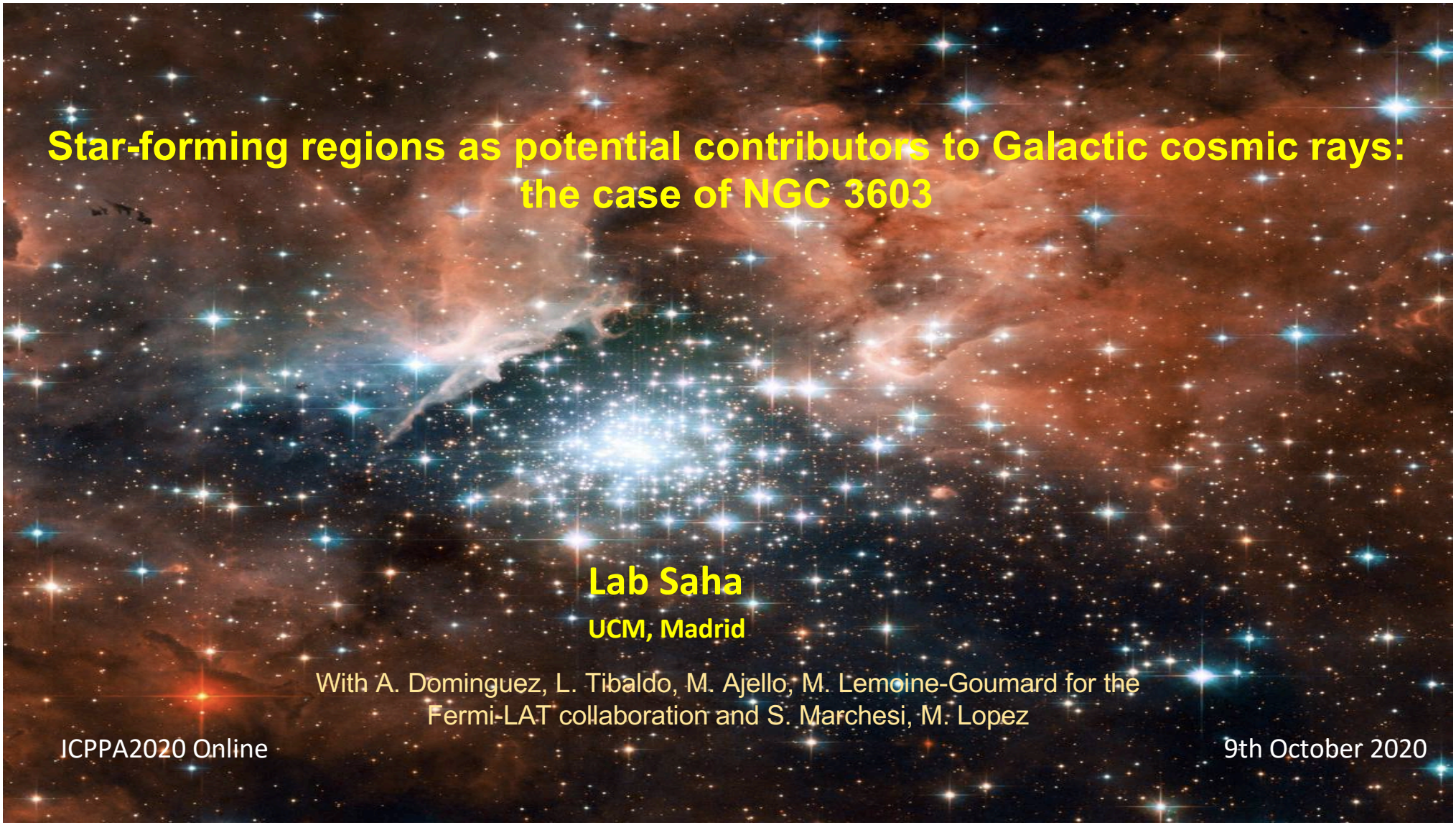

# Star-forming regions as potential contributors to Galactic cosmic rays: the case of NGC 3603


**Lab Saha**

**UCM, Madrid**

With A. Dominguez, L. Tibaldo, M. Ajello, M. Lemoine-Goumard for the Fermi-LAT collaboration and S. Marchesi, M. Lopez


