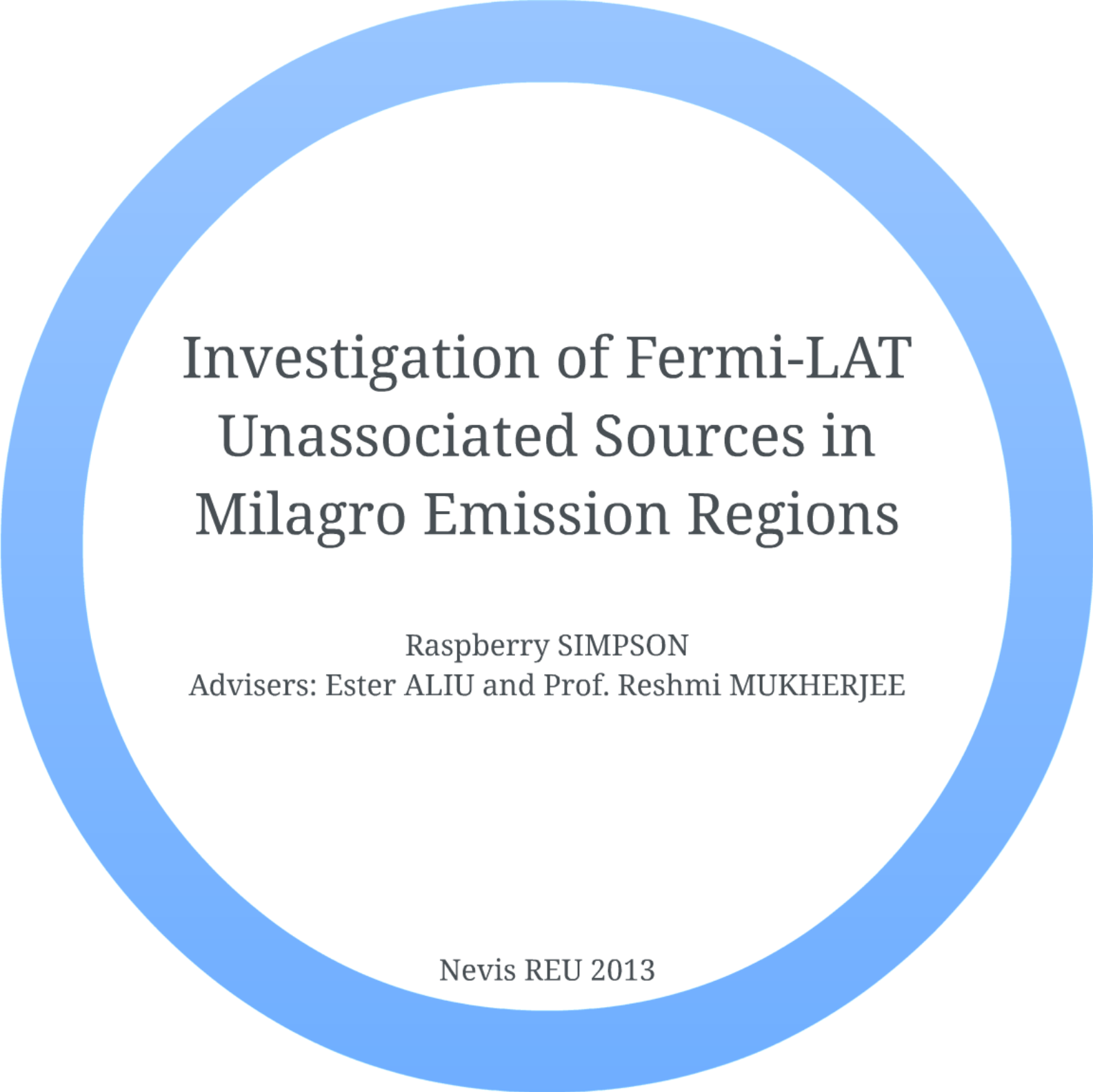




Investigation of Fermi-LAT Unassociated Sources in Milagro Emission Regions

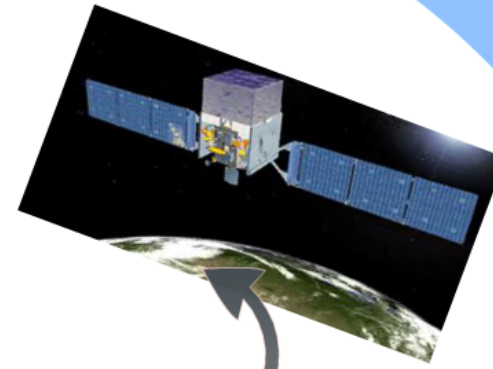
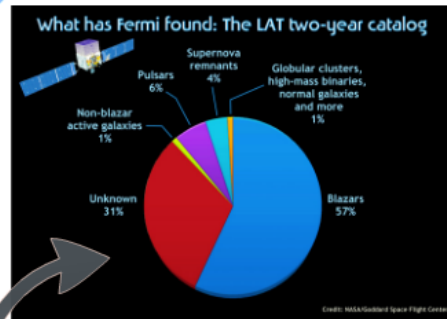
Raspberry SIMPSON

Advisers: Ester ALIU and Prof. Reshmi MUKHERJEE

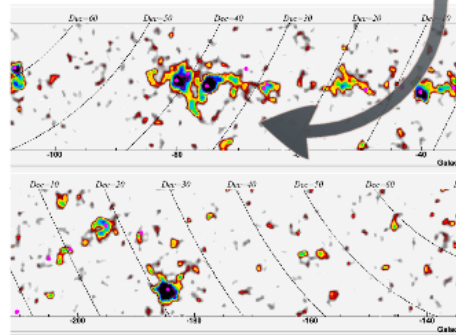
Nevis REU 2013

Outline

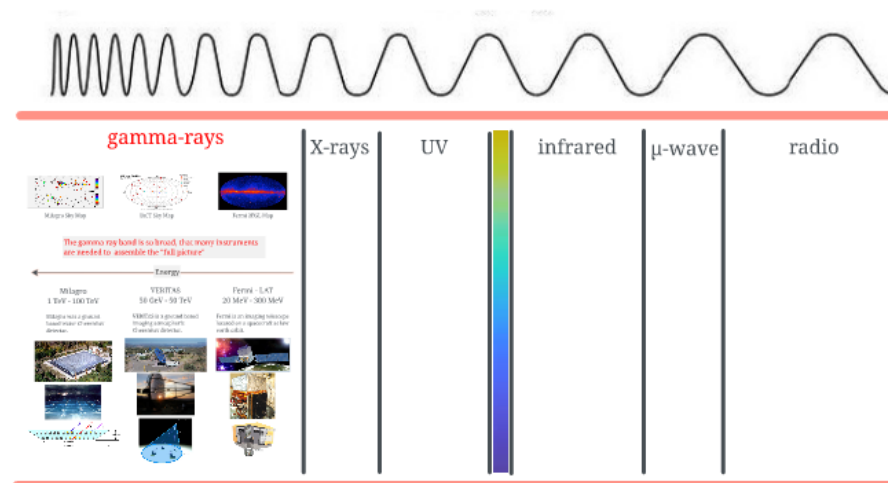
- Project Summary and Goals
- Project Context - Gamma Ray Experimentation
- Research Methods and Analysis
- Conclusions and Future Work

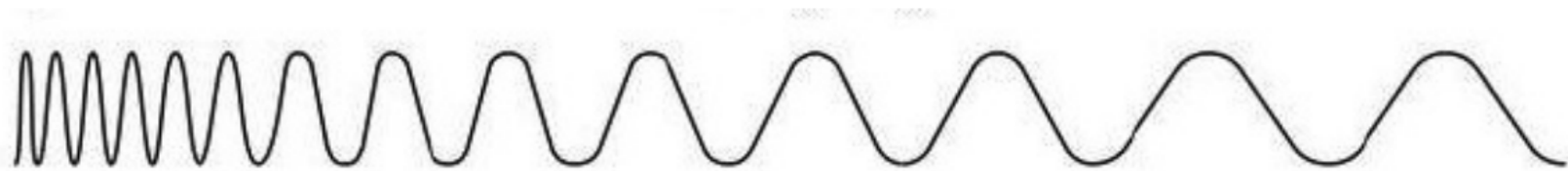


Investigation of Fermi-LAT Unassociated Sources in Milagro Emission Regions



Project Context





gamma-rays

X-rays

UV

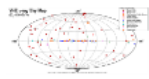
infrared

μ -wave

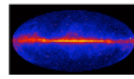
radio



Milagro Sky Map

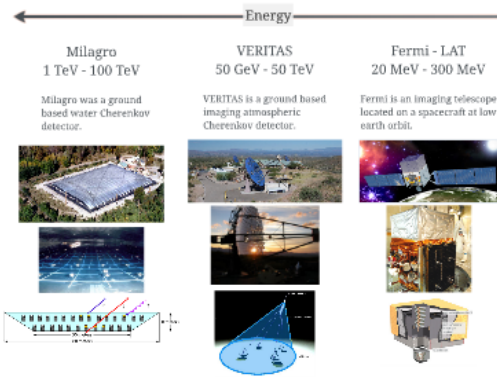


IACT Sky Map

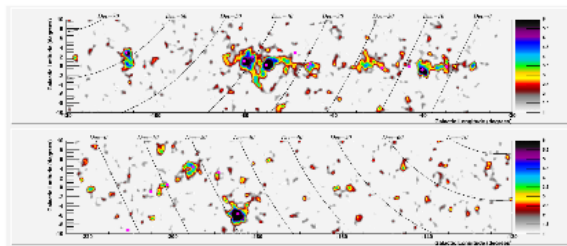


Fermi 2FGL Map

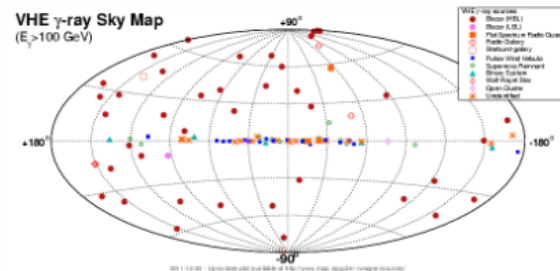
The gamma ray band is so broad, that many instruments are needed to assemble the "full picture"



