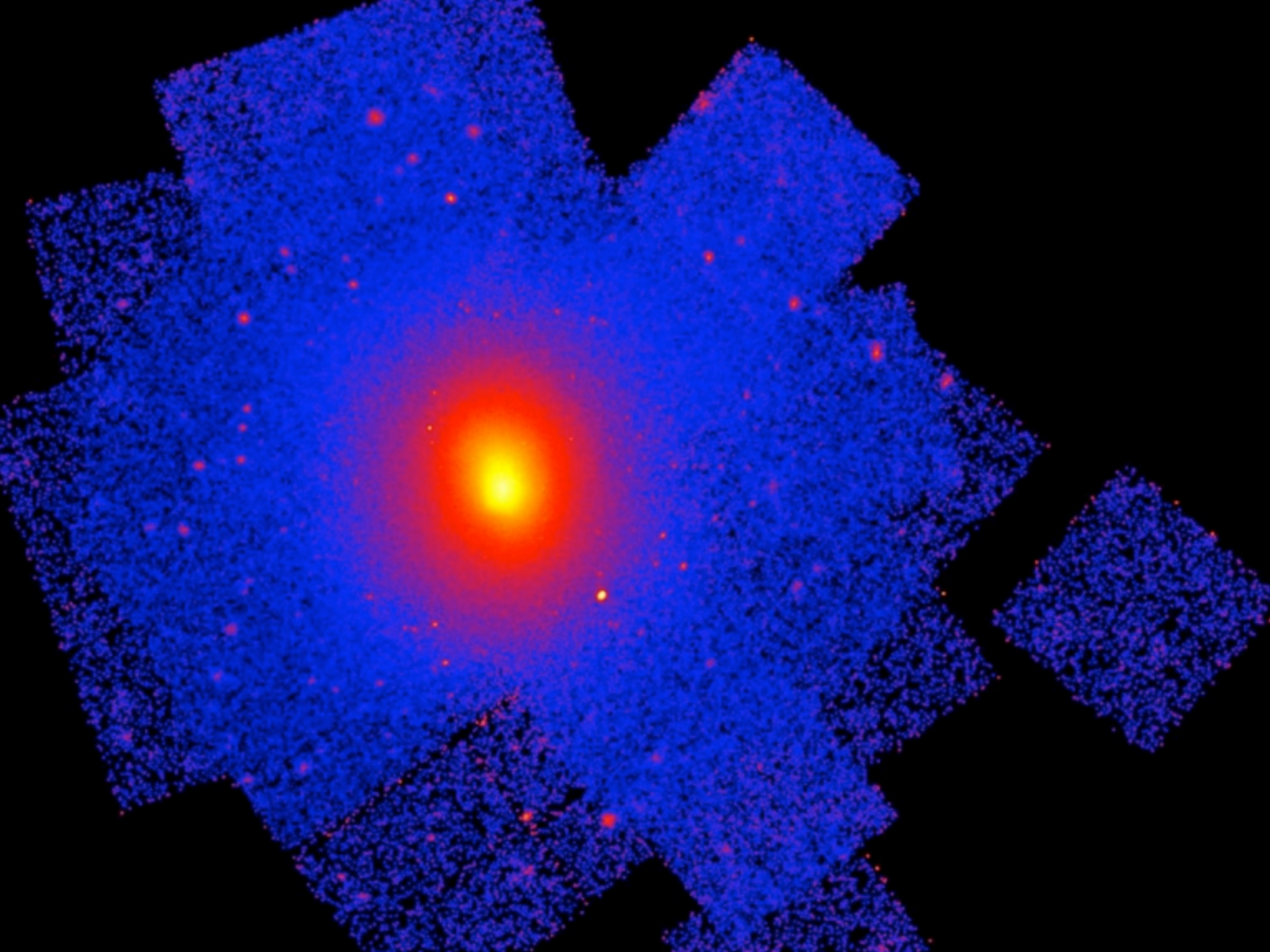
X-ray Imaging

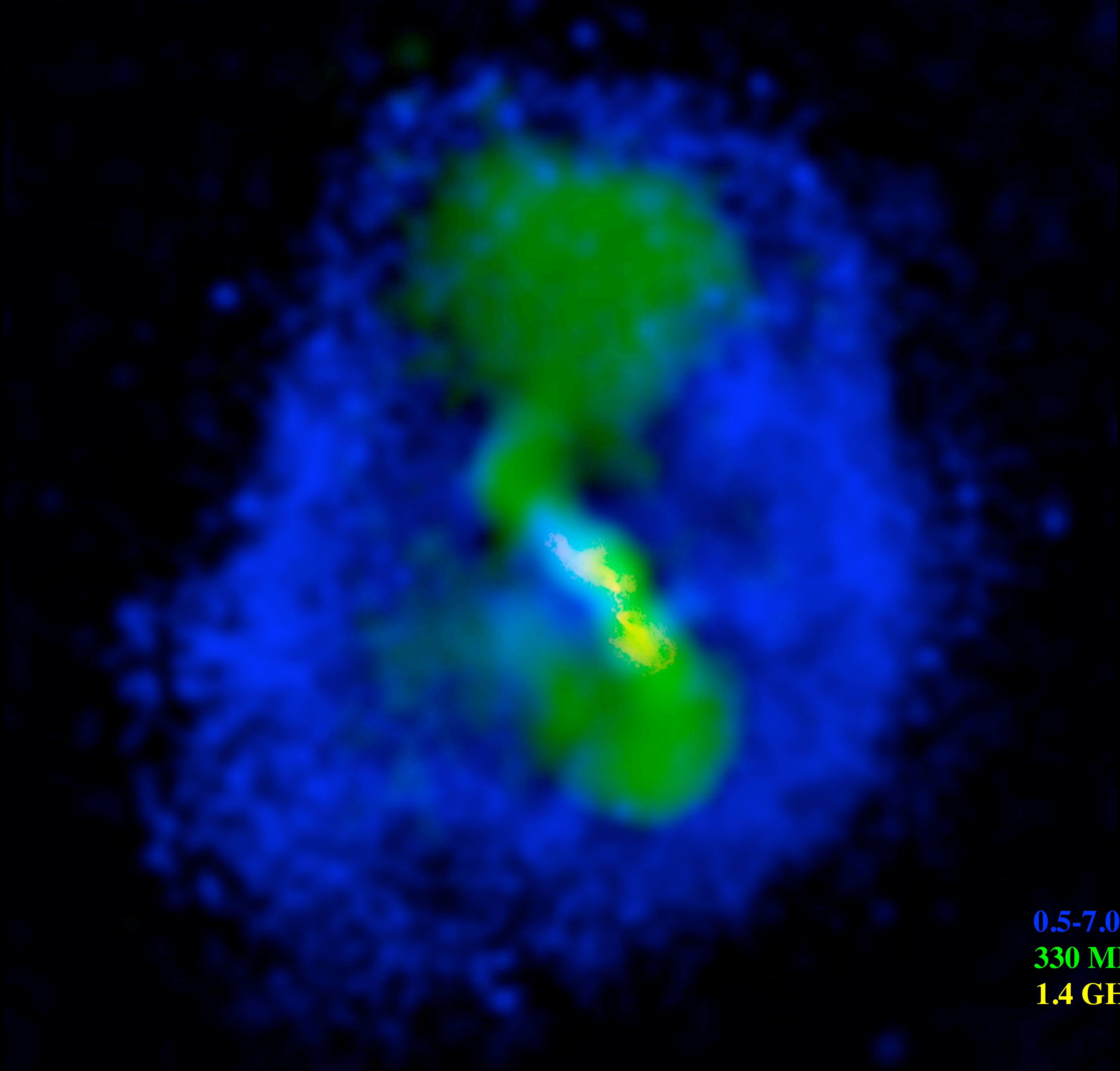
2nd School on Multi-wavelength Astronomy

06 July 2010

Michael Wise

ASTRON / LOFAR / UvA



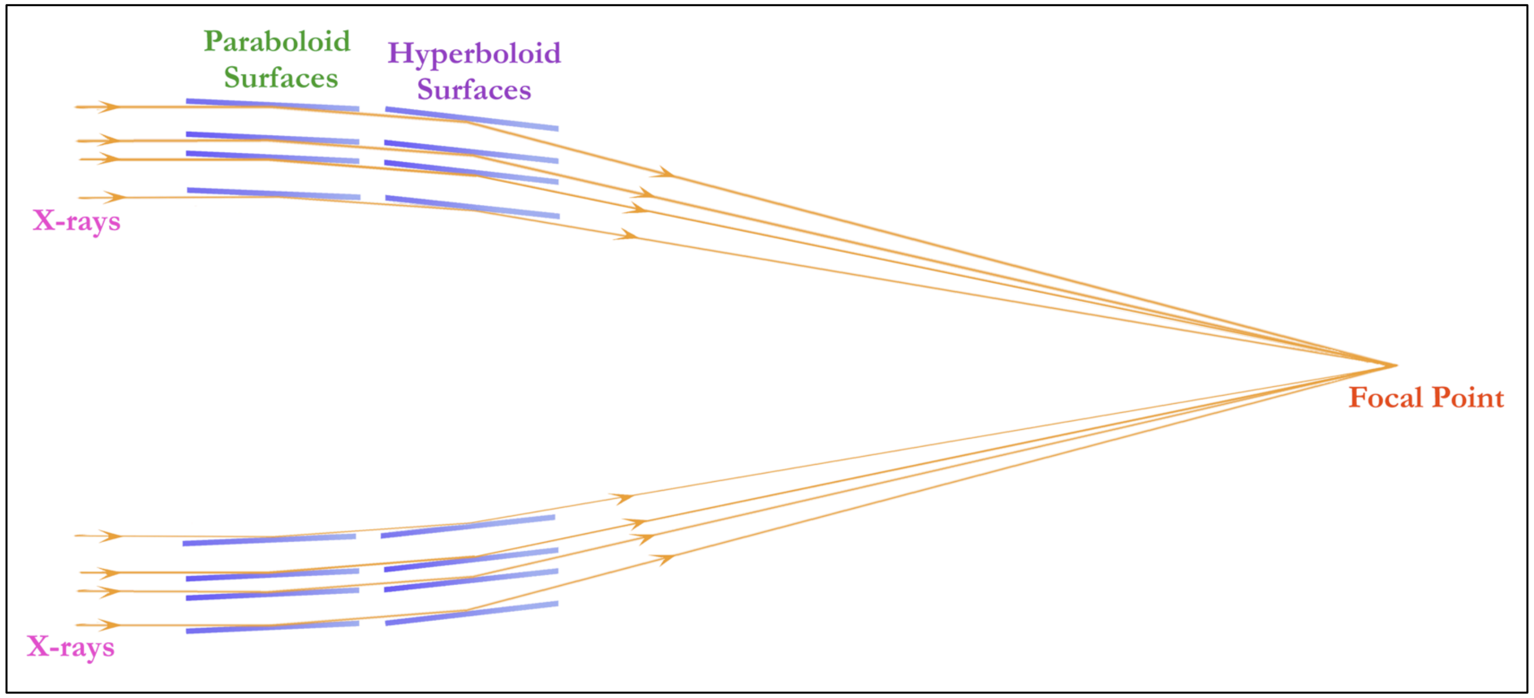

0.5-7.0 keV
330 MHz
1.4 GHz

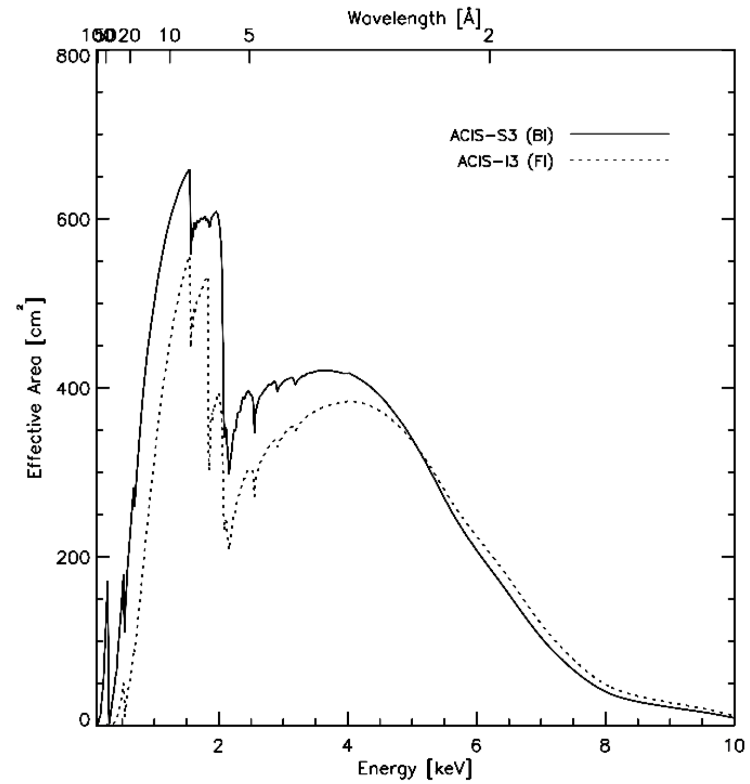
Overview

- X-ray data (*event files, filtering, and binning*)
- Standard re-processing (*bad aspect, flares, CTI correction, etc.*)
- Imaging point sources (*counts images, flux images, backgrounds*)
- Image analysis (*PSFs, region files, detection, spectral analysis*)
- Imaging diffuse emission (*Exposure maps, profile fitting, etc.*)

Caveats ⇒ ***Chandra data (XMM, Suzaku, etc..)***
CIAO and HEASoft
ACIS (HRC, EPIC, etc.)

X-ray Data and Instruments

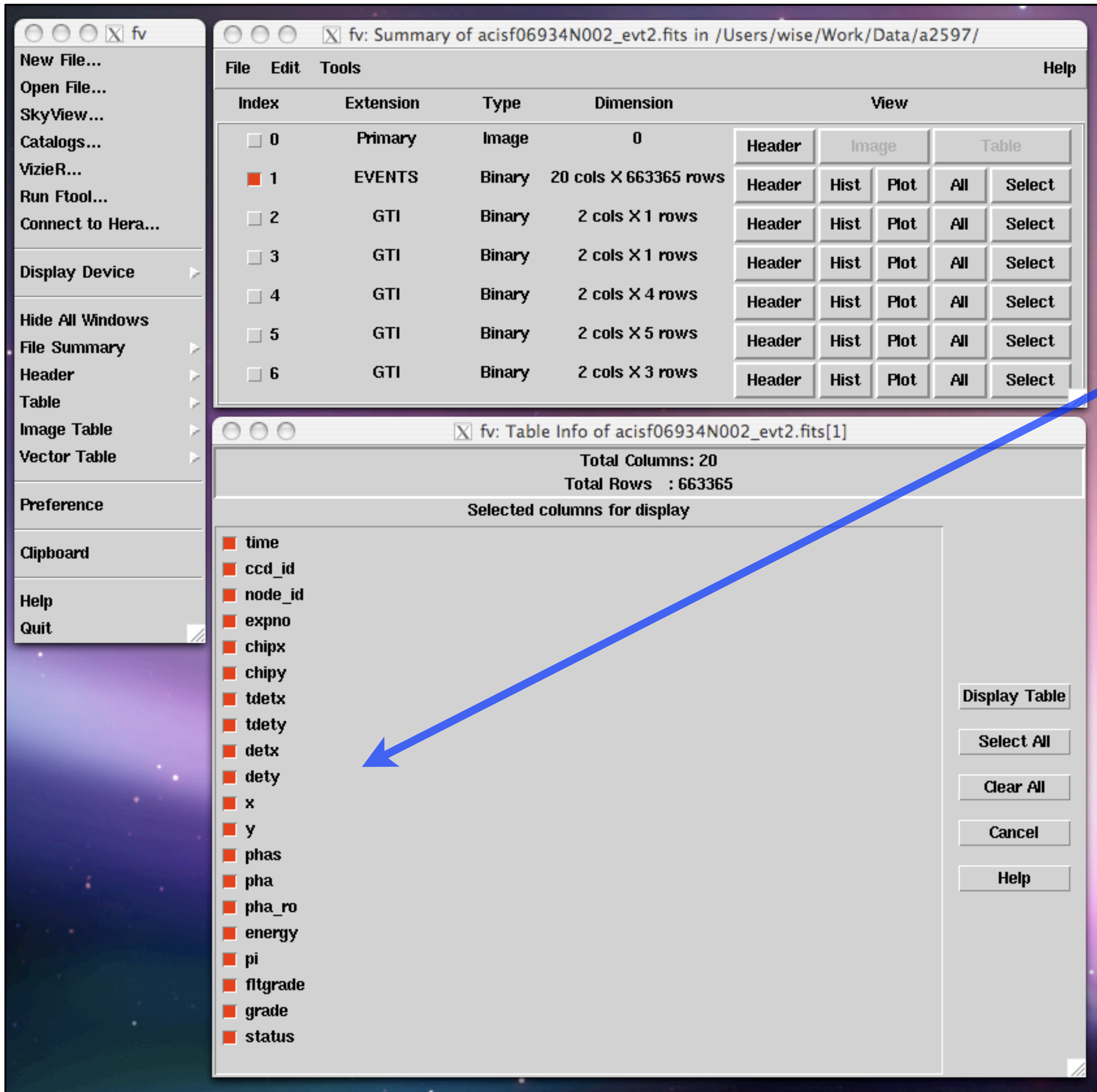




- Instruments are photon counting (*small number statistics*)
- Instruments are broad-band (*strong energy dependent response*)
- Grazing incidence optics (*PSF degrades rapidly off axis*)
- Operate in space (*Flares, radiation damage, aspect, etc.*)

Advantage ⟹ ***More information on each photon (x, y , E, t)***

X-ray Event Files



- Fundamental data product
- Equivalent to optical images, radio visibilities, etc.
- Table of event properties
- Each “event” is a possible detected photon
- Will also contains spurious events that must be filtered

