OUTLINE

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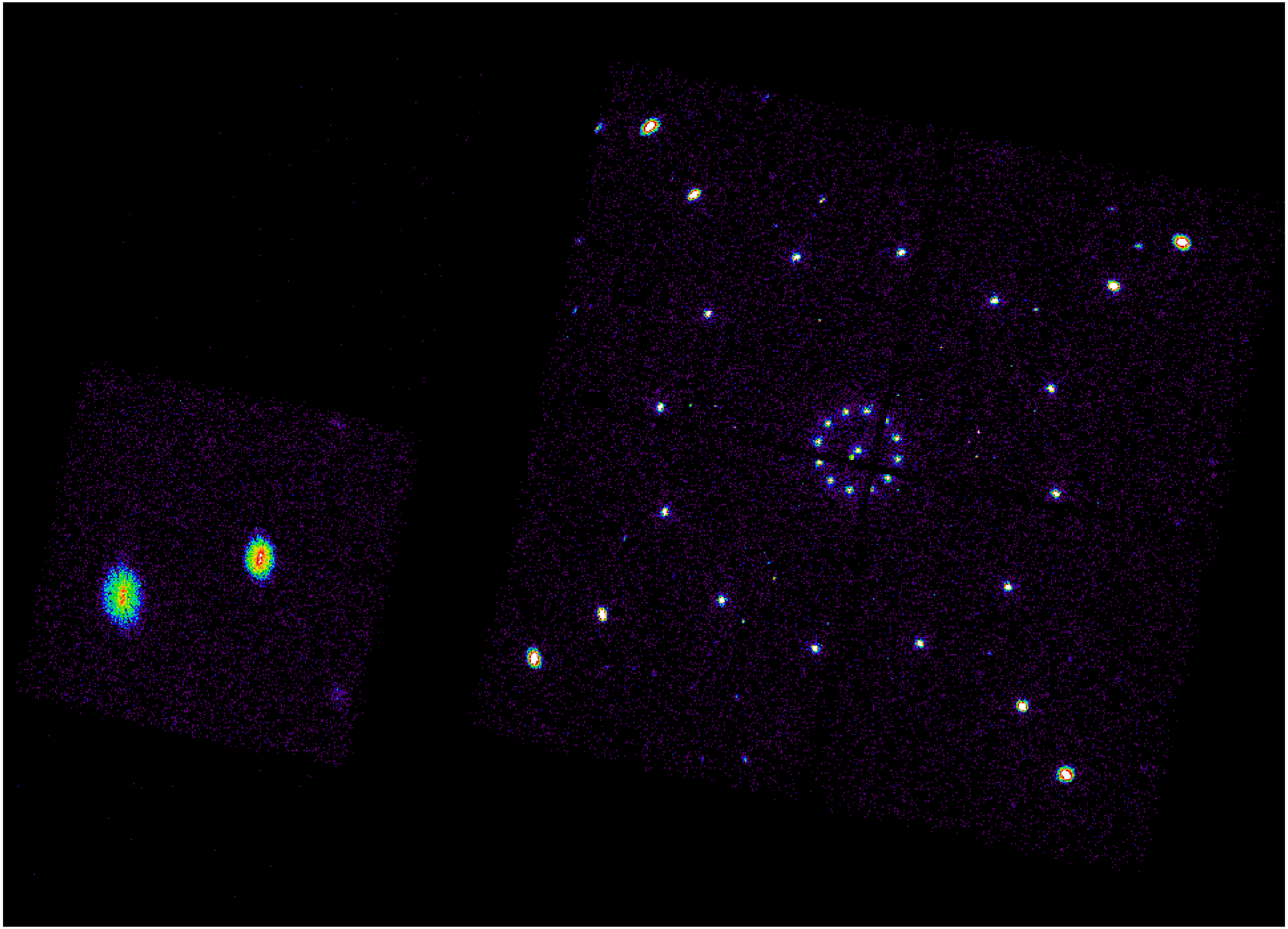
Introduction

- Source Detection Goal
  - Identify statistically significant brightness enhancements, over local background, deriving from both unresolved (point) and resolved (extended) x-ray sources. Other properties, like intensity and size, may also be reported, but may be more reliably evaluated separately.
- Realities
  - This is often a difficult (or at least challenging) task.
  - CIAO provides 3 different tools, each with its own strengths and weaknesses. A reliable source list may require running more than one tool, or one tool multiple times.

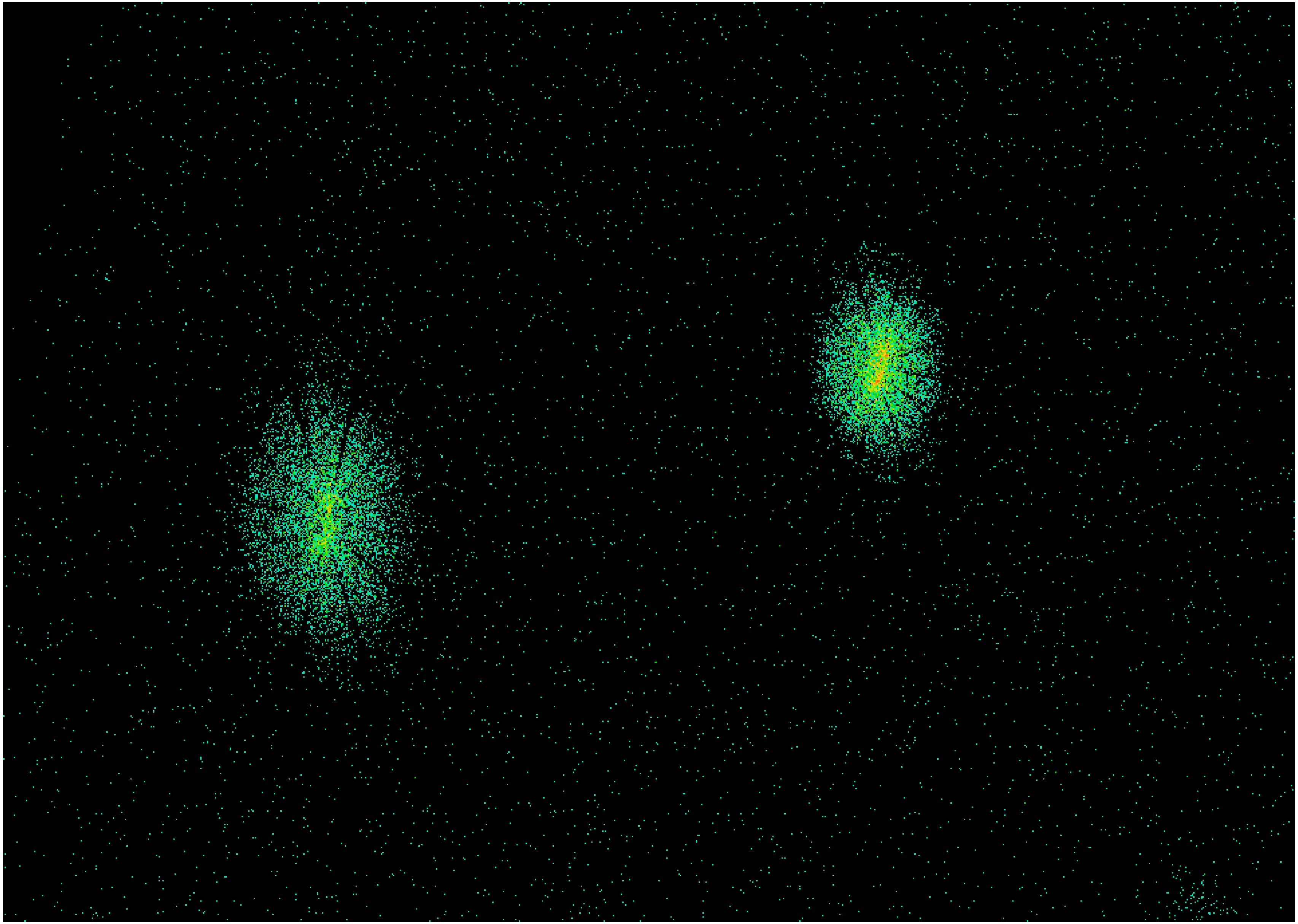
DETECT Challenges

- Chandra mirrors have a ~10X higher angular resolution than other x-ray telescopes:
  - Complex source structures often seen;
  - Point sources in other telescopes are resolved into multiple, overlapping sources;
  - Extended sources often have low surface brightness;
- Point Spread Function changes dramatically with position in the image;
- Images typically have only a few events per pixel.

