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Clustering analysis of Fermi-LAT unidentified point sources

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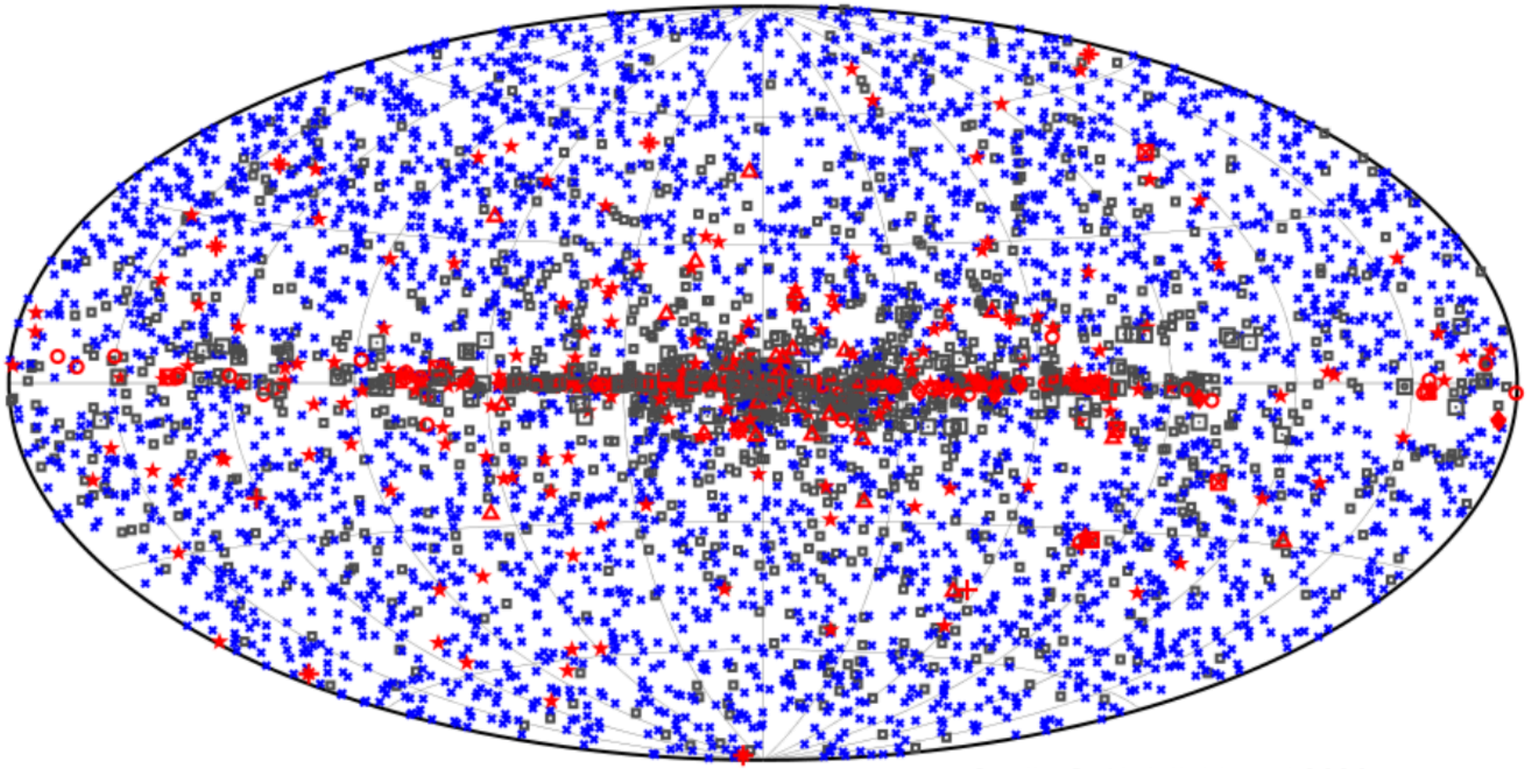
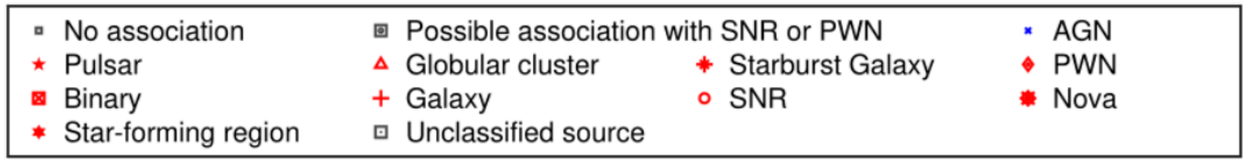
Fermi Point Source Catalog

