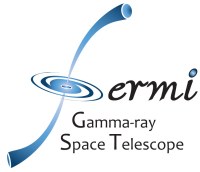


# Analysis of the Spatial Extent of Sources in the Fermi-LAT 1 Year Catalog



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on behalf of the Fermi Large Area Telescope Collaboration



A large number of candidate Fermi-LAT source classes are expected to show spatially extended emission. The significance of extension was tested for all of the sources in the Fermi-LAT 1 year catalog and several significantly extended sources were found.

## Abstract

Several candidate source classes for the Fermi-LAT, including SNRs, Molecular clouds, PWN, Galaxy clusters, and Dark Matter satellites, are expected to have resolvable angular extents. For both the identification of these sources as well as for the interpretation of observations of these source classes, information on the angular extents of the emission regions are of tremendous value. The significance of extension was calculated for all of the sources in the Fermi-LAT 1-year catalog that is now in development. Each of the significantly extended sources was fit as an azimuthally symmetric Gaussian and the extension of each source was estimated.



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## Method

The Fermi Large Area Telescope (LAT) is a pair-conversion gamma-ray telescope operating in the energy range 20 MeV to >300 GeV. A method was developed to search for signs of spatially extended emission from LAT sources. The method, named Sourcelike, works by convolving the intrinsic LAT PSF with a spatial model of the candidate source to create a "pseudo-PSF" of the expected source appearance. The source centroid and angular extent are then varied to find the shape that most closely matches the spatial distribution of observed photons. Centroid and source extension are fit simultaneously.

The foremost challenge of measuring angular extents with the LAT is to properly account for a PSF that ranges a full 2 orders of magnitude in size over the energy range of the instrument and has a long non-Gaussian tail. Source photons also must be fit above a diffuse celestial background. In order to address these complications, Sourcelike groups photons into separate energy bands. Photons in each energy band are spatially binned with a size that scales with the PSF. The model is fit to the data using a binned likelihood analysis.

The gamma-ray sky contains both structured and isotropic diffuse backgrounds. When fitting a candidate source, the absolute normalizations of both the source and the background components are allowed to float until the PSF-convolved spatial model of the region best fits the observation.

## Extension Significance

The significance of the detection of a source's extension can be calculated using a likelihood ratio test

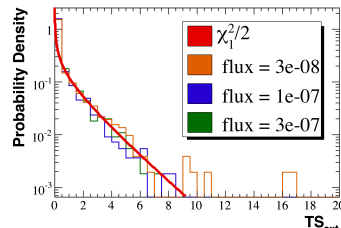
- $TS_{\text{ext}}$  is defined as twice the log(likelihood) difference between fitting with an assumed 2-dimensional Gaussian spatial extent and a point source
- Following from Wilks' Theorem,  $TS_{\text{ext}}$  when fitting the null hypothesis, a point source, is expected to be asymptotically distributed as  $\chi^2$  with one degree of freedom
- Half of the statistical fluctuations of a point source (the null hypothesis) would be unphysical and lead to no increase in likelihood when fitting with the extended hypothesis
- So the expected distribution of  $TS_{\text{ext}}$  for point sources is
 
$$P(TS_{\text{ext}}) = \frac{1}{2}(\delta(TS_{\text{ext}}) + \chi_1^2(TS_{\text{ext}}))$$
- It follows that  $\sqrt{TS_{\text{ext}}}$  is the  $\sigma$  of detection of angular extent

## Monte Carlo

This theoretically expected distribution was tested using a Monte Carlo simulation

- Our results were consistent with the theoretical distribution over much of parameter space

### $TS_{\text{ext}}$ in Null Hypothesis



The distribution of  $TS_{\text{ext}}$  fitting Monte Carlo power law point sources with a spectral index of two in the Galactic plane.

## Catalog of Extended Source

The Method was applied to all sources in the preliminary year-1 catalog

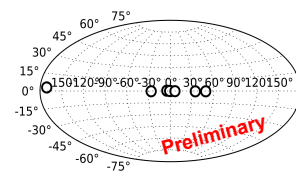
- All sources were fit using a point source and an extended source hypothesis
- The recommended Galactic and isotropic model were used to model the diffuse background
- The standard instrument response function was used
- A 105° zenith angle cut was used to avoid secondary gamma-rays from the Earth
- All catalog sources within 11° of each analyzed source were included in the background model

## Extended Sources

Nine sources were found to be significantly extended.

- The threshold for detection was  $TS_{\text{ext}} > 100$  ( $10\sigma$ )
- Detected sources include **W44**, **W51C**, and **IC443**
- The LMC showed signs of extension, but did not meet the  $10\sigma$  significance required by our strict threshold
- 3 had extensions less than 10', 3 had extensions between 10' and 20', and 3 had extensions between 20' and 30'
- TS maps (TS as a function of position in the sky) in the point source hypothesis of the sources were examined to look for possible source confusion
- Residual TS maps were created including in the background model all known background sources as well as the source being analyzed
- Sources whose residual contained unmodeled features were excluded
- Our nine sources passed all these criteria

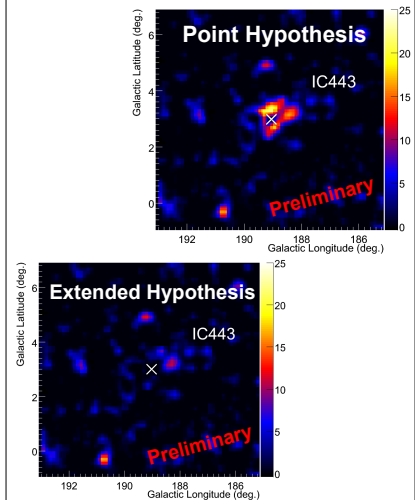
## Skymap



The positions of the 9 significantly extended sources

- Plotted in Galactic coordinates
- All extended sources were found in the Galactic plane

## IC443 Residual TS Maps



Residual TS maps of IC443 fitting with a point and an extended hypothesis

- There is substantial residual when fitting with the point hypothesis
- This residual is removed by fitting with the extended hypothesis

## Acknowledgments

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