Spatial and Time Cluster Analysis of Fermi-LAT High Energy Gamma Ray Photons

Summer Project Presentation

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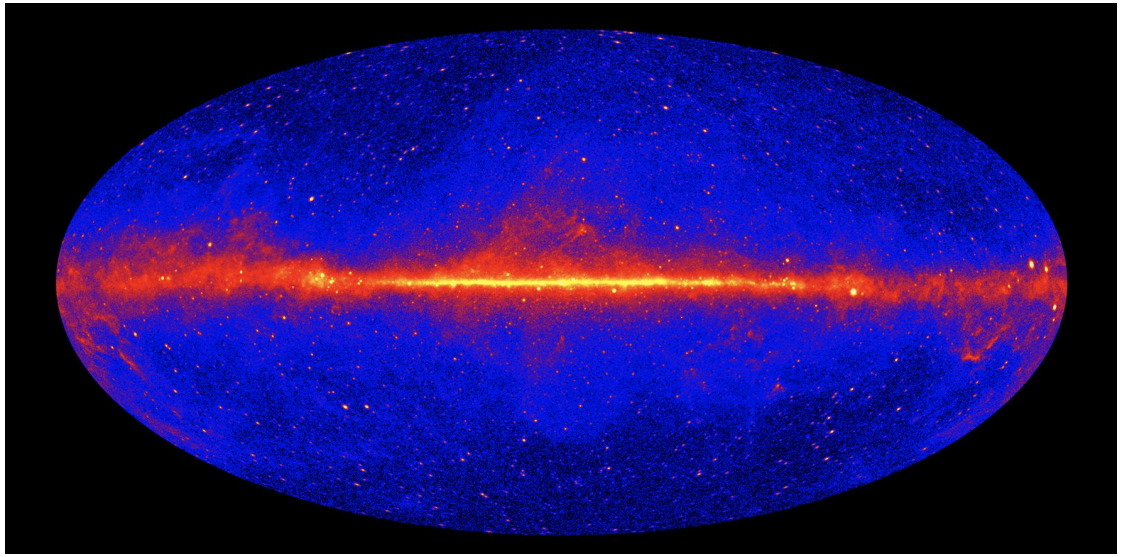
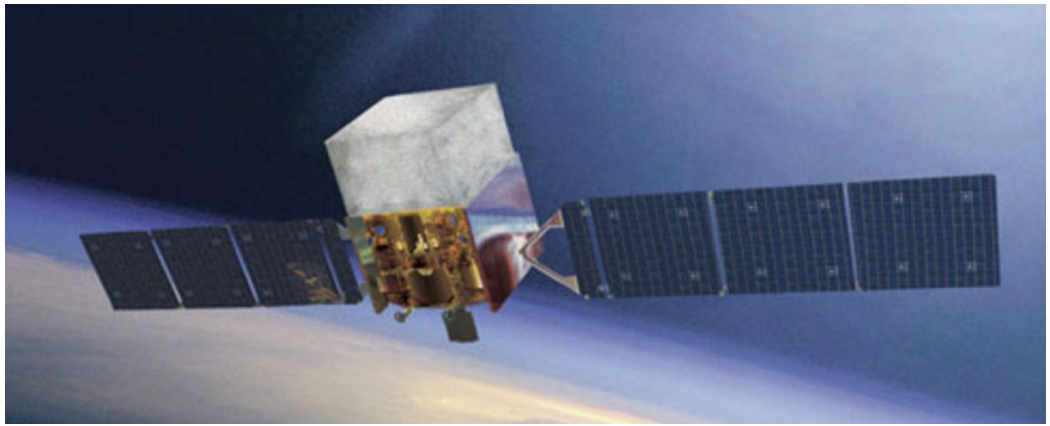
Fermi - LAT

- Energy Range: 20 MeV to > 300 GeV

- Provide event-resolved observational data
- Events described by tuples: sky coordinates, arrival time, energy
- Capabilities: Maps γ-ray sources, studies cosmic bursts, pulsars, blazars, dark matter
- Data Products: 3FHL, 4FGL



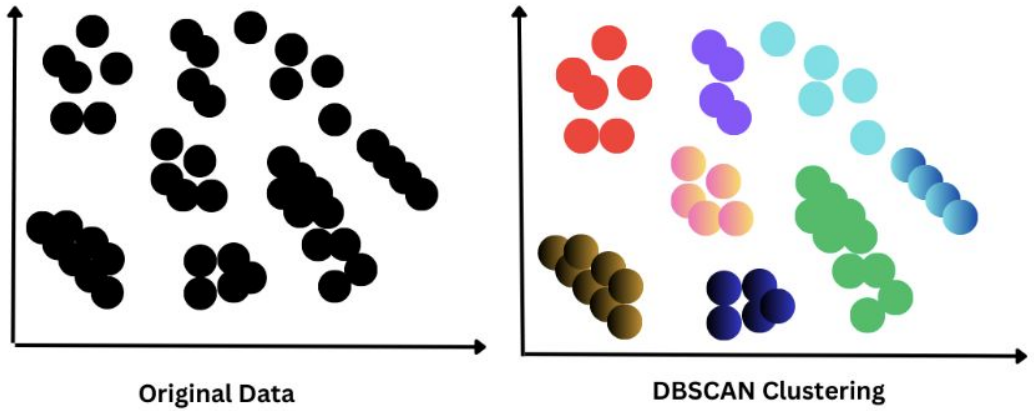


Motive and Objectives

- Large Number of data points and modest resolution with all sky survey
- Identify Spatial and Temporal Clusters from Fermi photon counts images
- Using AI or ML automation to detect spatial clusters
- Follow up CTA Cherenkov small patch observations

DBSCAN (Unsupervised Density Based Algorithm to identify Spatial Clusters)

- Clusters spatial data affected by background noise
- Discriminates signal (cluster) from background (noise) based on the local density of the event



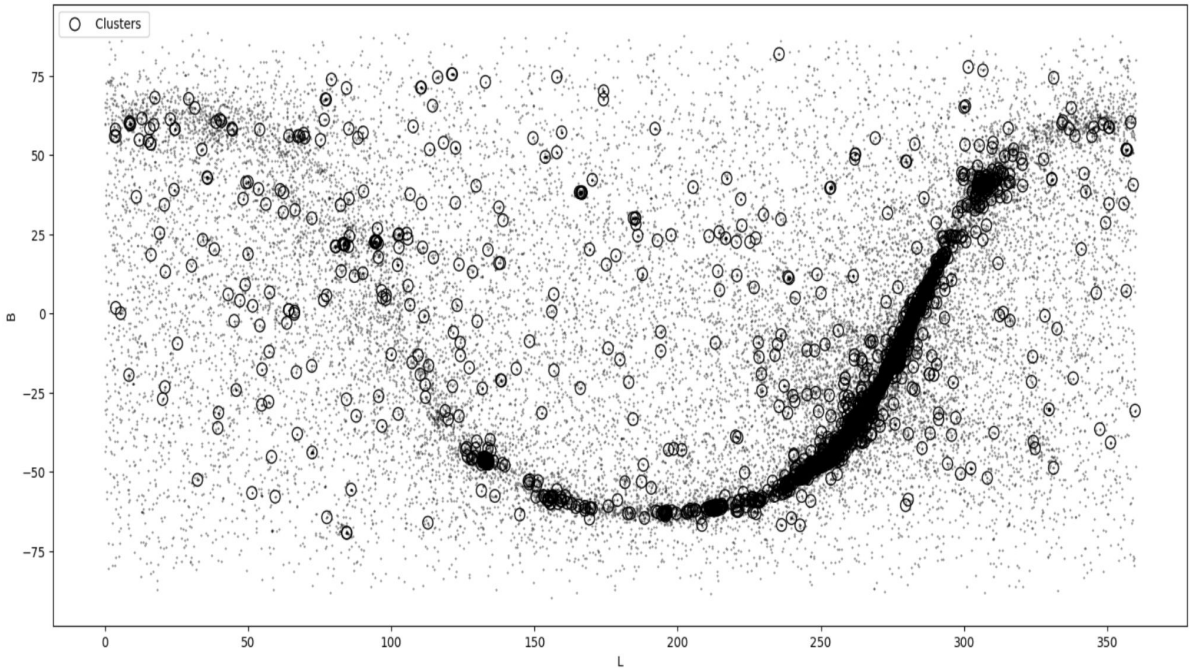
Reference image : https://medium.com/@jayaramganesh238/dbscan-clustering-dea27873ed30

Initial Scan of (photons with energy > 50 GeV)

