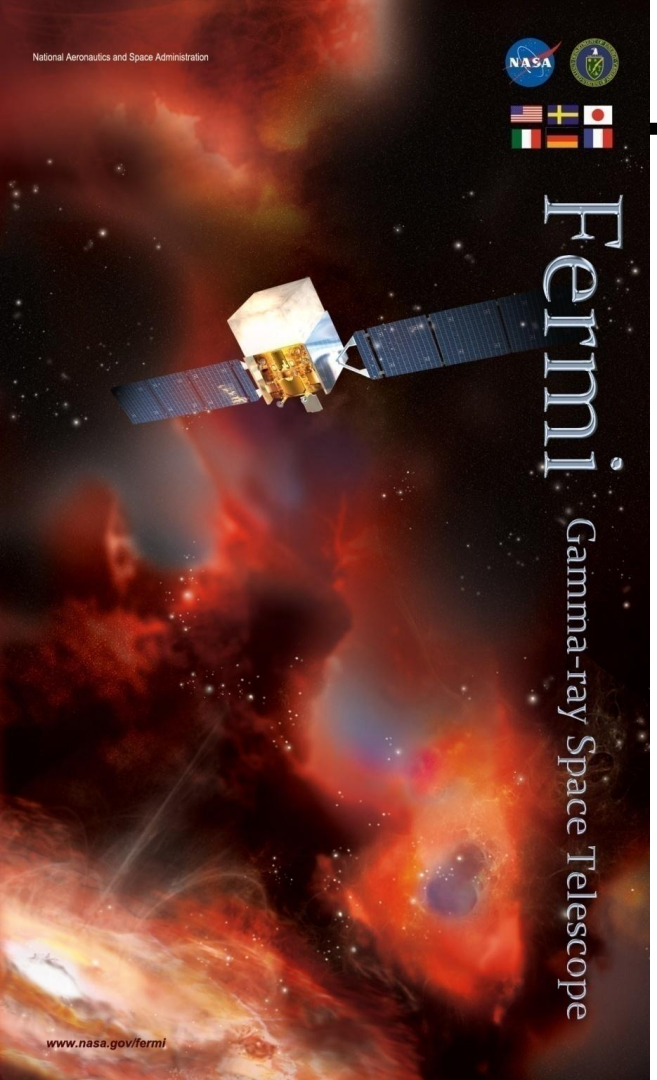

Fermi Gamma-ray Space Telescope

Star-Forming regions as potential contributors to Galactic cosmic rays: the case of NGC 3603

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ICRC 2021

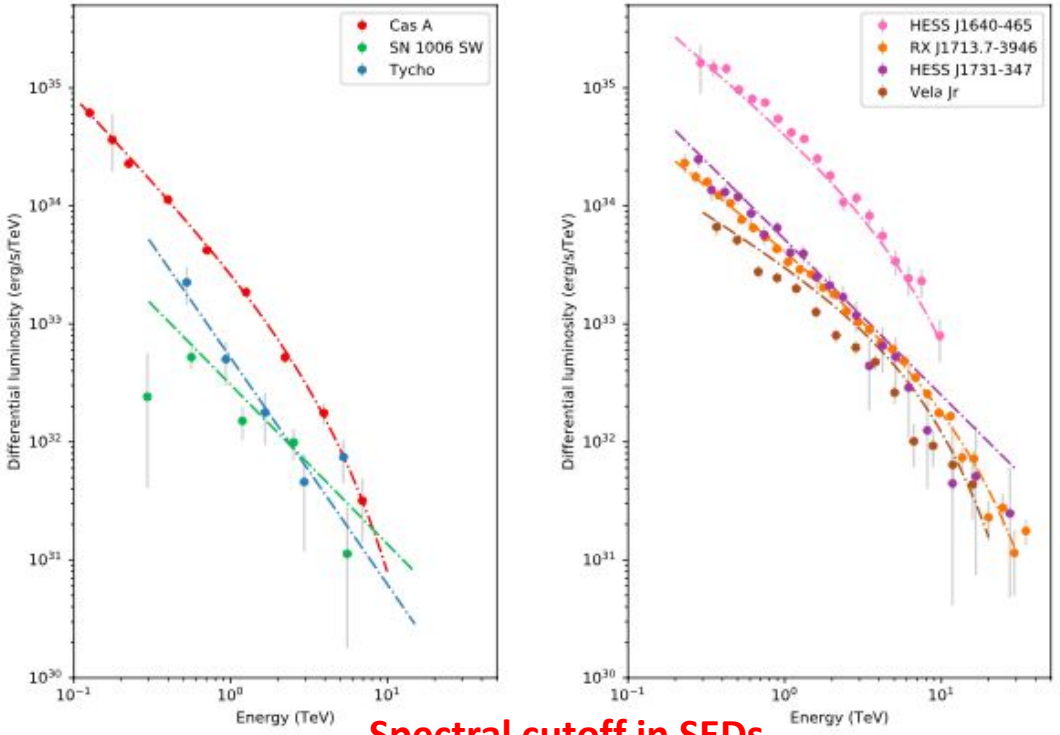
Origin of Galactic Cosmic Rays & Supernova Remnants