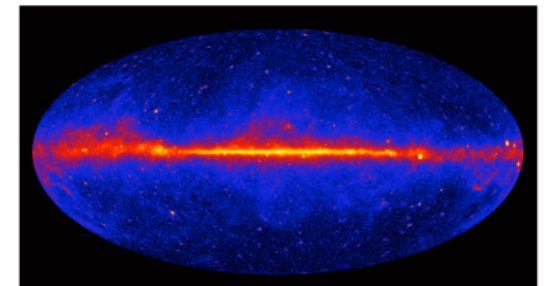
gamma-rays



Milagro Sky Map



IACT Sky Map



Fermi 2FGL Map

The gamma ray band is so broad, that many instruments are needed to assemble the "full picture"

Energy

Milagro

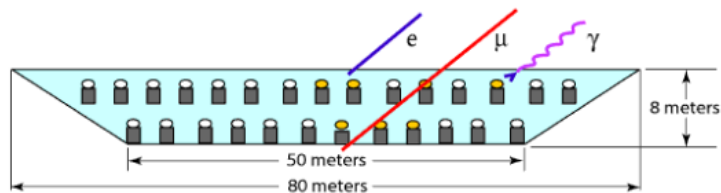
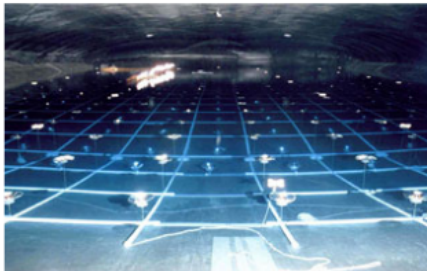
VERITAS

Fermi - LAT

Milagro

1 TeV - 100 TeV

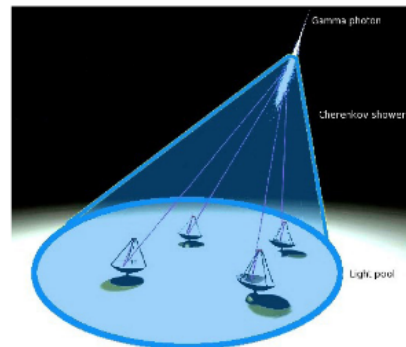
Milagro was a ground based water Cherenkov detector.



VERITAS

50 GeV - 50 TeV

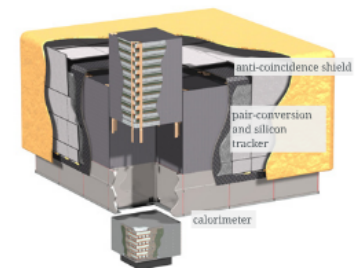
VERITAS is a ground based imaging atmospheric Cherenkov detector.



Fermi - LAT

20 MeV - 300 MeV

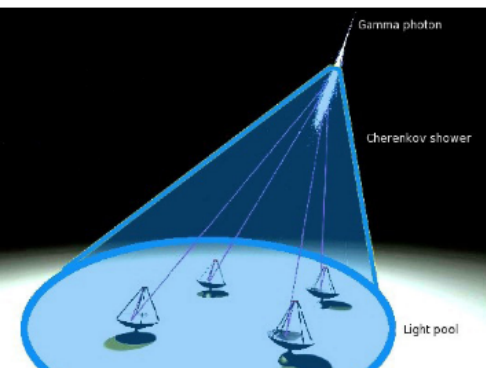
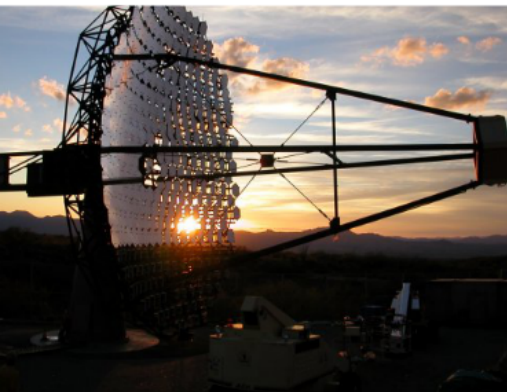
Fermi is an imaging telescope located on a spacecraft at low earth orbit.



VERITAS

50 GeV - 50 TeV

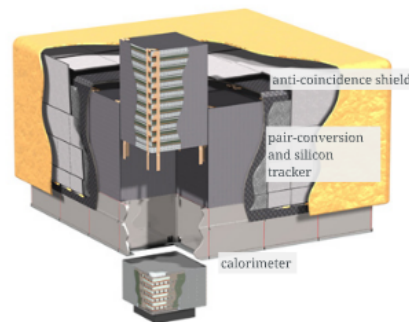
VERITAS is a ground based imaging atmospheric Cherenkov detector.



Fermi - LAT

20 MeV - 300 MeV

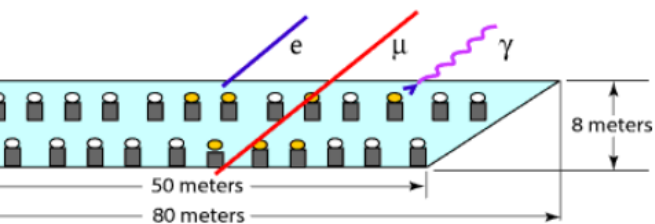
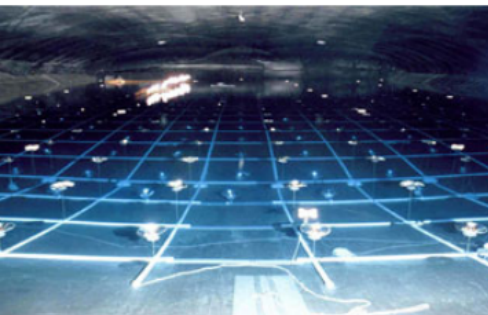
Fermi is an imaging telescope located on a spacecraft at low earth orbit.



Milagro

1 TeV - 100 TeV

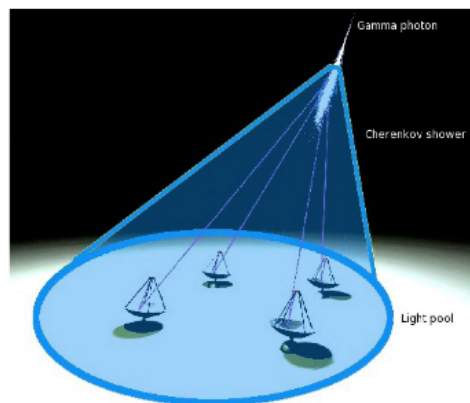
Milagro was a ground based water Cherenkov detector.



VERITAS

50 GeV - 50 TeV

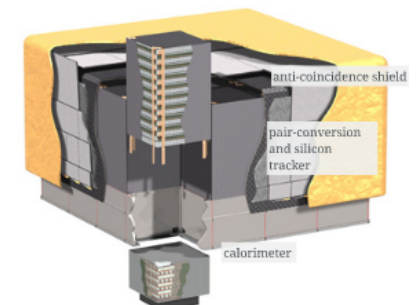
VERITAS is a ground based imaging atmospheric Cherenkov detector.



Fermi - LAT

20 MeV - 300 MeV

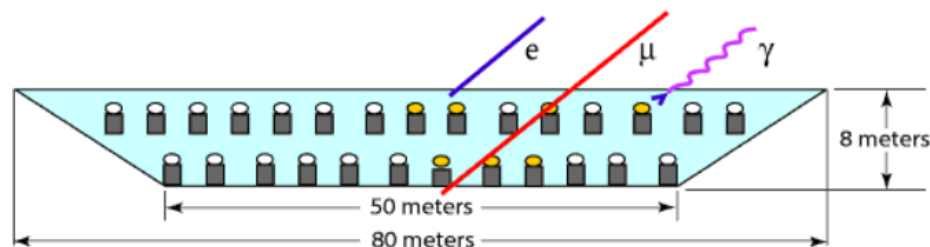
Fermi is an imaging telescope located on a spacecraft at low earth orbit.



Milagro

1 TeV - 100 TeV

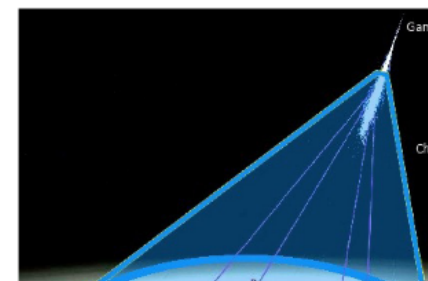
Milagro was a ground based water Cherenkov detector.



VERITAS

50 GeV - 50 TeV

VERITAS is a ground based imaging atmospheric Cherenkov detector.



Fermi 2FGL Catalog

Over 30 % of Fermi
Sources are unidentified
because of



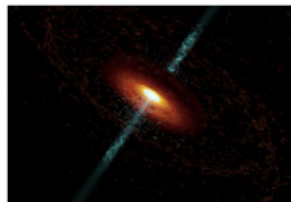
- Poor resolution of instruments that make source localization difficult
- Low photon statistics

The rest are mostly pulsars (5%) and blazars (45 %)

Blazars

Class of AGN (active galactic nuclei)

- Highly variable
- Bright radio, X-ray and gamma ray emission

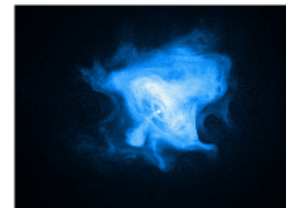


Artist's representation of a blazar

Pulsars

A Pulsating Star

- Rotating neutron star, emits beam of continuous radiation.
- Gamma-ray telescopes usually detect young, nearby pulsars



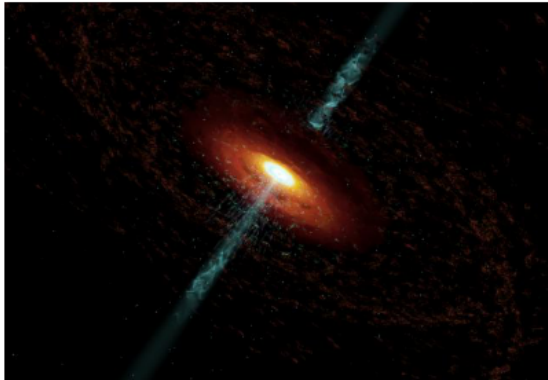
Crab - pulsar wind nebula

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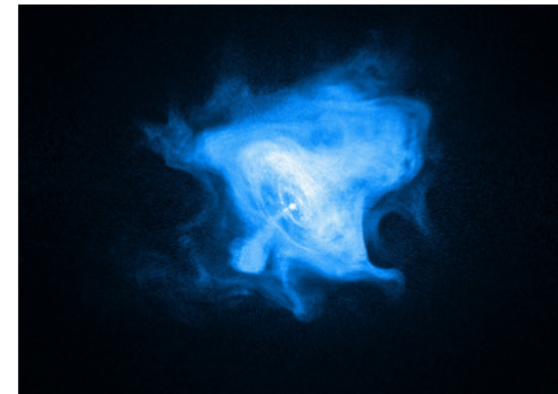