DBSCAN Input

Number of photons

Search radius : Directly correlated with PSF



Modification from DBSCAN output

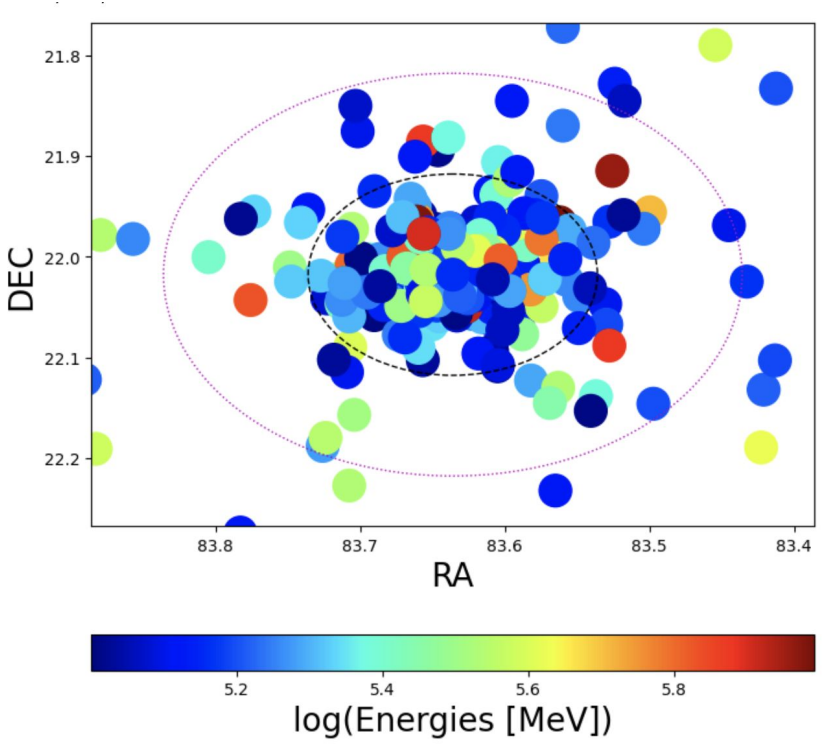
- Data Storage in a Tuple
- Coordinates of the cluster center
- Members of the cluster (location, arrival times, energy, total numbers)

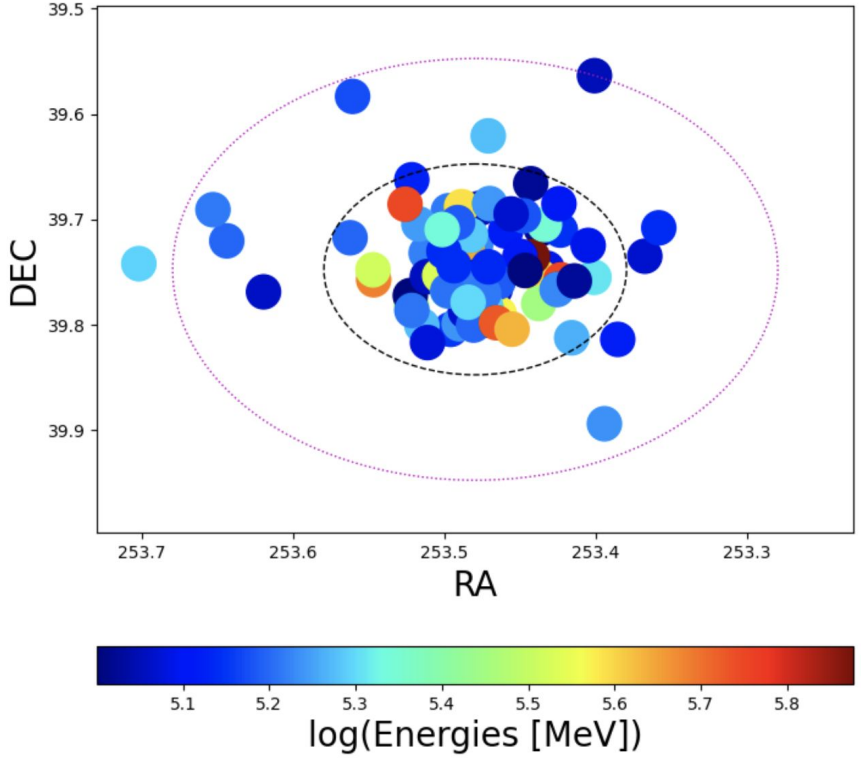
```
def cluster_from_X(X,r, n , energy, time): #
    db = DBSCAN(eps=r, min_samples=n).fit(X)
```

```
return cluster_centers , clusters, energies, arrival_time
```

```
def cluster_finder_updated(data, g_r, eg_r, g_n, eg_n):
```

Clusters Examples (0.1 and 0.2 degree circles)

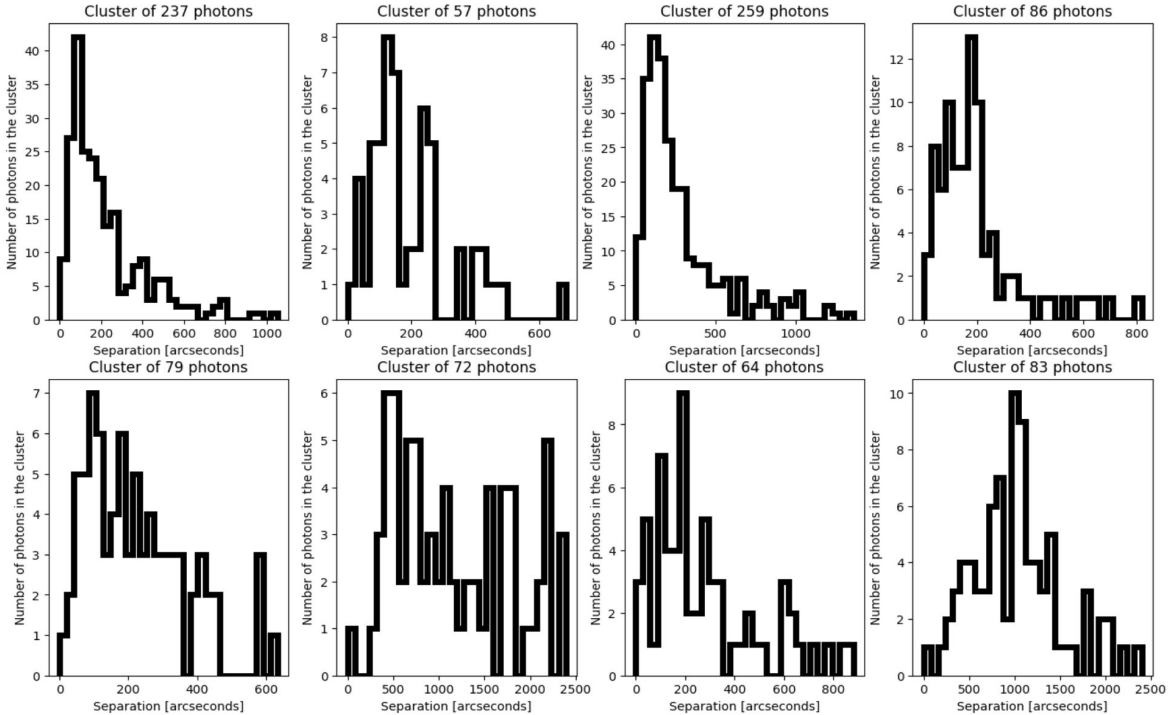




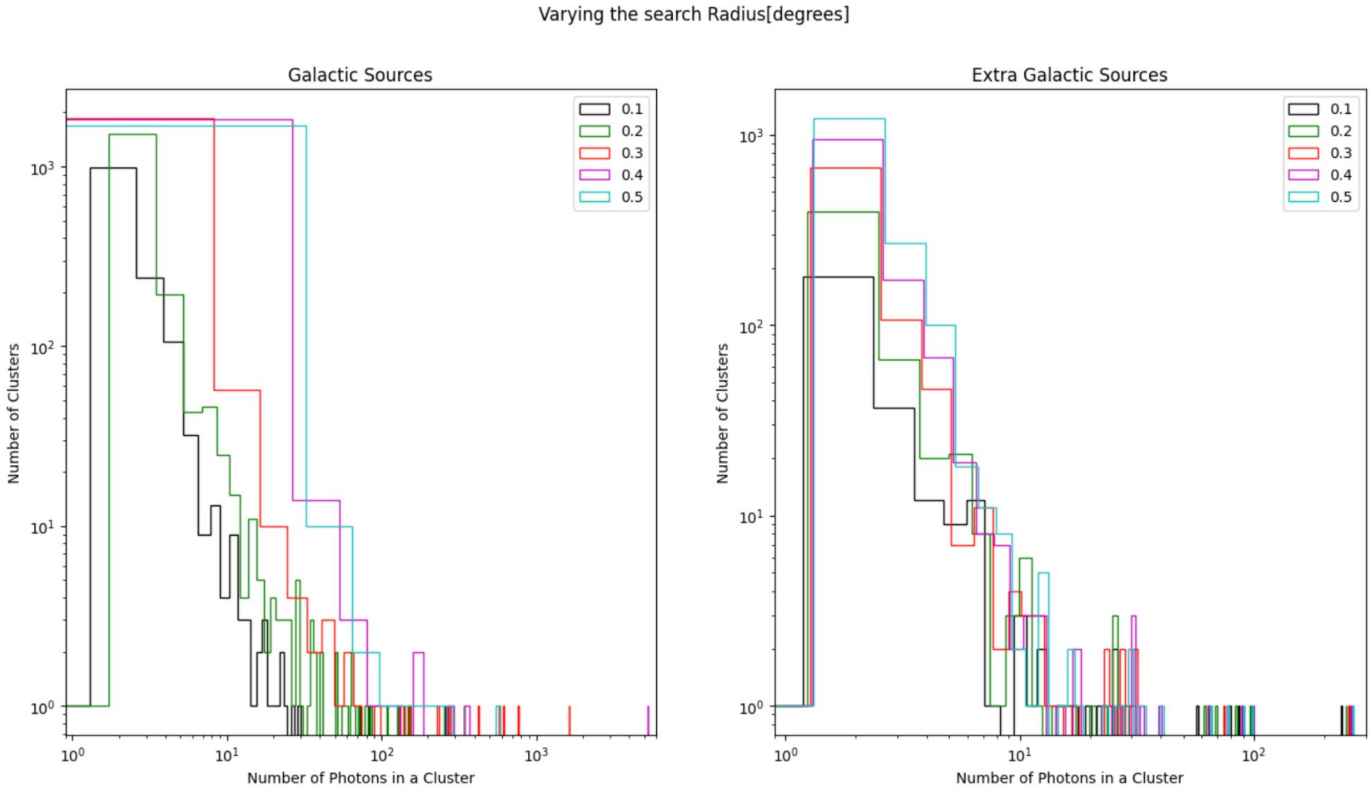
Radial Distributions - Point sources as well as Extended