⇒ ***X-ray images are binned event lists***

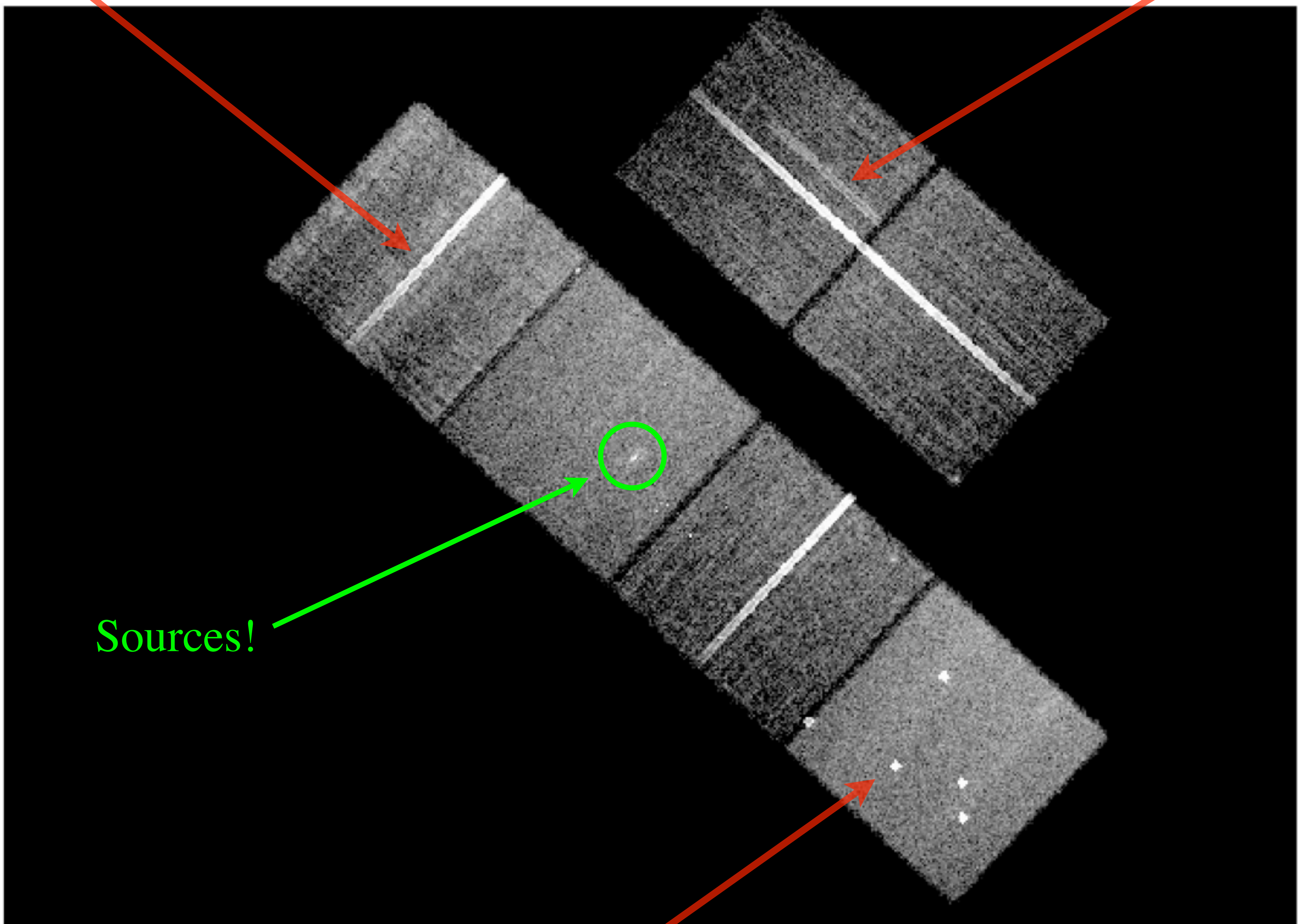
Standard Reprocessing

- Apply time dependent gain correction (*PHA to ENERGY/PI*)
- Correct for CTI in your data (*especially for FI chips*)
- Apply the L2 filters (*cosmic rays, bad pixels, etc.*)
- Filter out time intervals containing strong flares, bad aspect
- Apply energy filter from 0.3-7.0 eV (*reduce background*)

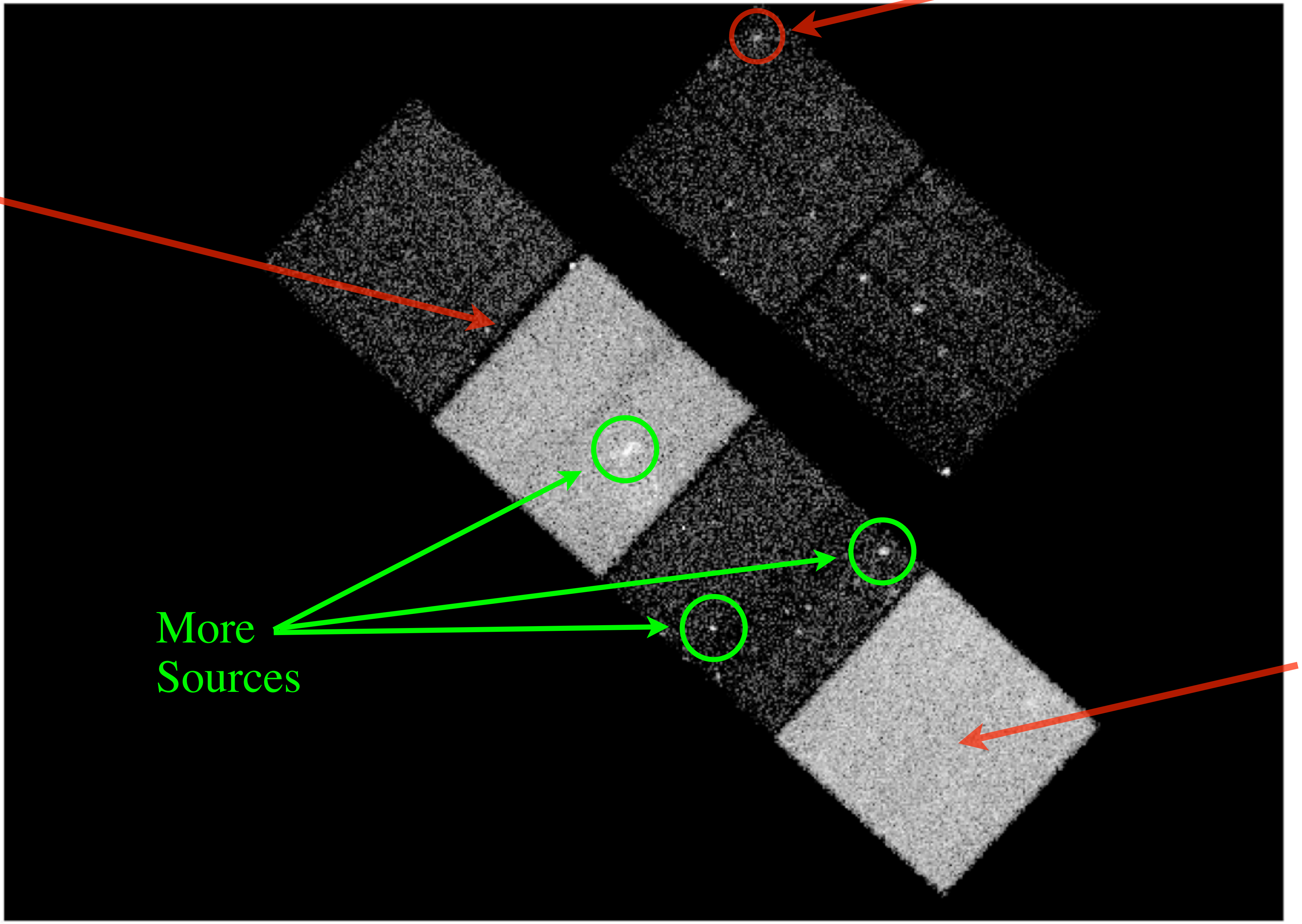
```
acis_process_events infile="../primary/acisf00922_000N003_evt1.fits"      \
                    outfile="acisf00922_000N004_evt1.fits"                 \
                    acaofffile="@pcad_files.txt"                           \
                    apply_cti=yes                                          \
                    apply_tgain=yes                                        \
                    badpixfile="acisf00922_000N004_bpix1.fits"             \
                    doevtgrade=yes                                         \
                    check_vf_pha=no                                        \
                    calculate_pi=yes                                       \
                    stop=sky

dmcopy "acisf00922_000N004_evt1.fits[status=0,grade=0,2,3,4,6]" \
       acisf00922N004_evt2.fits
```