Artist's representation of a blazar

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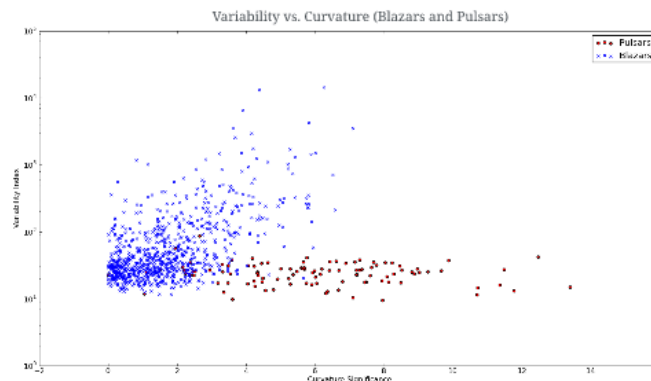


Crab - pulsar wind nebula

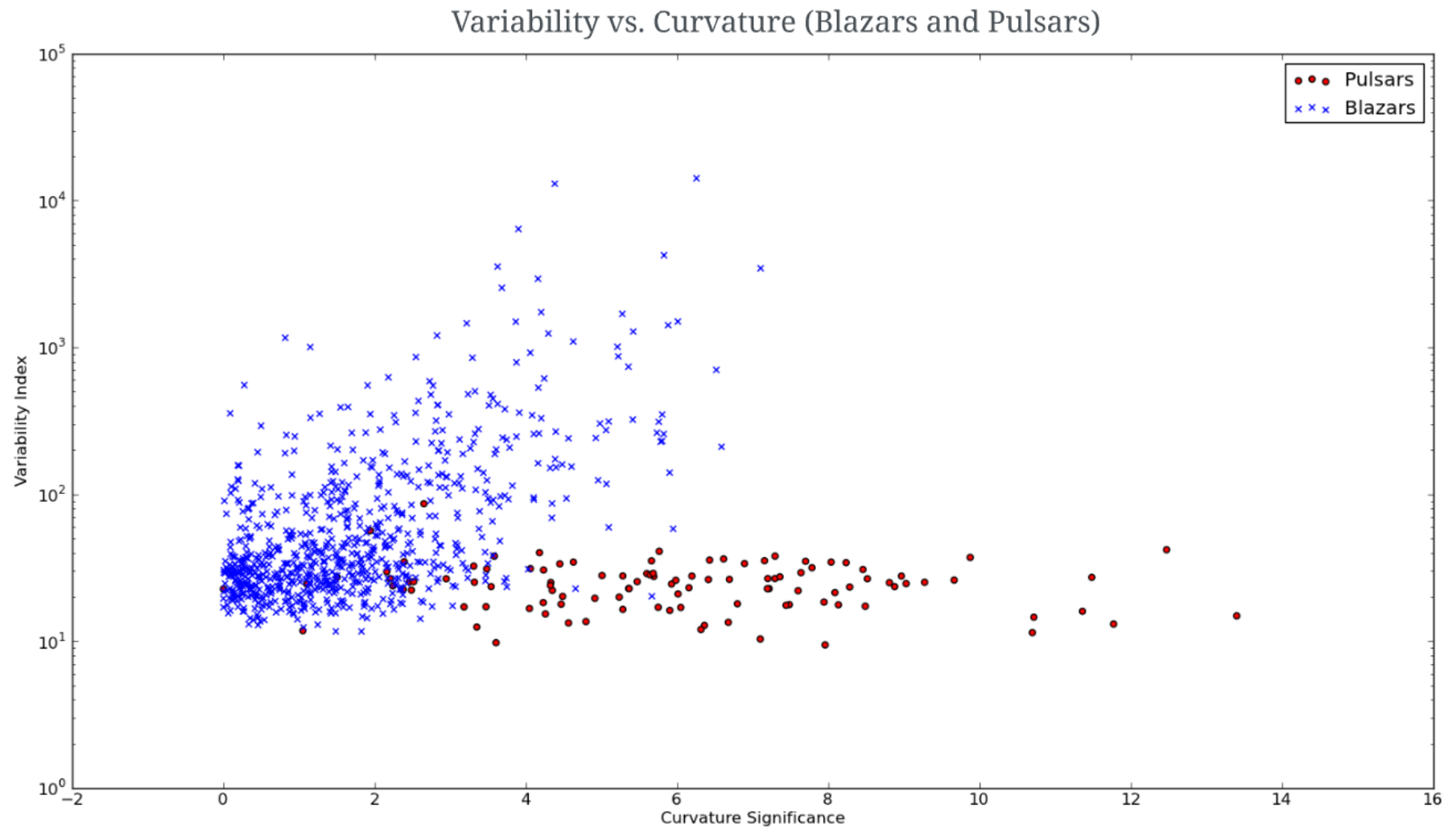
Characterization of Fermi Sources

The Fermi experiment has found that two parameters that can help distinguish between pulsars and blazars are:

- **variability index** - "defined as the χ^2 of the deviations of eleven monthly (30-day) source flux measurements from the average source flux"
- **curvature significance** - "measures the deviation of the spectrum from the simple power-law form for each source."

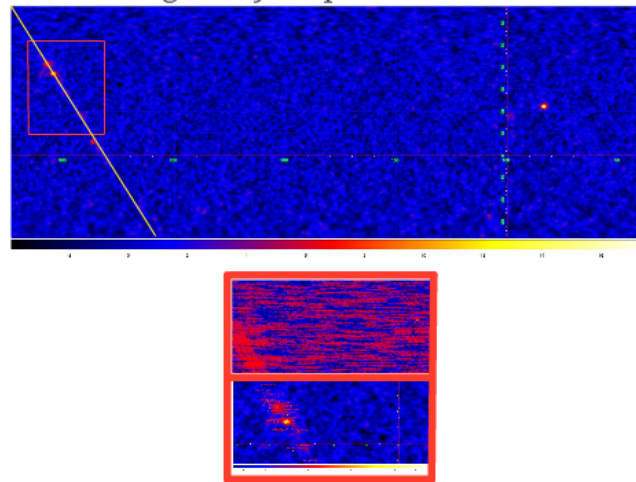


um from the simple power-law form for each

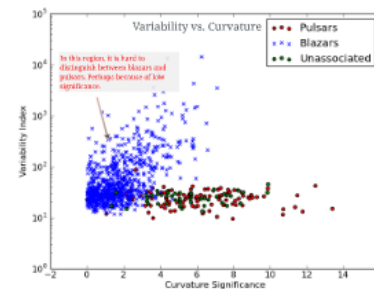


Selection of Unassociated Sources

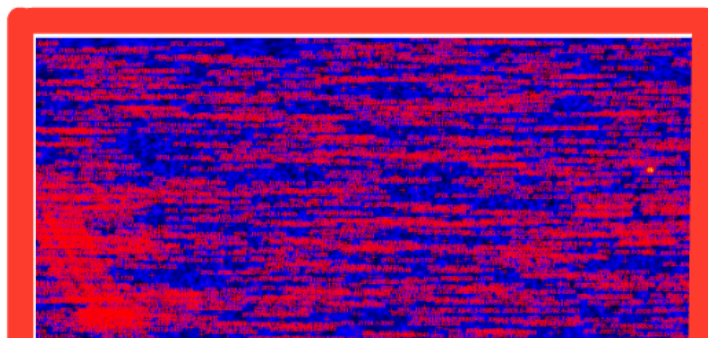
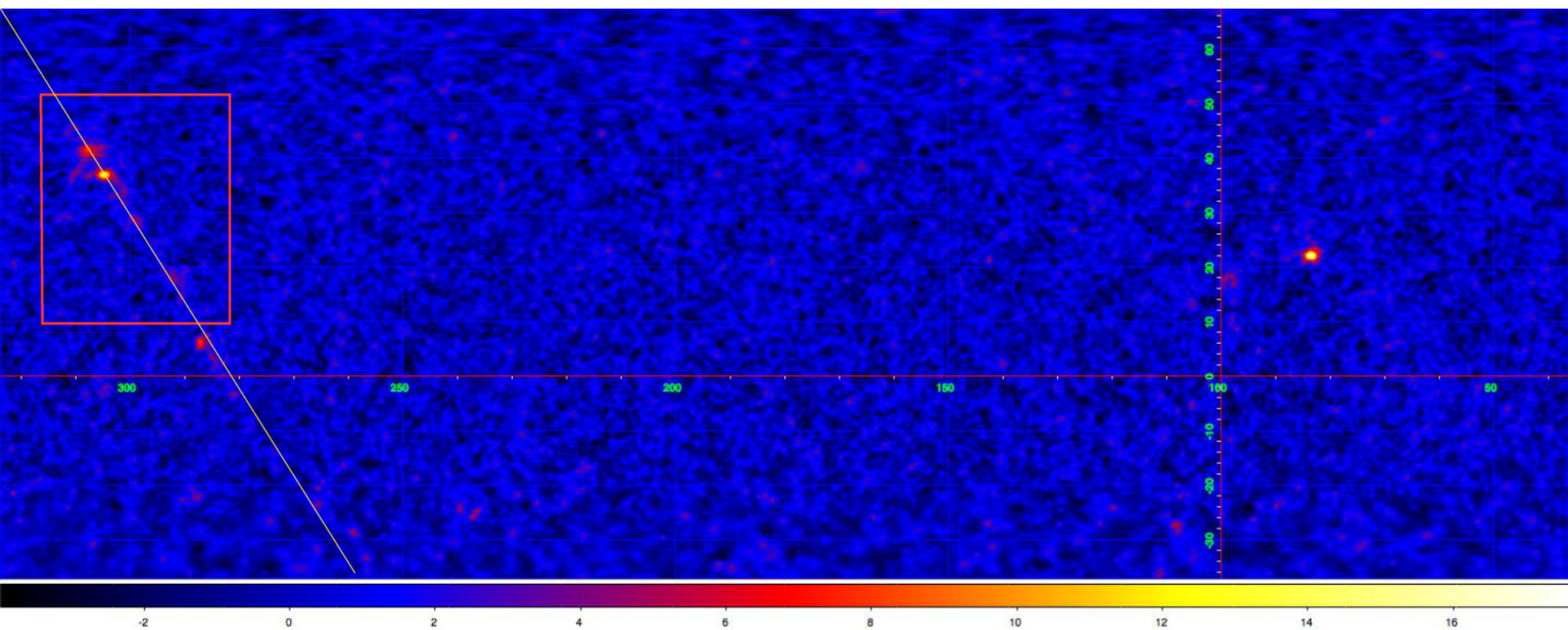
Milagro Sky Map of Galactic Plane

