DETECT Tools in CIAO

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OUTLINE

- Introduction – goals and realities
- Chandra challenges for source detection tools
- Current CXC Detect Tools:
  - CELLDETECT
  - VTPDETECT
  - WAVDETECT
  - Comparison of Detect Tools
- New Work on an x-ray version of SExtractor

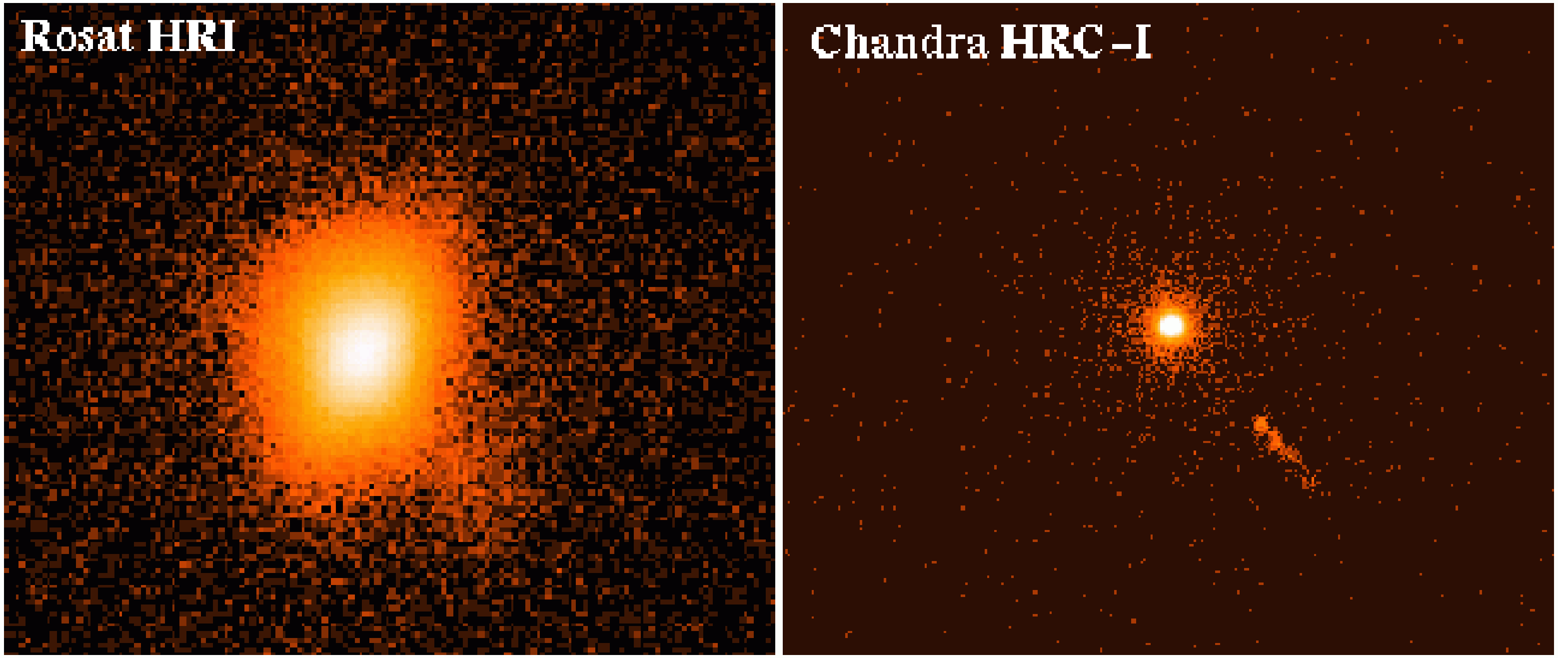
Introduction

- 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, or size, may also be reported. These are useful, but are usually evaluated more reliably separately.)
- Realities
  - 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.

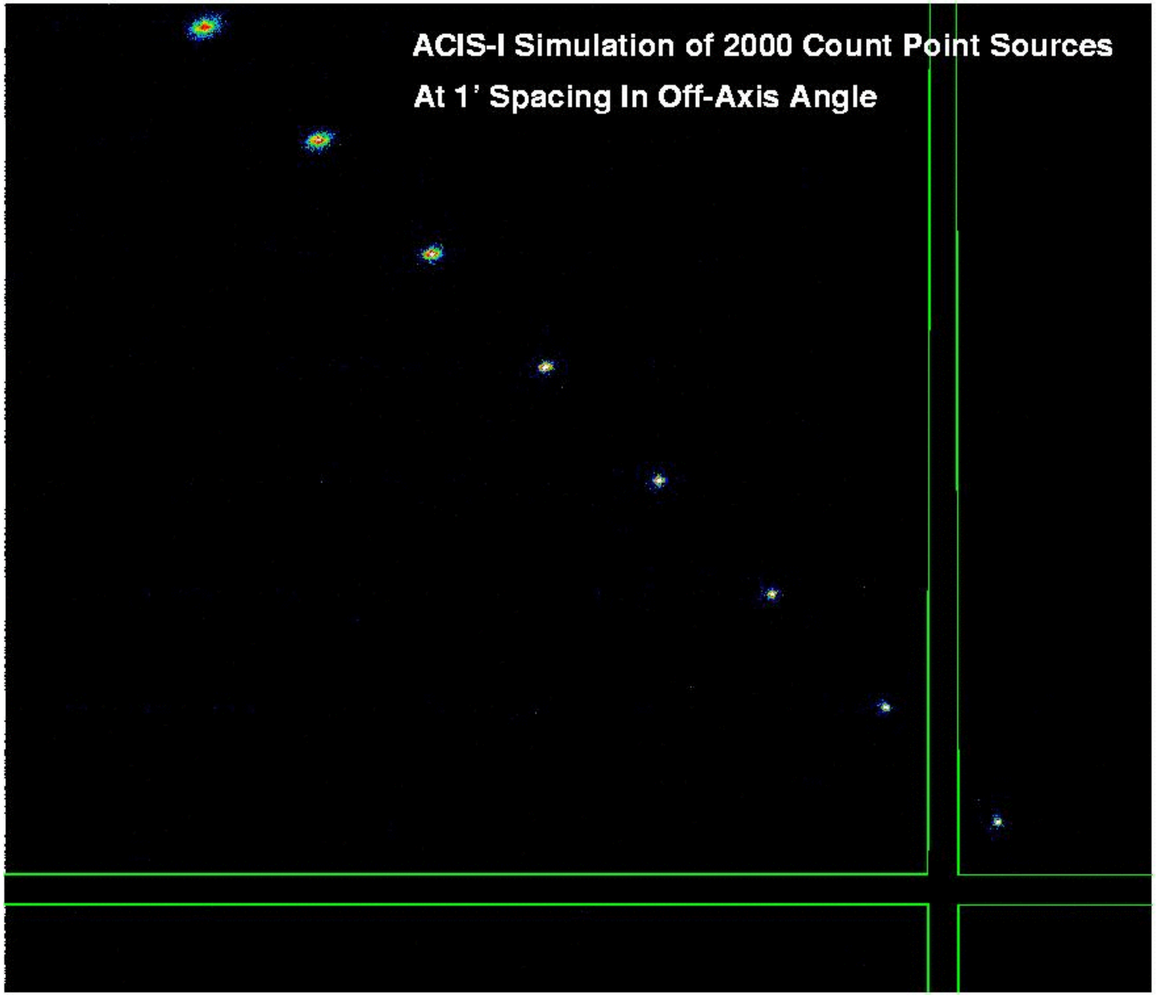
Chandra Challenges For Source Detection Tools

- Chandra mirrors have an angular resolution ~10 finer than any previous X-ray telescope:
  - Complex source structures are commonly seen; point sources and blobs in Rosat often turn out to be source complexes in Chandra;
  - Extended sources have low surface brightness.
- PSF changes dramatically with position;
- X-ray Images typically have only a few events per background pixel.

3C273 in Rosat and Chandra



Chandra PSF varies significantly with position



CIAO Detect Tools

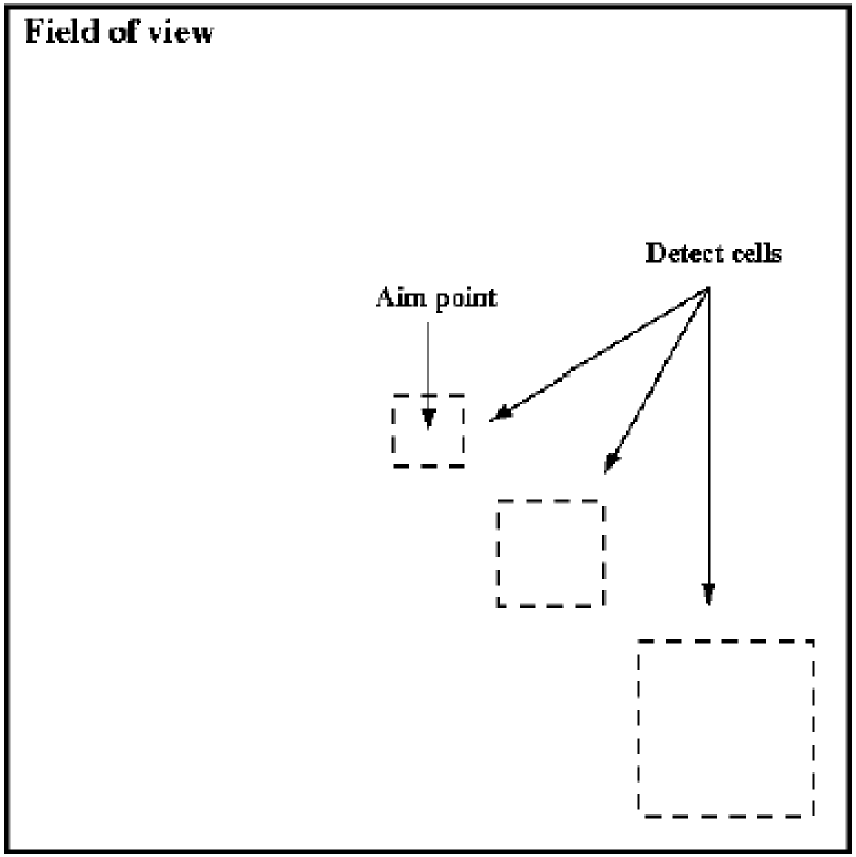
- CELLDETECT:
  - sliding detect cell, like Rosat and Einstein, plus:
    - variable cell size, based on PSF size;
    - 'recursive blocking' for spatially large data sets;
    - exposure map-based rejection of spurious sources at detector edges.
- WAVDETECT:
  - wavelet convolution, with iterative background determination; good for crowded regions; extensively calibrated, good for survey work.
- VTPDETECT:
  - Voronoi Tesselation and Percolation; scale free; good for low surface brightness, irregularly shaped sources.

