

Blind Detection of Ultrafaint Streaks with a Maximum Likelihood Method

CASIS

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Real Data GEO

Real GEO Data: PSF convolved detection seems to work very well.

- Consistently detects streaks and stars
- Star/streak separation based off multivariate Gaussian fit

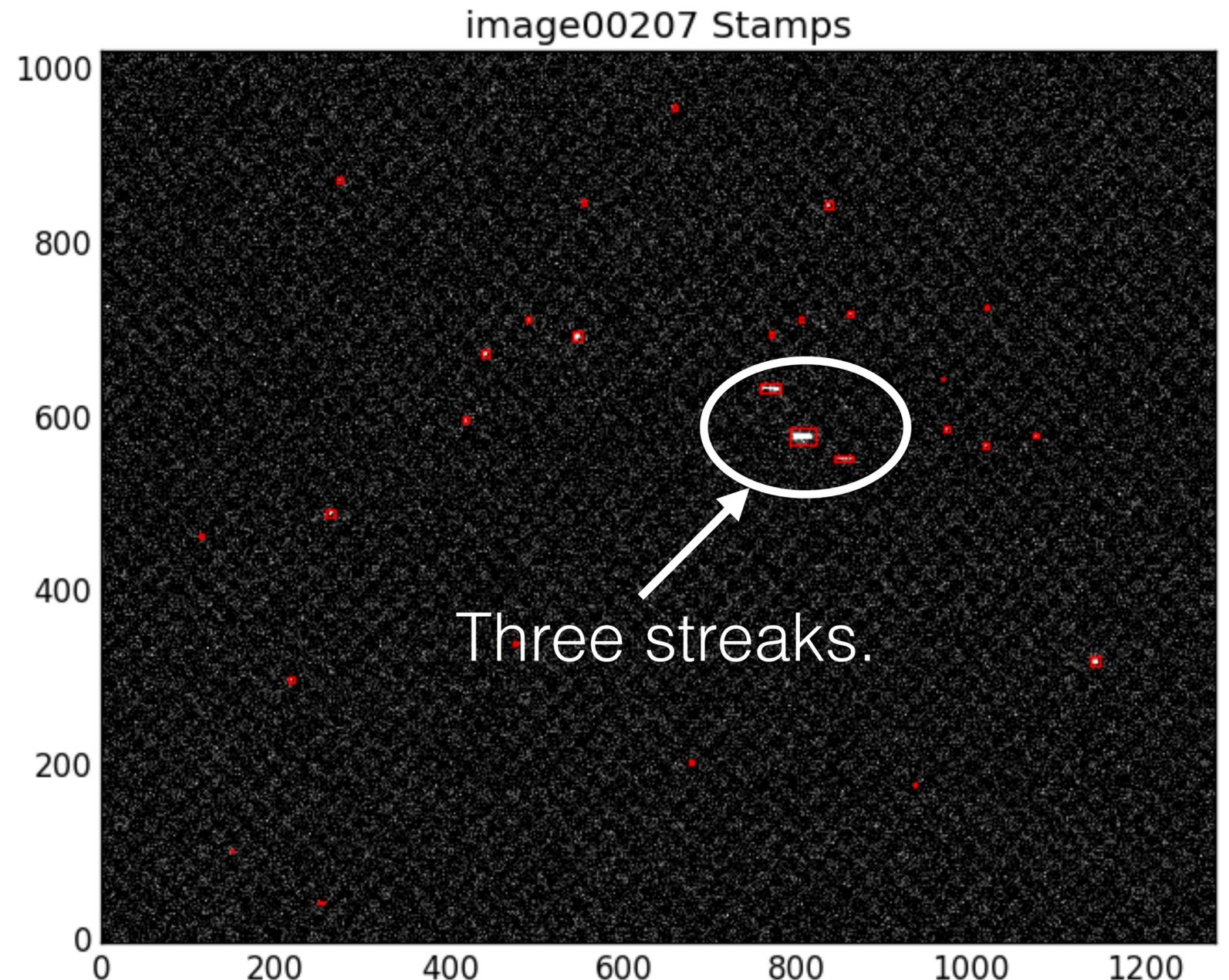
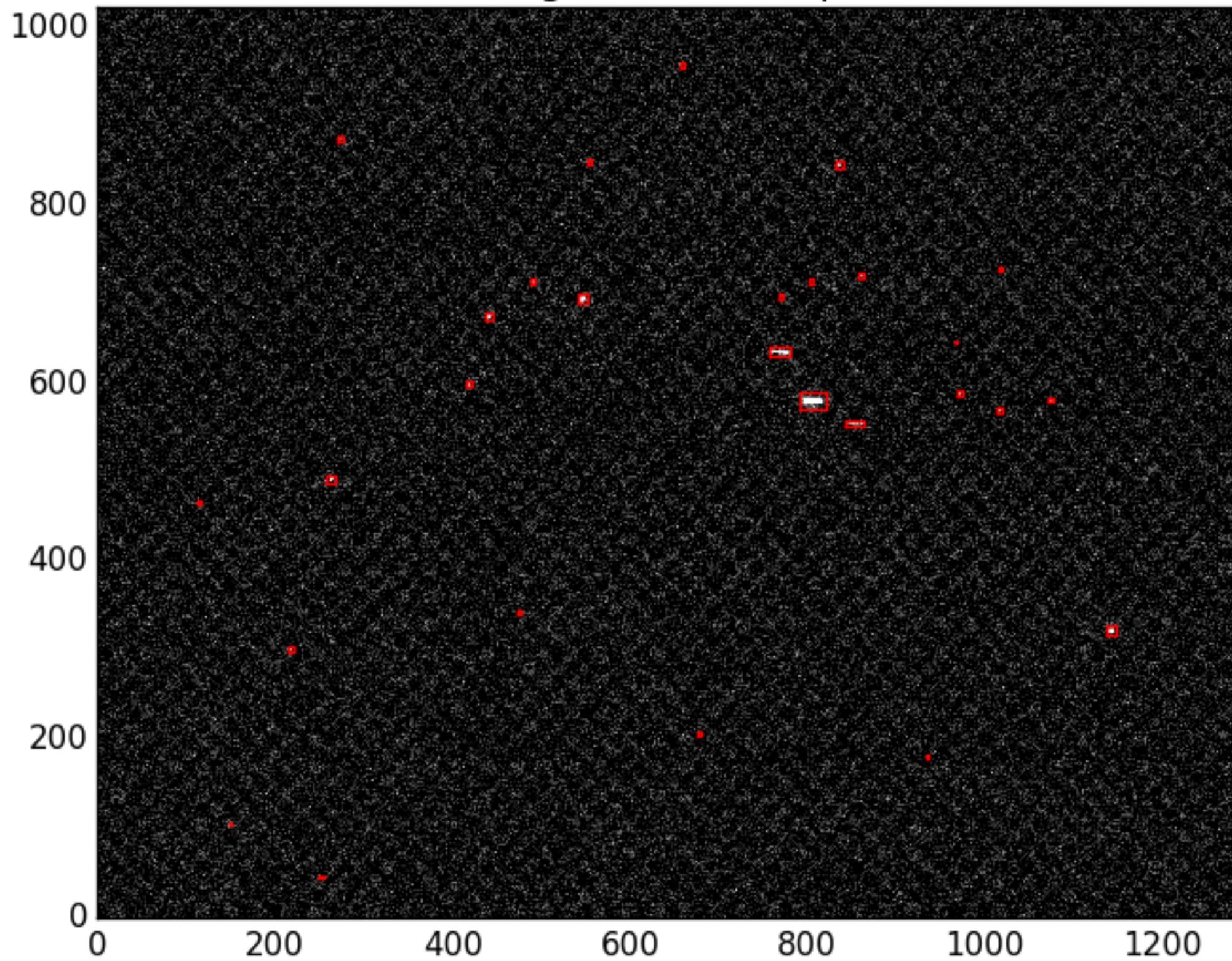
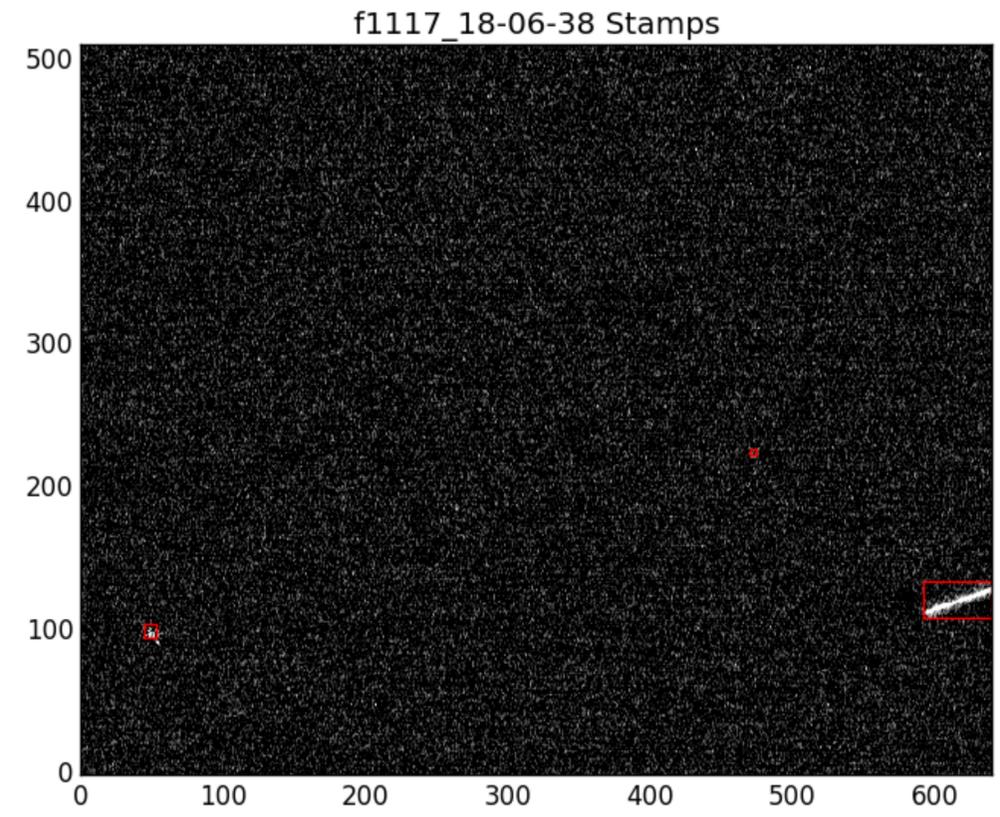
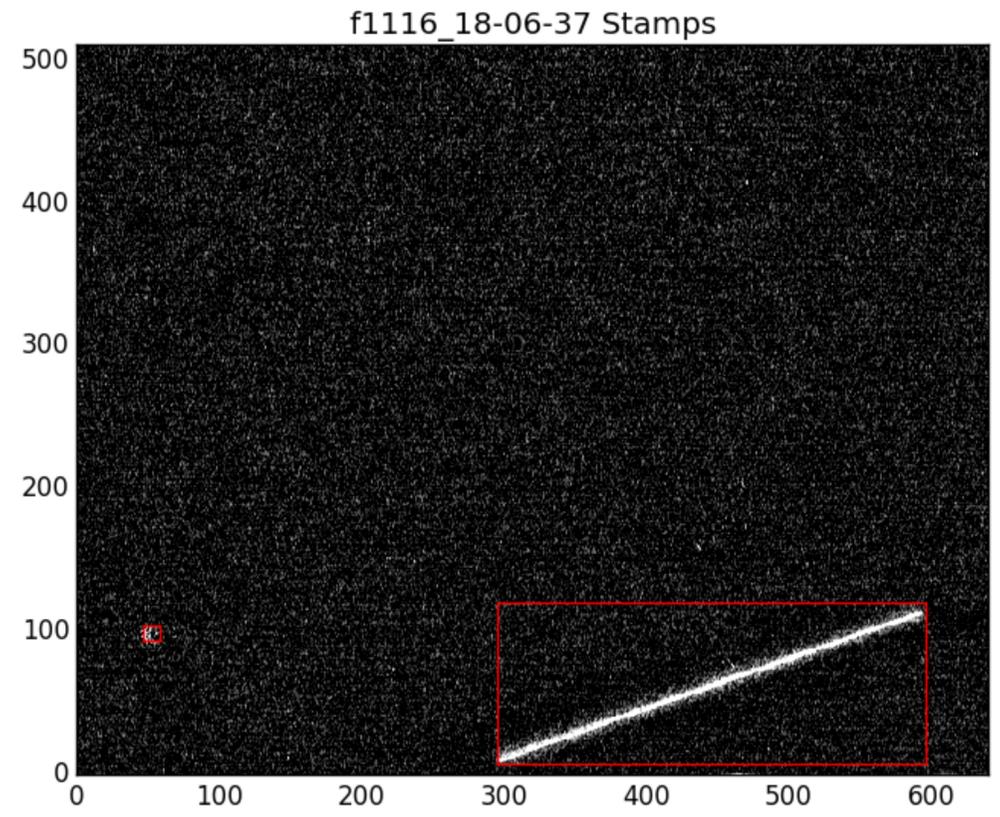
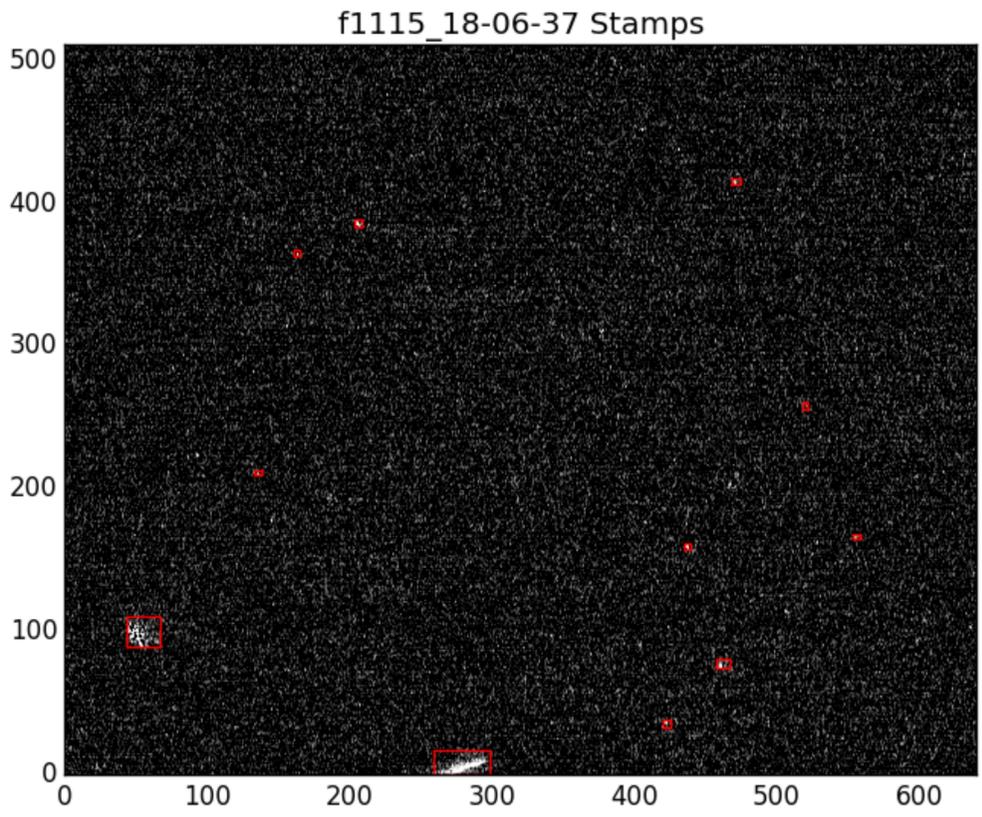


