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

Summer Project Presentation

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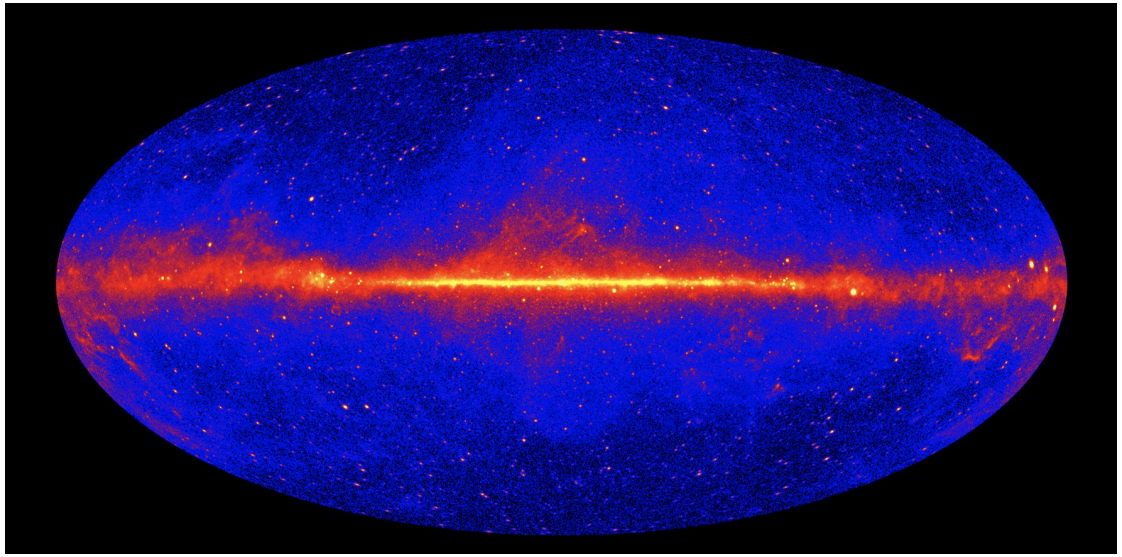
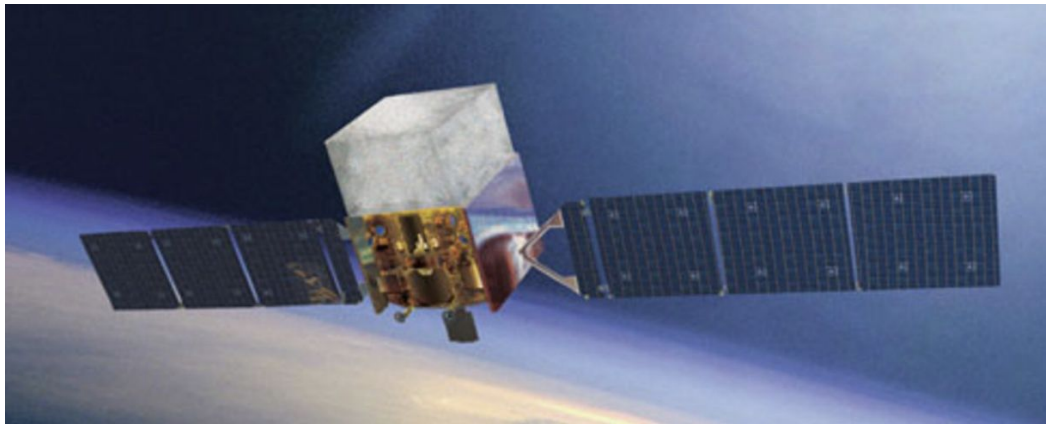
# Fermi - LAT

- 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



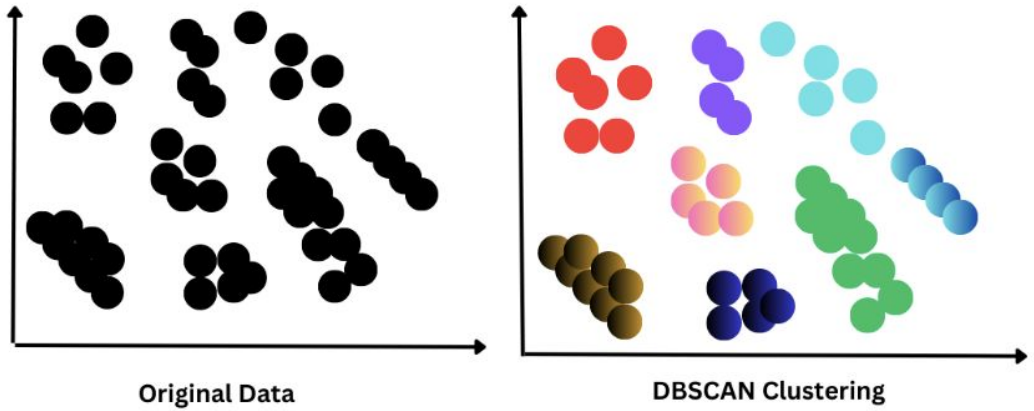


# Motive and Objectives

- 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



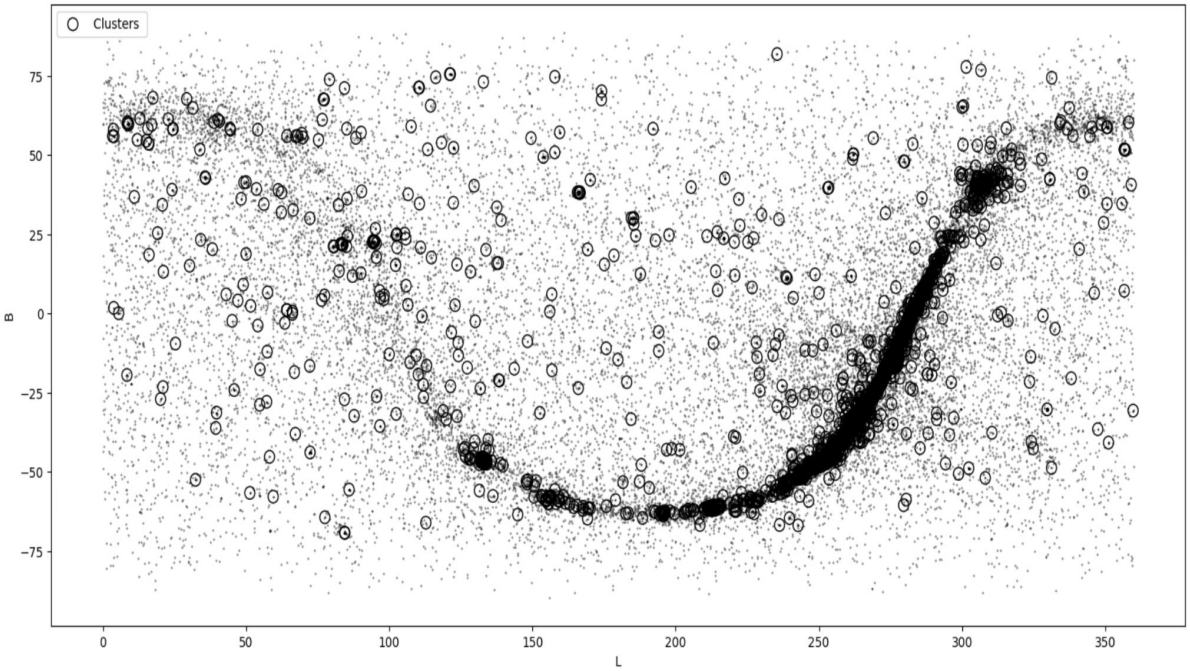

Reference image : https://medium.com/@jayaramganesh238/dbscan-clustering-dea27873ed30

# Initial Scan of (photons with energy > 50 GeV)

DBSCAN Input

Number of photons

Search radius : Directly correlated with PSF



# Modification from DBSCAN output

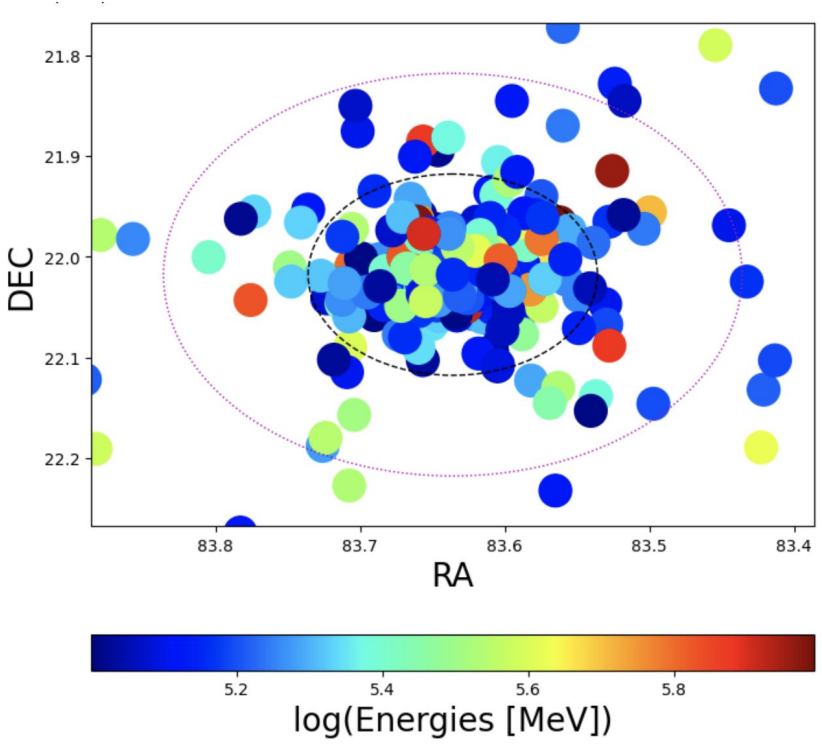
- Data Storage in a Tuple
- Coordinates of the cluster center
- Members of the cluster (location, arrival times, energy, total numbers)