CELLDETECT

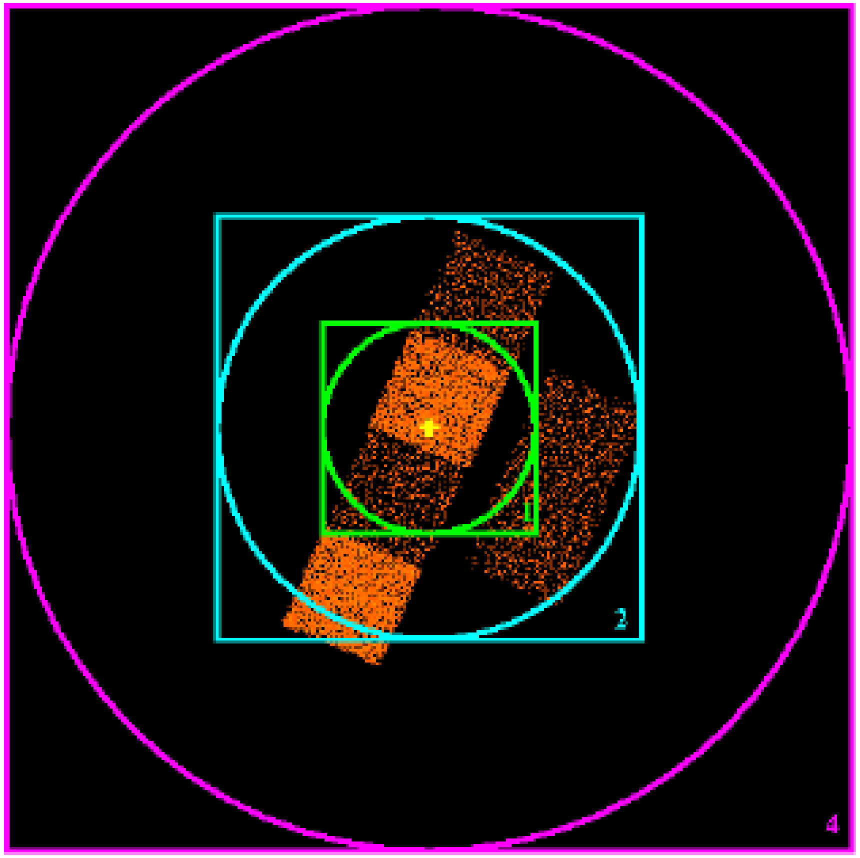
- X-ray image scanned with a sliding, square 'detect cell'. The signal to noise ratio is calculated by comparing the total counts in the cell and predicted background counts, estimated from either a surrounding background frame or a background map.
- Size of detect cell varies with off-axis angle to 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: variable cell

- The size of the detect cell is based on the PSF size. The user can select what fraction of the source counts should fall into the cell (eenergy), and at what energy this is specified (eband).
- Can be overriden with fixedcell



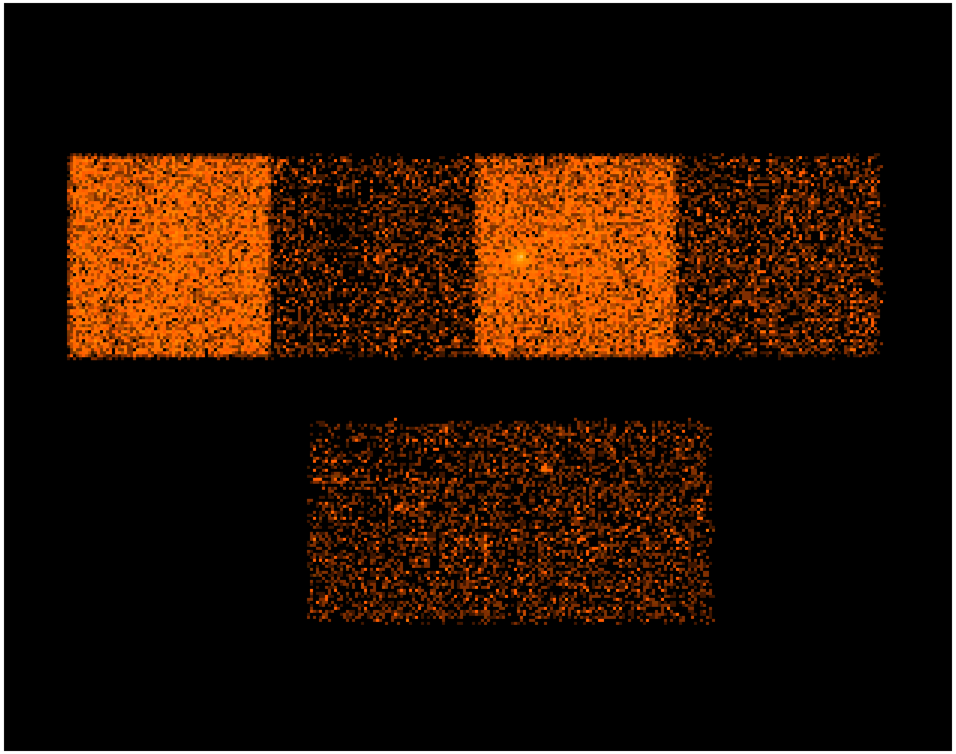
CELLDETECT: recursive blocking



- "Recursive blocking":
  - Center 2k x 2k scanned for sources in full resolution, only selecting sources inside the circle totally enclosed in the selected data set,
  - Center 4k x 4k blocked by 2, excluding region analyzed in step 1,
  - Etc.

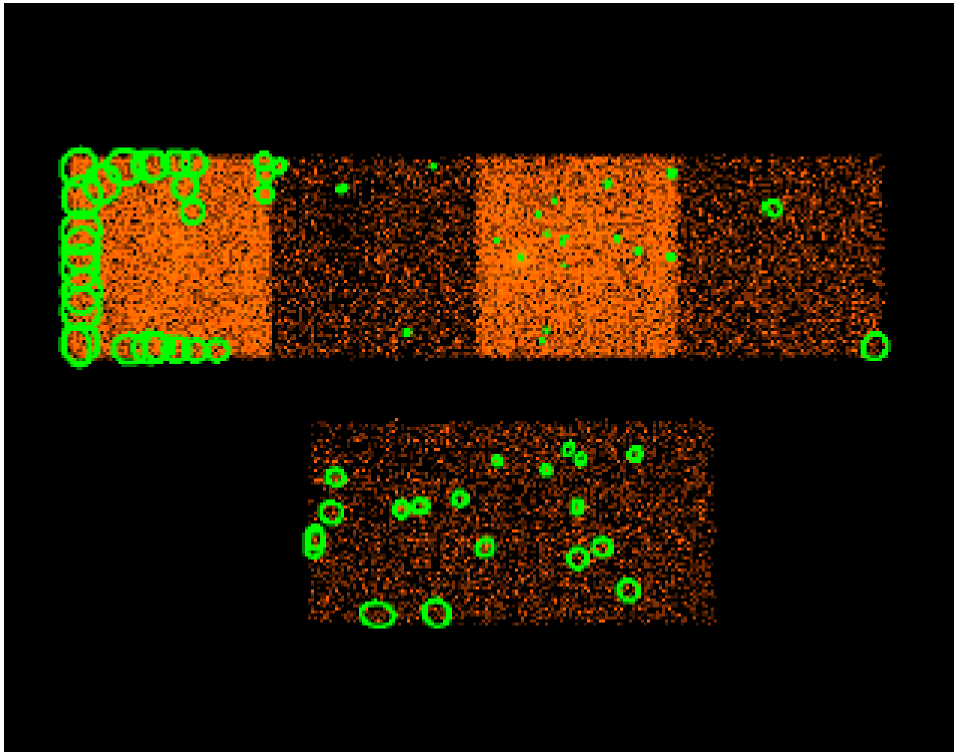
CELLDETECT: edge effects

- Chandra data have several edge effects:
  - field of view boundaries,
  - jumps in background between BI and FI chips in ACIS,
  - node boundaries inside ACIS chips.