Next step:

To find good input parameters



Varying the Cluster Radius



Time Clustering

For 78 months, probability of 2 photons occurring in 3°

$$P(k) = \lambda^k \cdot \frac{e^{-\lambda}}{k!}$$

$$k = 2\,\lambda^2 \cdot \frac{e^{-\lambda}}{2!} = 0.25$$

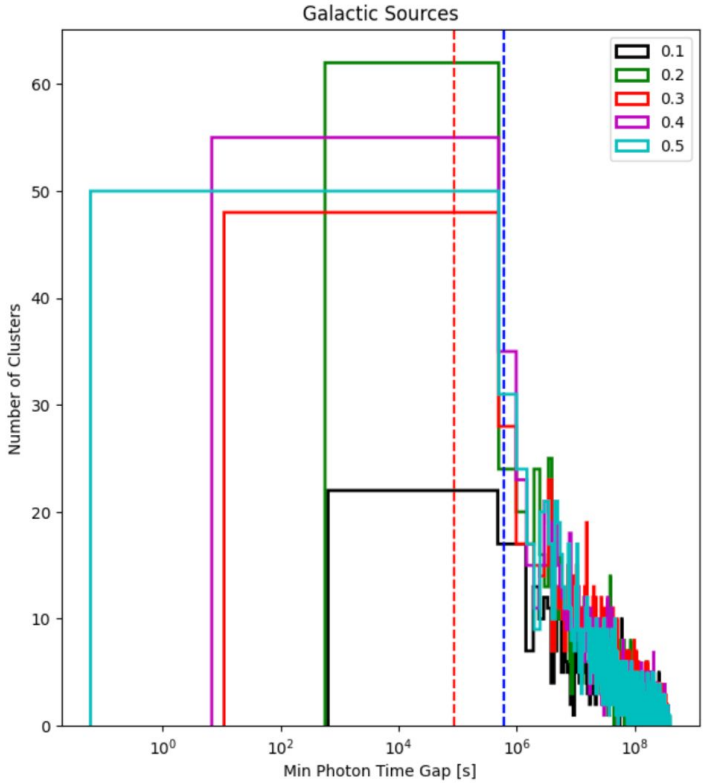
$$k = 3\,\lambda^3 \cdot \frac{e^{-\lambda}}{3!} = 0.21$$

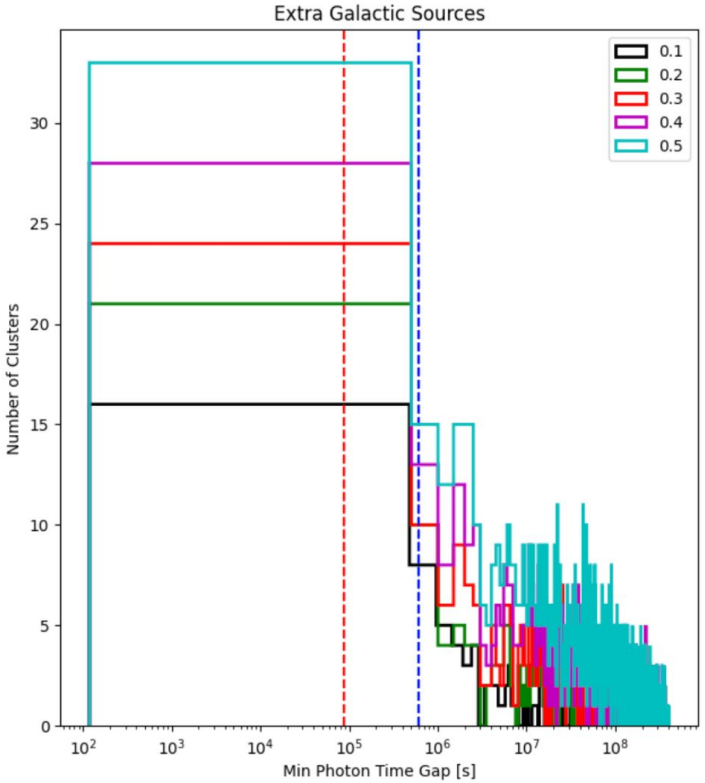
For one day : k = 0.00001

For one week : k = 0.007

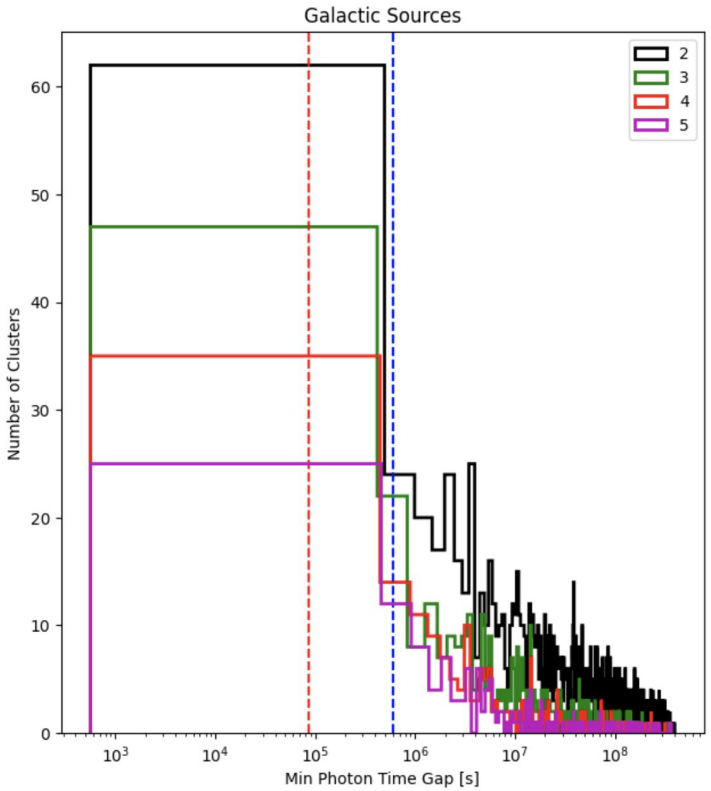
(Reference : Principe G. Master Thesis, 2015)

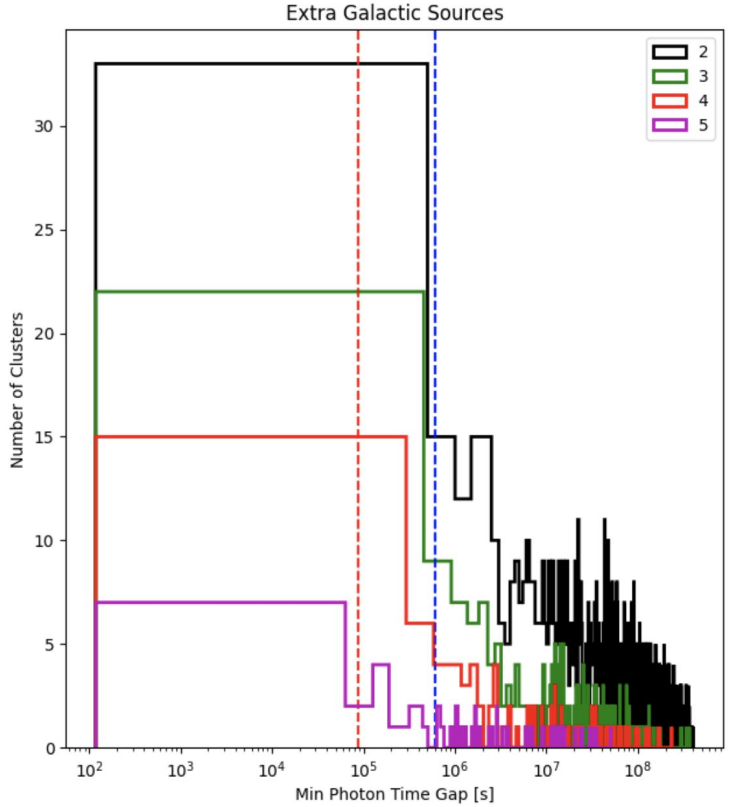
Varying the Cluster Radius





Varying the Photon Numbers with fixed Cluster Radius 0.2° for |b| < 10° and 0.5° for |b| > 10°