ICPPA2020 Online

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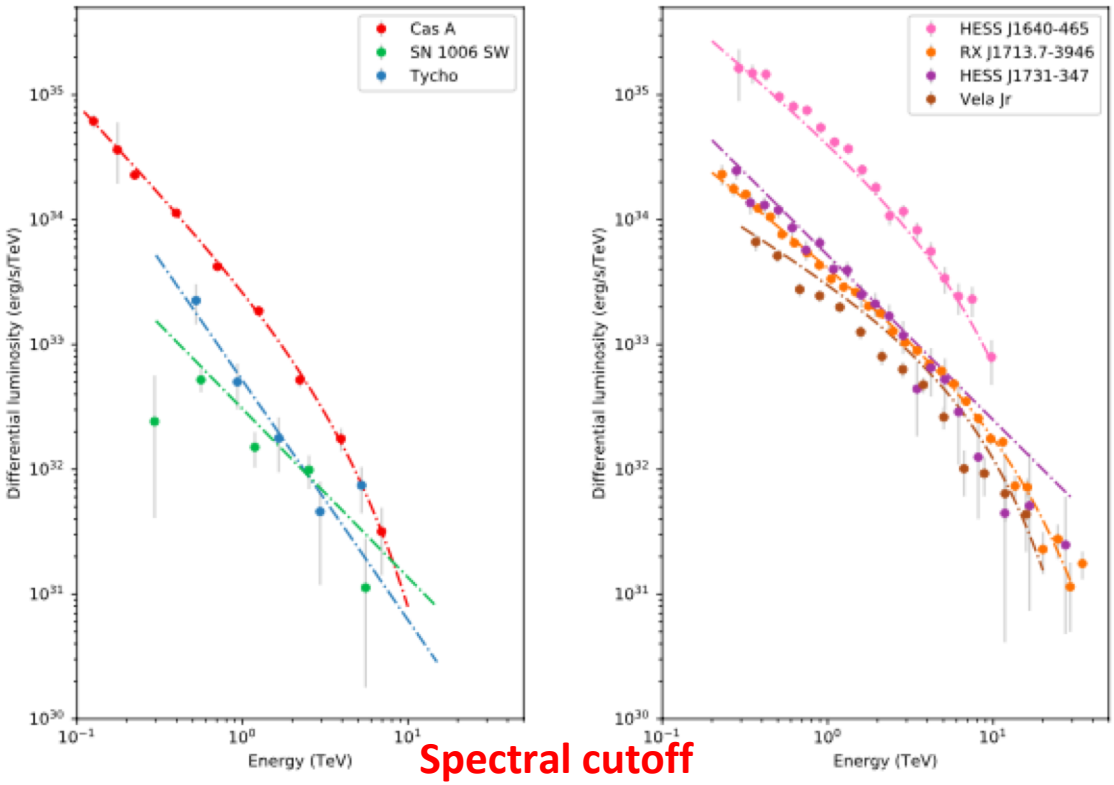
# Origin of Galactic Cosmic Rays and Supernova remnants

- Prominent representatives of SNR at energies above 100 GeV.
- Most of them show shell-like morphology supporting that SNR shocks as effective particle accelerators.
- 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