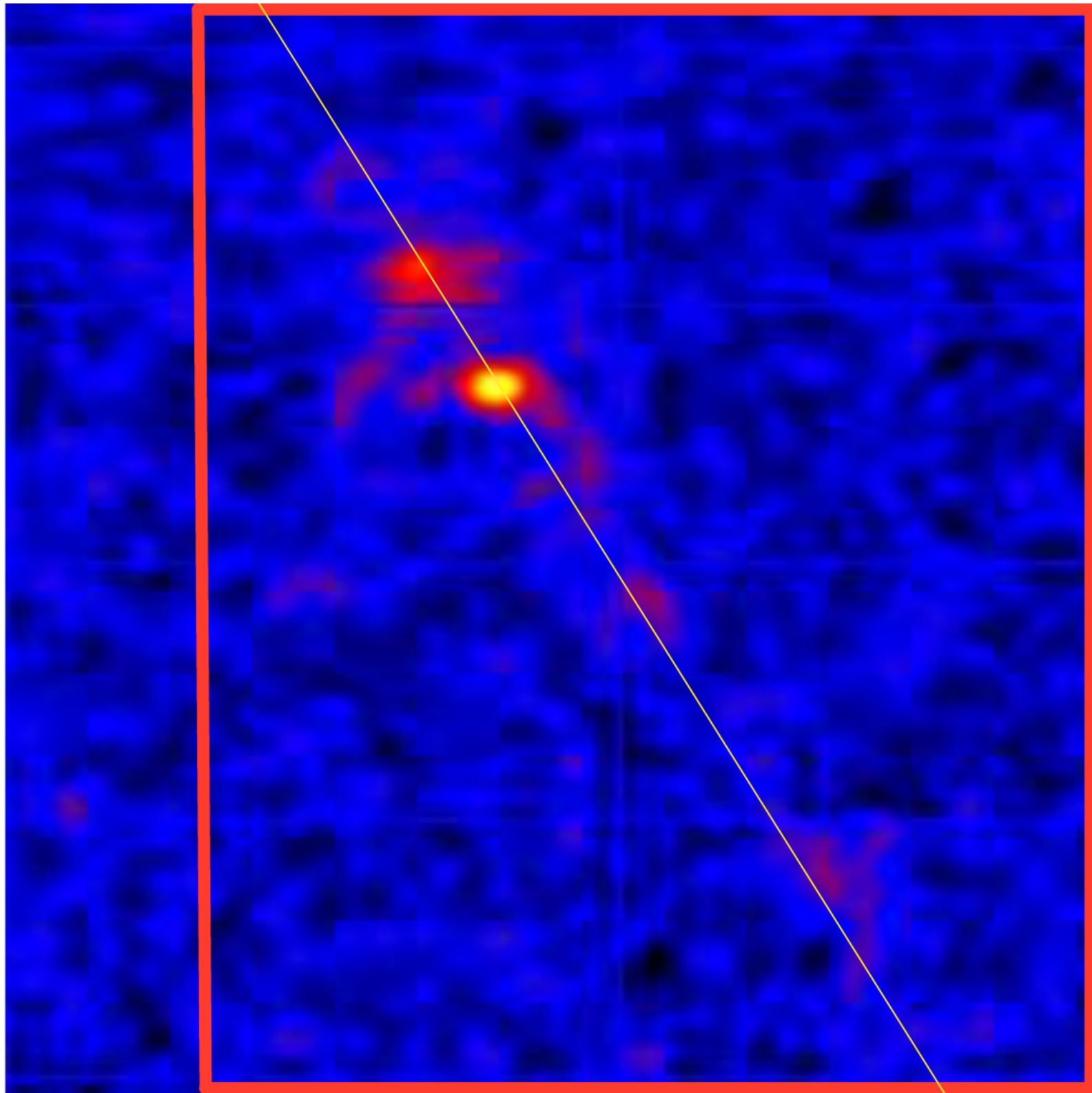


After making our selection, we found a **total of 46 unassociated sources** in the Milagro emission region.

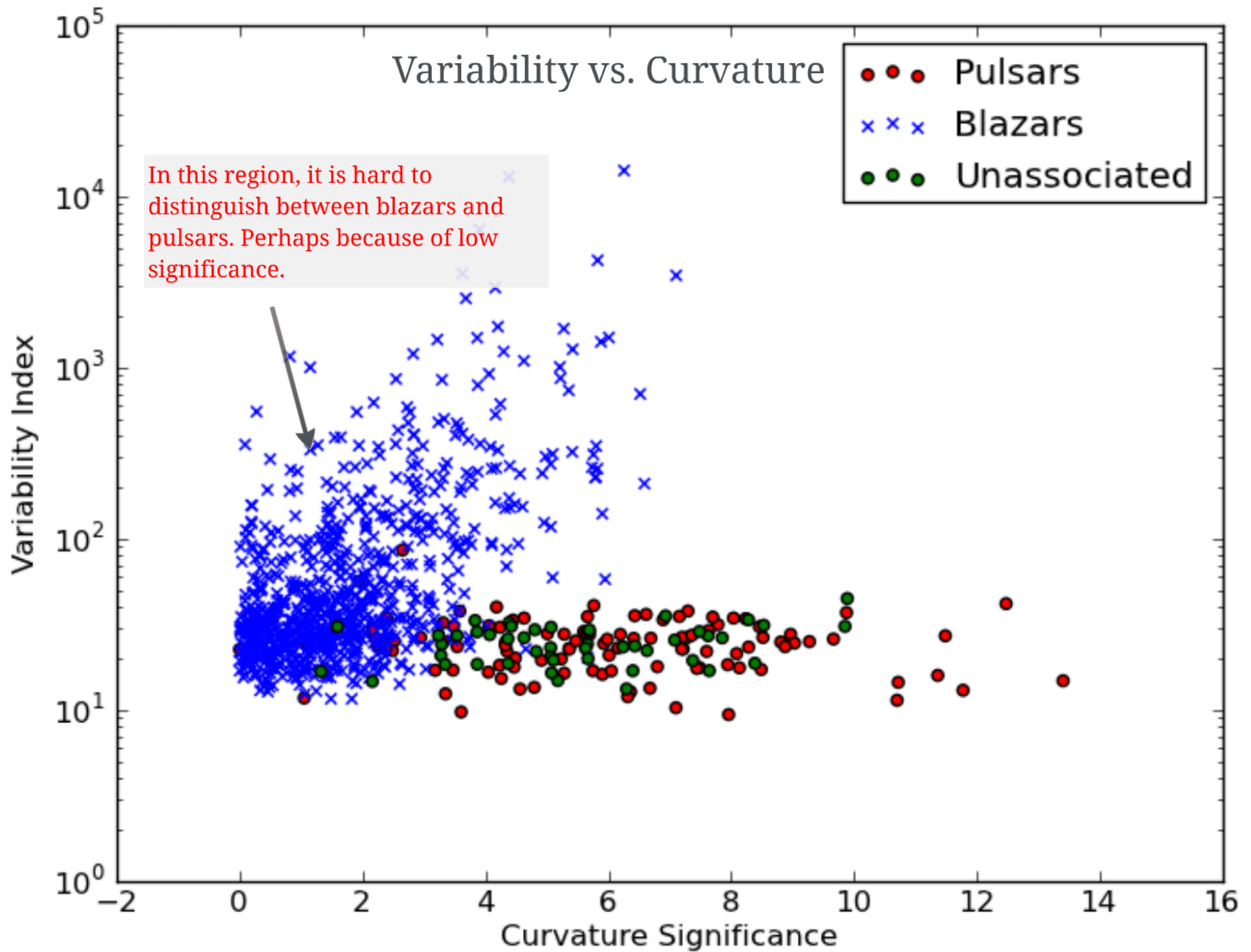


Milagro Sky Map of Galactic Plane





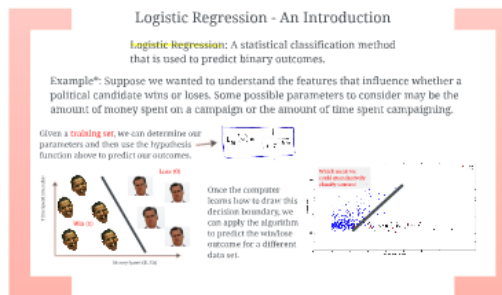
After making our selection, we found a total of 46 unassociated sources in the Milagro emission region.



Statistical Approach - Logistic Regression

Gamma ray astrophysicists often rely on statistical methods to establish the significance of a data sample.

Following in that tradition, we used the statistical method of **Logistic Regression** to classify our Fermi sources as pulsars or blazars.



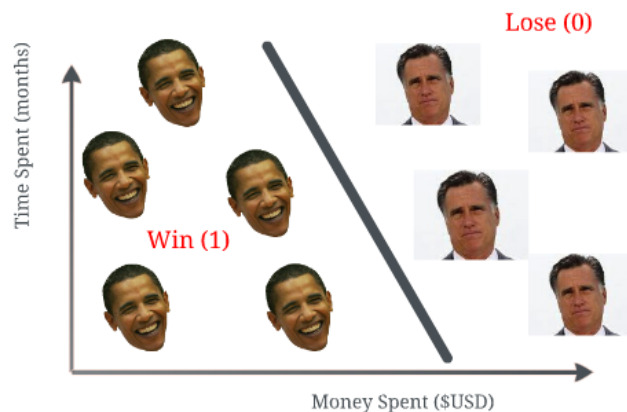
Logistic Regression - An Introduction

Logistic Regression: A statistical classification method that is used to predict binary outcomes.

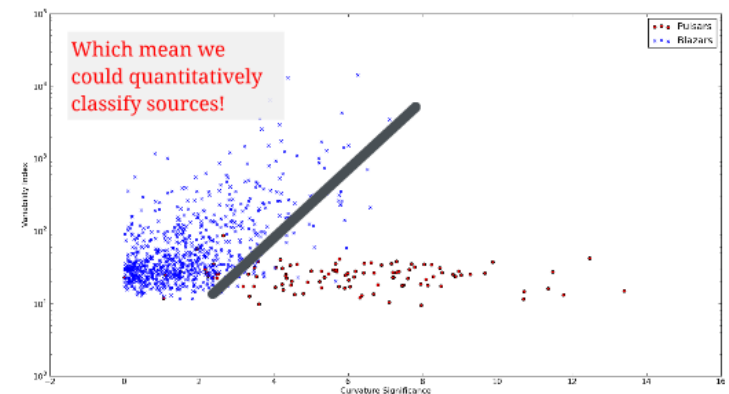
Example*: Suppose we wanted to understand the features that influence whether a political candidate wins or loses. Some possible parameters to consider may be the amount of money spent on a campaign or the amount of time spent campaigning.