image00207 Stamps



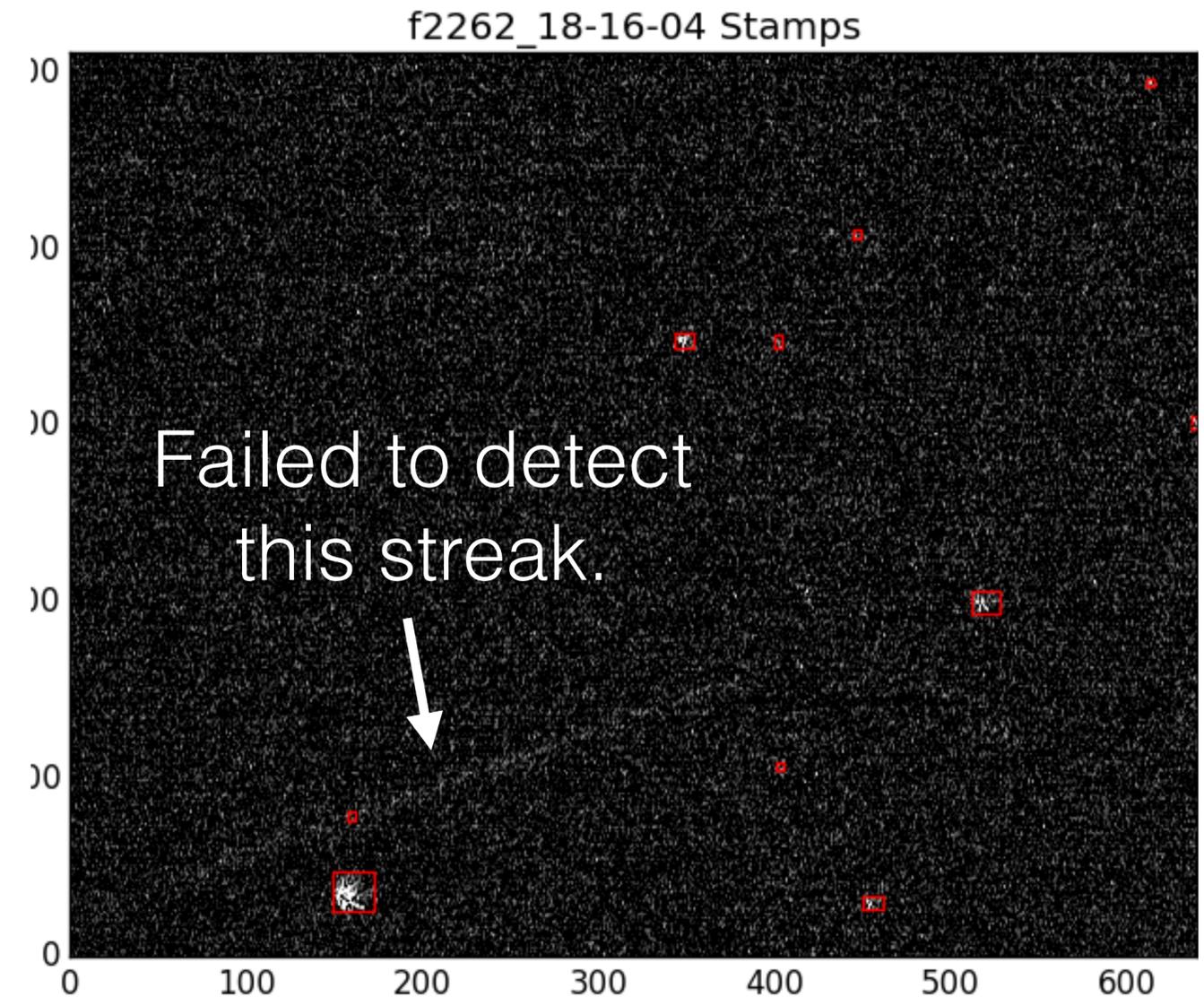
Real Data
LEO

PSF convolved detection worked in some cases



Failed on some LEO data

- Shorter exposures = lower SNR = detection “issues”
- Many fainter streaks that could be seen by eye were not detected



Maximum Likelihood Detection

$$m(x, \theta) = \int s(x, \theta) \phi(x) dx \quad \text{source model convolved with PSF}$$

$$\ln \mathcal{L}(x, \theta) = -\frac{1}{2} [d(x) - m(x, \theta)]^T \Sigma^{-1} [d(x) - m(x, \theta)] + C \quad \text{Log likelihood}$$

$$m(x, \theta) = \alpha \mu(x, \Theta) \quad \text{separate the flux from the other model parameters}$$

$$\Phi(x, \Theta) = \mu(x, \Theta)^T \Sigma^{-1} \mu(x, \Theta) \quad \text{noise weighted model auto-correlation}$$

