Search for γ-ray emission from SNRs in the Large Magellanic Cloud: preliminary results of a new cluster analysis at energies above 4 GeV

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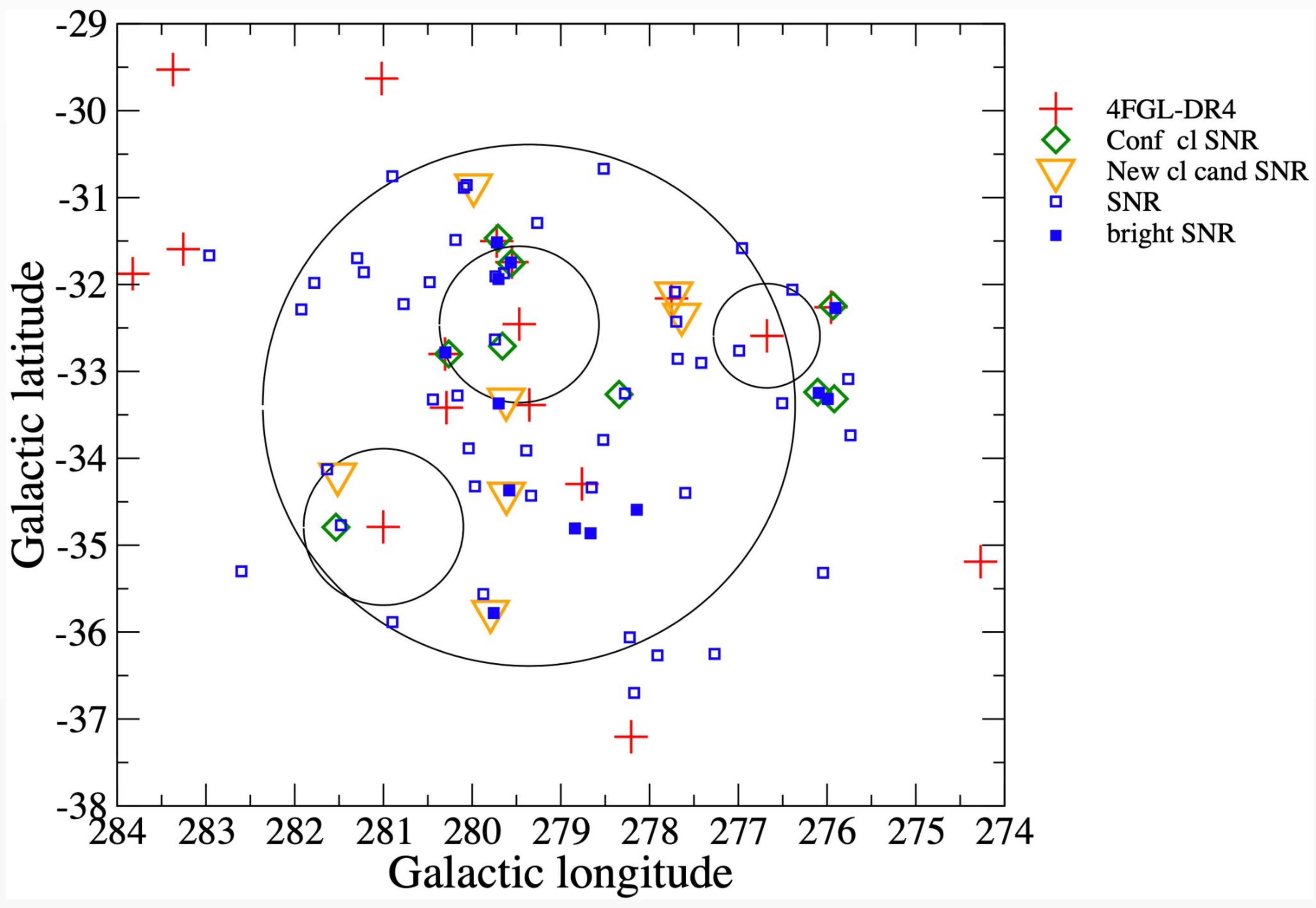
In a previous analysis (Campana et al. 2022, MNRAS 515, 1676) we presented the results of a search for **γ-ray emission** from **SNRs in the Large Magellanic Cloud (LMC)** based on the detection of concentrations in the arrival direction of **Fermi-LAT** photons of at energies >10 GeV, in the time window since August, 4 2008 to August, 4 2020 (12 years) and applied two different clustering methods: Minimum Spanning Tree (**MST**; Campana et al. 2008, 2013), and Density Based Spatial Clustering of Applications with Noise (**DBSCAN**; Tramacere & Vecchio 2013). **In the present contribution** we report the preliminary results of a new search **using a 15-year-long (up to August, 4 2023)** data set, a broader energy range (**>4 GeV**), and combining the **DBSCAN with the DENCLUE algorithm** (Tramacere et al. 2016). We confirm the results of previous paper and found positive indication for at least 8 new clusters with a spatial correspondence with other SNRs, increasing thus the number of remnants in LMC candidate or detected in the high energy γ rays to more than 14 sources.



Left: Map in Galactic coordinates of the sky region. Red crosses mark the positions of 4FGL-DR4 sources; blue squares are the SNRs in the Maggi et al. (2016) catalogue and filled squares are those with an X-ray luminosity higher than 10^{36} erg/s; green diamonds are confirmed sources found in Campana et al. 2022; orange triangles are new candidate sources found in the present analysis.

