

OBSERVATIONS OF PWNE WITH THE FERMI GAMMA-RAY
SPACE TELESCOPE

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I certify that I have read this dissertation and that, in my opinion, it is fully adequate in scope and quality as a dissertation for the degree of Doctor of Philosophy.

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Abstract

Two things fill the mind with ever-increasing wonder and awe, the more often and the more intensely the mind of thought is drawn to them: the starry heavens above me and the moral law within me.” – Immanuel Kant

The launch of the *Fermi* Gamma-ray space telescope in 2008 offered an unprecedented view into the γ -ray sky.

All the things we can learn with the LAT

Development of a new analysis method for studying spatially-extended PWNe using `pointlike`.

A monte-carlo validation of the analysis method.

Search for new spatially-extended sources with the LAT.

Observations of PWNe in the off-peak region of LAT detected pulsars.

Search for PWNe counterparts to TeV sources.

Using the population of PWNe to understand the radiation mechanism of PWNe.

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1.1.2 H.E.S.S.

1.2 Galactic Gamma-ray Astrophysics

1.2.1 Pulsars

1.2.2 Pulsar Wind Nebulae

1.2.3 Supernova Remnants

1.3 Radiation Processes

- The non-thermal radiation processes typical in astrophysics are most commonly

1.3.1 Synchrotron

1.3.2 Inverse Compton

1.3.3 Bremsstrahlung

1.3.4 Pi^0 Decay

1.4 Modeling the Galactic Diffuse and Isotropic Gamma-ray Background

- Historical Observations of galactic diffuse emission
- GALPROP model of diffuse emission. Reference: <http://arxiv.org/abs/1202.4039>
- Empirical Ring model of galactic diffuse emission.
- The isotropic background: <http://arxiv.org/abs/1002.3603>
- Galactic diffuse emission is primarily composed of ...
- Something about how great galprop is.
- Something about

1.5 Sources Detected by the Fermi LAT

- A variety of sources detected by the LAT:

1.5.1 The Second Fermi-LAT Source Catalog

- Citation is Nolan et al. (2012)
- Source classification method

- Number of sources detected by the LAT
- Forward reference Chapter 2, which does a more thorough description of likelihood analysis method.
- Source classes/associations

1.5.2 The Second Fermi Pulsar Catalog

- Process of detecting Pulsars with the LAT
- Number of pulsars detected by the LAT

1.5.3 PWN Detected by the LAT

Crab

Vela X

MSH 15-52

1.5.4 HESS J1825

HESS J1857

2FGL J1857 + 026

1. Reference is Rousseau et al. (2012)
2. <http://arxiv.org/pdf/1206.3324v1.pdf>

Chapter 2

Maximum-likelihood analysis of LAT data

- The notation and terminology follows the convention in

2.1 Motivations for Maximum-Likelihood Analysis of Gamma-ray Data

- Traditional astrophysical analysis involves an on minus of background estimation.
- Analysis of LAT data more complicated due to:
 - Anisotropic background. See Section 1.4.
 - Energy-dependent PSF
 - High source density, especially in the Galactic plane.
- To avoid issues associated with this, we perform a maximum likelihood analysis
- Define a model of the sky.
- likelihood L is defined as $L = P(data|model)$, where $L = L(model\ parameters)$.

- Benefits: XXX

2.2 Defining a Model of the Sources in the Sky

- Sky model must predict the emission
- Issues with maximum

Each source can be characterized by its photon flux density (number of photons emitted per unit energy, time, into a unit solid angle $d\Omega$) at a given energy, time, and position $\vec{\Omega}$ in the sky:

$$\mathcal{F}(E, t, \vec{\Omega}) \tag{2.1}$$

2.3 The LAT Instrument Response Functions

- The instrument response of the LAT can be factored
- The exposure
-

2.4 Application of Binned Maximum-Likelihood to LAT Data with the Science Tools

- In the standard science tools, the data is binned in position and energy. The counts in each bin are
- In the standard science tools,
 - the binning is done with `gtbin`.
 - The instrument response is computed with a combination of `gtltcube`, `gtexpcube`
 - The integral over

- Bin the LAT data
- Convert a model of the sky into model predicted counts
- poisson likelihood
- Particular implementation of maximum likelihood analysis
- Describe `gtbin`, `gtselect`, `gtlike`

2.5 The Alternate Maximum-Likelihood Package `pointlike`

- Developed for Speed
- Sparse Matrices,

2.6 Extended Source Analysis in `pointlike`

Chapter 3

Search for Spatially-extended Sources

3.1 Analysis Method

3.2 Validation of the TS Distribution

3.3 Extended Source Detection Threshold

3.4 Testing Against Source Confusion

3.5 Test of 2LAC Sources

3.6 Systematic Errors on Extension

3.7 Extended Source Search Method

3.8 New Extended Sources

3.9 Discussion

Chapter 4

Search for PWNe associated with Gamma-loud Pulsars

Chapter 5

Search for PWNe associated with TeV Pulsars

5.1 List of Candidates

5.2 Analysis Method

5.3 Sources Detected

Chapter 6

Search for PWNe associated with High Edot Pulsars

Chapter 7

Population Study of LAT-detected PWNe

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