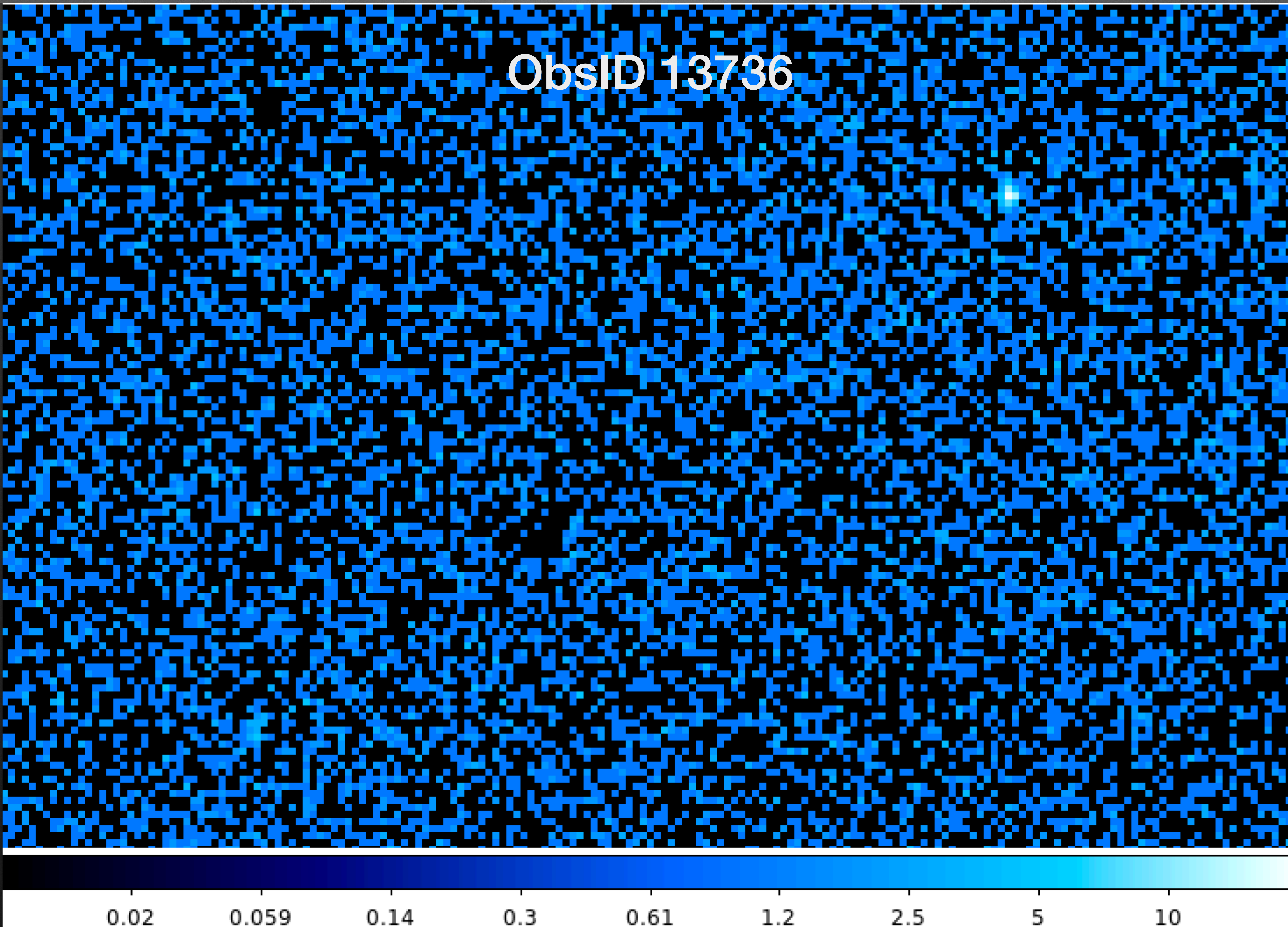
Source Detection

Vinay Kashyap
CXC/CfA

Outline

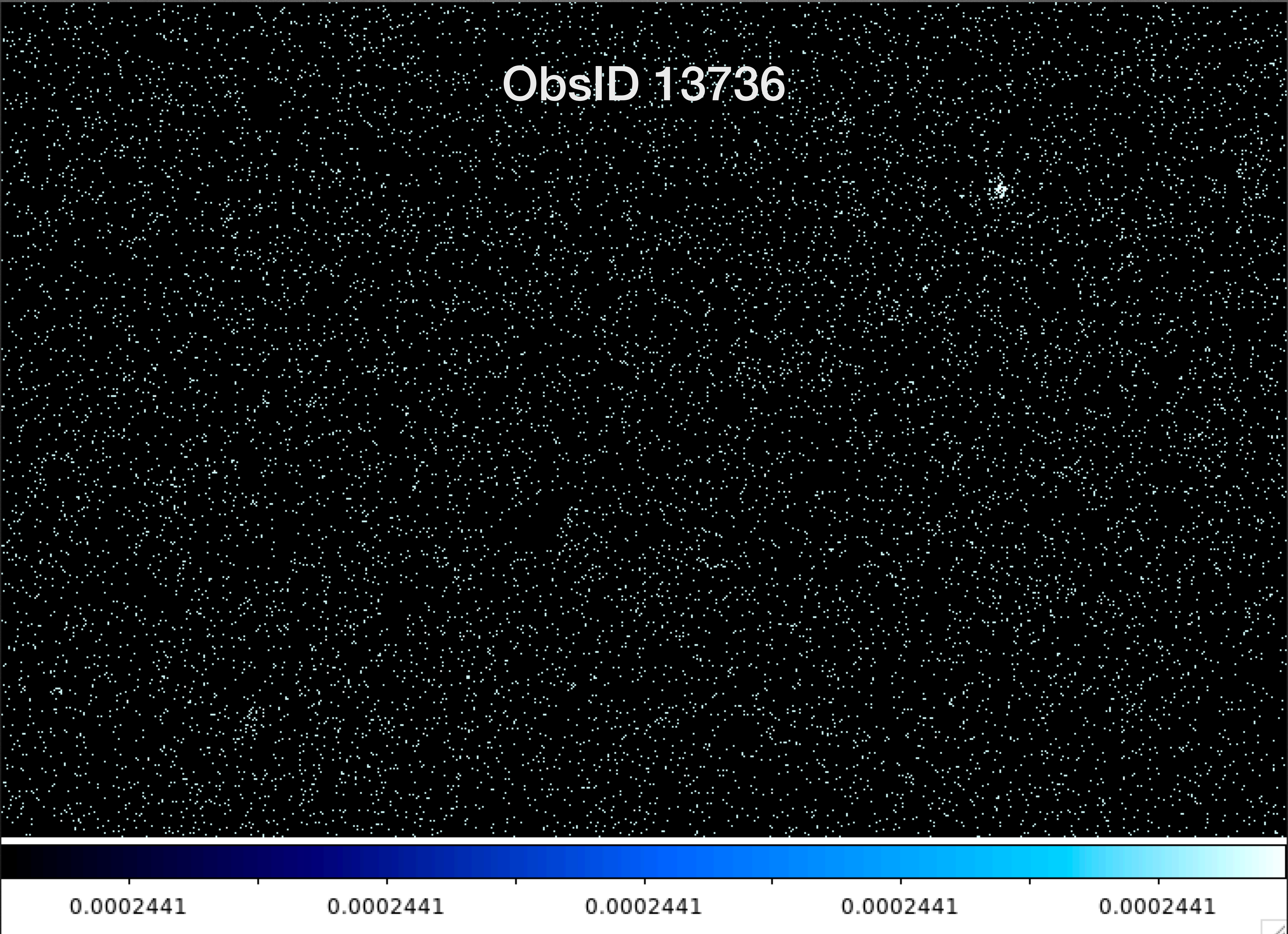
- Aperture Photometry
- “Detection”
- Upper Limits
- Detection algorithms in CIAO
  - celldetect
  - wavdetect
  - vtpdetect

