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Galactic Sources in Gamma-Ray Diffuse Emission

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Introduction

High-energy gamma rays detected by the decade-old Fermi Large Area Telescope are divided into two groups:

1. **Point sources**: individual pinpoints of light, either of galactic origin (pulsars, supernova remnants) or extragalactic origin (quasars, blazars)
2. **Diffuse emission**: spread-out distribution of light, mainly from interactions between cosmic rays and matter

Excess diffuse emission may actually be point sources too far, too dim, or too close together to make out. This project aims to estimate the contribution to the diffuse emission from sources below this sensitivity threshold, and to describe source properties.

Figure 1 – Gamma-ray Sky

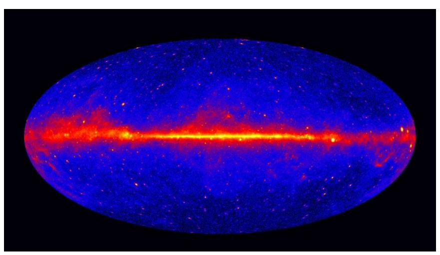


Image from LAT. We detect many more gamma-rays from the bright red line, the galactic plane, than from high latitudes above or below the disk.

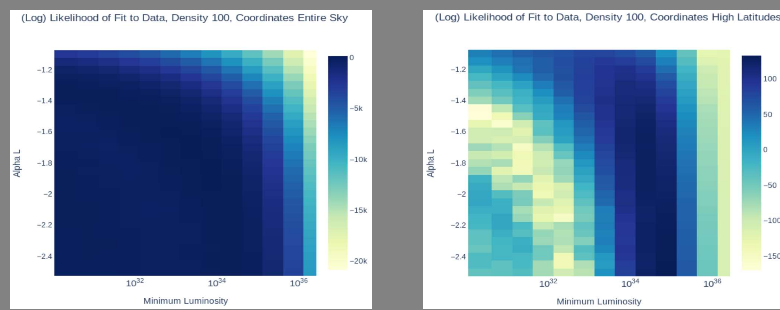
Methods

Predicting the number of pulsars below the sensitivity threshold requires a model for pulsar counts. A population synthesis study to determine this model depends on a two functions:

1. Density function: describes spatial source distribution; scaled with **density**
2. Luminosity function: describes brightness source distribution; shape determined by **index of luminosity**; bounded by **minimum** and **maximum luminosity**

In this project, I first explored these parameters, then scanned for the best-fit parameters, then predicted the number of low-flux pulsars below the sensitivity threshold.

Figure 2 – Log-likelihood by Sky Area



Results of a parameter scan for different values of minimum and index of luminosity, for density 100 pulsars/kpc^3. Darker colors indicate greater likelihood. Analysis of high latitudes, right, provides more precise values than analysis of the whole sky, left.

Results

Best-fit: Maximum Luminosity
Initial exploration: above approx. 2x10^39 photons/s, max. luminosity ceases to affect the model; below, fit worsens.
Max. Luminosity: 2 x 10^39 photons/s

Best-fit: Density
Rough scans over multiple densities showed that increasing density correlated with decreasing minimum luminosity and index of luminosity. Though difference was slight, the best fit occurred as shown in Table 1.
Density: 100 pulsars/kpc^3

Best-fit: Min, Index of Luminosity
Scan at best-fit density: Detailed scans at density 100 pulsars/kpc^3 found values that had a log-likelihood of 170.
Min. Luminosity: 2 x 10^33 photon/s
Index of Luminosity: -1.7

By Sky Area
Sparsity of light in upper latitudes allows LAT to potentially identify dimmer sources there. Figure 2 demonstrates the narrower restrictions on parameters by the high latitudes.
Min. Luminosity: between 2 x 10^34 and 6 x 10^34 photons/s

By Data Set
In addition to comparing models to a dataset of associated pulsars, we also compared them to a extreme case dataset that assumed all unassociated sources were pulsars (see Figure 3). The best fit case obtained a log-likelihood of 4,140.
Min. Luminosity: 2 x 10^34 photon/s
Index of Luminosity: -1.85

Table 1- Best Fit Density Values

Density (pulsars/kpc^3)	Min. Luminosity (photons/s)	Index of Luminosity	Log-likelihood
4	1 x 10^36	-2.4	6
10	1 x 10^35	-1.8	66
20	1 x 10^34	-1.6	129
50	1 x 10^34	-1.8	152
100	1 x 10^33	-1.6	154
200	1 x 10^33	-1.8	141

Best-fit minimum and index of luminosity for six densities tested. Note that the best-fit values occurred at density 100 pulsars/kpc^3.

Conclusion

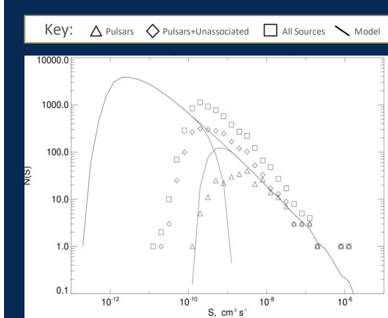
In addition to the best fit parameters shown in Results, and predictions of the number of pulsars below the sensitivity threshold, one example of which is Figure 3, we have a few other takeaways with areas for future research:

Small differences in log-likelihood indicate that scans of the whole sky may only imprecisely determine parameters and low-flux pulsars.

Improved distinction of log-likelihood in the high-latitude sky area suggests that dividing up the sky further may improve model precision.

Drastically higher log-likelihood for extreme case dataset encourages work to determine which unassociated sources are likely actually pulsars.

Figure 3 – Pulsar Counts v. Flux, Pulsars and Unassociated Datasets



The total line indicates the prediction of number of pulsars at each flux with minimum luminosity 2 x 10^34 photon/s and index of luminosity -1.85. The line matches the Pulsars + Unassociated diamonds well, above the sensitivity threshold, which occurs at about 5 x 10^-10 cm^-2/s.

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