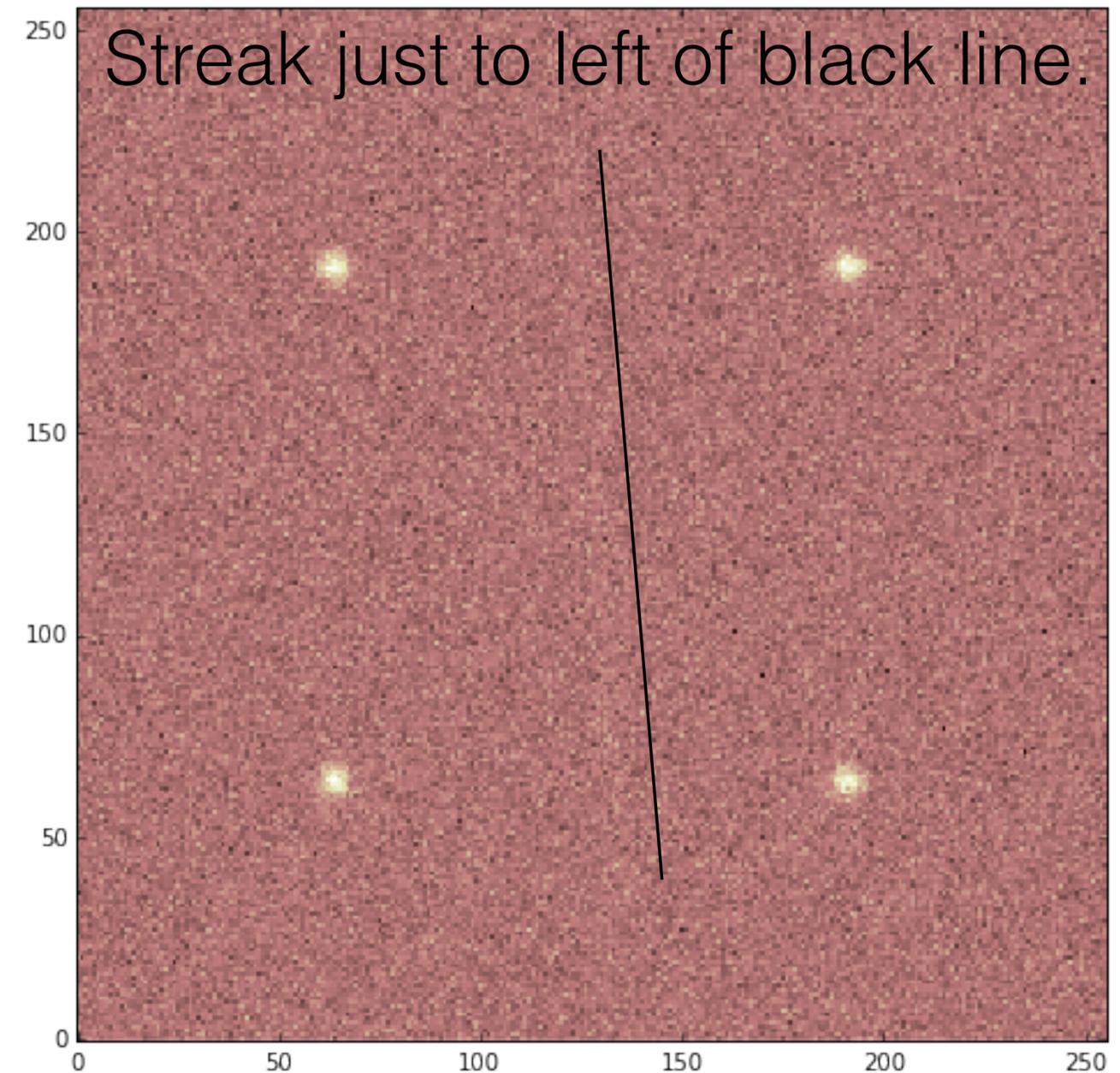
$$\Psi(x, \Theta) = d(x)^T \Sigma^{-1} \mu(x, \Theta) \quad \text{noise weighted data-model cross-correlation}$$

$$\frac{\partial \ln \mathcal{L}}{\partial \alpha} = \alpha \Phi(x, \Theta) - \Psi(x, \Theta) = 0 \quad \left| \quad \alpha_{\text{ML}} = \frac{\Psi(x, \Theta)}{\Phi(x, \Theta)} \quad \left| \quad \ln \mathcal{L}_{\text{ML}} = \frac{\Psi^2(x, \Theta)}{2\Phi(x, \Theta)} \quad \left| \quad \nu(x, \Theta) = \frac{\Psi(x, \Theta)}{\sqrt{\Phi(x, \Theta)}} \right. \right. \text{Significance}$$

Faint Source Pipeline: Tests on Simulated Data

Testing detection pipeline on faint simulated streak

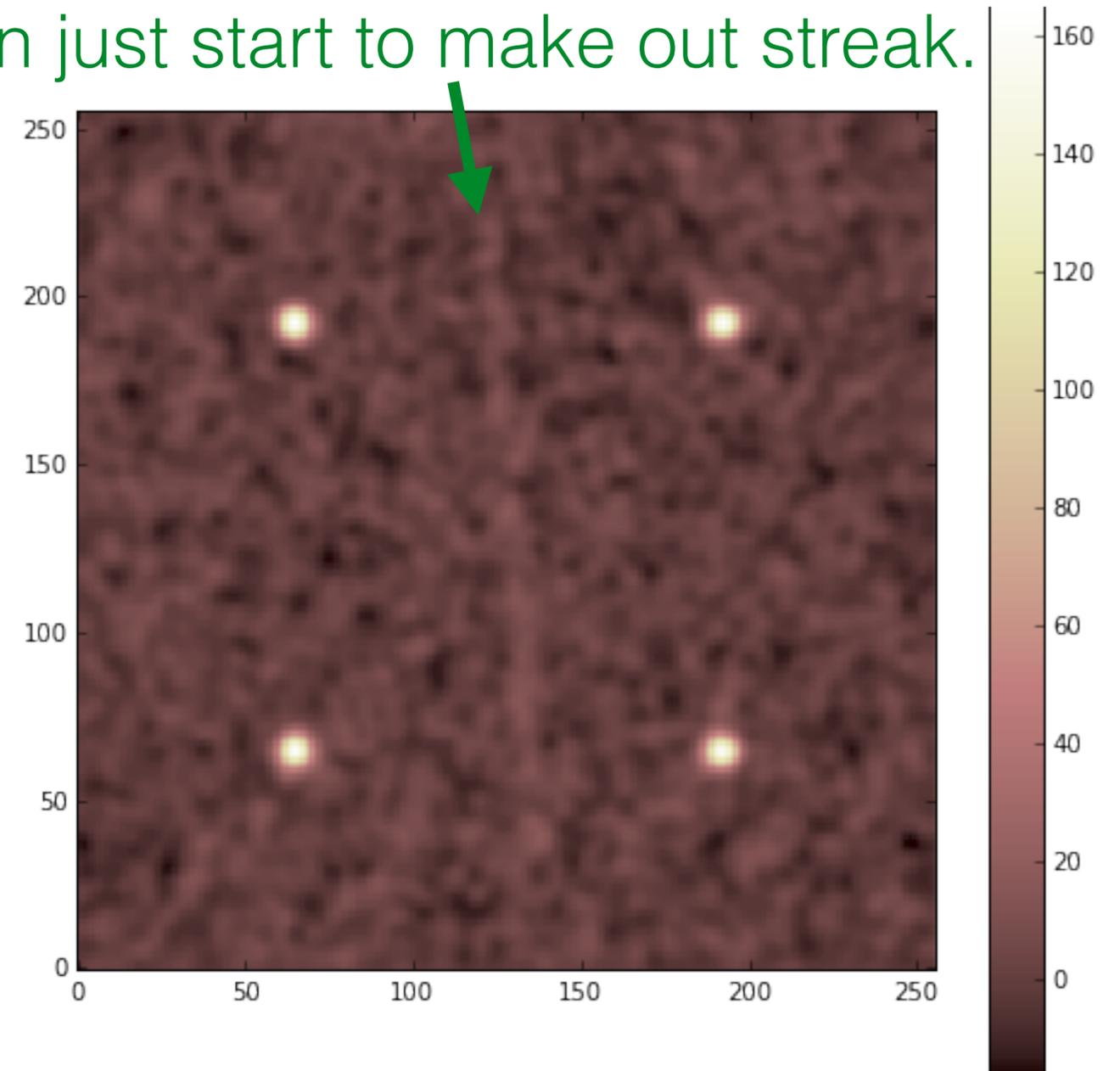
- Create simulated image with 4 high SNR stars and one faint streak.
- Convolve image with initial PSF guess. This creates Ψ_{PSF} image
- Estimate Φ_{PSF} (currently constant across image), and combine with Ψ_{PSF} for ν_{PSF}
- Detect sources in ν_{PSF} image above a SNR threshold (footprints)
 - Star/streak separation, estimate PSF, repeat above with more accurate PSF.
- Mask detected footprints in Ψ_{PSF} image
- Convolve Ψ_{PSF} image with streak model (i.e. line), and repeat detection process. (ν_{streak_i})