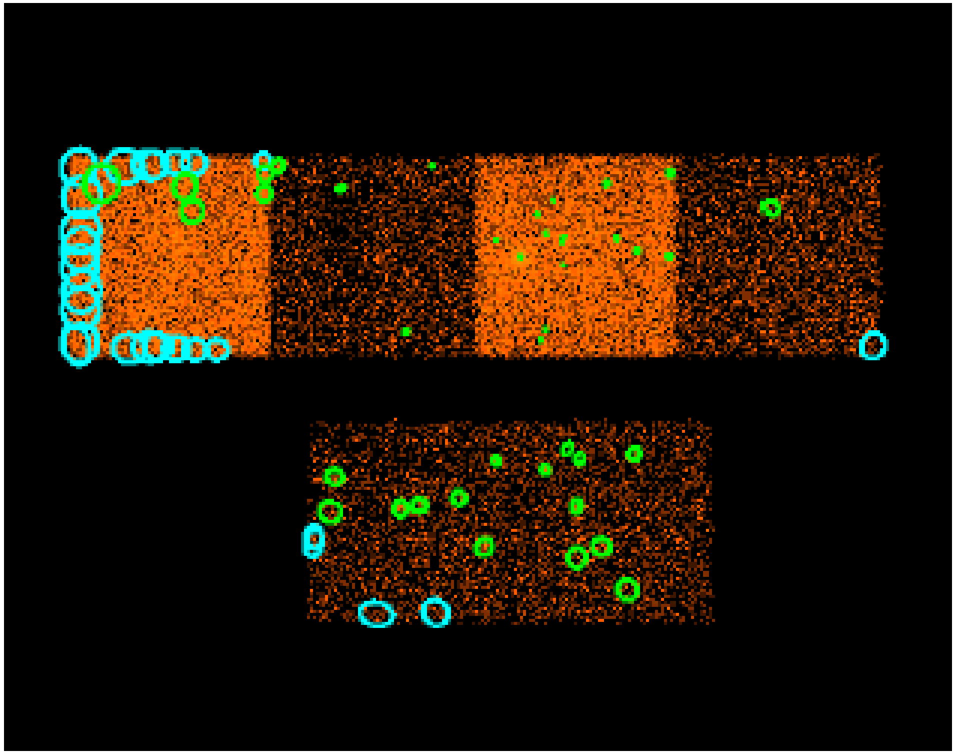
CELLDETECT: edge effects

- 'Vanilla' CELLDETECT run leads to several spurious detections at detector edges.



CELLDETECT: edge effects

- The user may provide a stack of exposure maps (expstk) and select only sources for which the ratio of exposures in the detect and background cells is higher than user-defined value (expratio).



CELLDETECT: PROS and CONS

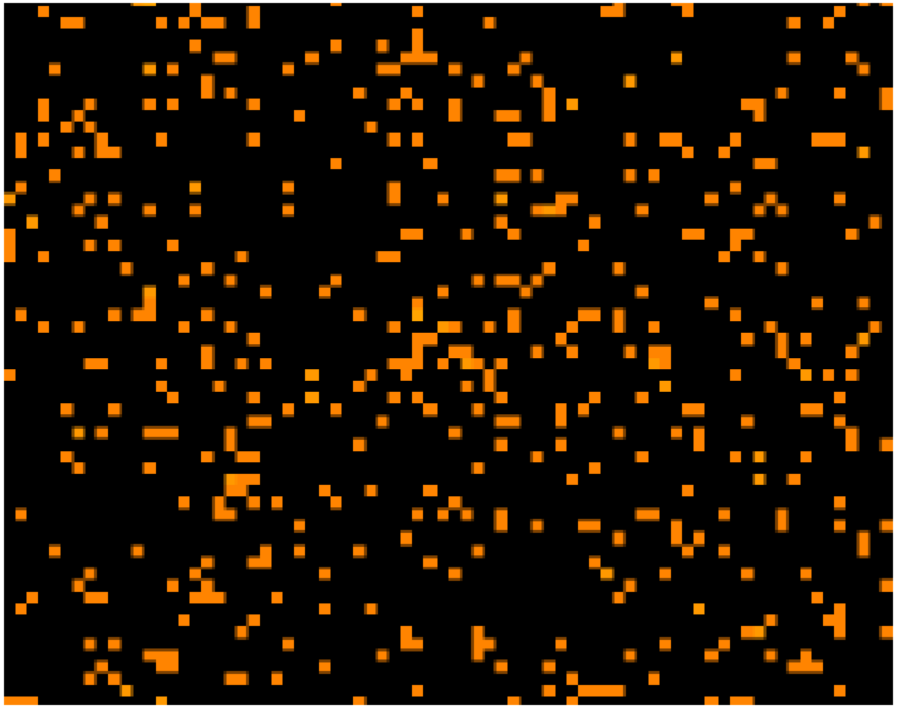
- Fast and robust
- Works well for point sources
- PSF shape not important; only approximate size needed
- Familiar to community
- Can swallow entire Chandra observation with one gulp

- Problems with extended sources; requires proper cell size and background
- Gets confused in crowded fields if background calculated locally
- 'Edge' sources unless exposure maps used
- 'Local' detect option not very sensitive, but bgd maps may be hard to make

VTPDETECT

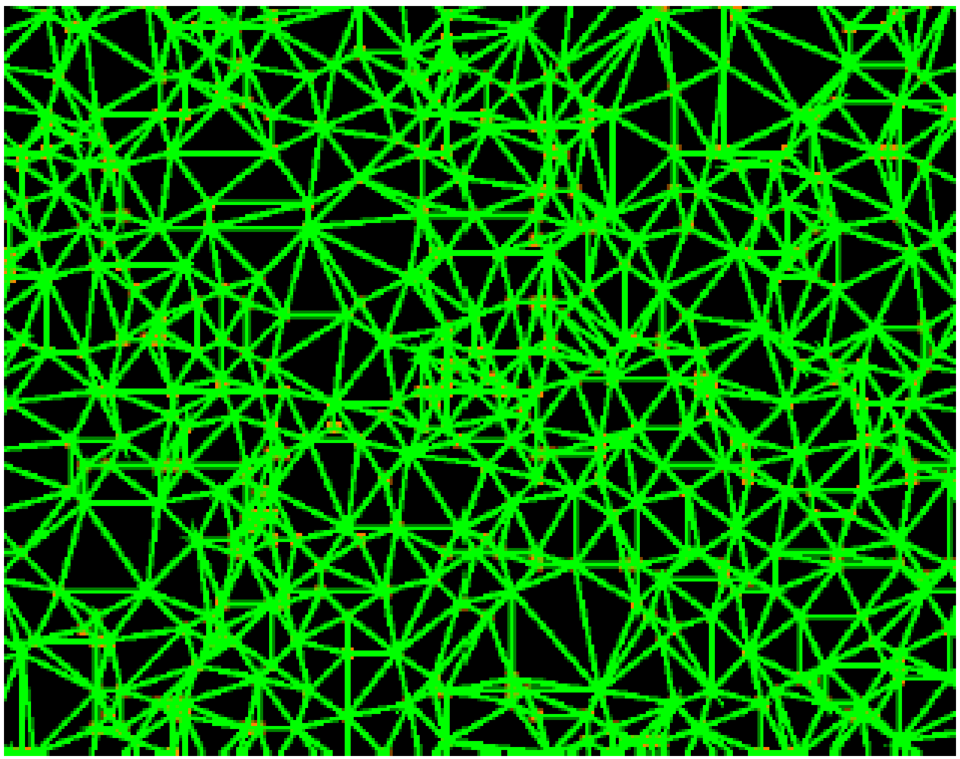
- A 'friend-of-friend-of-friend' algorithm.
- Scale-independent: good for extended/irregular sources, but encounters problems in crowded fields.
- References:
  - CXC Detect Manual
  - Ebeling & Wiedenmann 1993, Phys.Rev.E, 47, 704
  - Ebeling et al. 1996, MNRAS, 281, 799
  - Jones et al. 1998, ApJ, 495, 100

VTPDETECT: how it works



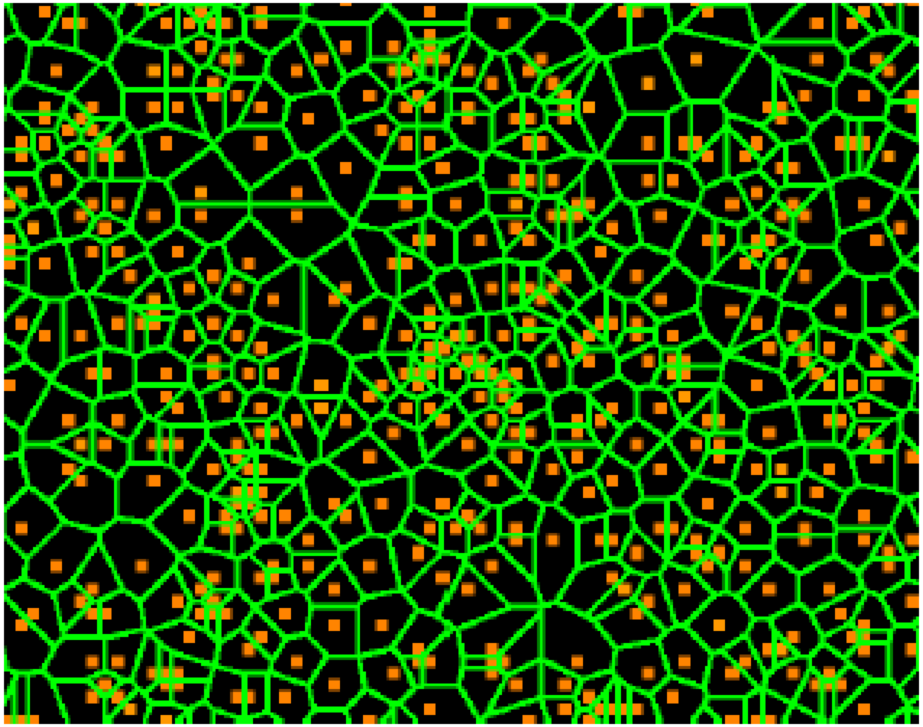
- Small (ca. 75 x 50 pixels) fragment of Chandra/ACIS observation of 3C295