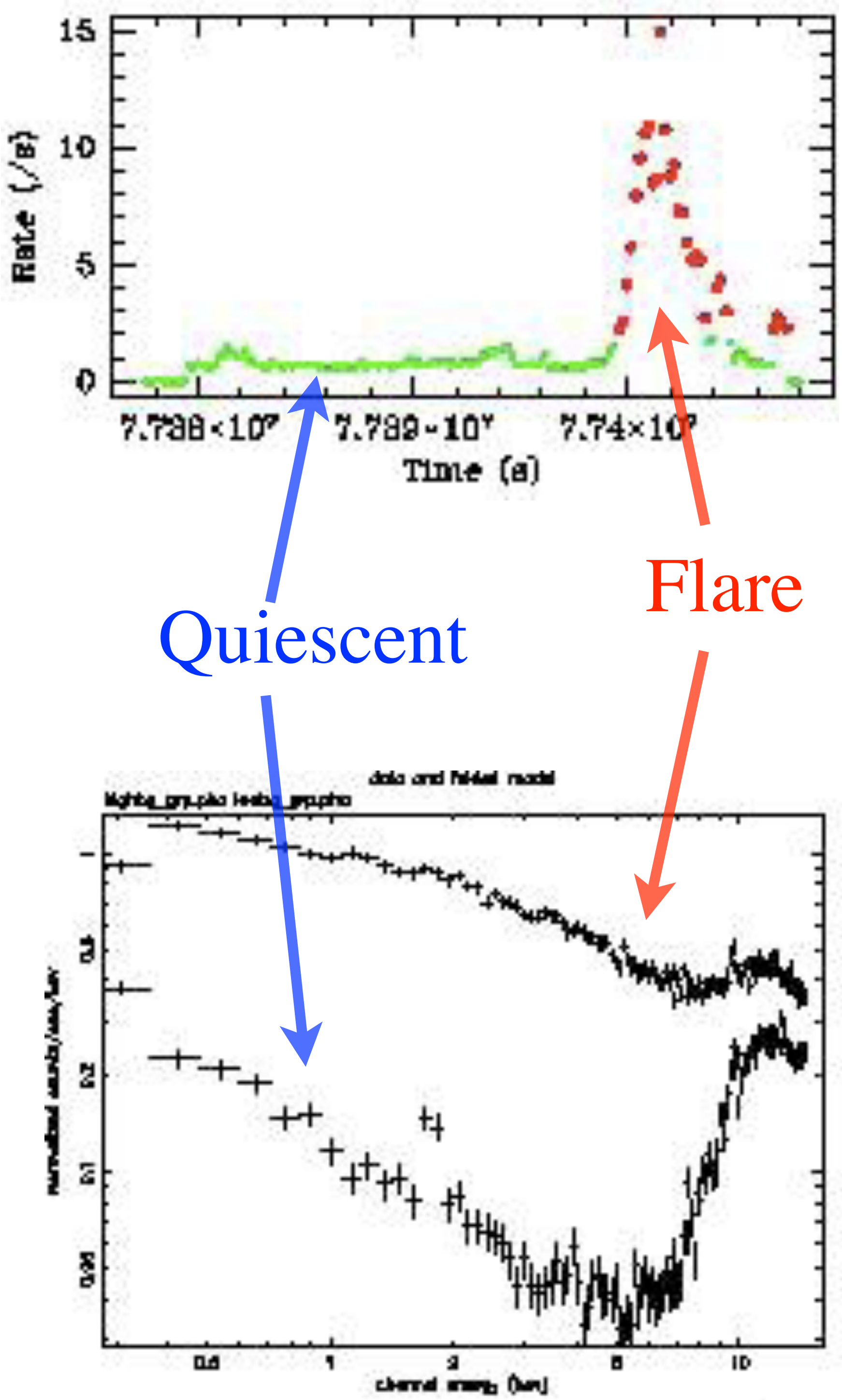
Level 1 Event Files

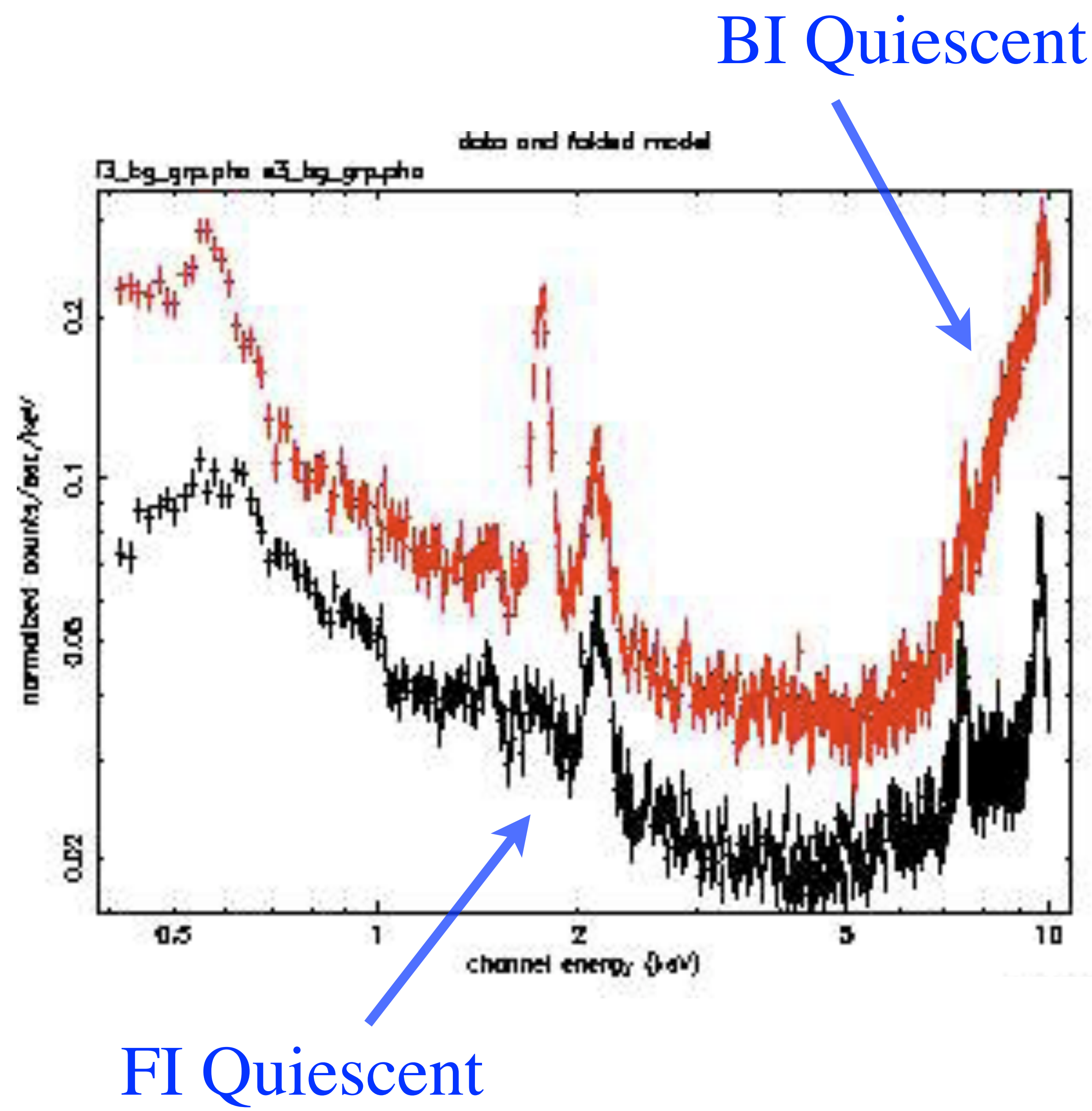


Level 2 Event Files



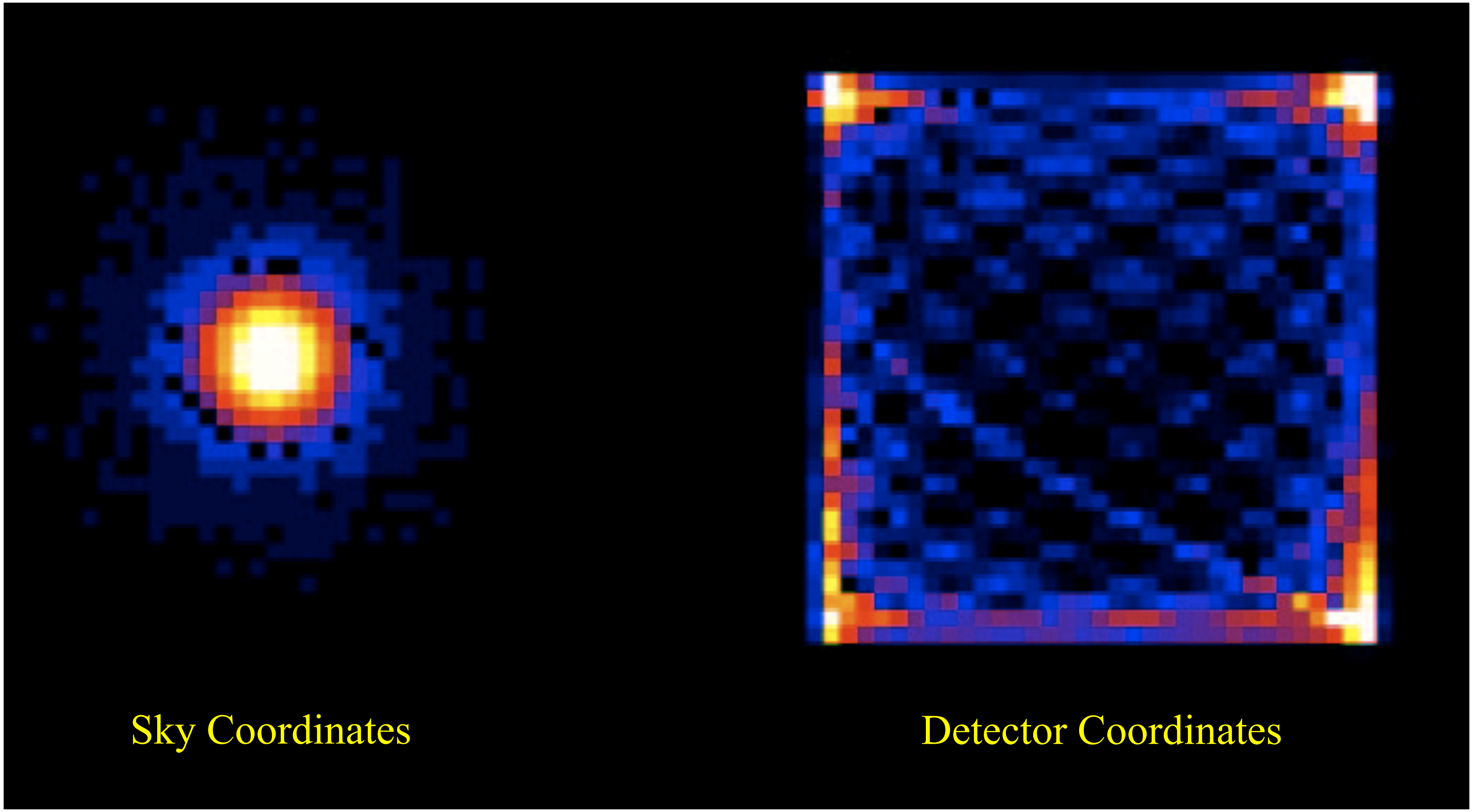
Background Flares



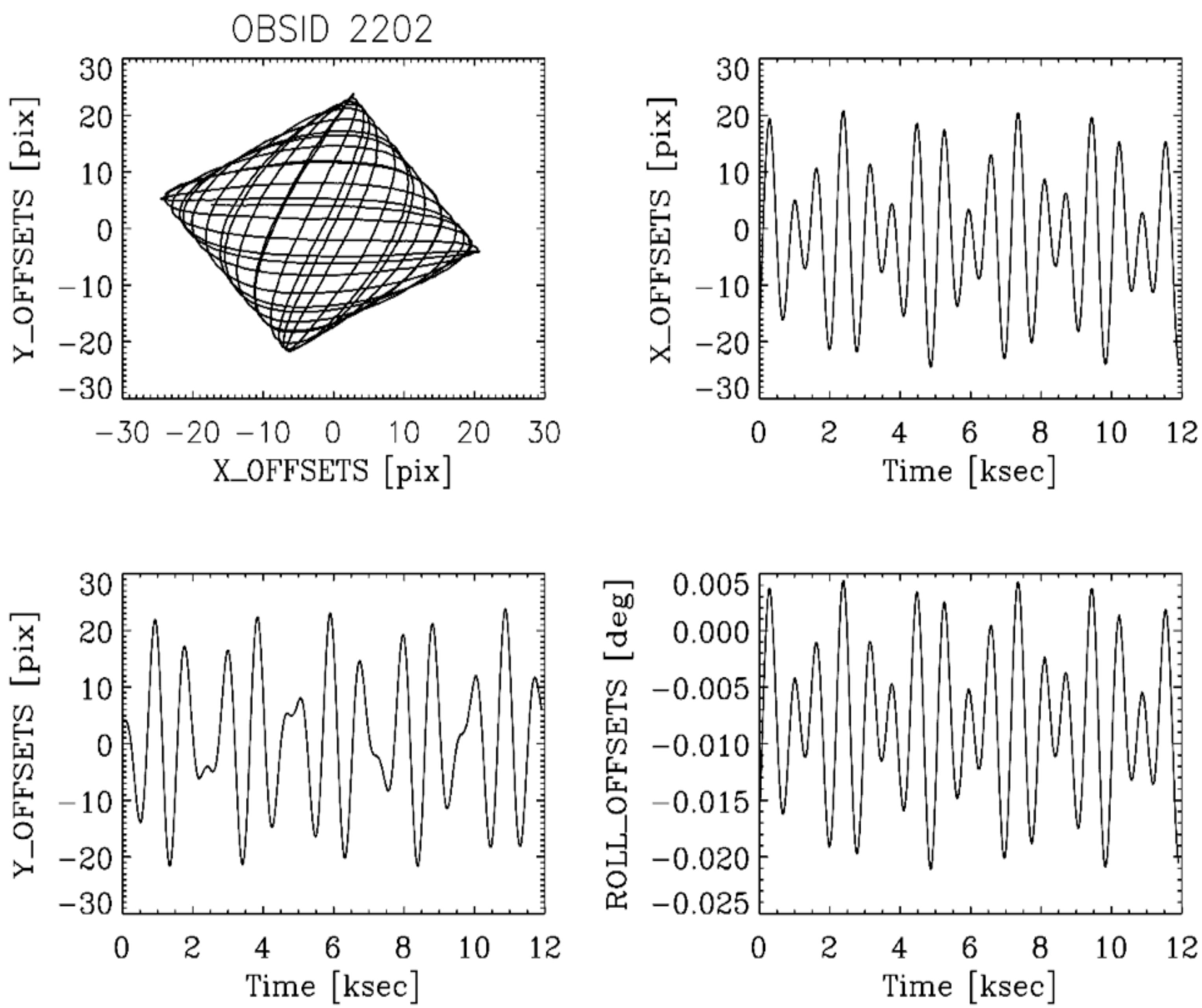


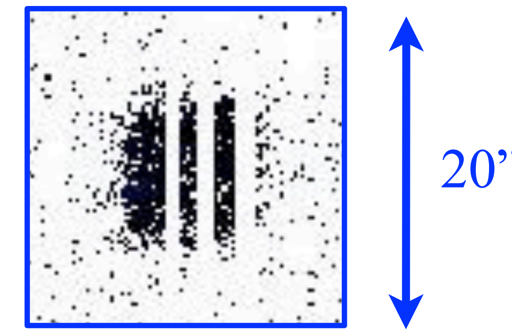
⇒ Filter out using dmcopy

The Aspect Solution



The Aspect Solution

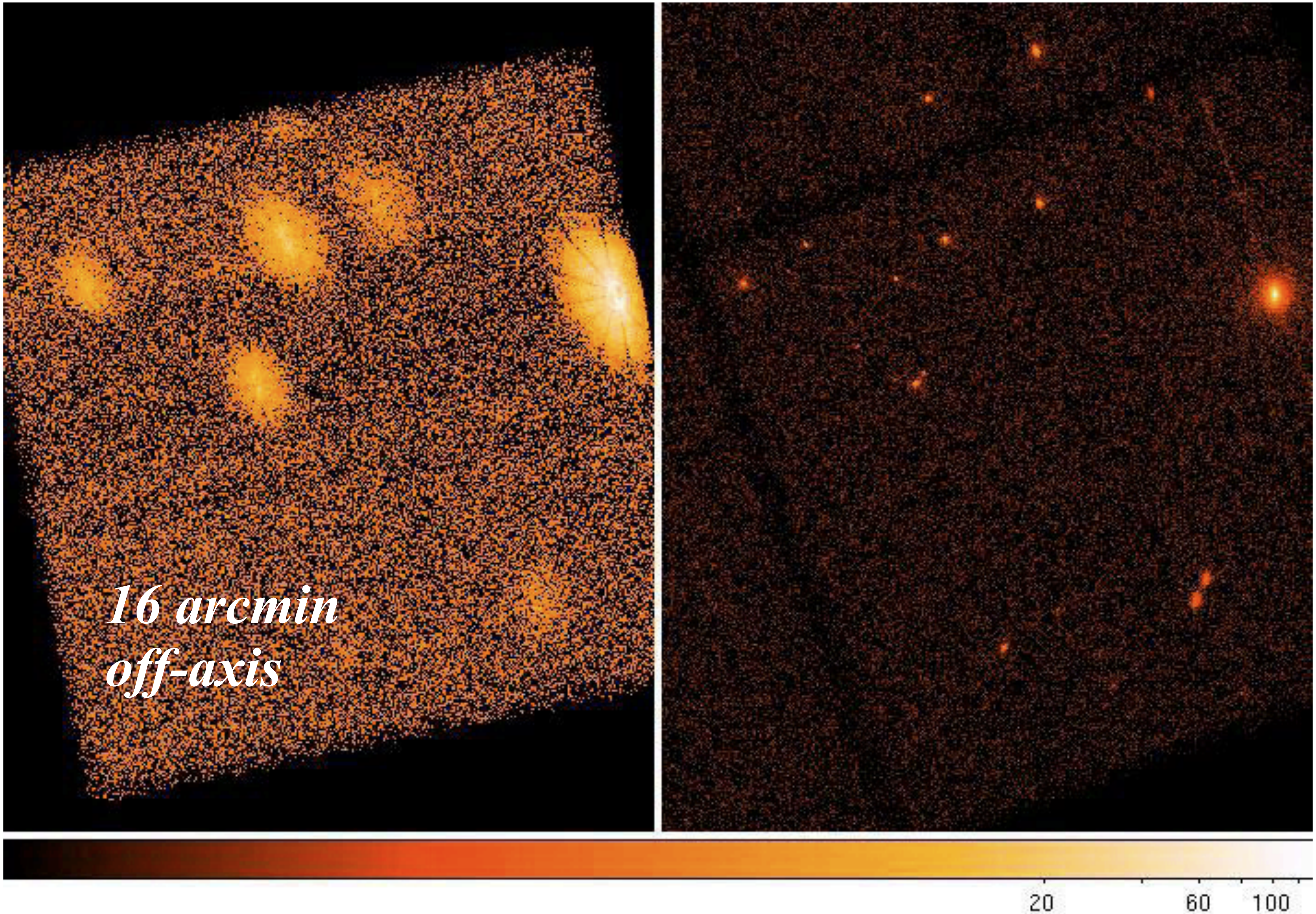




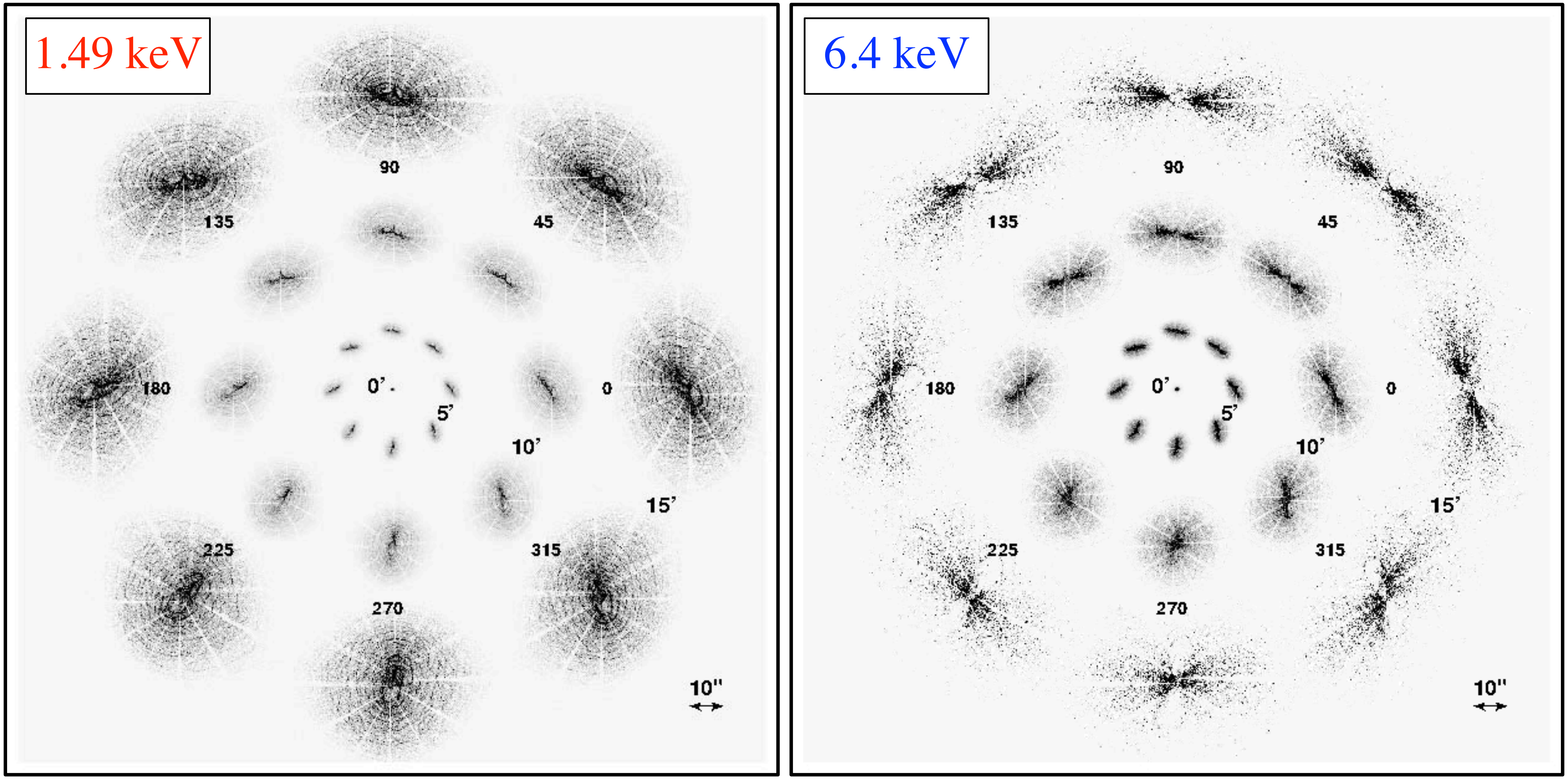
- During an observation, Chandra's optical axis describes a “dither pattern” on the sky
- The RA, Dec, and roll angle of the telescope versus time is called the “aspect solution”
- The aspect solution is used to reconstruct the image