Given a **training set**, we can determine our parameters and then use the hypothesis function above to predict our outcomes.

$$h_{\theta}(x) = \frac{1}{1 + e^{-\theta^T x}}$$



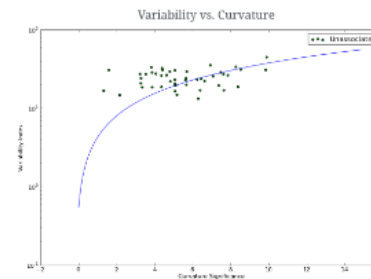
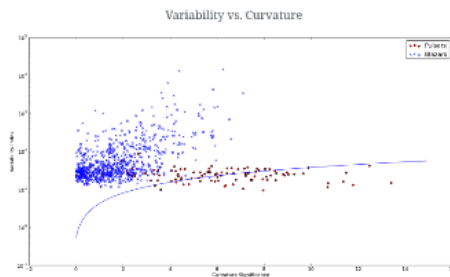
Once the computer learns how to draw this decision boundary, we can apply the algorithm to predict the win/lose outcome for a different data set.



LR Model Implementation

We utilized python to implement our logistic regression model without the use of library packages.

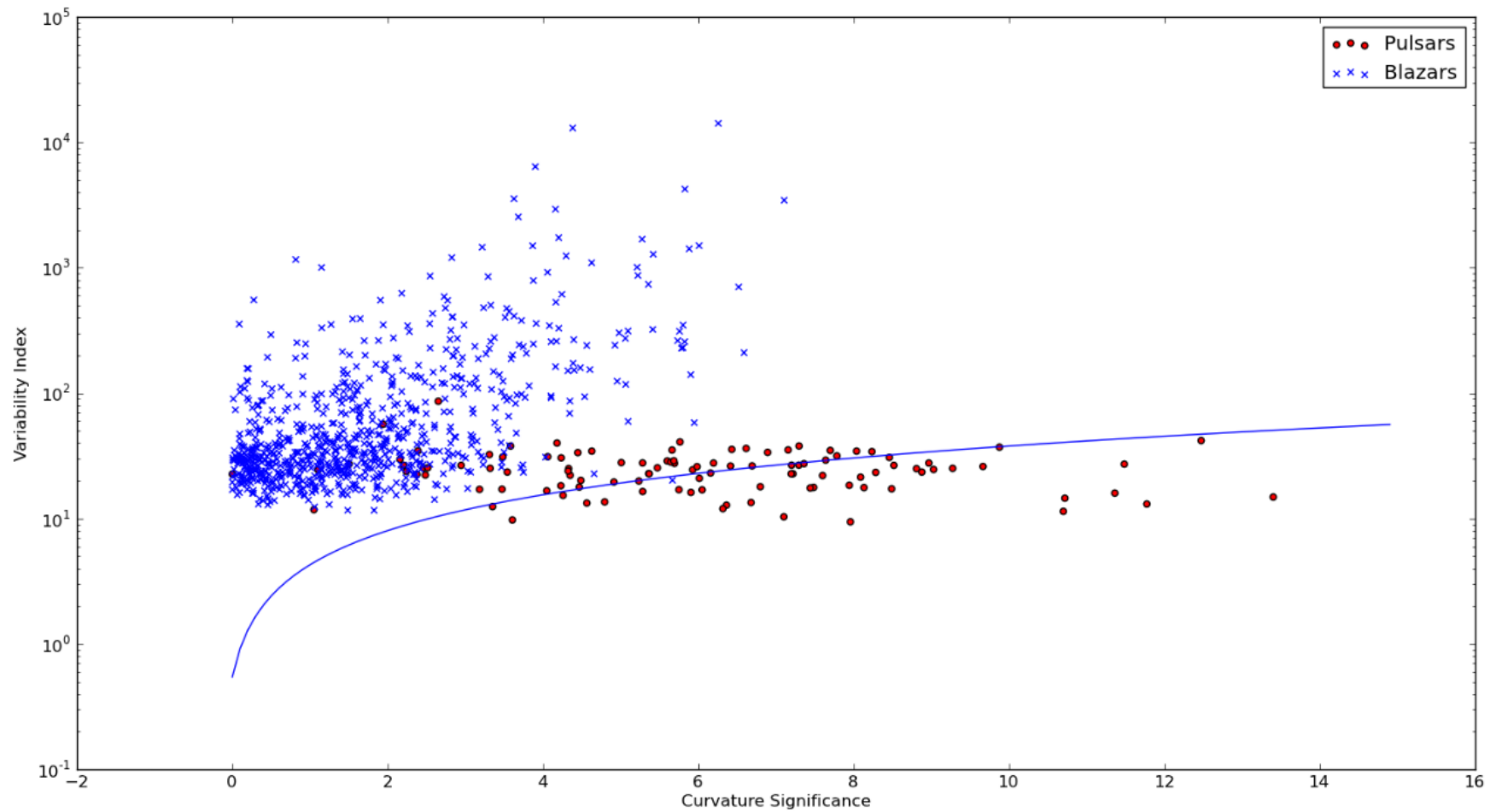
Our **training set** included all known blazars and pulsars in the 2FGL catalog.



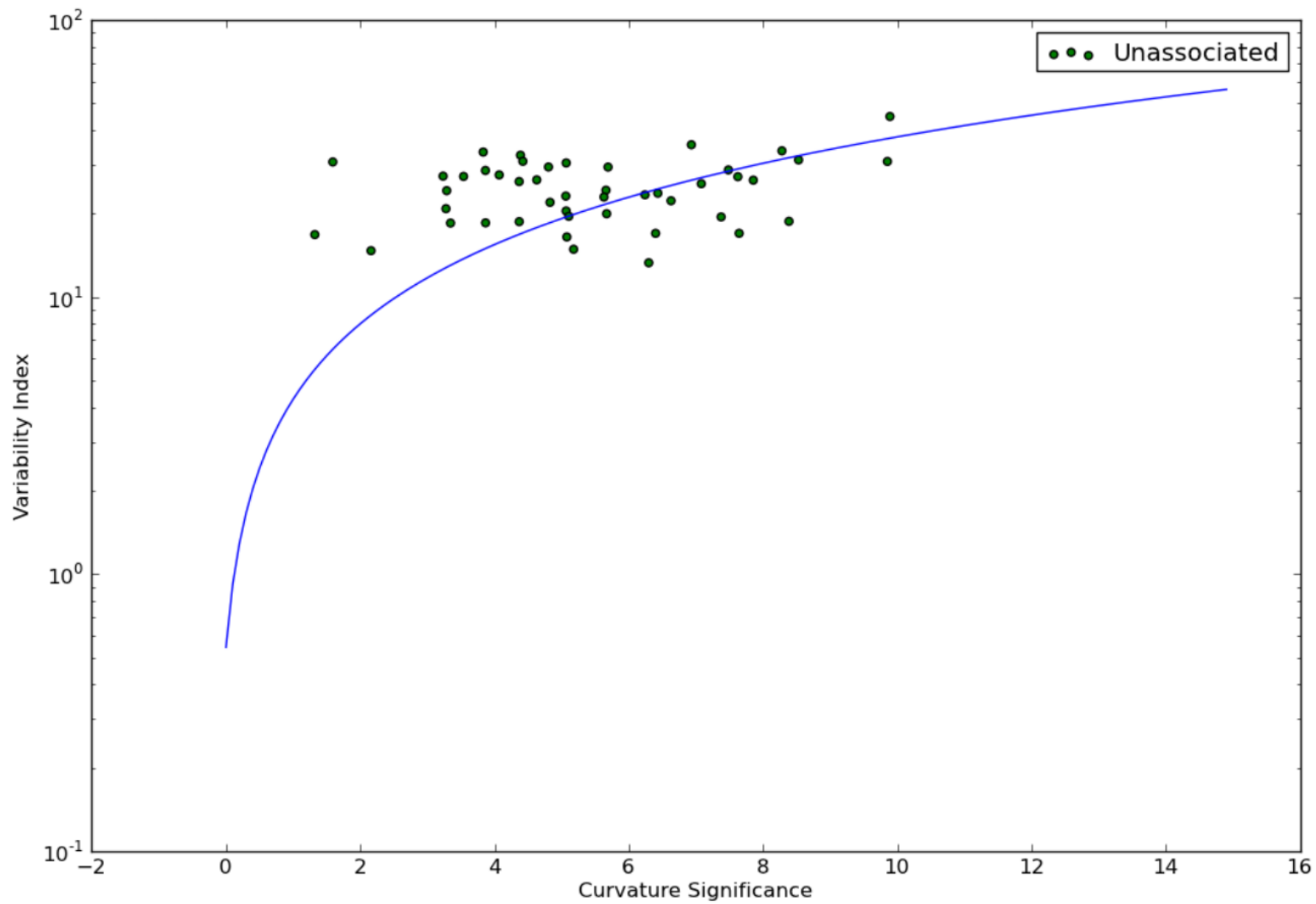
- Address under-fitting of data
- Add new parameters to model
- Improve optimization method

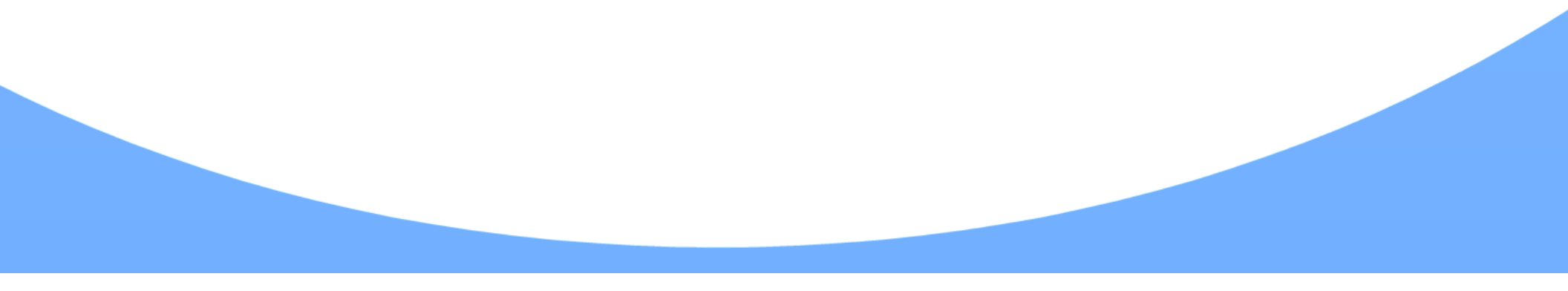
In the ZFGL Catalog.