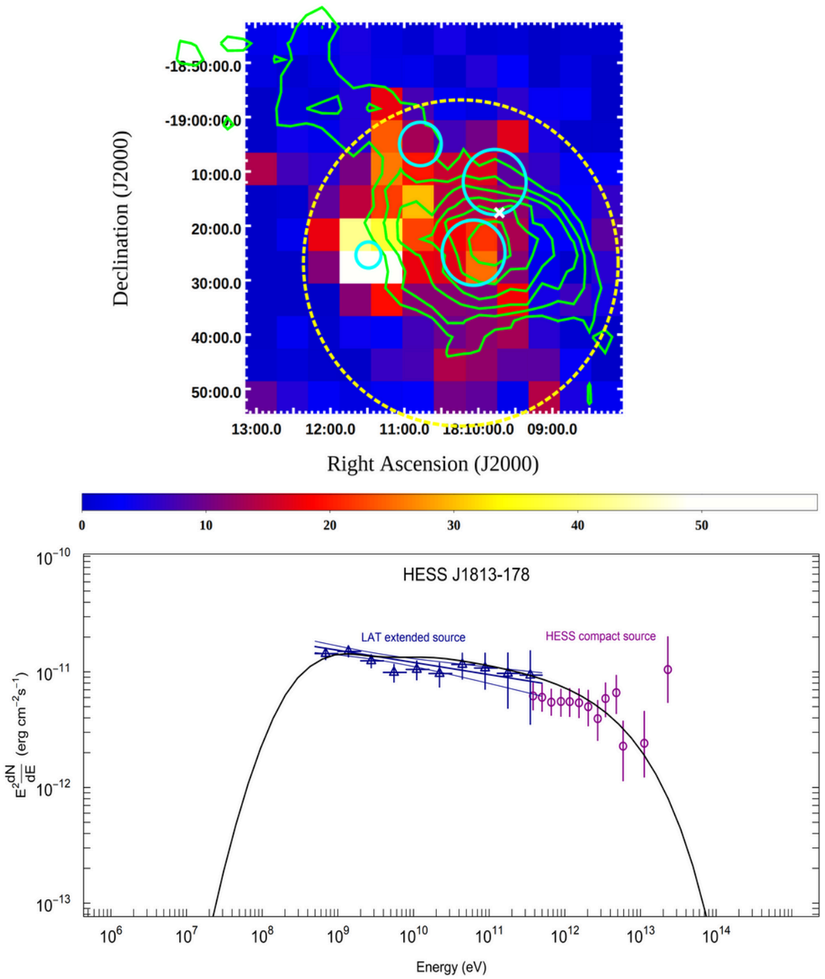


Credit: S. Abdollahi et al 2020.