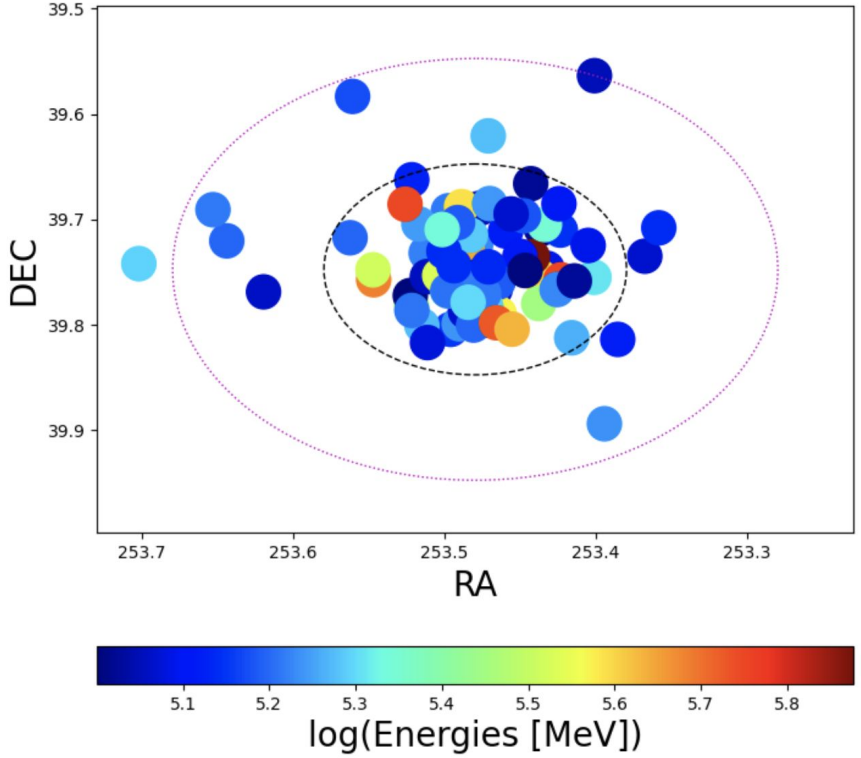
```
def cluster_from_X(X,r, n , energy, time): #
    db = DBSCAN(eps=r, min_samples=n).fit(X)
```

```
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)

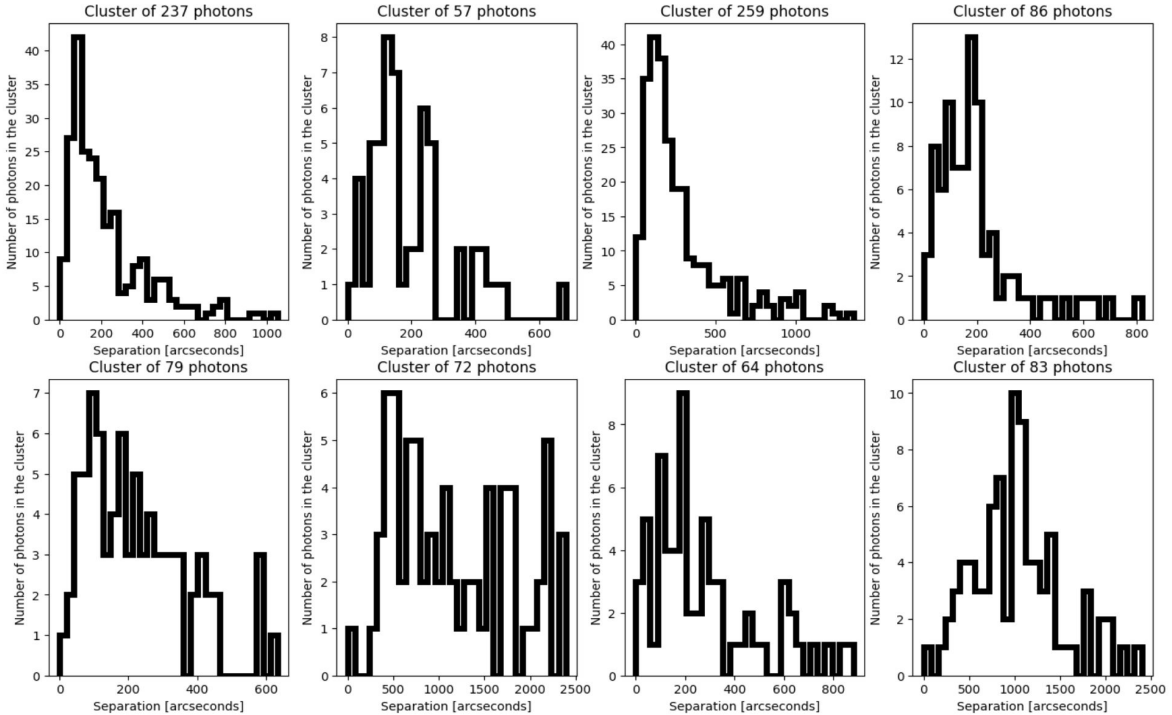


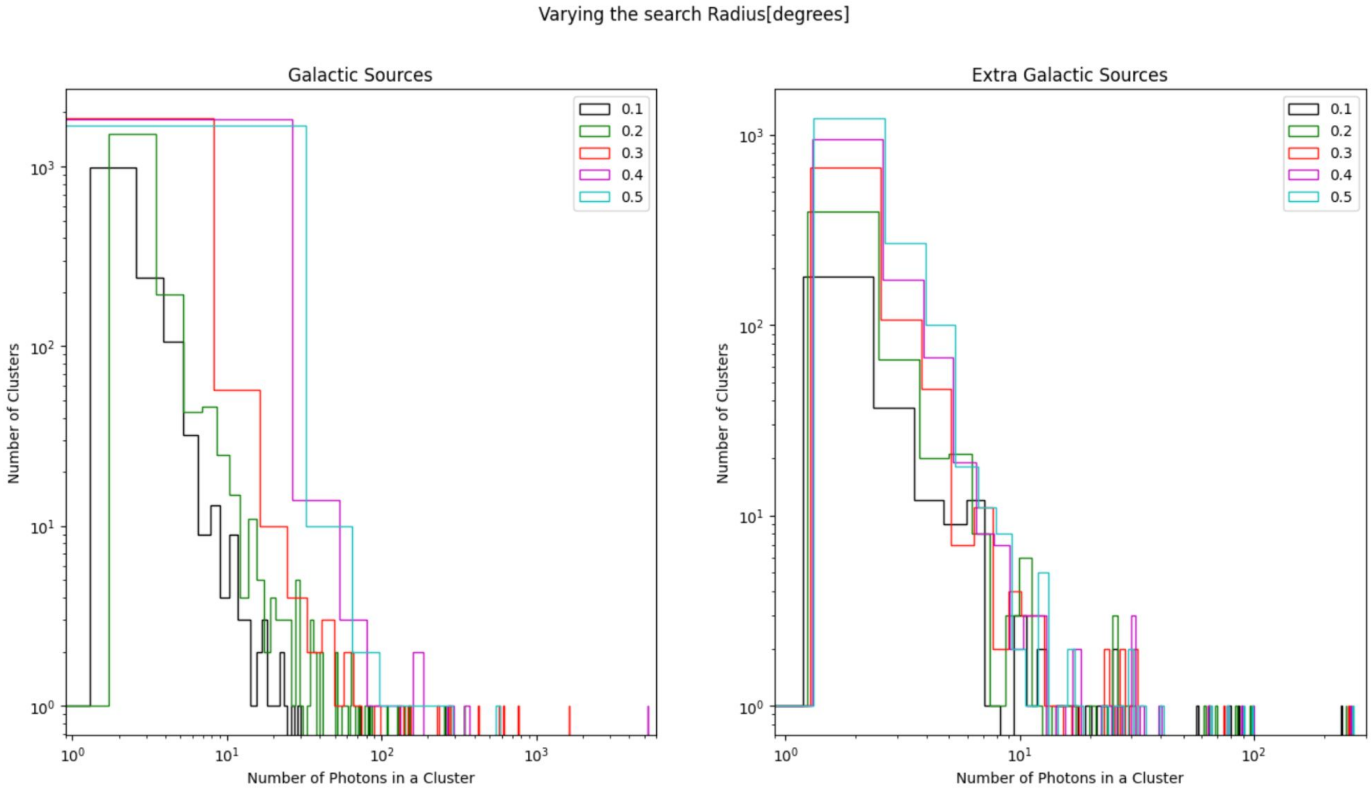
# Radial Distributions - Point sources as well as Extended

Next step:

To find good input parameters



# Varying the Cluster Radius



# Time Clustering

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