Variability vs. Curvature



Variability vs. Curvature



- Address under-fitting of data
 - Add new parameters to model
 - Improve optimization method
- 
- A solid blue decorative wave shape that spans the width of the slide, starting from the bottom left, dipping into a curve, and rising towards the bottom right.

Multi-wavelength Analysis

Investigate possible associations by determining if counterparts existed in other energy bands, i.e. X-ray.



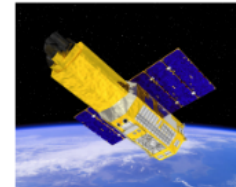
SWIFT experiment



Chandra



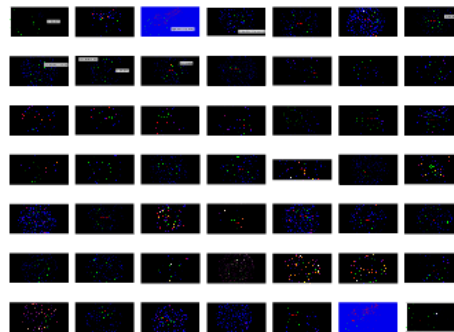
XMM Newton



Suzaku

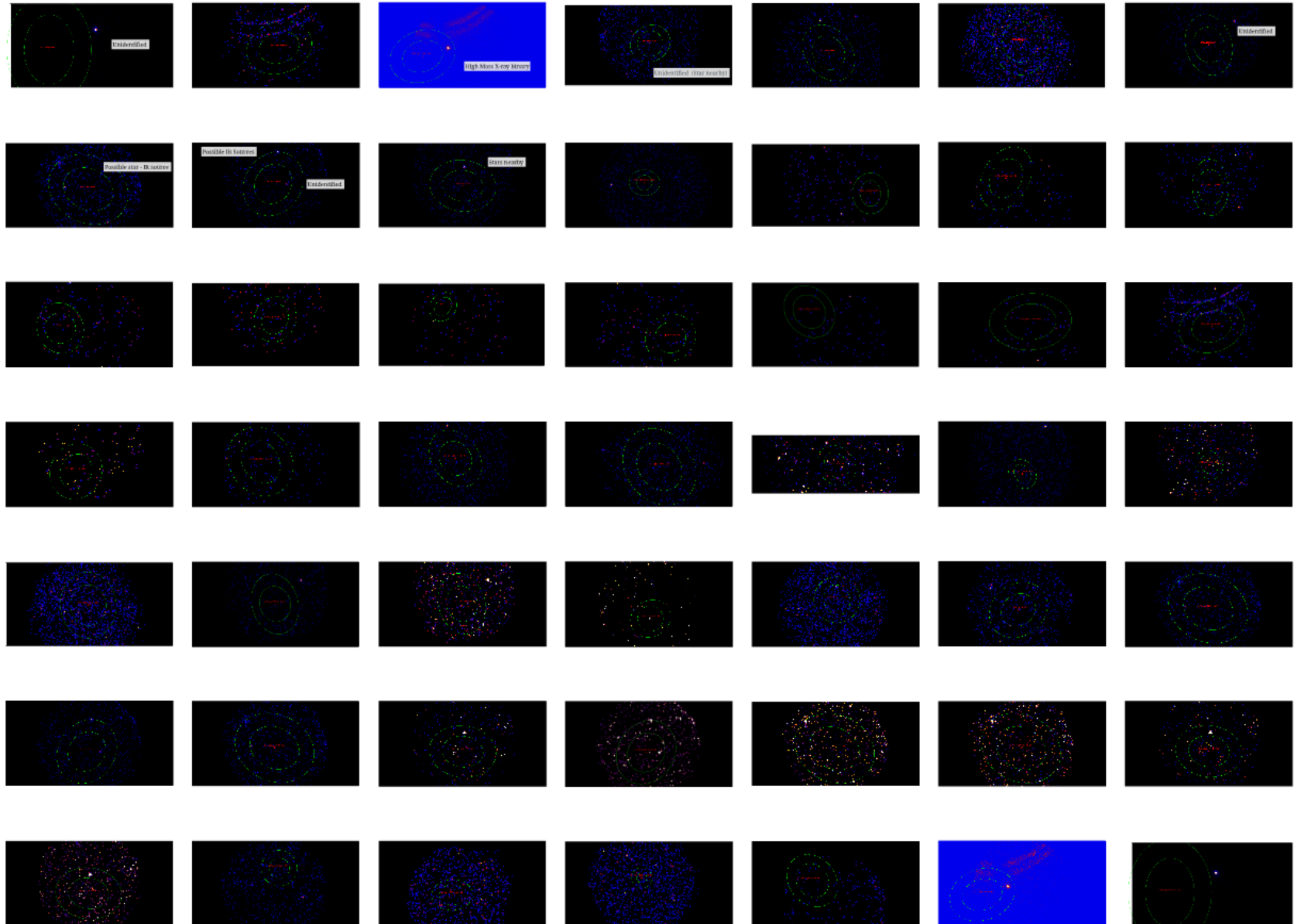
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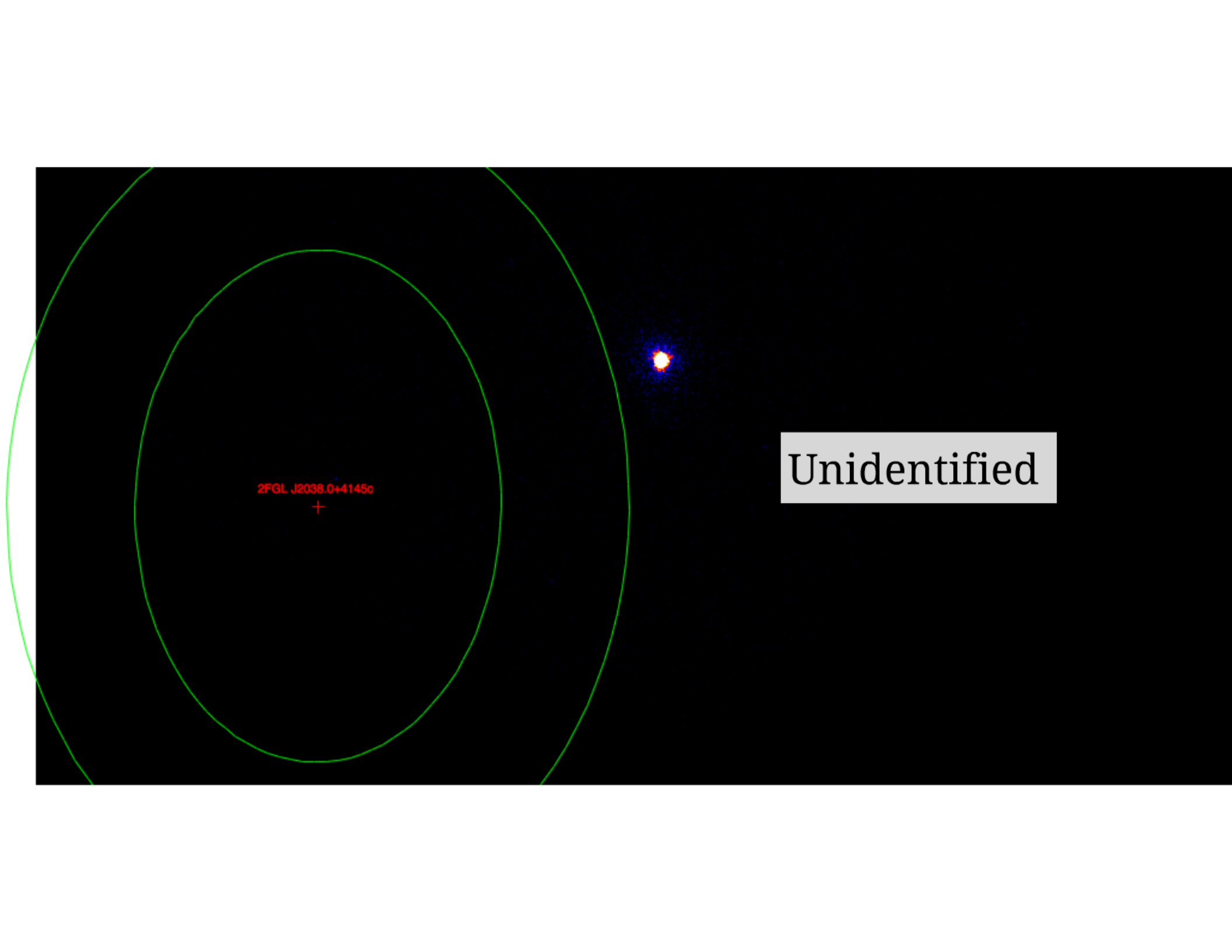
SWIFT Images



Fermi Source Name	Chandra	Swift-XRT	XMM-Newton
2FGL J1857.2+0055c	Exposure: 10070 s Offset: 5.9968 arcmin	Exposure: 453.215 s Offset: 6.1534 arcmin	None
2FGL J1842.8-0359c	None	Exposure: 513.23 s Offset: 8.4557 arcmin	Exposure: 26953 s Offset: 1.3321 arcmin
2FGL J1844.3-0343c	None	Exposure: 67904.679 s Offset: 1.0426 - 9.8324 arcmin	None
2FGL J1843.7-0312c	None	Exposure: 506.5 s Offset: 7.7901 arcmin	Exposure: 31919 s Offset: 9.5120 arcmin
2FGL J1847.2-0236	None	Exposure: 897.599 s Offset: 4.8058 arcmin	None
2FGL J1848.2-0139c	None	Exposure: 493.93100 s Offset: 6.8104 arcmin	Exposure: 65149 s Offset: 3.8670 arcmin
2FGL J1849.9-0125c	None	Exposure: 455.81900 s Offset: 4.3941 arcmin	None
2FGL J1857.2+0055c	None	Exposure: 453.21500 s Offset: 6.1534 arcmin	None
2FGL J1858.5+0129c	None	Exposure: 668.19800 s Offset: 5.9348 arcmin	None
2FGL J1857.6+0211	None	Exposure: 11127.638 s Offset: 1.5763 - 8.3669 arcmin	None
2FGL J1859.3+0312c	None	Exposure: 2799.617 s Offset: 8.0175 - 9.4414 arcmin	None
2FGL J1857.8+0355c	None	Exposure: 493.027 s Offset: 5.3467 arcmin	None
2FGL J1901.1+0427	None	Exposure: 4715.848 s Offset: 0.362 - 9.4495 arcmin	None
2FGL J1906.5+0720	None	Exposure: 11264.895 s Offset: 1.0935 - 7.0505 arcmin	None
2FGL J1914.4+0951c	None	Exposure: 13069.055 s Offset: 0.8656 - 7.3889 arcmin	None
2FGL J1921.1+1436c	None	Exposure: 421.34600 s Offset: 6.8801 arcmin	None
2FGL J1914.0+1436	None	Exposure: 3756.999 s Offset: 1.4945 - 2.5999 arcmin	None
2FGL J1924.8+1724c	None	Exposure: 656.03900 s Offset: 3.6831 arcmin	None
2FGL J2028.3+3332	None	Exposure: 10427.484 s Offset: 1.3277 - 2.2050 arcmin	None
2FGL J2028.4+3332	None	Exposure: 4092.754 s	None

