Detection of Supernova Remnants in the Large Magellanic Cloud At Energies Higher Than 6 GeV by Means of Cluster Analysis

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We applied a blind search for **spatial photon clusters** at energies higher than 6 and 10 GeV to sky maps in the **Large Magellanic Cloud** (LMC) region of **Fermi-LAT** sky, using events collected in the first 12 years of operation. We used the **Minimum Spanning Tree** (Campana et al. 2008, 2013) and **DBSCAN** (Tramacere & Vecchio 2013) **source-detection algorithms**, which provided fully consistent results, detecting **13 clusters above 10 GeV**. Six clusters have coordinates corresponding to known SNRs within a few arcminutes, in a very good agreement with the instrumental positional accuracy. We **confirmed** the detection of the known remnants **N157B, N63A, N49B** and report **three new detections, of N49, N186D, B040-693,** and of the complex **N44** at energies higher than 6 GeV. An analysis on the LMC SNR population shows that these remnants are the **most luminous in the X-ray band** and correspond to **core-collapse supernovae with shock expanding in dense HII regions**. This result suggests that the **hadronic** emission is the most relevant process for high energy gamma-ray loud SNRs.

12 YEARS FERMI-LAT DATA ABOVE 6 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...

MST ALGORITHM

DBSCAN ALGORITHM

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

SOURCE CANDIDATE LIST: LOOK FOR SNRS

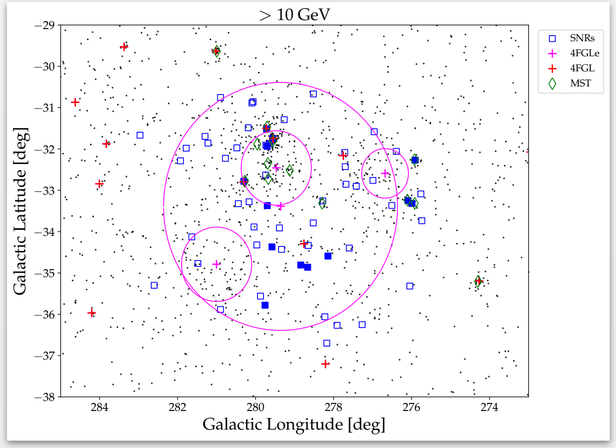
...and look for **associations** between the clusters found and **known LMC SNRs** (from the Maggi et al. 2016 list).

N157B ✔ Confirmed
N63A ✔ Confirmed
N49B ✔ Confirmed

We **confirm** the detection of these SNRs, already reported by us (Campana et al, 2018) and by the Fermi/LAT collaboration (Ackermann et al., 2016)

N49 ⚠ NEW!
N186D ⚠ NEW!
B040-693 ⚠ NEW!

...but we report also the discovery of several **new SNRs** in γ-rays.



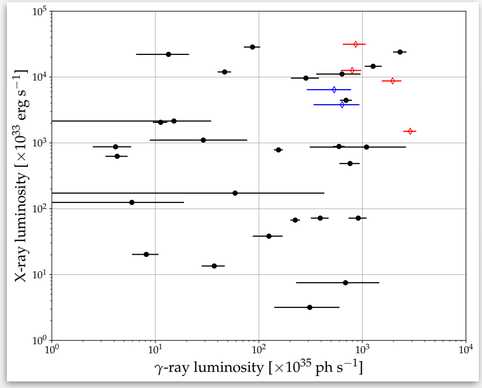
Above: Photon map in Galactic coordinates of the sky region at energies higher than 10 GeV. Red and magenta crosses mark the positions of 4FGL-DR2 sources (point-like and extended), magenta circles are the sizes of the extended ones; blue squares are the SNRs in the Maggi et al. (2016) catalogue and filled squares are those with an X-ray luminosity higher than 10^{36} erg/s; green diamonds are MST candidate sources found in the analysis.

SNR	MCSNR	X size ′	L_X 10^{35} erg s^{-1}	$S_{1\,\mathrm{GHz}}$ Jy	Type	Age kyr	MST/DBSCAN detection	γ-ray flux* 10^{-11} ph cm^{-2} s^{-1}	Interaction w/ dense CSM
N 132D	J0525−6938	2.1	315.04	5.26	CC	2.4	yes	9.2 ± 2.3	yes
N 63A	J0535−6602	1.4	126.00	1.86	CC	3.5	yes	8.5 ± 1.9	possible
B0540−693	J0540−6920	1.2	87.35	1.03	CCP	1.14	yes	20.9 ± 4.5	no
N 49	J0526−6605	1.4	64.37	1.66	CC	4.8	yes	5.7 ± 2.6†	yes
N 49B	J0526−6605	2.8	38.03	0.63	CC	∼ 10	yes	6.8 ± 3.2†	possible
N 157B	J0537−6910	2.0	15.00	2.88	CCP	∼ 5	yes	30.9 ± 4.5	yes
SNR1987A	J0535−6916	0.03	27.39	0.82	CC	0.03	confused		yes
B0453-685	J0453−6829	2.0	13.85	0.21	CC	12.0	no		no
N 23	J0505−6802	1.6	26.25	0.39	CC(?)	4.6	no		no
N 103B	J0509−6843	0.5	51.70	0.58	Ia	0.86	no		no
DEM L71	J0505−6753	1.3	44.59	0.01	Ia	4.4	no		no
B0519−690	J0519−6902	0.6	34.94	0.13	Ia	0.6	no		no
B0509−67.5	J0509−6731	0.53	16.51	0.10	Ia	0.4	no		no
B0450-709	J0450−7050	5.67	0.59	0.69	CC(?)	∼ 70	no		no
DEM L316B	J0547−6942	3.17	1.47	0.73	CC(?)	40.5	no		yes
DEM L316A	J0547−6941	3.17	1.26	0.52	CC(?)	33.0	no		yes
DEM L328	J0550−6823	5.20	1.22	0.65	CC(?)		no		possible

(*) Photon flux evaluated in the 3–300 GeV energy band. – (†) Values possibly affected by the nearby SNR. – CC = Core collapse; CCP = Core collapse Plerion

Left: SNRs in the LMC region with a X-ray luminosity in the band 0.3–8 keV higher than 10^{36} erg/s from the Maggi et al. (2016) list. Radio flux densities at 1 GHz are from Bozzetto et al. (2017).

Right: Unabsorbed X-ray luminosity of SNRs (0.3–10 keV band) versus the corresponding γ-ray luminosity, as measured by *Fermi*-LAT in the 1–100 GeV band. Luminosities for **N 132D, N 63A, B0540-693, N 157B** (**red** diamonds), and for **N 49** and **N 49B** (**blue** diamonds) were derived from the values reported in the table on the left, assuming a photon index $\Gamma = 2$ and a distance of 51 kpc.



References

This work has been submitted to MNRAS (Campana et al., 2022)

For **MST**: Campana et al. (2008), MNRAS 383, 1166; Campana et al. (2013), Ap&SS 360,19

For **DBSCAN**: Tramacere & Vecchio (2013) A&A 549, A138

Previous work on LMC γ-ray data: Campana et al. (2018), Ap&SS 363, 144