

# Finding new MSP candidate **sources** in the gamma-ray sky

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for the Fermi-LAT collaboration

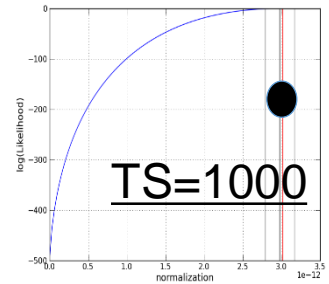
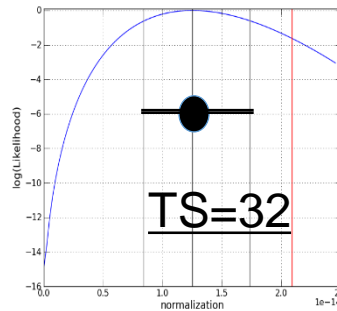
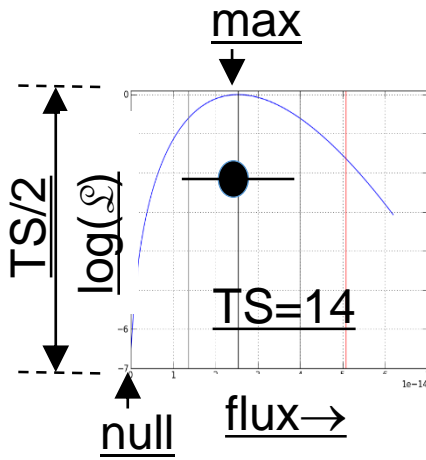
Aspen Winter Conference:

Millisecond Pulsars

20 Jan 2013

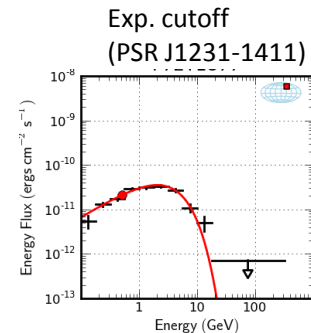
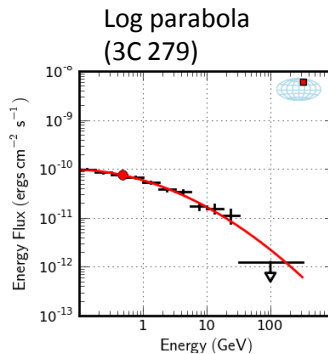
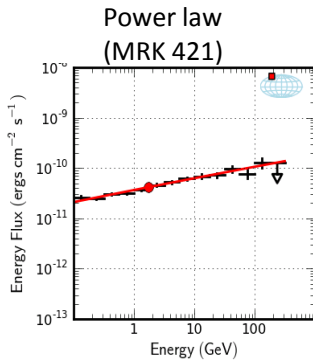
# Weak sources

- Weak gamma-ray sources can be strong in the radio – see Elizabeth’s preceding talk
- Fermi-LAT catalog policy is to require “5-sigma” (TS>25) significance: all the sources she talked about satisfy that.
- What is TS? the *Test Statistic*,  $-2 \ln(L(\text{source})/L(\text{no source}))$



# Going below $TS=25$

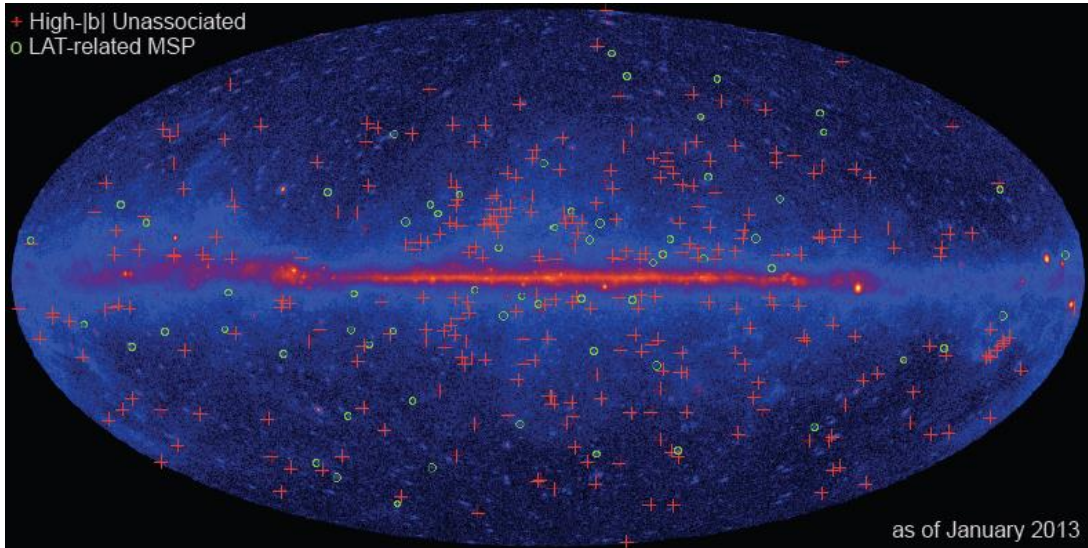
- Consider consequences of relaxing the requirement
- We have not specifically *looked* for weak pulsar-like sources
  - We always assume a power-law unless an already-significant source is better fit with a log parabola; only use exponential cutoff when pulsation is seen