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

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

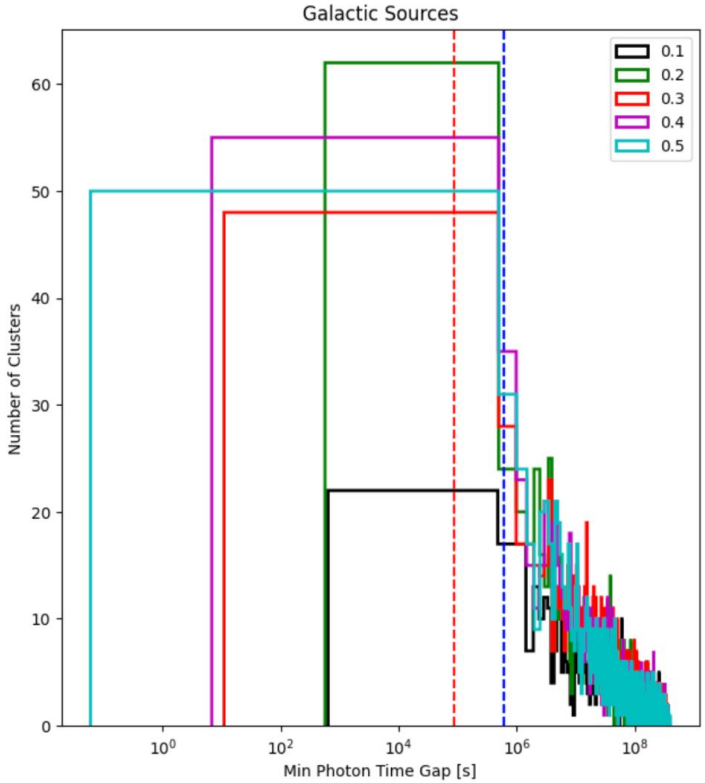
$$k = 3\,\lambda^3 \cdot \frac{e^{-\lambda}}{3!} = 0.21$$

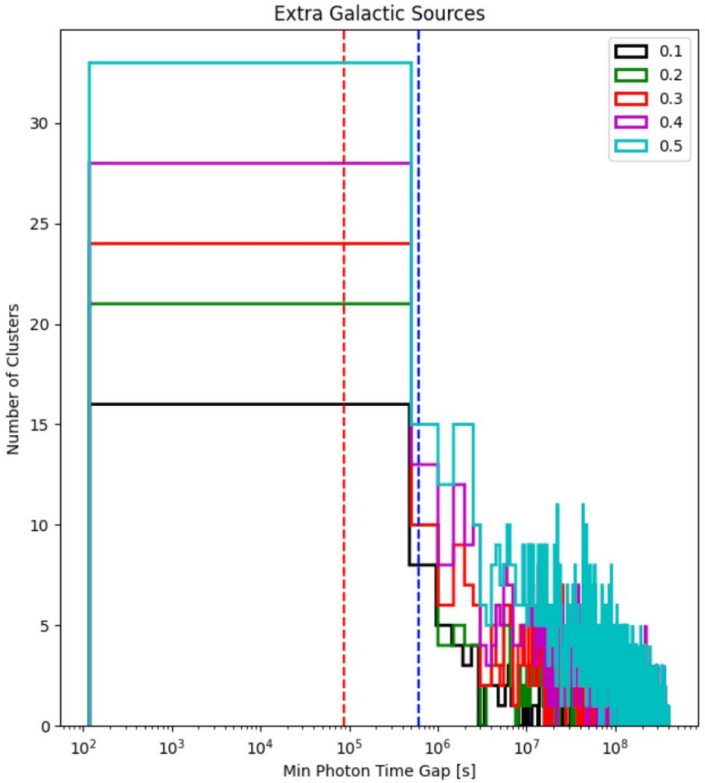
For one day : k = 0.00001

For one week : k = 0.007

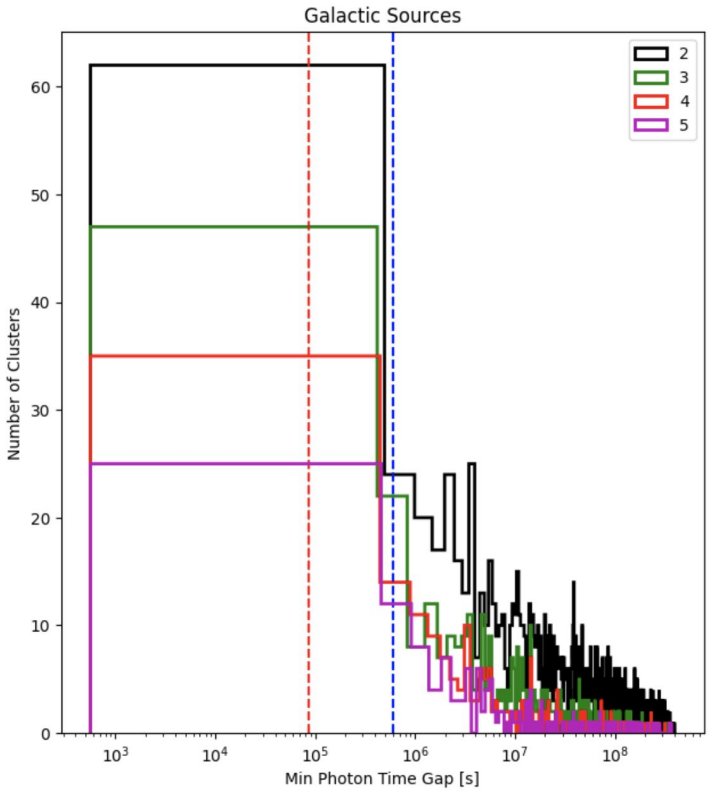
(Reference : Principe G. Master Thesis, 2015)

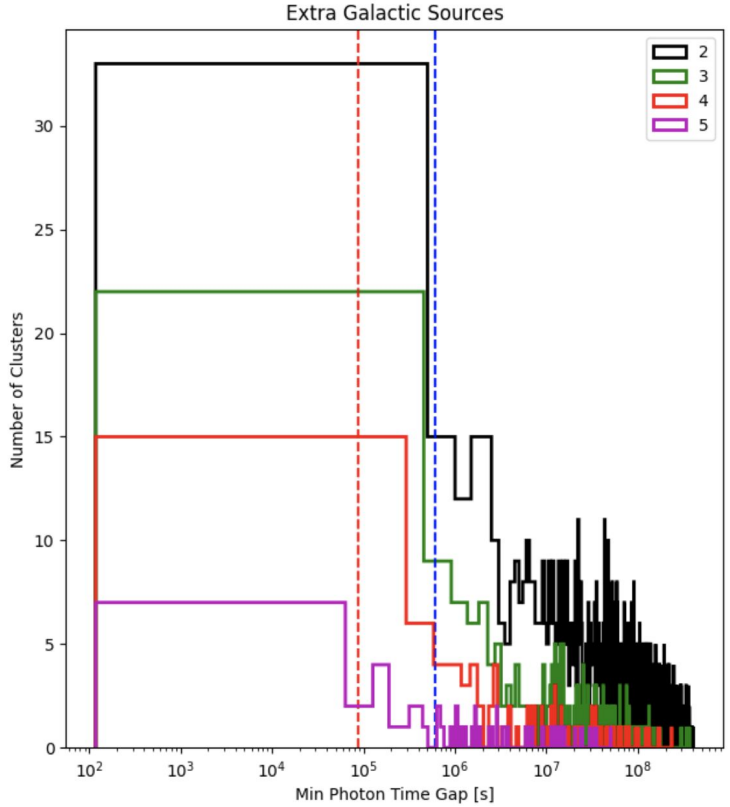