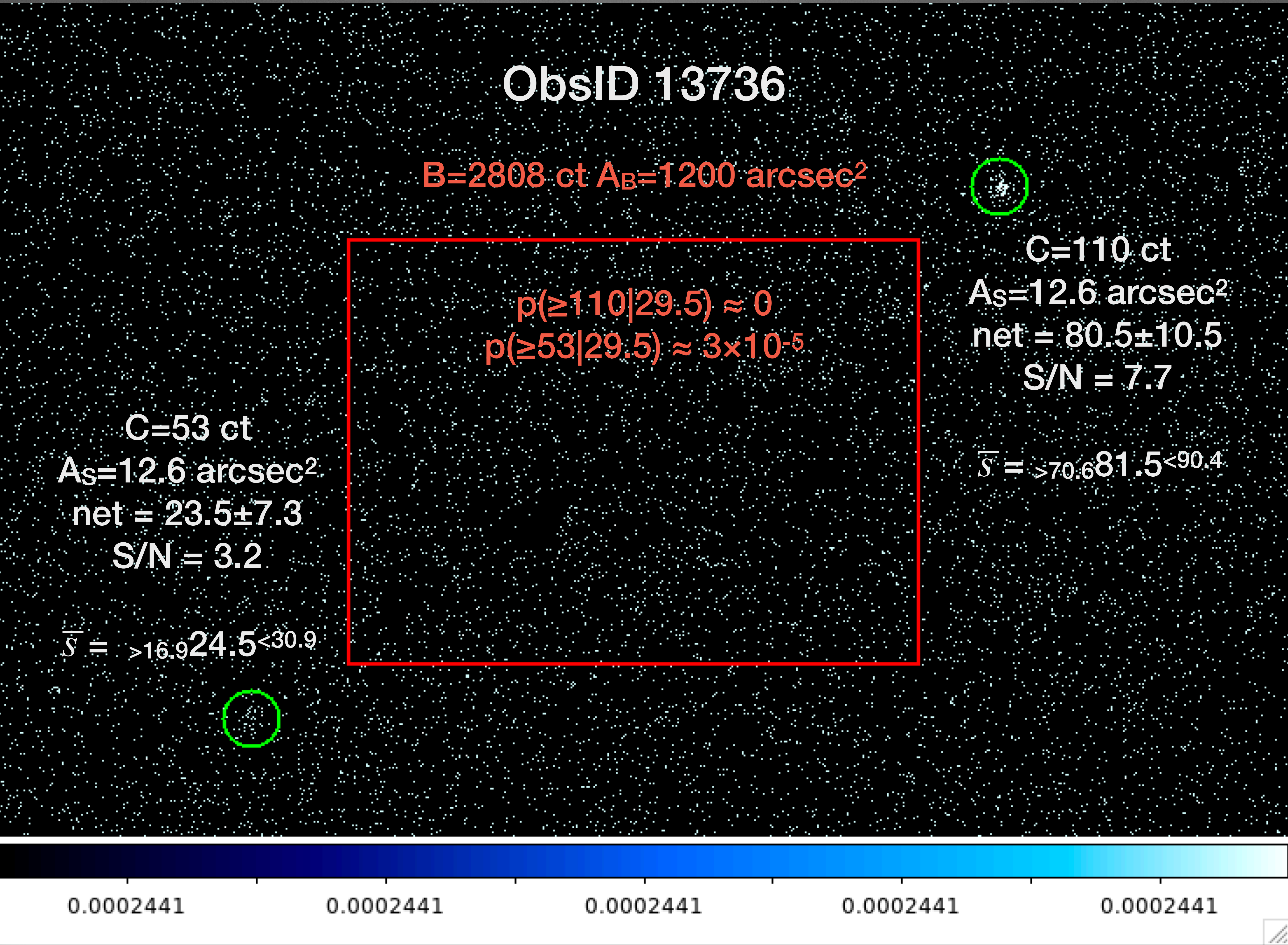


ObsID 13736
0.02
0.059
0.14
0.3
0.61
1.2
2.5
5
10

X-Ray Aperture Photometry

- Collect counts C in a region of area A_S that includes the source
- Collect counts B in a region of area A_B that excludes the source
- net counts = $C - (B/A_B) \cdot A_S$
- Propagate the error on net counts:
- $\sigma^2(\text{net}) = \sigma^2(C) + \sigma^2(B) \cdot (A_S/A_B)^2 \equiv C + B \cdot (A_S/A_B)^2$
- **aprates**: computes the Bayesian solution, $p(s|C,B,A_S,A_B,psf_A,psf_B)$


ObsID 13736
0.0002441
0.0002441
0.0002441
0.0002441
0.0002441


ObsID 13736
B=2808 ct A_B=1200 arcsec^2
p(≥110|29.5) ≈ 0
p(≥53|29.5) ≈ 3×10^{-5}
C=110 ct
A_S=12.6 arcsec^2
net = 80.5±10.5
S/N = 7.7
$\overline{S} = {}_{>70.6}81.5^{<90.4}$
C=53 ct
A_S=12.6 arcsec^2
net = 23.5±7.3
S/N = 3.2
$\overline{S} = {}_{>16.9}24.5^{<30.9}$
0.0002441
0.0002441
0.0002441
0.0002441
0.0002441

What does detection mean?

