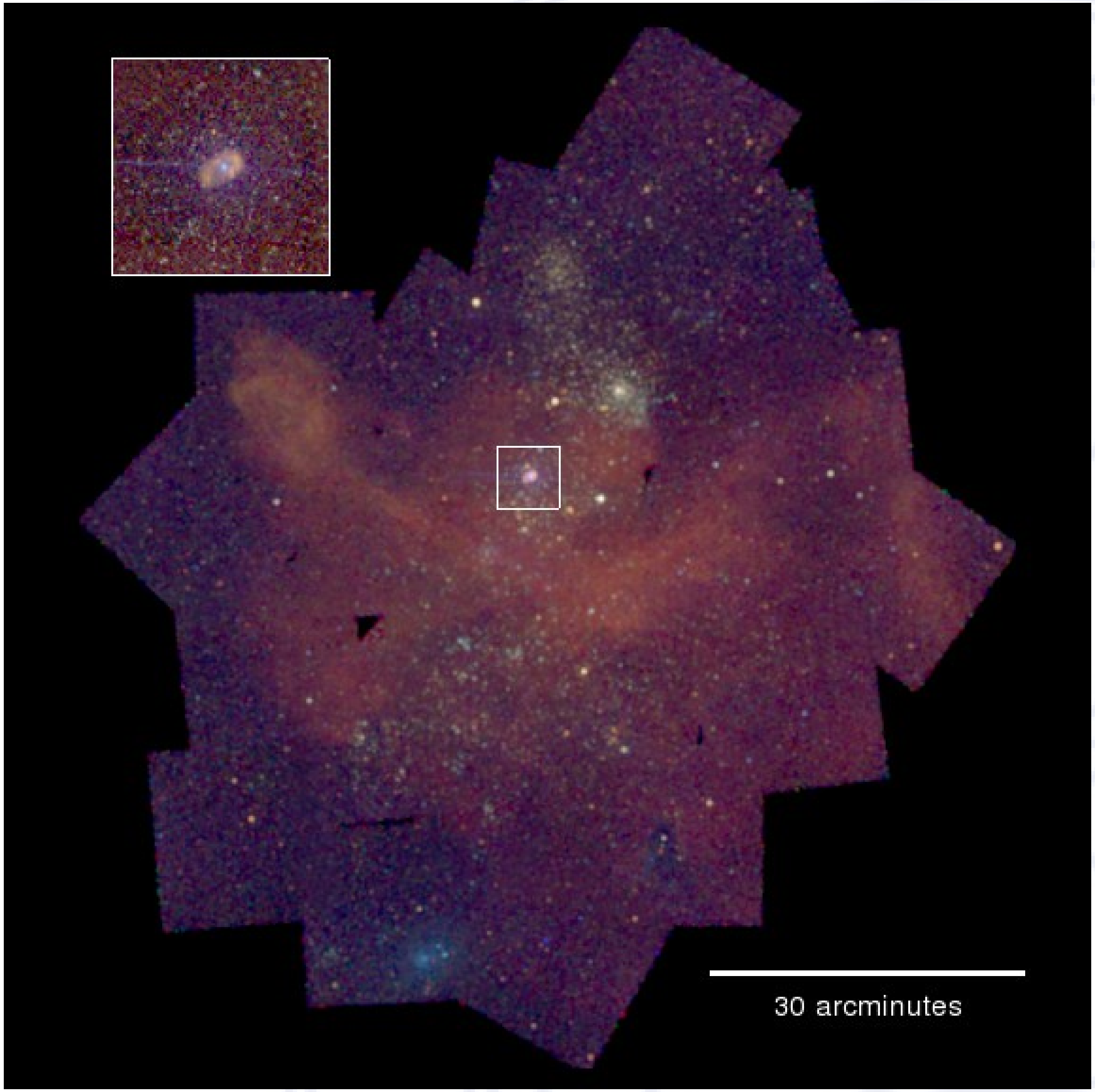
Images: Putting the “I” in ChIPS


Cas A


Cassiopeia A, ObsID 4638
58.84
58.82
58.8
58.78
1 arcminute
350.9
350.85
350.8

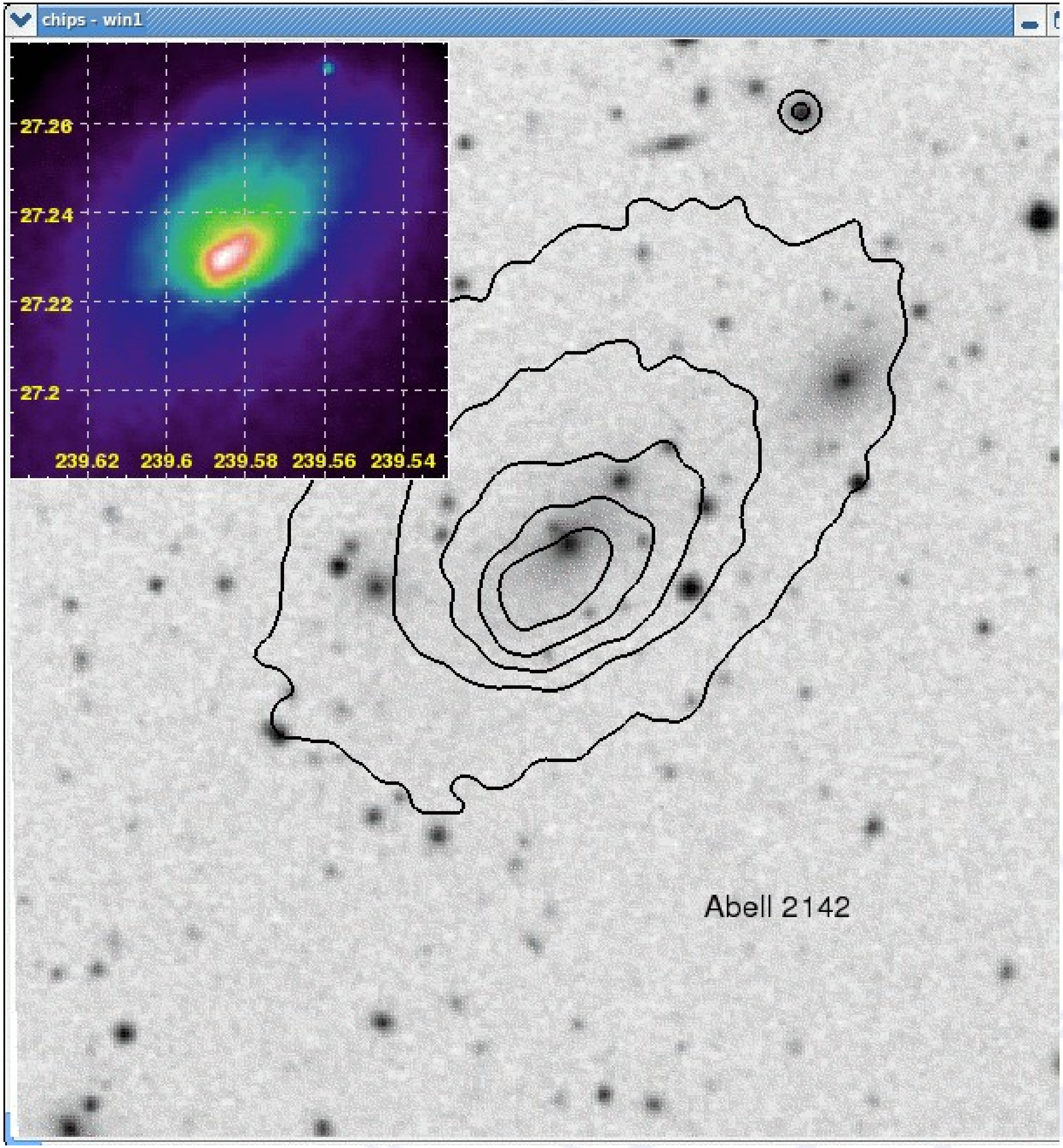

Obsid 6431
Dec
RA


15:58:30
15:58:20
15:58:10
+27:18:00
+27:16:00
+27:14:00
+27:12:00
8
6
4
2
0

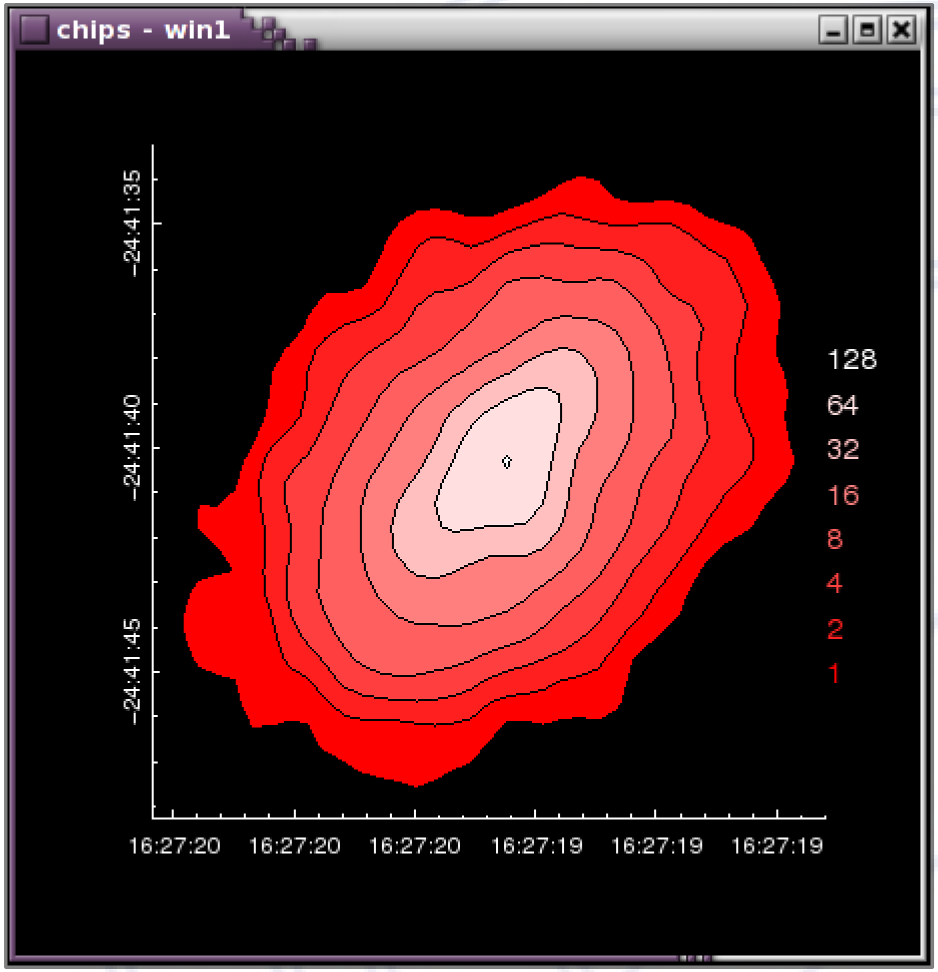


A Chandra mosaic of the Carinae Nebula with Eta Carinae shown at full resolution in the inset image.

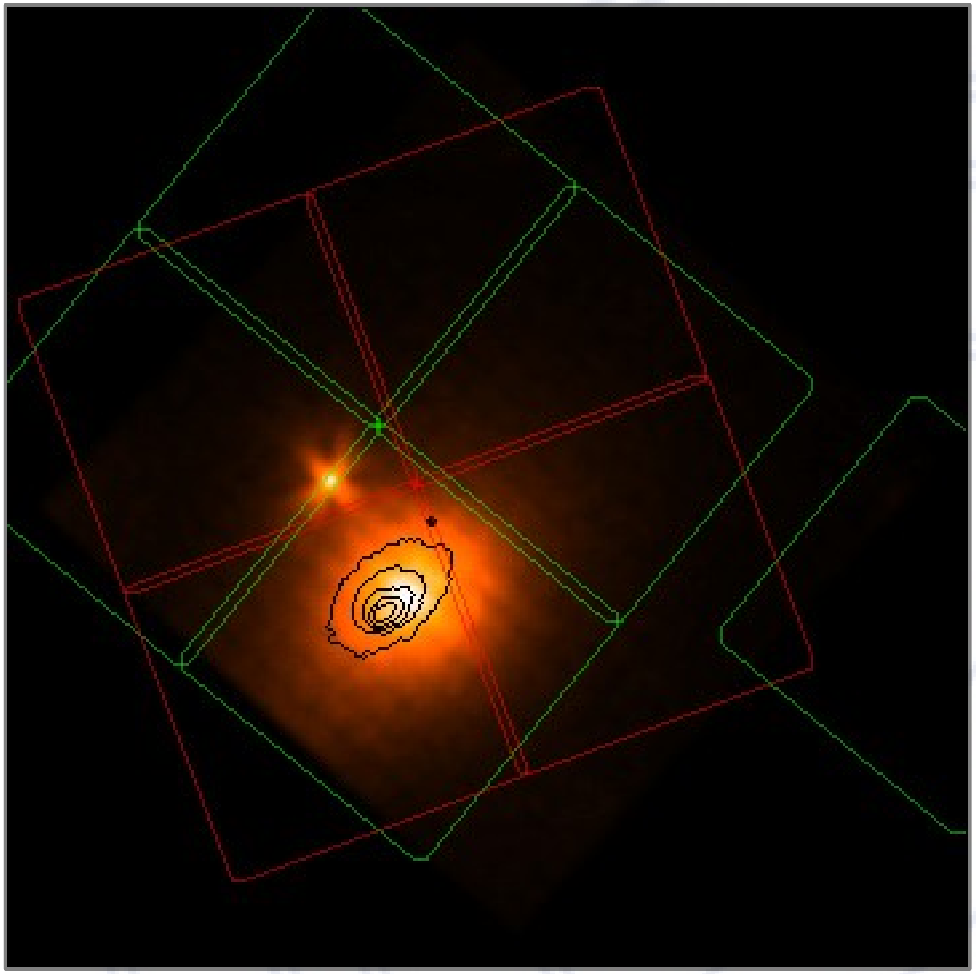
Interactive pan and zoom is built into ChIPS.