# Cons: reduced purity

- Low significance: higher spurious probability.
  - But a few percent would not matter
- Light curve less likely to discriminate against AGN
  - Weakness means only a few time periods
- Larger error circle
  - Problem if exceeds radio FOV

# Want to add even more unassociated!



From Elizabeth's talk

Note concentrations of sources, correlated with Galactic structure: not all real

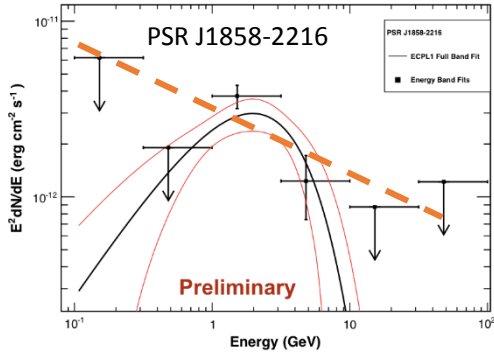
But high-lat MSPs should be lonely

# How do we detect sources?

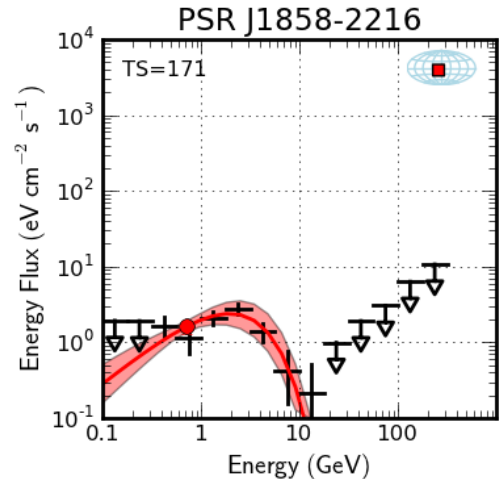
- Many ways, but the most efficient uses likelihood!
  - Why likelihood?
    - Cramer-Rao lower bound: it provides the best estimate of parameters
    - Any candidate must have successful fit anyway
  - CPU intensive
- Assume a spectral shape
  - we have assumed a power-law pattern: does it lose sensitivity for pulsars?

# Spectral shapes and our sensitivity

From Elizabeth's talk



index: 0.8, cutoff: 1.7 GeV  
(large, correlated errors)

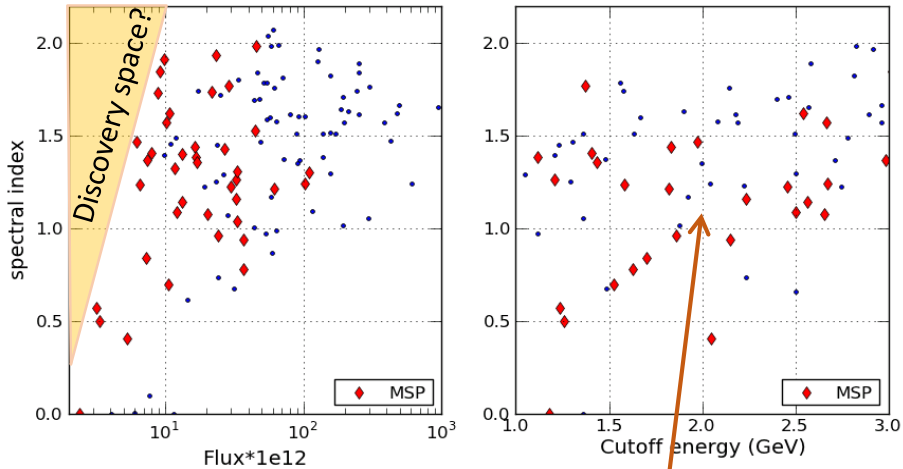


Low energy: background limited  
High energy: counts limited  
Can one tell that it is not a power law?

