Two New Radio-dim, γ-ray-bright Supernova Remnants

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We report the detection with Fermi LAT of two newly established supernova remnants (SNRs) which belong to a class of radio-faint, yet gamma-ray bright SNRs. SNR G189.6+3.3 overlaps with the smaller and brighter SNR IC 443. It's X-ray emission shows a radiative recombining continuum that evidences an ongoing or past interaction with a dense medium. The gamma-ray emission is extended, matching the size of the SNR in radio and X-rays, with a spectral index of 2. The SNR candidate G107.5-5.2, also named the Nereides Nebula, is detected in deep [O III] and Hα narrow-band images. Its large 3 degree diameter makes it comparable to the Cygnus Loop, albeit much fainter. It is spatially coincident with the extended gamma-ray source FHES J2304.0+5406. No radio or X-ray emission has yet been detected. Their large gamma-ray extension is well-matched to the sizes of the SNRs, supporting an association.

SNR G189.6+3.3

- Identified by Hα and faint radio shell [1], but uncertain if SNR or HII region S249. ROSAT detected faint, soft thermal X-rays [2]. Suzaku identified recombining plasma [3]: mixed-morphology SNR, past interaction with denser material.
- eROSITA X-ray studies [4] reveal G189.6+3.3 is in front of IC 443. High abundance ratios favor a faint SN explosion. Unclear if two are SN are physically associated (i.e., from the same star system)

Distance: 1.3-1.7 kpc (closer than IC 443)

Age: 30-100 kyr

Diameter: 1.3° ≈ 40 pc

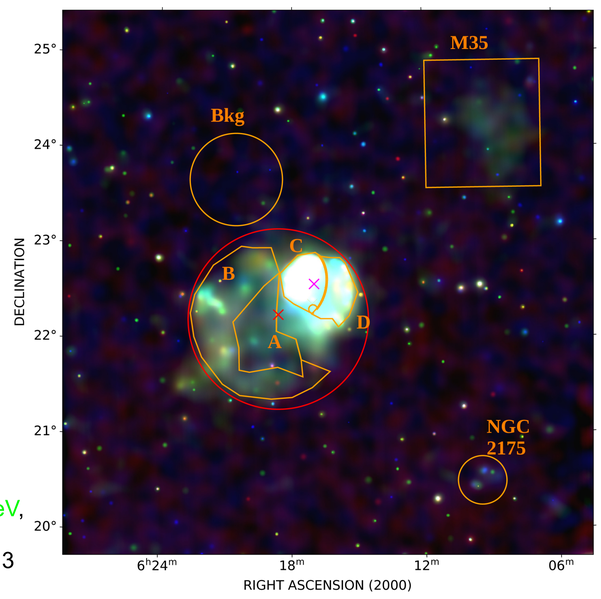


Figure. eROSITA color image (0.2-0.7 keV, 0.7–1.1 keV, 1.1–10 keV) of IC 443 (C,D) and SNR G189.6+03.3 (A,B) from [4]. Image is adaptively smoothed to S/N = 3 to 5. Red circle indicates extension of G189.6+3.3.

SNR Candidate G107.5-5.2 “Nereides”

The SNR candidate G107.5-5.2 was discovered through wide-field narrowband imaging of the Cassiopeia region by amateur astronomers. Amassing 260 hours across 3 continents, they discovered a faint 3° diameter nebula [7]. They named it “Nereides” after the sea nymphs of Greek mythology (Cassiopeia once boasted that she and her daughter were more beautiful than the Nereides).

This is likely an SNR due to the strength of Hα, [OII], and [SII] line emission, however no radio or X-ray emission has yet been detected. Little is known about this SNR, but diameter means it must be within 2 kpc, or it would exceed 100 pc in size.