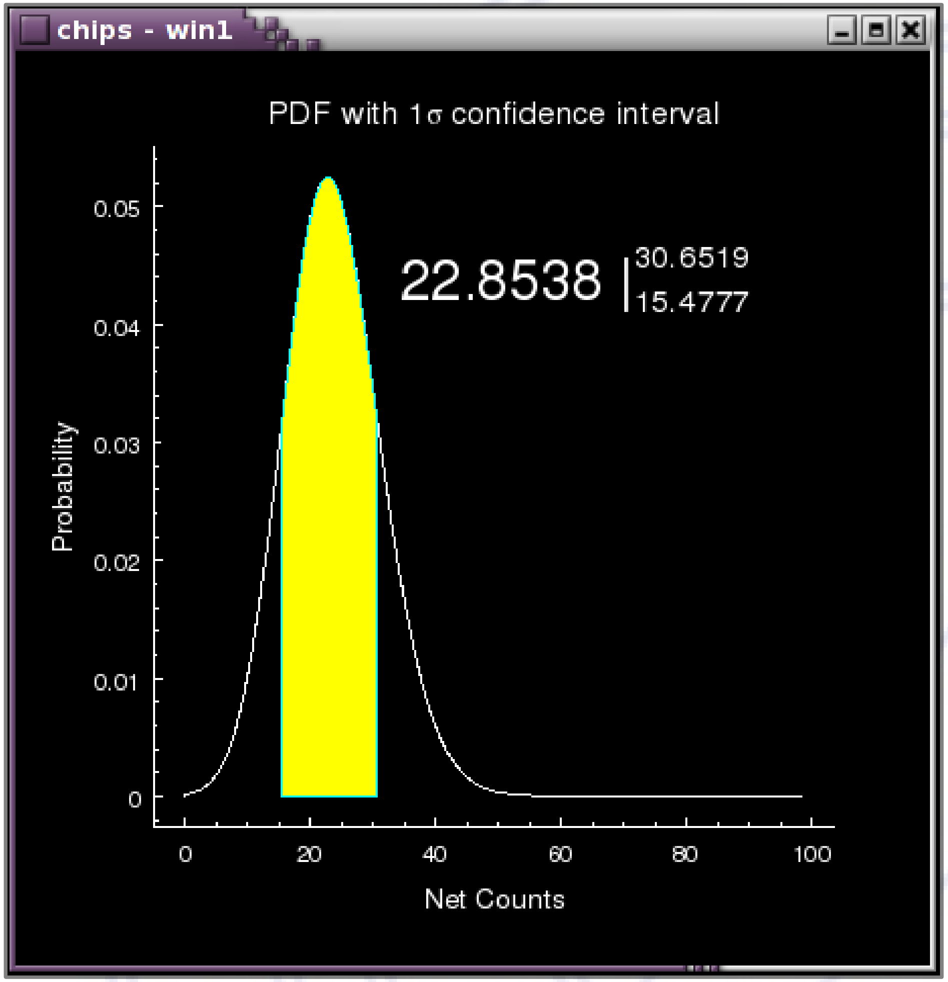
ChIPS Gallery



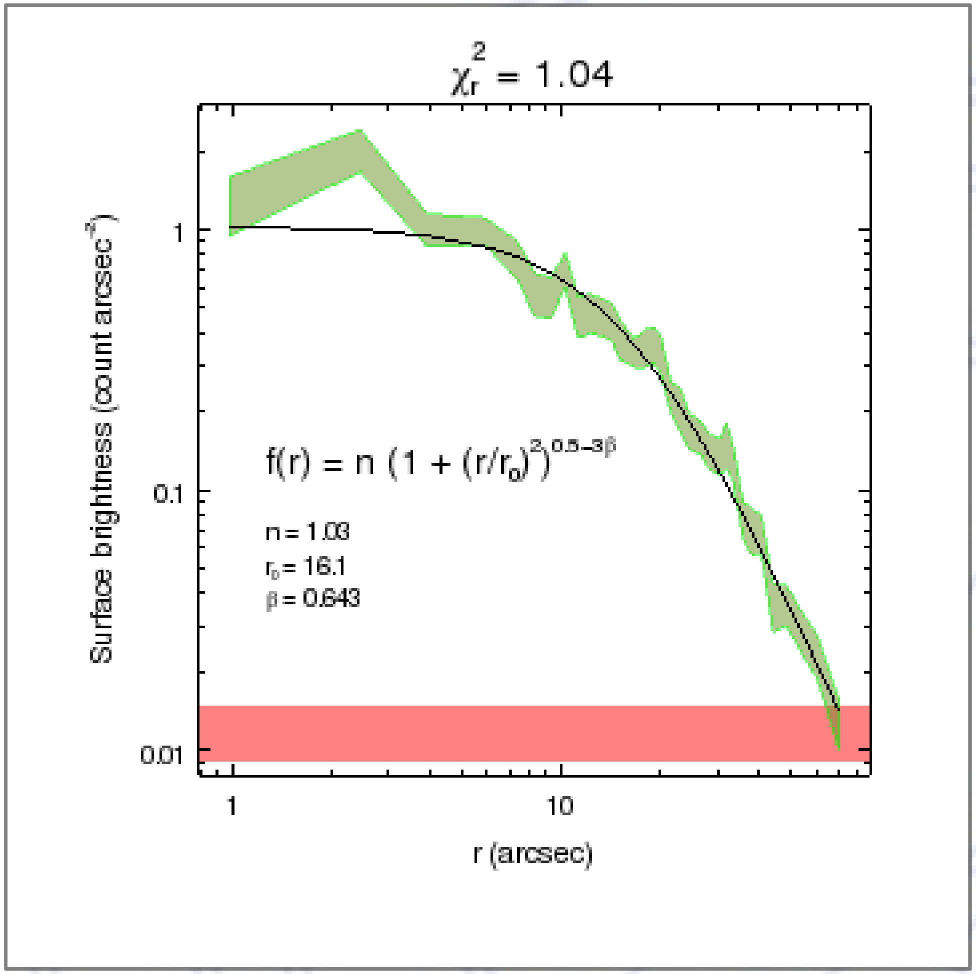
An image of an off-axis point-like source, CXO J162719.5-244140, imaged in OBS_ID 635. Counts are shown as a series of contours created with dmcontour and drawn as regions.



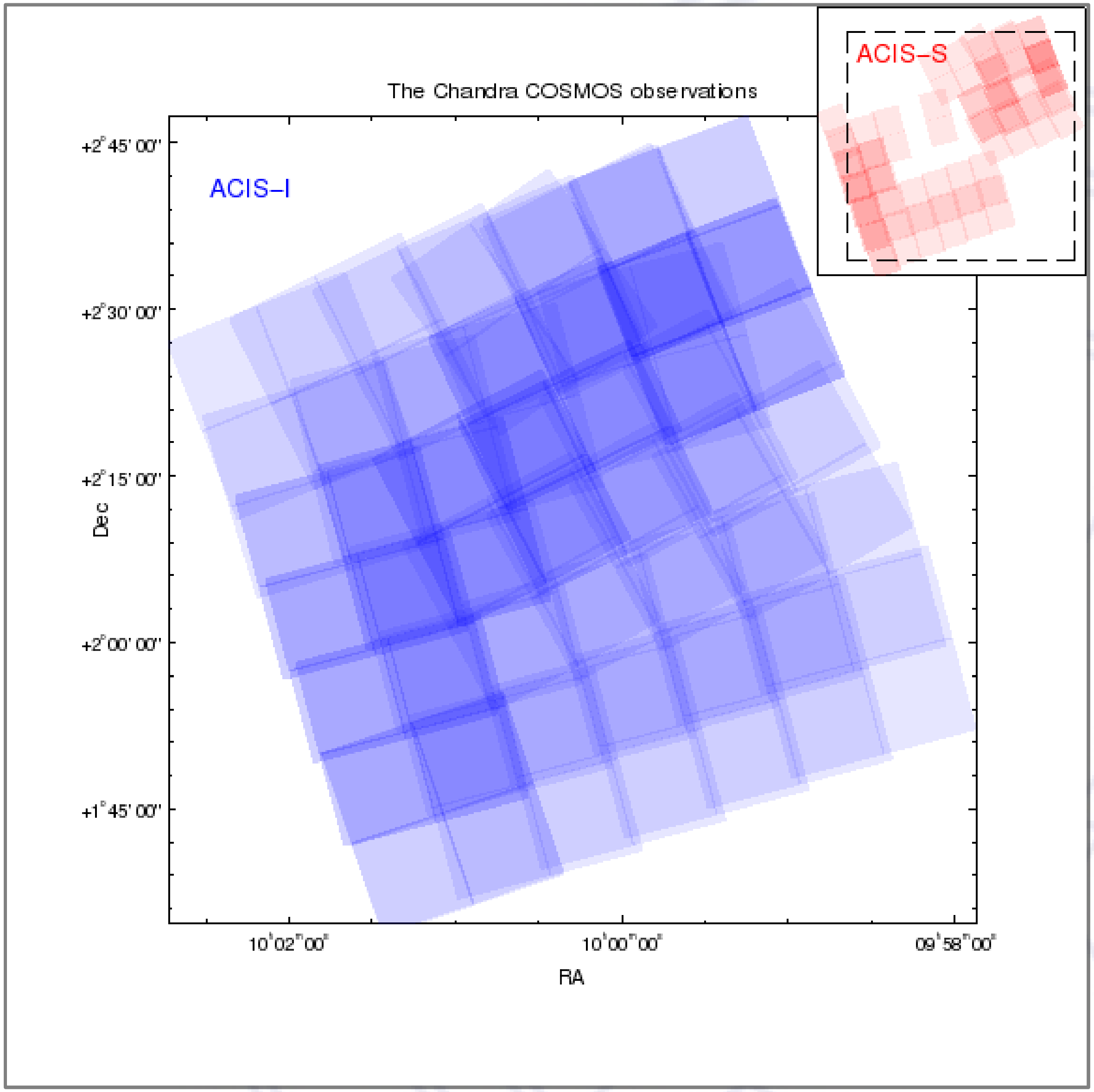
A Suzaku dataset of Abell 2142 with Chandra contours drawn on the cluster. Chandra FOV files are also shown.



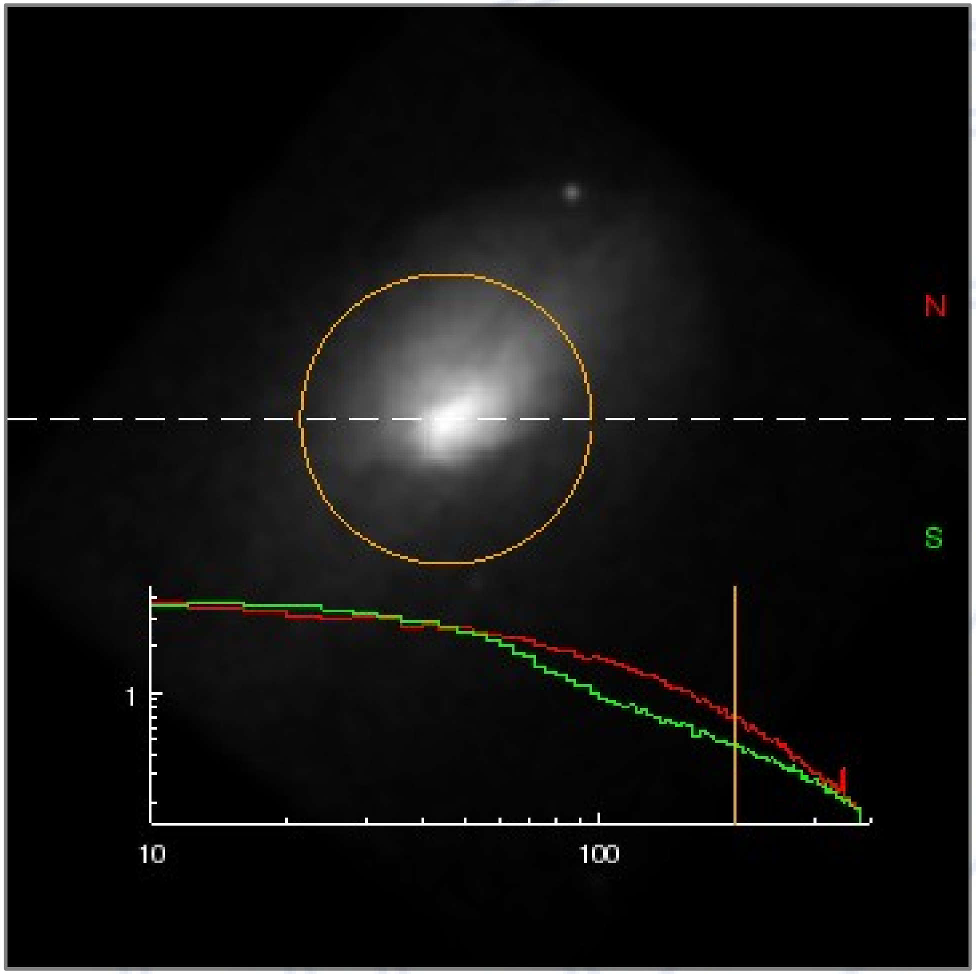
The PDF output from aprates showing the 1σ confidence interval. Histograms can be filled. Support for Greek letters and many other LaTeX symbols, as well as super and subscripts.