- SNRs are prominent representatives of contributors to Galactic CRs.
- Most of them show shell-like morphology supporting that SNR shocks as effective particle accelerators.

However, presence of spectral cutoff in the SEDs @VHE gamma rays indicate **breaks in proton spectrum**.

The detection of just VHE gamma rays does not prove the dominant role of SNRs in the production of Galactic CRs.

Aharonian et al., Nature Astronomy, 3, 2019



Spectral cutoff in SEDs

Differential spectrum of historical (left panel) and other (right panel) TeV emitting SNRs.

A new class of potential CR accelerator

Over the last decade, the space- and ground-based telescopes have revealed many classes of Galactic gamma-ray source populations.

An alternative to SNRs:

Massive Stars clusters/Star-forming regions!!

1980: First proposed as Potential CR accelerator. However no direct evidence.

Potential site of acceleration: The vicinity of the stars or superbubbles, a multi-parsec structure caused by collective activity of massive stars.

The multiple shocks can raise the maximum energy of CR protons out to **1 PeV.**

Casse, M. & Paul, J. A. 1980, Cesarsky, C. J. & Montmerle, T. 1983

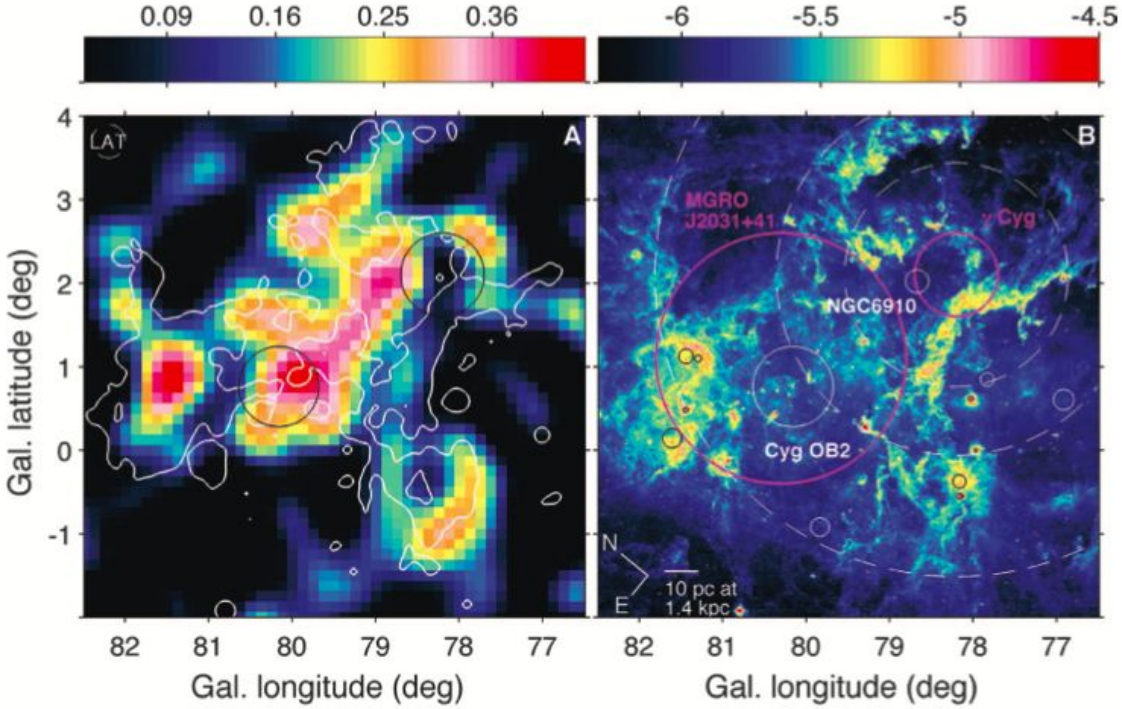
Cygnus Cocoon: 1st evidence of CR acceleration on SFR