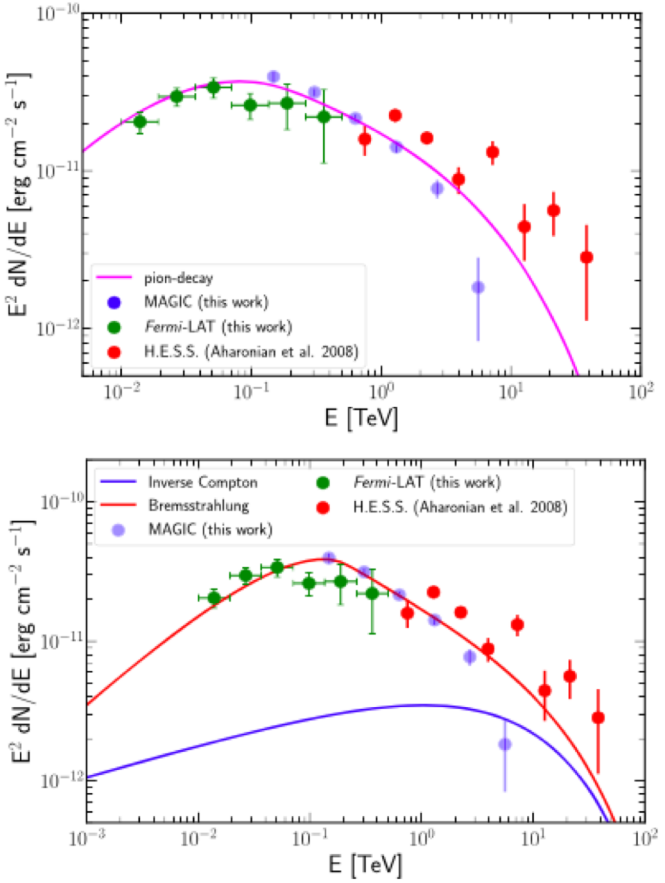
**Differential spectrum of historical (left panel) and other (right panel) TeV emitting SNRs.**

# Another important issue with Supernova remnants

- The main problem is the difficulty of **disentangling** the hadronic and leptonic contributions.

- Both **pion decay** process and **inverse Compton process** with 2.7K CMB photons or non-thermal Bremsstrahlung process are equally effective.

**With 'pros' and 'cons' for both the process gamma-radiation detected from all SNRs is under intense debate.**




MAGIC Coll., MNRAS, 497, 2020

# A new class of potential 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.**

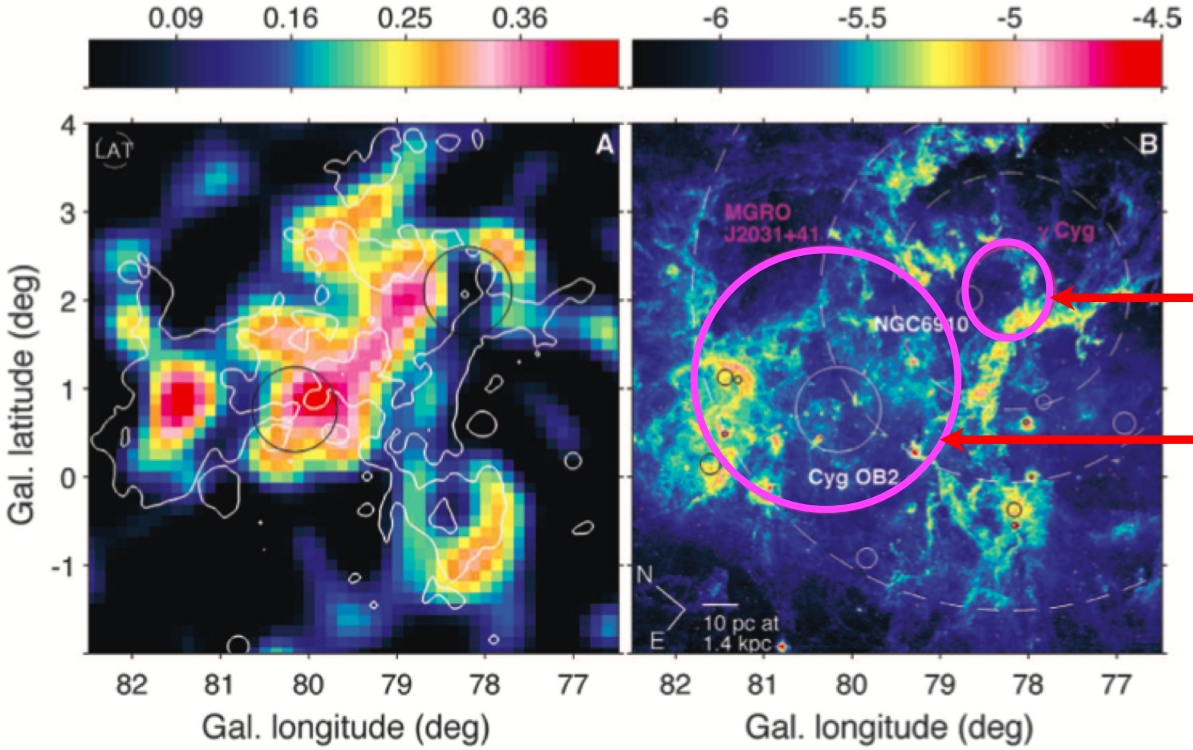
# Cygnus Cocoon: 1st evidence of CR acceleration in SFR