- That there is an astrophysically relevant source of emission,
- distinct from a background noise level,
- with a sufficiently low chance of being a false positive.

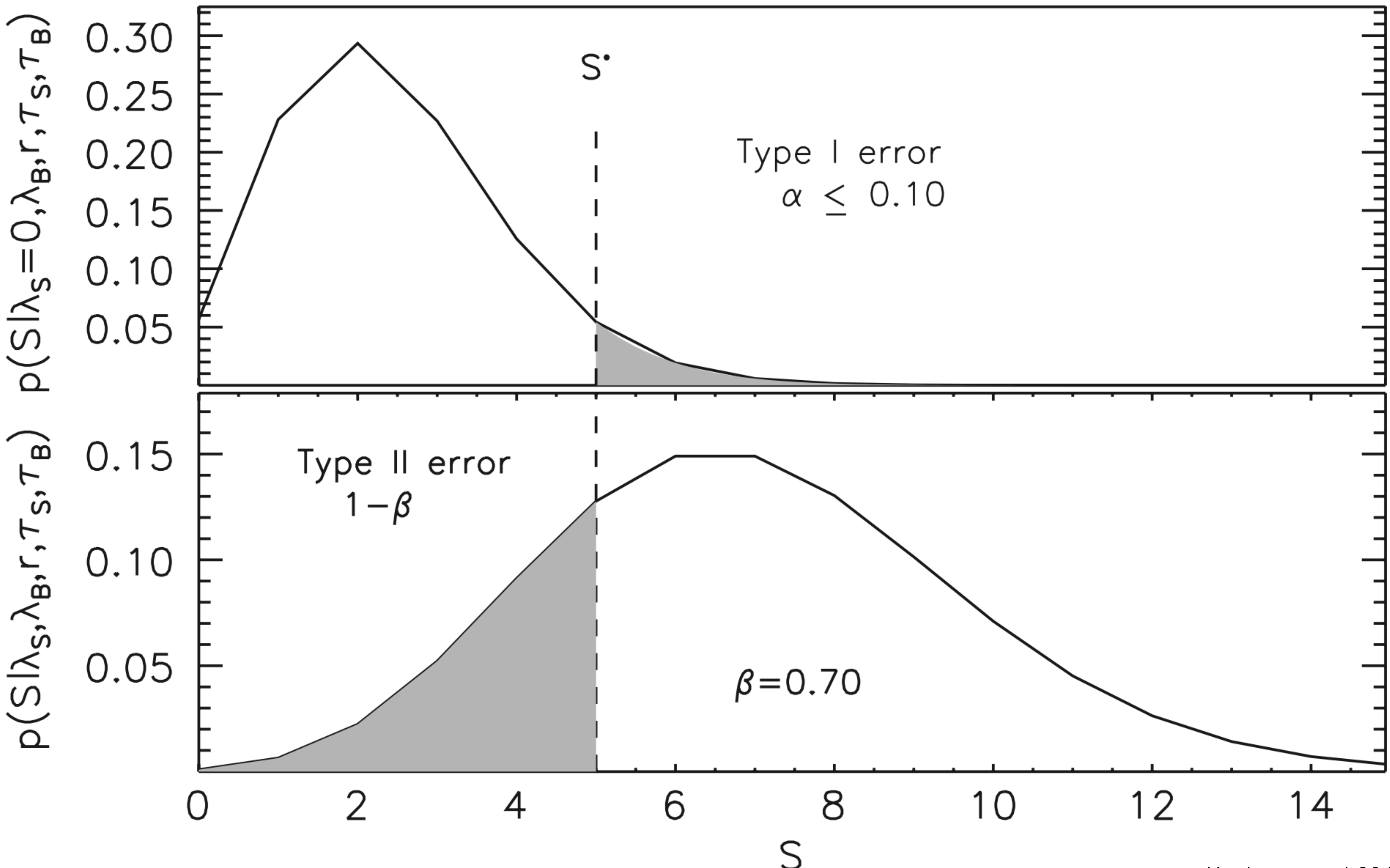
There is no dispute for strong sources, but you need an objective method of identifying plausible sources