VTPDETECT: how it works



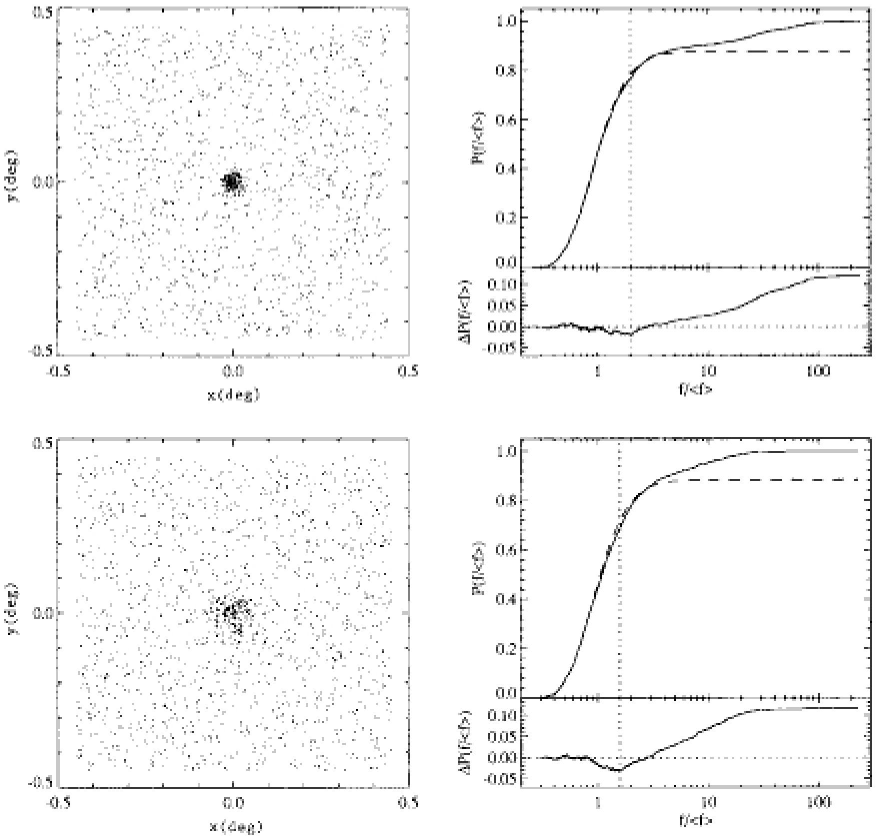
- A triangulation network is built on all events in the considered region.

VTPDETECT: how it works



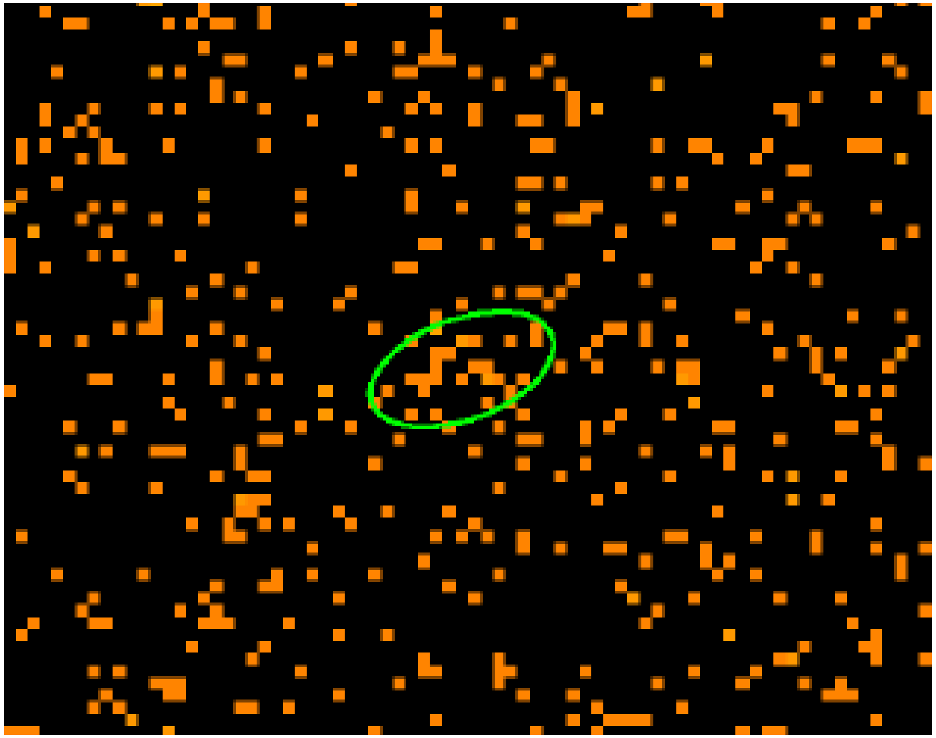
- The triangulation network is used to construct Voronoi tesselation. Cumulative distribution of the inverse areas of the Voronoi cells is compared with Poisson distribution.

VTPDETECT: how it works



- Cumulative distribution of the inverse areas of the Voronoi cells is compared with that expected from randomly distributed events to determine threshold;
- Can be adjusted by user via scale parameter; values of 0.8 – 3 are reasonable choices.

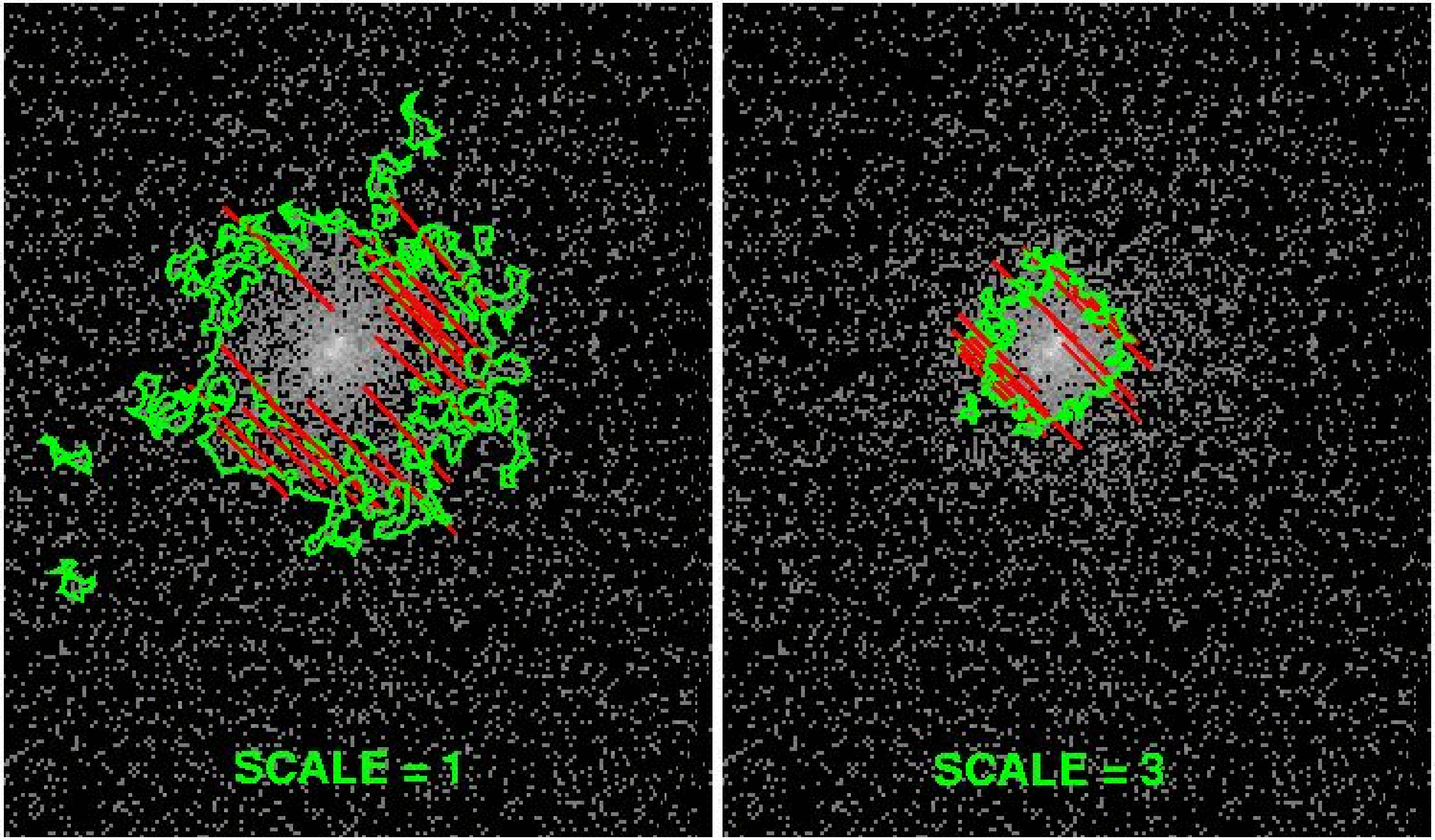
VTPDETECT: how it works



- Percolation is run on the individual cells, grouping neighboring cells above threshold into source candidates;
- The source is output if the number of events in the candidate exceeds user-defined minimum (coarse).