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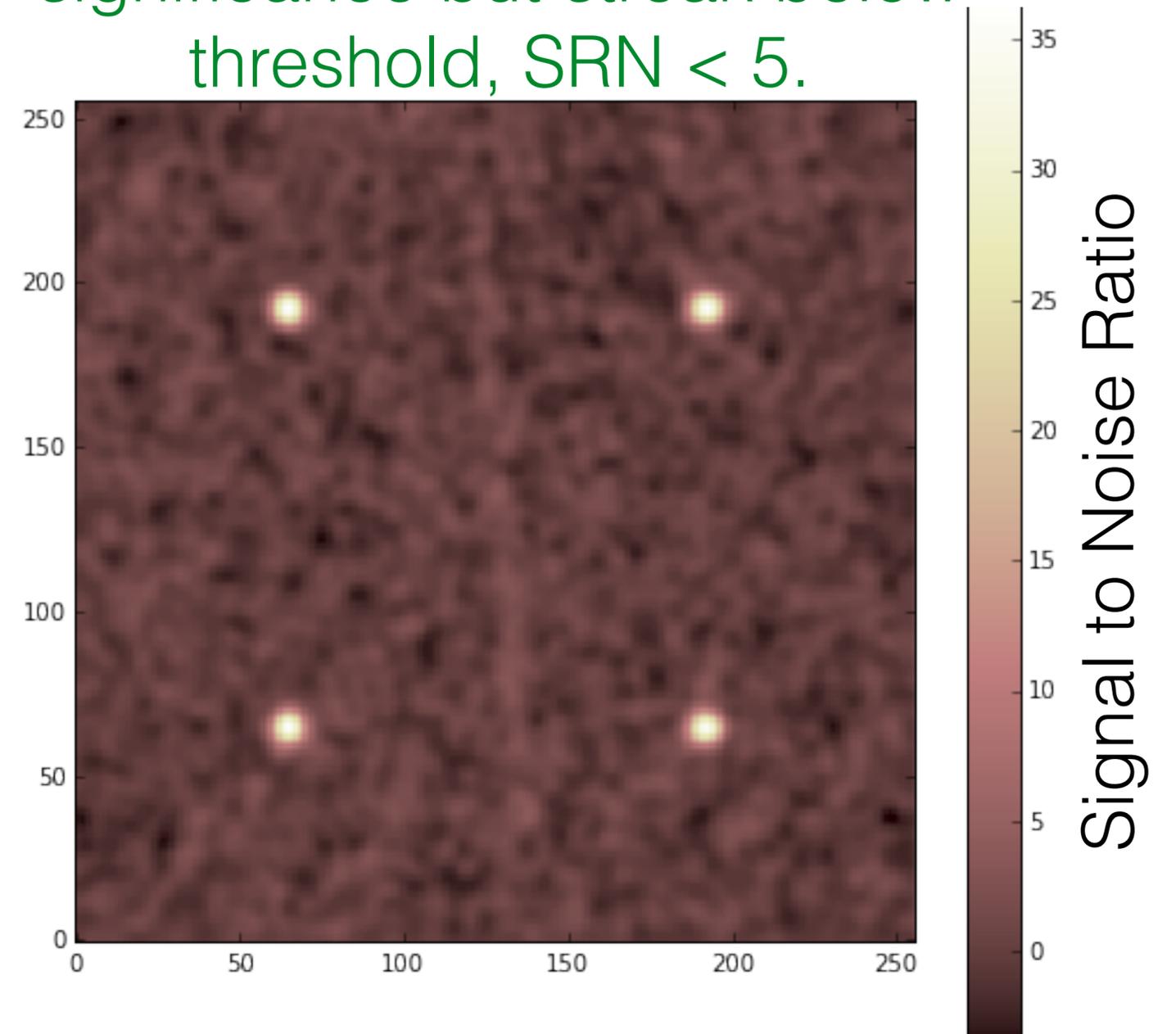
Can just start to make out streak.



Testing detection pipeline on faint simulated streak

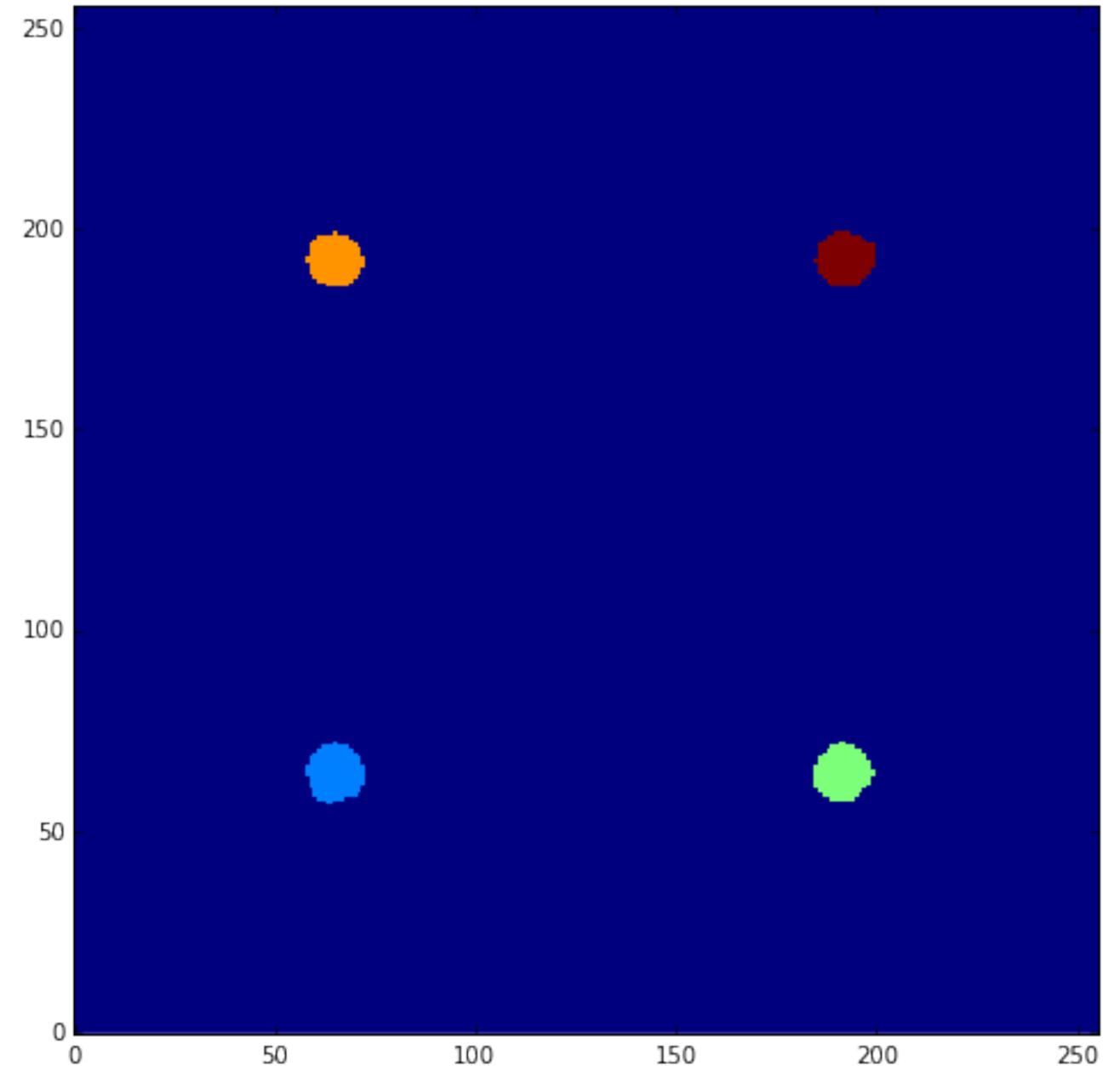
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Point sources detected at high significance but streak below threshold, $\text{SRN} < 5$.