# Varying the Cluster Radius



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



# Final Parameters

## Galactic

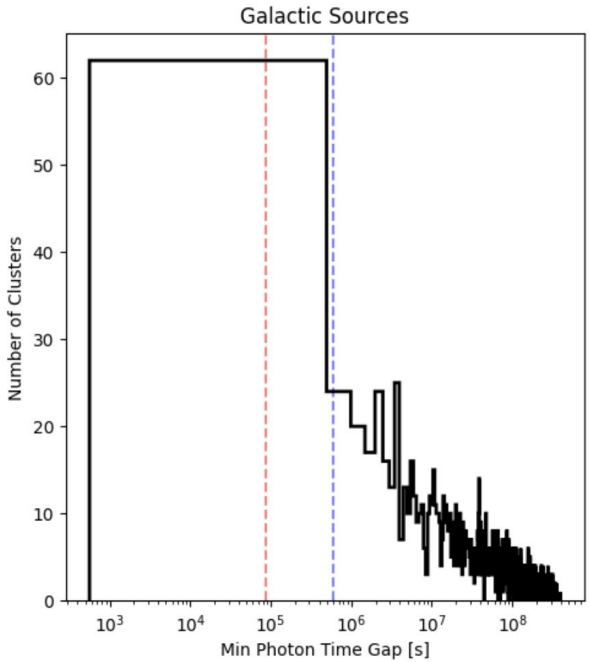
Cluster Radius : 0.2

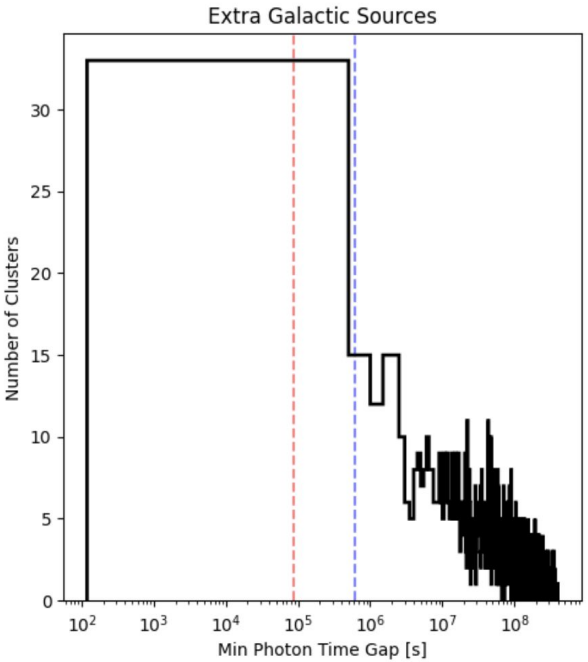
Min Photon Number : 2

## 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

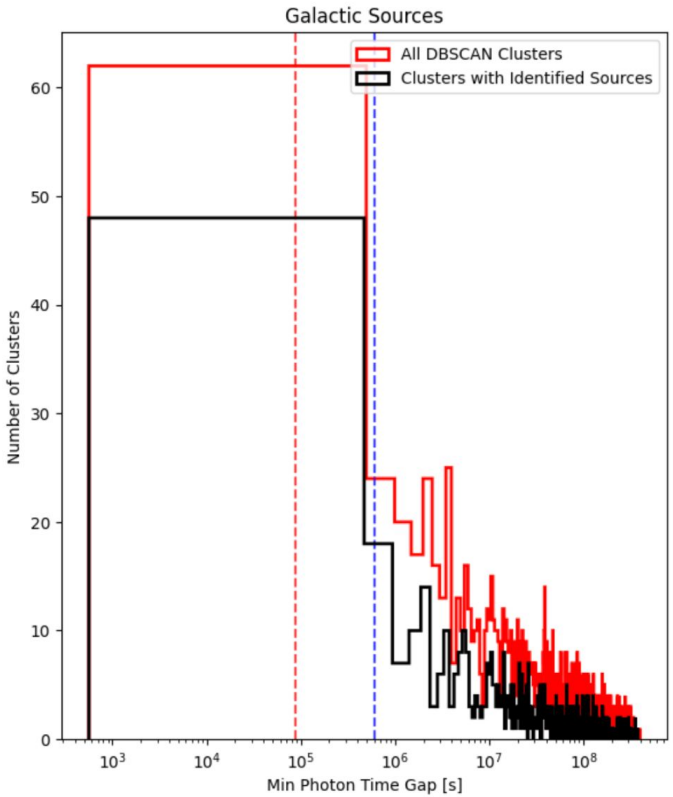
**4FGL (Fourth Fermi-LAT Catalog)**

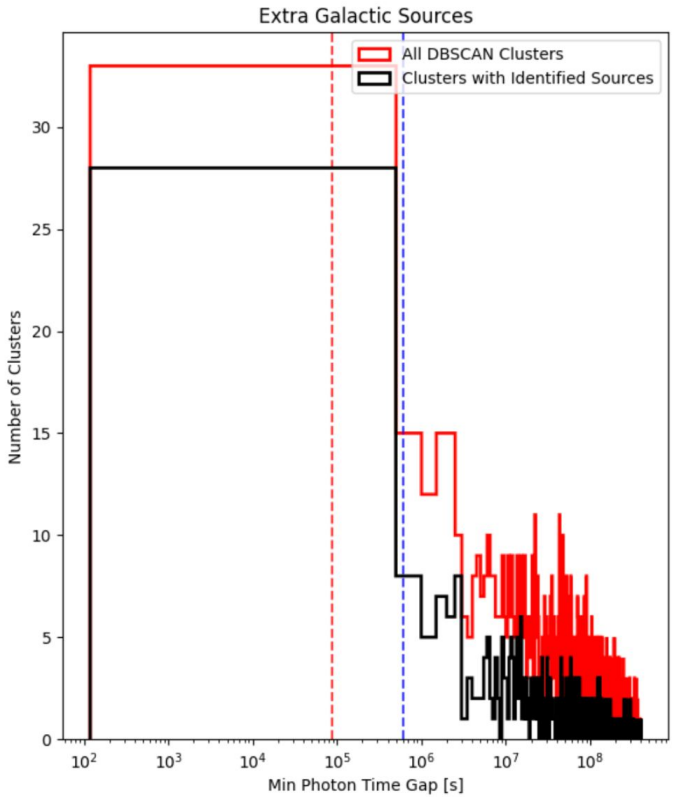