An Example Chandra Image



Same Observation, Chip 6, Full Resolution

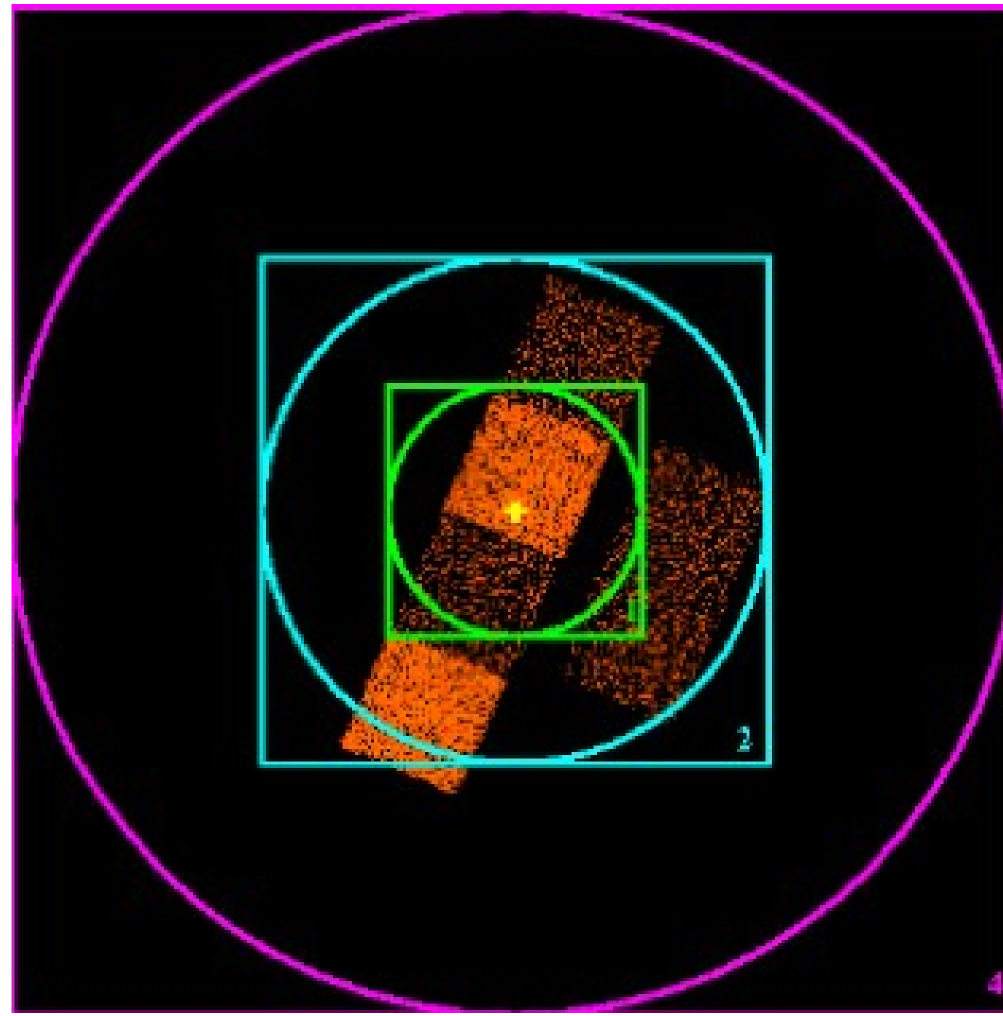


CELLDETECT

- X-ray image scanned with a sliding, square 'detect cell'. The signal to noise ratio is calculated by comparing the total counts in the cell and predicted background counts, estimated from either a surrounding background frame or a background map.
- Size of detect cell varies with off-axis angle to account for changing PSF size.
- References:
  - CXC Detect Manual
  - Calderwood et al. 2001, ADASS X, ASP Conf. Ser. 10, 443
  - Dobrzycki et al. 2000, AAS/HEAD, 32, 2708

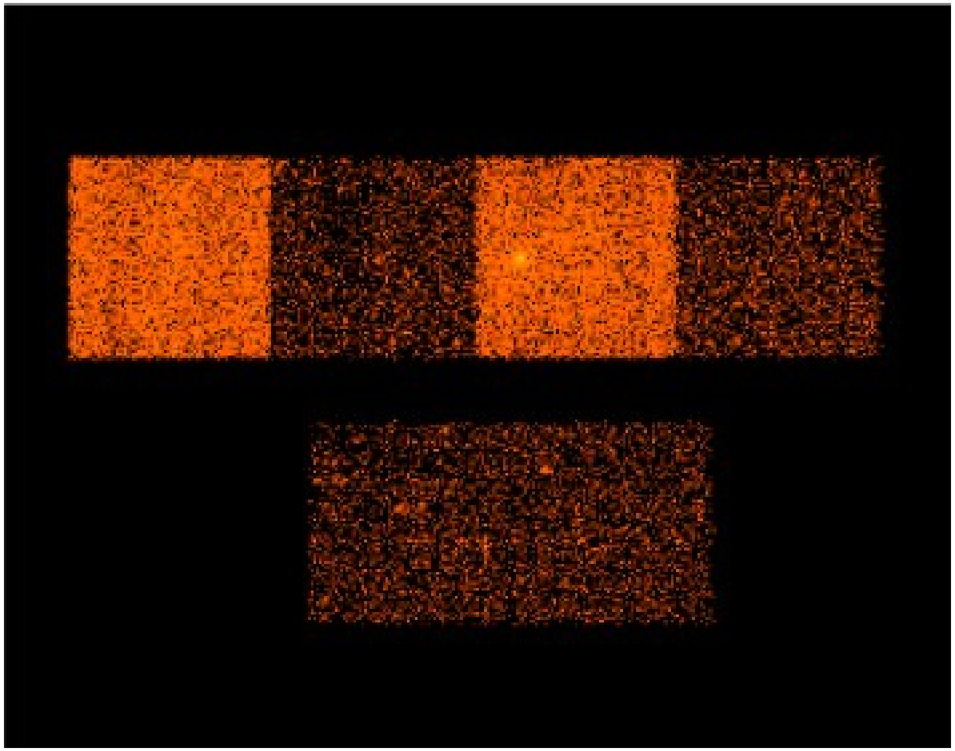
CELLDETECT: Recursive Blocking

- Center 2k x 2k scanned at full resolution, only selecting sources contained in inscribed circle;
- Center 4k x 4k scanned at block=2 resolution, excluding region included in previous step;
- Etc.



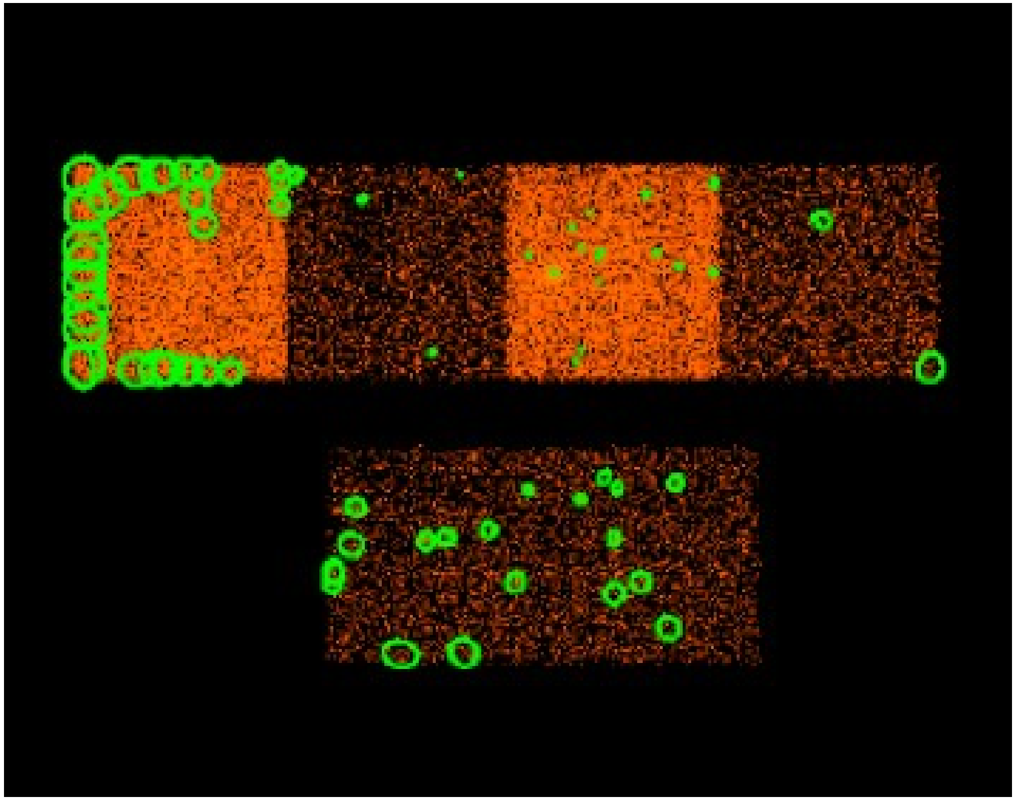
CELLDETECT: Edge Effects

- Chandra data have several edge effects:
  - Field-of-view boundaries;
  - Jumps in background between FI and BI chips;
  - Node boundaries inside ACIS chips;