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**



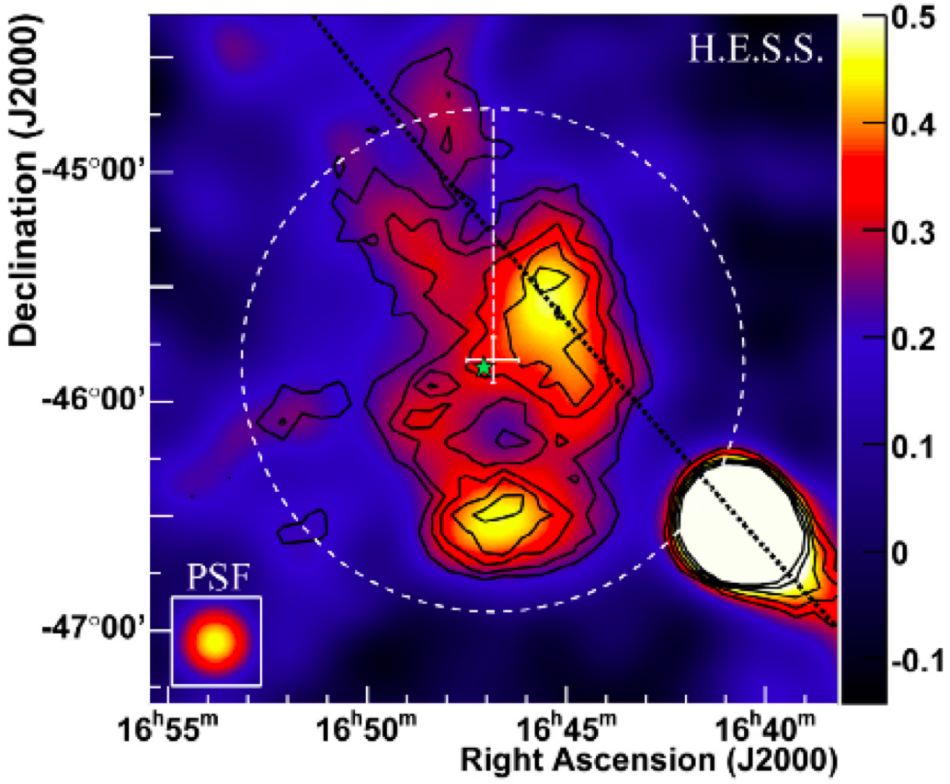

A supernova remnant

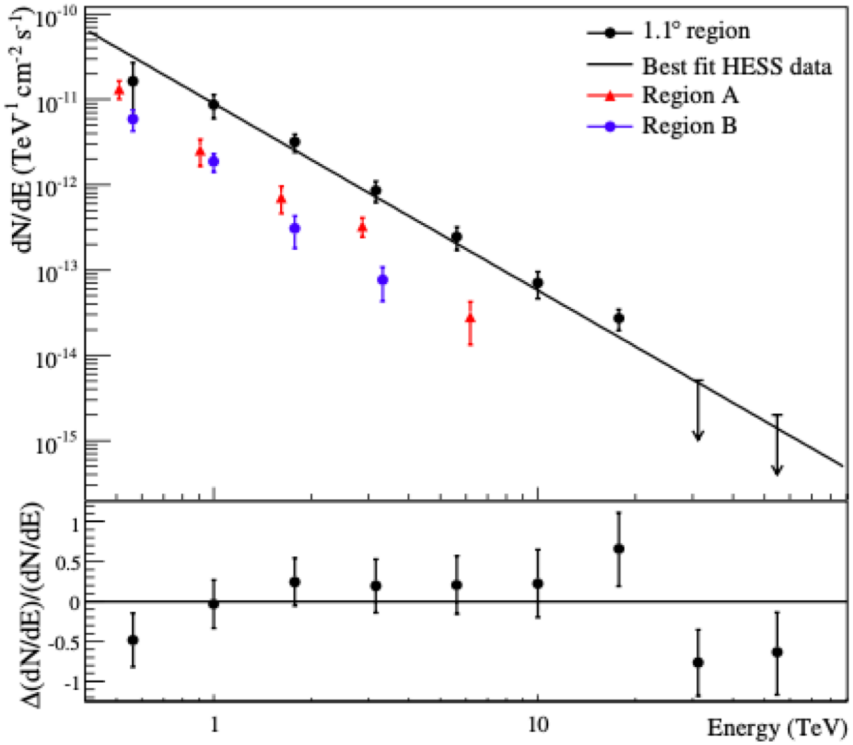
A TeV diffuse emission

Science, 334, 2011

