Sensitivity of Blind Pulsar Searches with the Fermi-LAT

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Abstract

There have been two dozen gamma-ray pulsars discovered to date in blind frequency searches of Fermi-LAT photon data. While there is a general idea of the relative blind search sensitivity compared to gamma-ray pulsation searches using known radio ephemerides, the actual sensitivity has not been well established quantitatively. We detail a sensitivity study of the blind search code used to discover the new gamma-ray pulsars using a large scale simulation of gamma-ray pulsars and LAT source locations. We establish detection limits on signal flux, signal photons, and signal to background photons, and we establish an all-sky sensitivity map to pulsation searches.

Creating the population and LAT source locations

In order to test the sensitivity of the blind search, we create a population of simulated pulsars across a wide range of locations and rotational & spectral parameters for 1 year of photon data. We sample locations based on the ATNF pulsars[1], the rotational parameters in a uniform, logarithmic fashion from ($0.1 \le f \le 64$) Hz and ($10^{-15} \le f1 \le 10^{-10}$) Hz s^{-1}, and the spectral parameters in a similar fashion to those pulsars seen in the Fermi Pulsar Catalog[2]. Our fluxes range uniformly in log space from $10^{-9} \le F_{100} \le 10^{-6}$ ph cm^{-2} s^{-1}. *N.B. these parameters may not necessarily be physical, but are to simply test the limits of the blind search.*

To study a potential pulsar source, we need enough significant signal above a background to indicate a source detection. Since the blind search relies on source positions, this is a hindrance to detecting dim gamma-ray pulsars. We use the same seed detection and source localization methods as those in the Bright Source List[3]. Examples can be found in figure 1.