Bad aspect $\Rightarrow$ ***Blurry image!***

PSF Variations



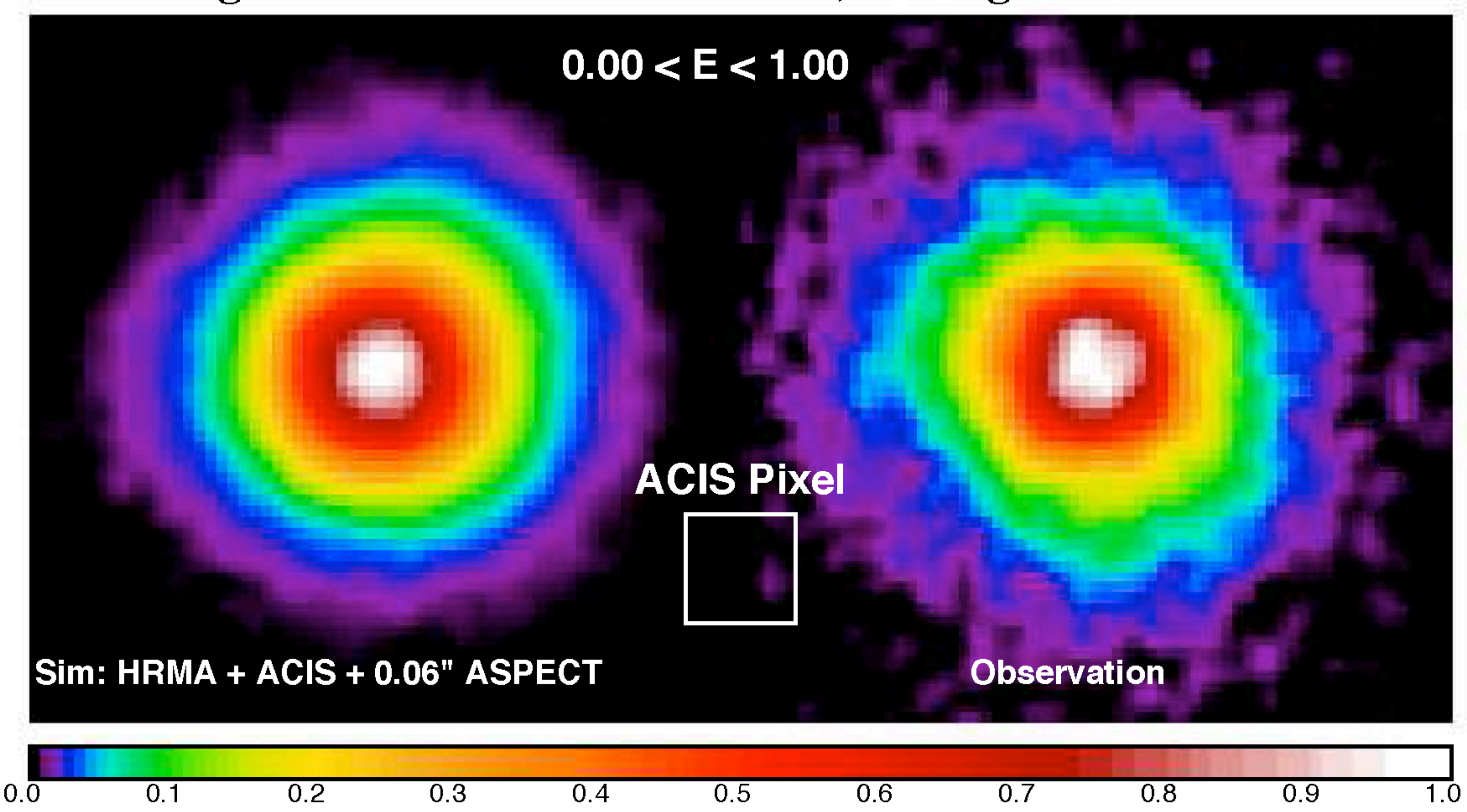
Off-Axis Angle PSF Variations



Chandra Ray Tracer (ChaRT): http://cxc.harvard.edu/chart

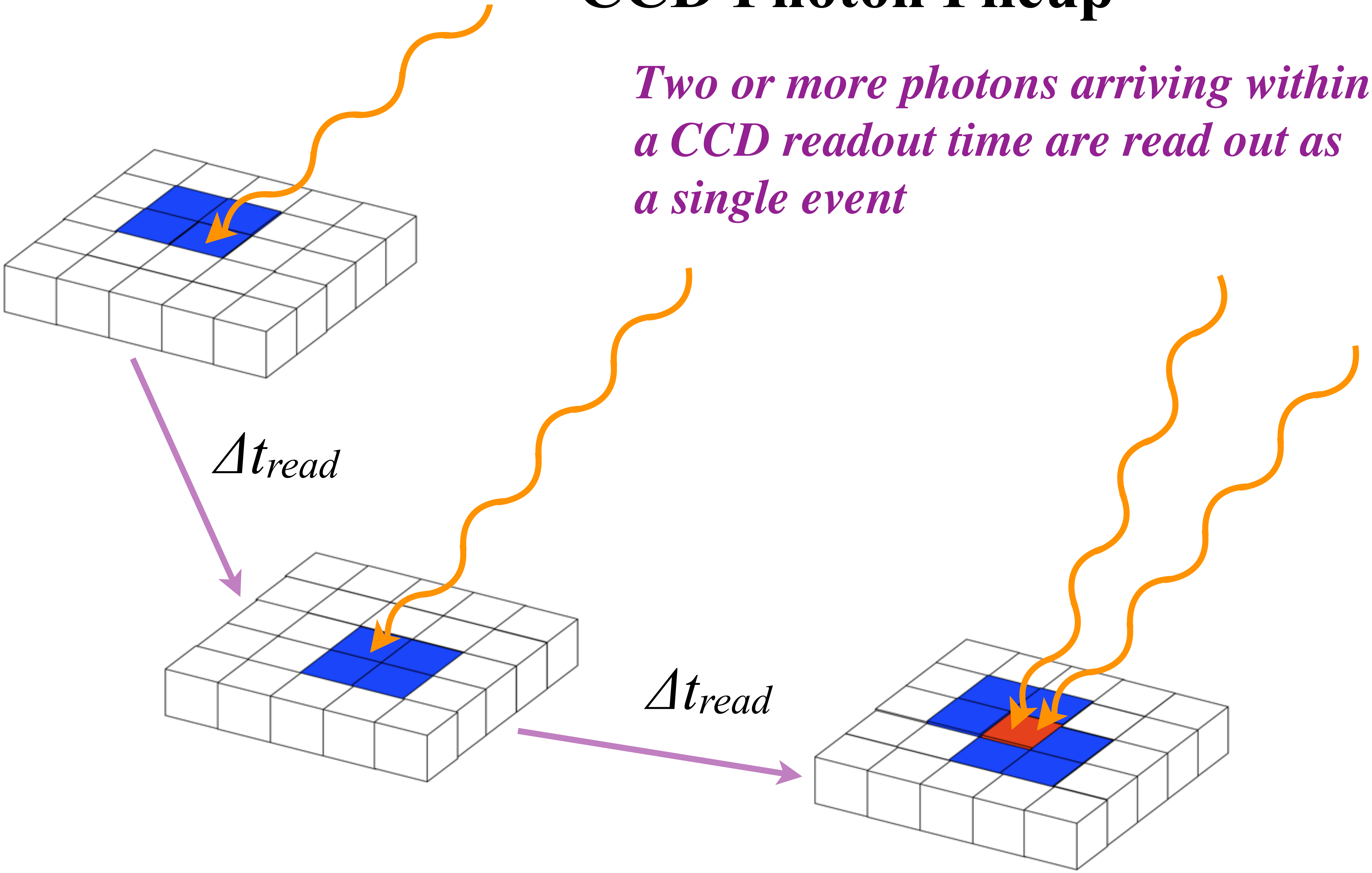
PSF Variations with Energy

Merged off-axis ACIS Data: 7.7", 132deg az

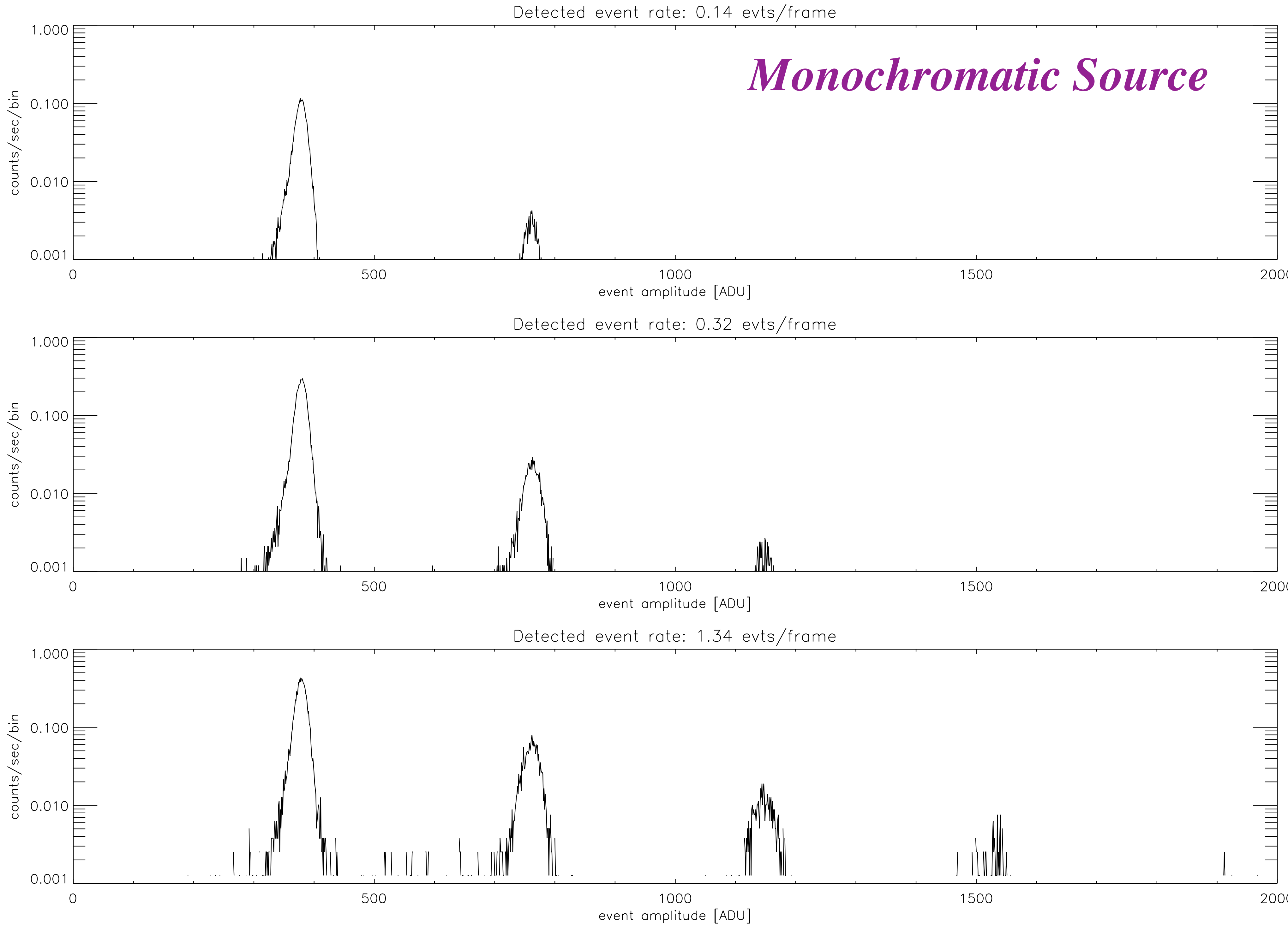


CCD Photon Pileup

Two or more photons arriving within a CCD readout time are read out as a single event

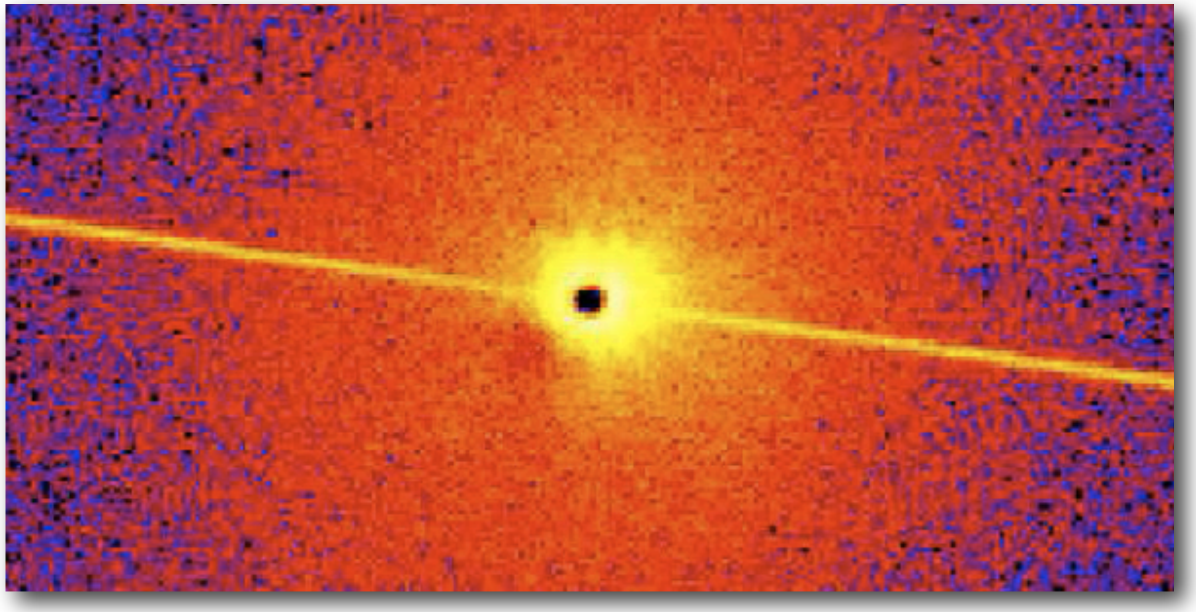


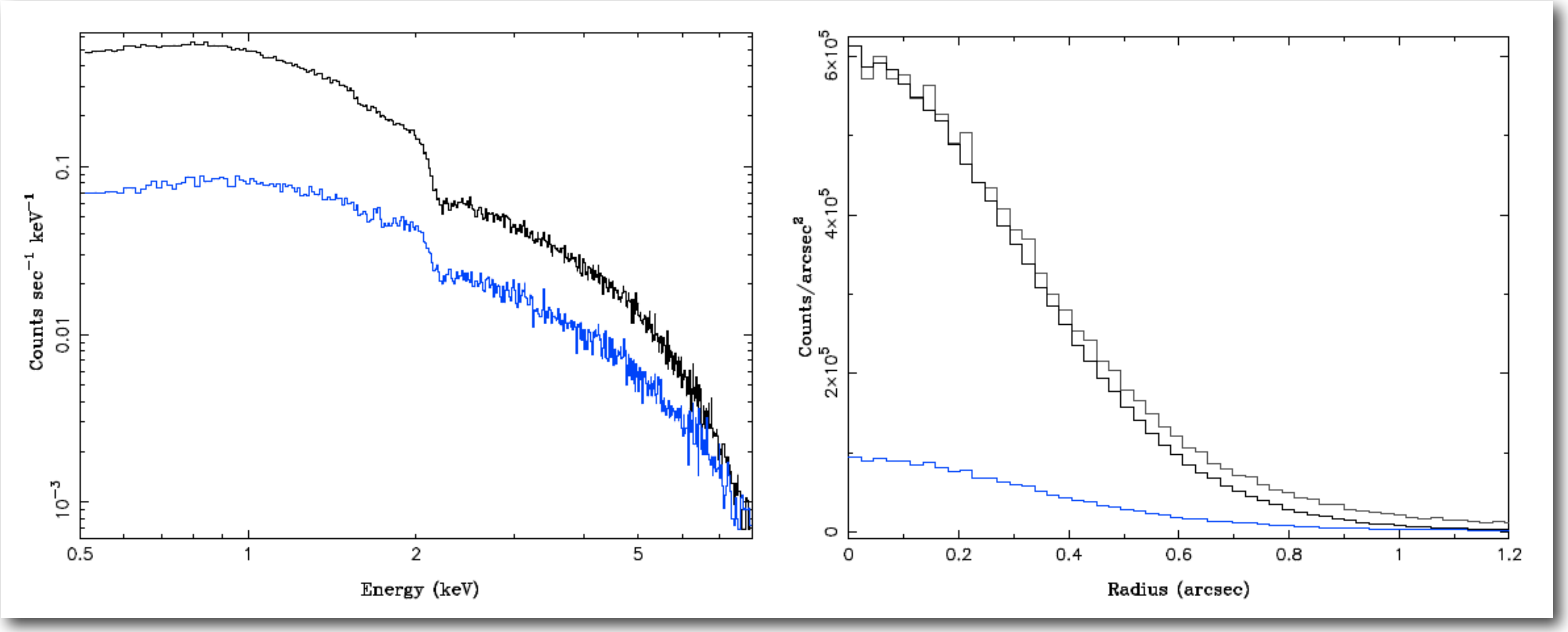
The Spectral Effects of Pileup



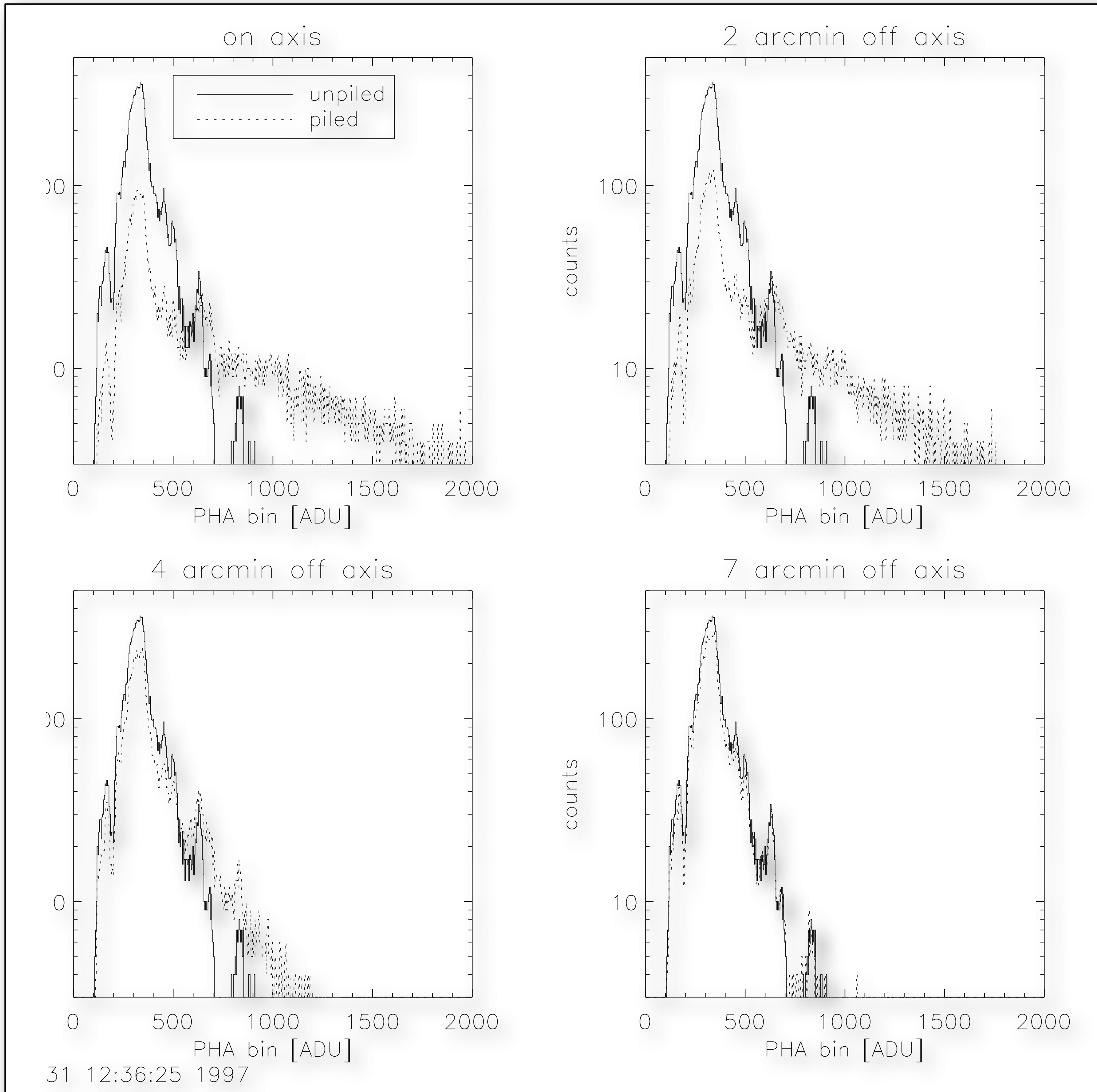
Spatial Effects of Pileup

- Spectrum becomes harder
- Surface brightness is suppressed
- PSF becomes broader





Mitigating the Effects of Pileup

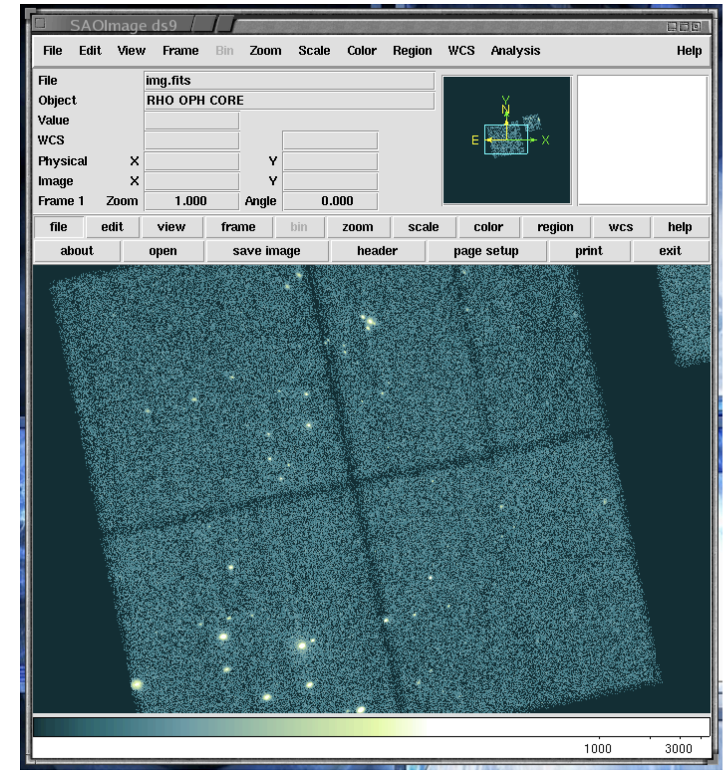


- Offset pointing
- Shorter readout time
- CCD sub-arrays
- Turn off some CCDs
- Insert the gratings!

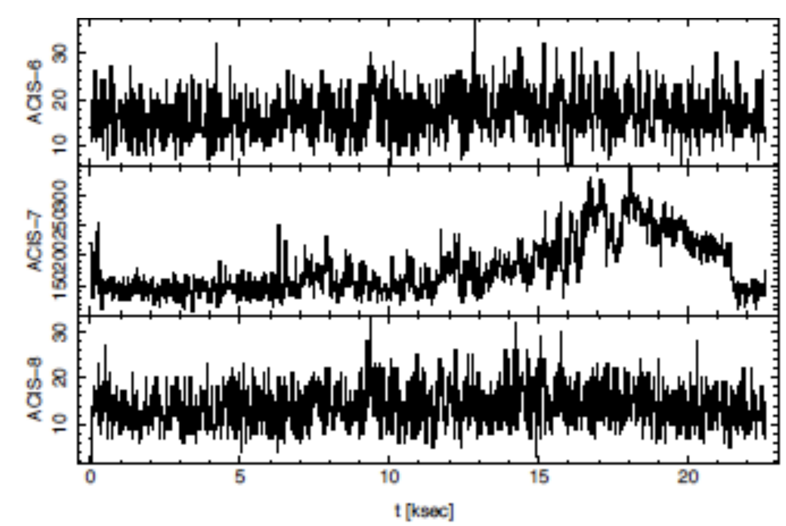
If you can't avoid it, include it in your fit!