- The catalog 4FGL-DR4 has **7194 sources**.
- To date, **2065 are unclassified** sources.
- Extended source are 81.
- In the Galactic plane, **are there extended sources currently being described as a bunch of unidentified point sources?**

The case of 4FGL J1813.1-1737e

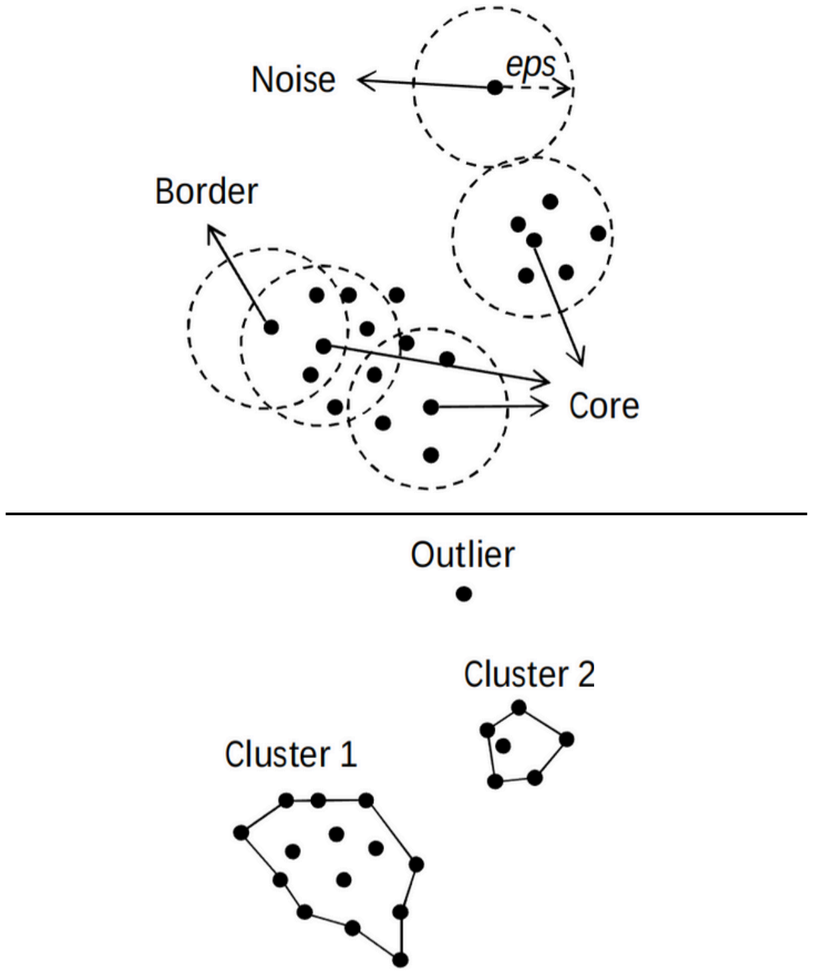


Credit: Araya 2018.

- **Unidentified Fermi-LAT point sources** (3FGL J1814.0-1757c and 3FGL J1814.1-1734c) in the region of HESS J1813-178, associated with a γ-ray PWN (Acero et al. 2015).
- **TS greater for the disc morphology than for the two point sources**, criterion applied to distinguish between an extended source and point sources (The Fermi LAT Collaboration et al. 2017).
- **Comparable spectral indices** measured at GeV and TeV (Araya 2018).
- The Fermi-LAT and H.E.S.S. **data can be described by a single source model** (H.E.S.S. Collaboration et al. 2024).