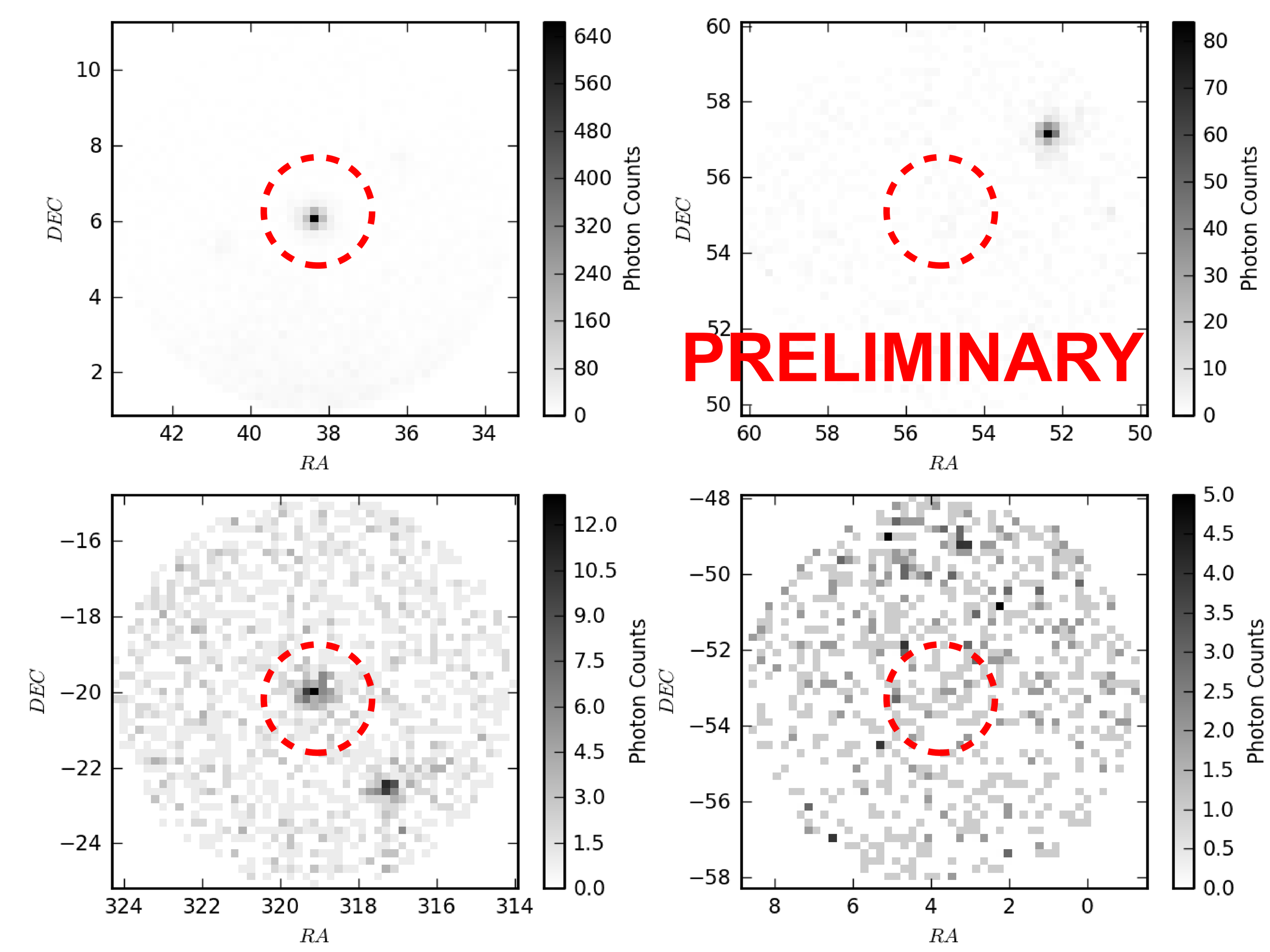

Figure 1: Counts maps for four different simulated pulsars, illustrating different examples of source localizations. The dashed red circles indicate positions of simulated pulsars. The upper left has good localization (r = 8") and a highly significant detection (TS=5000), the upper right has poor localization (r > 2˚) and a highly significant detection (TS>25), the lower left has good localization (r < 0.1˚) but low significance (TS<25), and the lower right has poor localization and low significance.

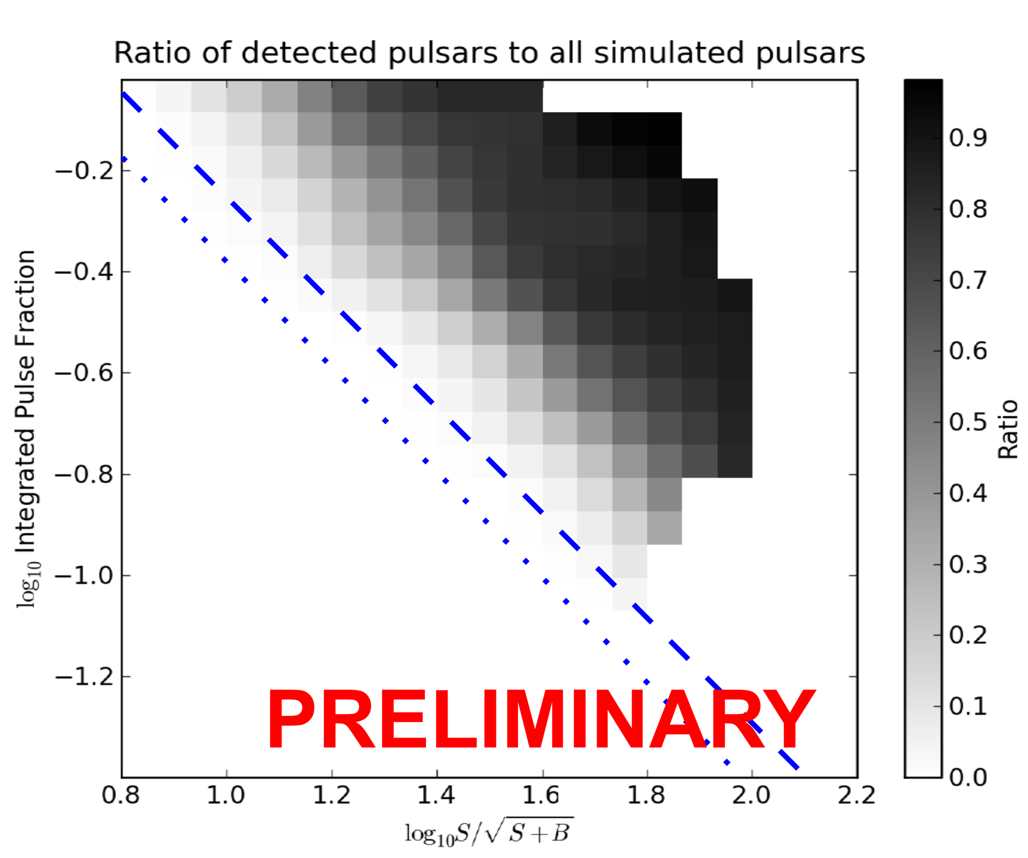

Figure 2: Integrated pulse fraction v. S/N ratio of detected pulsars to all pulsars. A pulsar with a large IPF is easier to detect in a blind search, and conversly a pulsar with IPF < 0.1 cannot be detected. The dashed line illustrates LAT threshold, and dotted line illustrates counterpart threshold.