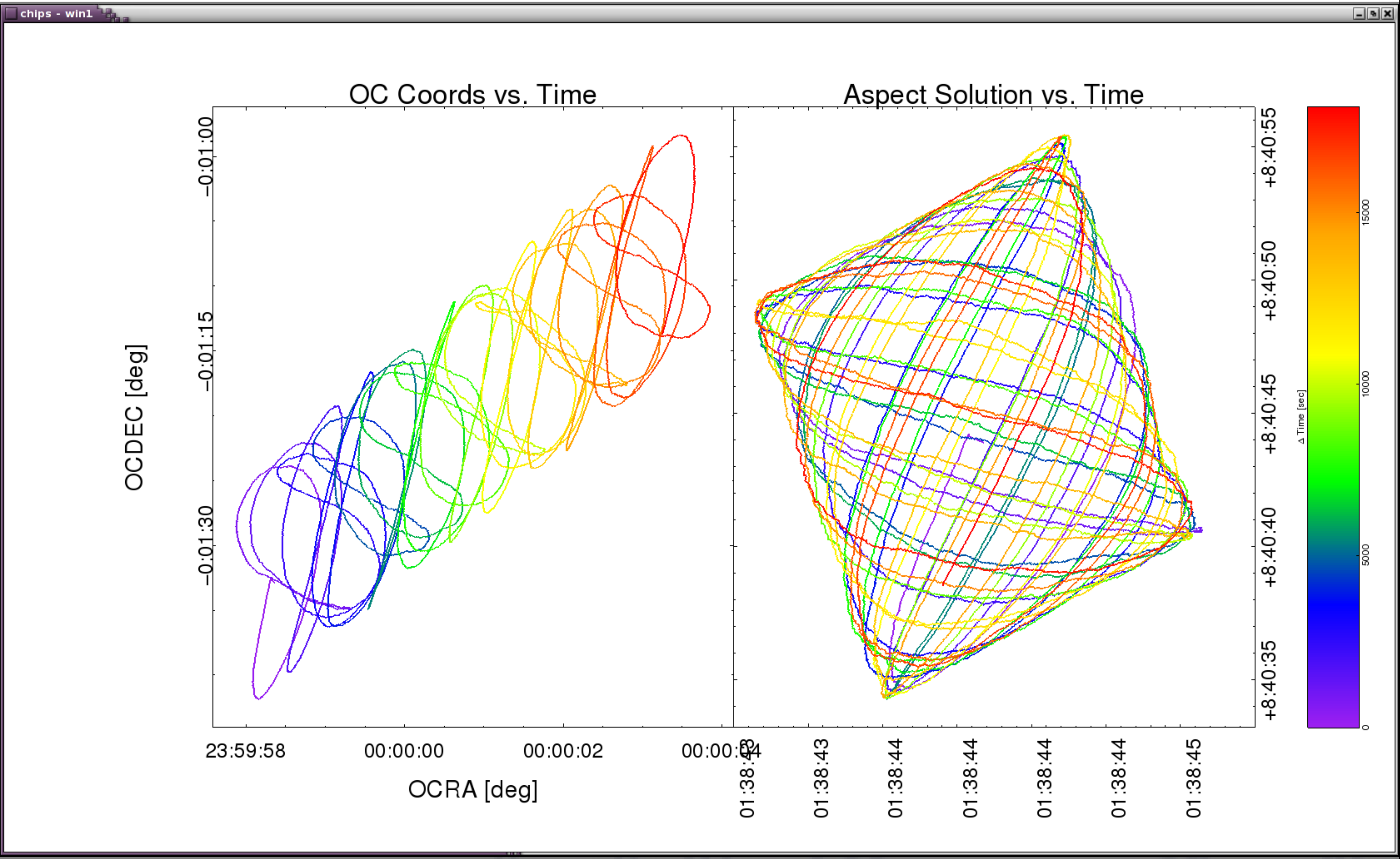
Supports complicated expressions in labels



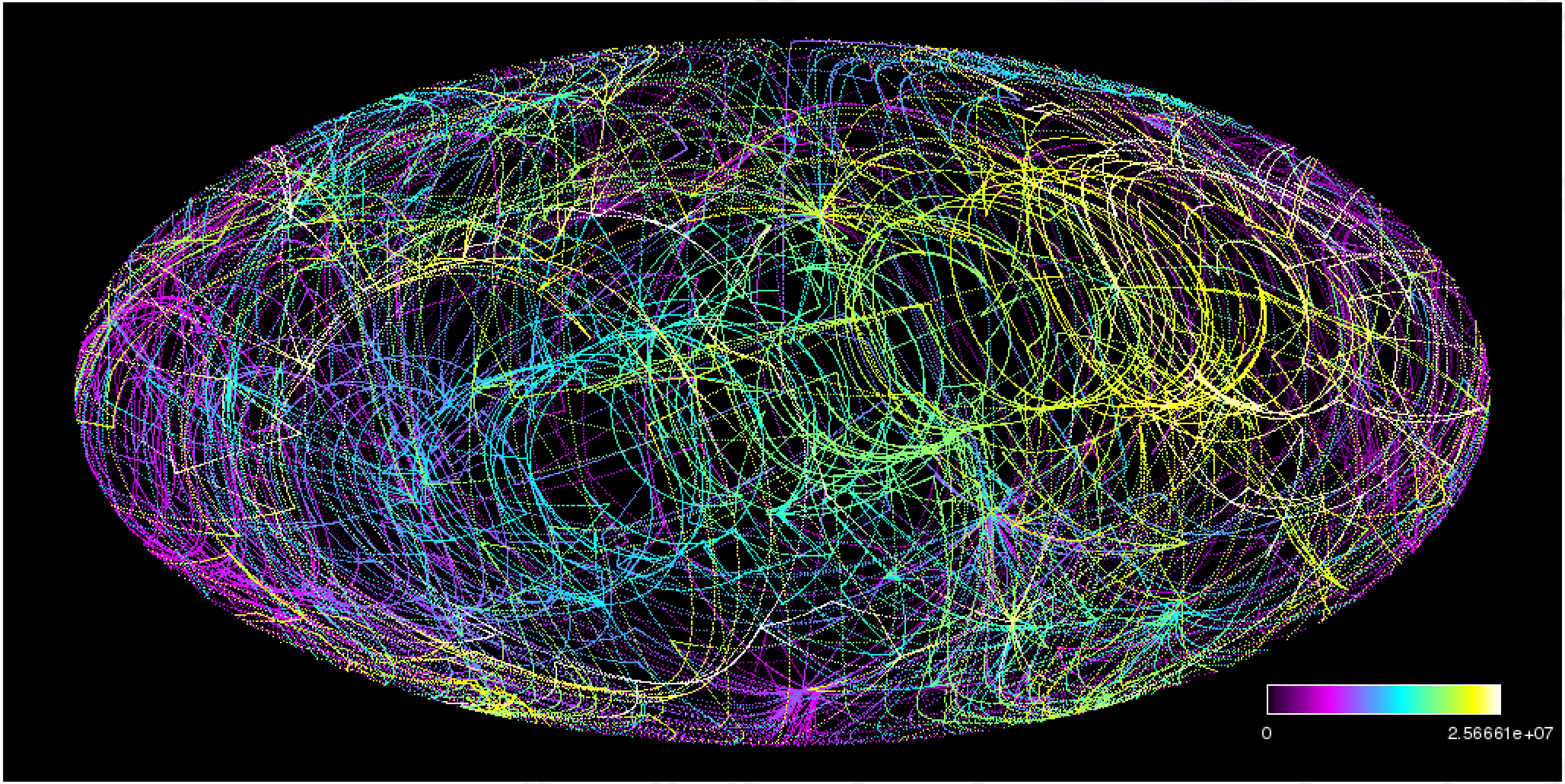
Field of view files can be plotted using the Python add_fov_region routine.



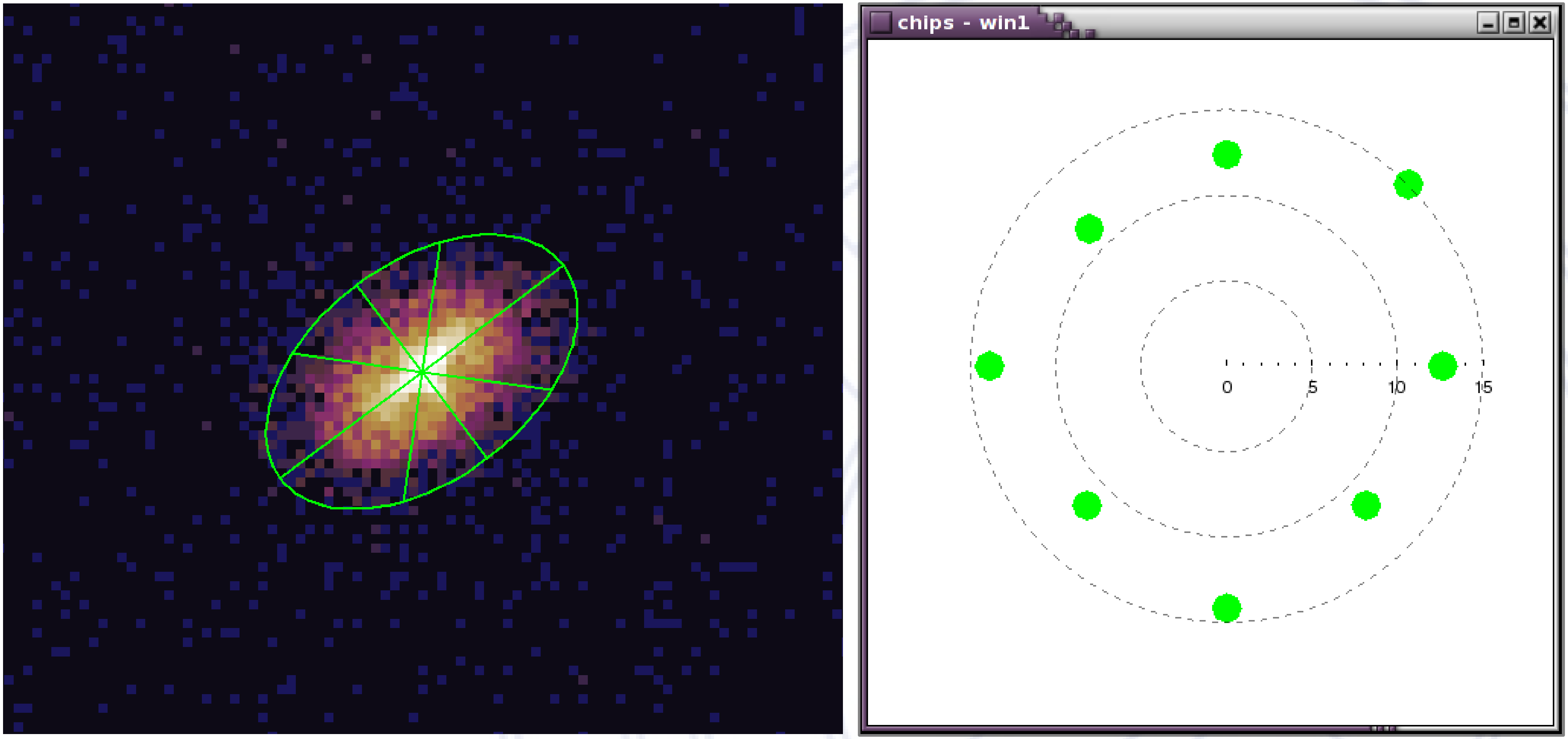
Plots can be drawn on images and images can be inset into plots as seen in this North vs. South radial profile plots of Abell 2142.



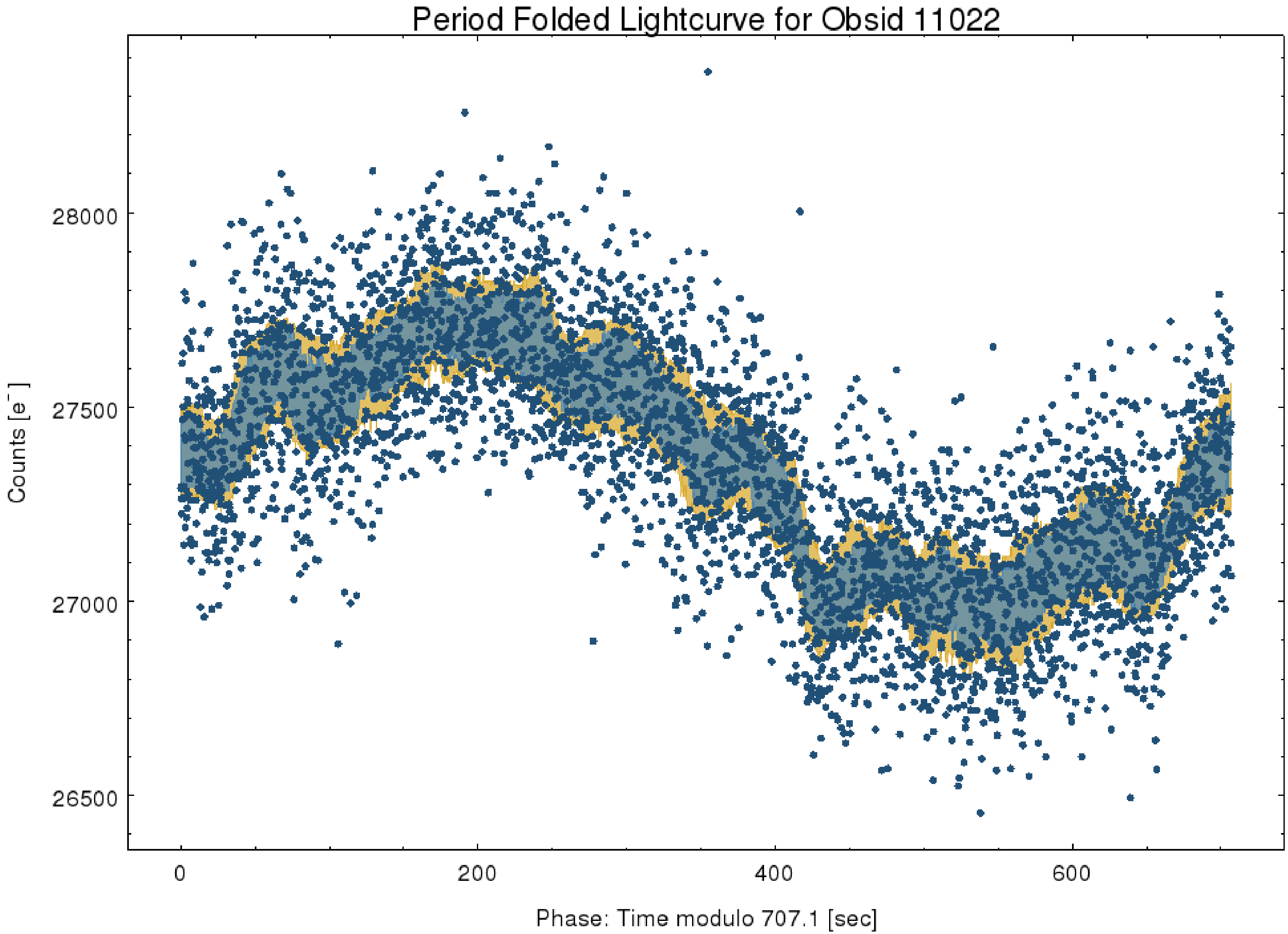
Complex plots can be made using multiple curves as in this time-color-code plot of the Object Center (OC) aspect solution for Jupiter that was output from sso_freeze



