Classification and Detection of Swift X-ray Counterparts to the Fermi Unassociated Sources

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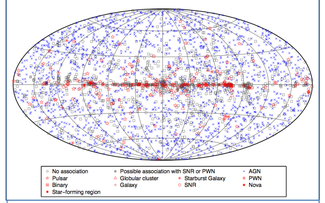
Abstract

The Fermi Gamma Ray Observatory has revolutionized gamma-ray astronomy by discovering thousands of sources since its launch in 2008. However, the unidentified population of these sources in the Fermi catalogs is still substantial, e.g. one third of the Fermi sources in the latest 3FGL catalog are unidentified. Swift-XRT observations of these Fermi unassociated fields have found possible X-ray counterparts in ~30% of these Fermi unassociated uncertainty regions, and approximately half of these sources were previously uncataloged in either radio/optical/X-ray catalogs. The main objective of this work is to identify the nature of these possible counterparts, utilizing the properties of known Fermi sources coupled with the X-ray source properties. The majority of the known sources in the Fermi catalogs are blazars, which constitute the bulk of the extragalactic gamma-ray source population. The galactic population on the other hand is dominated by pulsars. Overall, these two categories constitute the majority of all gamma-ray objects. Blazars and pulsars occupy different parameter space when X-ray fluxes are compared with various gamma-ray properties. In our work, we utilize the X-ray observations performed with the Swift-XRT telescope for the unknown Fermi sources and compare their X-ray and gamma-ray properties to differentiate between the two source classes. These initial investigations can help discriminate between blazars and pulsars, and will be further investigated by utilizing the principles of multivariate principle component analysis as well as machine learning techniques.

Introduction

- Fermi source catalogs present ~1000s of new gamma-ray sources
- About 1/3 of the total are still unidentified /unassociated in the latest (3FGL) catalog
- Multiwavelength observations of the unknown population revealed myriad new blazars, MSPs (black widows+ redbacks), HMXBs etc *(e.g. see Abdo+09, Saz Parkinson +10, Ransom+11, many more)*
- The emission processes of these newly discovered and identified objects is an active field of research
- Associating, classifying, and characterizing the unassociated sources could contribute to the understanding of this emission, and could yield new source classes



3FGL sky map

Method : Swift-XRT Monitoring Program

- Swift-XRT observations of Fermi source catalogs (1FGL+2FGL+3FGL)
- Monitoring program (fill in + GI : PI – Falcone)
- Exposure time ~ 4ksec per source
- Criteria :
  - Not listed as a confused source
  - Not on galactic ridge where positions are not clearly defined
  - No existing Chandra /*Swift*-XRT/XMM-Newton data
  - Uncertainties smaller than the *Swift*-XRT field of view
- Details at : ***www.swift.psu.edu/unassociated***

Total 3FGL fields observed **739** (exptime > 2 ksec)

- Sources within 3FGL uncertainty region **280** **(SNR > 3)**
- Sources within 3FGL uncertainty region **121** **(SNR > 4)**

3FGL unassociated observations at present

Monitoring Results

Publicly available at www.swift.psu.edu/unassociated/

- Automated pipeline
  - Detects X-ray sources in the given Fermi source region
  - Estimate the count rate for all the detections
- Three examples shown below demonstrates the monitoring results as shown on the webpage. (**Fig 1. see below**)

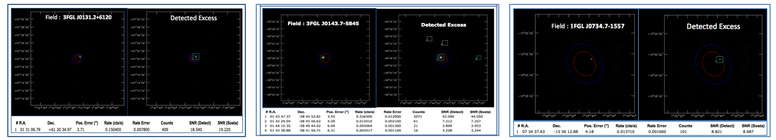
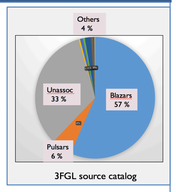


Fig 1. *(left)* An unassociated source with 3FGL uncertainty regions(68% and 95%) overlapped, *(center)* A source with multiple newly detected X-ray sources, *(right)* A source in 1FGL catalog later discovered as a gamma-ray pulsar discovered in LAT blind searches (See Parkinson et al 2010).