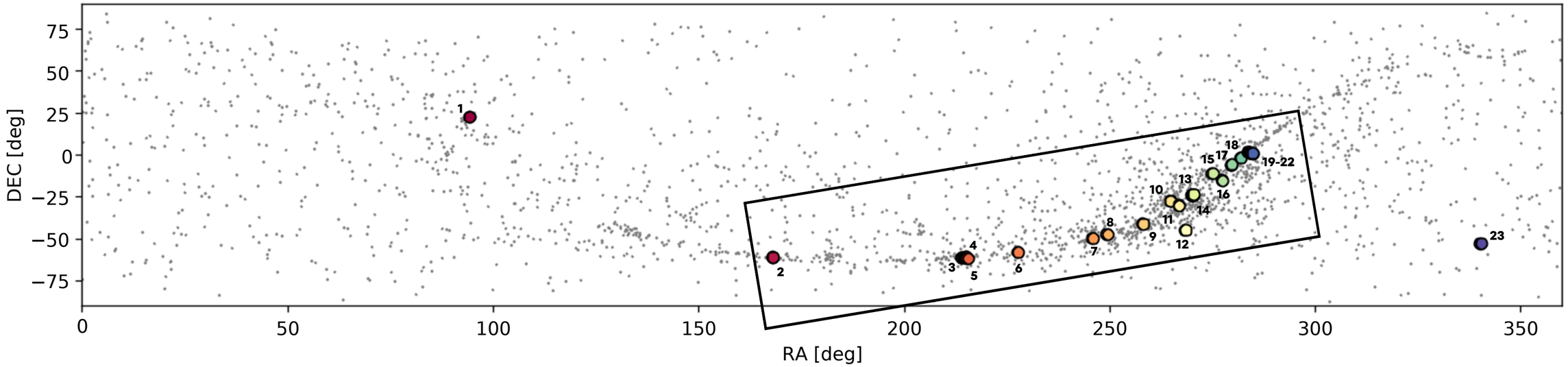
https://arxiv.org/abs/2403.16802

Spatial clustering



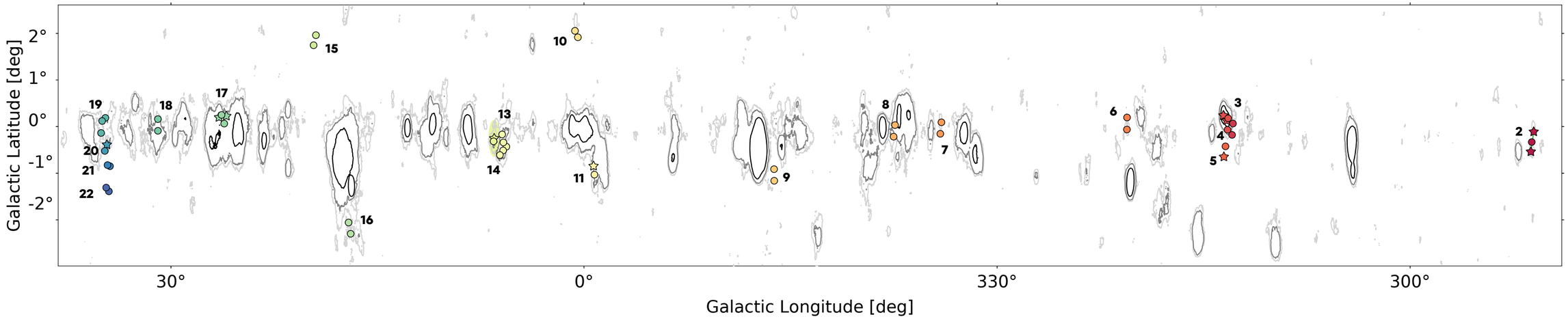
- **DBSCAN** (Density-Based Spatial Clustering of Applications with Noise) creates a circle of epsilon radius around every point and classifies them into **core**, **border** or **noise** points.
- A point is a core if the circle around it contains at least a certain number of points.
- The maximum distance between two samples for one to be considered as in the neighborhood of the other (**eps**) is 1.
- The number of samples in a neighborhood for a point to be considered as a core point (**minPts**) is 5.

Fermi-LAT clusters map



- We set **eps = 0.005 rad** ≈ 0.3 deg and **minPts = 2**.
- Data from the **catalog 4FGL-DR4**, without any cut on significance.
- We kept only **unassociated sources** and the ones classified as **PSR**, **MSP**, **PWN**, **SNR** and **SPP**.
- We found **23 clusters (56 sources)** including at least 1 unidentified source.

H.E.S.S. contours map



- Contours from the **HGPS** (HESS Galactic Plane Survey) map, at 3, 5 and 15 sigma.
- **17 out of 23 clusters** are superimposed on H.E.S.S. sources.
- Clusters **1, 12 and 23 are not showed** (they are far from any HGPS source).