A cocoon of freshly accelerated Cosmic Rays detected by Fermi in the Cygnus superbubble.

A 50-parsec-wide cocoon of freshly accelerated cosmic rays that flood the cavities carved by the stellar winds.

Extended emission

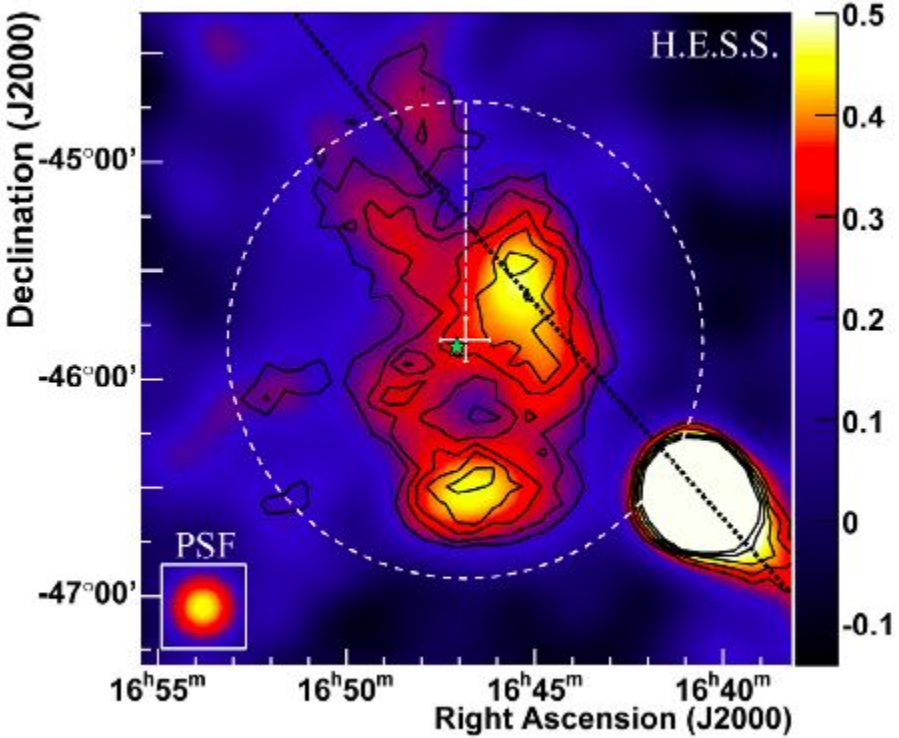
1-100 GeV image

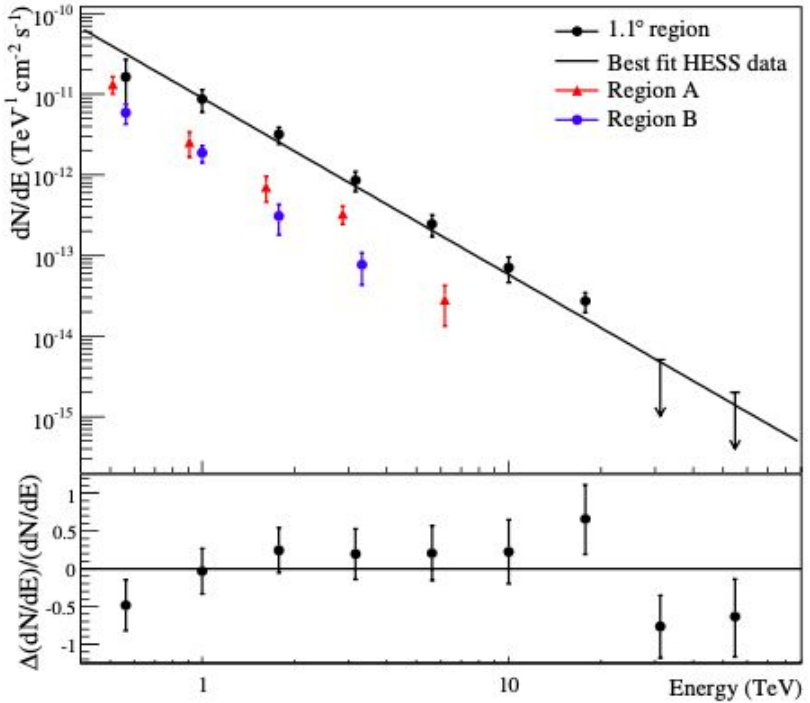


Science, 334, 2011

Westerlund 1: A young massive stellar cluster

Extended VHE Gamma-ray radiation from the vicinity of Westerlund 1





A&A 537, A114 (2012)