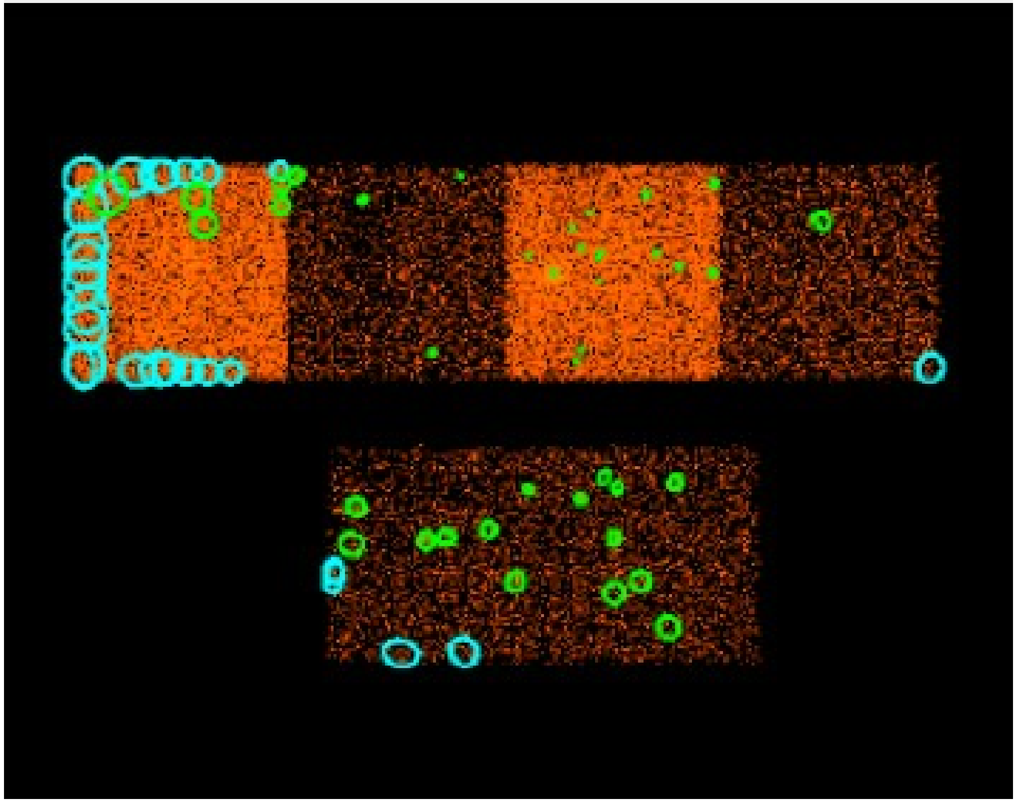
CELLDETECT: Edge Effects

- Run without use of exposure maps, CELLDETECT can lead to spurious detections at detector edges.



CELLDETECT: Edge Effects

- The user may provide a stack of exposure maps (expstk), congruent with the recursively-blocked images;
- CELLDETECT then selects only those sources for which the ratio of exposures in the detect and background cells is greater than a user-defined value (expratio).



CELLDETECT: Pros and Cons

- Fast and Robust;
- Works well for point sources;
- Detailed PSF shape not needed, only approximate size;
- Can swallow entire observation in one gulp.

- Extended sources can be difficult, without careful selection of cell sizes;
- Can get confused in crowded fields;
- Exposure maps needed to eliminate edge sources;
- Not very sensitive, unless background maps are used, but these can be difficult to make.

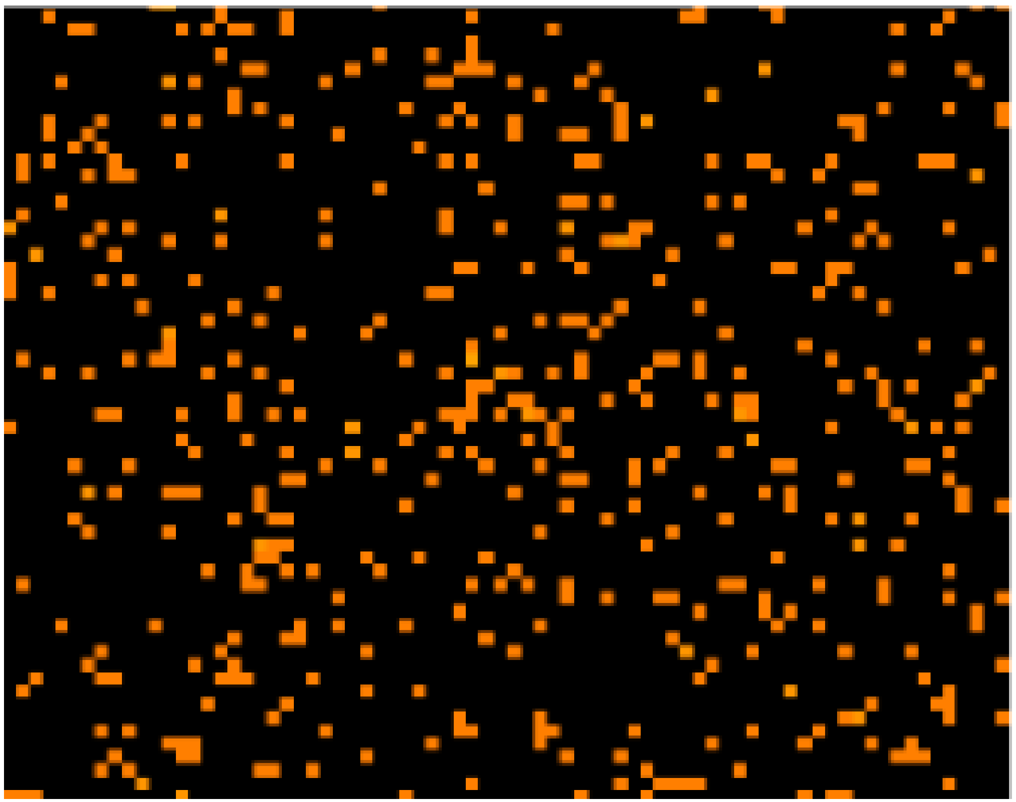
CELLDETECT Parameters:

name	type	ftype	def	min	max	units	reqd	stacks	autoname
infile	file	input					yes		
expstk	file	input						yes	
outfile	file	output					yes		yes
regfile	file		none						yes
clobber	boolean		no						
thresh	real		3						
findpeaks	boolean		yes						
centroid	boolean		yes						
ellsigma	real		3						
expratio	real		0						
fixedcell	integer		0			pixels			
xoffset	integer		INDEF			pixels			
yoffset	integer		INDEF			pixels			
eband	real		1.4967			keV			
eenergy	real		0.8						
psftable	file	ARD							
cellfile	file	output							yes
bkgfile	file	input							
bkgvalue	real		0						
bkgerrvalue	real		0						
convolve	boolean		no						
snrfile	file	output							yes
verbose	integer		0	0	5				
log	boolean		no						