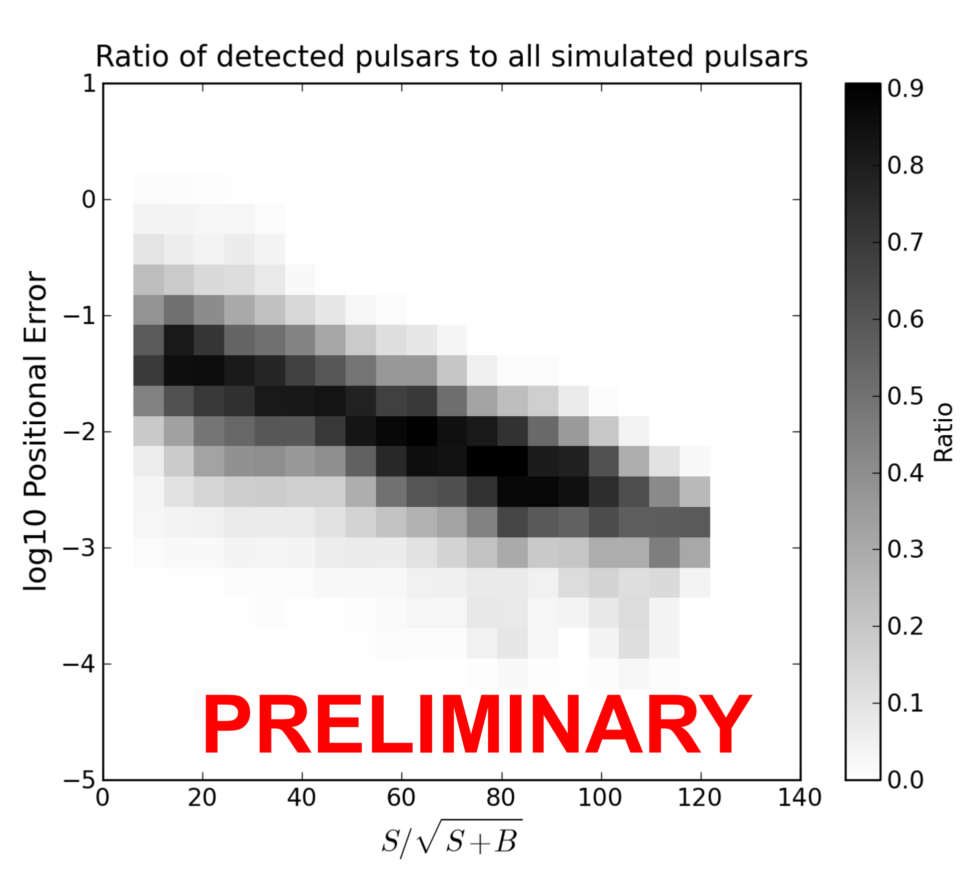

Figure 3: Positional error (in degrees) v. S/N ratio of detected pulsars to all pulsars. Image has been smoothed by a Gaussian kernel of 2 pixels.

Using multiwavelength counterpart locations

Dim pulsars may benefit in blind searches if we used counterpart locations from other wavelengths, for example X-rays. A typical X-ray source positional uncertainty is between 0.1" and 10", which is much smaller than the typical LAT error location of about ~ 0.1˚.

We repeated the same blind search analysis of the pulsars using a simulated X-ray position and found the sensitivity threshold to be lower. We compared the LAT location threshold with the counterpart location threshold (figure 4). For a source in the plane, the counterpart location is about 15% fainter than the LAT, and out of the plane it is nearly 20%.