Final Parameters

Galactic

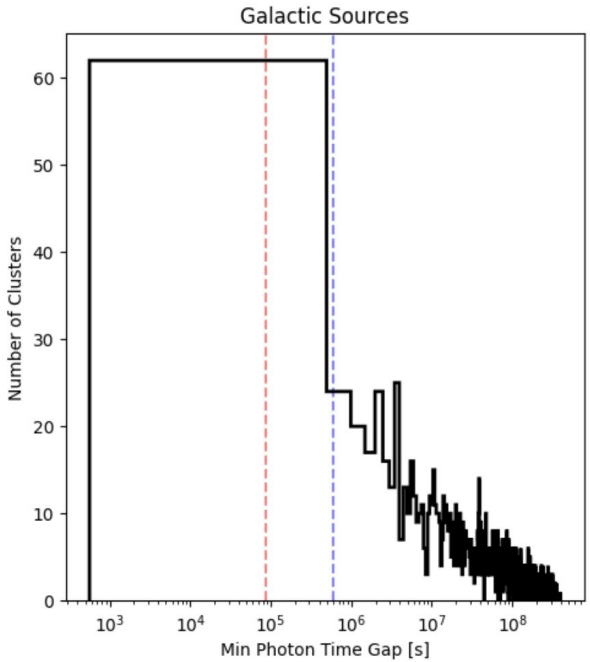
Cluster Radius : 0.2

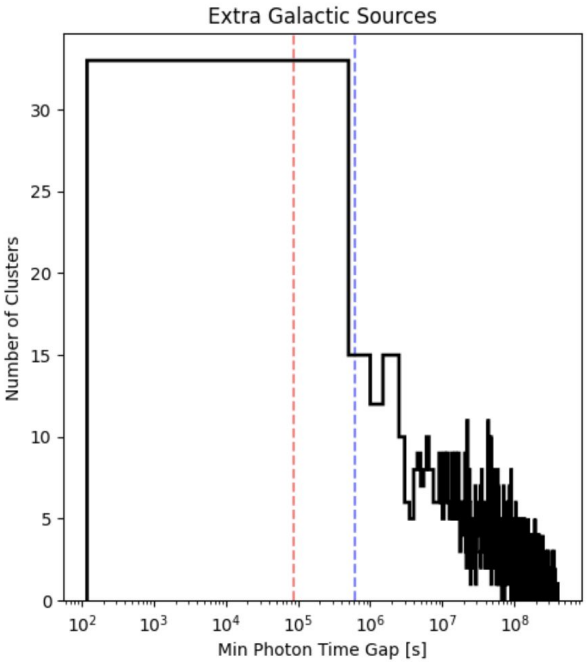
Min Photon Number : 2

Extra - Galactic

Cluster Radius : 0.5

Min Photon Number : 2





Source Catalogs to check counterpart presence

3FHL (Third Catalog of Hard Fermi-LAT Sources)

- Covers energy range from 10 GeV to 2 TeV
- Includes 1,556 sources
- Utilizes 7 years of Fermi-LAT data
- Focuses on sources with high-energy γ-ray emissions
- Key for studying extreme γ-ray phenomena

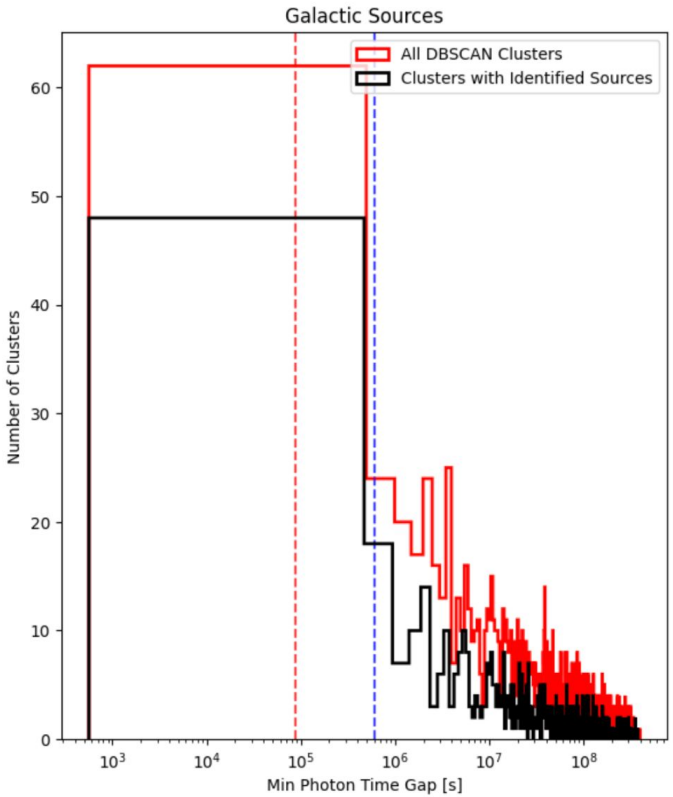
4FGL (Fourth Fermi-LAT Catalog)

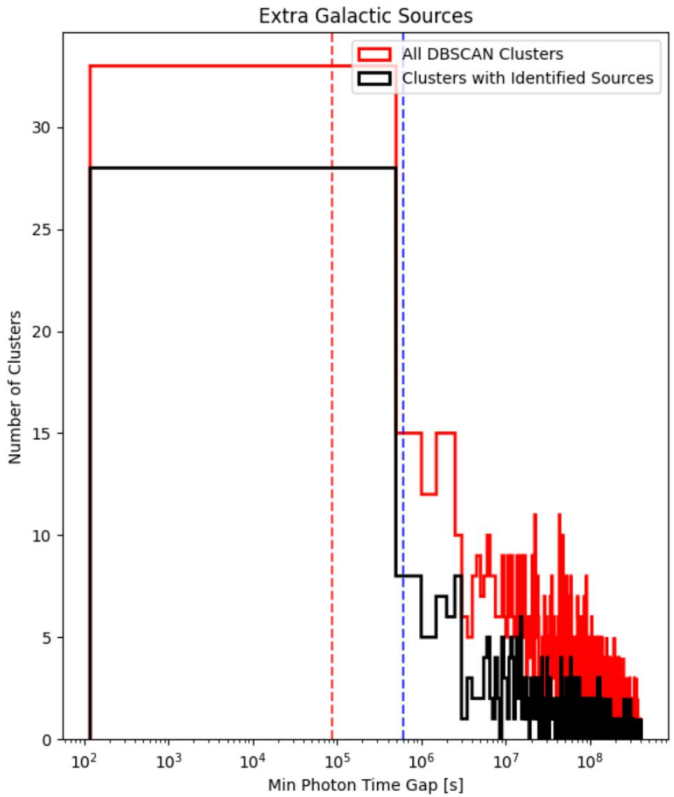
- Covers energy range from 50 MeV to 1 TeV
- Includes over 5,000 sources
- Utilizes 8 years of Fermi-LAT data
- Comprehensive catalog with improved source localization
- Important for multi-wavelength and multi-messenger astronomy

TeV Catalogs

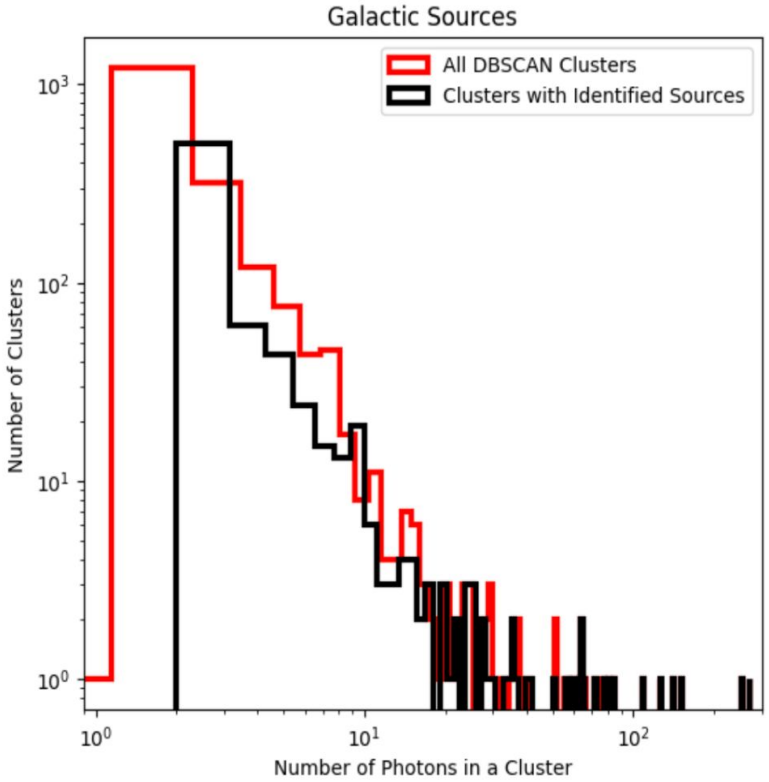
- Collects data from ground-based observatories (e.g., H.E.S.S., MAGIC, VERITAS)
- Covers energy range above 1 TeV
- Includes sources detected at very high energies
- Energetic astrophysical processes
- Complements Fermi-LAT catalogs for a full spectrum analysis