Chandra Detect Manual:
http://cxc.harvard.edu/ciao/download/doc/detect_manual/

Upper Limits

- Surprisingly difficult to say what it is and how to calculate it, though everyone *knows* what it is
- The largest intensity that a source can have without being detected, OR the smallest intensity that a source can have and still be detected.
- Notice reliance on detection, which is defined based on measured counts, and intensity, which is an intrinsic property of the source and comes with a probability distribution

8. Type I and Type II Errors



Kashyap et al 2010

Upper Limits

- First set the detection (aka false positive) threshold α, and the false negative threshold β, which says how much you are willing to tolerate missing the detection
- Quote the value of the intrinsic brightness for which the probability distribution exceeds β above α

Detection Algorithms in CIAO

- **`celldetect`**: sliding cell with built in background subtractor, uses S/N as threshold criterion
- **`wavdetect`**: Mexican Hat wavelet correlations, uses background fluctuations to set local thresholds
- **`vtpdetect`**: Voronoi Tesselation of event locations, uses distribution of areas as a way to identify possible sources, and percolates to include nearby cells that are above a background

celldetect

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1
0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0
0	0	0	0	0	0	0	3	0	1	0	1	0	0	0	0
0	0	0	0	0	0	2	3	1	0	1	0	0	1	0	0
0	0	1	0	0	0	2	2	2	0	0	0	1	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	1	0	0	0	0	1	2	0	0	0	0	0	0	0
0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0

celldetect

C	1
B	0
net	1

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1
0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0
0	0	0	0	0	0	0	3	0	1	0	1	0	0	0	0
0	0	0	0	0	0	2	3	1	0	1	0	0	1	0	0
0	0	1	0	0	0	2	2	2	0	0	0	1	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	1	0	0	0	0	1	2	0	0	0	0	0	0	0
0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0

celldetect

C	1	1	0	4	12	13	11	5	3	3	4	3
B	0	0	5	9	4	3	8	12	6	5	2	2
net	1	1	-2.8	-1.1	9.7	11.3	6.5	-1.7	-0.4	-0.2	2.9	1.9

0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1
0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0
0	0	0	0	0	0	0	3	0	1	0	1	0	0	0	0
0	0	0	0	0	0	2	3	1	0	1	0	0	1	0	0
0	0	1	0	0	0	2	2	2	0	0	0	1	1	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1
0	0	1	0	0	0	0	1	2	0	0	0	0	0	0	0
0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0

celldetect

http://cxc.harvard.edu/ciao/download/doc/detect_manual/cell_theory.html#SECTION00920000000000000000

$$C = \alpha S + B$$

$$T = \beta S + \left(\frac{b}{d}\right)^2 B.$$

$$S = \frac{C(b^2 - d^2)d^{-2} - Q}{\alpha b^2 d^{-2} - \beta}$$

$$\sigma_S^2 = \frac{\sigma_C^2 (b^2 - d^2)^2 d^{-4} + \sigma_Q^2}{(\alpha b^2 d^{-2} - \beta)^2}$$