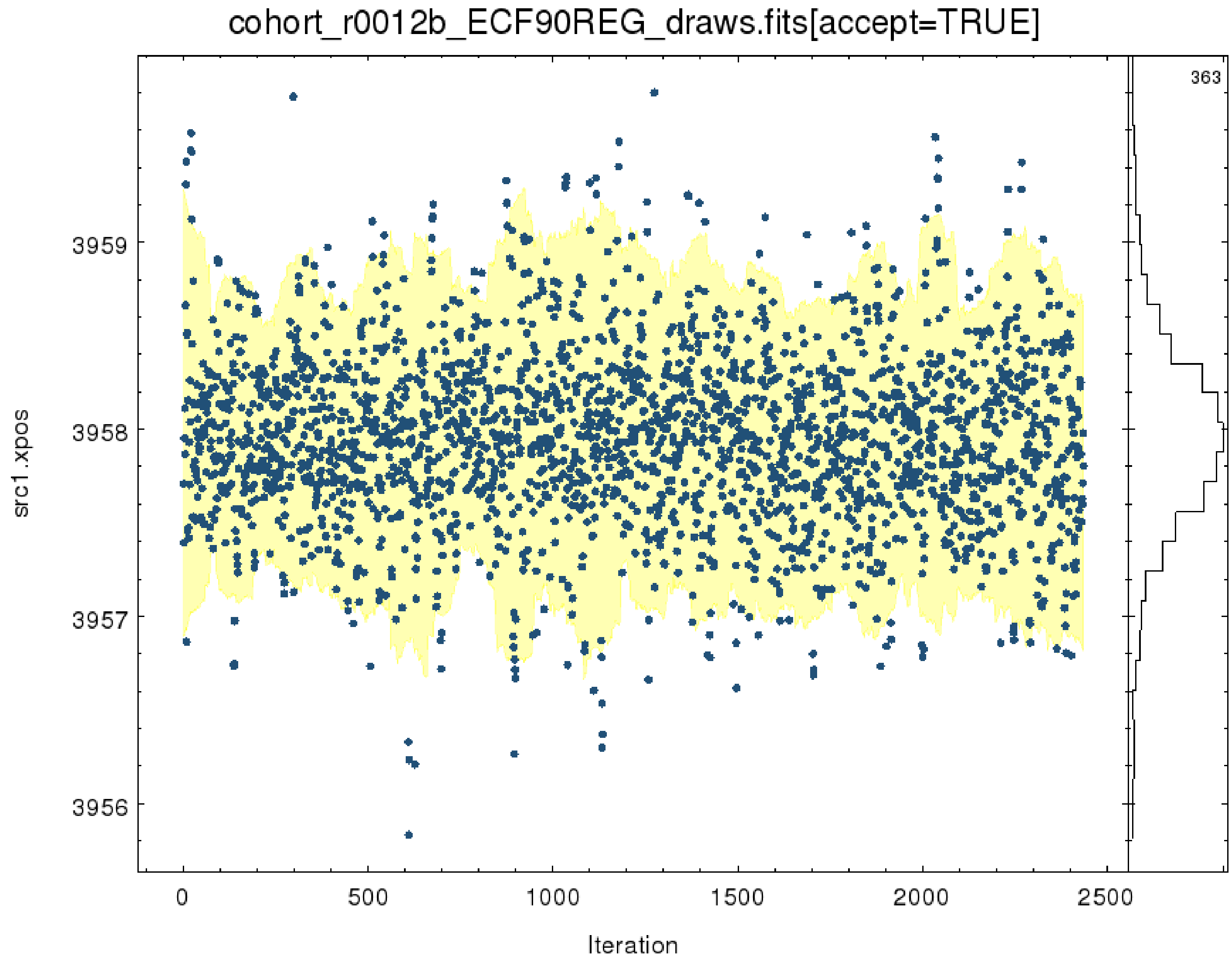
Where has Chandra been? All of the on board aspect solution (osol) files for 2010 were merged into a single dataset with dmmerge and then down-sampled with dmtcalc. Above is the RA and Dec for the entire year plotted in ChIPS where the color represents the time (seconds) since the beginning of the year.



Plots can be highly customized. (Left) an off-axis source with PIE shaped regions. These regions are used with dmextract to get the number of counts in each angular slice. (Right) the data are plotted in ChIPS on a polar grid.

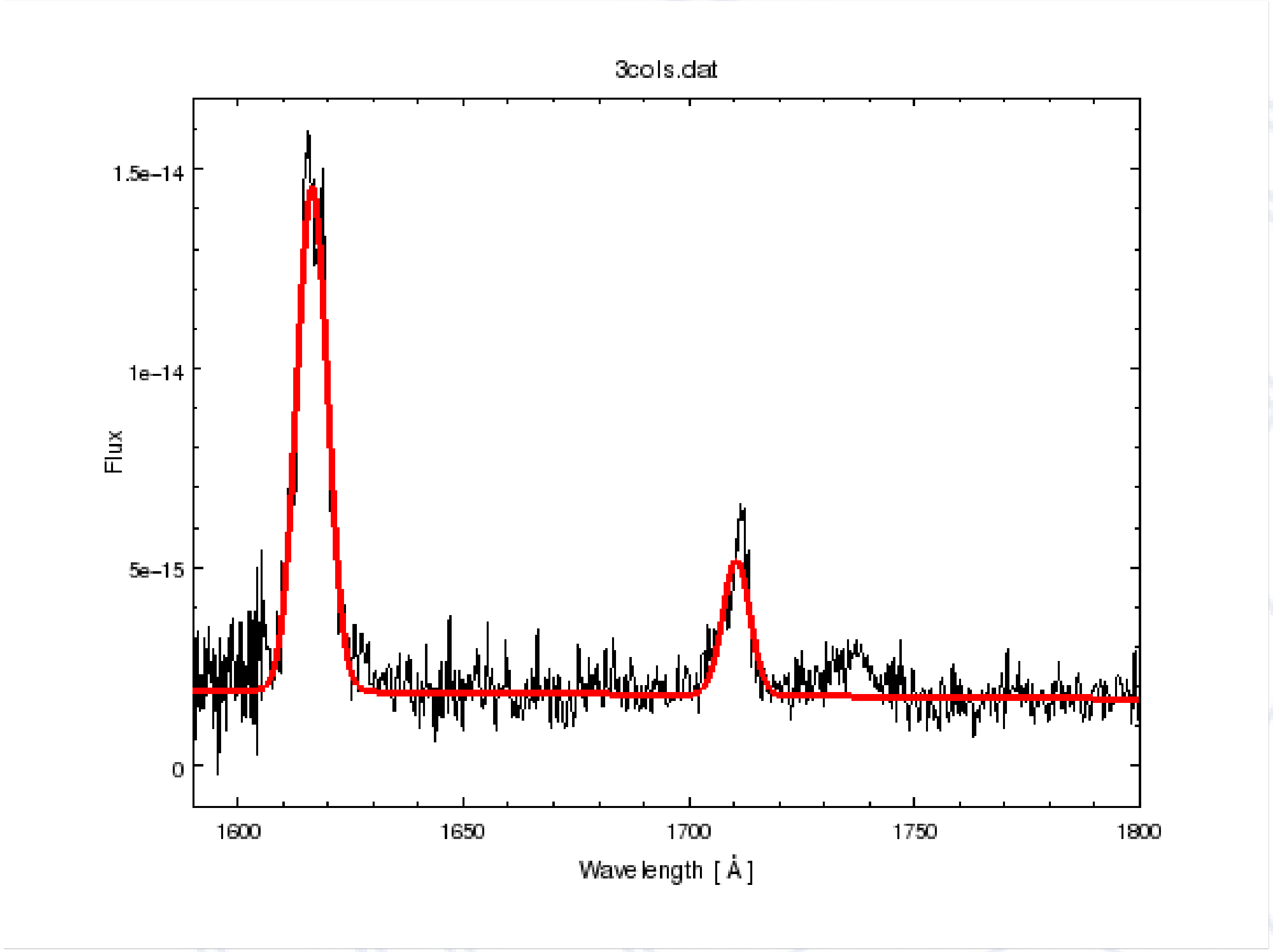


An optical light curve taken from an ACA Optical Monitor observation, created with monitor_photom, that has been folded at the 707.1 sec dither frequency (dmtcalc). The inner blue curve represents the 33% to 67% quantile region within a +/- 50 sample window; the yellow curve is the 25% to 75% quantile region. Both were computed with dmtabfilt.

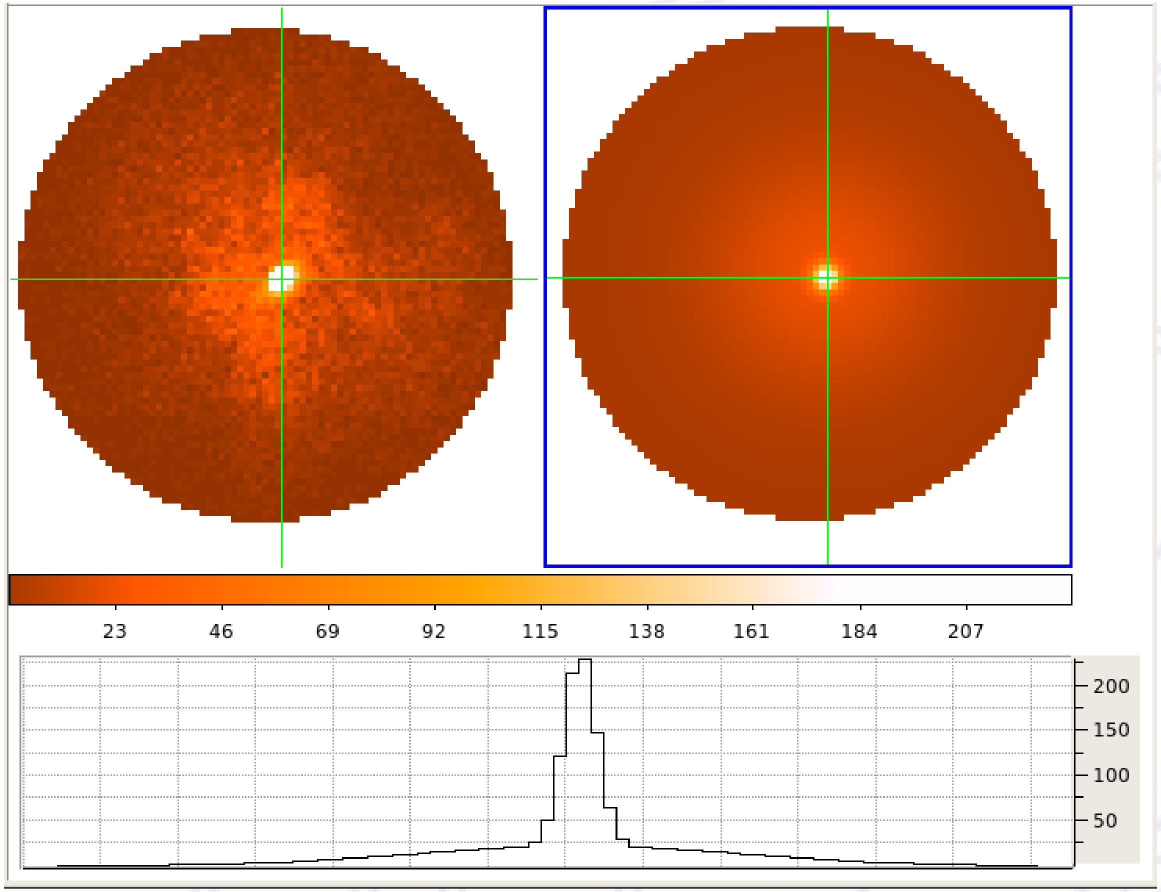


The output from sherpa's get_draws() routine showing the results of several MCMC iterations. The yellow region represents the local +/- 2 σ envelope. The vertical histogram is computed with NumPy and is centered on the mean of the sample.

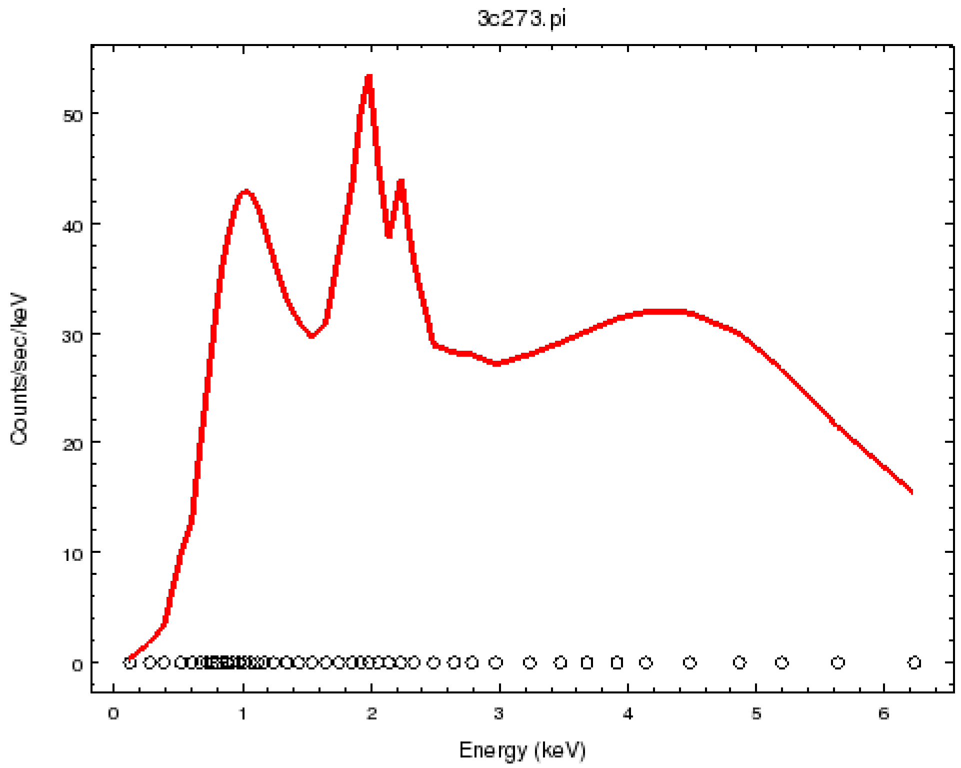
Sherpa



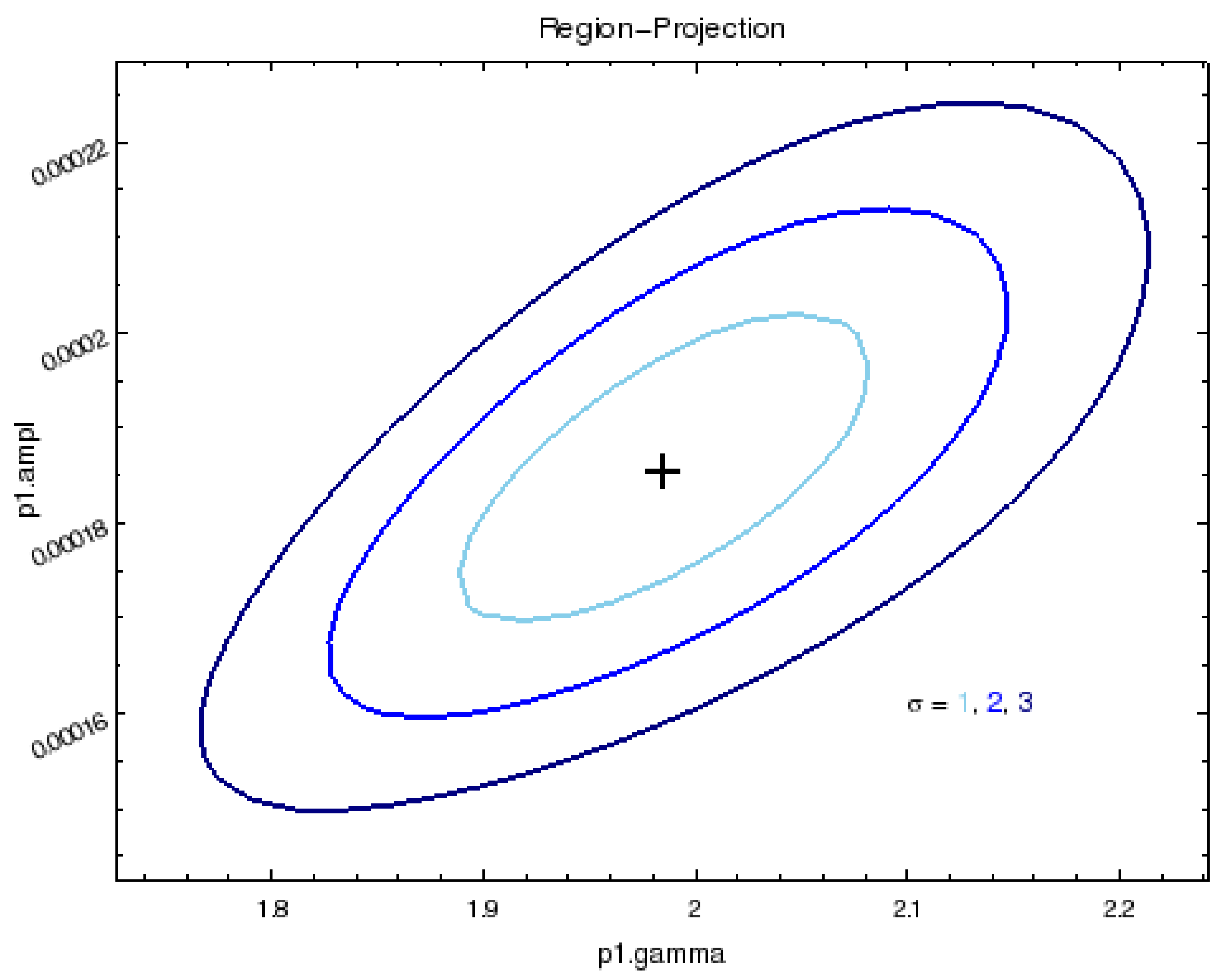
Sherpa is a general purpose modeling and fitting engine. While it has certain short cuts for high energy astronomy conventions, it can be used to model all types of data. Above is an optical wavelength dataset imported from an ASCII file.