Spatial and Spectral Analysis

Counts image



- Spatial analysis (*lose time and energy information*)
  - Create and display images: dmcopy, ds9
  - Create instrument maps: mkinstmap
  - Create exposure maps: mkexpmap
- Spectral analysis (*lose time and spatial information*)
  - Extract spectra using: dmextract
  - Create instrument responses: mkacisrmf
  - Create effective area: mkwarf
- Temporal analysis (*lose energy and spatial information*)
  - Extract light curves using: dmextract

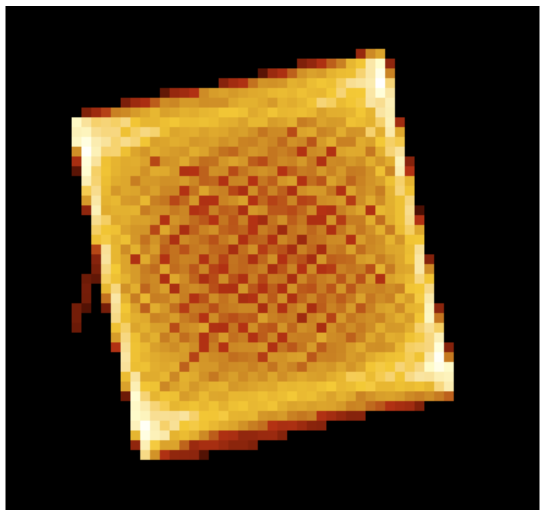


CCD light curves

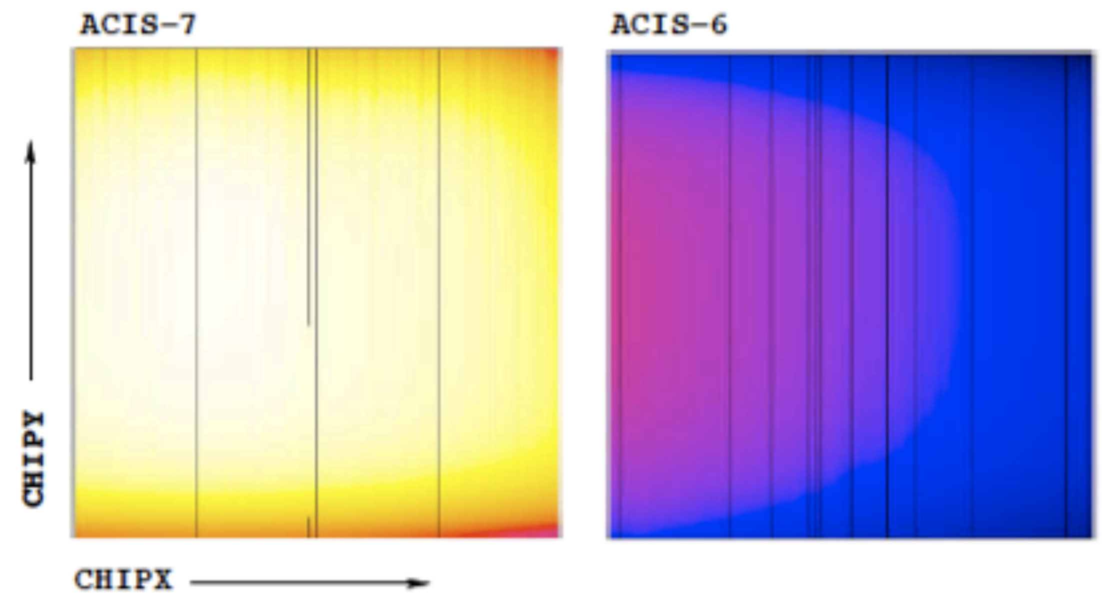
Advice ⇒ ***Don't make an image too quickly. Binning the data loses information.***

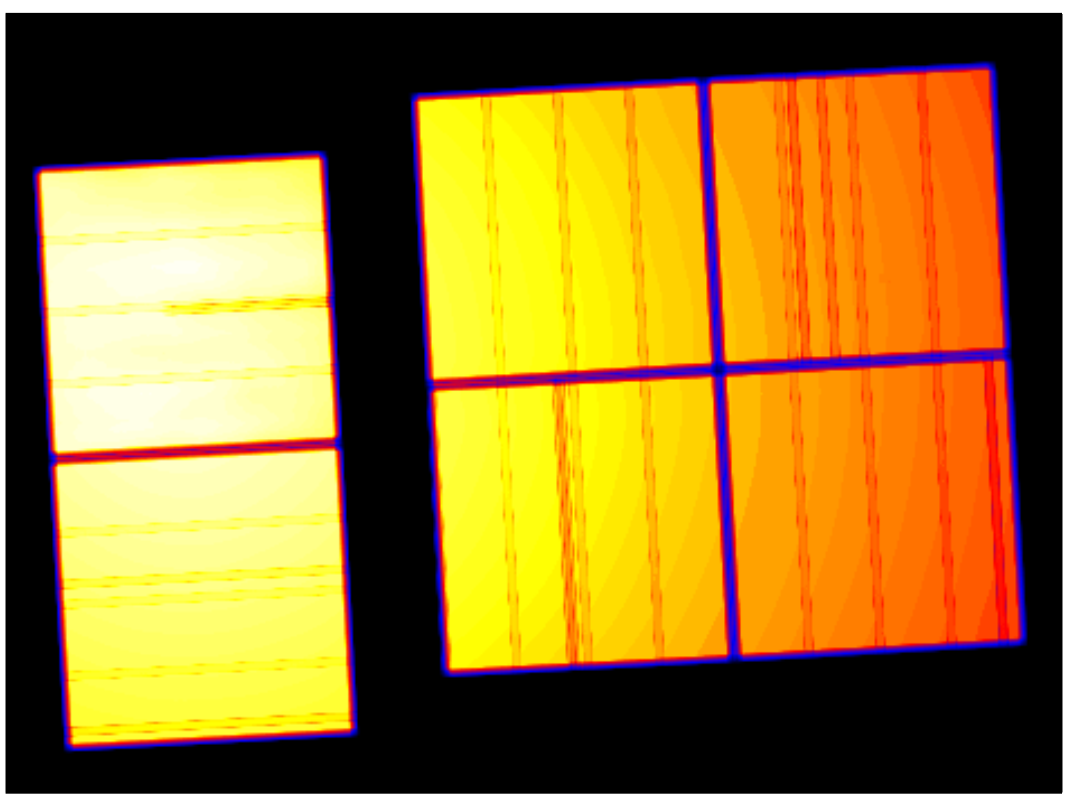
Instrument and Exposure Maps

Aspect solution



Instrument maps = mirror area x detector QE



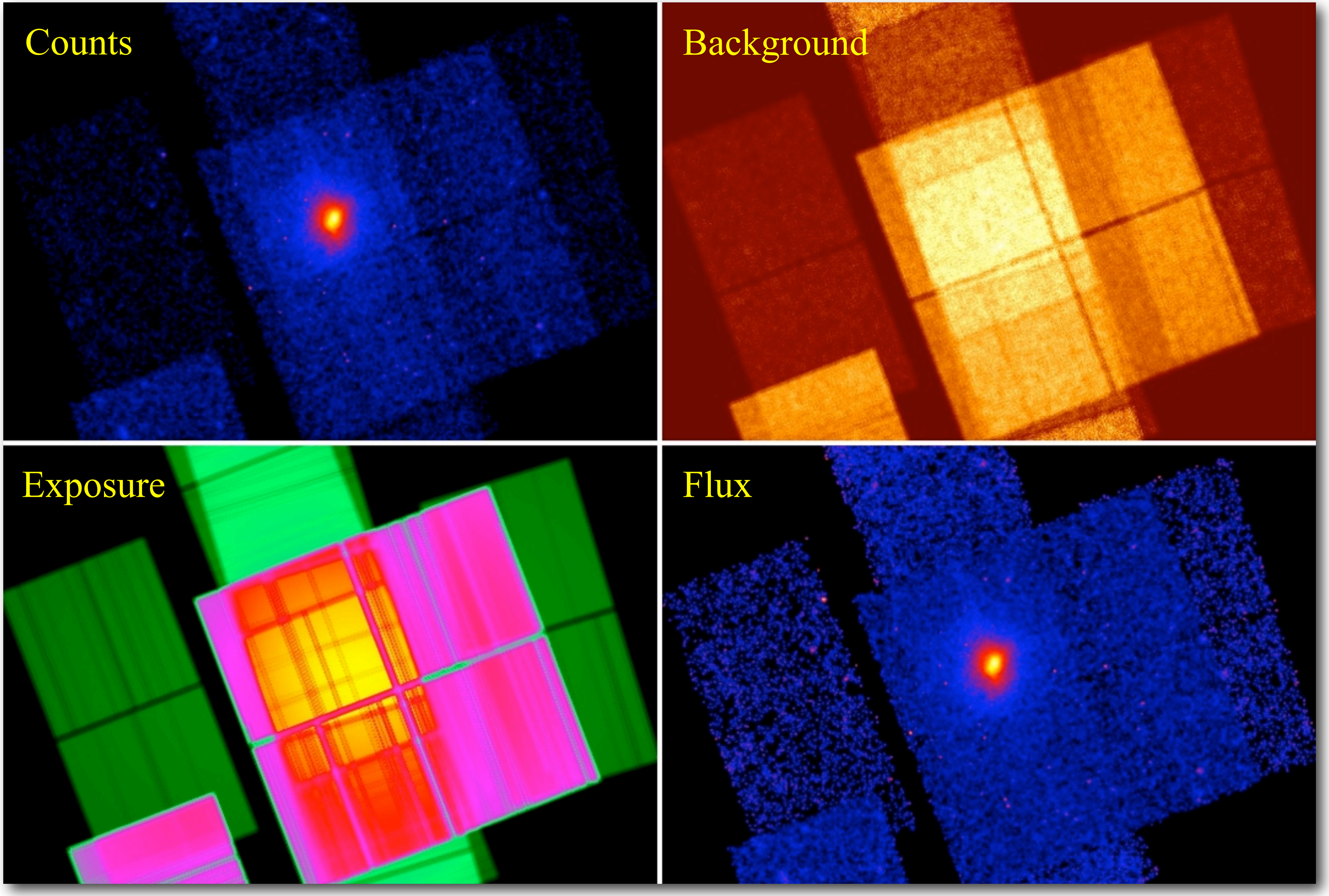


Exposure maps gives total effective area over the observation [cm^2 x sec]

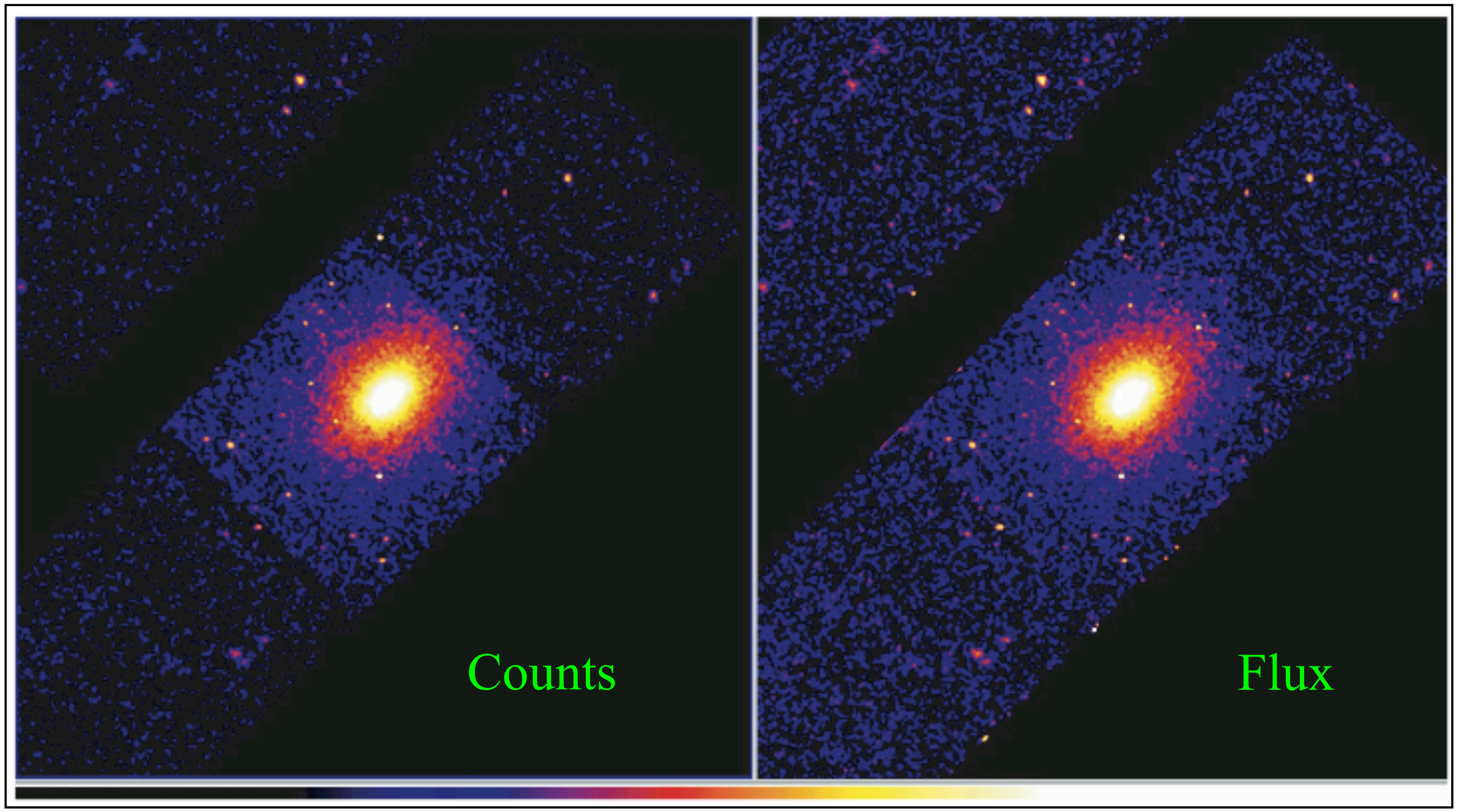
$$\int_{\Delta E} \mathrm{d}E\, \mathcal{S}_{\mathrm{PSF}}(E, \hat{\mathbf{p}}) \approx \frac{1}{\tau_{\mathrm{eff}}} \frac{C(\Delta h, \hat{\mathbf{p}})}{\mathcal{A}(\Delta h, E, \hat{\mathbf{p}})}$$

(see Davis 2001, ApJ, 548, 1010)

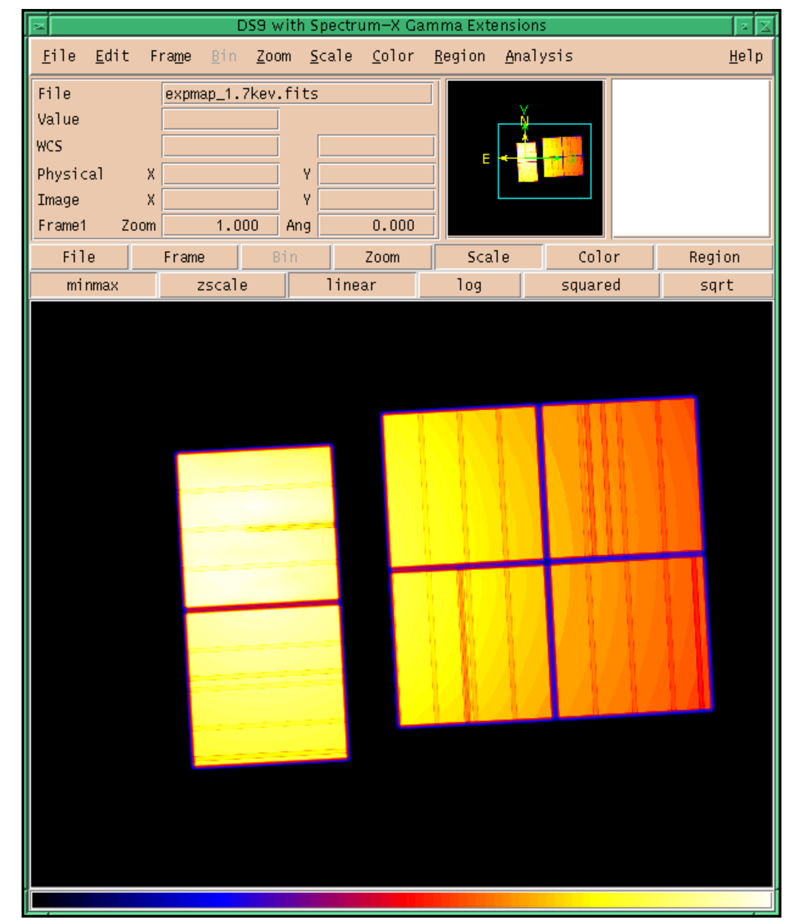
Exposure Corrected Images



Exposure Corrected Images

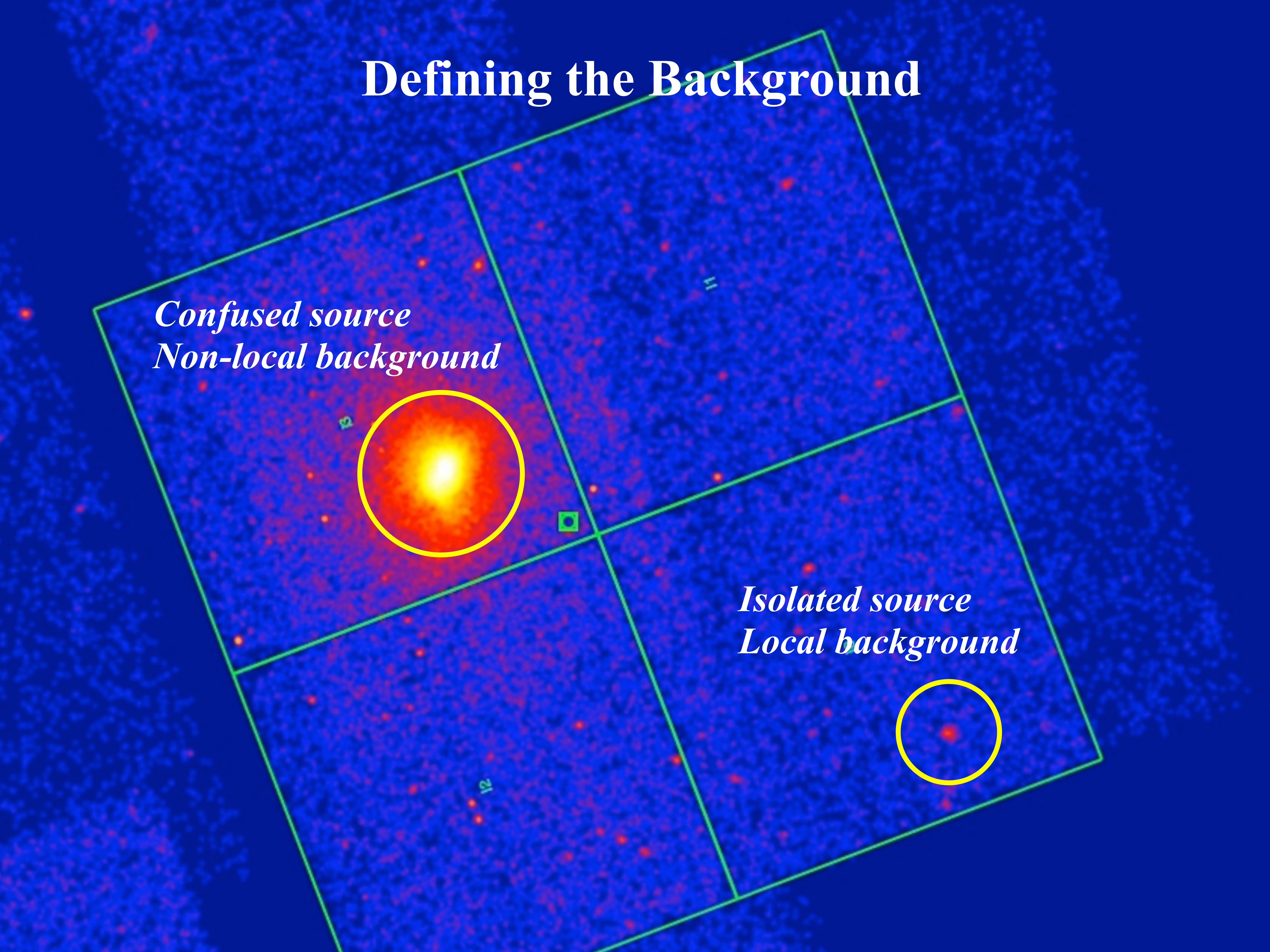


- Create counts image of field [`dmcopy`]
- Create instrument map for each chip [`mkinstmap`]
- Create exposure map for each chip [`mkexpmap`]
- Combine single exposure maps [`dmregrid`]
- Divide counts image by exposure map [`dmimgcalc`]