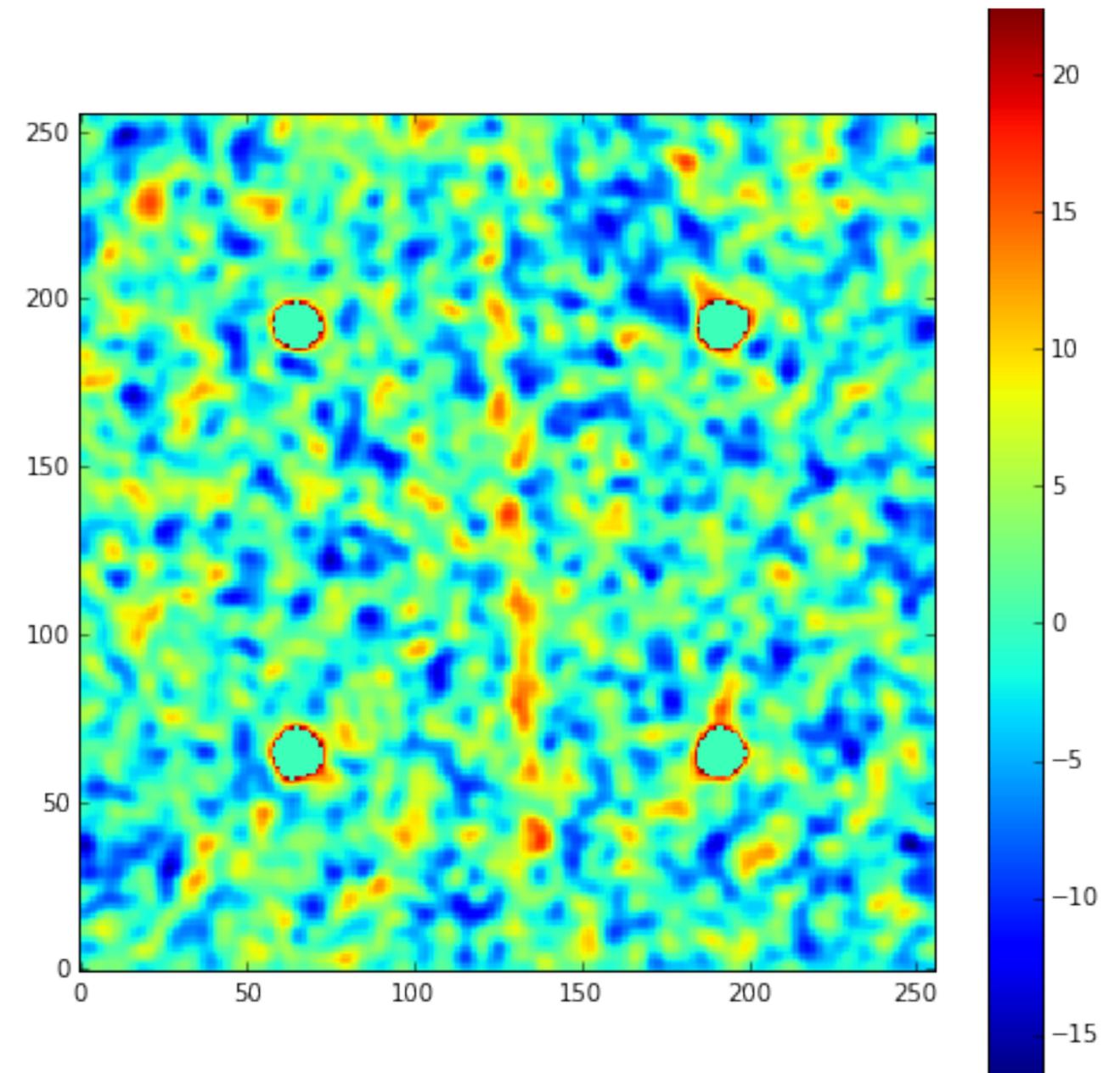
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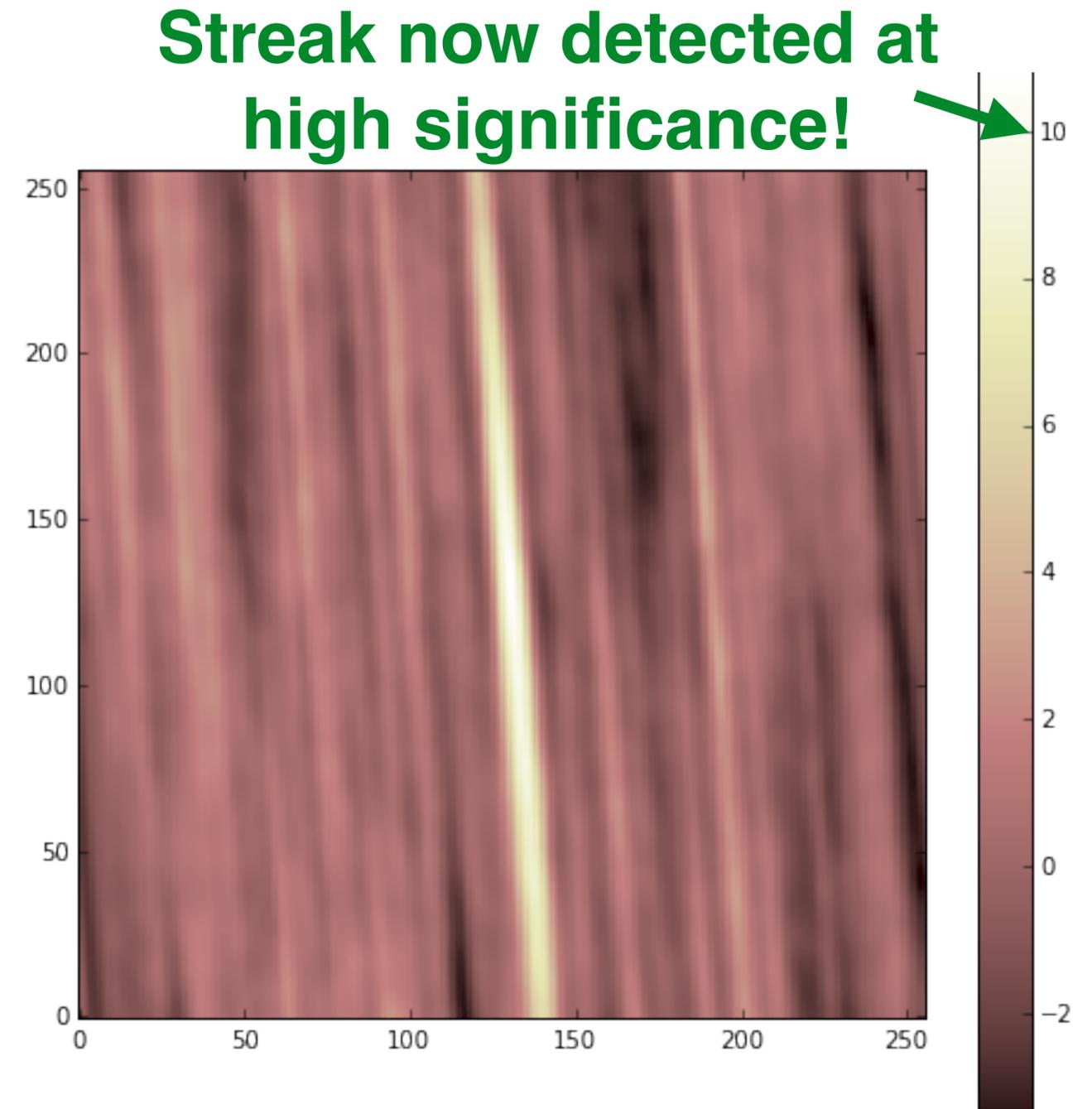
Testing detection pipeline on faint simulated streak