Cluster candidates

cluster	n	target	classes	potential associations
1	2	4FGL J0616.5+2235	SNR	IC 443
2	3	4FGL J1111.8-6039	PSR	
3	2	4FGL J1415.3-6110c		Kookaburra (Rabbit)
4	5	4FGL J1417.7-6057	PSR, PWN	Kookaburra (Rabbit), Kookaburra (PWN)
5	2	4FGL J1422.5-6137	PSR	
6	2	4FGL J1510.1-5750		
7	2	4FGL J1622.7-4934c		
8	2	4FGL J1636.9-4710c		HESS J1634-472
9	2	4FGL J1711.9-4056c		
10	2	4FGL J1739.2-2717		
11	2	4FGL J1747.2-2957	PSR	
12	2	4FGL J1754.3-4443		
13	5	4FGL J1759.7-2354		HESS J1800-240B
14	2	4FGL J1801.3-2326e	SNR	W 28
15	2	4FGL J1819.4-1102		
16	2	4FGL J1829.4-1500c		
17	4	4FGL J1838.7-0601	PSR	LHAASO J1839-0545
18	2	4FGL J1847.2-0141		HESS J1848-018
19	3	4FGL J1854.1+0142c		
20	2	4FGL J1855.9+0121e	SNR	
21	2	4FGL J1857.1+0056		
22	2	4FGL J1859.2+0046		
23	2	4FGL J2240.3-5241	MSP	

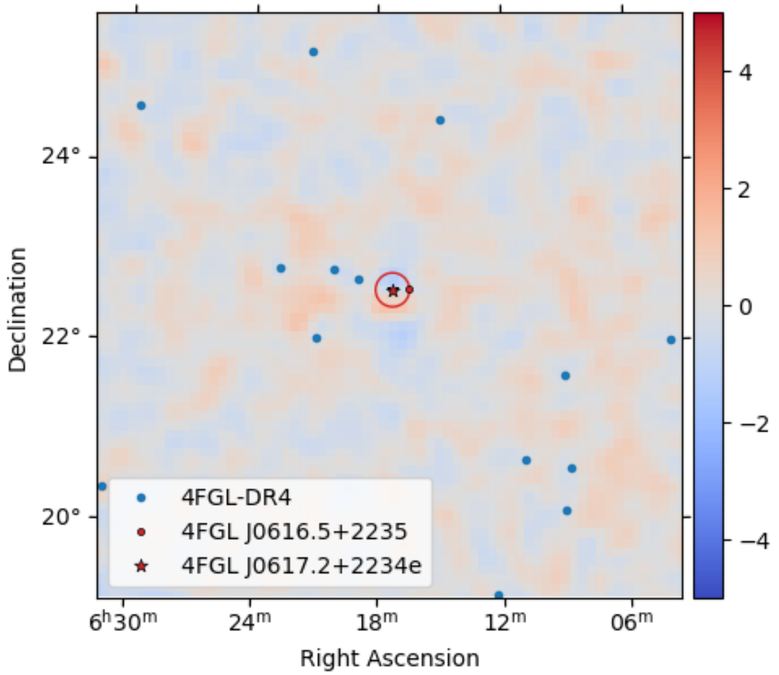
- We are interested in **TeV counterparts**.
- The last column shows potential associations with sources from **TeVCat** within 0.5 degrees.
- Some cluster members are actually **associated with TeV sources** in 4FGL-DR4 (e.g., 4FGL J1420.3-6046e with HESS J1420-607 in cluster 4).
- Targets are the sources with the **smallest RA and DEC** values for each cluster.