VTPDETECT

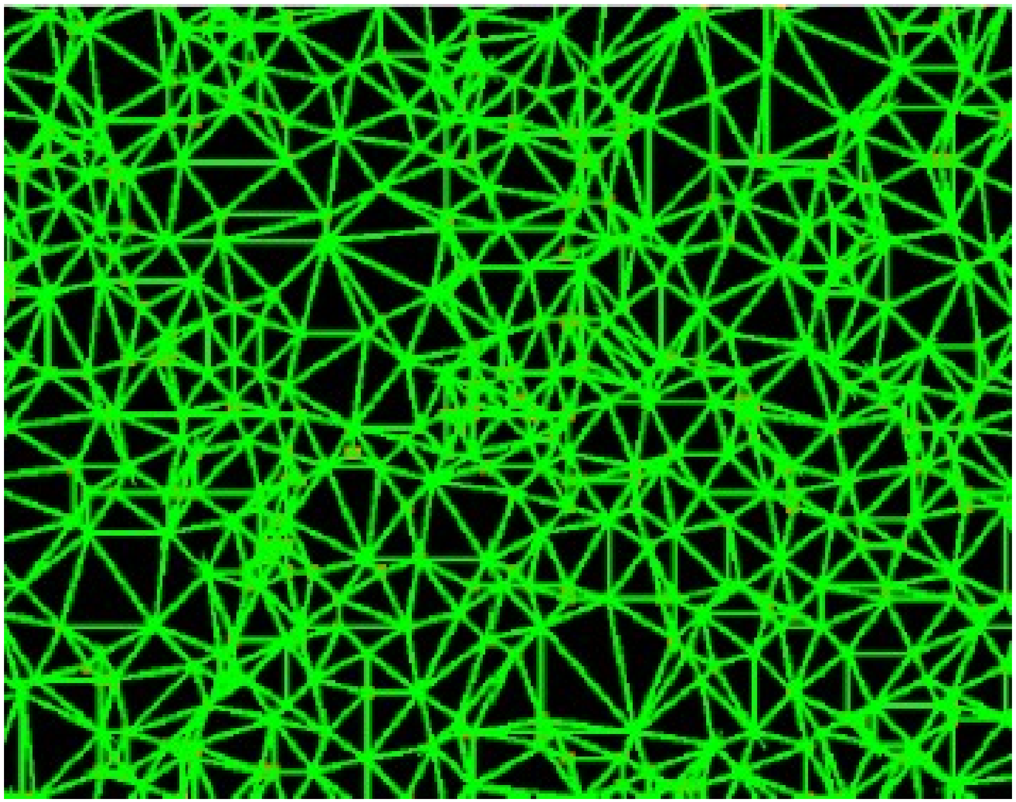
- Compares observed clustering of event positions with that expected from Poisson distribution;
- Scale-independent: good for extended/irregular sources, but encounters problems in crowded fields;
- References:
    - CXC Detect Manual;
    - Ebeling & Weidenmann 1993, Phys.Rev.E, 47,704;
    - Ebeling et al. 1996, MNRAS, 281, 799;
    - Jones et al. 1998, ApJ, 495,100.

VTPDETECT: How It Works



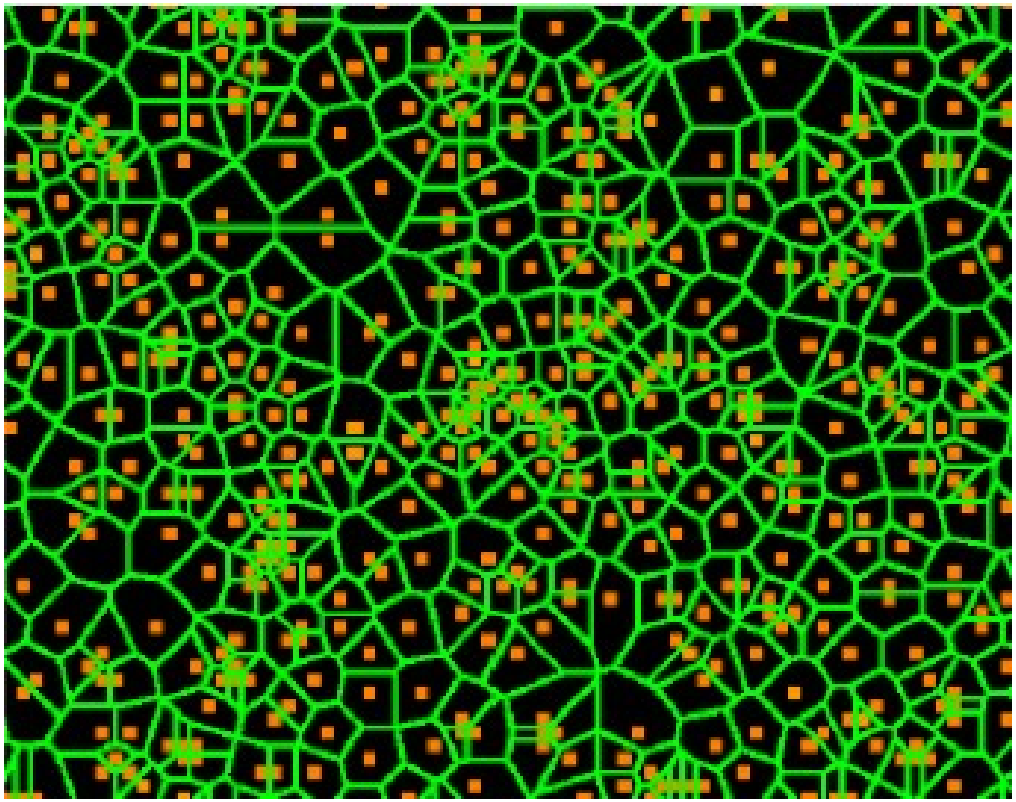
- Consider a small (~75 x 50 pixel) segment of an ACIS observation of 3C295

VTPDETECT: How It Works



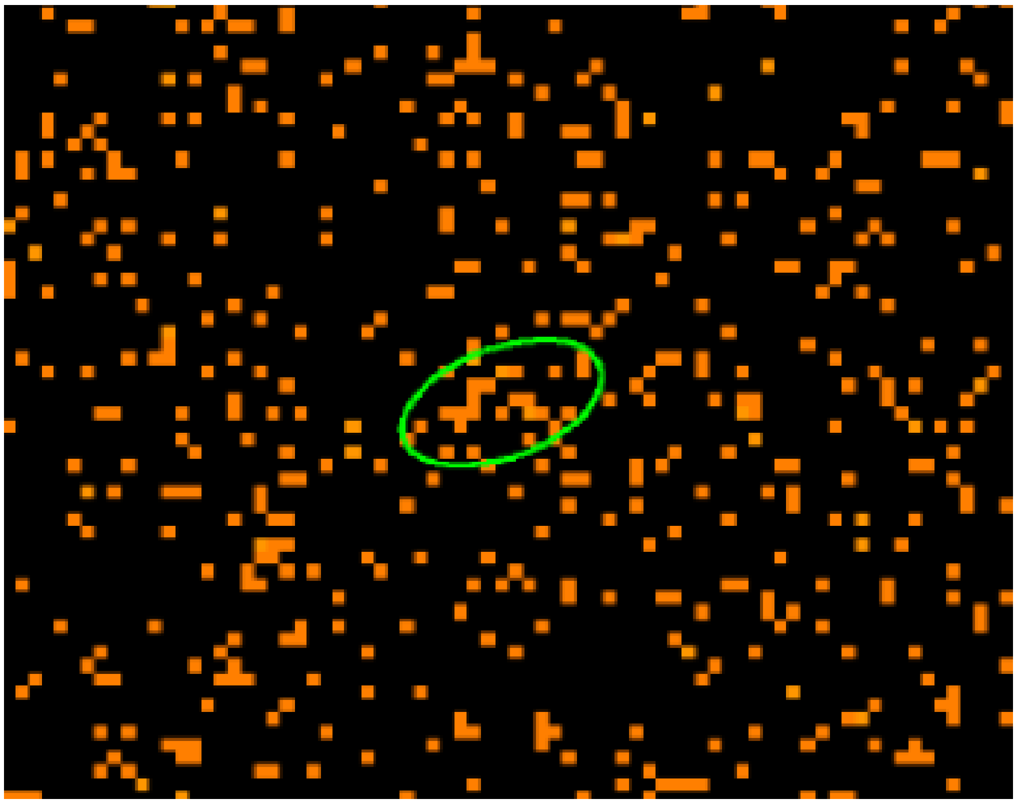
- A triangulation network is built from all the events in the region

VTPDETECT: How It Works



- The network is used to construct a “Voronoi Tesselation”.
- The cumulative distribution of the inverse areas of the Voronoi cells is compared to that expected from a Poisson distribution, to determine a threshold (which can be tweaked by the user).