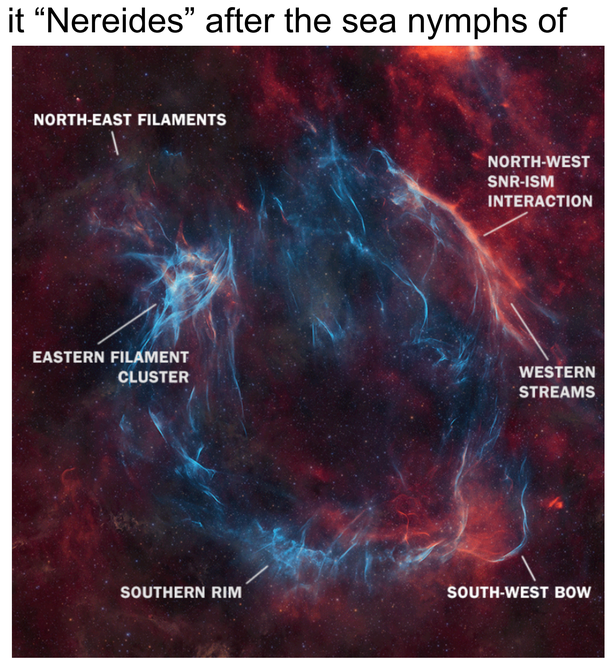


Figure. Optical narrowband image showing [OIII], Hα, and [SII]. Distinct features across the 3° SNR candidate are labeled.

Fermi-LAT Analysis of G189.6+3.3

- Previously detected extended source, FGES J0619.6+2229, with 6 years, >10 GeV, had insufficient statistics to confirm a detection [5].
- Analyze 15 years of Pass 8 LAT data using 4FGL-DR4 model [6] plus new spatial template for SNR IC 443.
- Best-fit with a radial disk model using `fermipy` [10] with disk radius of 0.92°±0.03° (TS_{ext} = 154)
- Power-law spectral index = 2.00±0.06.

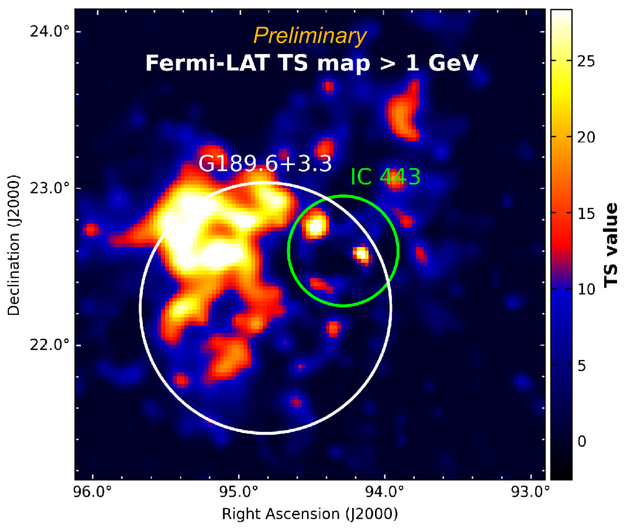
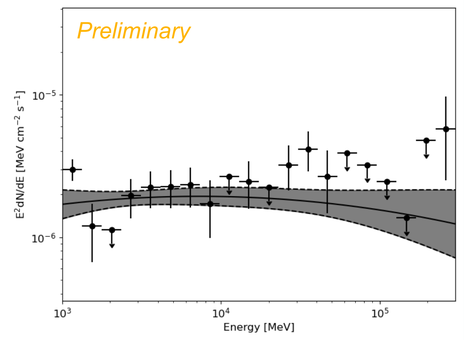


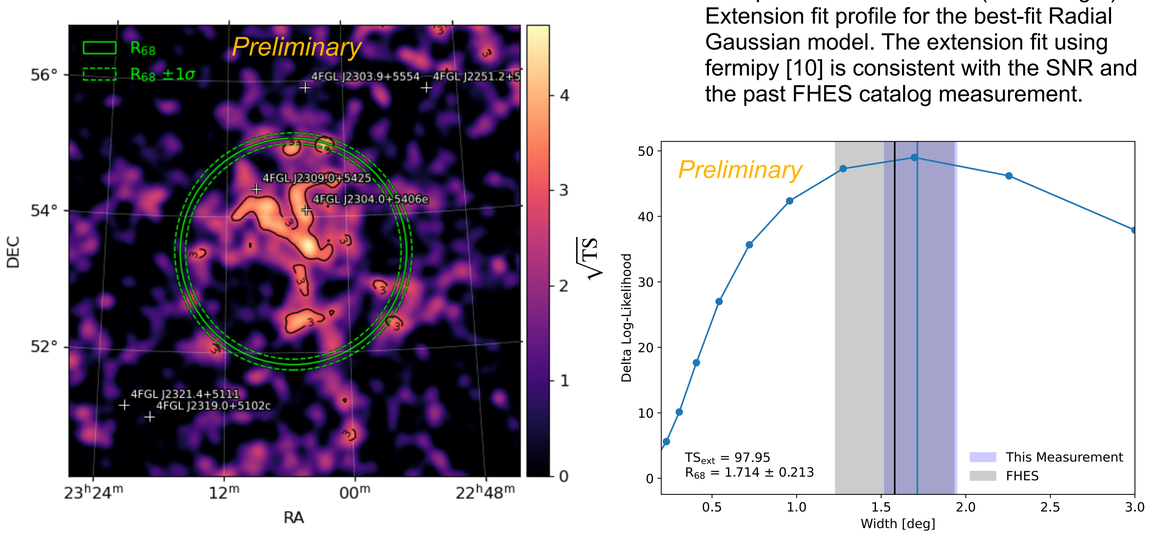
Figure. LAT TS map for SNR G189.6+3.3, for >1 GeV photons, with all other sources removed. Emission is clearly seen across the SNR, particularly along the NE edge, where X-rays are also most prominent.