VTPDETECT: how it works

- The SRC_REGION extension contains polygons that outline the actual shape of the merged source cells



VTPDETECT: PROS and CONS

- Does not assume anything about source size/shape (works well when sources are extended/irregular)
- Photon-based, thus can work on large areas in full resolution
- Works well on low surface brightness extended sources

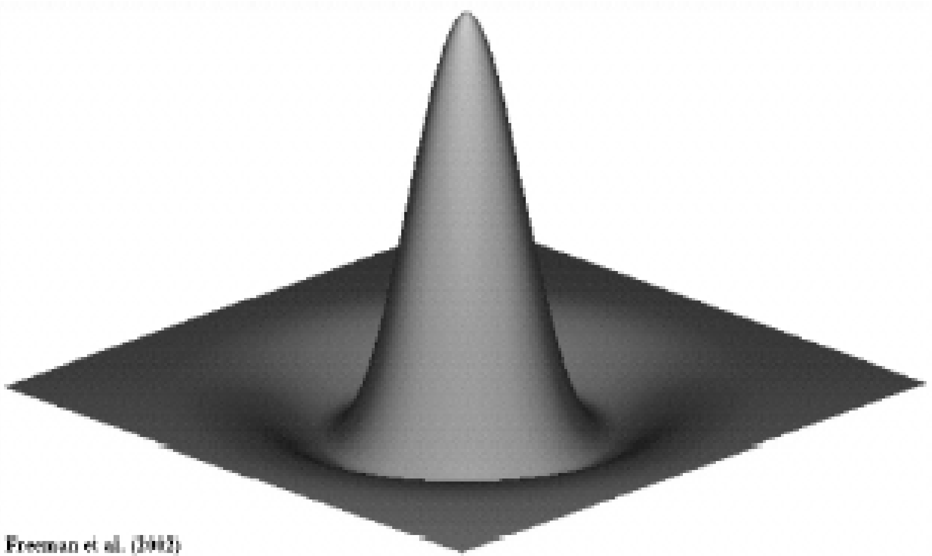
- Does not assume anything about source size/shape (gets confused in crowded fields)
- Very slow if number of photons is large and if there is low contrast between background and sources

WAVDETECT

- The data image is convolved with a wavelet (which spatially integrates to zero) for a set of wavelet scales.
- The tool consists of two separate parts:
  - WTRANSFORM: produces correlation map at each scale and generates lists of candidate positions
  - WRECON: uses WTRANSFORM outputs to define a source cell and obtain source parameters
- References:
  - CXC Detect Manual
  - Freeman et al. 2002, ApJS, 138, 185

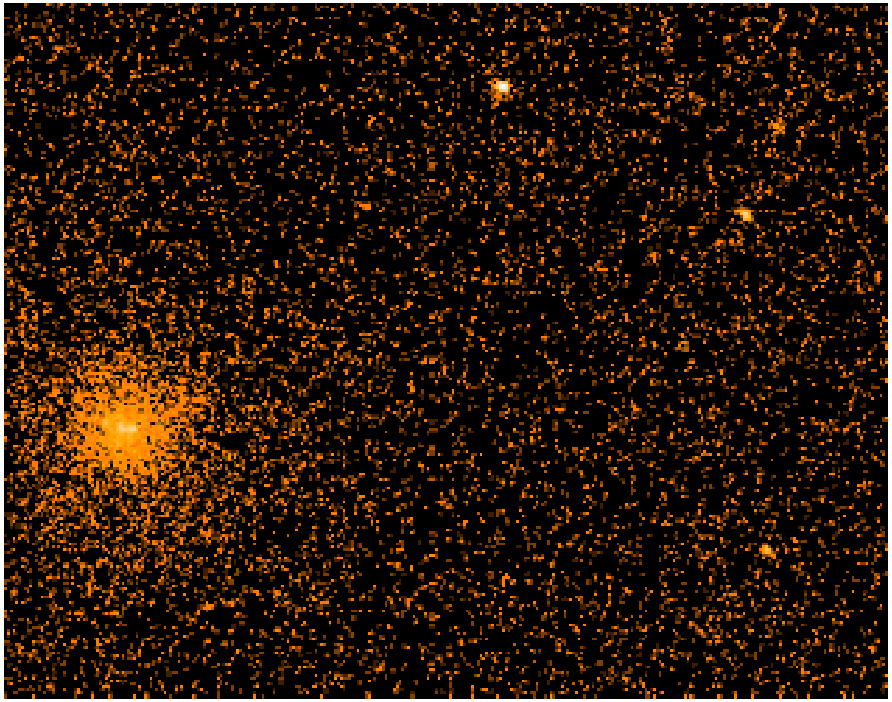
WAVDETECT

- The tool uses 'Mexican Hat' wavelet.
- The detection process is repeated for a set of wavelet scales, usually separated by a factor of sqrt(2) or 2.
- CAVEAT: both a large number of scales and large sized scales affect machine memory and run time.



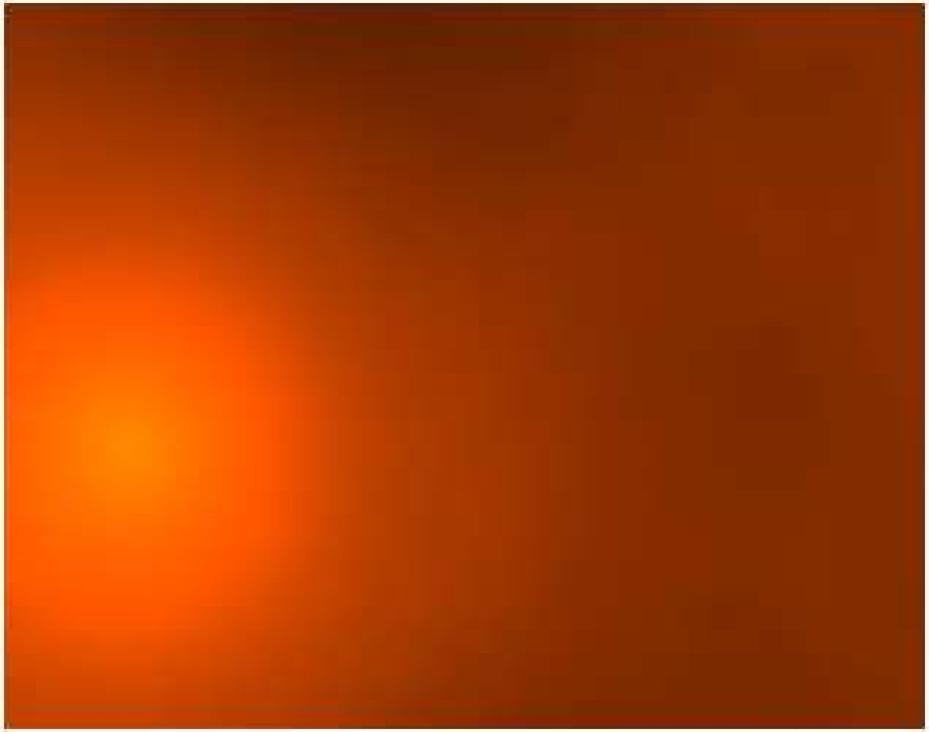
Freeman et al. (2002)

WAVDETECT: test run



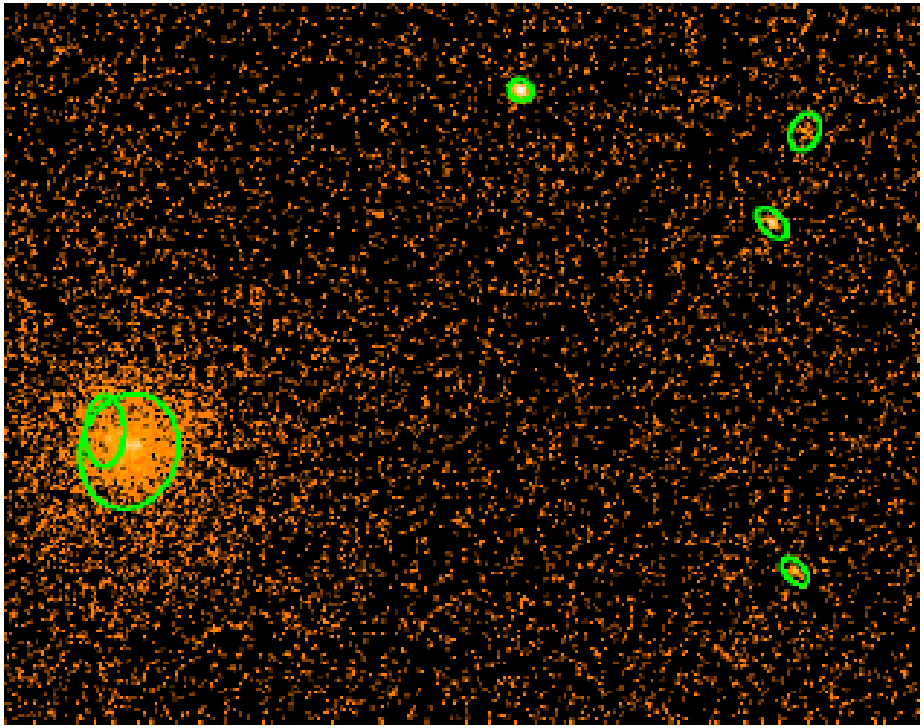
- Chandra/ACIS observation of 3C295. WAVDETECT was run with five scales: 2, 4, 8, 16, and32 pixels. Image shown is ca.120 x 85 pixels.

WAVDETECT: background



- Background map is determined iteratively; the user can specify how hard the tool is to work on that (bkgsigthresh, maxiter, iterstop).
- The user can provide own background map (bkginput, bkgerrinput).