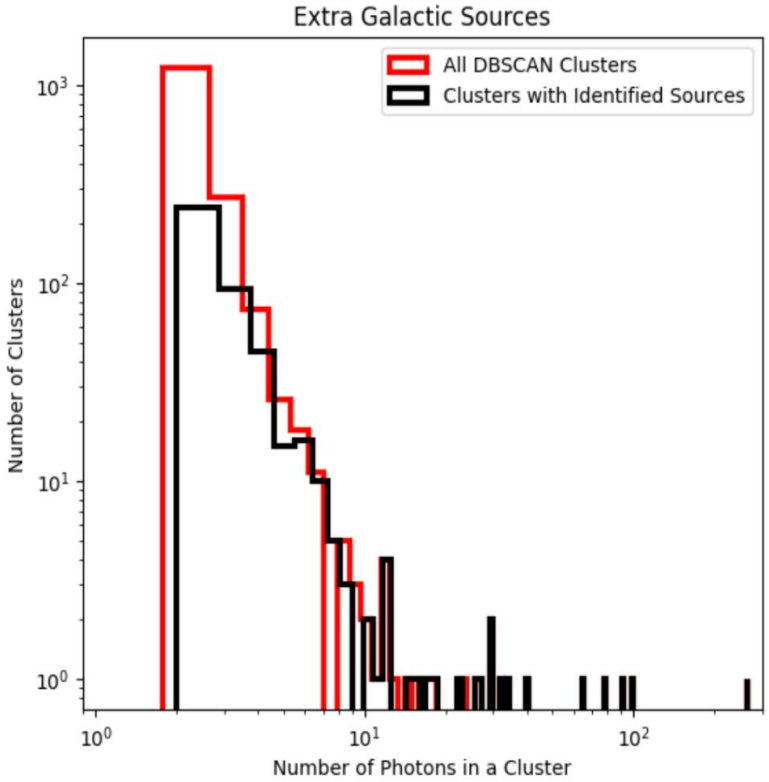
Counterparts in 3FHL, 4FGL and TeV catalogs