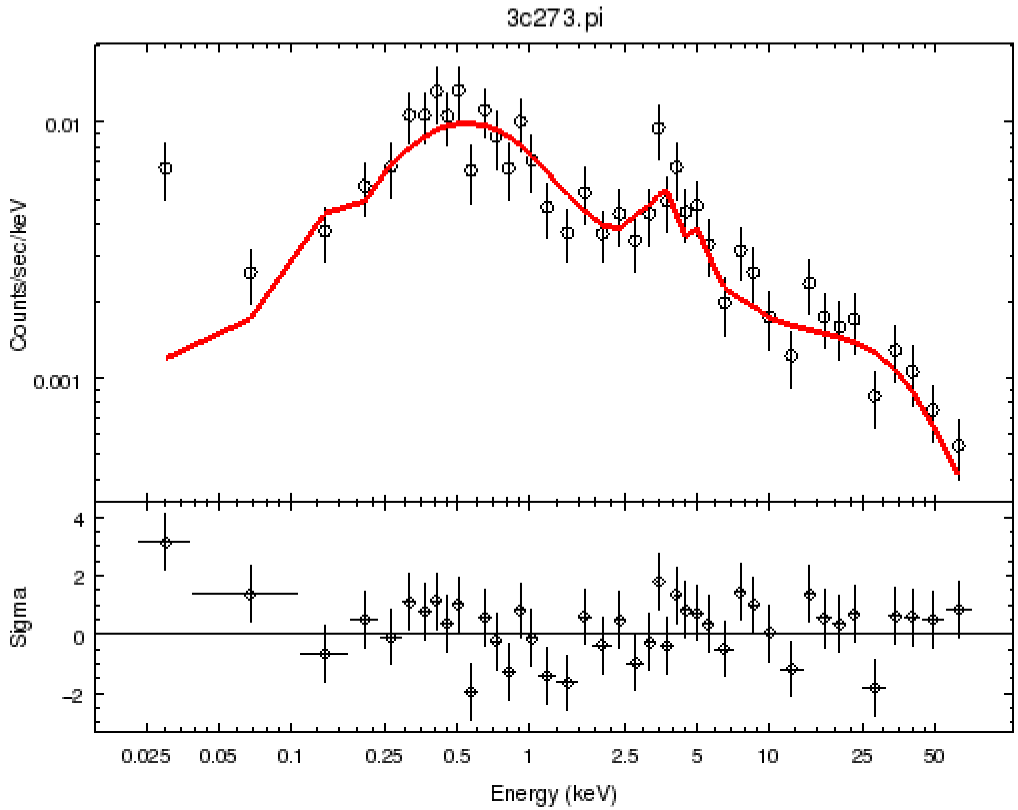
Sherpa also natively supports 2D and higher dataset. Above is a model fit to some Chandra imaging data.



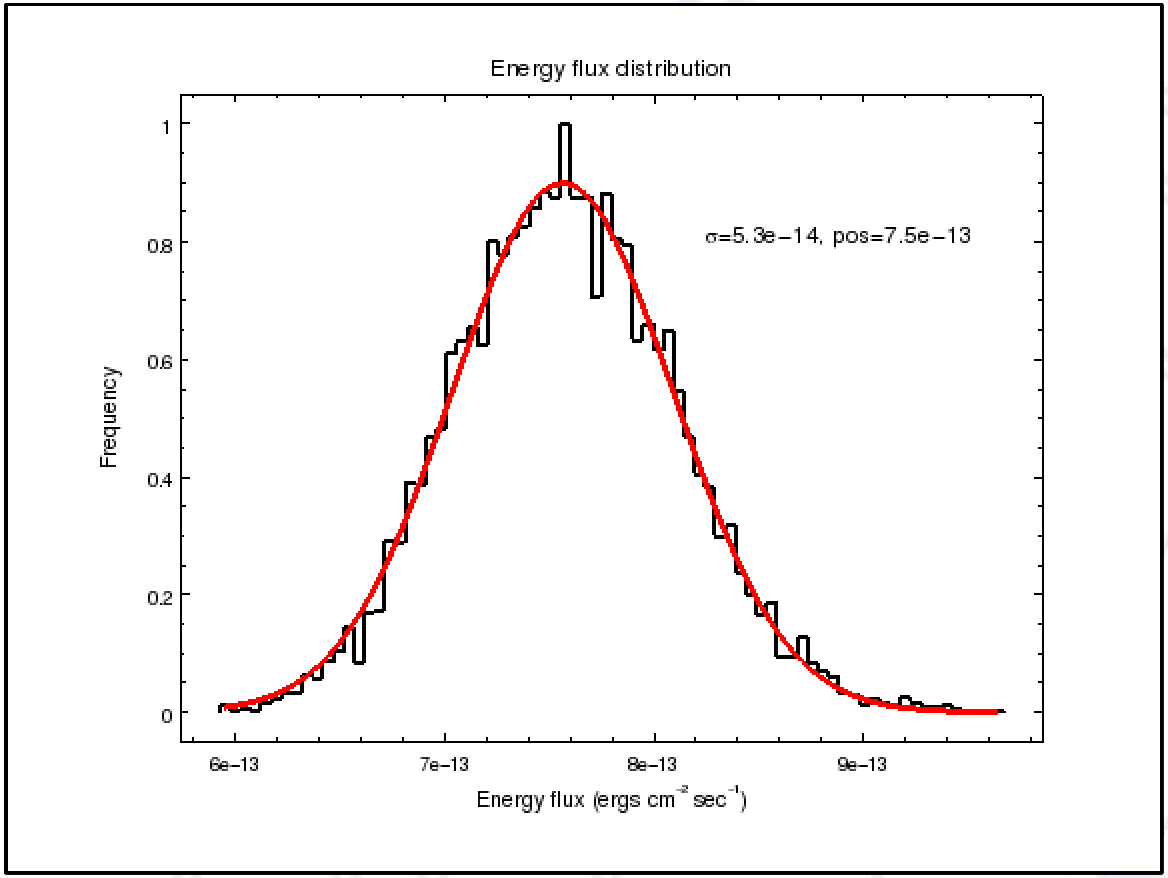
There are tradeoffs when fitting so sherpa provides several different fitting optimization methods. Users can also write their own.



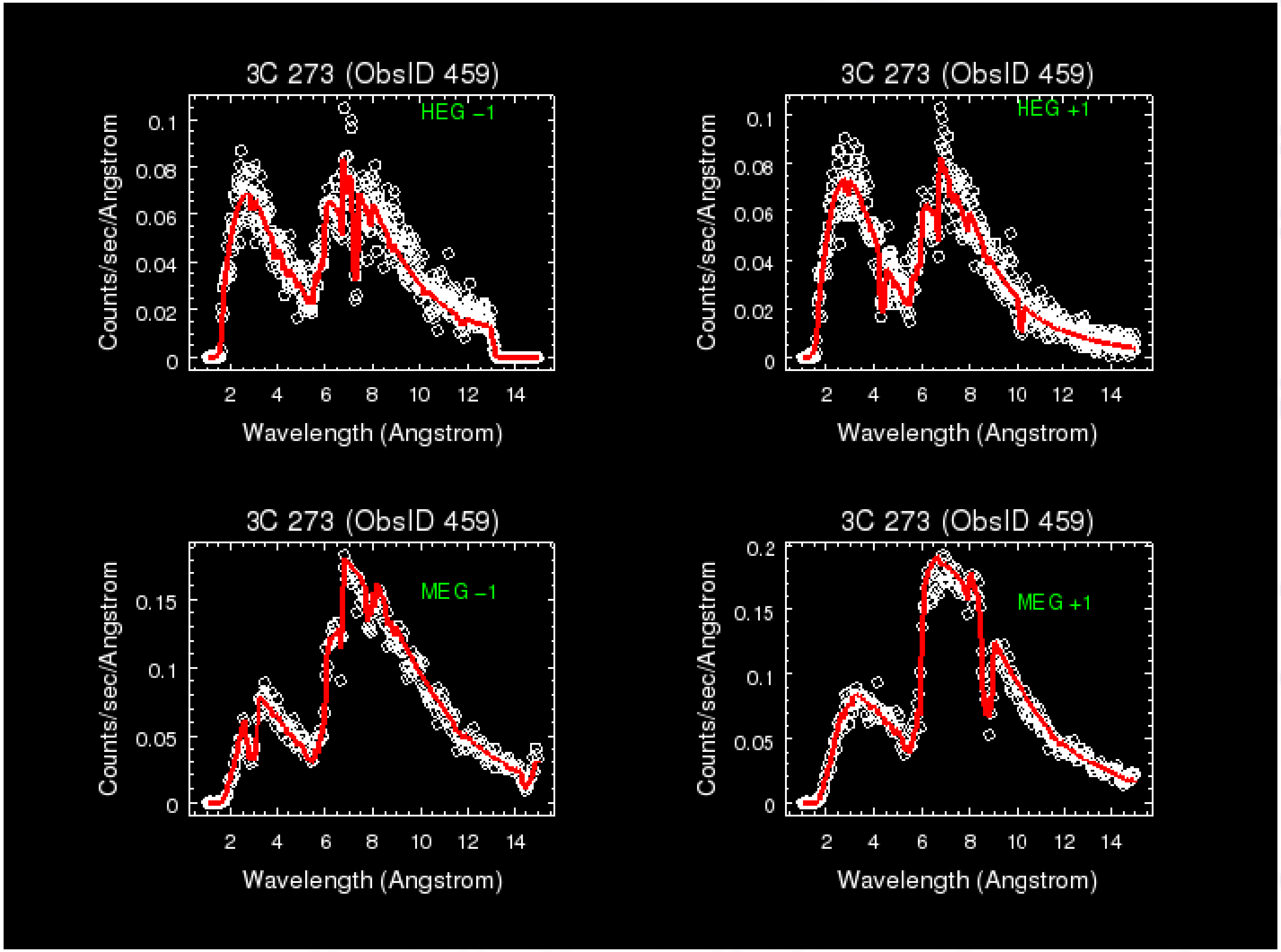
Sherpa provides several methods to compute the confidence limits on parameters, and to visualize the correlation between model parameters as is shown in this 2D region projection drawn as N-σ contours.



For X-ray data analysis, the canned sherpa plots should look familiar to most users. Above is an example of XMM-Netwon spectrum fit in the 0.025 to 50 keV range.



Using the uncertainty on individual parameters, sherpa can compute the estimated uncertainty on the integrated flux in the user specified energy band.



Multiple datasets can be fit simultaneously as in this example of a Chandra HETG grating spectrum where the different grating arms and orders are simultaneously fit.