- Covers energy range from 50 MeV to 1 TeV
- Includes over 5,000 sources
- Utilizes 8 years of Fermi-LAT data
- Comprehensive catalog with improved source localization
- Important for multi-wavelength and multi-messenger astronomy

**TeV Catalogs**

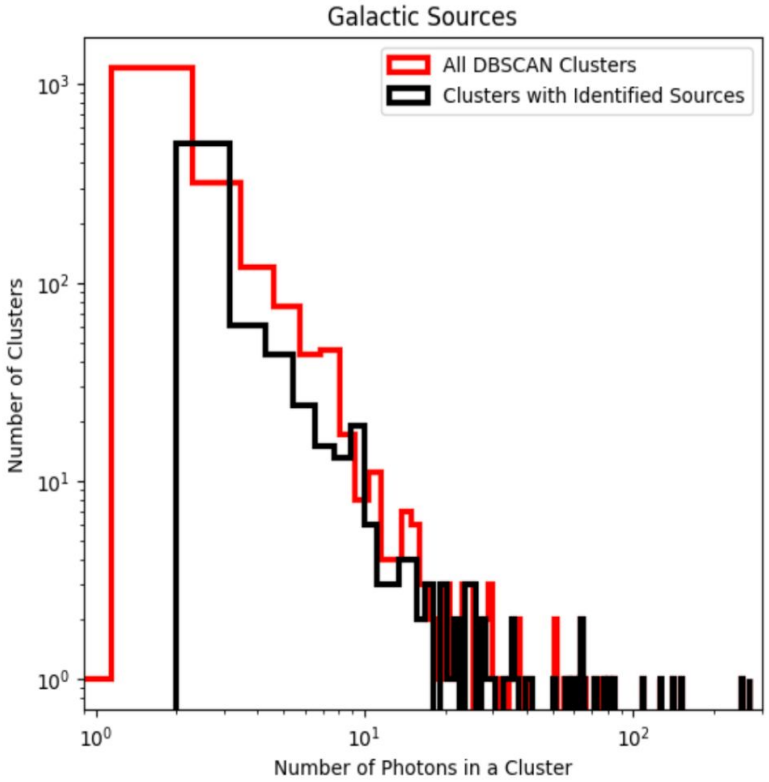
- Collects data from ground-based observatories (e.g., H.E.S.S., MAGIC, VERITAS)
- Covers energy range above 1 TeV
- Includes sources detected at very high energies