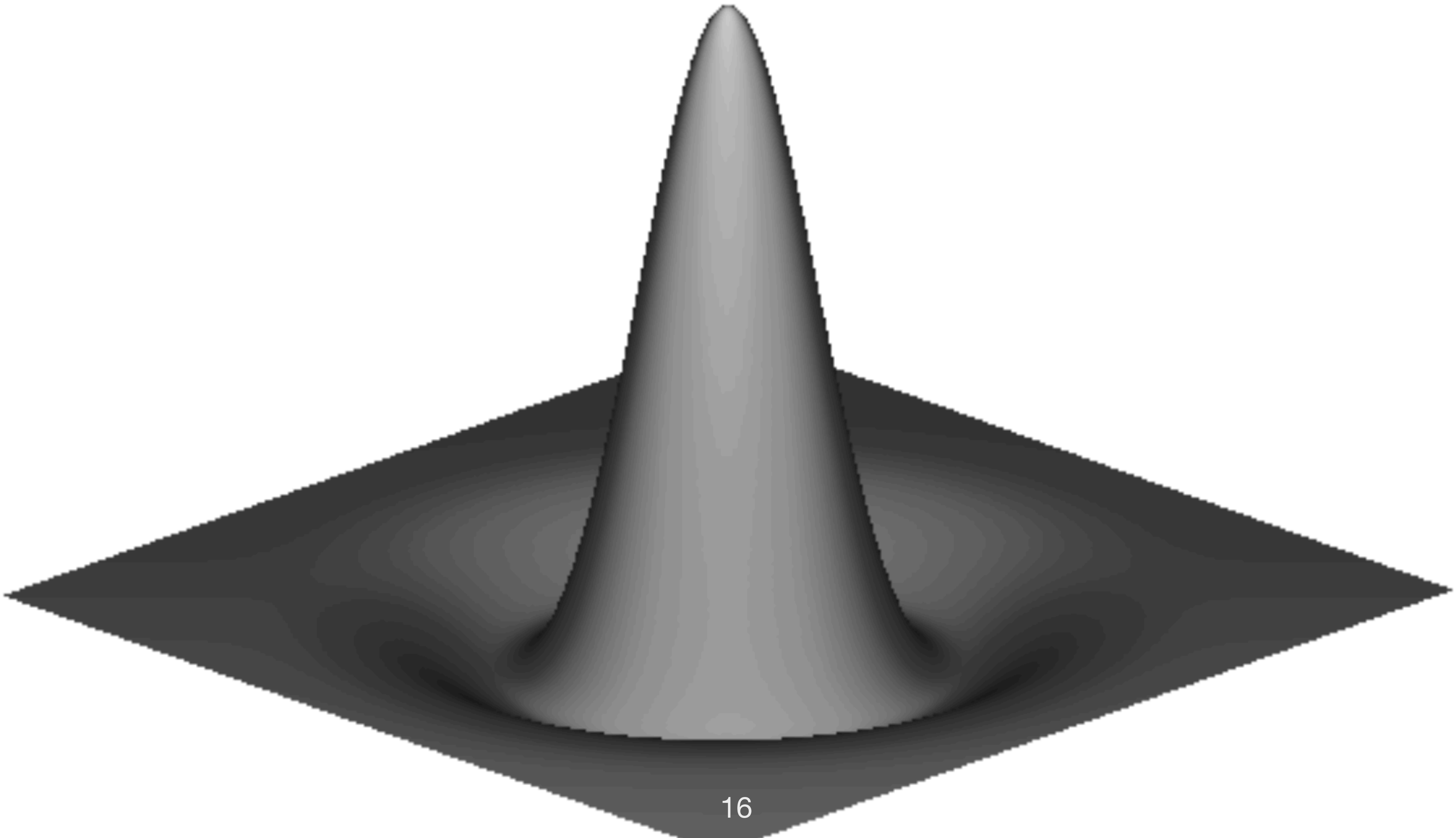
$$\mathrm{S/N} = \frac{S}{\sigma_S} = \frac{C(b^2 - d^2)d^{-2} - Q}{\sqrt{\sigma_C^2 (b^2 - d^2)^2 d^{-4} + \sigma_Q^2}}$$

$$\sigma_N = 1 + \sqrt{N + 0.75}$$

wavdetect

Correlate image with Mexican Hat wavelet

$$W\left(\frac{x}{\sigma_x},\frac{y}{\sigma_y}\right) = \frac{1}{2\pi\sigma_x\sigma_y}\left[2-\frac{x^2}{\sigma_x^2}-\frac{y^2}{\sigma_y^2}\right]\times e^{-(x^2/2\sigma_x^2)-(y^2/2\sigma_y^2)}$$