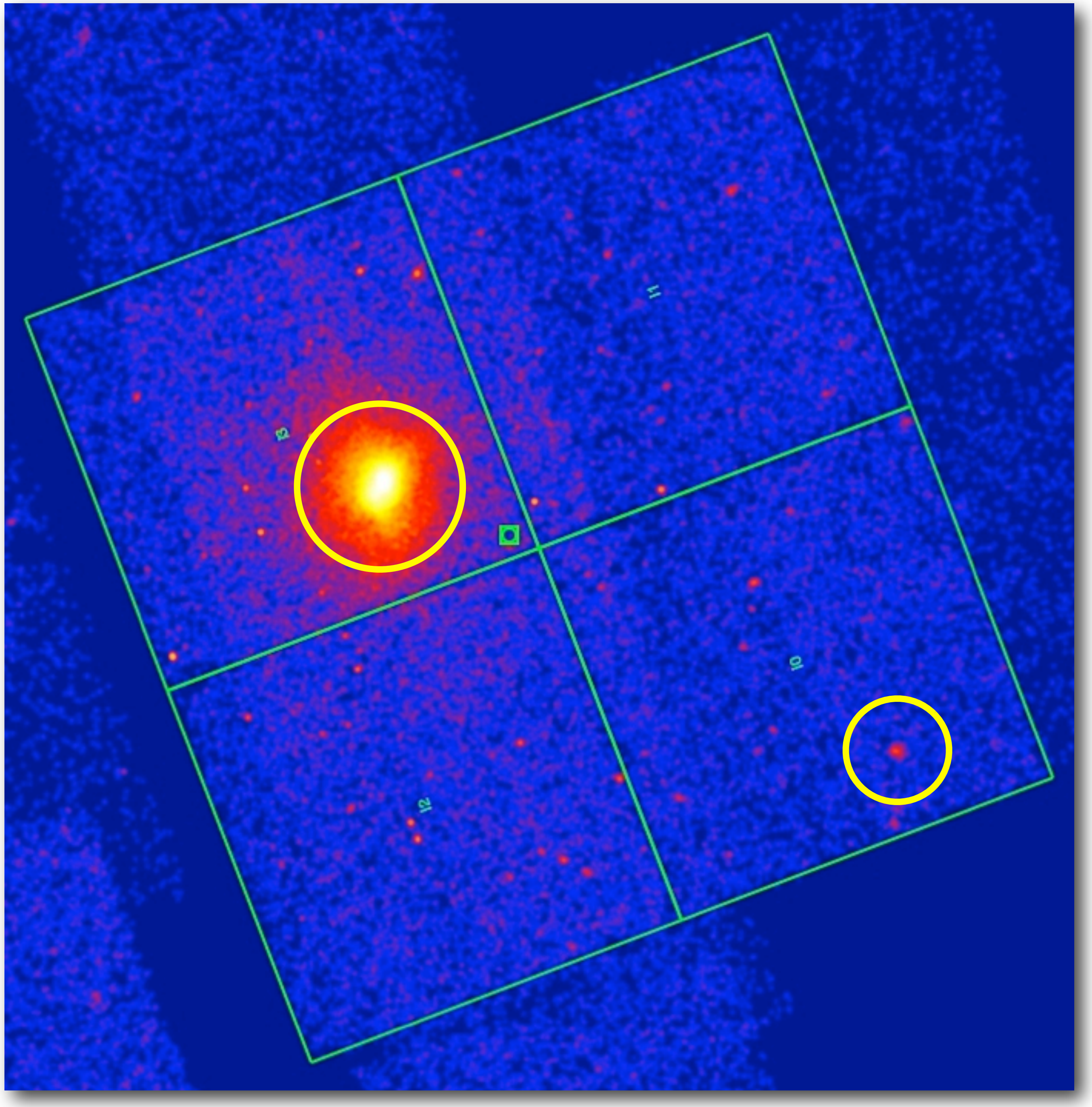


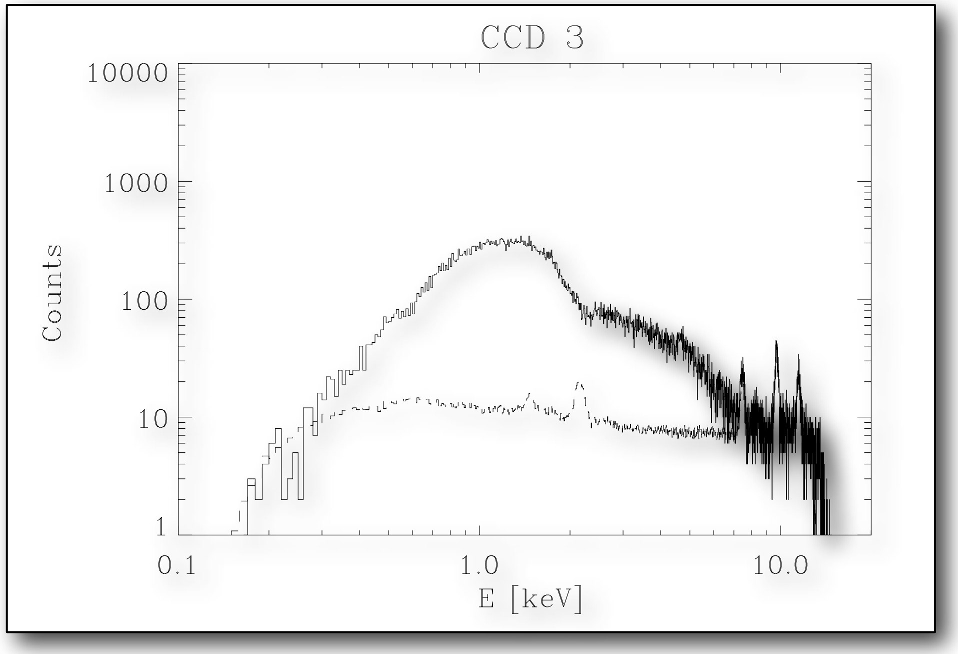
Exposure Map

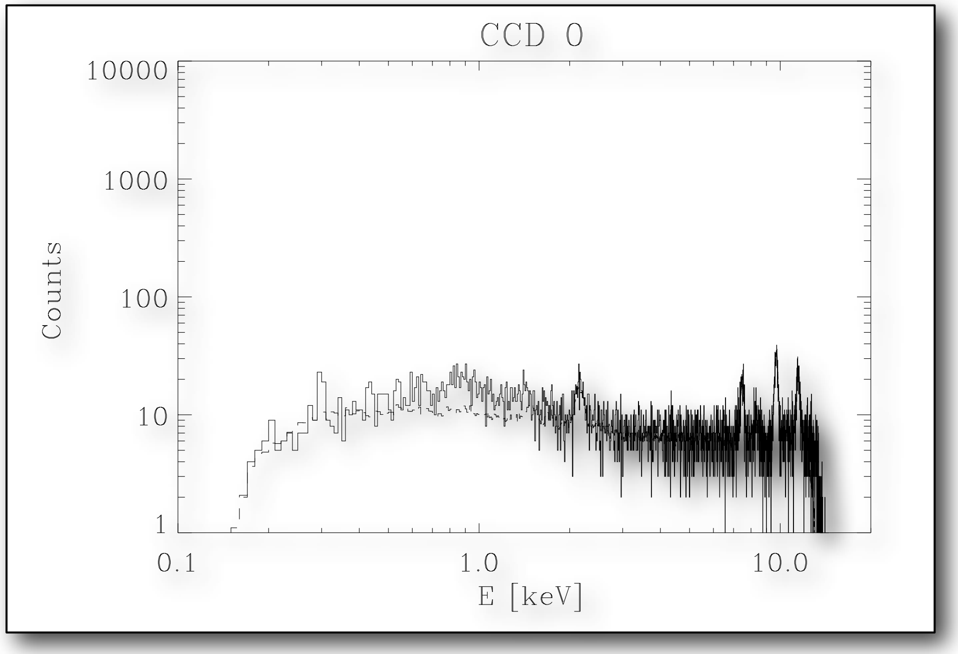
Defining the Background



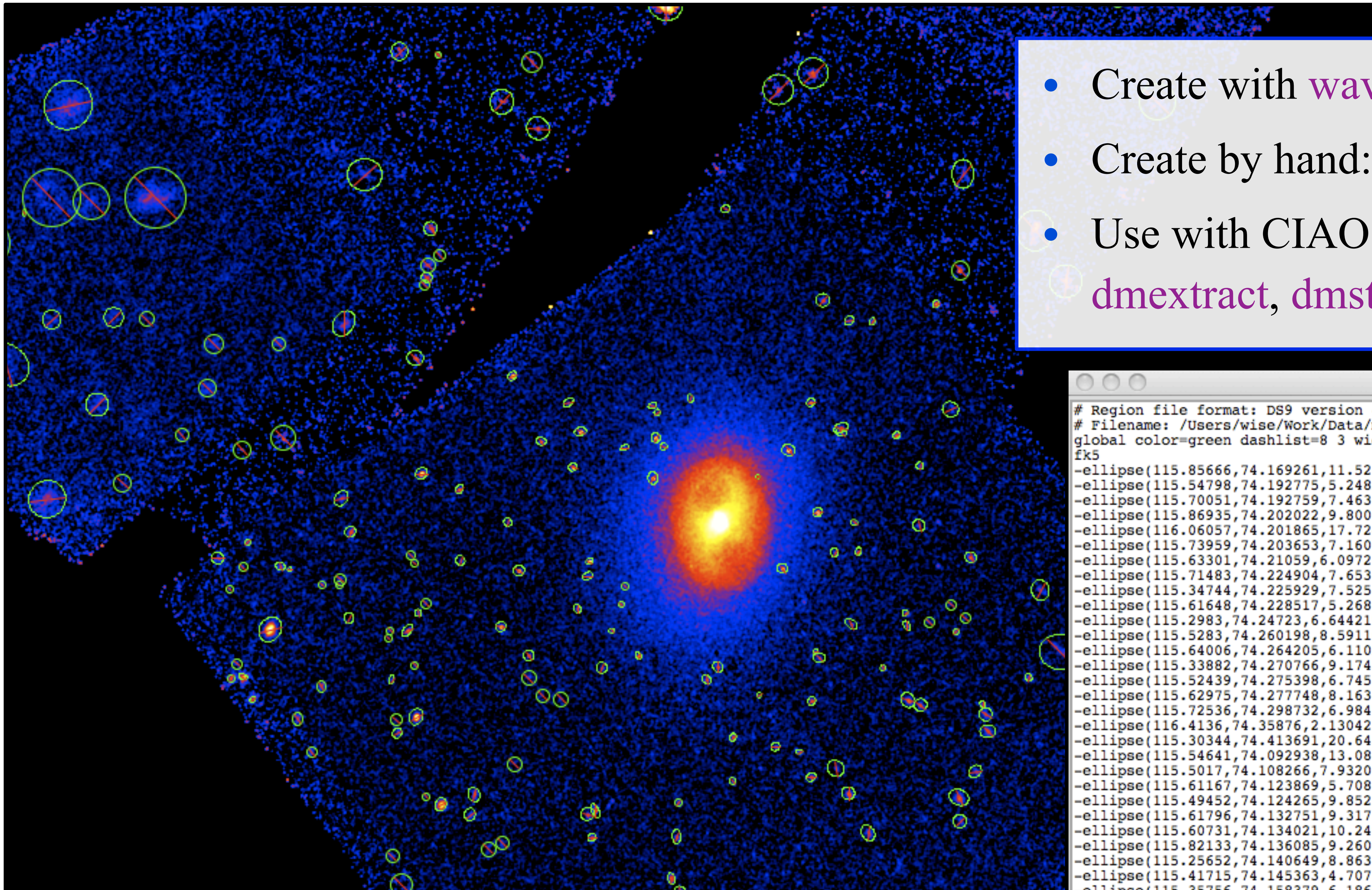
"Blank-sky" Background Files



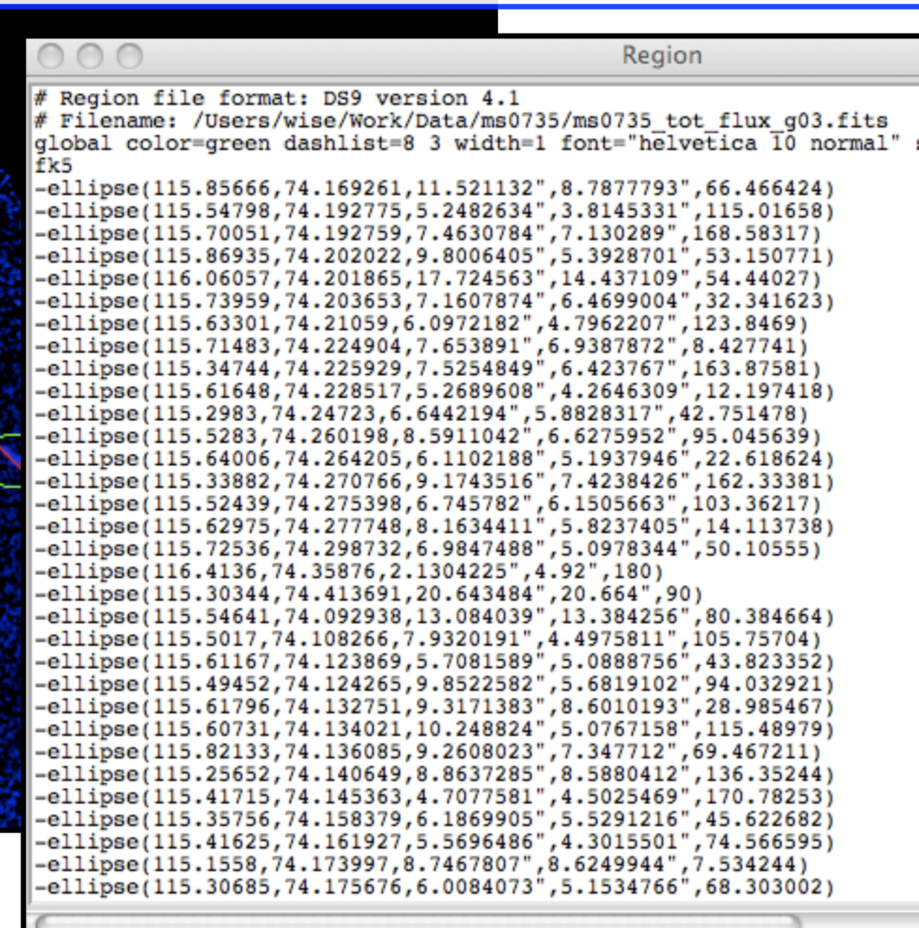




Region Files

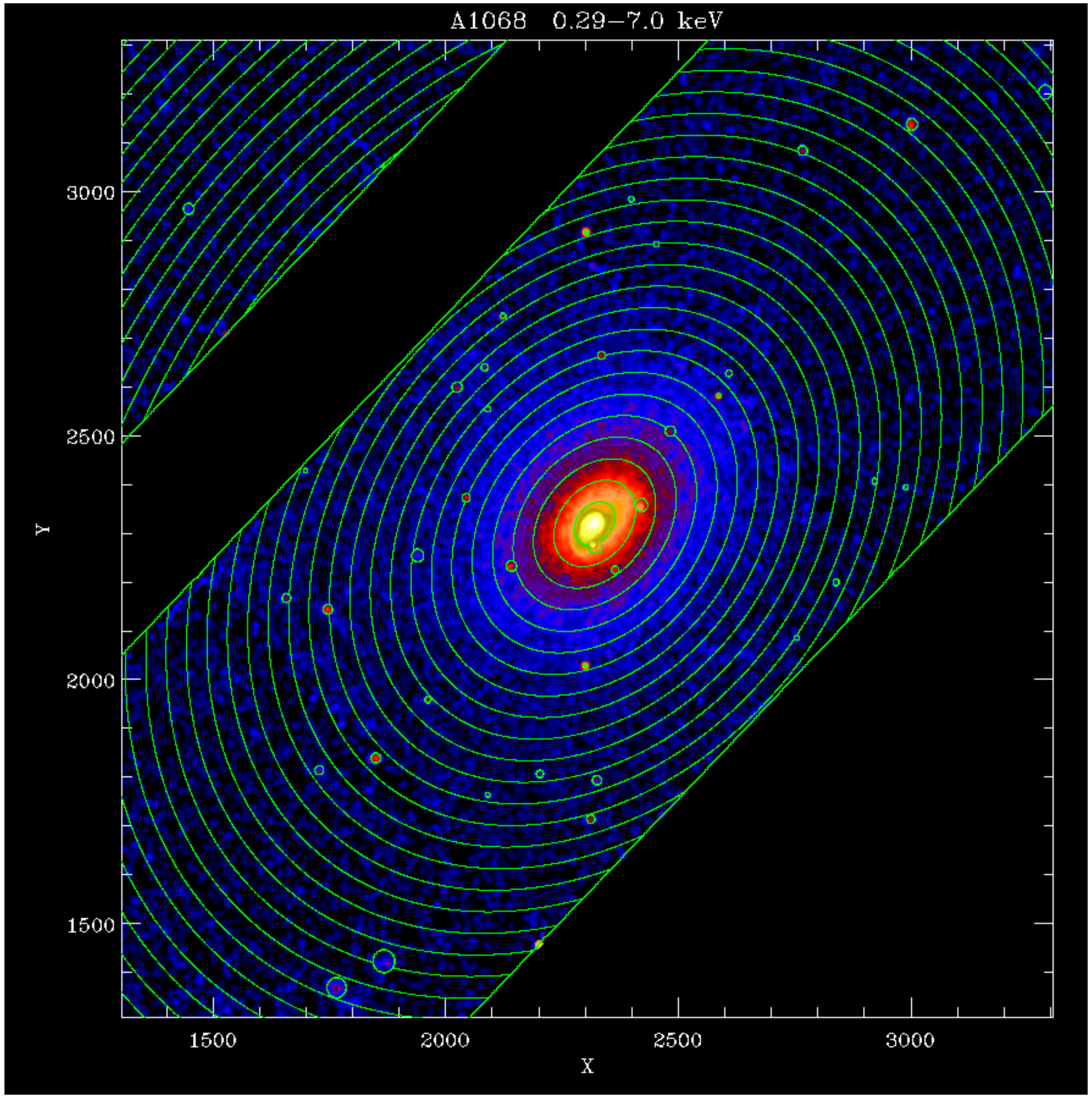


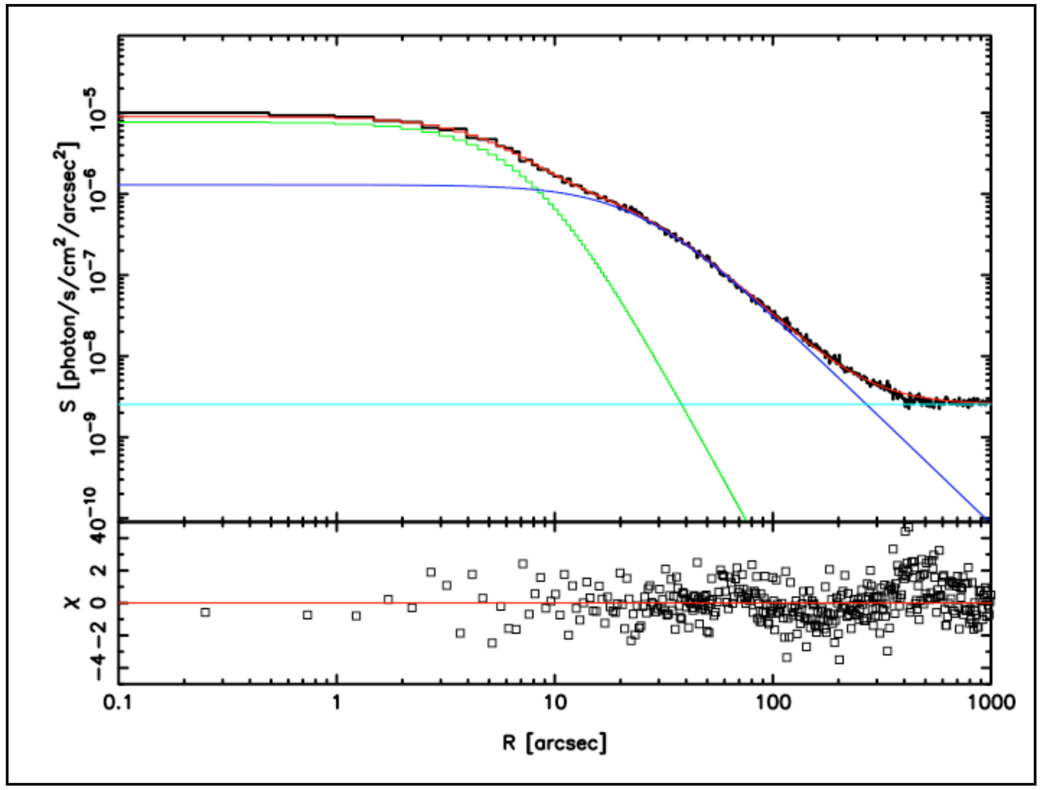
- Create with wavdetect, vtpdetect
- Create by hand: ds9
- Use with CIAO tools: dmcopy, dmextract, dmstat, etc.




```
# Region file format: DS9 version 4.1
# Filename: /Users/wise/Work/Data/ms0735/ms0735_tot_flux_g03.fits
global color=green dashlist=8 3 width=1 font="helvetica 10 normal" se
fk5
-ellipse(115.85666,74.169261,11.521132",8.7877793",66.466424)
-ellipse(115.54798,74.192775,5.2482634",3.8145331",115.01658)
-ellipse(115.70051,74.192759,7.4630784",7.130289",168.58317)
-ellipse(115.86935,74.202022,9.8006405",5.3928701",53.150771)
-ellipse(116.06057,74.201865,17.724563",14.437109",54.44027)
-ellipse(115.73959,74.203653,7.1607874",6.4699004",32.341623)
-ellipse(115.63301,74.21059,6.0972182",4.7962207",123.8469)
-ellipse(115.71483,74.224904,7.653891",6.9387872",8.427741)
-ellipse(115.34744,74.225929,7.5254849",6.423767",163.87581)
-ellipse(115.61648,74.228517,5.2689608",4.2646309",12.197418)
-ellipse(115.2983,74.24723,6.6442194",5.8828317",42.751478)
-ellipse(115.5283,74.260198,8.5911042",6.6275952",95.045639)
-ellipse(115.64006,74.264205,6.1102188",5.1937946",22.618624)
-ellipse(115.33882,74.270766,9.1743516",7.4238426",162.33381)
-ellipse(115.52439,74.275398,6.745782",6.1505663",103.36217)
-ellipse(115.62975,74.277748,8.1634411",5.8237405",14.113738)
-ellipse(115.72536,74.298732,6.9847488",5.0978344",50.10555)
-ellipse(116.4136,74.35876,2.1304225",4.92",180)