- Energetic astrophysical processes
- Complements Fermi-LAT catalogs for a full spectrum analysis

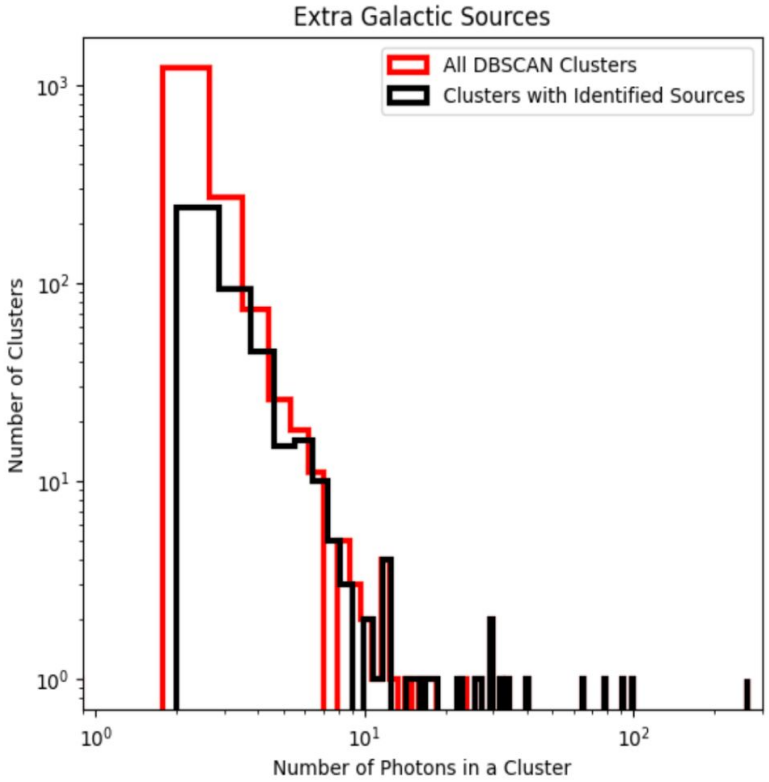
# Counterparts in 3FHL, 4FGL and TeV catalogs



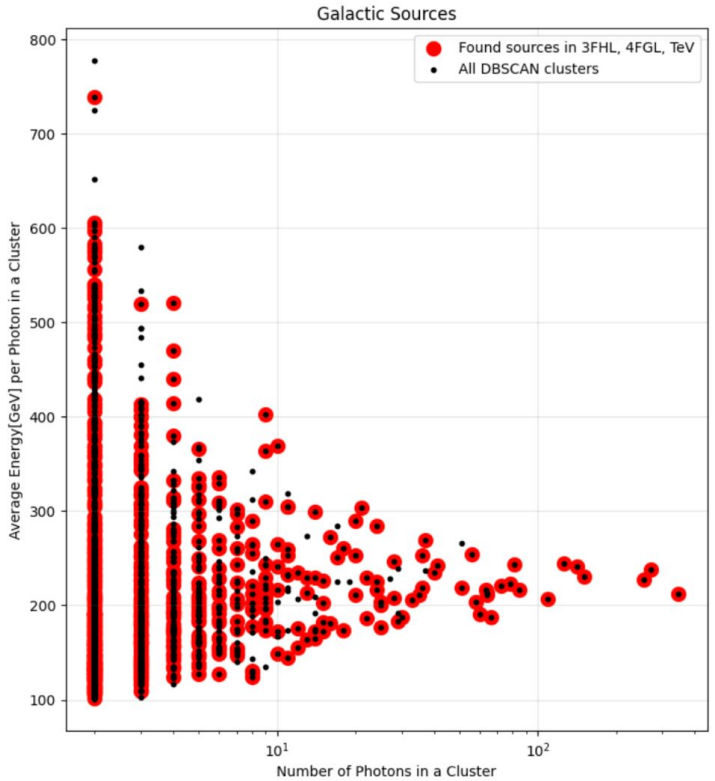



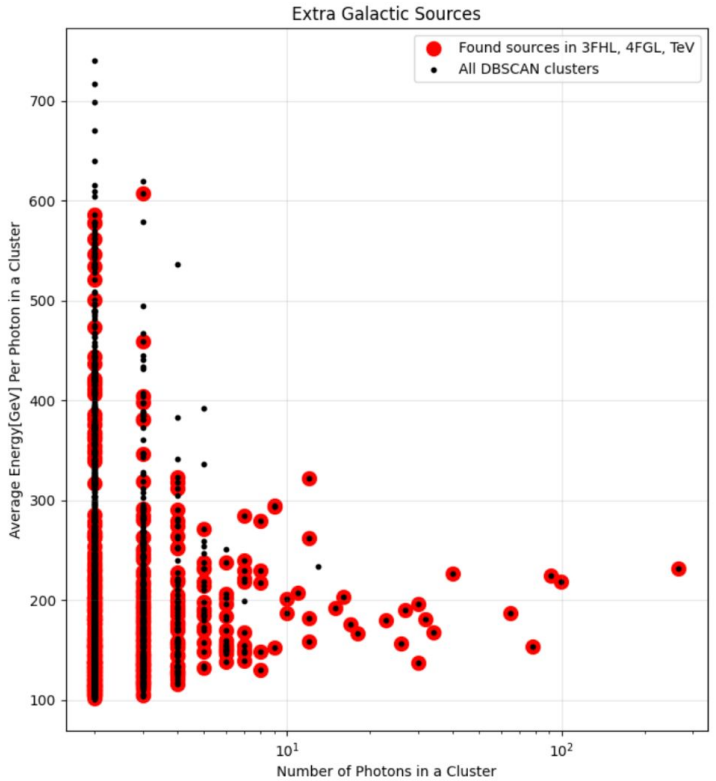
# Photon Distributions



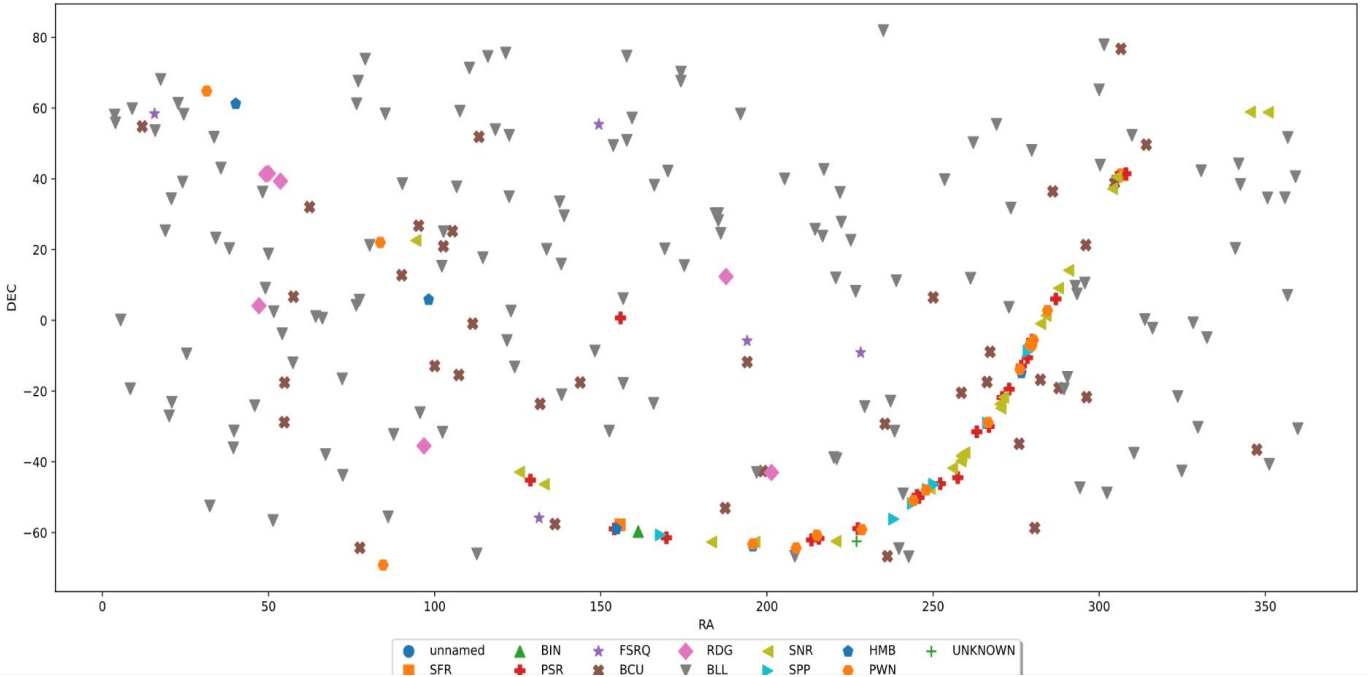



# Photon Numbers vs Average Energy inside the Clusters

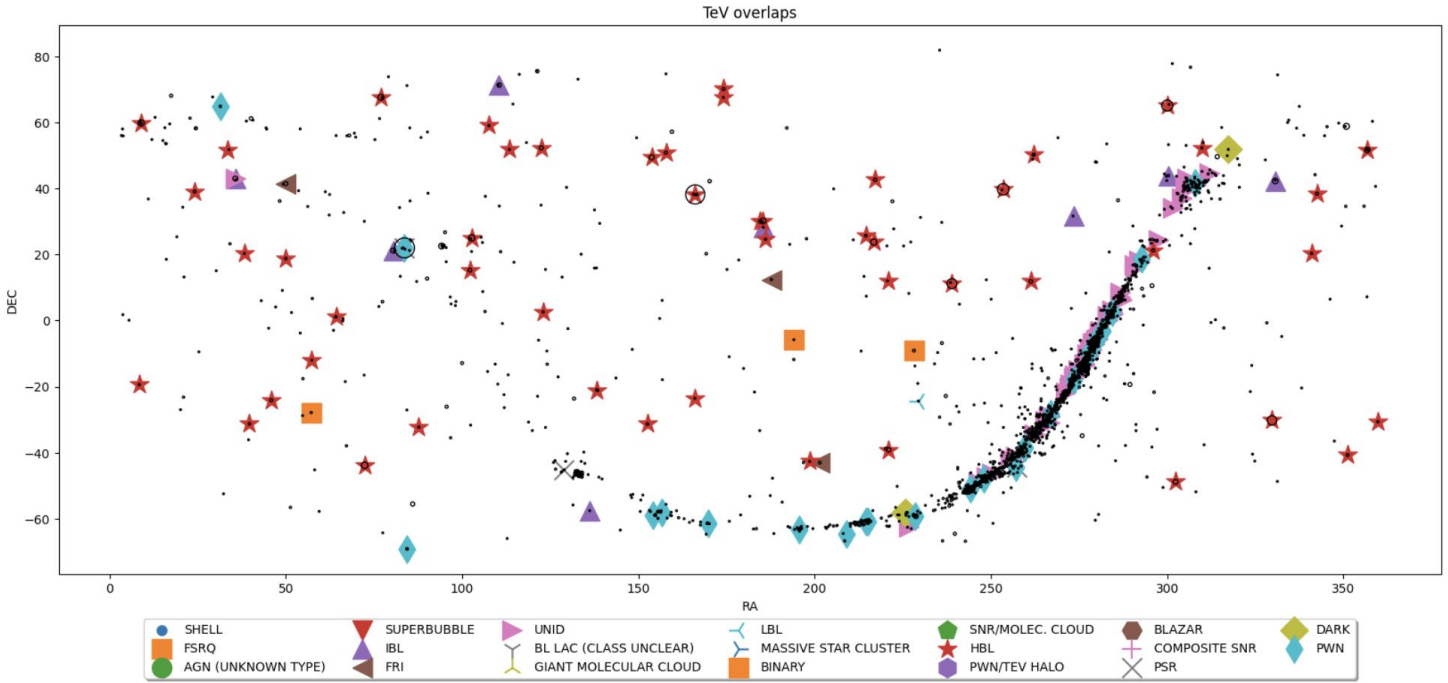


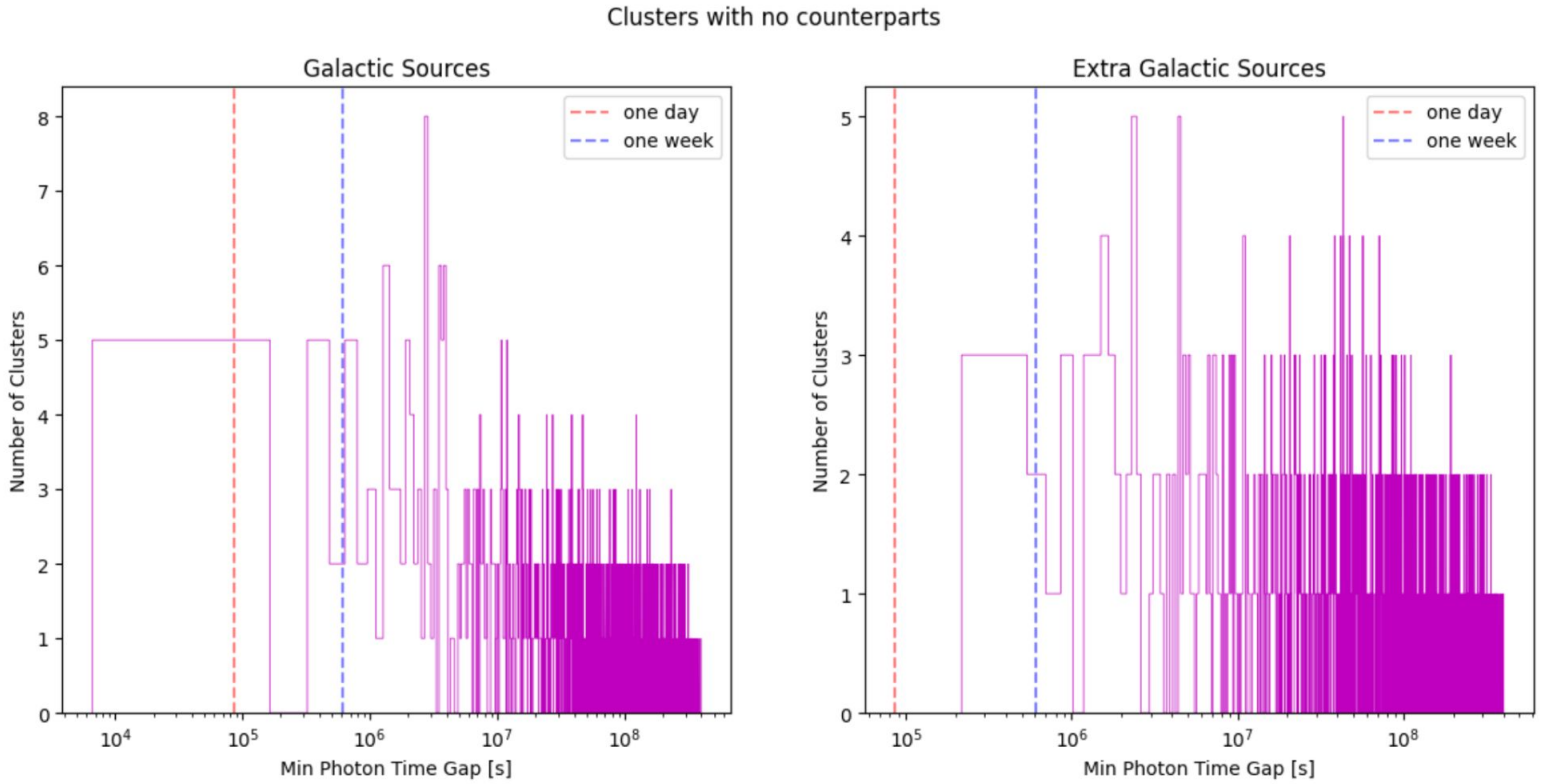