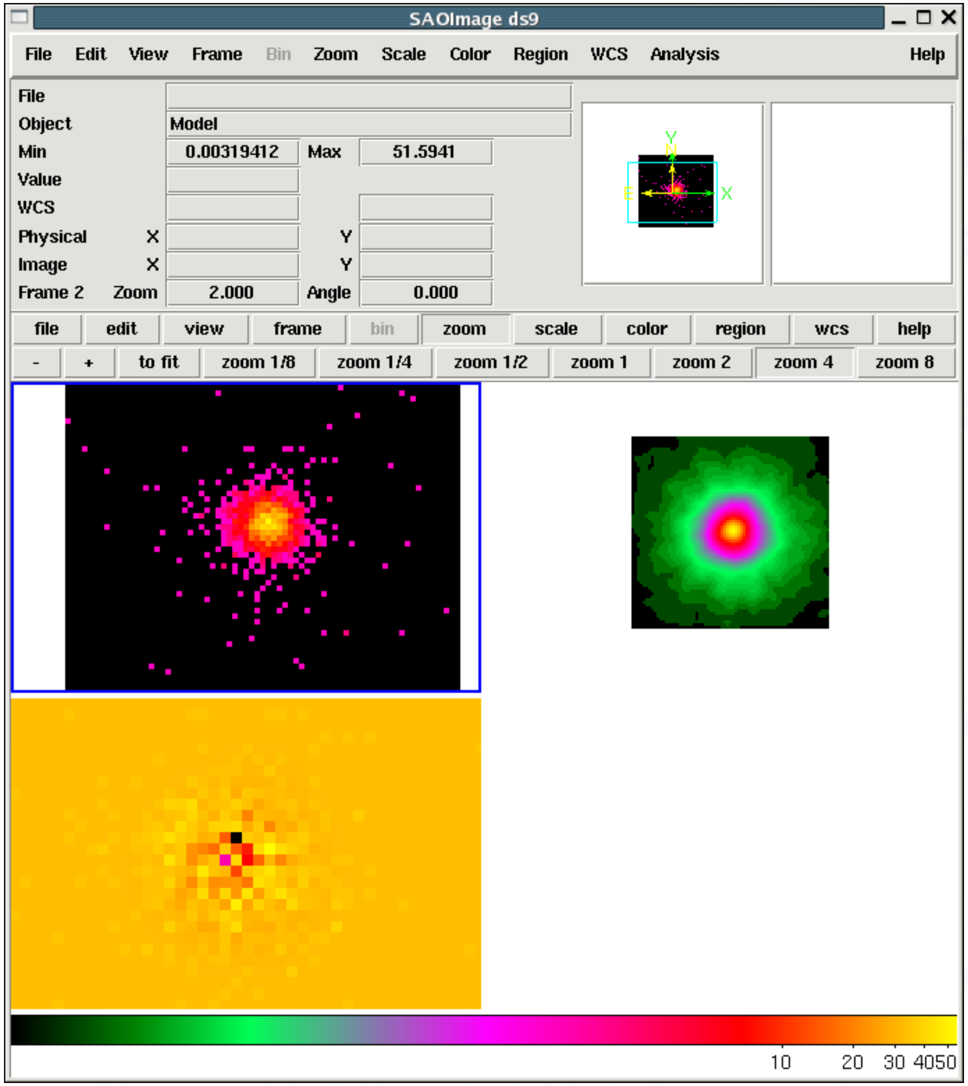
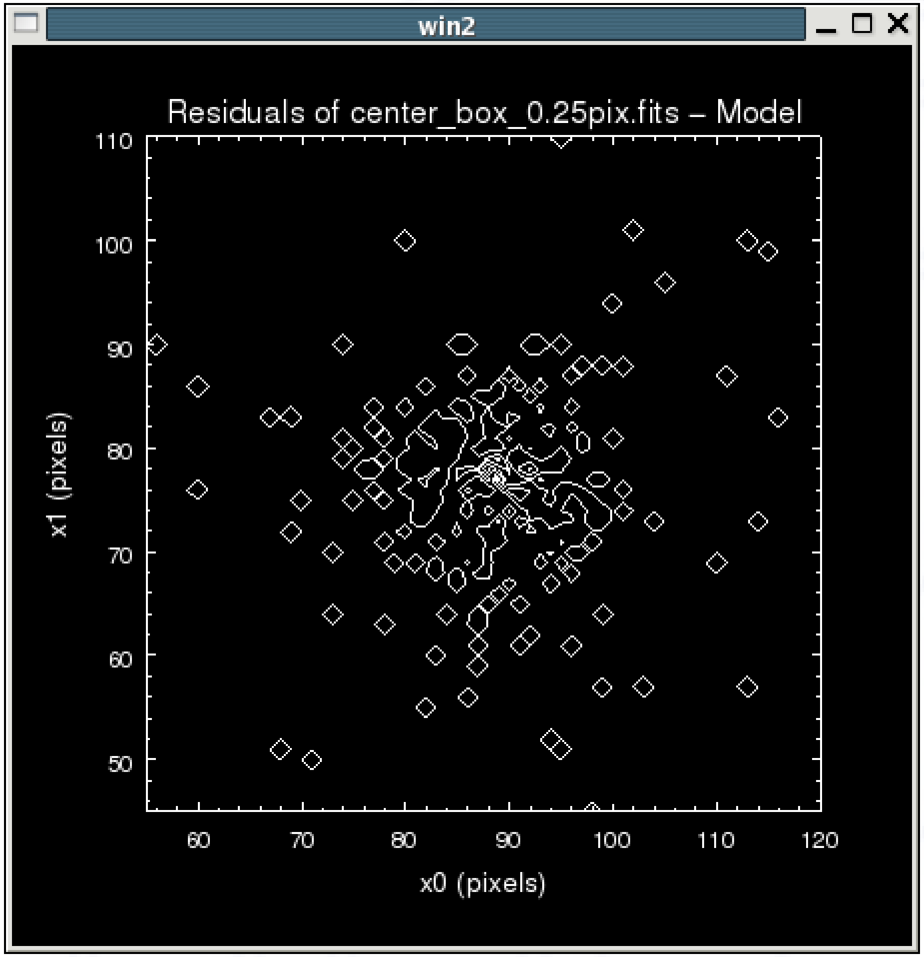
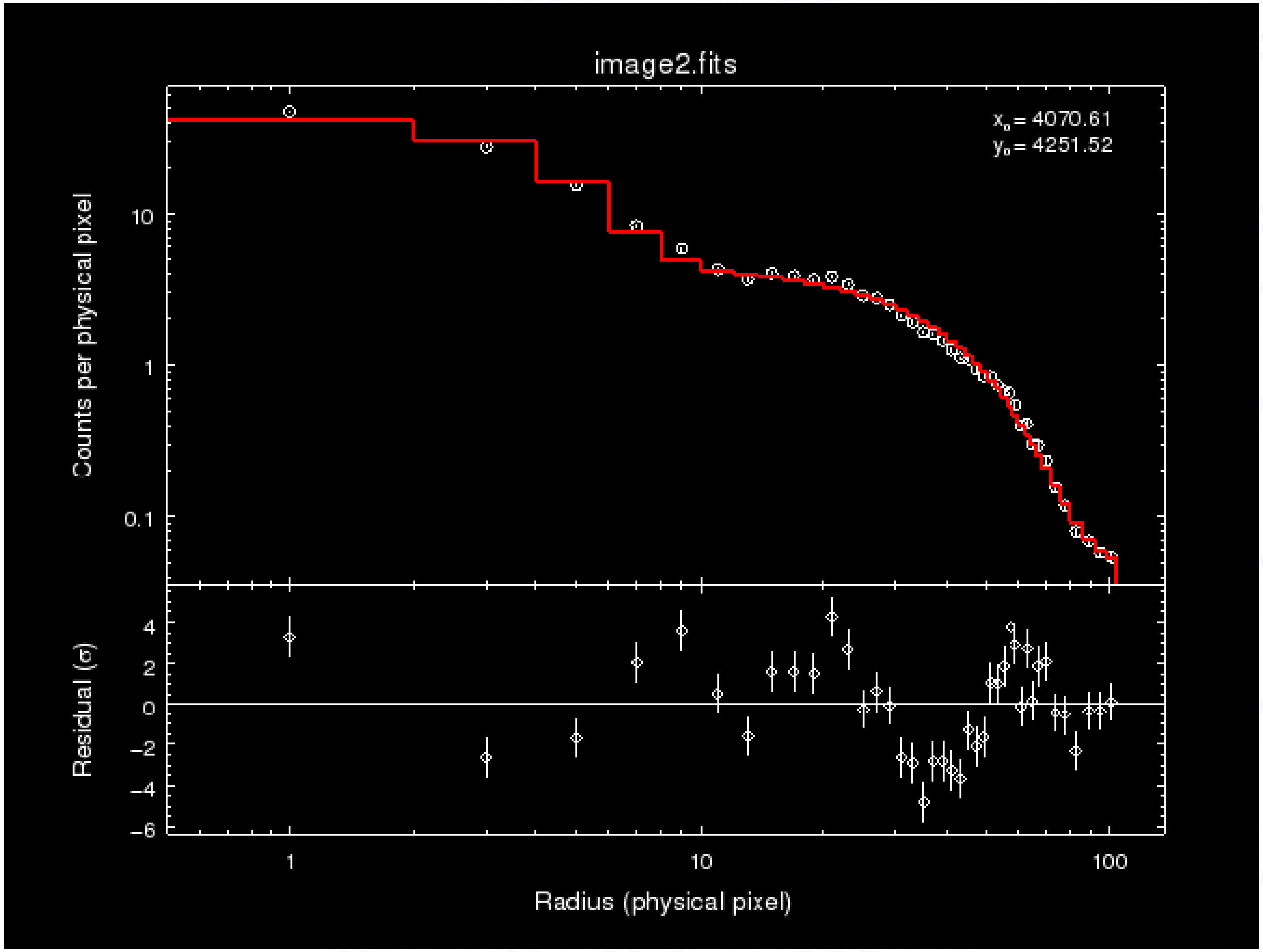


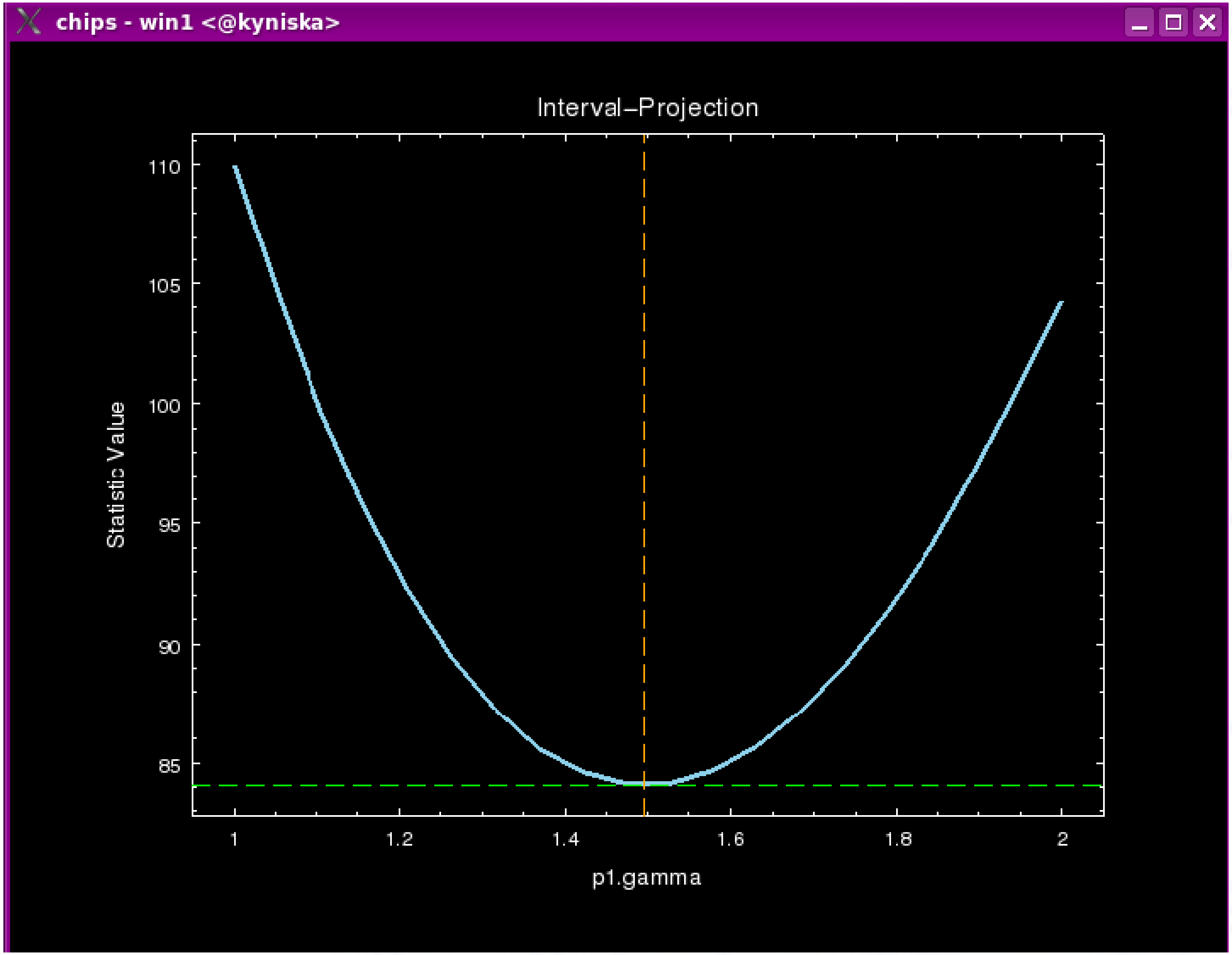
Image fitting has the same interface and look-and-feel as fitting spectra. Ds9 is used to image the data, model, and fit residuals.



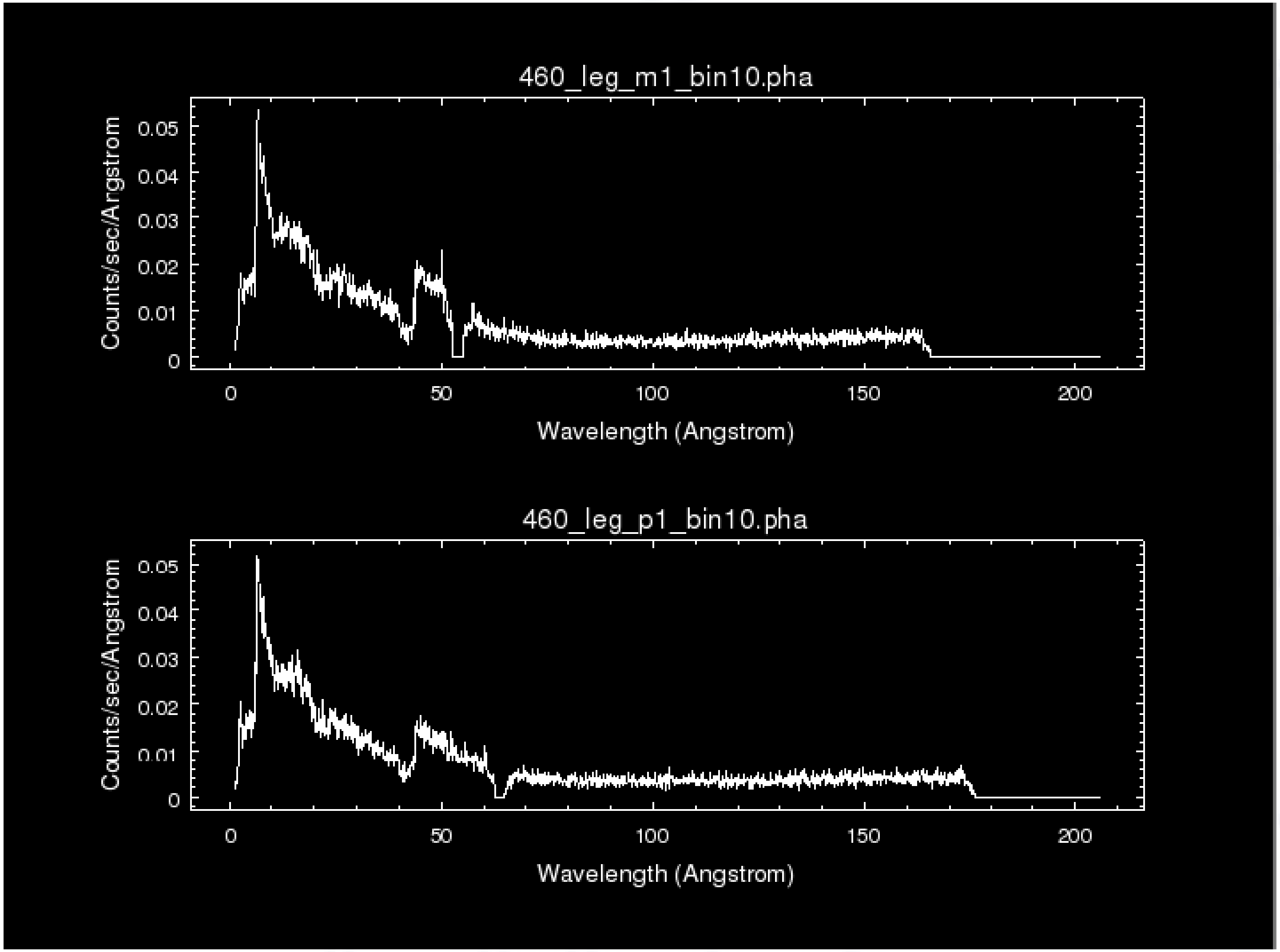
2D fits can also be imaged as contours using ChIPS