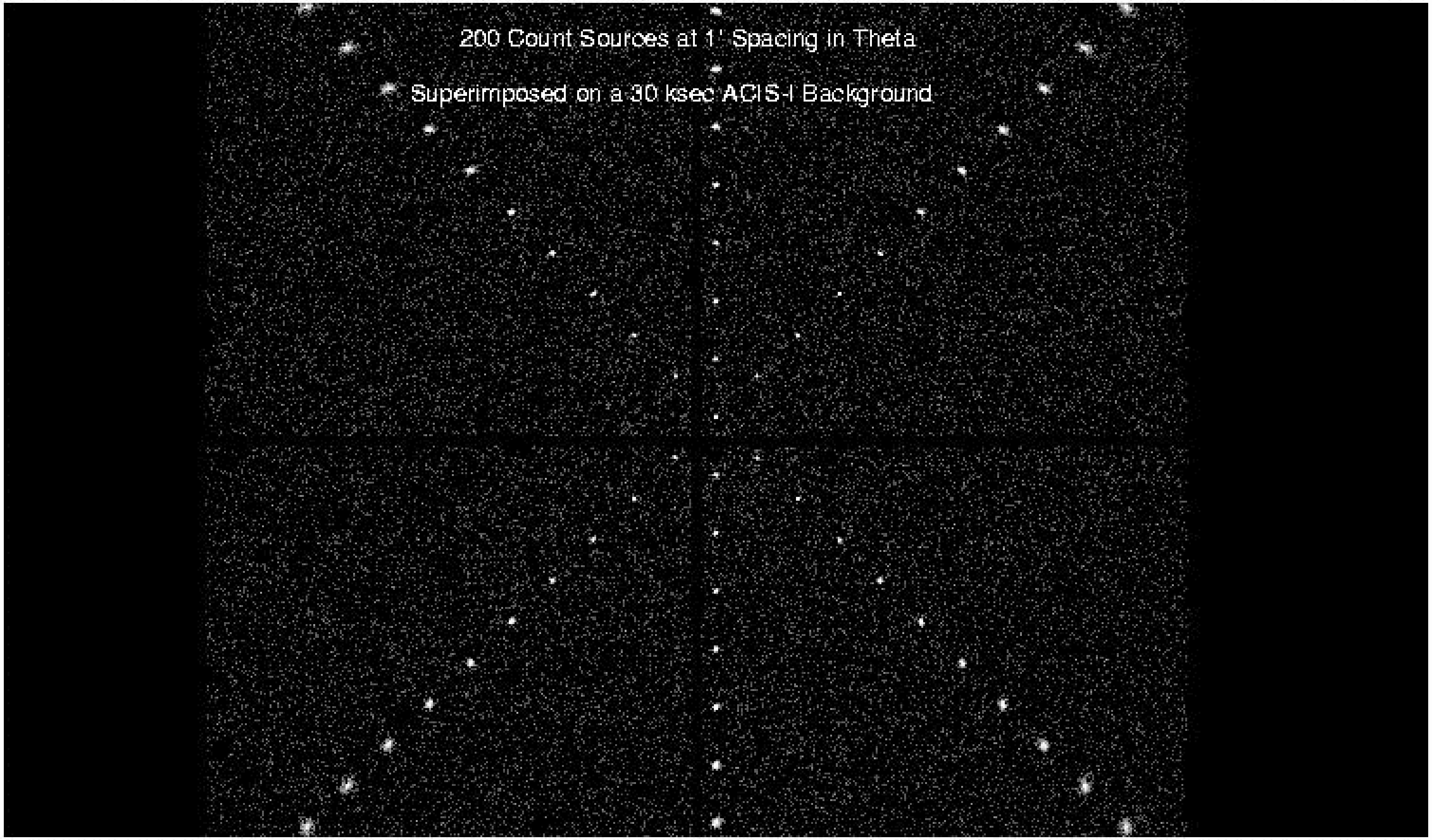
WAVDETECT: outcome



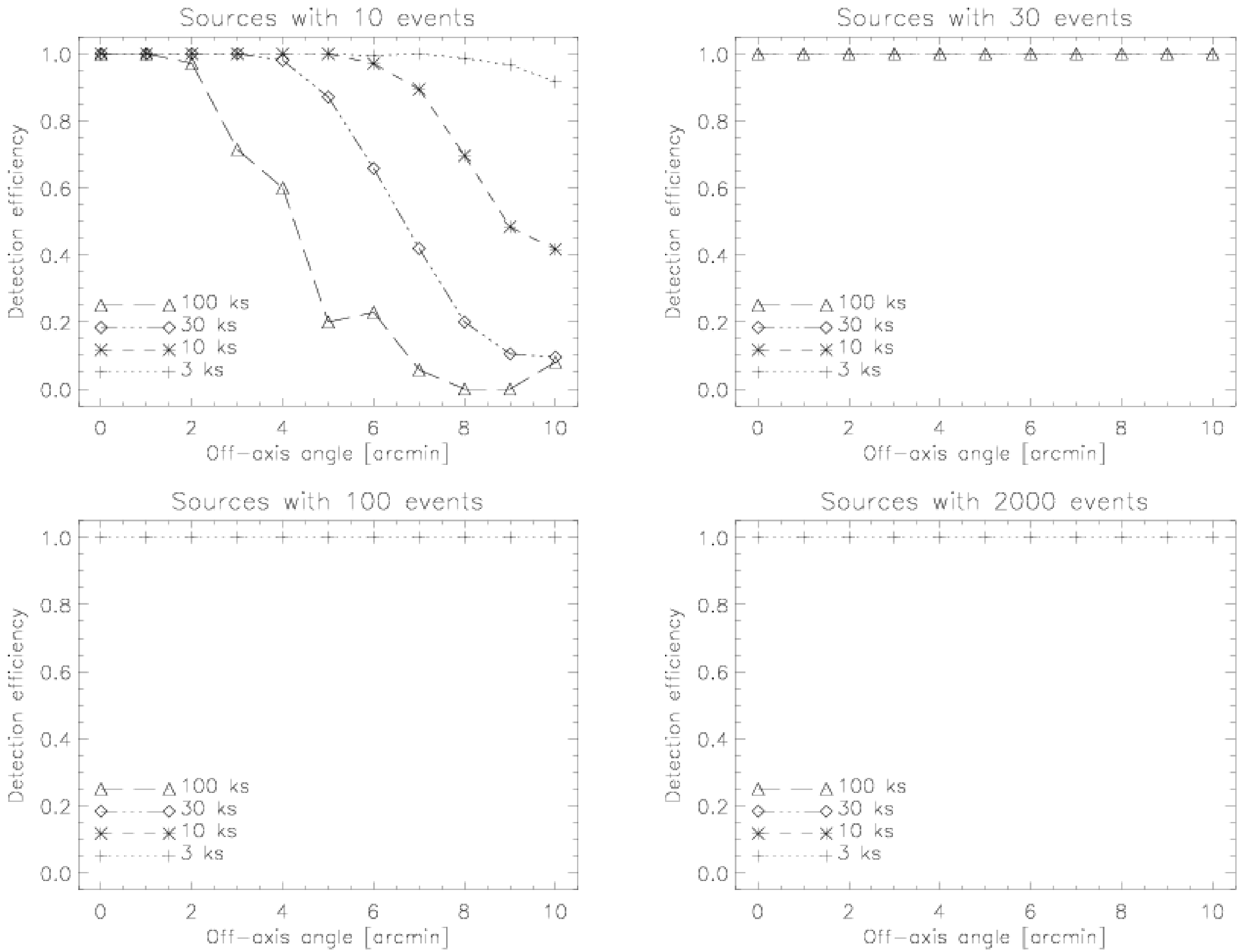
- For each candidate, detection with highest correlation maximum from all WTRANSFORM runs is selected. The user can affect the outcome by modifying detection threshold (sigthresh).

WAVDETECT: Calibration

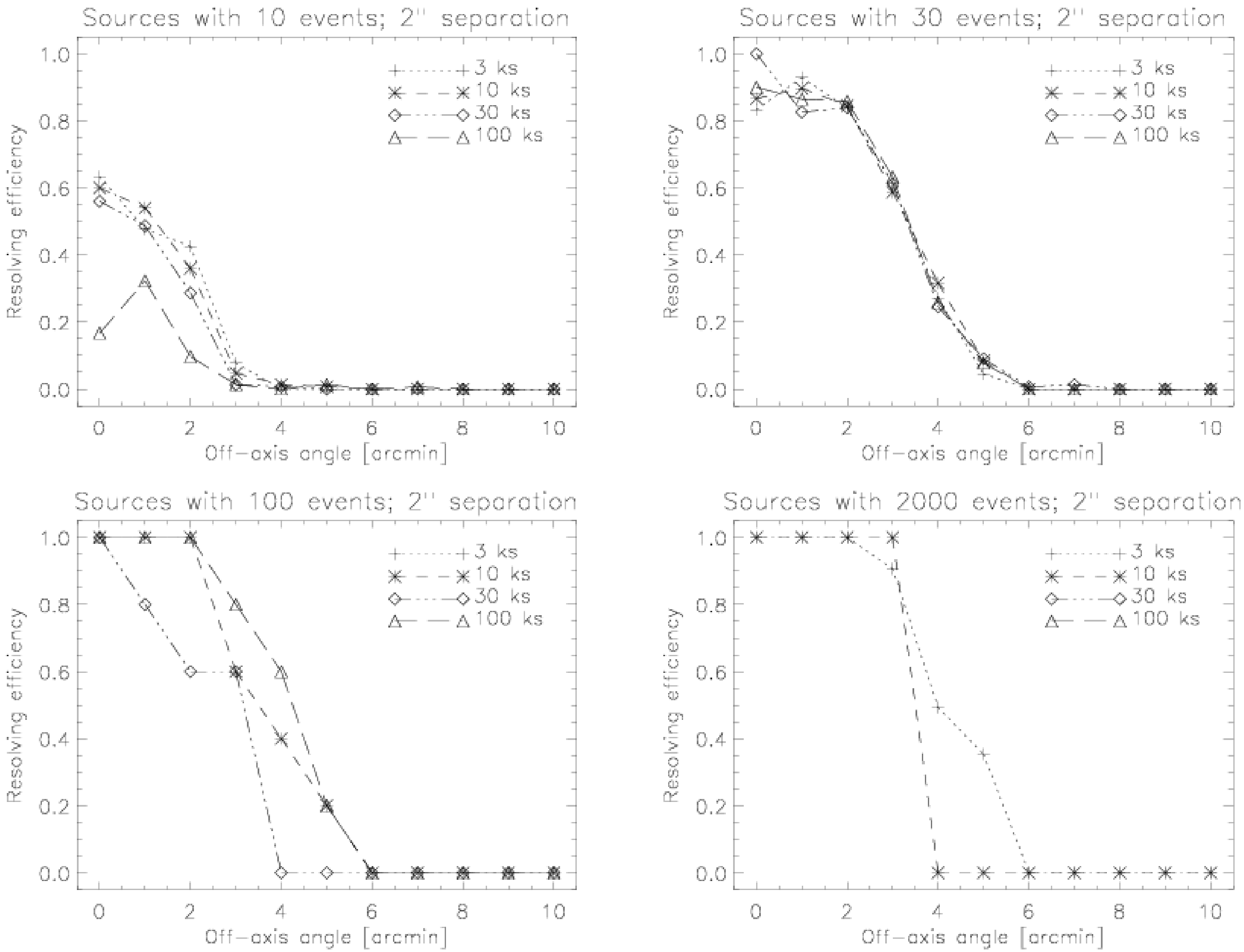
Analysis of multiple simulations for various combinations of source counts and background allow determination of such quantities as detection efficiency and resolving power vs. off-axis angle.