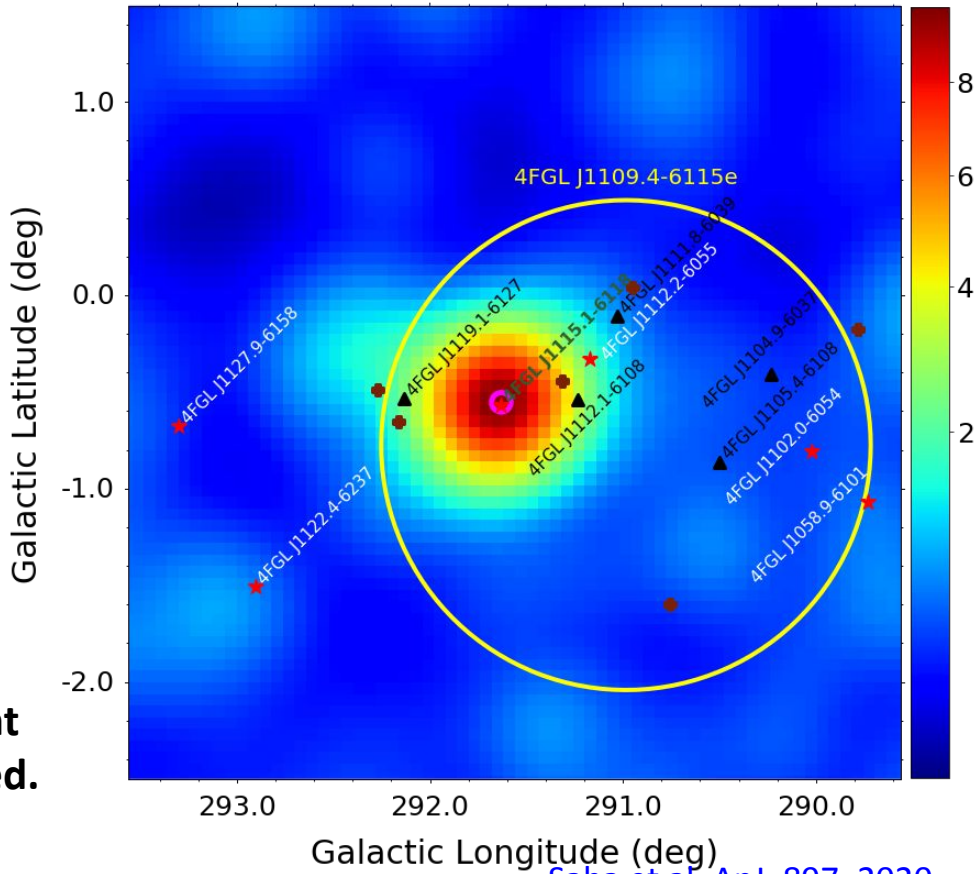
NGC 3603: A young massive stellar cluster

VHE Gamma-ray radiation from the vicinity of NGC 3603 -> 4FGL J1115.1-6118

Morphological analysis

Best-fit location and extension of **4FGL J1115.1-6118**

RA = 168.78 +/- 0.01,
DEC=-61.29 +/- 0.02 (in deg)
Extension: **0.08 +/- 0.02** (in deg)
TS_ext = **7.7**



However, the emission from the source 4FGL J1115.1-6118 positionally coincident with NGC 3603 is not significantly extended.