`wavdetect`

Local background component estimated from negative annulus

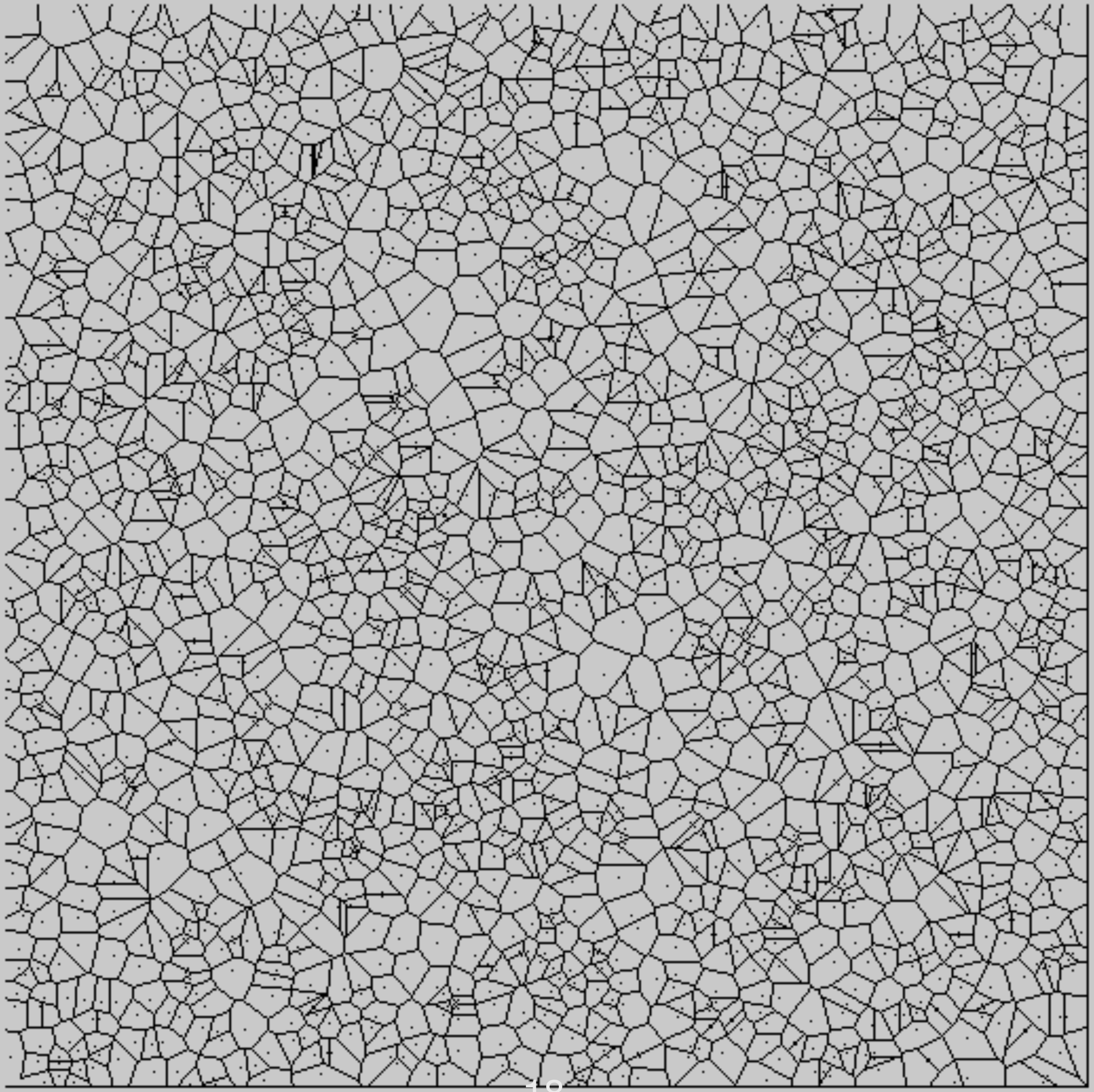
Threshold applied in correlation space based on simulations

Threshold set to expect 1 false source in image

Sources detected separately at different scales,
and merged using `wrecon`

vtpdetect

Construct Voronoi tessalations, then percolate to add nearest neighbors



http://cxc.harvard.edu/ciao/threads/detect_overview/

Summary of CIAO detect

- **celldetect**: conceptually simple, low false positive rates, but also high false negative rates, good measurement of brightness
- **wavdetect**: works very well for point sources, sources can be at many scales, but does not provide a reliable measure of source intensity (use **srcflux**)
- **vtpdetect**: works well for diffuse extended sources, does not handle large changes in exposure maps, computationally expensive