WAVDETECT: Calibration



WAVDETECT: Calibration

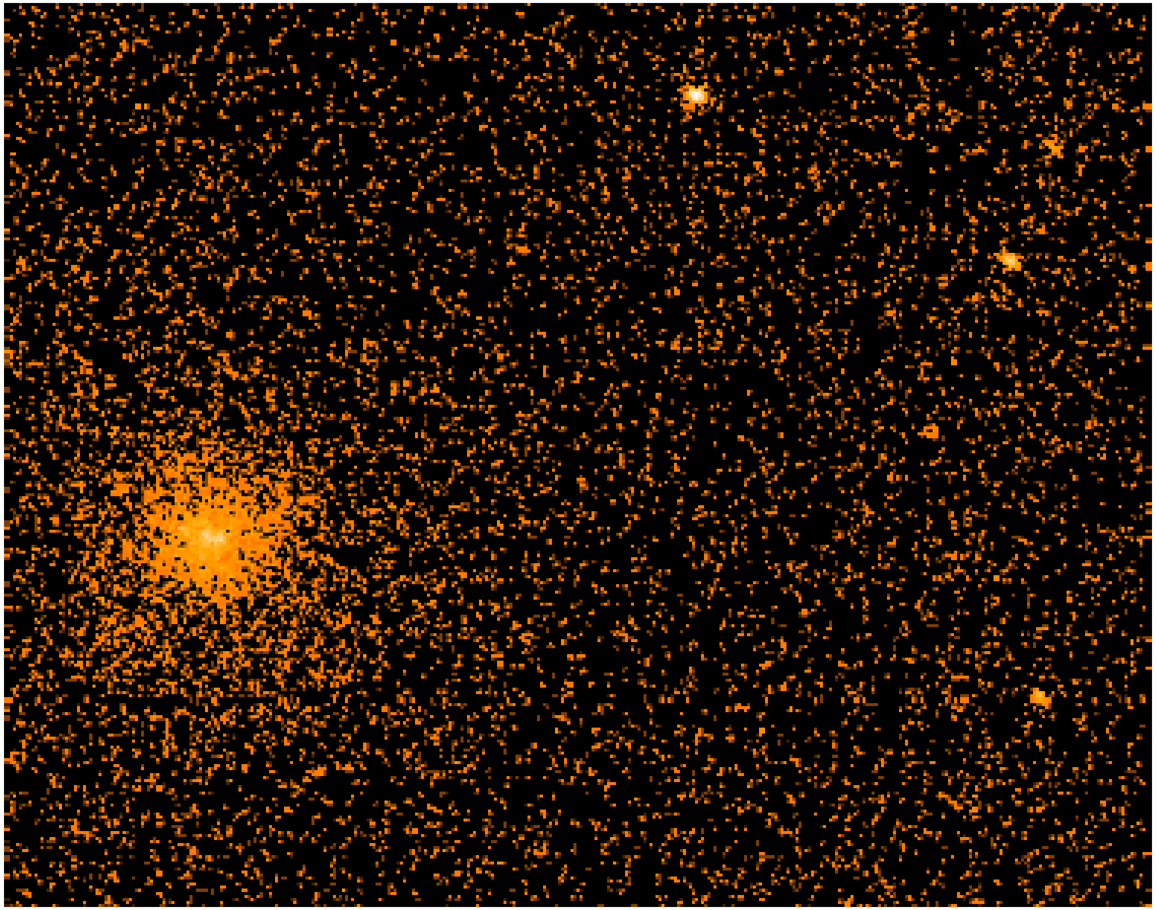


WAVDETECT: PROS and CONS

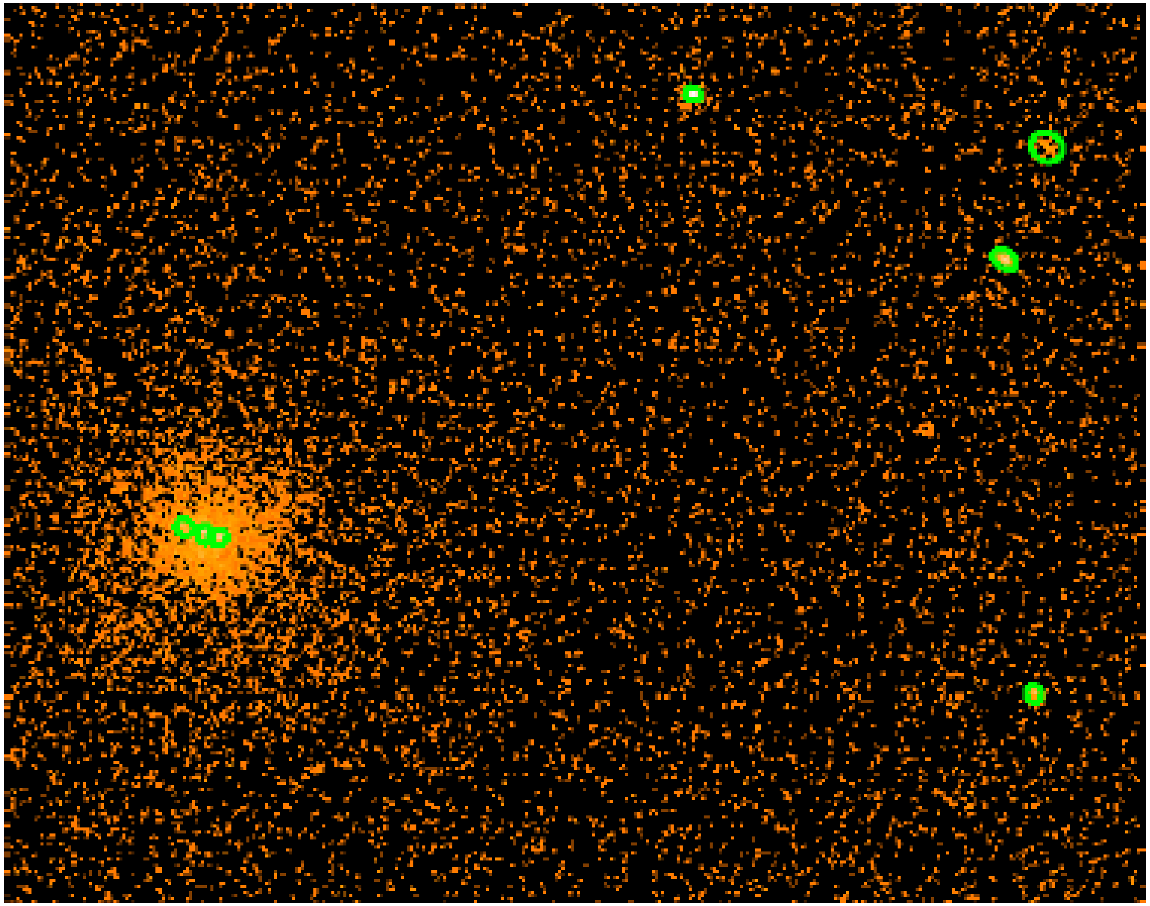
- Works well in crowded fields; background determination is iterative
- Works well for point sources on top of extended emission
- Shape of PSF not important, only approximate size needed
- Edge-of-field and vignetting effects handled correctly

- Much slower than sliding cell, especially if many wavelet scales are analyzed
- Currently limited to small chunks of data (1k x 1k - OK, 2k x 2k - pushing it)
- Requires tricks (like binning) for large areas, thus in principle losing resolution