Analysis of the clusters

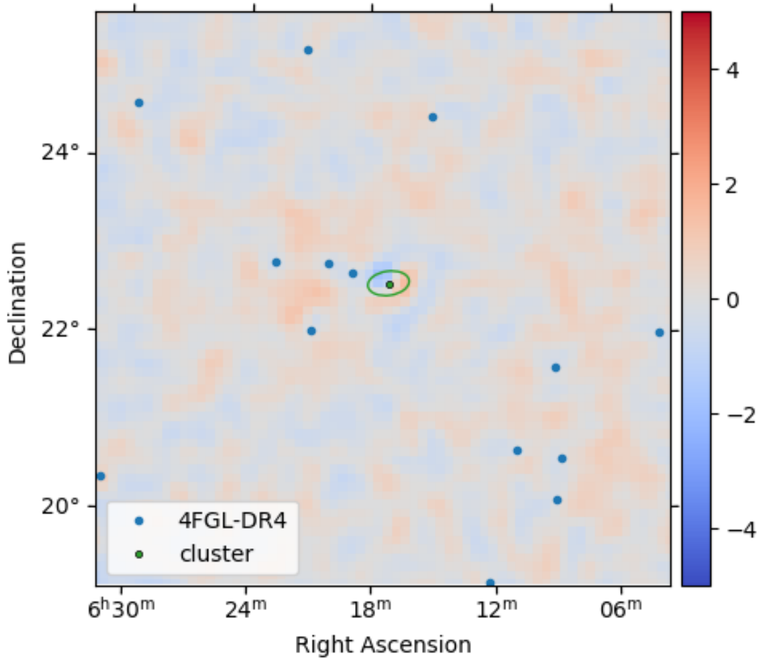
1. We utilized data from **4FGL-DR4**.
2. We extracted observations spanning approximately **14 years** within the energy range of **1 to 300 GeV**, covering a ROI of **20 degrees** centered on the cluster's center.
3. We performed **data preparation, response calculations and model optimization**, using *fermipy* v1.2 (Wood et al. 2017).
4. We conducted **cluster spatial and spectral fitting**, by using gammapy v1.2 (Donath et al. 2023).
5. We **compared the TS values for each model** to determine which model better describes the observations.
6. We **compared the SEDs** of the catalog sources with those of the extended source.

Preliminary example with cluster 1

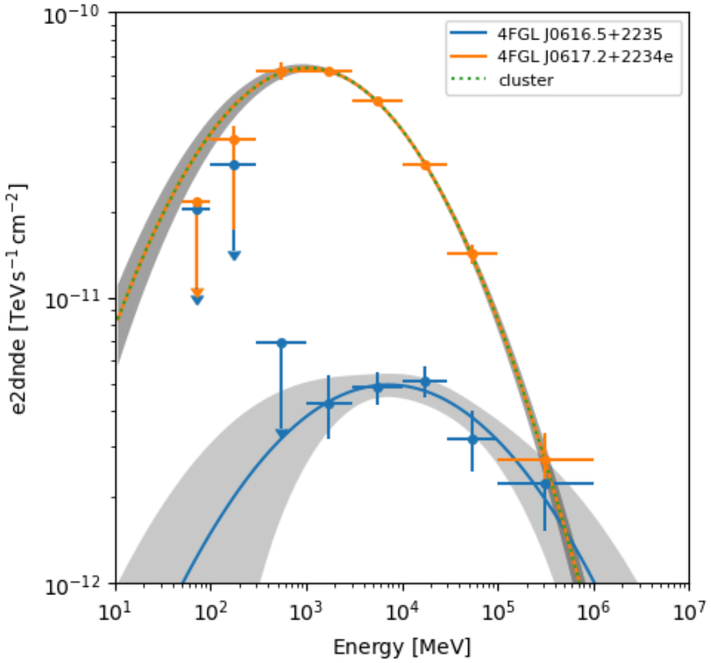
2 sources fit



1 source fit



2 sources vs 1 source SED



- The star marker indicates an **identified source**, the circle shows the source extension.
- The second fit has **5 degrees of freedom fewer** (2 spatial and 3 spectral parameters).
- The **two-sources model is preferred**, with 10 sigma against the cluster model.