-ellipse(115.30344,74.413691,20.643484",20.664",90)
-ellipse(115.54641,74.092938,13.084039",13.384256",80.384664)
-ellipse(115.5017,74.108266,7.9320191",4.4975811",105.75704)
-ellipse(115.61167,74.123869,5.7081589",5.0888756",43.823352)
-ellipse(115.49452,74.124265,9.8522582",5.6819102",94.032921)
-ellipse(115.61796,74.132751,9.3171383",8.6010193",28.985467)
-ellipse(115.60731,74.134021,10.248824",5.0767158",115.48979)
-ellipse(115.82133,74.136085,9.2608023",7.347712",69.467211)
-ellipse(115.25652,74.140649,8.8637285",8.5880412",136.35244)
-ellipse(115.41715,74.145363,4.7077581",4.5025469",170.78253)
-ellipse(115.35756,74.158379,6.1869905",5.5291216",45.622682)
-ellipse(115.41625,74.161927,5.5696486",4.3015501",74.566595)
-ellipse(115.1558,74.173997,8.7467807",8.6249944",7.534244)
-ellipse(115.30685,74.175676,6.0084073",5.1534766",68.303002)
```

Surface Brightness Profiles

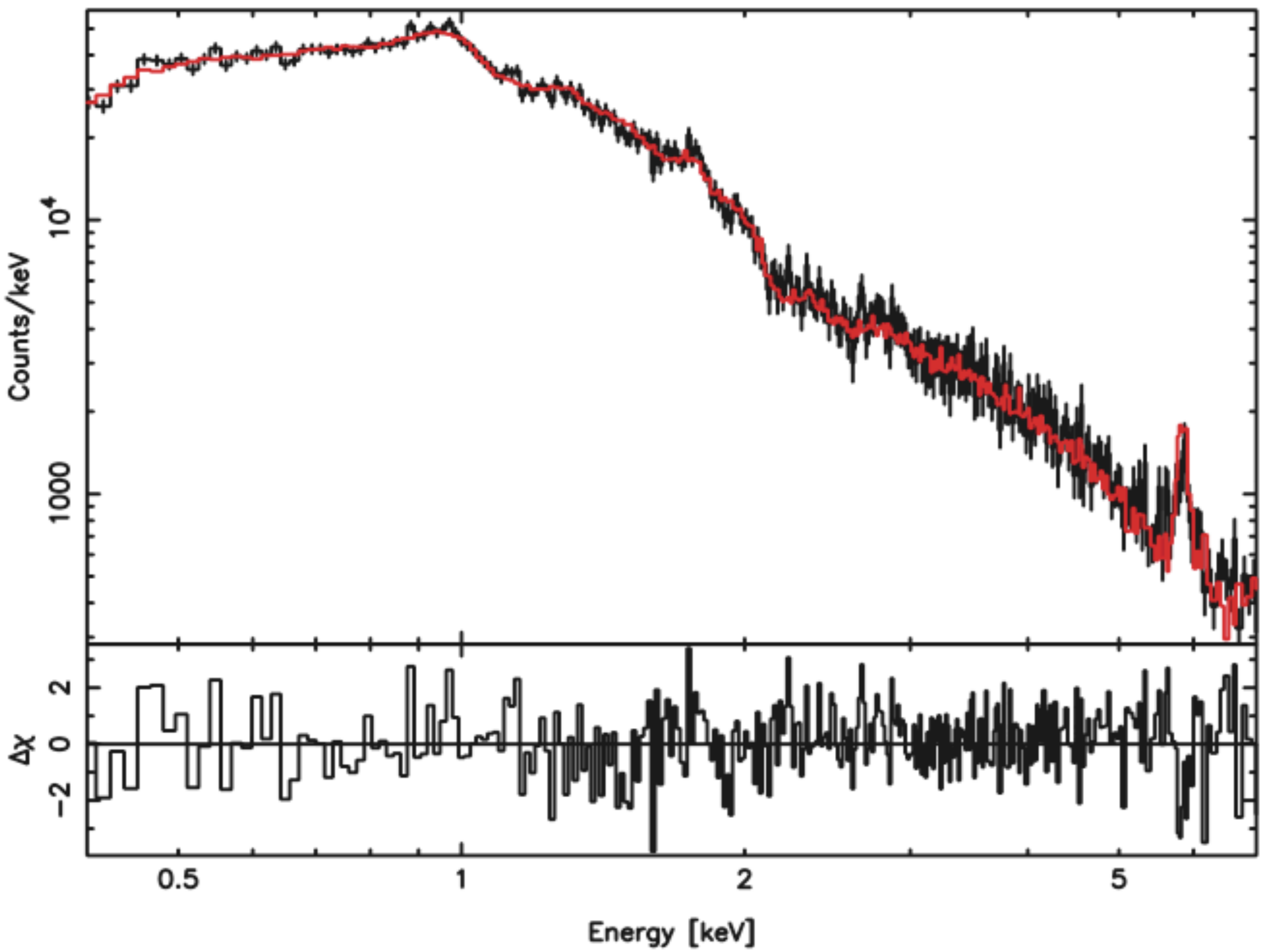




- Find and remove point sources
- Define annular regions
- Extract counts in each annulus
- Cut point source regions from exp. map
- Extract exposure in each annulus
- Divide counts by exposure
- Fit β model to profile

Tools: `dmcopy`, `ds9`, `dmextract`, `dmtcalc`, `sherpa`

Spectral Analysis



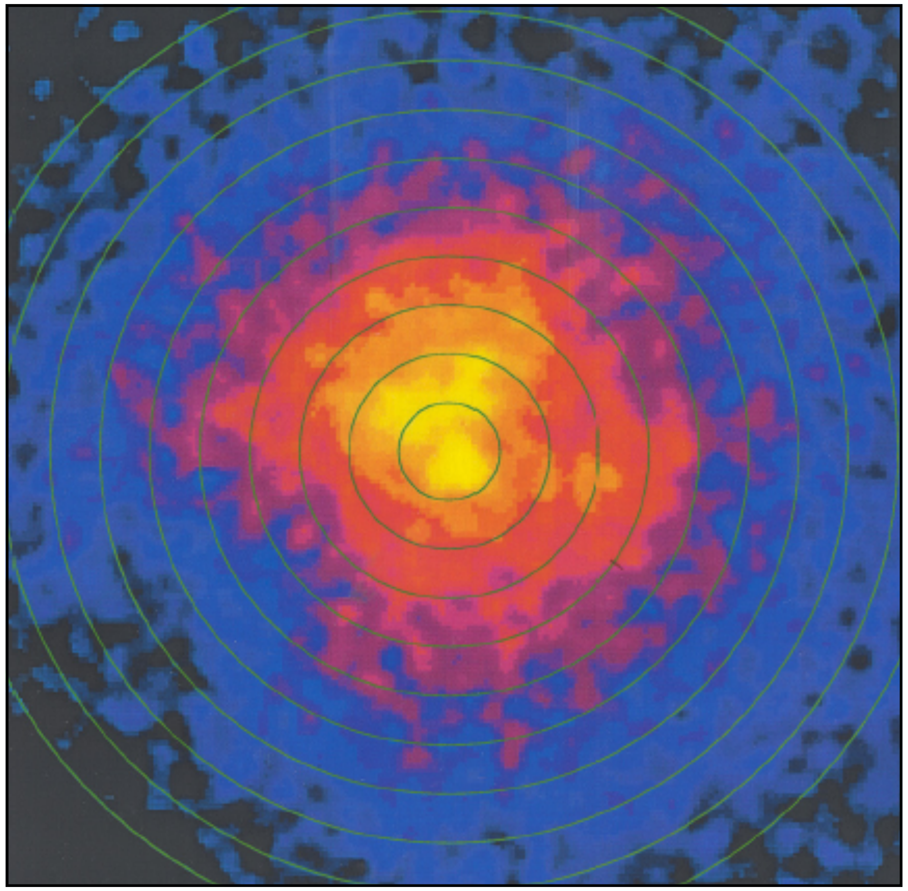
Procedure

- Find and remove point sources
- Extract spectrum (and background)
- Create weighted ARF
- Create weighted RMF
- Correct ARF for contamination
- Define model and fit
- Save fitted spectrum

Tools

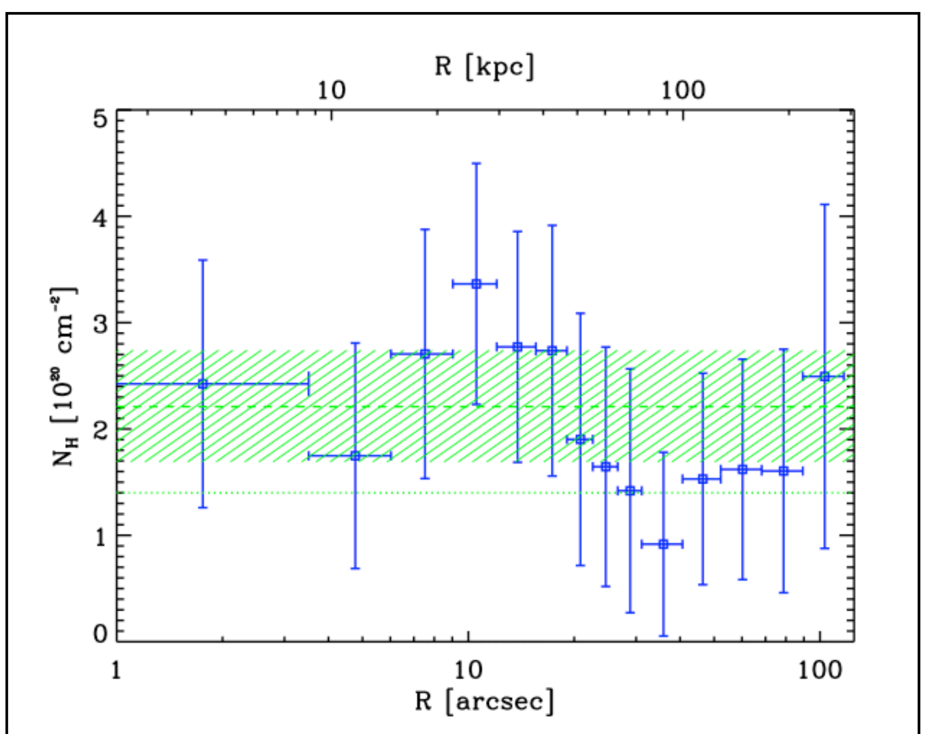
- wavdetect, dmcopy
- dmextract
- mkwarf
- mkacisrmf
- sherpa

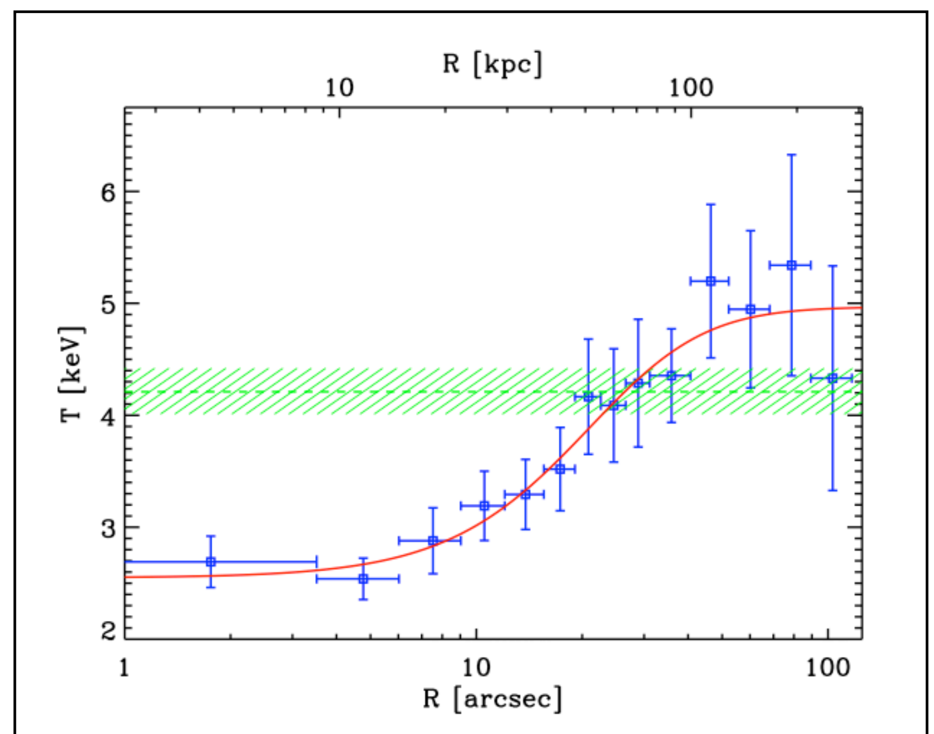
```
dmextract infile=”evt2.fits[sky=circle(4024.0,4240.0,300.0)][bin pi]” \
          outfile=“spect.pi” wmap="det=8"
```