15 YEARS FERMI-LAT DATA ABOVE 4 AND 10 GEV FOR THE LMC REGION

Prepare **data** accumulated by **Fermi/LAT** between 2008 and 2020 in the 73° < l < 285° and −38° < b < −29° **LMC** region, above 6 and 10 GeV, and apply…

DBSCAN+DENCLUE ALGORITHM

initial estimation of background angular density

Initial guess of background angular density ρ_{bkg}: number of photons within the field divided by the field angular extent

- DBSCAN detection
- First list of clusters
- updated BKG estimation

2X

DBSCAN *EPS* parameter: radius of the scanning brush set close to the PSF(E) value, ~ 0.1 Deg in the present analysis

DBSCAN *K* parameter: threshold for core points, set to K= N sqrt($\Omega_{EPS}\rho_{bkg}$), where N is the BKG rejection confidence level (4 in the present analysis) and Ω_{EPS} is the angular extent of the scanning brush

- eval significance (Li&Ma) ← (Li & Ma ON/OFF problem)
- cleaned list of clusters
- DENCLUE detection separate blended clusters
- eval significance (Li&Ma)
- final list of clusters

$$S_{cls} = \sqrt{2\left(N_{src}^{in}\ln\left[\frac{2N_{src}^{in}}{N_{src}^{in}+N_{bkg}^{eff}}\right] + N_{bkg}^{eff}\ln\left[\frac{2N_{src}^{in}}{N_{src}^{in}+N_{bkg}^{eff}}\right]\right)}$$

N^{in}_{src} : numbers of photons within the cluster radius

N^{eff}_{bkg} : numbers of expected bkg photons within the cluster radius, estimated from the angular density of photons, once the DBSCAN detected cluster are removed, and the sum of their angular extent has been subtracted from the field angular extent

$S_{cls}>3$ in the present analysis

…two different **source detection algorithms** able to find **photon clusters** in γ-ray data…

MST ALGORITHM

The MST is used for searching concentrations in a field of points by means of tree connecting all the points with the minimum total distance and cutting all the edges above a fixed value. The significance of a cluster is measured by the parameter M, depending on its number of points and the concentration ratio to the mean in the entire field.

SOURCE CANDIDATE LIST: LOOK FOR SNRS

…and look for **associations** between the clusters found and **known LMC SNRs** (from the Maggi et al. 2016 catalogue).

✔**Confirmed** **SNRs** in γ-rays, already reported by us (Campana et al, 2018,2022) and by the Fermi/LAT collaboration (Ackermann et al., 2016)

SNR	RANGE GeV	TYPE	D ′	L_X 10^{35} erg s^{-1}	$S_{cls}4$	$S_{cls}10$	Δ ′	MST M	Notes
N 44	>6;10	–	4.3	0.90	4.8	3.3	3.7	28.7	
N1 32D	>6;10	CC	2.1	315.04	6.6	4.6	1.8	57.6	4FGL
N 49B	>6*;10	CC	2.8	38.03	*5.6	*3.9	3.4	20.0	
N 49	>6*;10	CC-SGR	1.4	64.37	*5.6	*3.9	3.5	18.4	
B0528−692	>10		4.5	1.99	4.4	3.5	4.1	58.8	
N 63A	>6;10	CC	1.4	185.68	6.5	4.1	0.4	53.7	4FGL
N 157B	>6;10	CC-PWN	2.0	15.00	18.8	11.6	1.6	577.4	4FGL
B0540−693	>10	CC-PSR	1.2	87.35	8.7	4.8	5.3	35.4	4FGL
N 186D	> 6		1.9	1.09	—	3.7			

* : unresolved cluster at energies lower than 10 GeV
D : SNR diameter
Δ : angular separation
L_X : X-ray luminosity in the band 0.3–8 keV from the Maggi et al. (2016) catalogue

⚠️ **NEW!** **SNRs** in γ-rays

SNR	RANGE GeV	TYPE	D ′	L_X 10^{35} erg s^{-1}	$S_{cls}4$	Δ ′	MST M	Notes
B0453−685	>4	CC	2.0	13.85	3.7	2.0	18.3	m
DEM L241	>4		5.3	3.84	5.2	1.2	56.7	m
B0532−675	>4		4.7	2.48	3.1	5.4	23.5	
(HP99)1139	>4		4.4	1.44	3.1	6.4	17.8	e
N 103B	>4	Ia	0.5	51.70	3.3	2.7	18.8	m
B0519−690	>4	Ia	0.6	34.94	4.2	5.0	26.6	m
DEM L316A	>4	CC?	3.2	1.26	4.7	4.1	21.5	Nf, m

m : angular distance from MST centroid position
e : MST magnitude at energies >6 GeV.
Nf : M value obtained in a field with $b > -31^o$.

We report the significant detections of six SNRs, including the most energetic remnants of Core-Collapse (CC) type. The high energy detection of the very young SN1987A remains uncertain because it is located in the bright diffuse local emission in the 30 Doradus complex. We remark that the emission from **N63A, early reported by Campana et al. 2018, is now confirmed by its presence in the 4FGL-DR4** catalog of the Fermi-LAT collaboration