In Yang & Aharonian 2017 it was found to be extended.

Saha et al, ApJ, 897, 2020

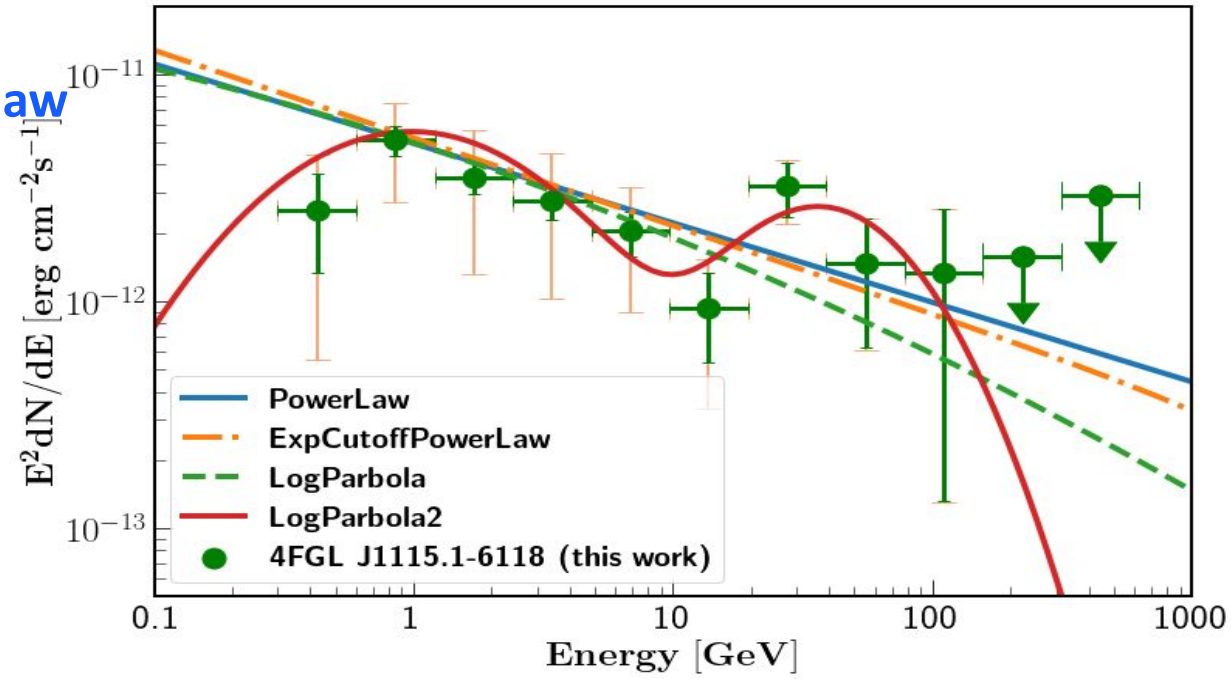
NGC 3603: A young massive stellar cluster

Spectral analysis

To understand the significance of the spectral curvature, we fit the data with different spectral shapes:

- Power-law
- Exponential cutoff power-law
- Log parabola
- Sum of two Log parabola models

PL provides best-fit



Saha et al, ApJ, 897, 2020

SED modelling

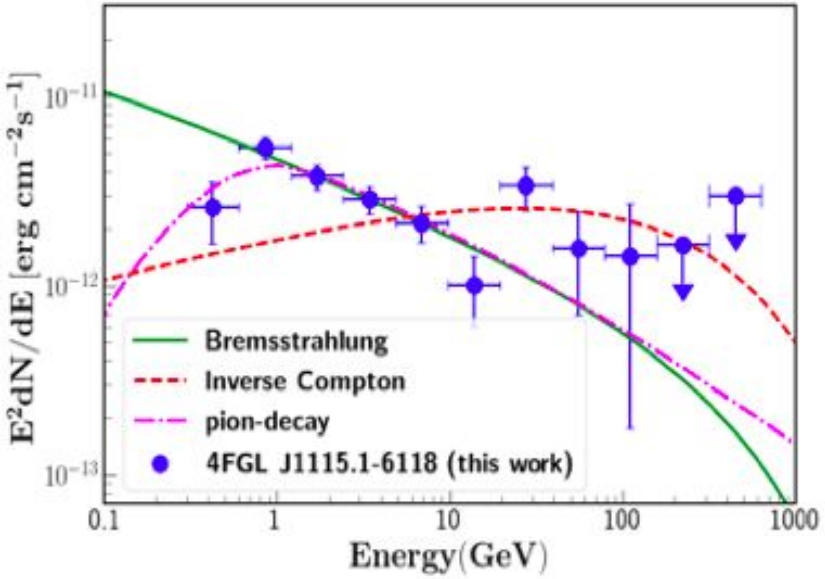
Leptonic model:

- Bremsstrahlung and Inverse Compton.
- Ambient matter density: **35/cm^3**
- Bremsstrahlung can explain SED **below 10 GeV** whereas **IC** can explain SED **above 10 GeV**.
- Estimated synchrotron contribution. Not significant.

Hadronic model:

- SED can be explained with the hadronic model
- Ambient matter density: **35/cm^3**

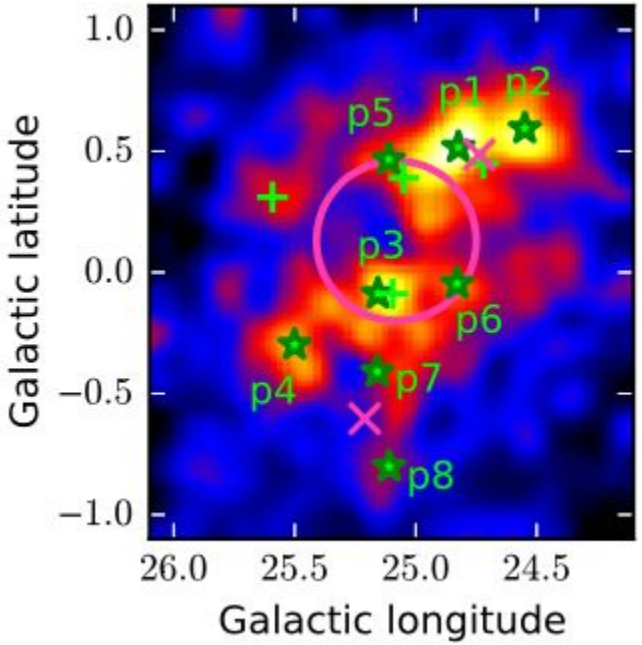
Parameters	Leptonic	Hadronic
spectral index (α)	2.5	2.3
Low energy cutoff, E_{min} (GeV)	10^{-3}	1.0
High energy cutoff, E_{cutoff} (GeV)	1.0×10^2	50×10^3
Ambient proton density, n_0 (cm^{-3})	35	35
Total energy (10^{48} ergs)	4.6	5.5



Given the large uncertainties in the SED at high energies the parameters of the models are not well constrained.