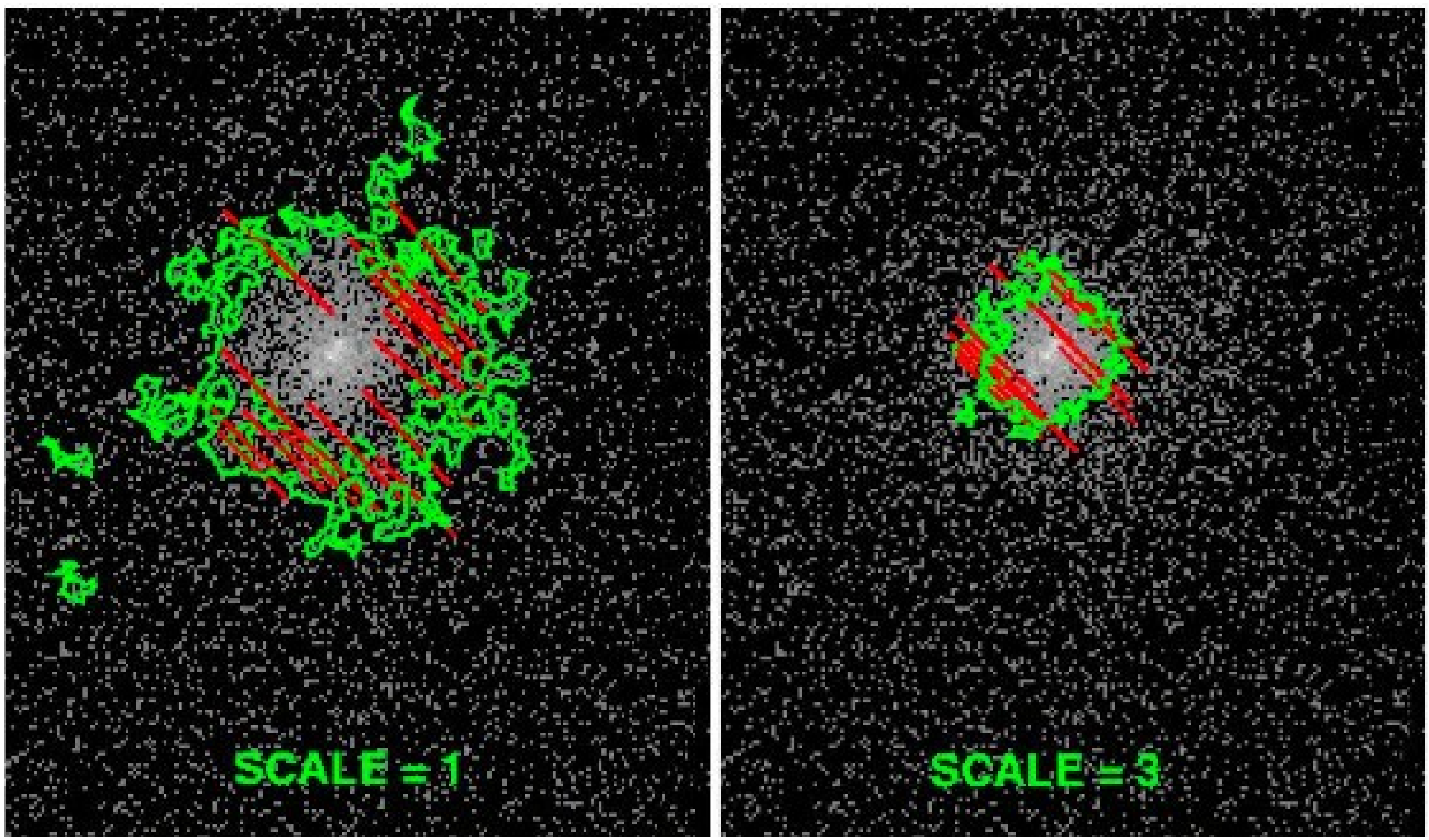
VTPDETECT: How It Works



- Neighboring cells above threshold are grouped together into source candidates.
- A source is identified if the number of events in the candidate is above a user-defined minimum.

VTPDETECT: How It Works

- The SOURCE_REGION extension contains polygons that outline the actual shape of the merged cells.



VTPDETECT: Pros and Cons

- Does not assume anything about source size/shape, and so works well for extended and/or irregularly-shaped sources.
- It's photon-based, and can work on large areas at full resolution.
- It works well for low-surface-brightness extended sources.

- Does not assume anything about source size/shape, and so can get confused in crowded fields.
- It's very slow if the number of photons is large and if the contrast between background and sources is low.

VTPDETECT Parameters:

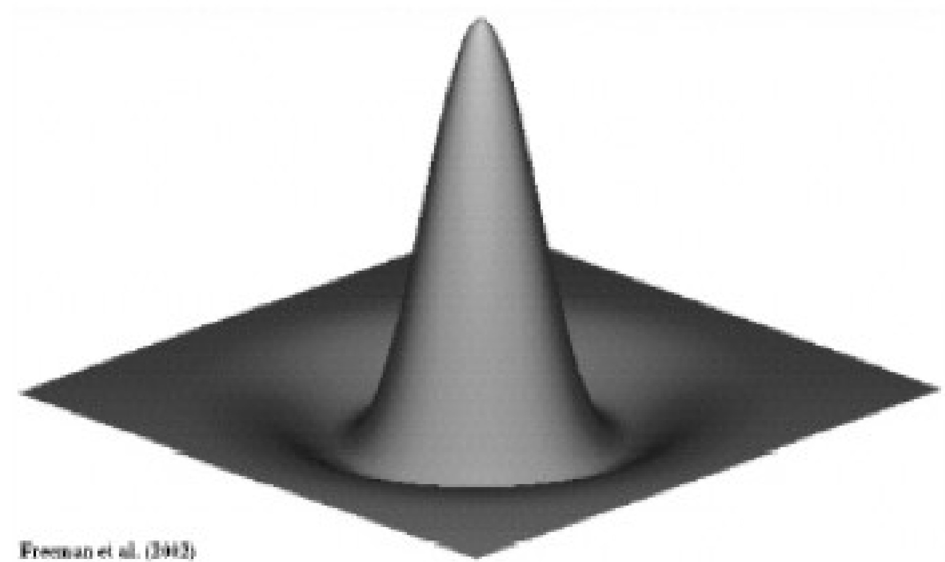
name	type	ftype	def	min	max	reqd
infile	file	input				yes
expfile	file	input	none			
outfile	file	output				yes
regfile	file		none			
ellsigma	real		3			
scale	real		1	0		
limit	real		1e-06	0	1	
coarse	integer		10	0		
maxiter	integer		10	0	100	
edge	integer		2	0		
superdo	boolean		no			
maxbkgflux	real		0.8	0		
mintotflux	real		0.8	0		
maxtotflux	real		2.6	0		
mincutoff	real		1.2	0	10	
maxcutoff	real		3	0	10	
fittol	real		1e-06	0		
fitstart	real		1.5	0.9	2	
clobber	boolean		no			
verbose	integer		0	0	5	
logfile	file	output	stderr			

WAVDETECT

- A data image is convolved with a “wavelet” (which spatially integrates to 0) for a set of user-defined scales.
- The tool consists of two programs:
    - WTRANSFORM: produces a correlation map at each scale and generates a list of candidate positions;
    - WRECON: uses WTRANSFORM outputs to “reconstruct” source positions and parameters;
- References:
    - CXC Detect Manual;
    - Freeman et al. 2002, ApJS, 138, 185.

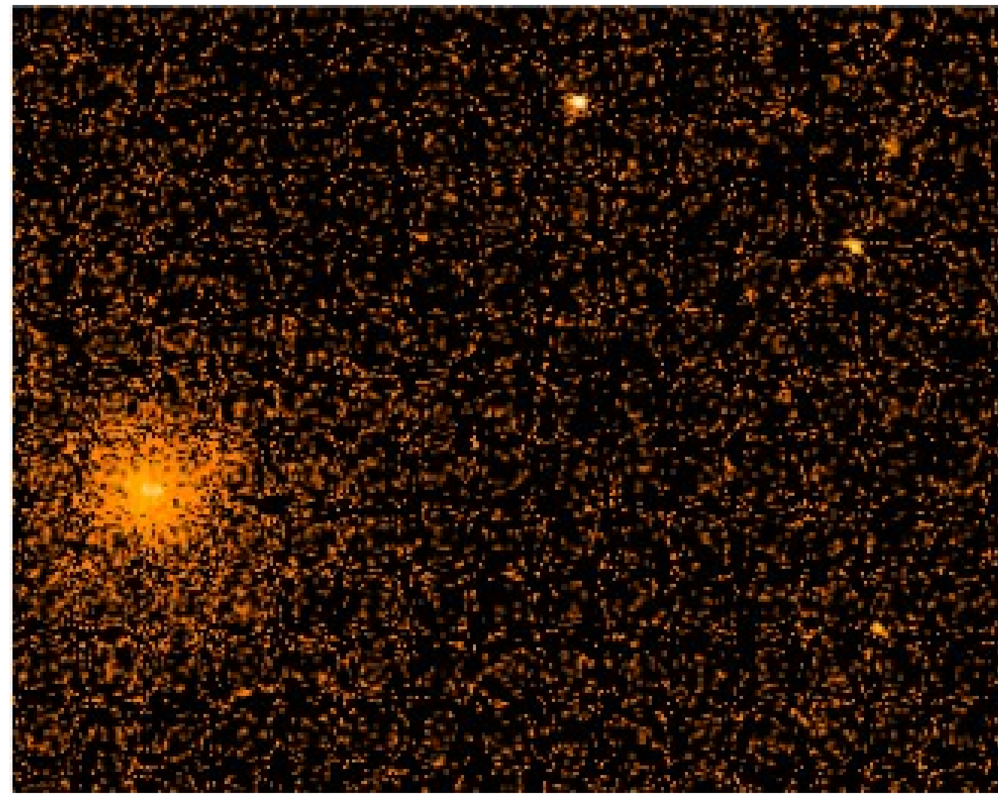
WAVDETECT

- A "Mexican-Hat" wavelet function is used.
- The process is repeated for a set of scales, usually separated by a factor of √2 or 2.
- WARNING: a large number of scales or large image size can drastically affect runtime.