Summary and outlook

- **Spatial clustering** using the DBSCAN algorithm and selection of **unidentified point sources** from the catalog **4FGL-DR4**.
- Reanalysis to evaluate the **difference in detection significance** between a **collection of point sources** and a **single extended source**.
- Comment on **TeV/MWL context**.
- Look at ROI's in depth (e.g. **joint analysis of Fermi-LAT and H.E.S.S. data**).

Thank you for listening!

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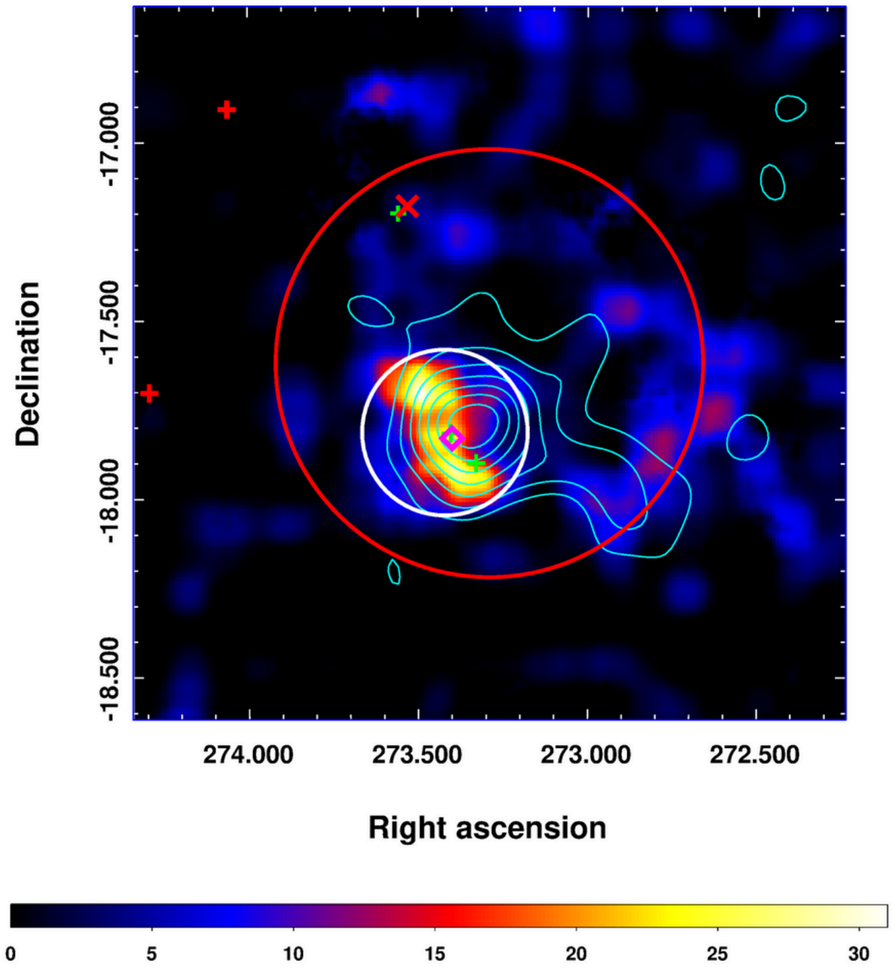
Back-Up



Credit: Xin & Guo 2021.

- The TeV emission from **HESS J1813–178 seems to be compact**, ~0.036° (H.E.S.S. Collaboration 2024), while the GeV emission from **4FGL J1813.1-1737e is very extended**, ~0.56° (Xin & Guo 2021).

Spatial model	HESS J1809-193	HESS J1813-178	D.o.f.[a]
Uniform disc	97.5	162	5
TeV counts map	76.7	—	2
1 point source	44	65	4 (2)[b]
2 point sources	60	92	8 (4)[b]
Disc + point source	—	180	9

Credit: Araya 2018.