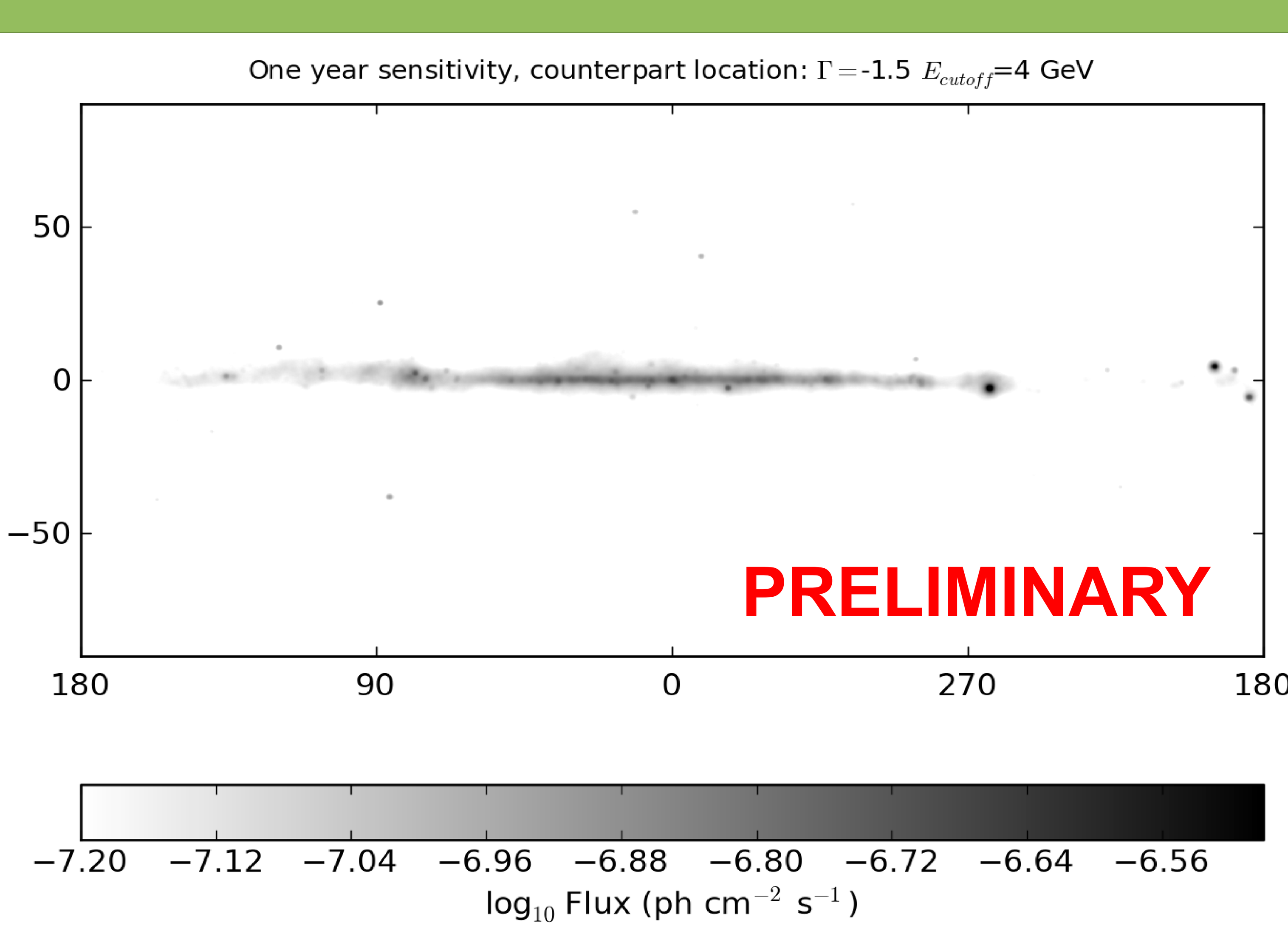

Figure 4: Detection threshold using counterpart locations, assuming a standard pulsar model. Using counterpart locations, we can improve our sensitivity in the plane (|b| < 5˚) by about 15%, and off the plane (|b| > 5˚) by about 20%.

Using the blind search limits:

We ran the blind search[4,5,6] on all simulated pulsars and looked for a detection. The ratio of detected pulsars to all pulsars is found in figures 2 and 3. This information can be used to determine a potential pulsar's blind search detectability in 1 year of LAT data, or to see if an unidentified source could possibly be detected as a pulsar. The prescription is as follows:

1. Assume a spectral model and pulse profile, typically Γ = -1.5, E_{cutoff} = 2 GeV, β = 1, F_{100} = 3 x 10^{-8} ph cm^{-2} s^{-1}, and two broad Lorentzian peaks. Also assume a spin frequency, important for measuring positional error.

2. Estimate number of diffuse class photons[7] within the region-of-interest (ROI) using an all-sky counts map. This is your signal + background.

3. Estimate number of photons within ROI using equation below:

$$n_{300} = 10^K F_{100} \frac{\int_{300\ \mathrm{MeV}}^{20\ \mathrm{GeV}} A(\sigma) E^{\Gamma} \exp\left[-\left(\frac{E}{E_{\mathrm{cutoff}}}\right)^{\beta}\right] dE}{\int_{100\ \mathrm{MeV}}^{20\ \mathrm{GeV}} E^{\Gamma} \exp\left[-\left(\frac{E}{E_{\mathrm{cutoff}}}\right)^{\beta}\right] dE}$$

Here K = 10.47 +/- 0.12. This is your signal.

3.5. A high frequency pulsar is sensitive to positional error, which spreads the Fourier power, affecting detectability. Assuming a frequency f the maximum positional error for detection is:

$$\epsilon \le \frac{1}{10^{-4} \frac{\pi}{180} (2 T_v \frac{f}{4})}$$

where ε is in degrees, $T_v = 2^{19}$ s, and *f* is spin frequency in Hz. If ε is greater than the error estimated from figure 3, we cannot detect it.

4. Integrating the pulse fraction (pulsed portion) and divide by integral of entire pulse profile by the background) and calculate S/N from steps 2 and 3. Now read probability from figure 2.

References

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