SWIFT Images



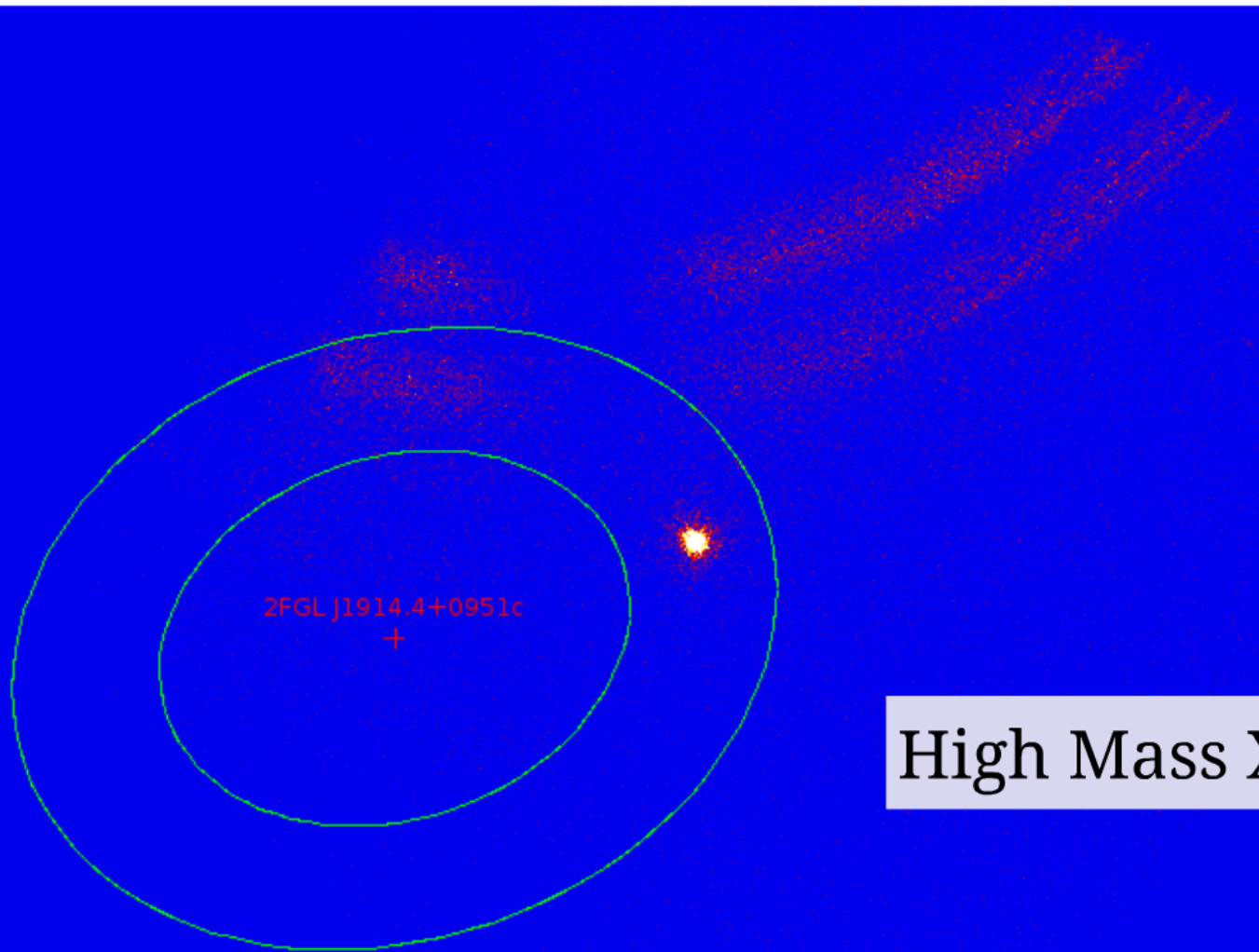


2FGL J2038.0+4145c

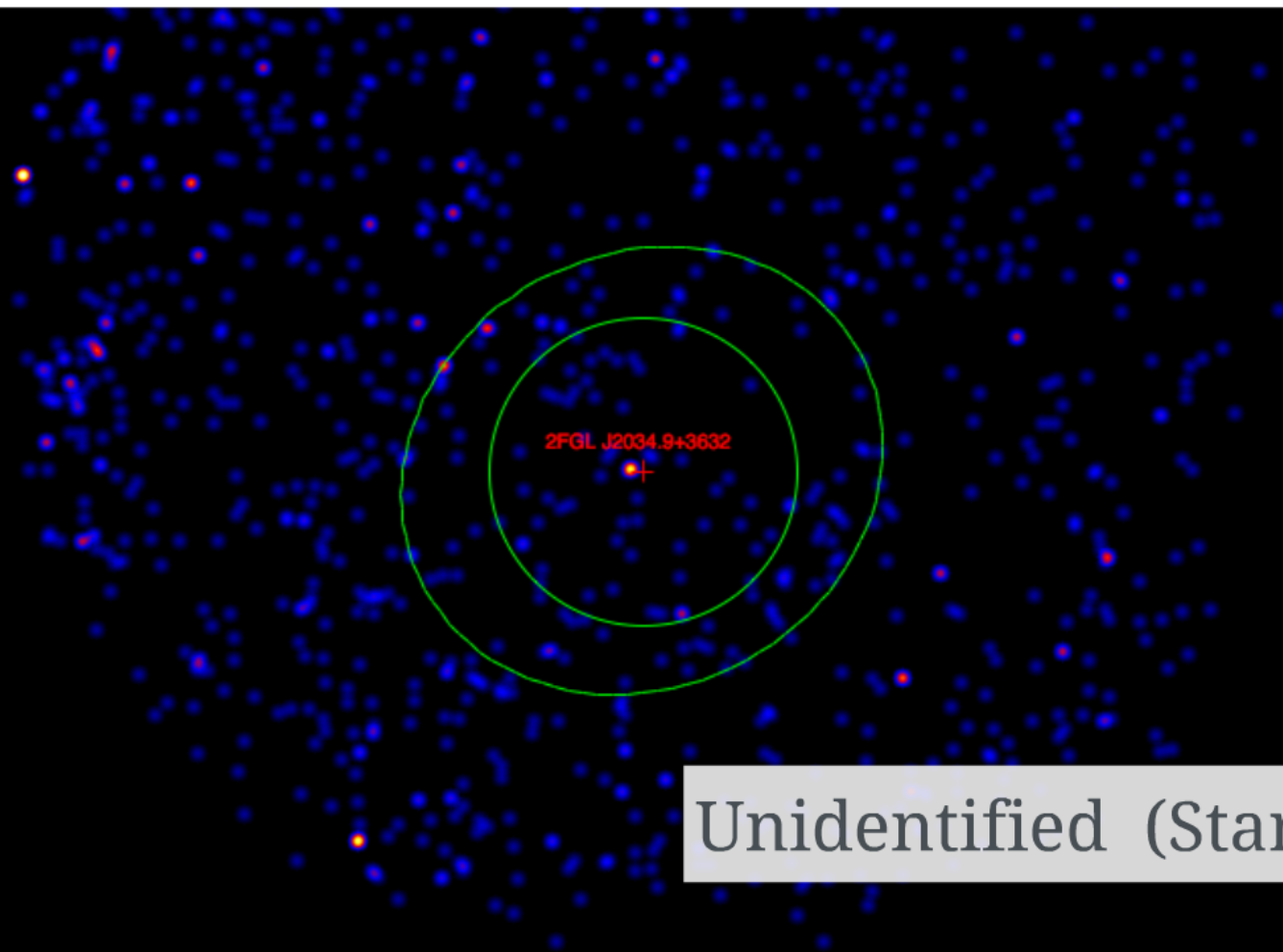
The image shows a dark field of stars. Two concentric green circles are centered on a red star labeled '2FGL J2038.0+4145c'. To the right of this star is another, slightly brighter star. The background is filled with numerous faint, distant stars.



