Source Detection

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Outline

• Aperture Photometry
• “Detection”
• Upper Limits
• Detection algorithms in CIAO
  • celldetect
  • wavdetect
  • vtpdetect
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, $p(s|C,B,A_S,A_B,\text{psf}_A,\text{psf}_B)$
ObsID 13736

B = 2808 ct  $A_B = 1200 \text{ arcsec}^2$

\[ p(\geq 110|29.5) \approx 0 \]
\[ p(\geq 53|29.5) \approx 3 \times 10^{-5} \]

C = 110 ct  
$A_S = 12.6 \text{ arcsec}^2$
\[ \text{net} = 80.5 \pm 10.5 \]
$S/N = 7.7$
\[ \overline{S} = \geq 70.6 \leq 81.5 < 90.4 \]

C = 53 ct  
$A_S = 12.6 \text{ arcsec}^2$
$\text{net} = 23.5 \pm 7.3$
$S/N = 3.2$
\[ \overline{S} = >16.9 \leq 24.5 < 30.9 \]
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

Type I error \( \alpha \leq 0.10 \)

Type II error \( 1 - \beta \)

\( \beta = 0.70 \)
Upper Limits

- First set the detection (aka false positive) threshold $\alpha$, and the false negative threshold $\beta$, 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 $\beta$ above $\alpha$. 
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 Tessellation 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
celldetect
# celldetect

<table>
<thead>
<tr>
<th>C</th>
<th>1</th>
<th>1</th>
<th>0</th>
<th>4</th>
<th>12</th>
<th>13</th>
<th>11</th>
<th>5</th>
<th>3</th>
<th>3</th>
<th>4</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>9</td>
<td>4</td>
<td>3</td>
<td>8</td>
<td>12</td>
<td>6</td>
<td>5</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>net</td>
<td>1</td>
<td>1</td>
<td>-2.8</td>
<td>-1.1</td>
<td>9.7</td>
<td>11.3</td>
<td>6.5</td>
<td>-1.7</td>
<td>-0.4</td>
<td>-0.2</td>
<td>2.9</td>
<td>1.9</td>
</tr>
</tbody>
</table>

![Cell detection image]
\[ C = \alpha S + B \]
\[ T = \beta S + \left( \frac{b}{d} \right)^2 B. \]
\[ S = \frac{C(b^2 - d^2)d^{-2} - Q}{\alpha b^2 d^{-2} - \beta} \]
\[ \sigma^2_S = \frac{\sigma_C^2(b^2 - d^2)^2 d^{-4} + \sigma_Q^2}{(\alpha b^2 d^{-2} - \beta)^2} \]
\[ \frac{S}{N} = \frac{S}{\sigma_S} = \frac{C(b^2 - d^2)d^{-2} - Q}{\sqrt{\sigma_C^2(b^2 - d^2)^2 d^{-4} + \sigma_Q^2}} \]
\[ \sigma_N = 1 + \sqrt{N} + 0.75 \]
wavdetect

Correlate image with Mexican Hat wavelet

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