Fermi-LAT Analysis of Nereides

Prior to it’s detection in the optical, an extended γ-ray source, FHES J2304.0+5406, was detected with no known counterpart [8]. We analyzed 15 years of Pass 8 data (doubling the previous work). The emission towards Nereides is best fit by a combination of a point source, 4FGL J2309.0+5425, plus a 2D Gaussian. While the point source and nebula have similar spectral indices, the PS+disk model is preferred over just a disk by a ΔTS=162. The disk has a spectral index of 1.8±0.1.



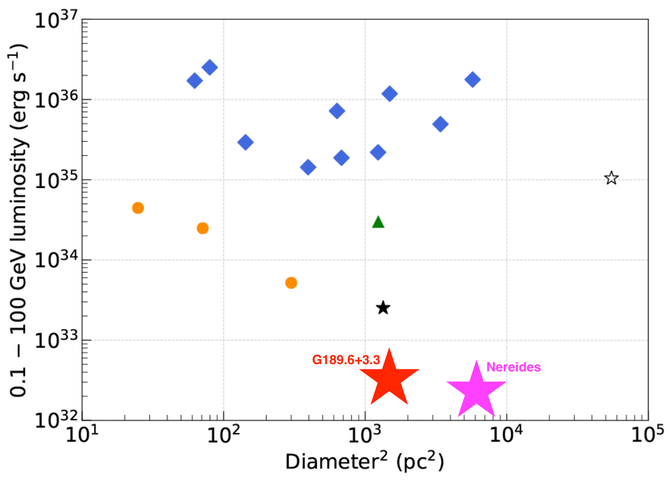
Figures. (Top) SED of Nereides 2D Gaussian model, best fit by a log-parabola with α=2.1±0.1, β=0.07±0.06. (Bottom Left) TS map >1 GeV showing the morphology of Nereides with all other sources subtracted. White circle shows the extent of the optical SNR candidate. (Bottom right) Extension fit profile for the best-fit Radial Gaussian model. The extension fit using fermipy [10] is consistent with the SNR and the past FHES catalog measurement.



Conclusions

In 15 years of operation, Fermi LAT has reached a sensitivity where it can detect very faint, large diameter SNRs, such as previously identified SNR candidate G150.3+4.5 [9].

Previously detected large diameter SNRs and TeV/GeV sources show similarly low radio and gamma-ray luminosities and may belong to this new source class. The low density makes an inverse Compton origin plausible. An alternative origin as pulsar wind nebulae will be explored.



SNR	Other Names	References
Large diameter SNRs		
G17.8+16.7	FHES J1723.50501	Araya, Hurley-Walker & Quirós-Araya 2022
G118.4+37.0	Calvera	Arias, et al. 2022; Araya 2023
G150.3 + 4.5		Gao & Han 2014; Devin et al. 2020
G279.0+1.1		Araya 2020
G323.7 1.0		Araya 2017
GeV/TeV sources of unknown nature		
G 44.5+0.14	HESS J1912+101	Zeng, et al. 2021
G60.6+0.0	1LHAASO J1945+2424	Araya & Álvarez-Quesada 2024
G350.6 4.7		Araya 2018
G71.32+1.16	2HWC J2006+341	Albert, et al. 2020

Figure. GeV luminosity (0.1–100 GeV) versus diameter squared for the SNRs detected with Fermi LAT from [9]. The two new dim SNRs are included on the plot as large stars approximating their uncertainty due to uncertain distances.

Table. Other GeV/TeV sources which may belong to this class of radio-dim SNRs, or may be other objects, such as pulsar wind nebulae.

References & Acknowledgements

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