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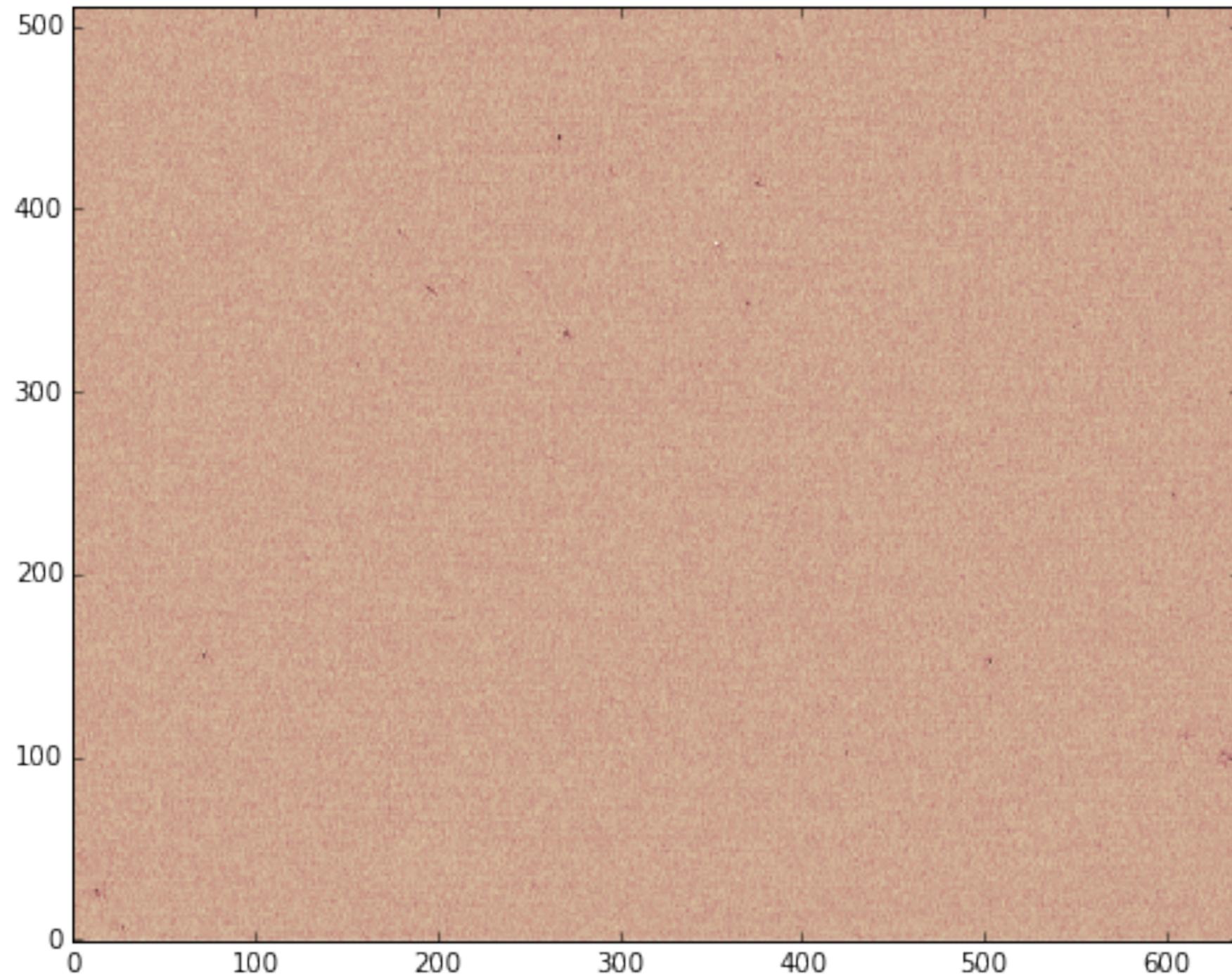
Iteratively determine the Maximum Likelihood Model (major room for computational optimization but fundamental method solid)

```
Considering streak of lengths: [ 50.  60.  70.  80.  90. 100. 110. 120. 130. 140.]
Using a delta_phi0 = 0.025
New best streak model: L = 50.0, phi0=0.0
nu_max_i = 8.31
New best streak model: L = 50.0, phi0=0.025
nu_max_i = 8.82
New best streak model: L = 50.0, phi0=0.05
nu_max_i = 9.18
New best streak model: L = 50.0, phi0=0.075
nu_max_i = 9.30
Using a delta_phi0 = 0.02083333333333333
New best streak model: L = 60.0, phi0=0.04166666666666667
nu_max_i = 9.38
New best streak model: L = 60.0, phi0=0.0625
nu_max_i = 9.63
Using a delta_phi0 = 0.0178571428571
New best streak model: L = 70.0, phi0=0.0535714285714
nu_max_i = 10.00
New best streak model: L = 70.0, phi0=0.0714285714286
nu_max_i = 10.23
Using a delta_phi0 = 0.015625
New best streak model: L = 80.0, phi0=0.0625
nu_max_i = 10.25
New best streak model: L = 80.0, phi0=0.078125
nu_max_i = 10.45
Using a delta_phi0 = 0.01388888888889
New best streak model: L = 90.0, phi0=0.06944444444444444
nu_max_i = 10.76
New best streak model: L = 90.0, phi0=0.08333333333333333
nu_max_i = 10.91
Using a delta_phi0 = 0.0125
New best streak model: L = 100.0, phi0=0.075
nu_max_i = 10.92
Using a delta_phi0 = 0.01136363636363636
Using a delta_phi0 = 0.010416666666666667
Using a delta_phi0 = 0.00961538461538
Using a delta_phi0 = 0.00892857142857
```