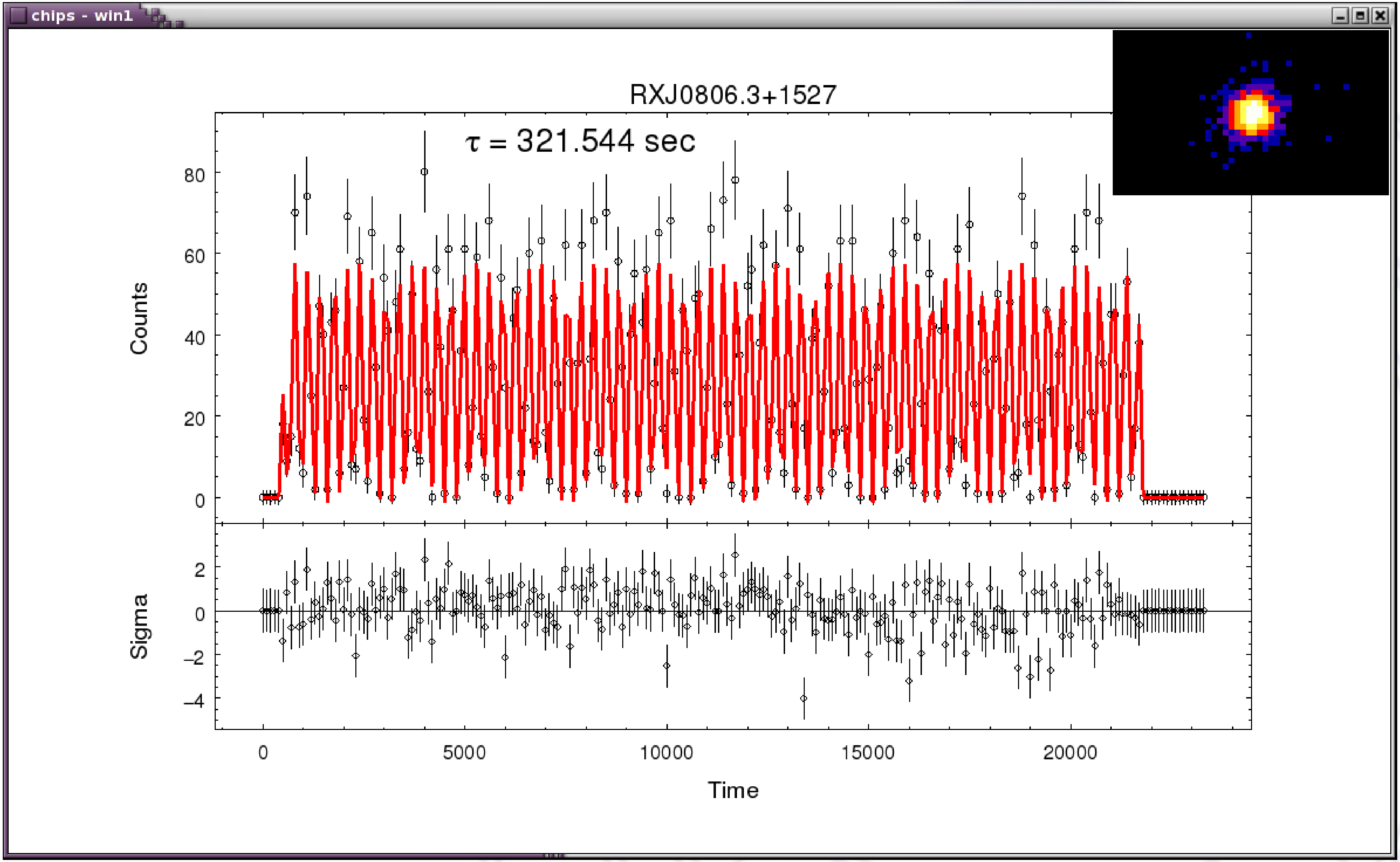
Radial profiles can be modeled in the same way as spectra.



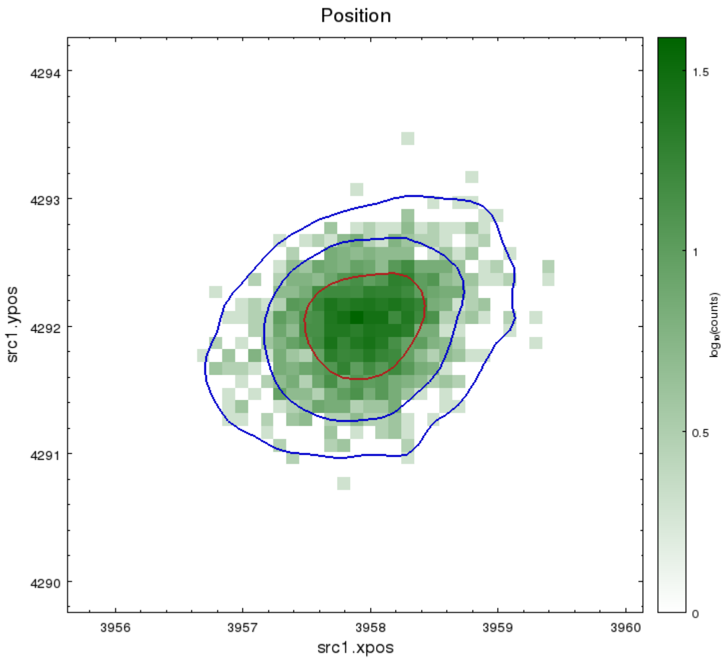
1D interval projections are also available.

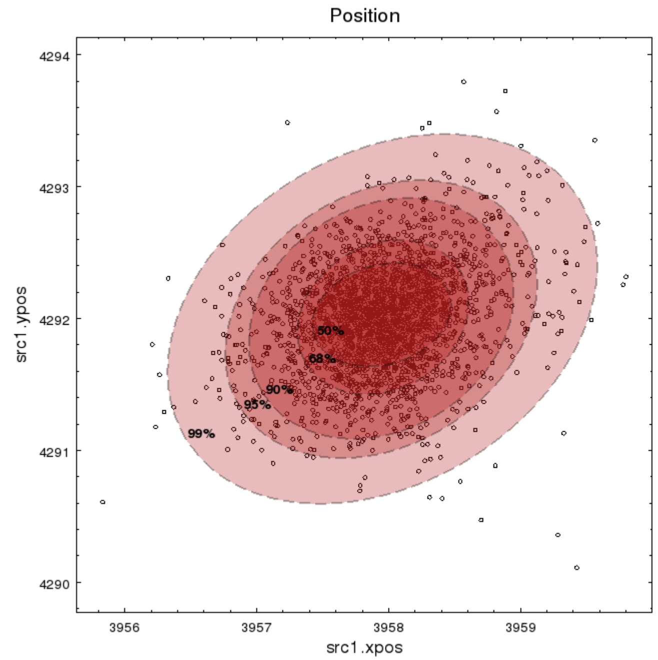


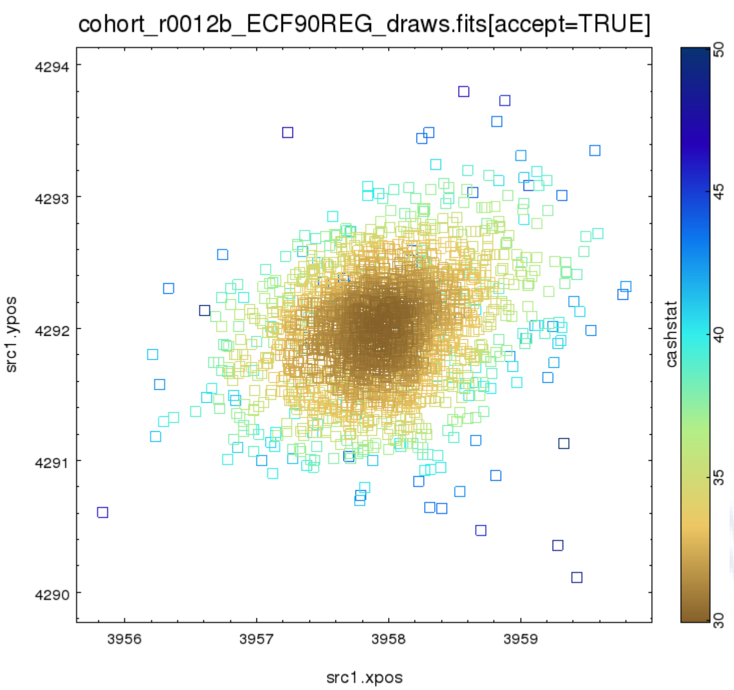
Sherpa has built in support for TYPE:II spectrum files commonly used in Chandra grating data analysis. Loading the file will automatically load all the spectra and setup the backgrounds.

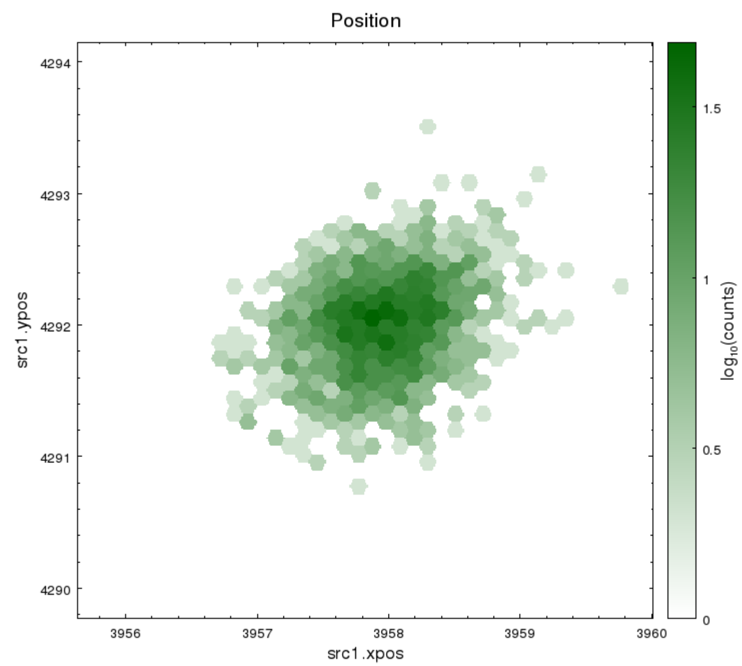


While not common, sherpa can also be used to model light curves including good-time-intervals (GTIs). A simple sinusoidal model is fit to these data yielding the same frequency as published in the literature. Sherpa uses ChIPS to plot meaning that images can be plotted together with the curves as is shown here.









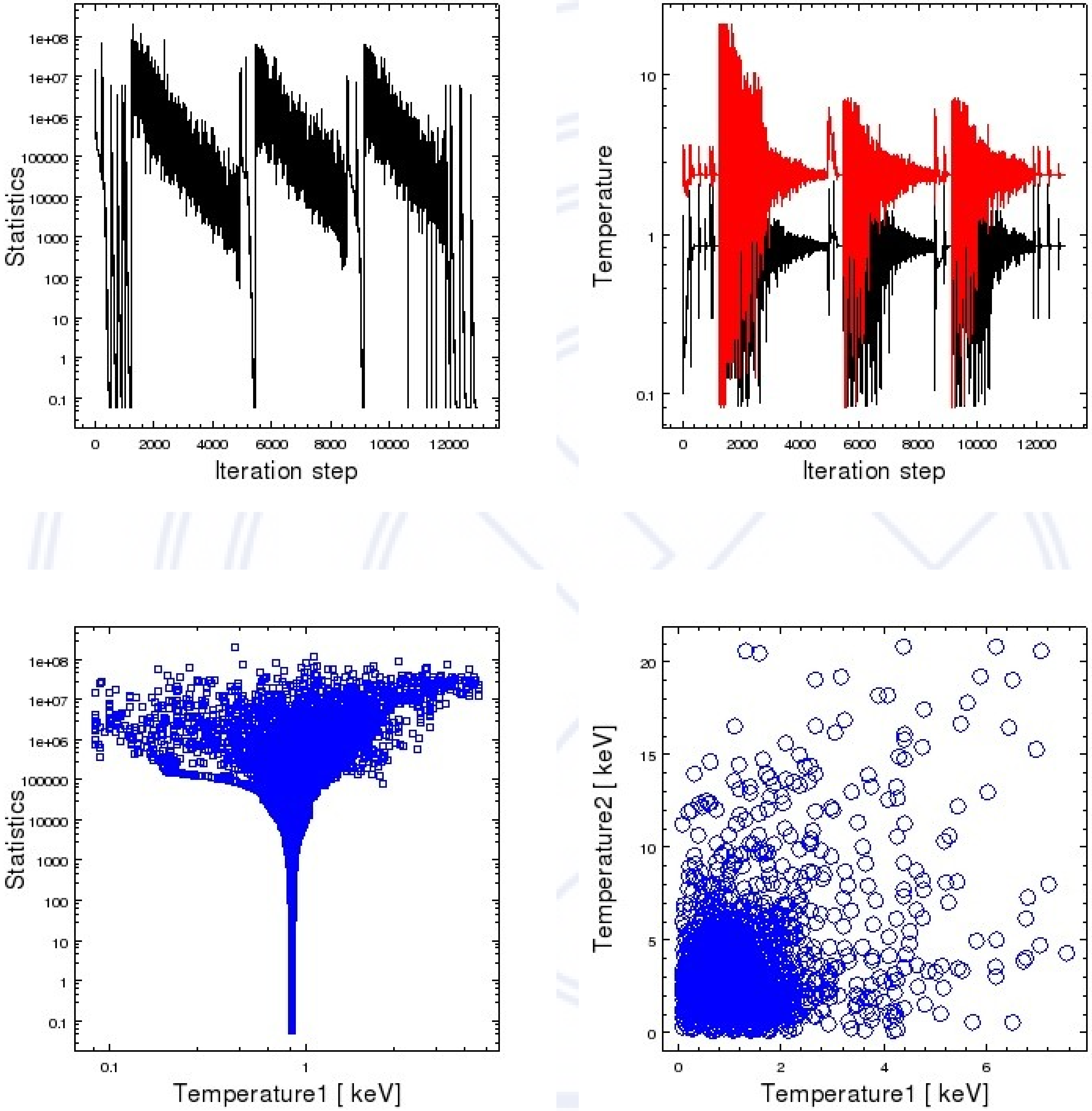
There is more than one way to visualize the same results.