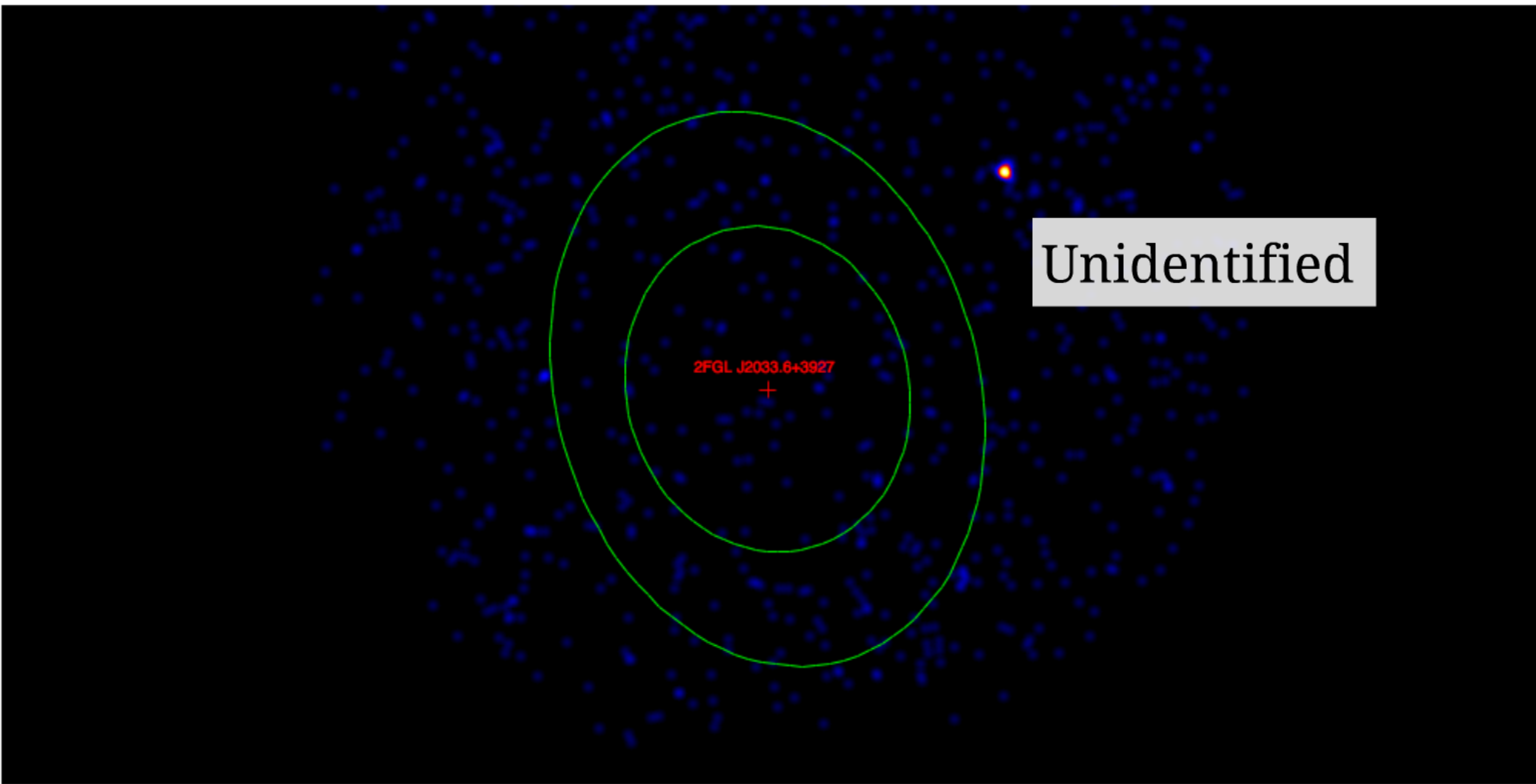
Unidentified



High Mass X-ray Binary



Unidentified (Star nearby)



Unidentified

2FGL J2033.6+3927

+

Possible star - IR source

2FGL J2221.0+6307

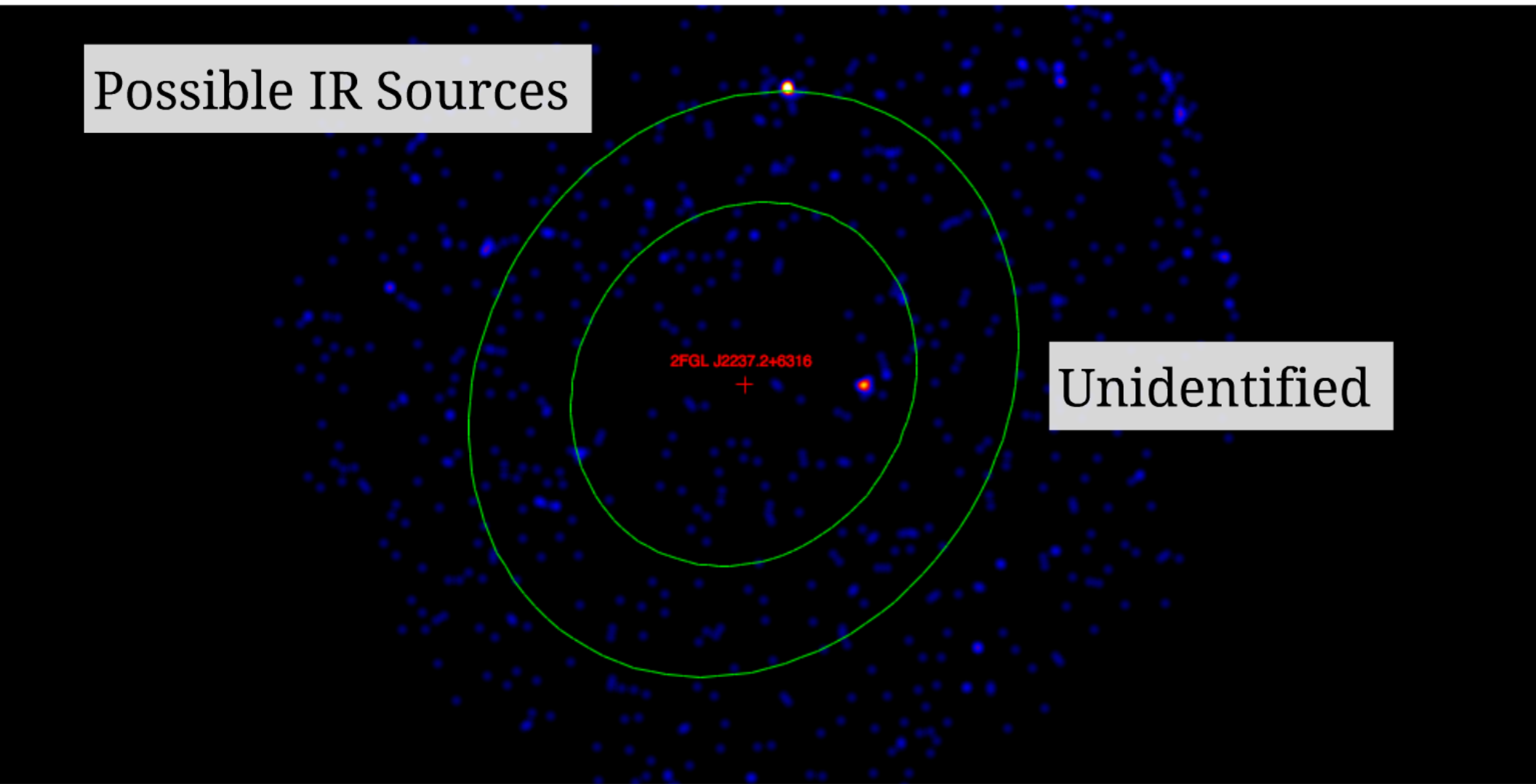


Possible IR Sources

2FGL J2237.2+6316

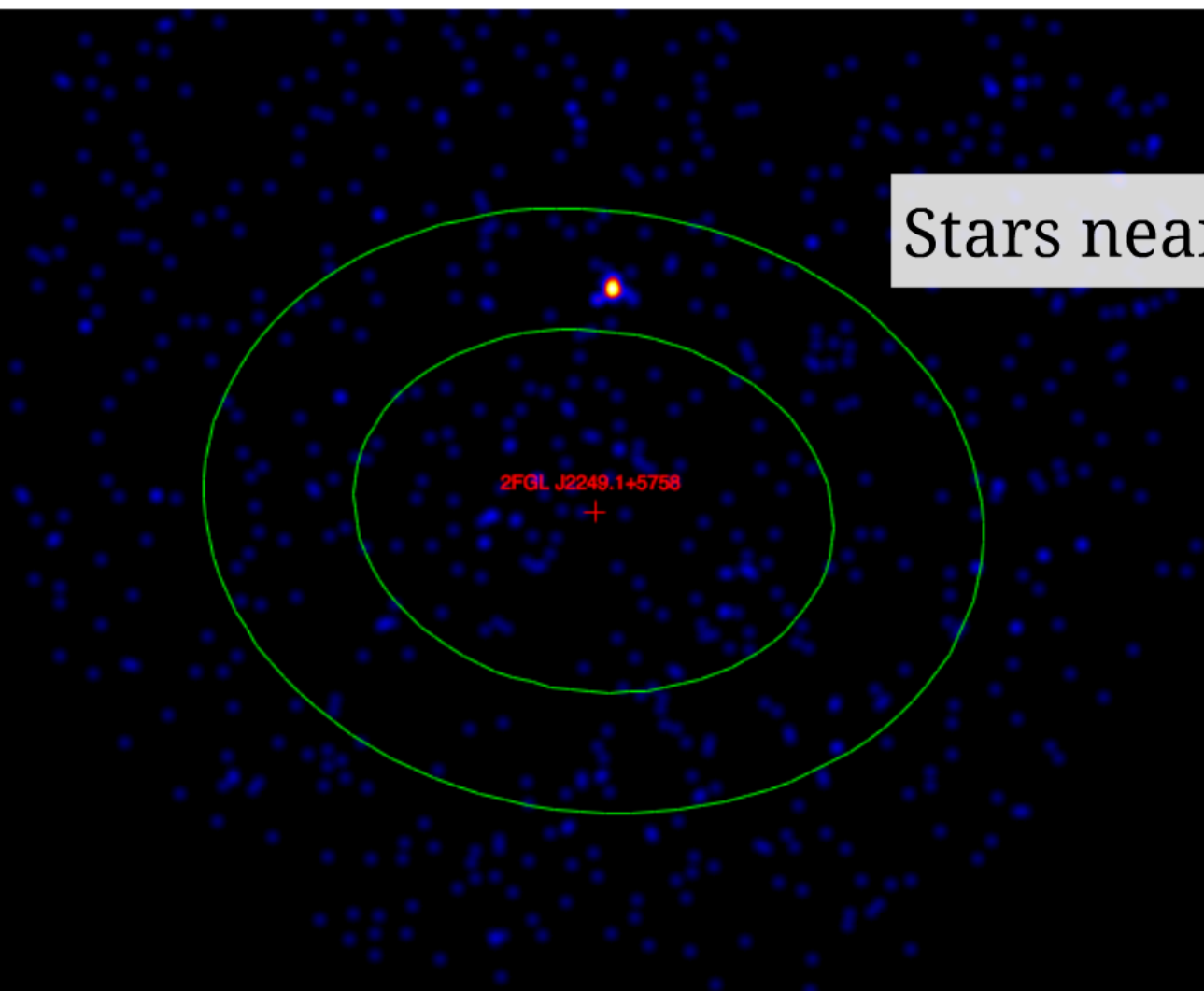
+

Unidentified



Stars nearby

2FGL J2249.1+5758
+



Conclusions

A combination quantitative study, the logistic regression model and qualitative study, the multi-wavelength comparisons, allow for promising investigation of Fermi's UFOs.

For the future ...

- Repeat LR model with Fermi 4th year catalog
- Research other classification methods
- An expanded multi-wavelength study may help make improved associations.
- Complete XMM-Newton observation proposal (~ October)
- Make proposals for more observation of sources with VERITAS

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I would like to thank the Nevis REU program for giving the opportunity to work with my great advisers Ester Aliu, Reshmi Mukherjee and Gunes Senturk!