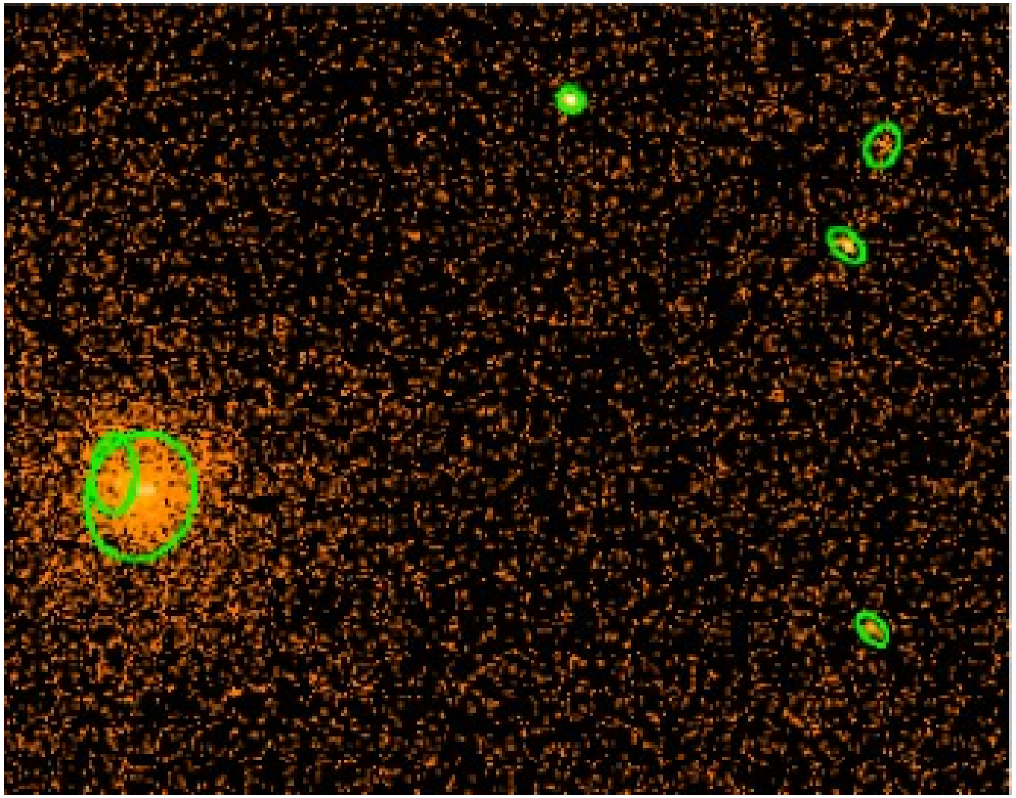
WAVDETECT: Test Run

- ACIS observation of 3C295;
- 120 x 80 pixel image;
- Run w/ “scales= 2 4 8 16 32”.



WAVDETECT: Test Run

- Be careful with scale sizes:
- Candidates are identified from correlation maxima at all scales, in ascending order of scale size;
- Maxima at larger scales near smaller scale sources are associated with them;
- Source properties are determined from data within “source cells”, defined using wavelet-smoothed data at the scale closest to the PSF size.



WAVDETECT: Pros and Cons

- Works well in crowded fields.
- Works well for point sources superimposed on extended emission.
- Only approximate PSF shape is needed.
- Edge of field effects not a problem.

- Slow, especially if many wavelet scales used.
- Memory-intensive, 2k x 2k OK, but larger image sizes can be a problem.
- No recursive blocking built-in, so running on entire image requires multiple, blocked images. Source lists must then be combined.

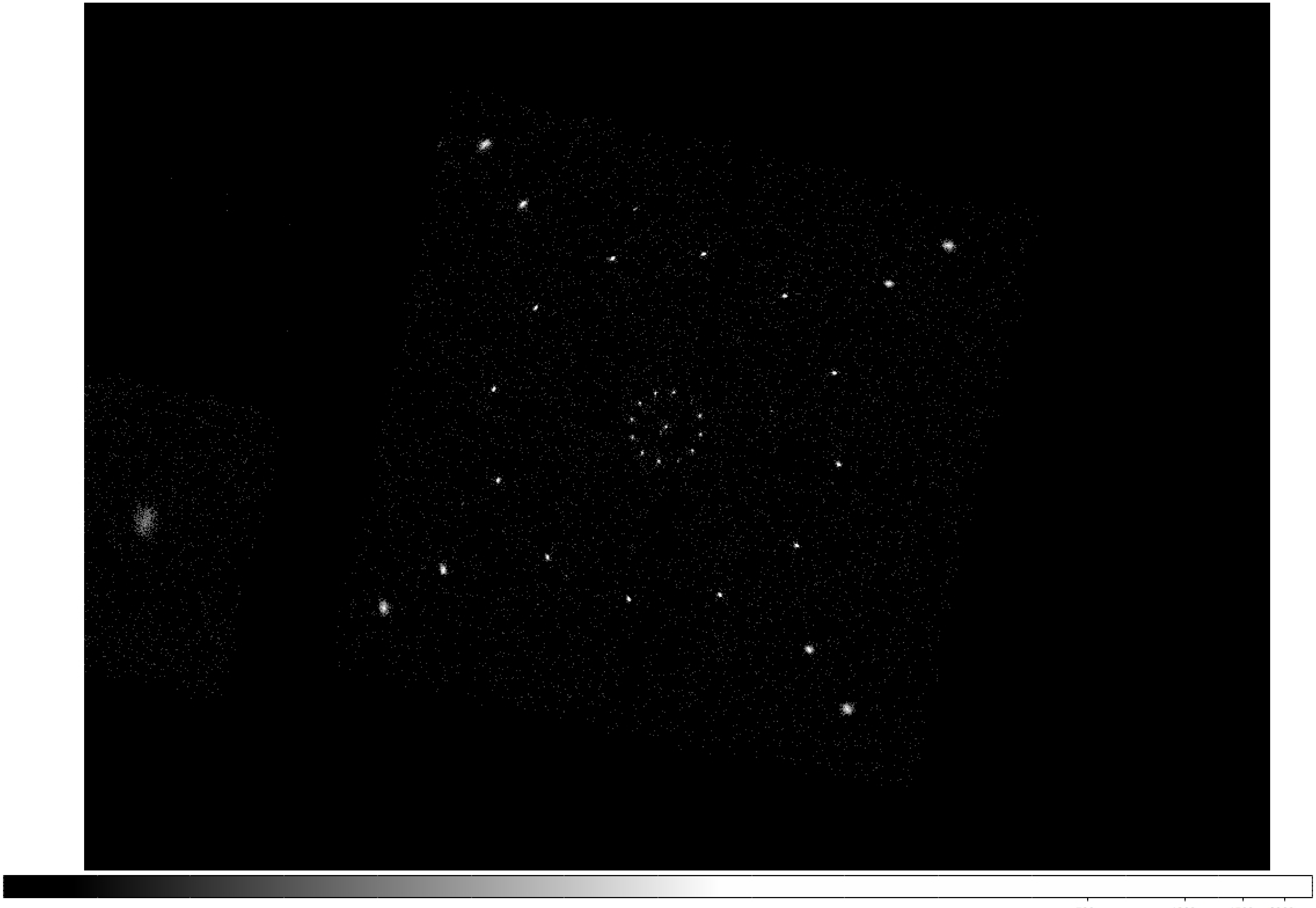
WAVDETECT Parameters:

name	type	ftype	def	min	max	units	reqd	autoname
infile	file	input					yes	
outfile	file	output					yes	yes
scellfile	file	output					yes	yes
imagefile	file	output					yes	yes
defnbkgfile	file	output					yes	yes
scales	string		2.0 4.0					
regfile	file							yes
clobber	boolean		no				no	
ellsigma	real		3.0					
interdir	file	output	.				no	
bkginput	file	input					no	
bkgerrinput	boolean		no				no	
outputinfix	file						no	
sigthresh	real		1e-06				no	
bkgsigthresh	real		0.001				no	
falsesrc	real		-1.0				no	
sigcalfile	file	ARD	$ASCDS_CALIB/wtsimresult.fits				no	
exptime	real		0			seconds		
expfile	file	input						
expthresh	real		0.1				no	
bkgtime	real		0				no	
maxiter	integer		2				no	
iterstop	real		0.0001				no	
xoffset	integer		INDEF			pixels	no	
yoffset	integer		INDEF			pixels	no	
eband	real		1.4967			keV		
eenergy	real		0.393				no	
psftable	file	ARD						
log	boolean		no				no	
verbose	integer		0	0	5		no	