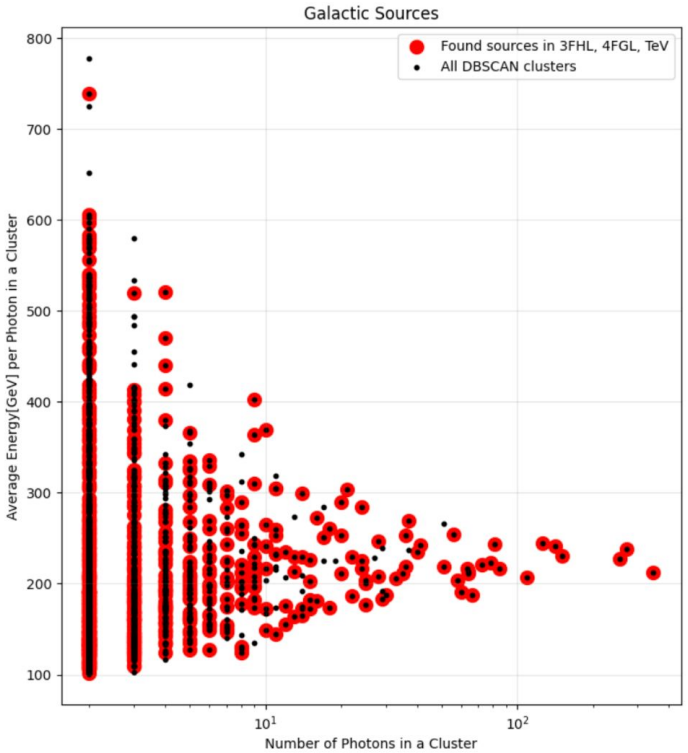


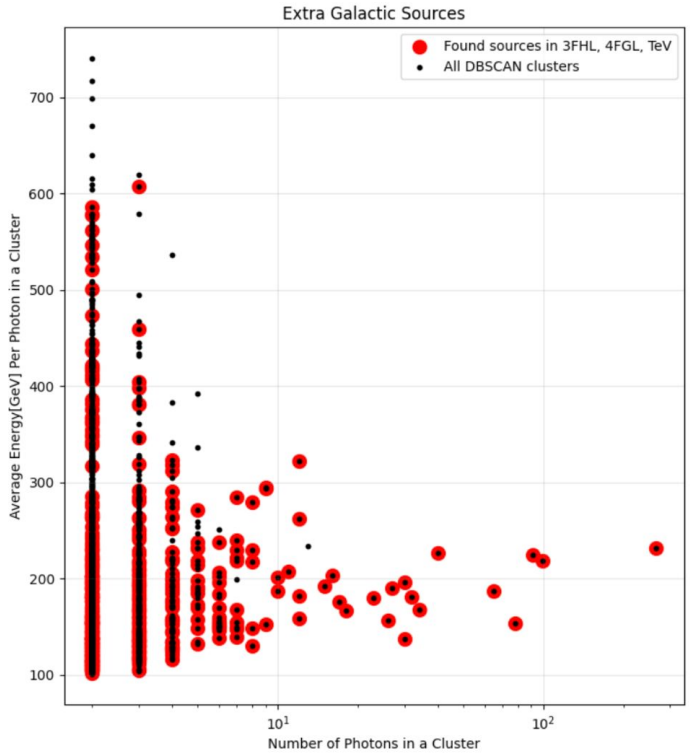
Photon Distributions



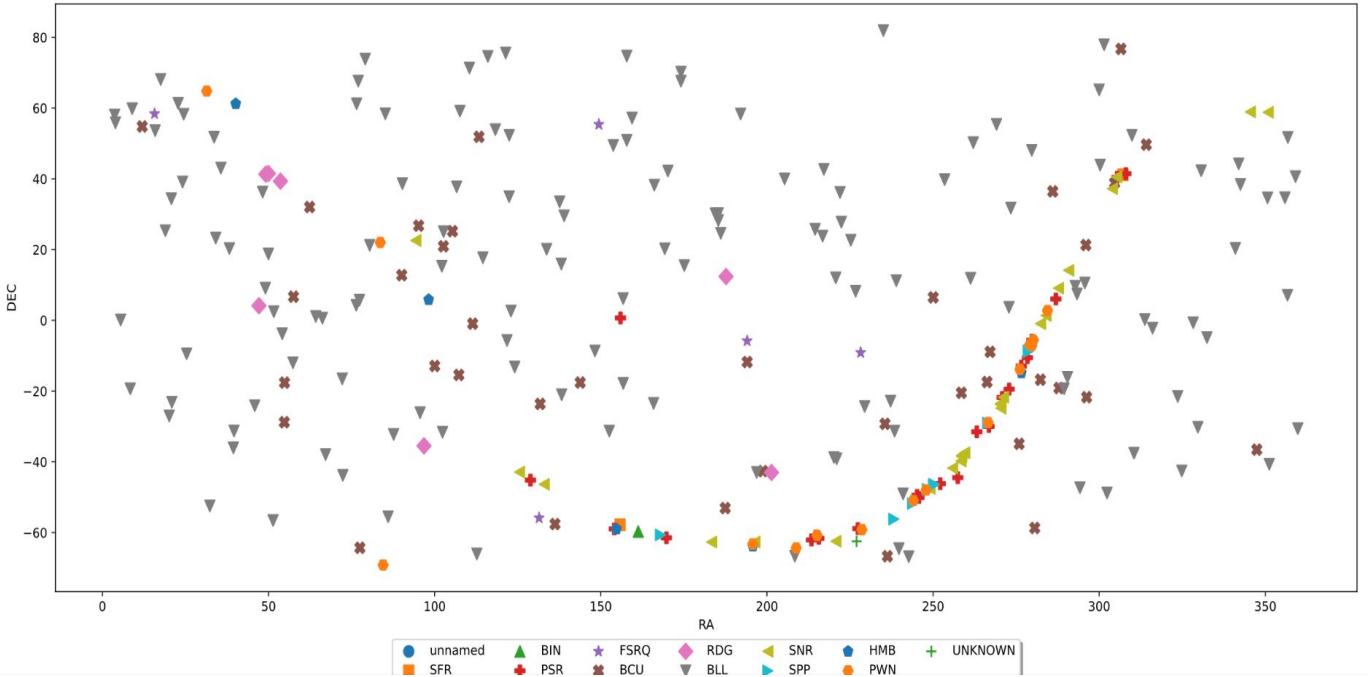


Photon Numbers vs Average Energy inside the Clusters

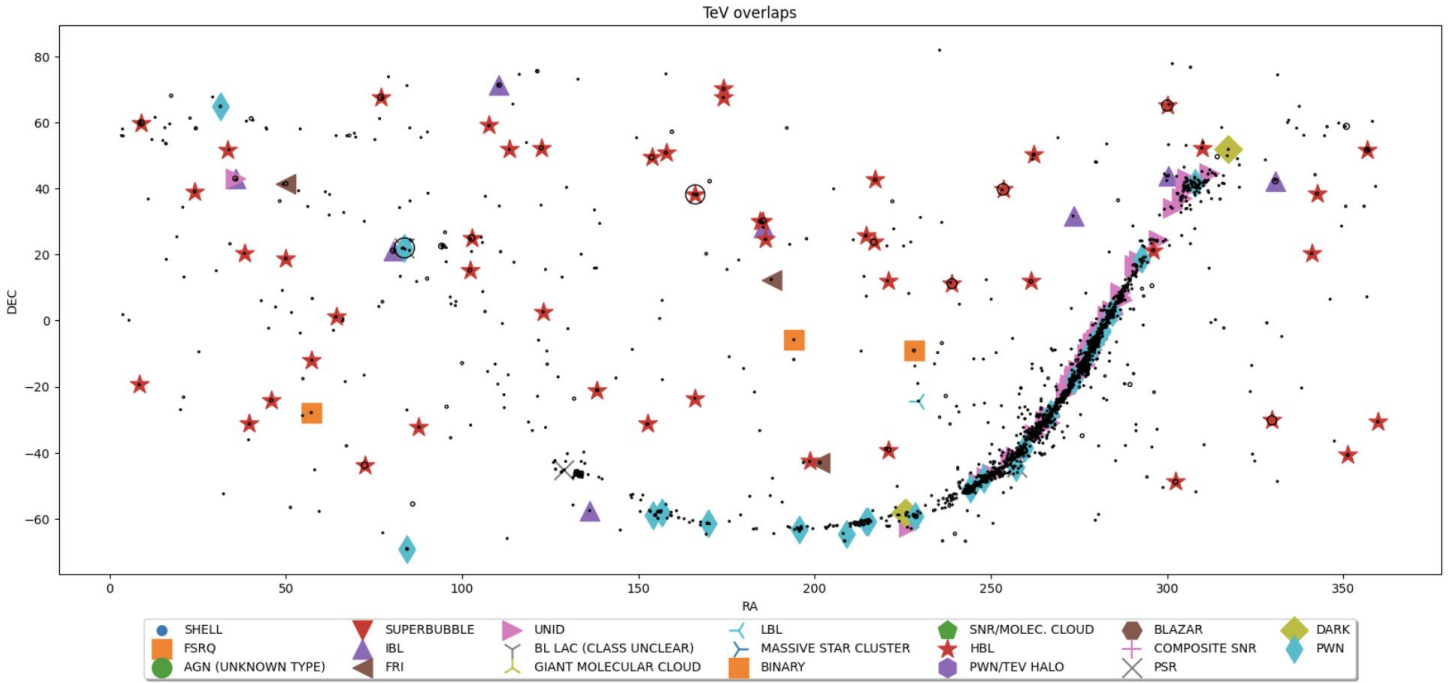




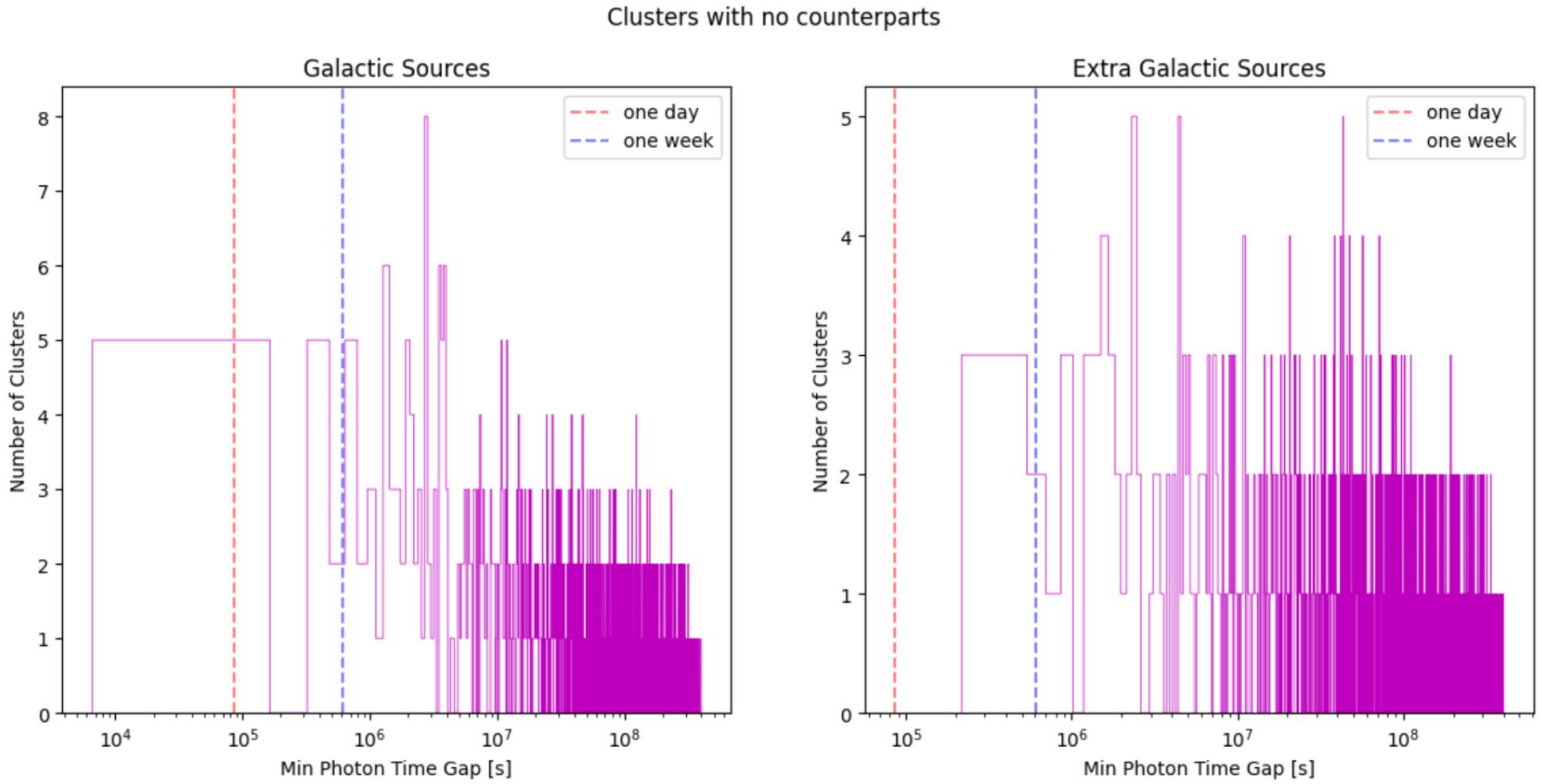
Type of overlapping 3FHL sources/clusters