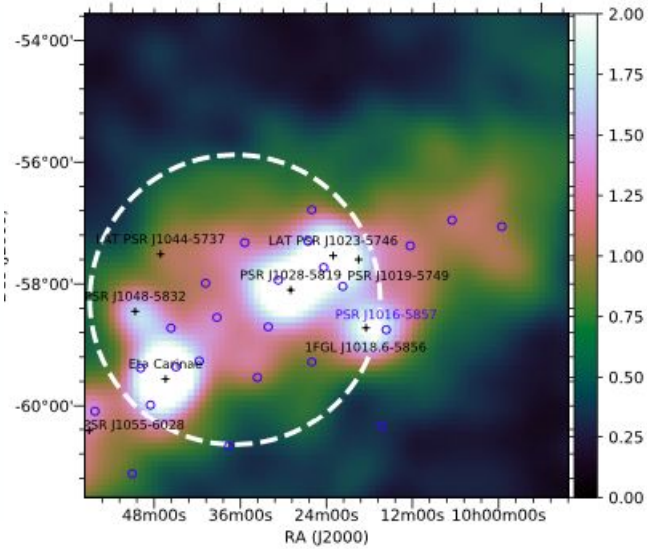
Some other potential cases

G25 region



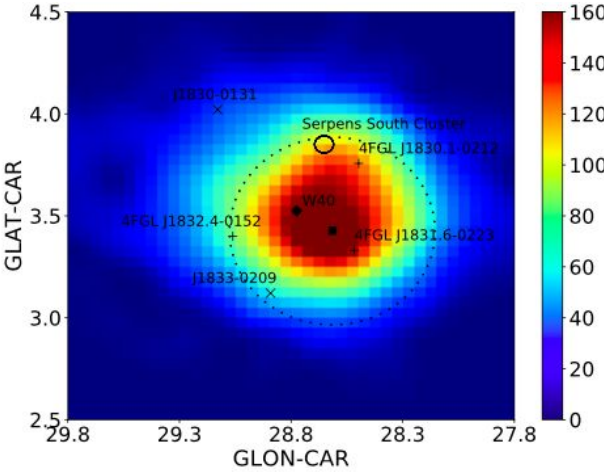
Katsuta et al 2017

Westerlund 2



Yang et al. 2017

W 40



Sun et al. 2020

Association of Fermi-LAT source with NGC 3603

- All possible association with known classes (e.g., SNRs, PWNe, AGNs) of sources are investigated but no association can be made.

- We can speculate that the observed emission is associated with the SFR.

- The gamma-ray luminosity of the source is only 0.2% of the total mechanical power of the winds from the SFR (8.5×10^{31} W)

  Therefore energetically the hypothesis that the source is powered by the SFR is also acceptable.

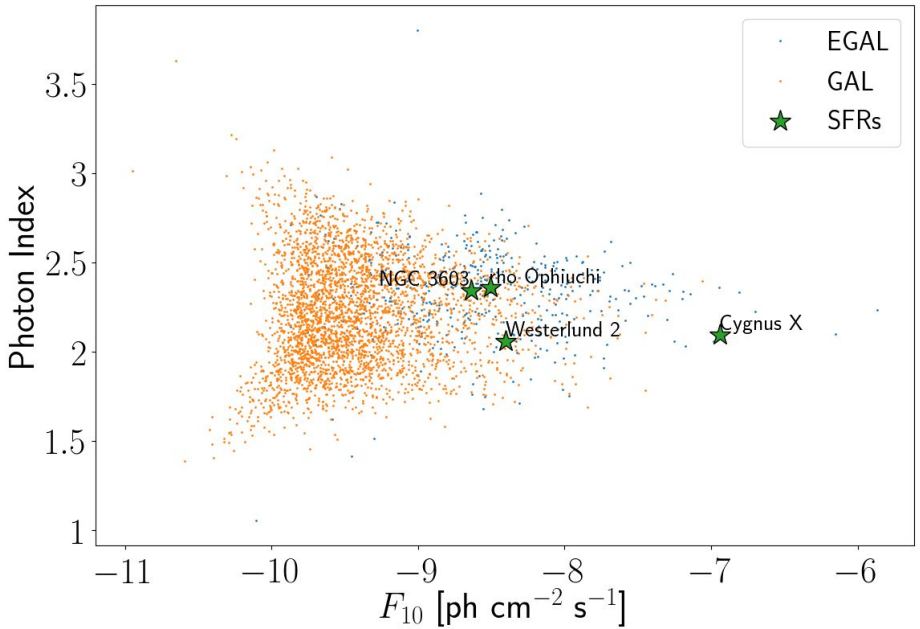
Future plan

- Interstellar background modelling brings a paramount source of uncertainty in the characterization of emission from Galactic sources, especially extended ones.

  A few alternate interstellar background models can be considered to assess the related uncertainties for extended SFRs.

- We also plan to perform a systematic search of gamma-ray emission from a large sample of stellar clusters.

- We can find out gamma-ray properties of the selected sources and compare them with the other known gamma-ray SFRs.



Summary

- We find that the observed gamma-ray emission from the source **4FGL J1115.1-6118 (NGC 3603)** is not significantly extended as reported elsewhere.

- No association with known classes of gamma-ray source can be made. Hence we speculate that 4FGL J1115.1-6118 is a case of gamma-ray emitting SFR.

- The detection of more γ-ray sources from the direction of SFRs or the non detection of many targets will tell us about this class of sources as possible sites of Galactic CR acceleration

- This detection also tells us how this CR acceleration depends on their properties such as age and stellar content.