A different analysis  
with 4 years

# Decide on a template pattern

From the Fermi-LAT list of pulsars

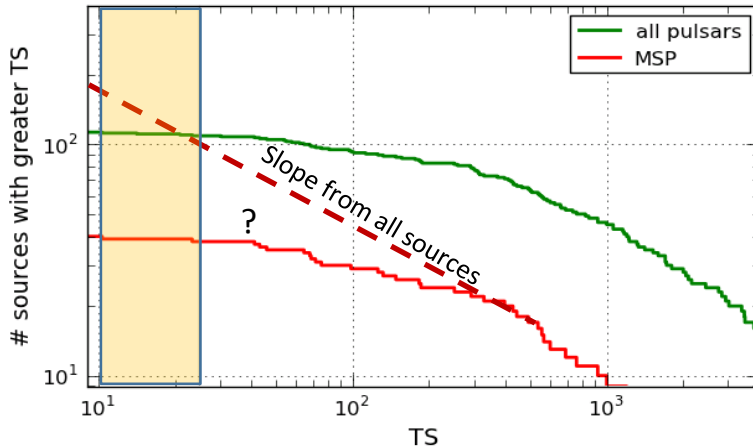


Choose 1.2, 2 GeV



# Characterize population with logN-logS...

...but use TS



From the '2PC'  
upcoming catalog

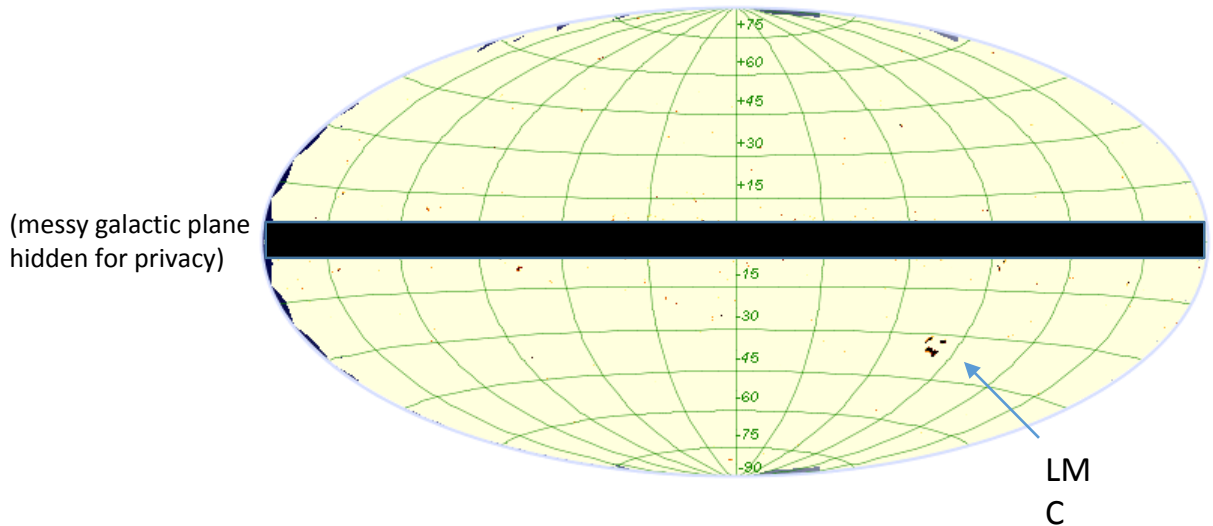
Slope derivable from populations.  
Potential for many more!

# Test on data (preliminary)

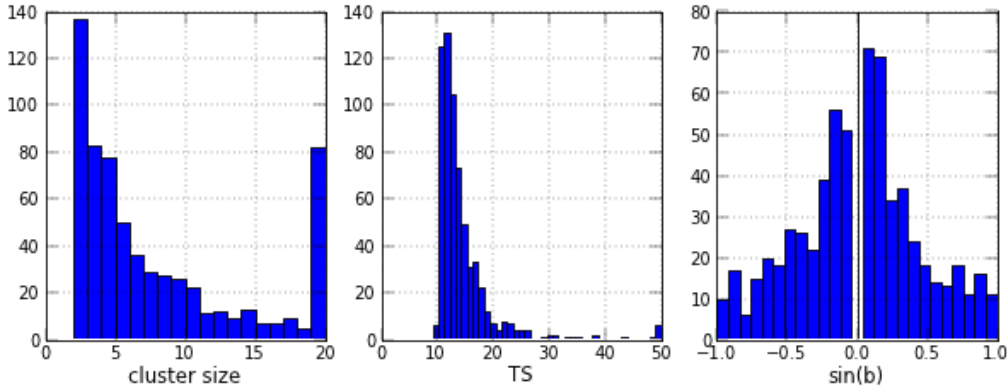
- Using the 4-year ‘reprocessed’ dataset, soon to be released
- Current ‘model’ representing the sky:
  - Interstellar diffuse
  - Isotropic diffuse (contains proton-induced background)
  - Limb background
  - Sun and Moon
  - 22 extended sources: LMC...
  - ~3500 point sources
    - But many of these are not in 2FGL, so not in the group that Elizabeth talked about
- Try to extend by looking for ‘residuals’ with pulsar-like spectra: can the fit be improved by adding pulsars?