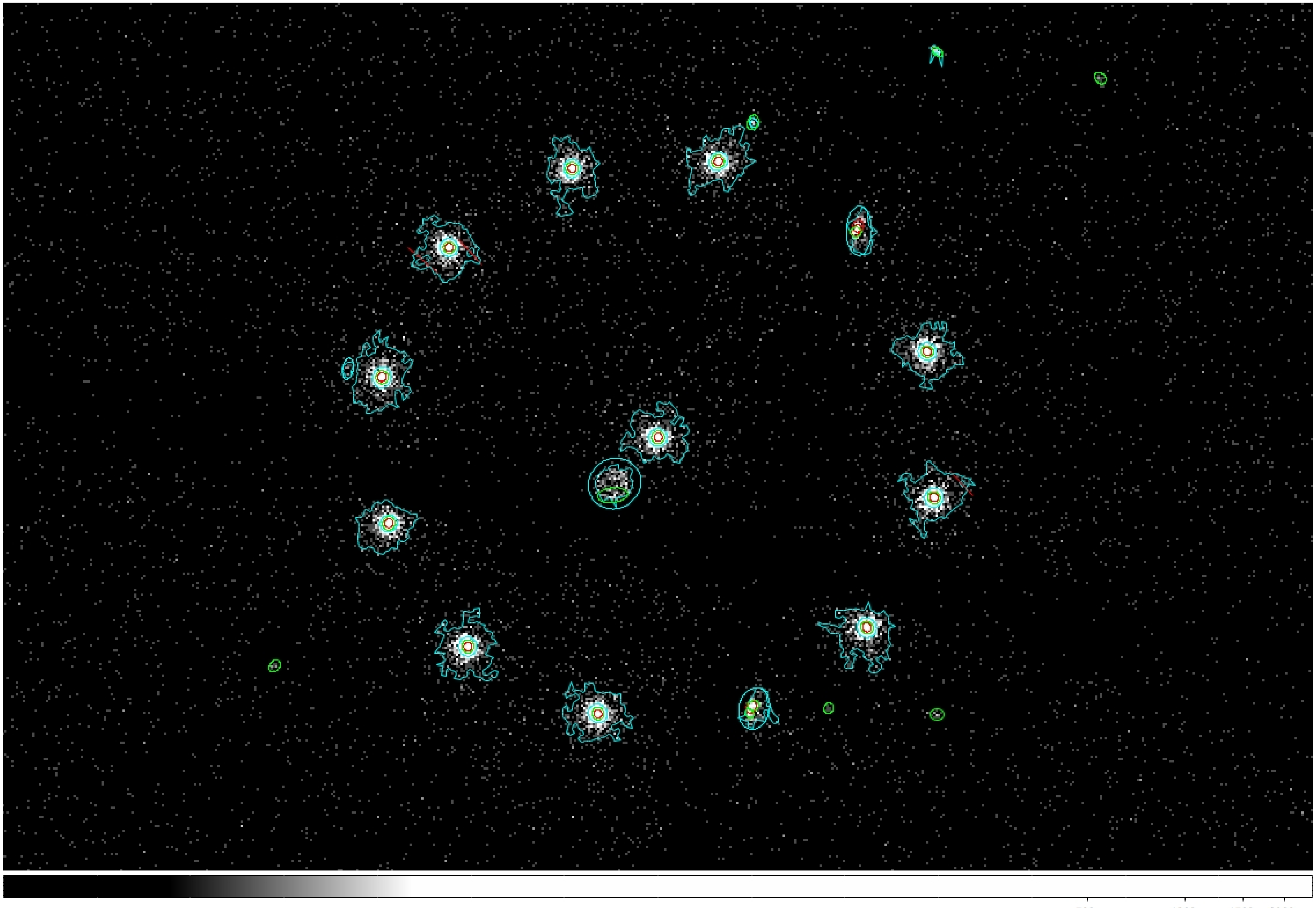
Tool Comparison

- Run all 3 DETECT tools on the same image and compare the source detections:
  - wavdetect infile=bl1_img.fits outfile=bl1_wav.fits scales=”1 2 4 8 16”
  - celldetect infile=bl1_img.fits outfile=bl1_cell.fits
  - vtpdetect infile=bl1_img.fits outfile=bl1_vtp.fits

