Analysis of Spatially Extended Sources with the Fermi-LAT

Joshua Lande (SLAC/KIPAC/Stanford) on behalf of the Fermi LAT Collaboration
With Keith Bechtol, Markus Ackermann, and Stefan Funk

Abstract
A large number of candidate Fermi-LAT source classes, including SNRs, Molecular clouds, PWN, Galaxy clusters, and Dark Matter satellites are expected to have angular extents comparable to or smaller than the characteristic per-photon size of the point-spread function. For the detection and identification of these sources as well as for the interpretation of the corresponding source classes, information on the angular extents of the emission regions is of tremendous value. We present an analysis technique developed to address the finite angular sizes of the sources in analysis of LAT data and take the extension into account in spectral and morphological studies. We then describe a series of Monte Carlo simulations analyzed using this technique that demonstrate the LAT’s ability to measure the extensions and spectral characteristics of gamma-ray sources.

Method

The Fermi Large Area Telescope (LAT) is a pair-conversion telescope operating in the energy range 20 MeV to >100 GeV. The LAT has 3 detector subsystems: an anticoincidence detector to identify charged particles entering the instrument, a tracker composed of sixteen tungsten conversion layers interleaved with silicon detector strips, and a calorimeter made up of calorimetric crystals to measure particle energy.

Photon direction is primarily reconstructed by following the trajectory of electromagnetic (e.m.) pairs back to the photon interaction vertex. Detector geometry and physical processes such as multiple scattering determine the intrinsic PSF of the instrument.

The extension fitting method, named Sourcelike, works by convolving the intrinsic LAT PSF with a spatial model of the candidate source to create a pseudo-PSF at the expected source position. Parameters of the spatial extension model 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 over 2 orders of magnitude in size over the energy range of the instrument (See Figure 1) and has a long non-Gaussian tail. Photons must also be fit above a diffuse photon flux.

Background components
The gamma-ray sky is filled by both structured and isotropic diffuse backgrounds. When fitting a candidate source, the absolute normalizations of both the source and background components are allowed to float until the PSF-convolved spatial model of the region mirrors the observation. The fraction of observed photons associated with the source can then be found directly from the relative normalizations of source and background in the best fit. The source signal fraction is computed independently in each energy band without the constraint of spectral models for source or background components.

Spectral analysis
Spectral analysis is a separate likelihood calculation following the localization and extension fitting step. Spectral fitting is independent of the particular spatial model because the flux in each energy bin can be calculated directly from the signal fraction in each energy bin. Therefore, the spectral fitting method can be applied to both point-like and extended gamma-ray sources. Spectral fitting proceeds using a similar binned likelihood maximization technique comparing the estimated number of observed source photons to the model predicted flux.

A large set of simulations involving extended observations of standard sources were simulated using Glotonsim in the LAT Science Tools. The simulation was of 1 year of data using a simulated survey mode pointing history. The diffuse galactic emission was simulated using the GALPROP code with a GALPROP model in 54.389984. The GALPROP model is described in [2] but an updated conventional model described in [3] was used.

The extragalactic diffuse emission was simulated as an isotropic power-law. Sources were simulated at a low galactic latitude (l=30°, b=2°) and a high galactic latitude (l=25°, b=85°). They were simulated with power-law spectra having photon spectral indices (Y) of 1.5, 2, and 3 and with >100 MeV fluxes of 3*10^{-9} ph cm^{-2} s^{-1} and 10^{-8} ph cm^{-2} s^{-1}. They were then simulated with Gaussian extensions with 50° confinement radii of 0.1°, 0.25°, 0.5°, and 1.9°.

Each source was analyzed using the Sourcelike code with both a point and an extended source hypothesis. For the measurement of angular extent, photons with energy between 200 MeV and 200 GeV were used. Photons below 200 MeV were excluded because of their large PSF. Spectral fitting of the source was performed using a power-law hypothesis and photons with energy between 200 MeV and 200 GeV. The initial guess for the source position was picked randomly within a Dec of ±0.1° and a RA of ±0.1°/cos(Dec).

Conclusion
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References
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