Gamma-ray and X-ray properties comparison

- Blazars and Pulsars dominate the known Fermi source population
- These occupy different parameter space when gamma-ray and X-ray properties are compared (*Falcone+15*)
- Compare known Fermi blazars (from 3LAC sample; Ackermann+15) and known Fermi detected pulsars (from Marelli+12,Pryal+15,Swift-XRT archive) with the unassociated sample
- For classification of unassociated sample, we chose high SNR (>4) sources **(121 in number)**
- X-ray flux for unassociated : preliminary estimate, assuming spectral index = 2 (refined spectral analysis is forthcoming)
- Compared gamma-ray properties with X-ray flux (**See Fig. 2. below**)



3FGL source catalog

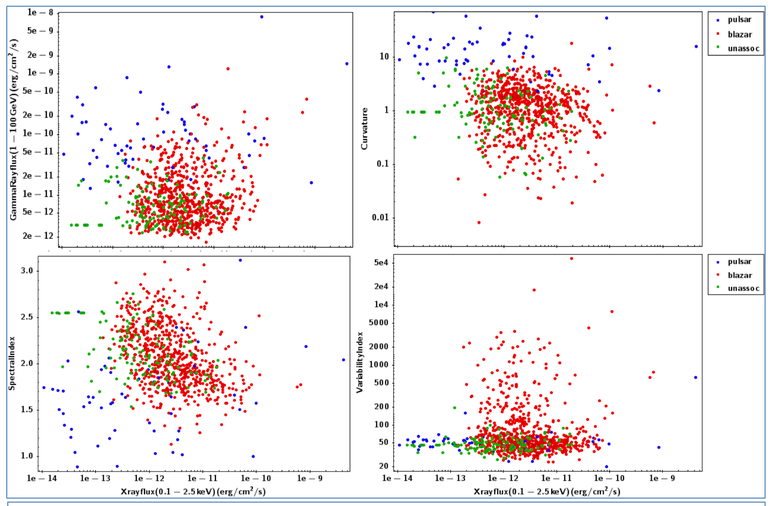


Fig. 2 : The unassociated sample plotted here consists of 121 sources (SNR > 4)

Machine Learning Methods

- We employ two methods commonly employed in Astrophysics: **Decision Tree** and **Random Forest**
- Five Parameters employed : 4 gamma-ray properties (See Fig 2.) and X-ray flux
- Sample :

Sample Size : 738
Blazars : 698
Pulsars : 47

- Training dataset : 638 (Blazars : 598, Pulsars : 40)
- Test dataset : 100 (Blazars : 93, Pulsars : 7)

- Decision Tree : Accuracy for the test dataset : 98 %
- Random Forest : Accuracy for the test dataset : 99%

Preliminary Results

- Decision Tree predicts **18 pulsars and 103 blazars**
- Random Forest predicts **21 pulsars and 100 blazars** assuming probability > ≥ 90 % implies a blazar (**See Fig 3. right**)
- Both methods yield consistent results except for 2 cases

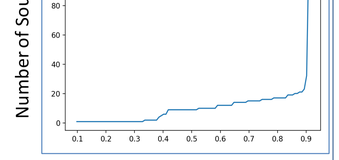


Fig 3: Class prediction for unassociated sources using Random Forest Method

Conclusions + Future Work

- Finalize classification of Fermi sources and publish new catalog of blazar and pulsar counterparts to Fermi unassociated sources.
- Adding spectral analysis pipeline to the online monitoring analysis for more accurate X-ray flux estimations for the unassociated sample (*spectral analysis pipeline already in place*)
- Apply non-supervised machine learning methods to firmly classify pulsars /blazars, and to investigate new classes that could be indicated by any unclassified sources.

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Collaborators

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