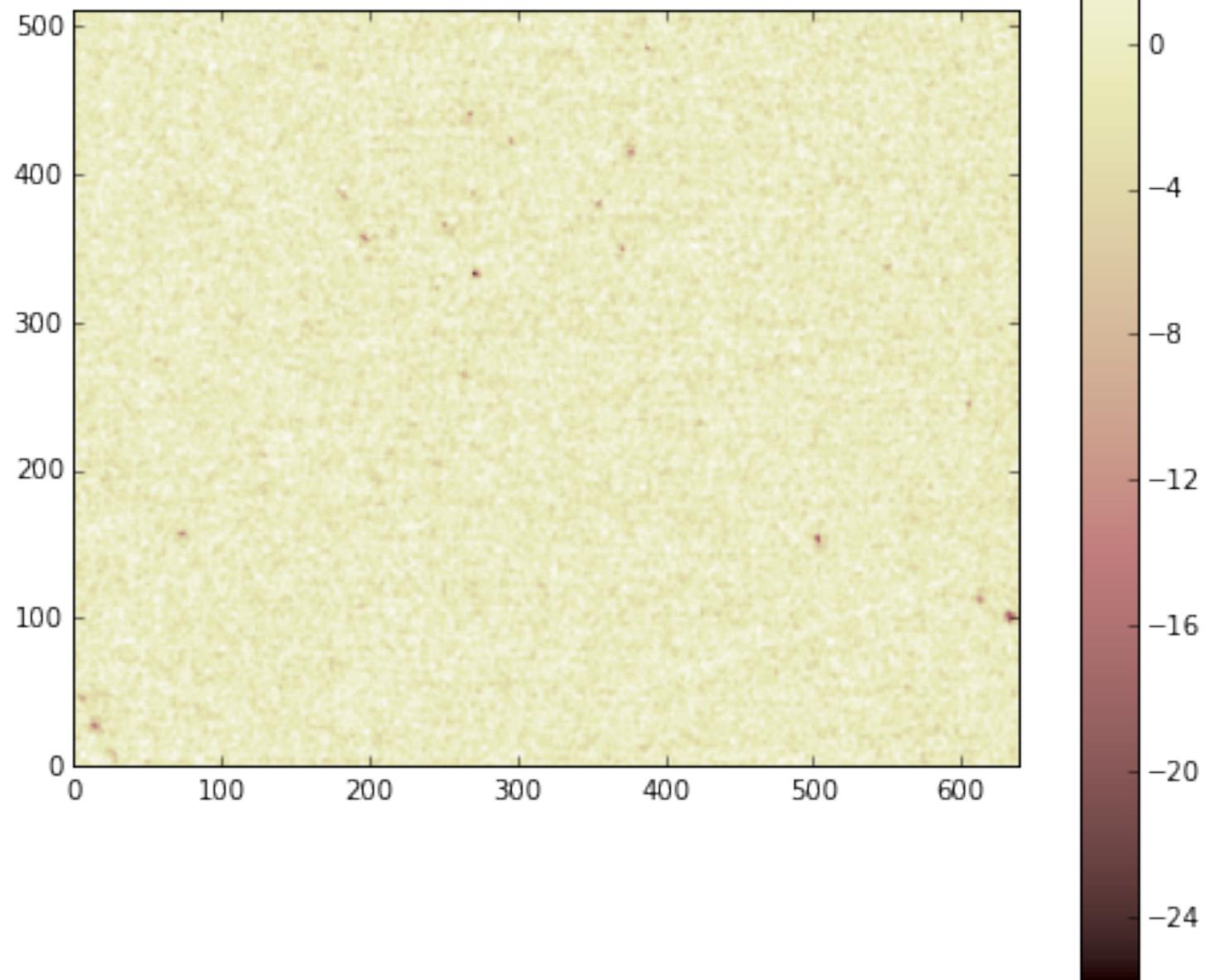
Faint Source Pipeline: Tests on Real Data

After worked on real data with faint streaks we ran it on an image with no apparent streak.

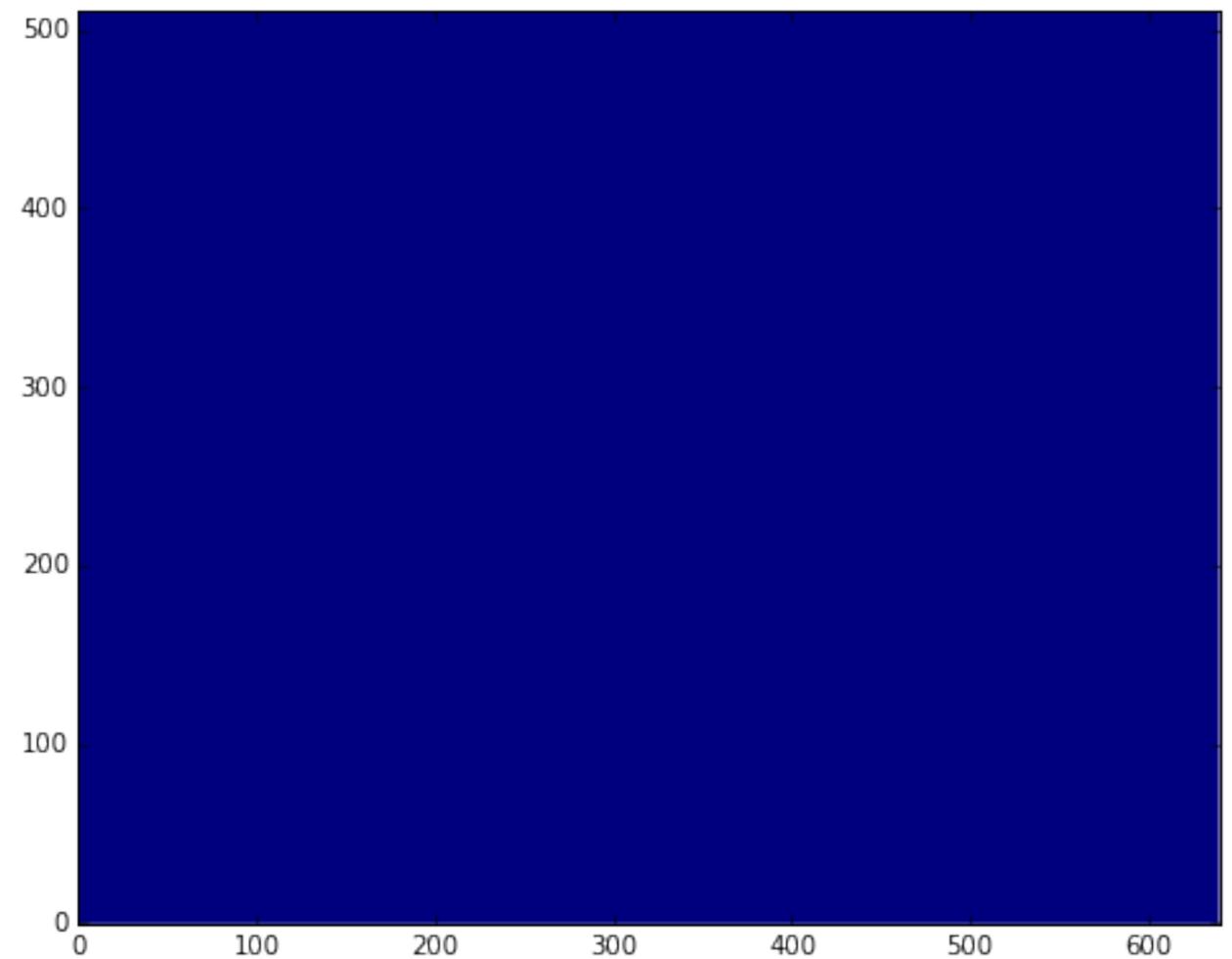


Nothing in the PSF convolved image.

\mathcal{V}_{PSF}



No “footprints” with SNR > 5



After running iterative maximum likelihood search...
found a very faint but significant streak!

\mathcal{V}_{PSF}