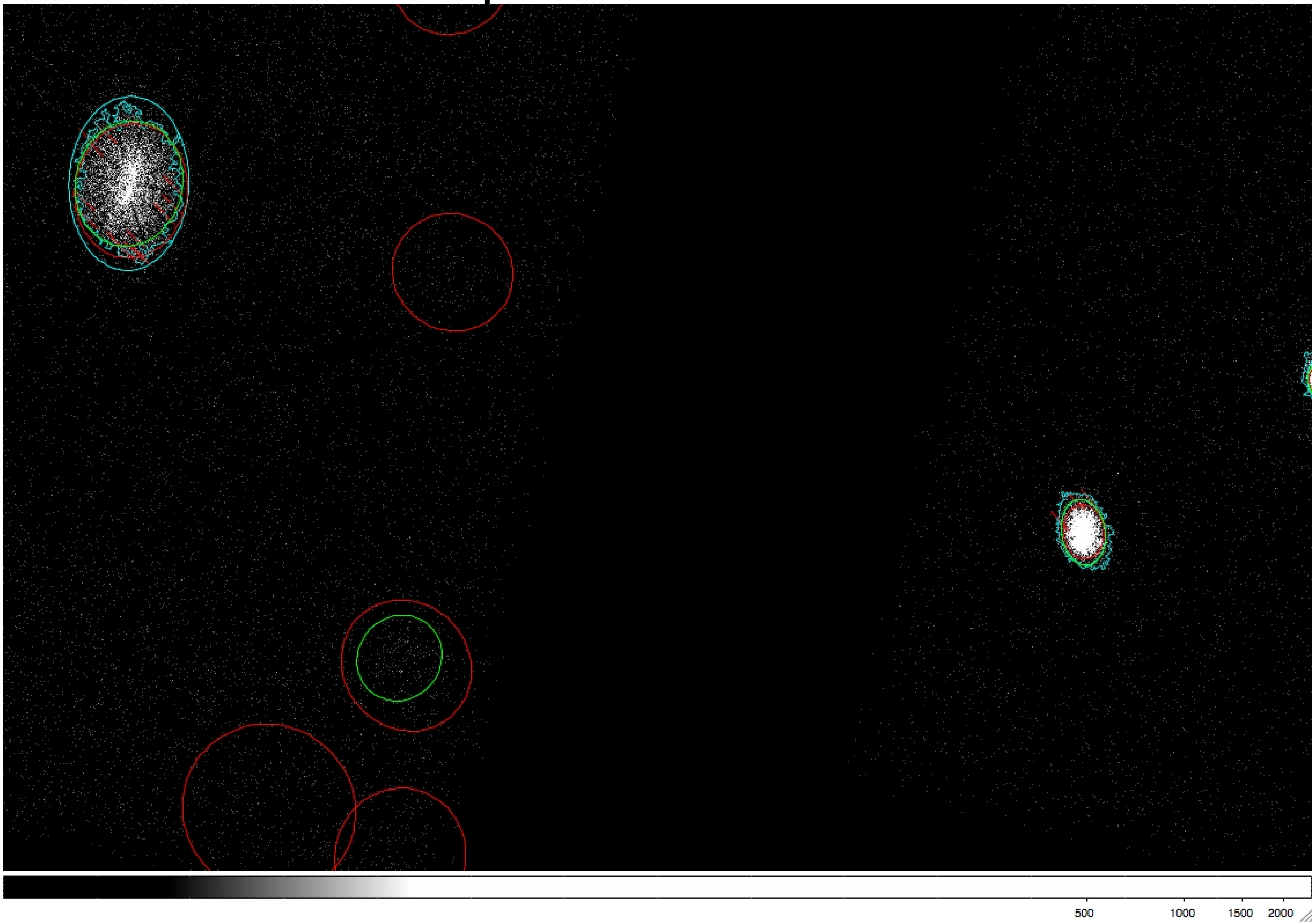
NGC 6822 plus Simulated Sources



NGC 6822 plus Simulated Sources

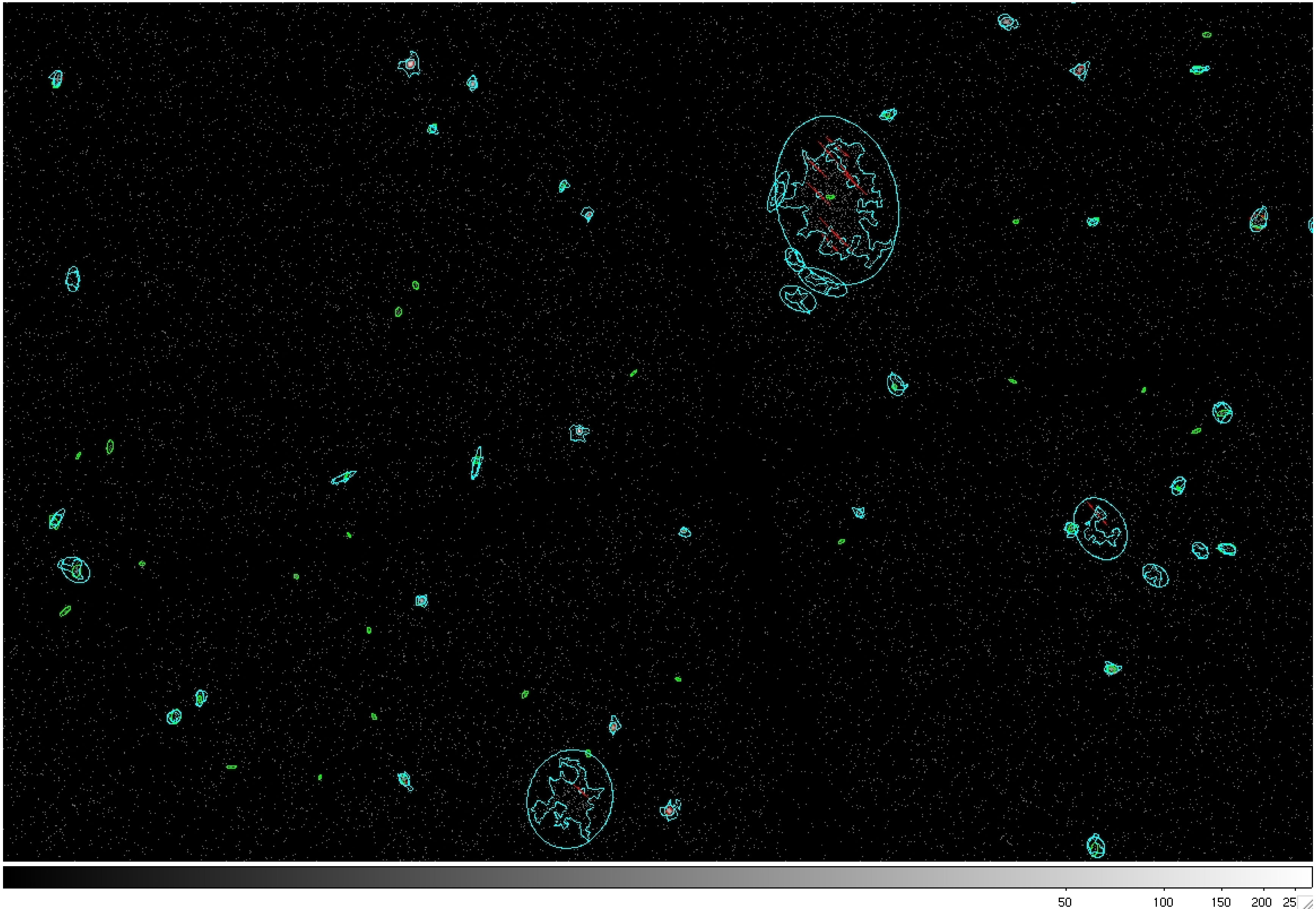


NGC 6822 plus Simulated Sources

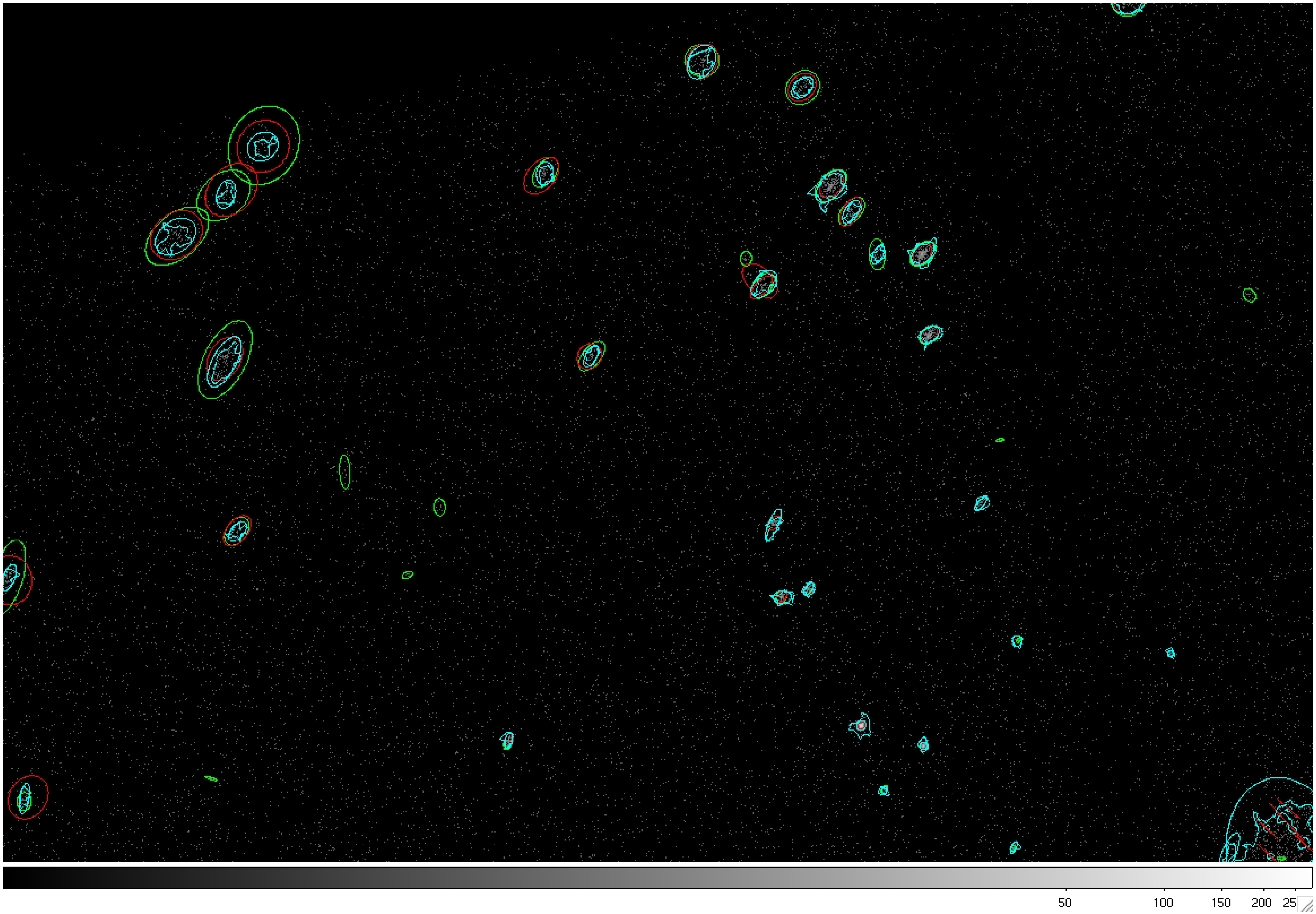


CL 0848.6+4453

CL 0848.6+4453



CL 0848.6+4453



SUMMARY

- CIAO's Source Detection tools all have advantages and disadvantages.
- They are complementary – what one tool lacks may be provided by a different tool.
- Which tool to use depends on users' analysis goals.
- As always, users need to examine their results carefully.