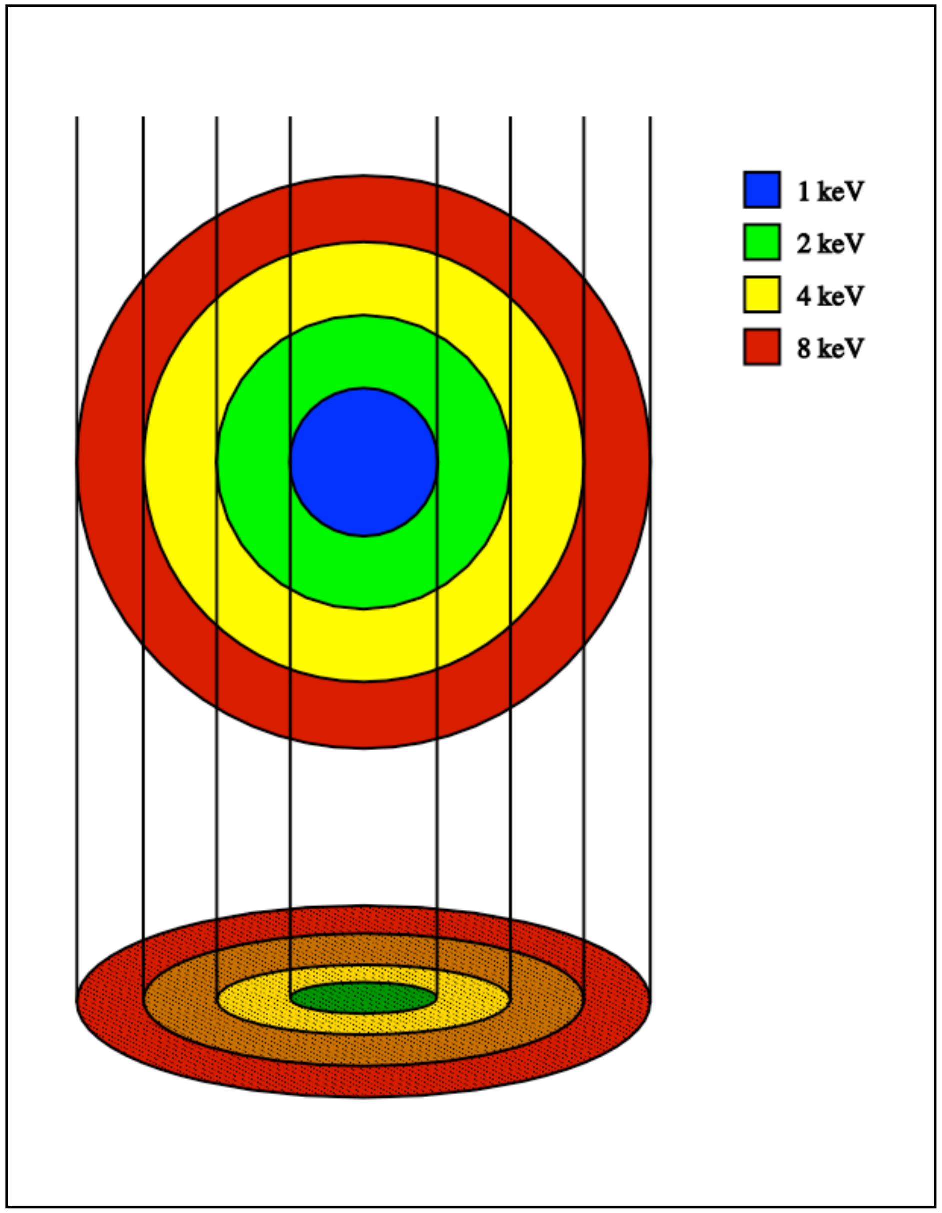
Imaging Spectroscopy

- Cut out point sources [`dmcopy`]
- Define annuli (equal counts?) [`ds9`, sherpa]
- Create spectrum and weighted RMF/ARF for each annulus [`dmextract`, `mkacisrmf`, `mkwarf`]
- Define spectral model [`sherpa`]
- Repeat spectral fit for each annulus





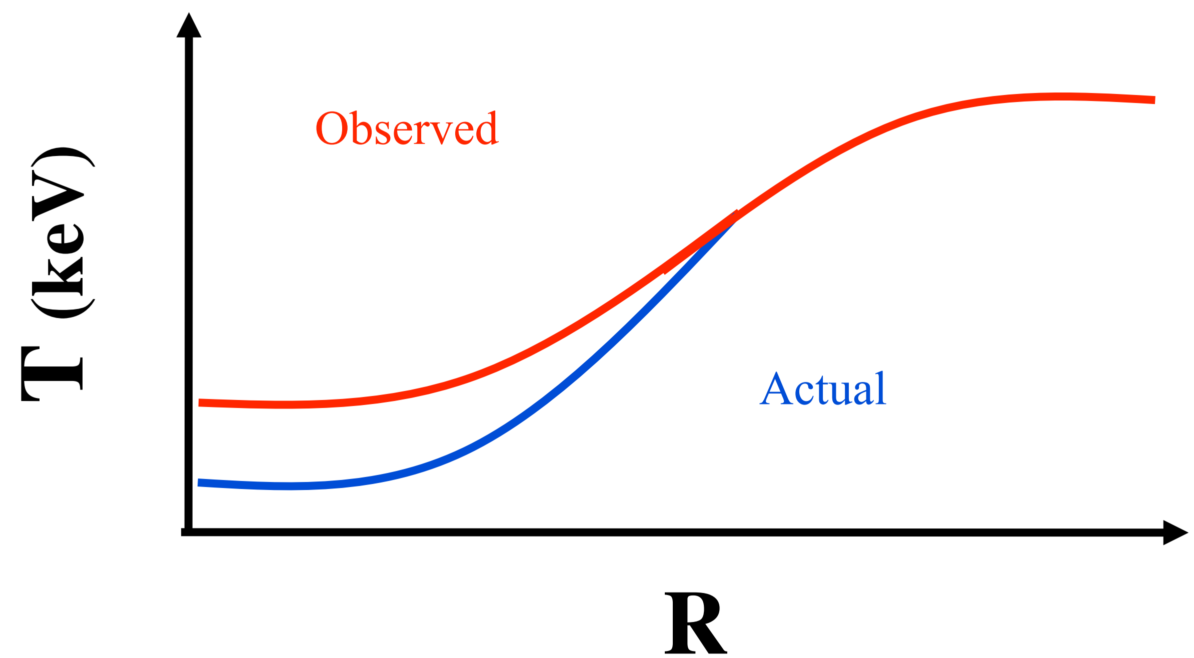
Deprojected spectral analysis



For an assumed geometry, one can calculate the partial volumes, V_{ij}, which contribute to any projected annulus

Problem: Projected spectra contain contributions for all annuli along line of sight

Effect: Measured <*T*> higher than true value

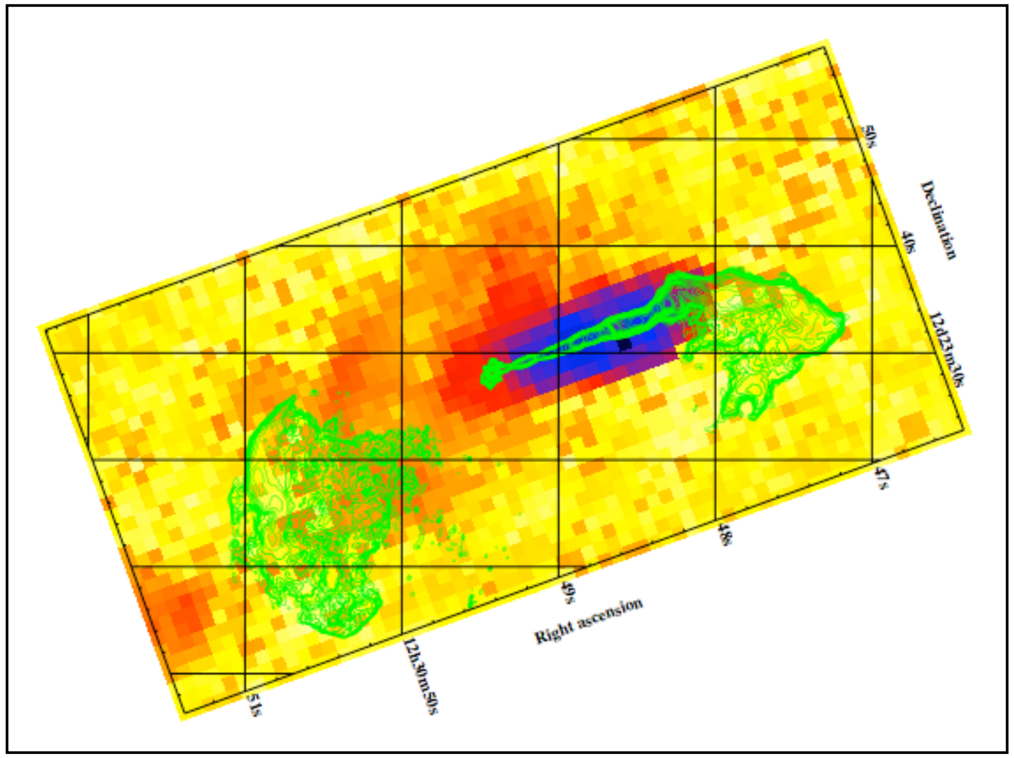


Solution:

- Calculate volume fractions
- Define custom spectral model
- Fit data from all shells simultaneously
- Coming soon to a thread near you

2D Spectral Mapping

- Map is just **many** spectral fits
- Define grid of boxes containing counts
- Extract spectrum, calculate RMF/ARF for each box
- Fit model at each grid point
- Write out fit parameters as a function of position
- Can map any fit parameter



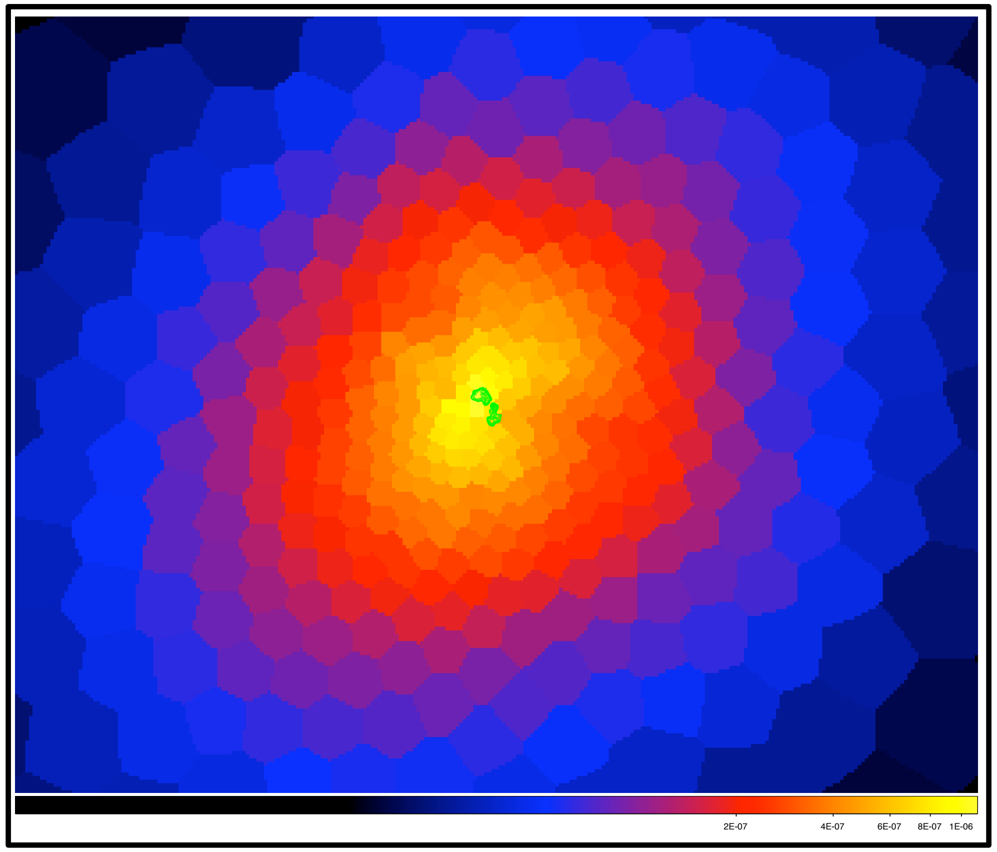
10^3-10^4 fits

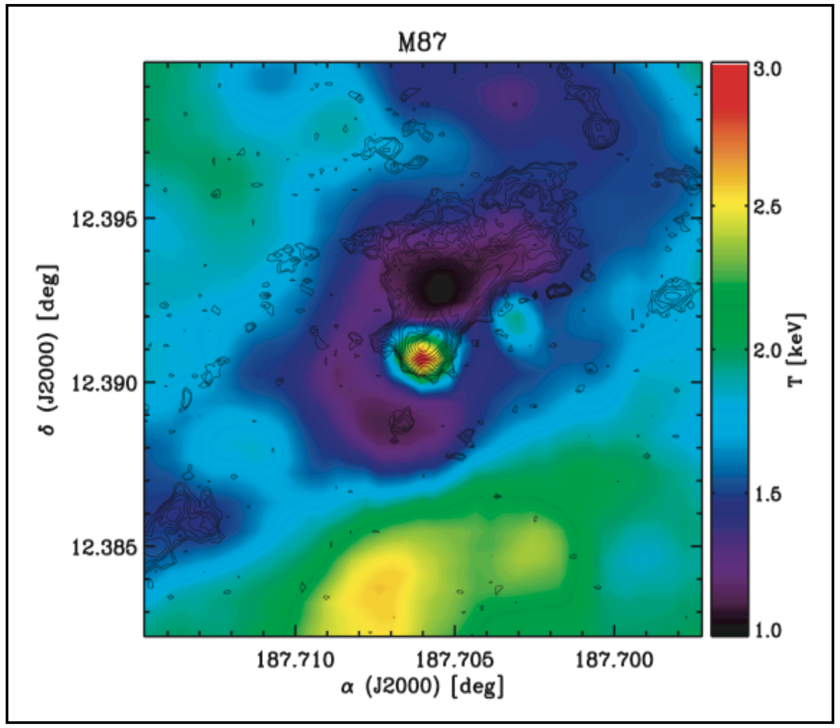
↓

CPU intensive

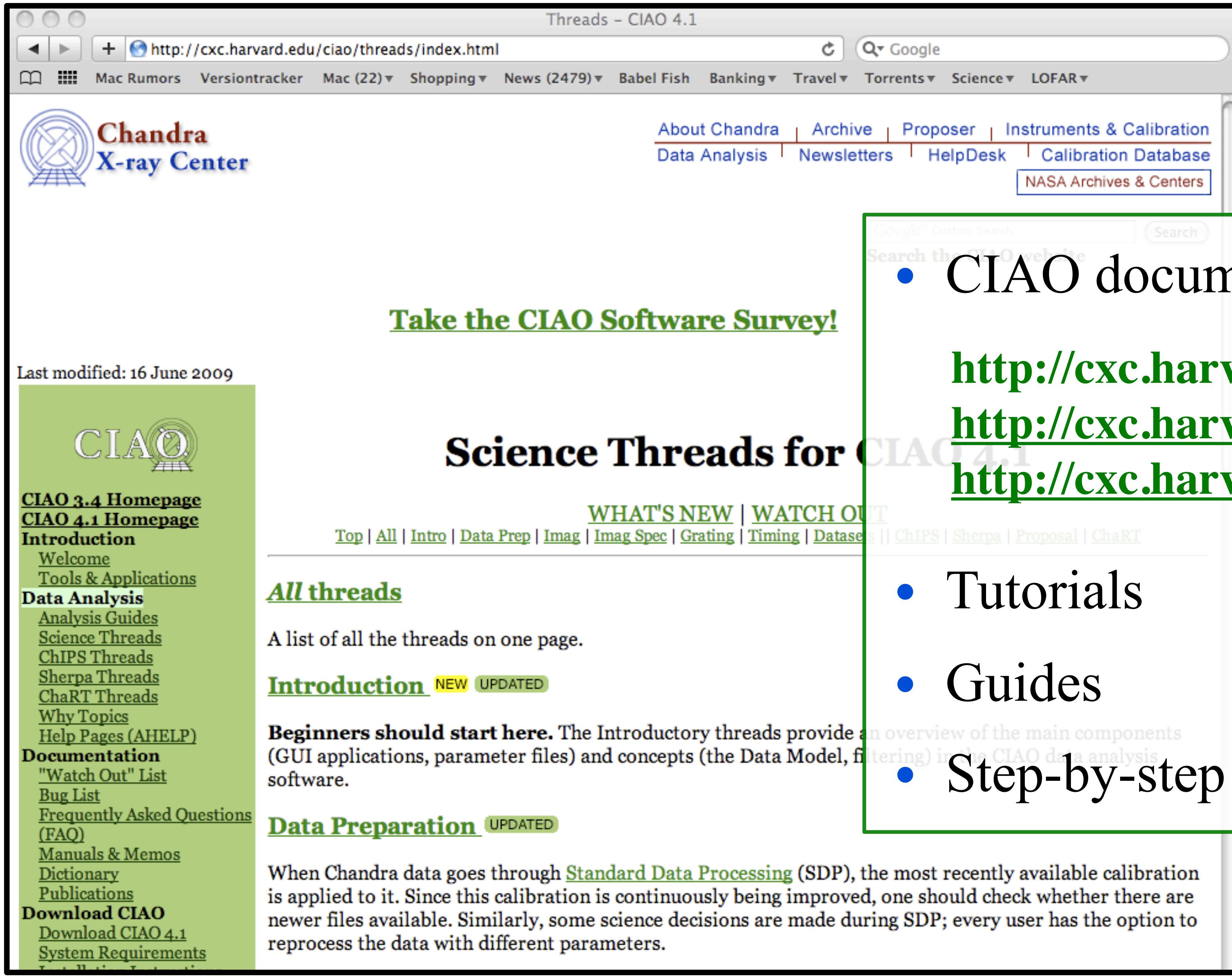
↓

Distributed processing





Online Documentation



- CIAO documentation online:

  http://cxc.harvard.edu/ciao/threads
  http://cxc.harvard.edu/ciao/guides
  http://cxc.harvard.edu/ciao/why

- Tutorials
- Guides
- Step-by-step instructions


The End