# Type of overlapping 3FHL sources/clusters



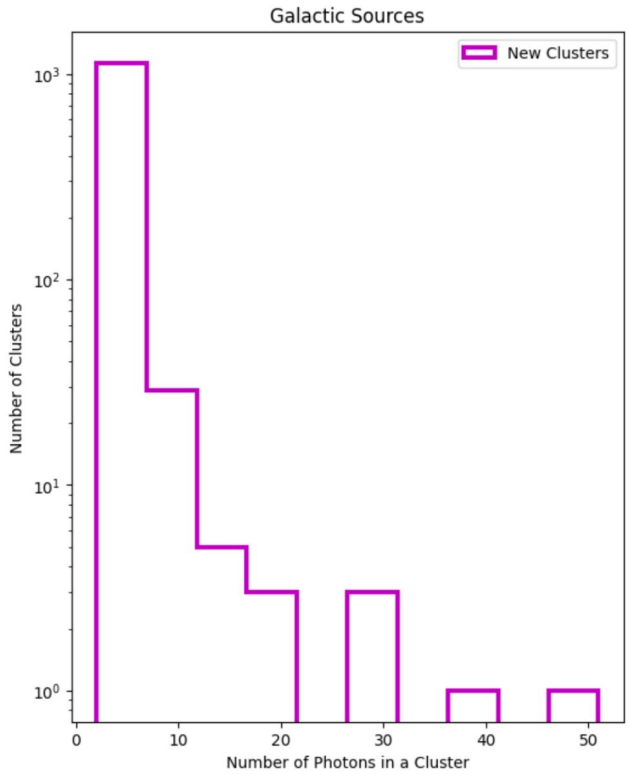
# Type of Overlapping TeV sources

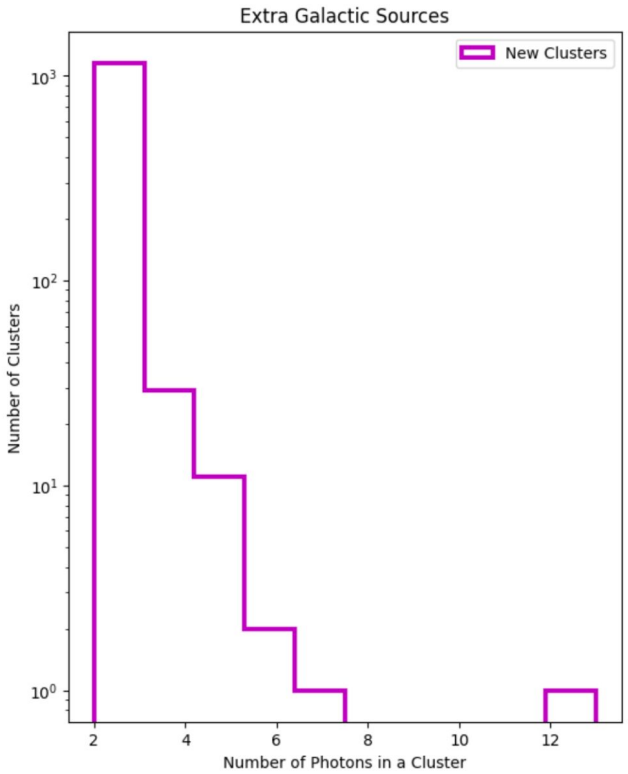


# Time Clustering of New Spatial Clusters



# Photon Number Distribution in New Clusters

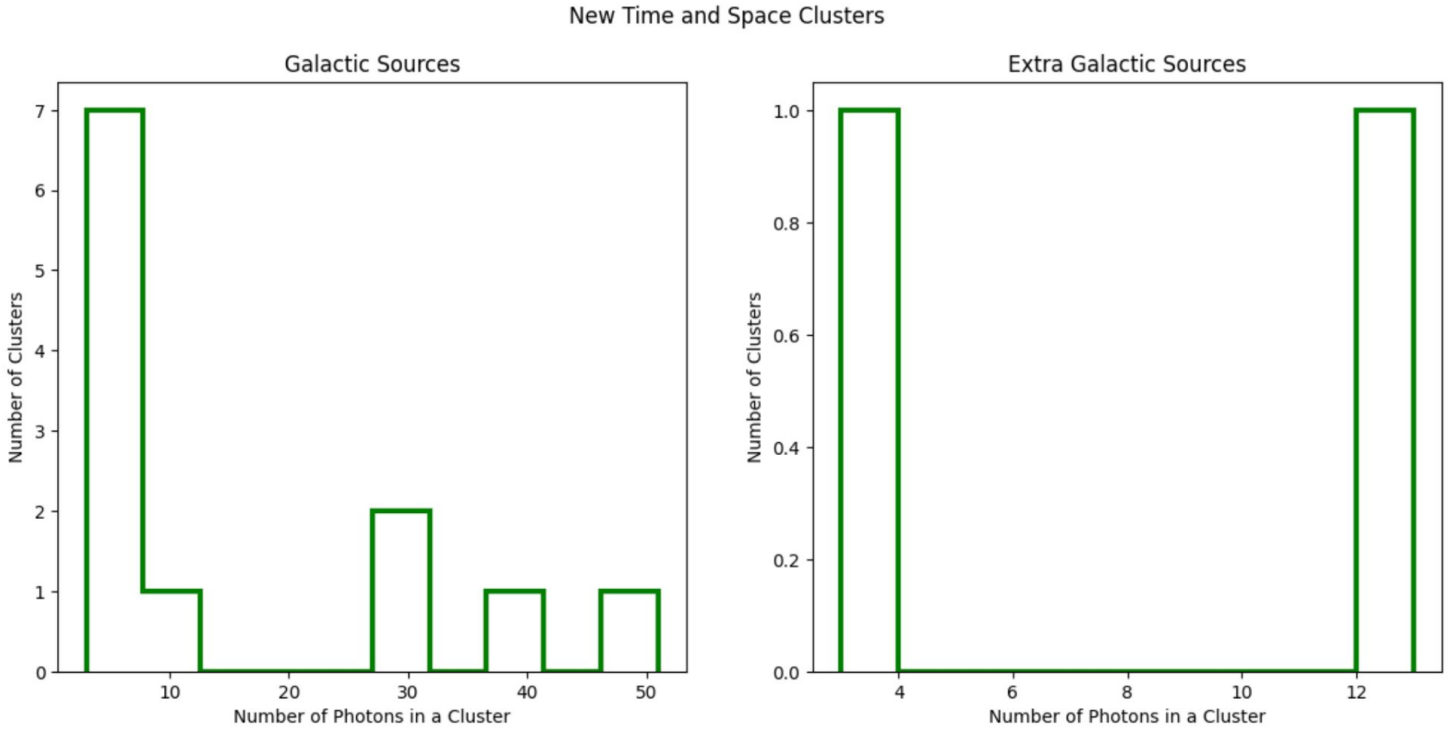


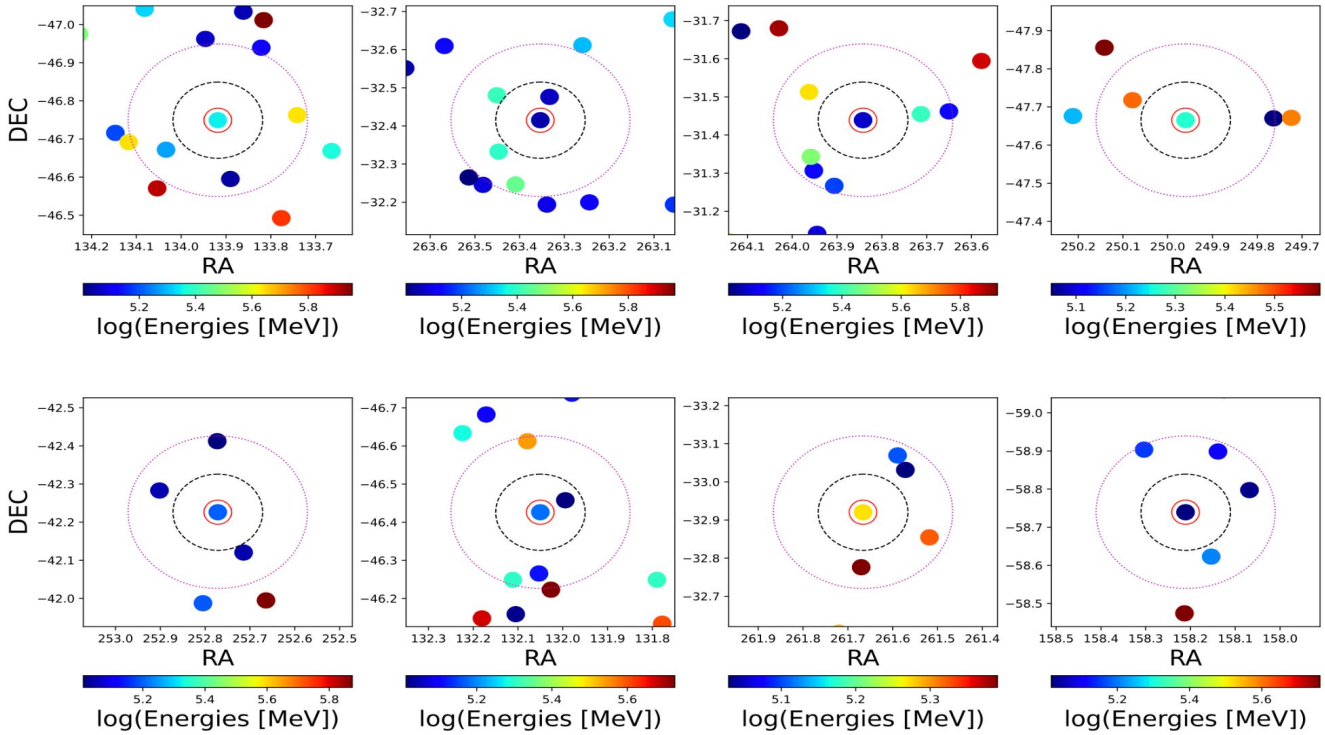
# New Clusters

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

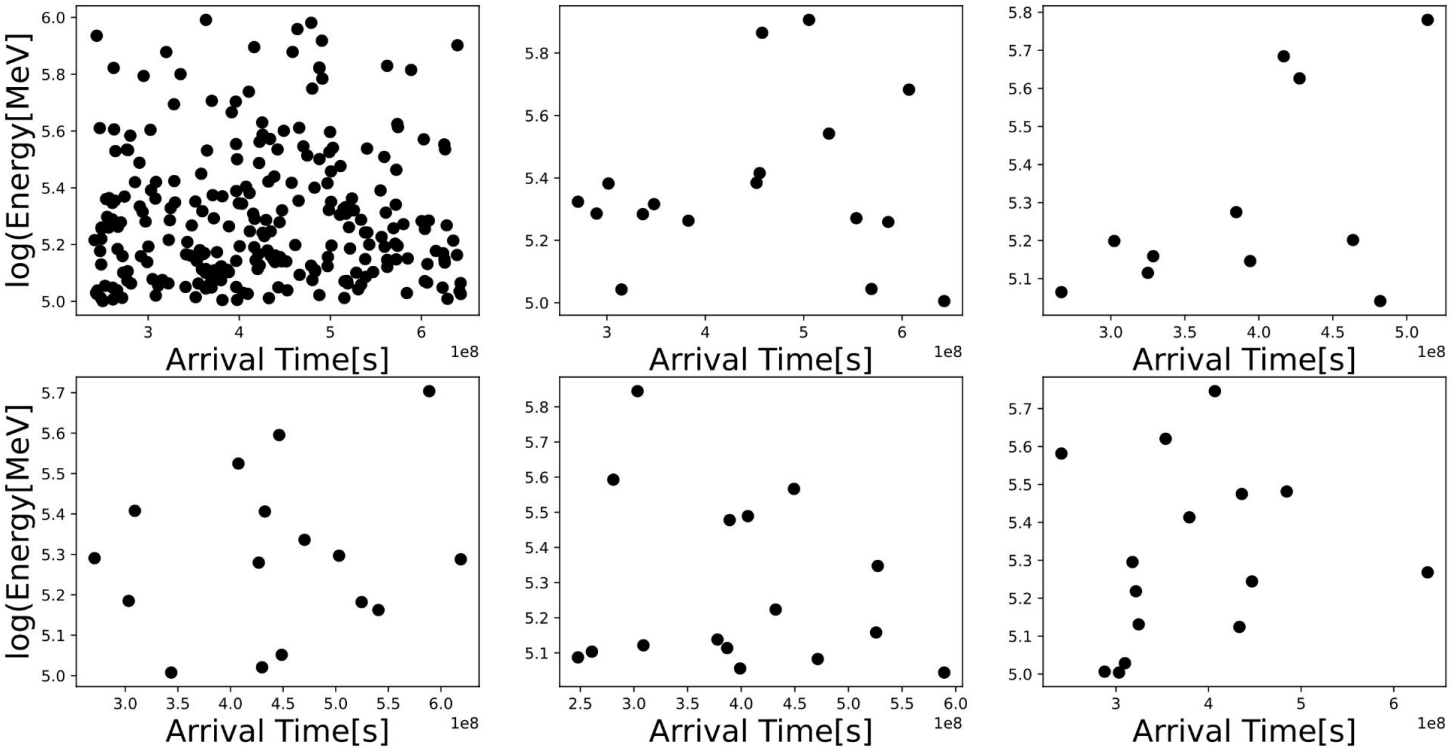