These data are some 2000 MCMC iterations fitting a PSF to determine the source position.

(Top Left) shows a ChIPS image, with a custom color scheme. (Top Right) shows the data as a scatter plot with ellipses created with dmellipse. (Bottom Left) shows the results color coded by fit statistic. (Bottom Right) shows the image rebinned with a hexagon scheme using dmmaskbin.

The per-iteration fit information can even be saved to provide additional diagnostics on the quality of the fit.

These are the results for a fit to a dataset using a 2 temperature model.



Want to know more?

New threads and documents are constantly being added to the CIAO web site.

http://cxc.cfa.harvard.edu/ciao

Be sure to check back frequently!

The CXC helpdesk is also ready to assist you.

cxchelp@head.cfa.harvard.edu

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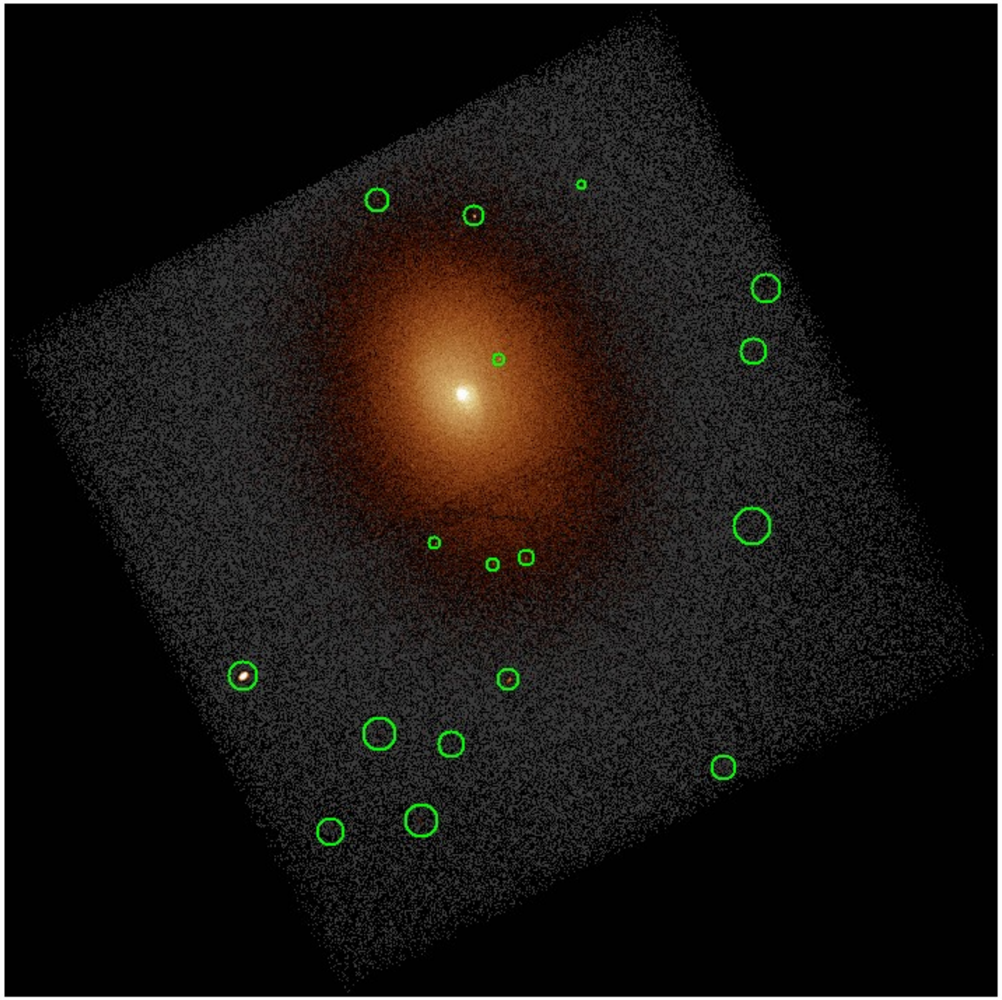
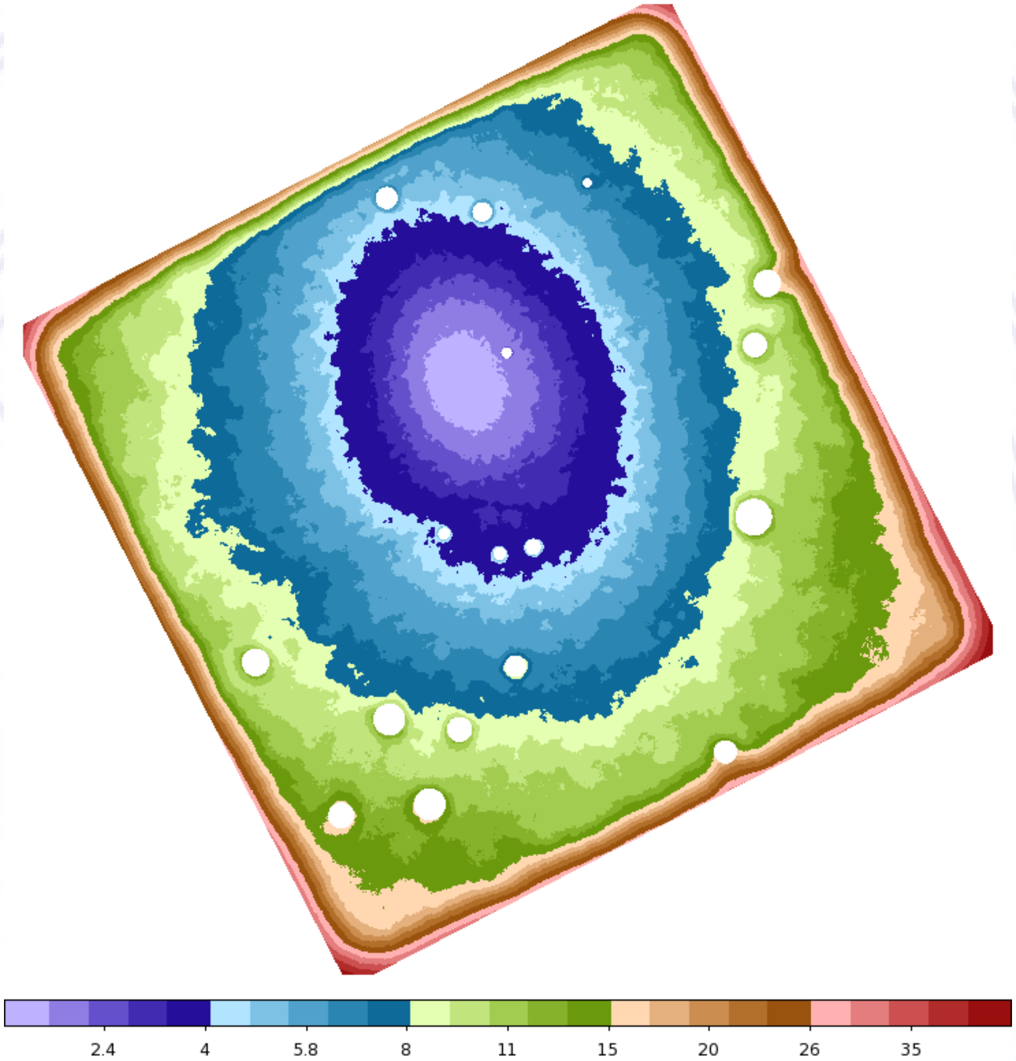
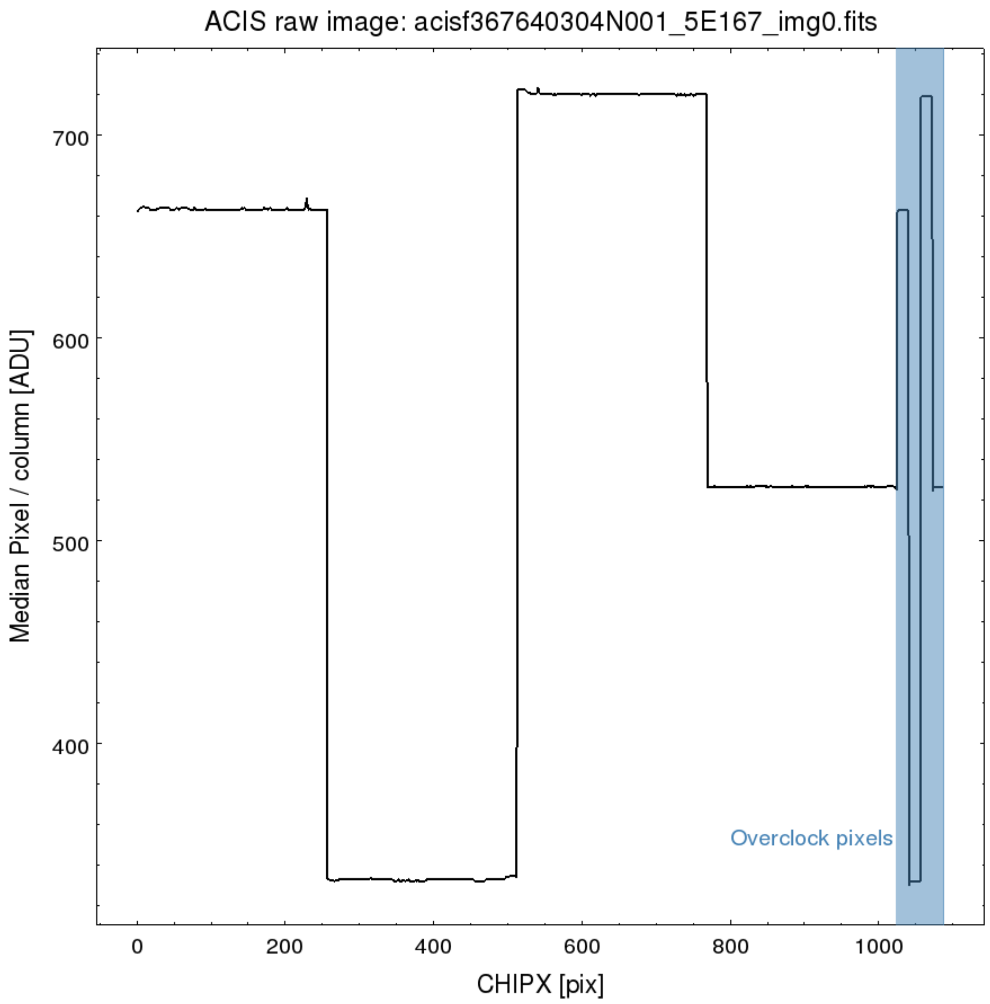
Later slides are not for IAU meeting.

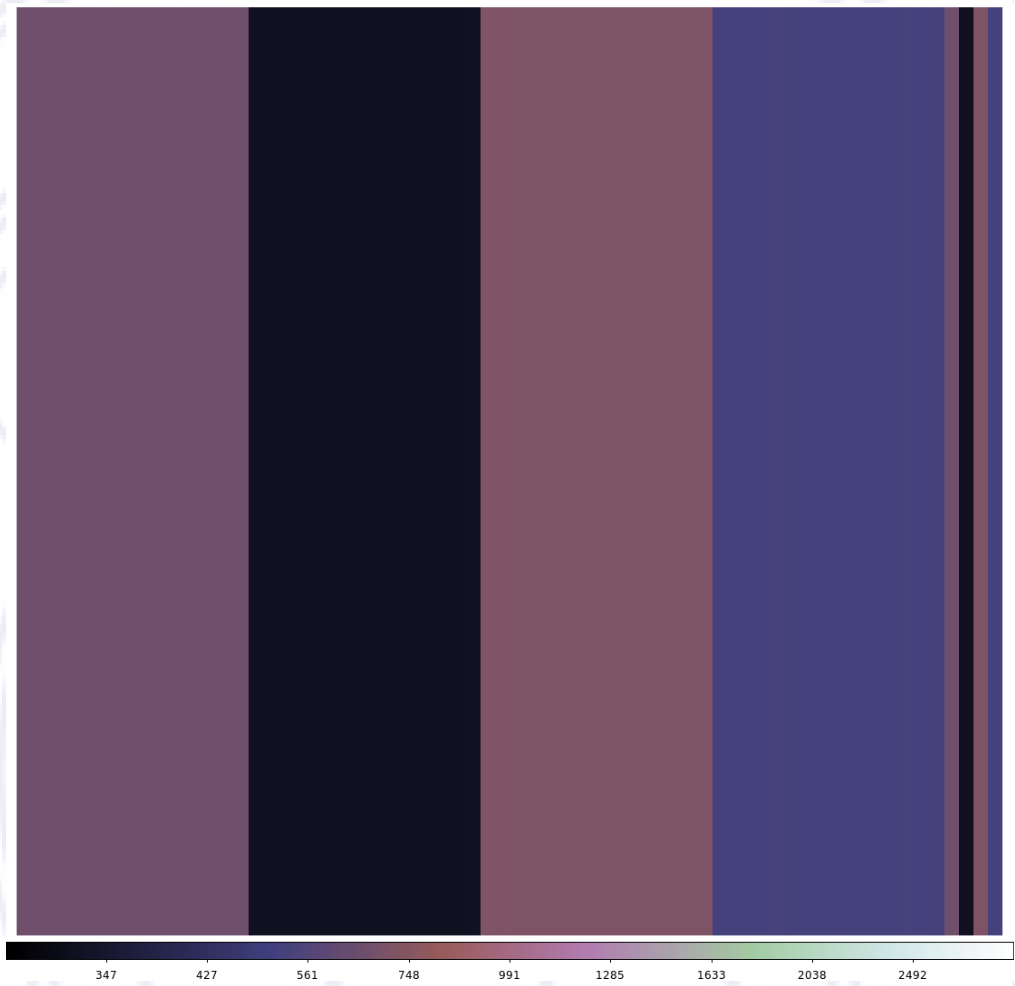
Want 250 counts per circular region to do spectral fitting?





(Left) Broad band image of Abell 2029, OBS_ID 4977. (Right) Using dmimgadapt with a tophat kernel we can quickly determine the size of a circle needed to enclose say 250 counts for every pixel in the image.





To remove the Node-to-Node variation, (Left) dmimgproject is used to get the median pixel value along each column and then (Right) dmimgreproject is used to replicate those values back into an image.