# Step 1:

- Add a 'seed' source to each of 3.2 M positions in sky (0.15 degree separation)
- Refit, with fixed spectral parameters, record resulting TS. (Unfeasible with released Science Tools.)
- Result: pixels >10

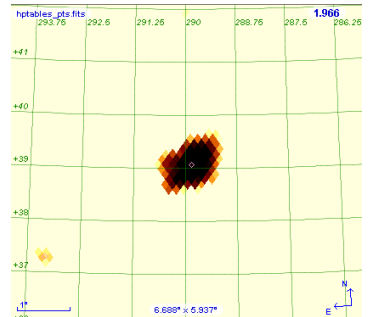


# Step 2: Analyze that map for clusters of pixels



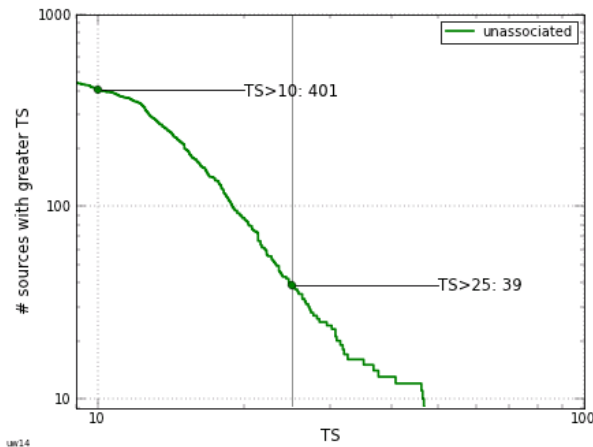
Require cluster to have  $>1$  pixels above  $TS=10$  threshold  
Require  $|b| > 5$  degrees (avoid that mess)  
Make list of seeds, position at weighted average position  
-> 644 total

## Two examples



# Step 3: add seed sources back to model

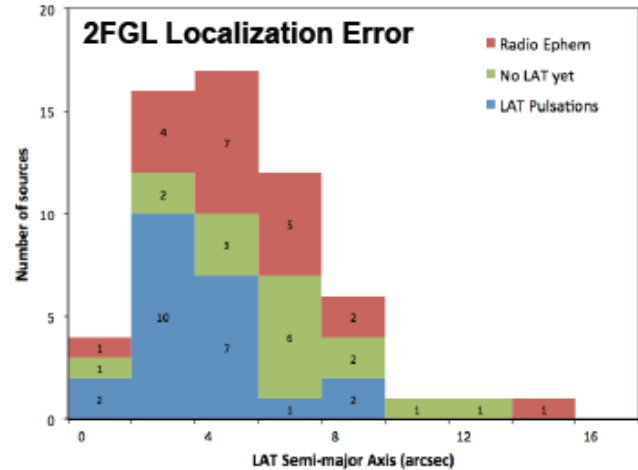
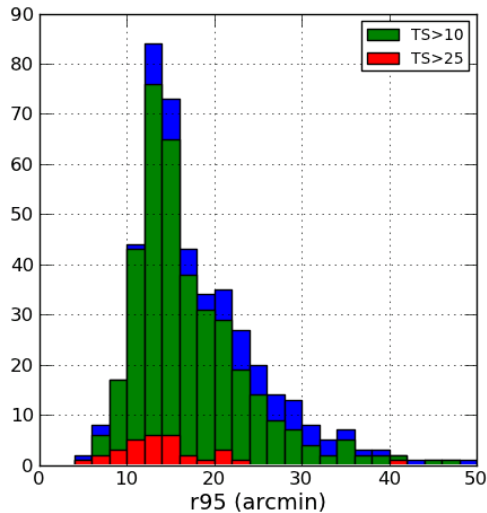
- Refit: adjust all spectral parameters
- Localize: adjust position to maximize likelihood
- Associate: check catalogs for possible match
  - One match to a MSP! [J1732-5049](#).
  - Exclude it, 60 blazar matches



# Localization: weak means larger error box

Possible problem for radio telescopes.

From Elizabeth's talk



# Summary

- Likelihood-based approach to source detection adapted to match pulsars, applied to 4-year data set
- Preliminary analysis finds 400 well-fit, unassociated candidates after standard source-finding for 4-year set.
- Plans:
  - Subdivide time region into months, years for light curves
  - Careful study of efficiency, purity
  - Understand expectation from population models