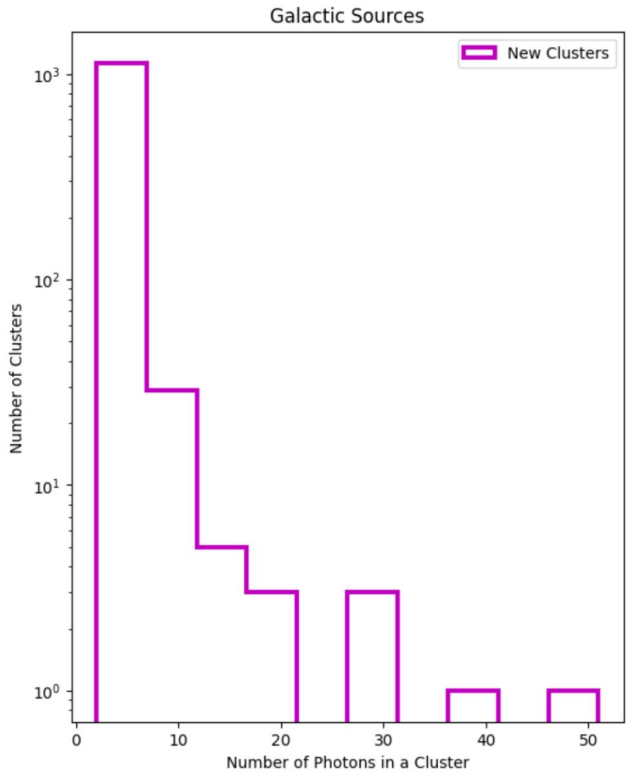
Type of Overlapping TeV sources

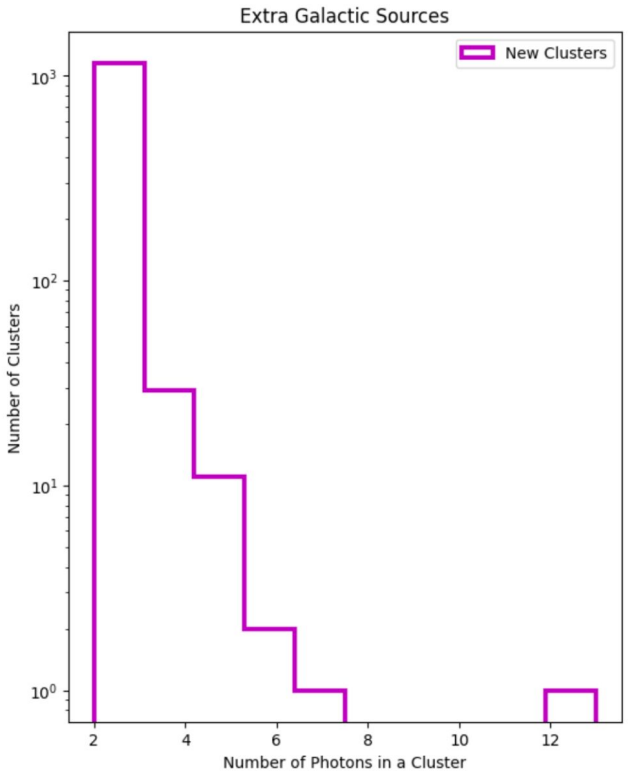


Time Clustering of New Spatial Clusters



Photon Number Distribution in New Clusters

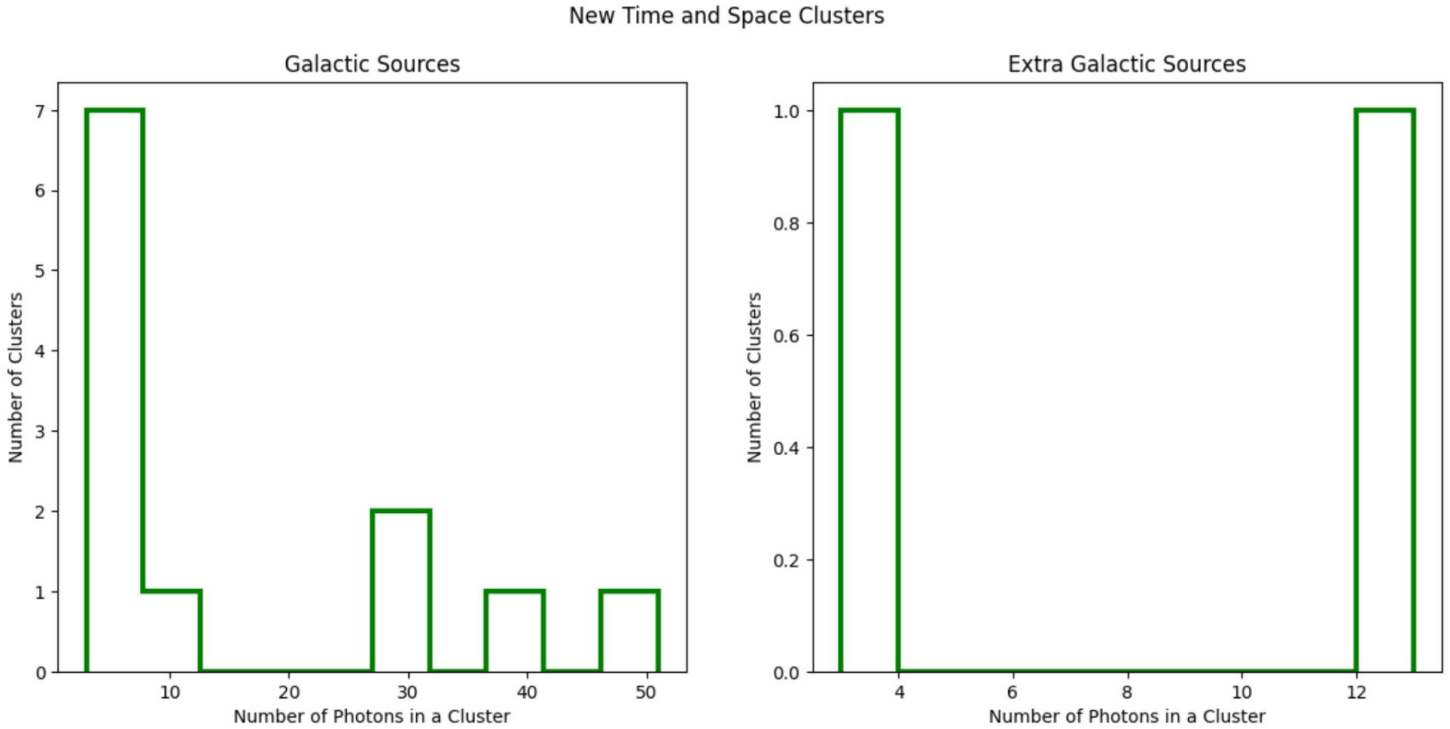




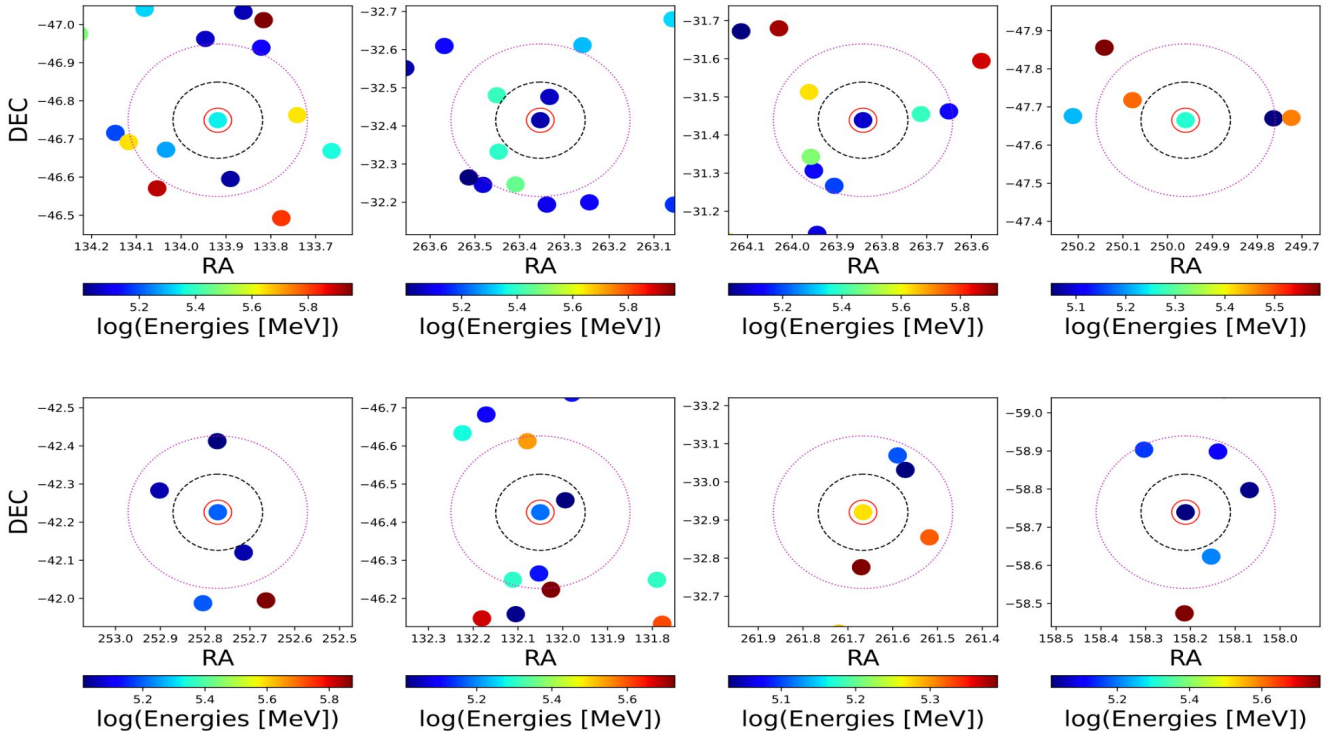
New Clusters

Total :	Galactic	Extra Galactic
Time Gap < 1 week :	12	7
N(Photons) > 2	338	221
N(Photons) > 2 & Time Gap < 1 week :	12	2

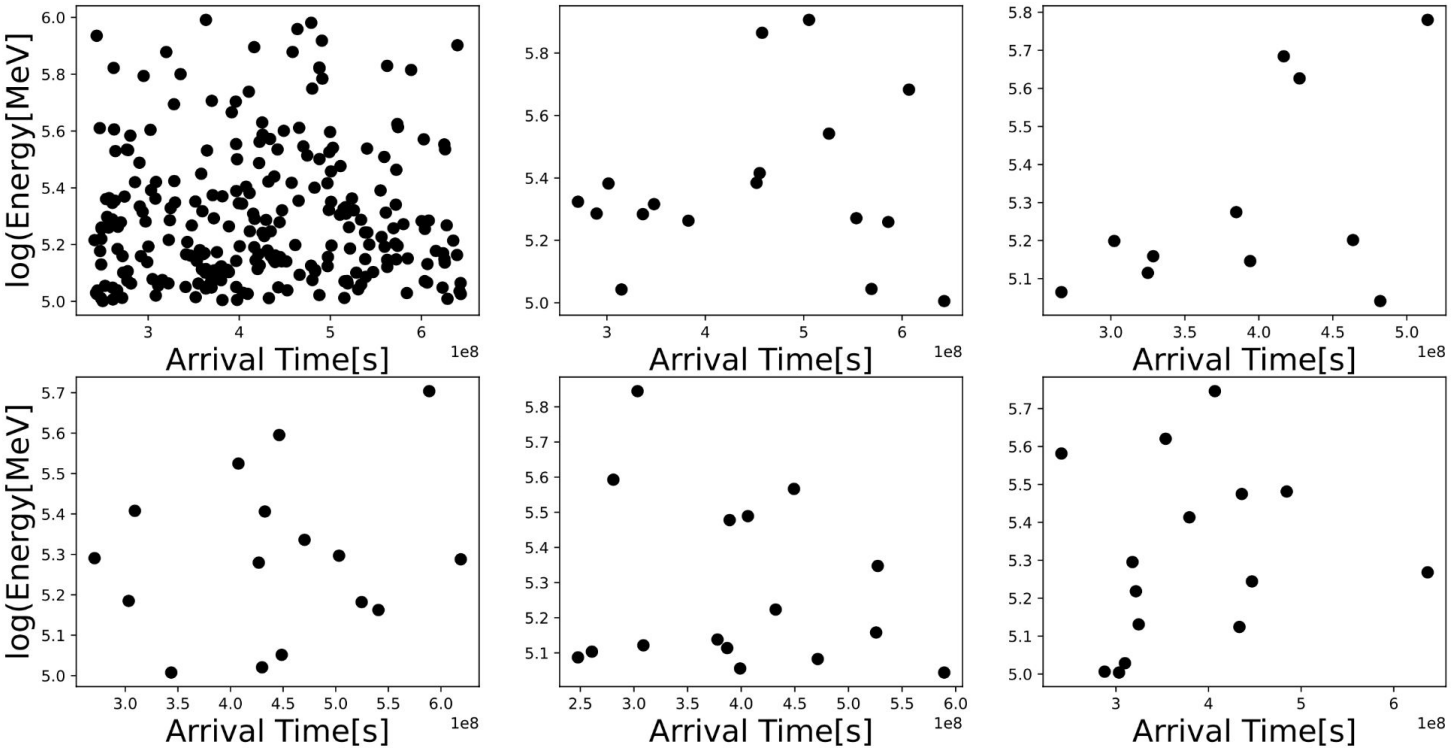
Spatial and Temporal Clustering Final Results



