OBSERVATIONS OF PWNE WITH THE FERMI GAMMA-RAY SPACE TELESCOPE

A DISSERTATION
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DOCTOR OF PHILOSOPHY

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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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Approved for the University Committee on Graduate Studies

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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- GALPROP model of diffuse emission. Reference: `http://arxiv.org/abs/1202.4039`
- Emperical Ring model of galactic diffuse emisson.
- 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 convetion in

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

- Traditonal astrophysical analysis involves an on minus of background estimation.
- Analysis of LAT data more complciated due to:
  - Anisotrpic background. See Section 1.4.
  - Energy-dependent PSF
  - High source density, espeically in the Galactic plane.
- To avoid issues assocaited with this, we perform a maximum likelihood analysis
- Define a model of the sky.
- likelihood L is defiend as $L = P(data|model)$, where $L = L(modelparameters)$.

- Benefits: XXX

2.2 Defining a Model of the Sources in the Sky

- Sky model must predict the emisson
- 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
- Define the response matrix
- Decompose it into expsoure x PSF x energy dispersion x temporal dispersion.
-

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

- For a standard LAT analysis, we perform a binned maximum-likelihood analysis:
- In the standard science tools, the data is binned in position and energy. and integrated in energy.
- For time-serires analysis, typically a time-summed analysyis is performed successivly in multiple time bins.

- The likelihood comes from a sum over each bin
- The likelihood is defined as

$$\mathcal{L} = \prod_j \frac{\theta_j^{n_j} e^{-\theta_j}}{n_j!} \tag{2.2}$$

  - Here, j is a sum over position/energy bins.
  - θ_j is the counts predicted by the model, which is defiend followign the discussion in Section 2.2.
  - n_j are the observed counts in the spatial/energy bin j
- In the standard *Fermi* science tools, the binning of photons over position in the sky and energy to compute n_j is done with `gtbin`.
- In the standard *Fermi* science tools, the model counts θ_j are computed in several steps ...
- The instrument response is computed with a combination of `gtltcube`, `gtexpcube`.
- Convert a model of the sky into model predicted counts
- poisson likelihood
- Particular implemenation of maximum likelihood anlaysis
- Describe `gtbin`, `gtselect`, `gtlike`

2.5 The Alternate Maximum-Likelihood Pacakge `pointlike`

- Developed for Speed
- Sparce Matricies,

2.6 Extended Source Analysis in `pointlike`

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Chapter 6

Search for PWNe associated with High Edot Pulsars

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Bibliography

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