# Spatial and Temporal Clustering Final Results



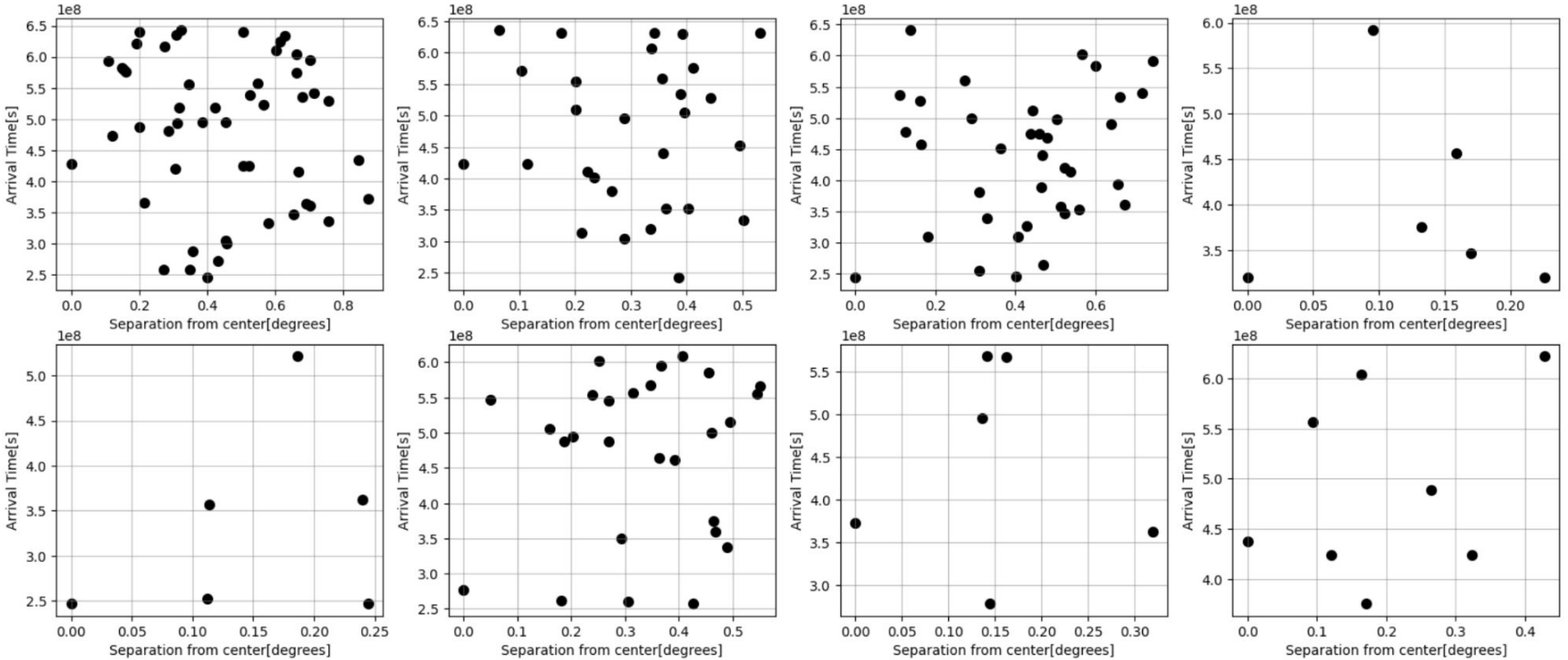
# New Photon Clusters



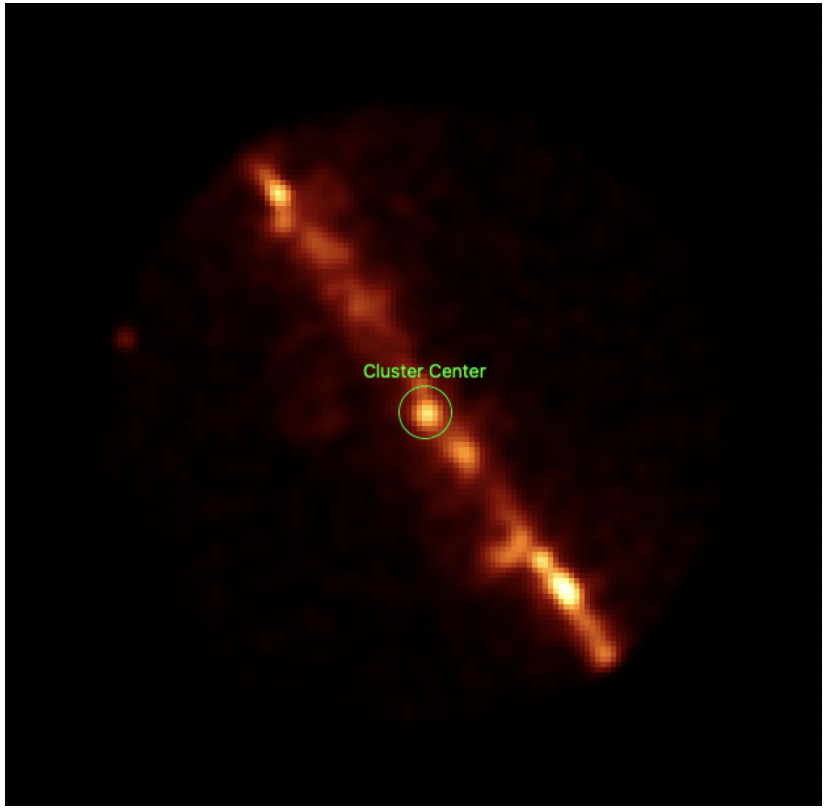
# Light Curves of some of the New clusters

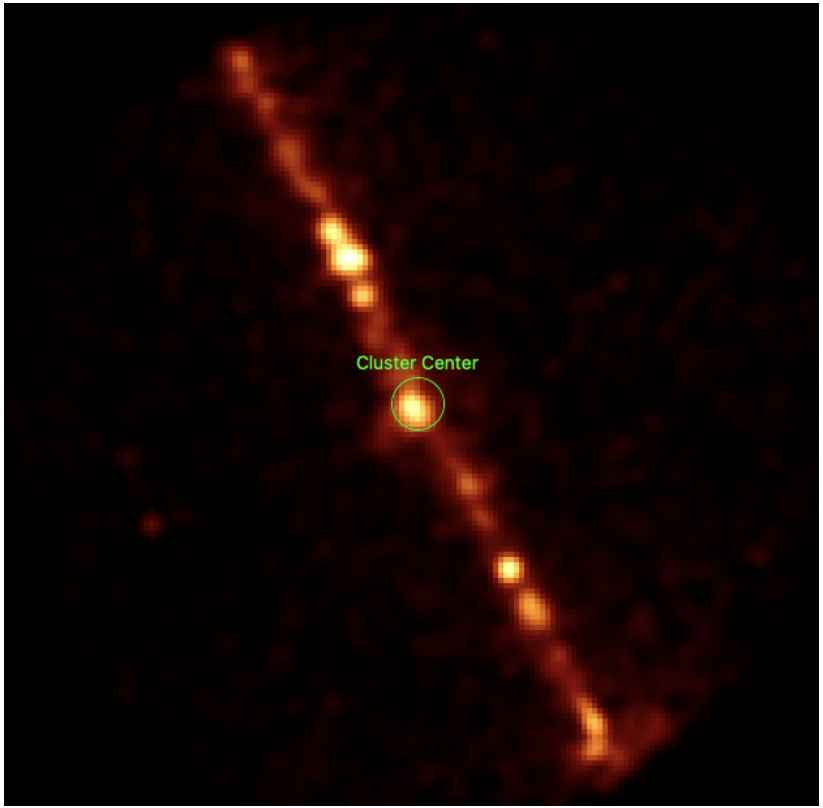


# Arrival Times vs Separation from Center



# Cmaps of some the regions



# Future work (next semester)

Matching Energy Cuts

More Fermipy Analysis

More Statistical Analysis work

Publishing a catalog