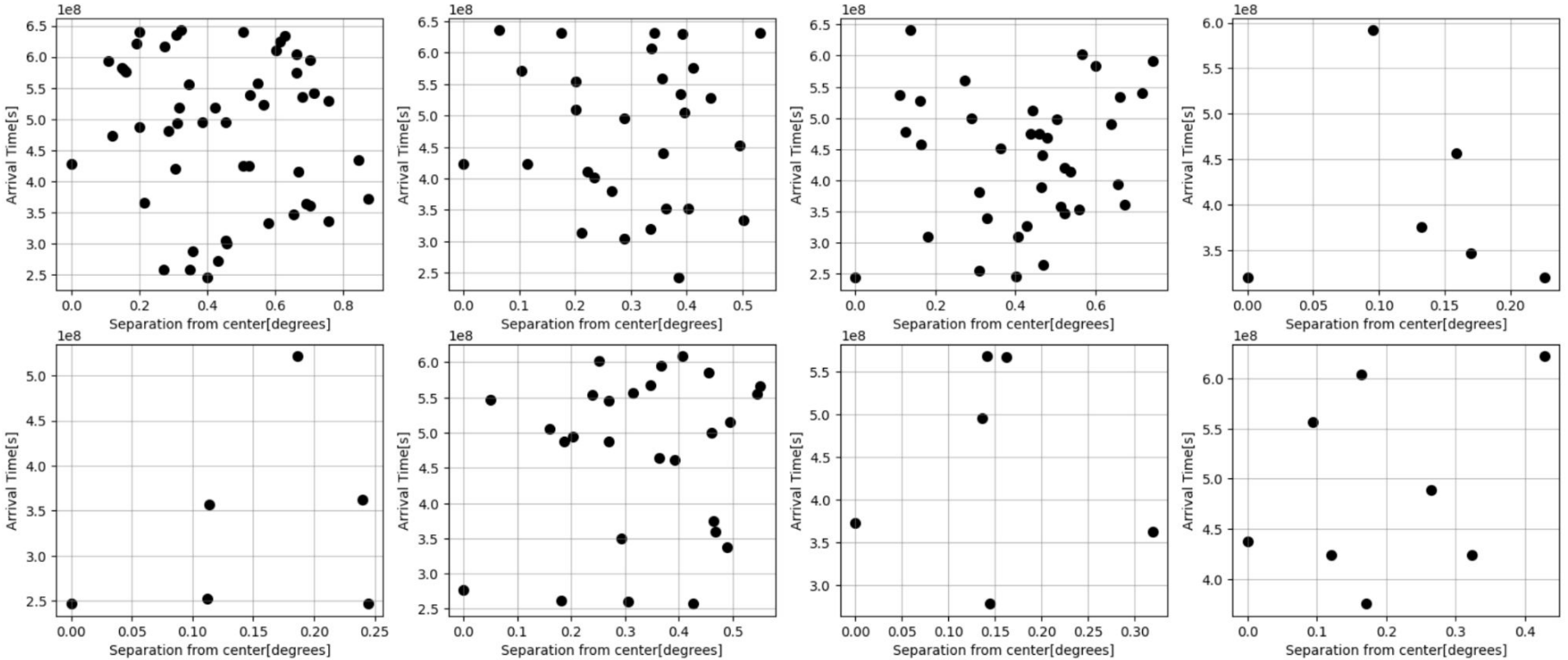
New Photon Clusters



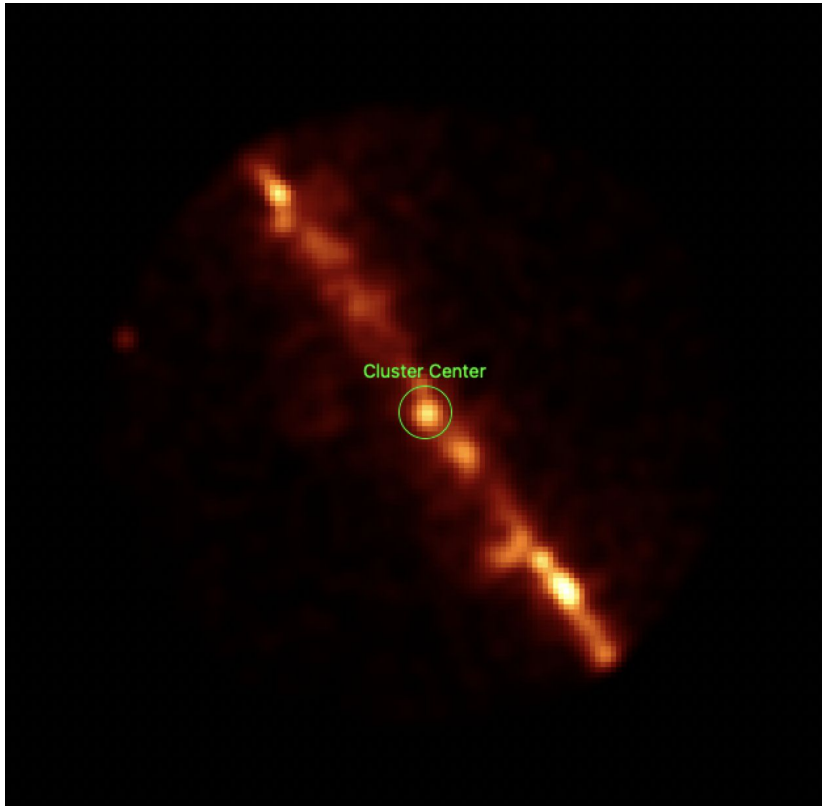
Light Curves of some of the New clusters

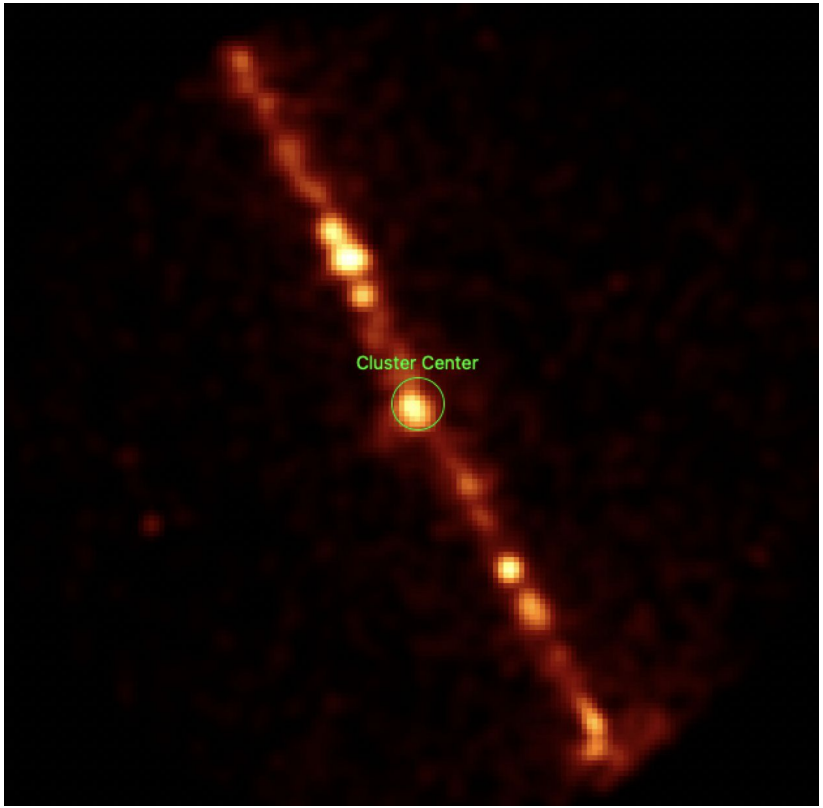


Arrival Times vs Separation from Center



Cmaps of some the regions





Future work (next semester)

Matching Energy Cuts

More Fermipy Analysis

More Statistical Analysis work

Publishing a catalog