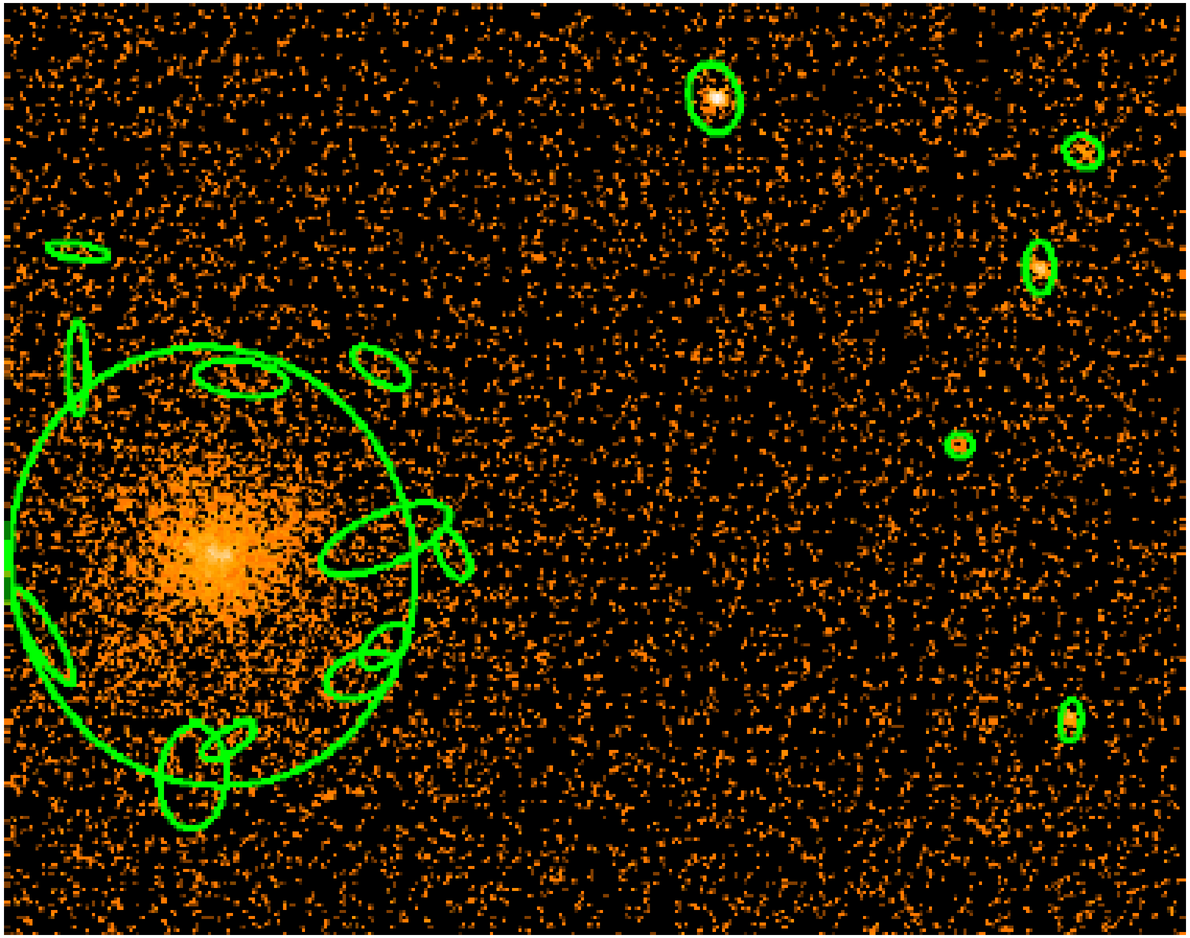
Tool Comparison



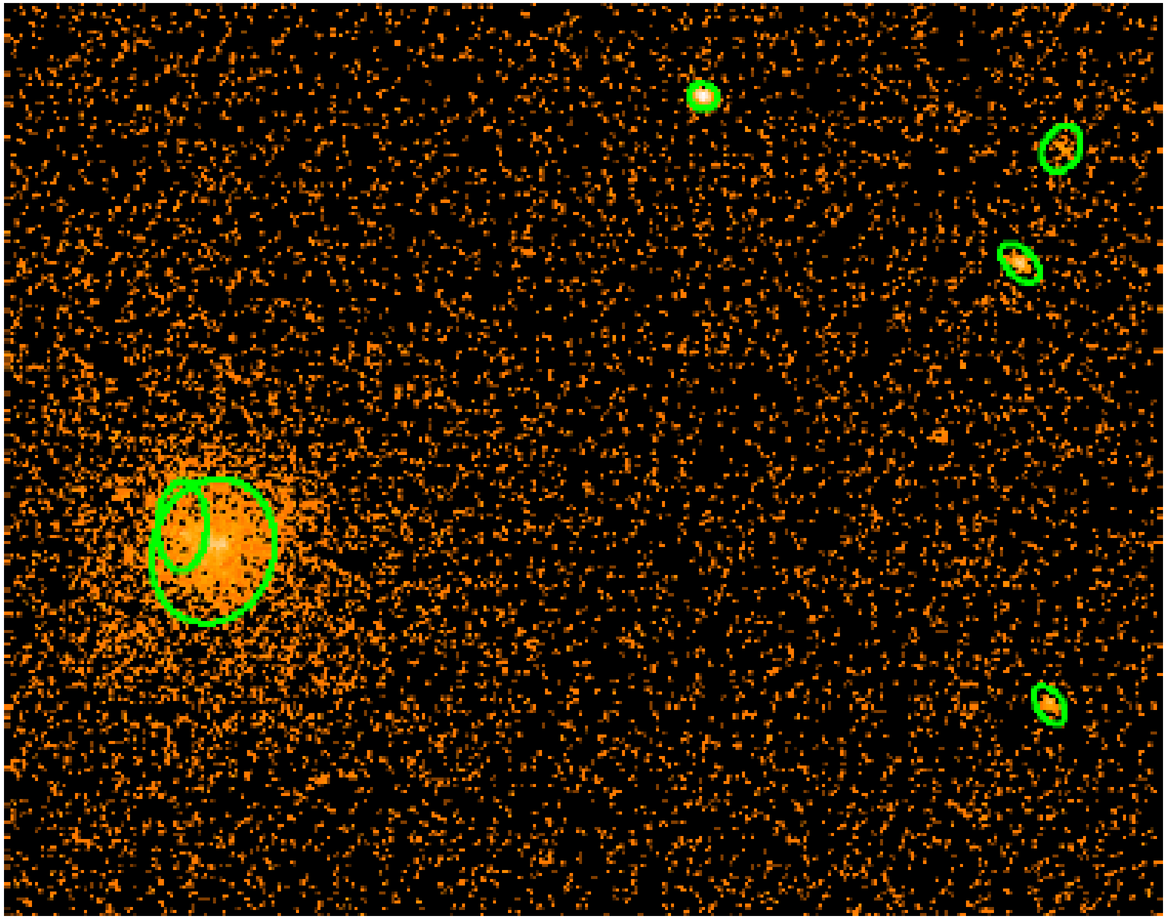
CELLDETECT: variable cell



VTPDETECT: scale=1



WAVDETECT: five scales



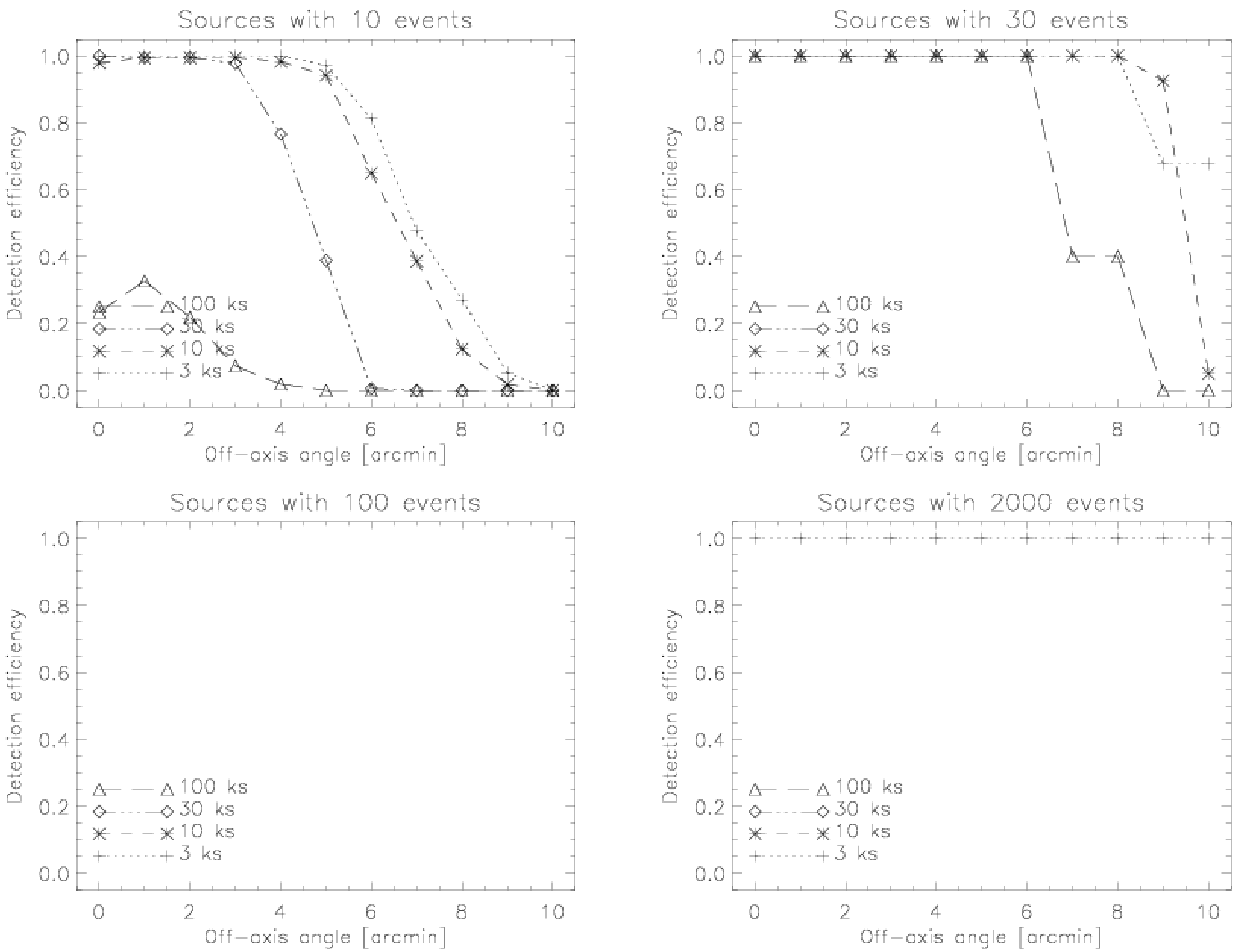
New Work: Using SExtractor

- Very fast - developed for large-format (galaxy-survey) images;
- Estimates local background and rms in image sub-sections via iterative sigma clipping/mode estimation;
- Bi-cubic spline interpolation to make global background map;
- Background-subtracted filtered image searched for 'source' pixels above n x background rms;
- Contiguous source regions searched for saddle points in intensity to deblend overlapping sources;
- References:
  - http://terapix.iap.fr/cplt/oldSite/soft/sextractor
  - Bertin & Arnouts, 1996, A&AS, 117, 393

X-ray Challenges for SExtractor

- Gaussian statistics (usually) do not apply to x-ray images, leading to erroneous estimates for background rms and many spurious '1 count' sources;
  - Smooth images prior to running;
    - Valtchanov et al. 2001, A&A, 370, 689
  - Input smoothed background map;
    - Stern et al. 2002, AJ, 123, 2223
  - Simple Anscombe image transform (y'=sqrt(y+c));
  - Modification of rms calculation to account for non-Gaussian statistics;
- PSF changes dramatically with position;
  - Incorporate recursive blocking scheme, with convolution filter tuned to off-axis angle;

Sextractor: Calibration



SExtractor: Calibration