# Westerlund 1: A young massive stellar cluster

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

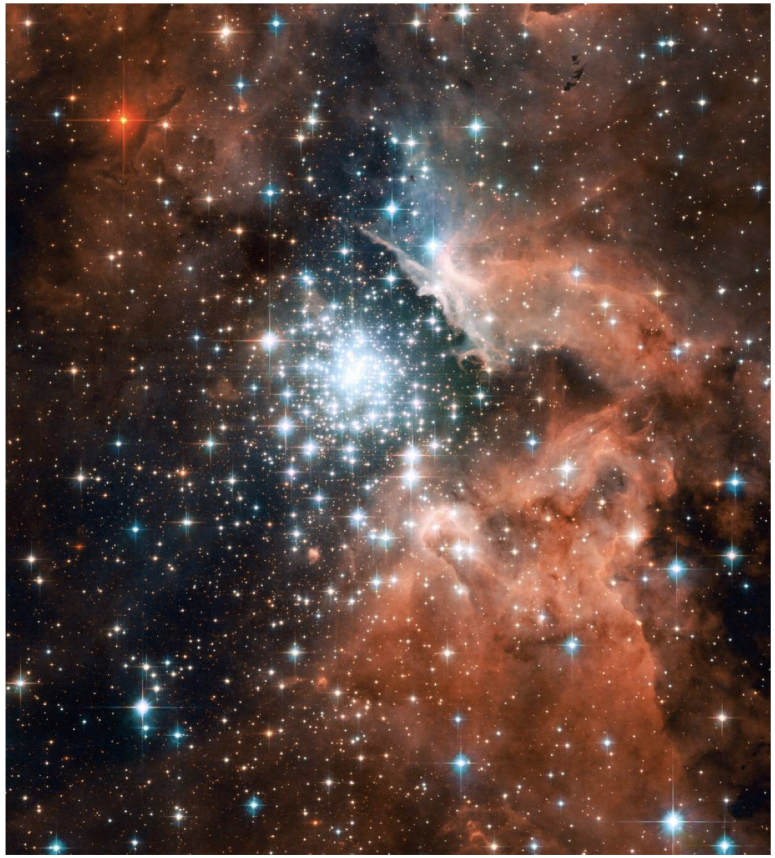



A&A 537, A114 (2012)

# The case of the NGC 3603

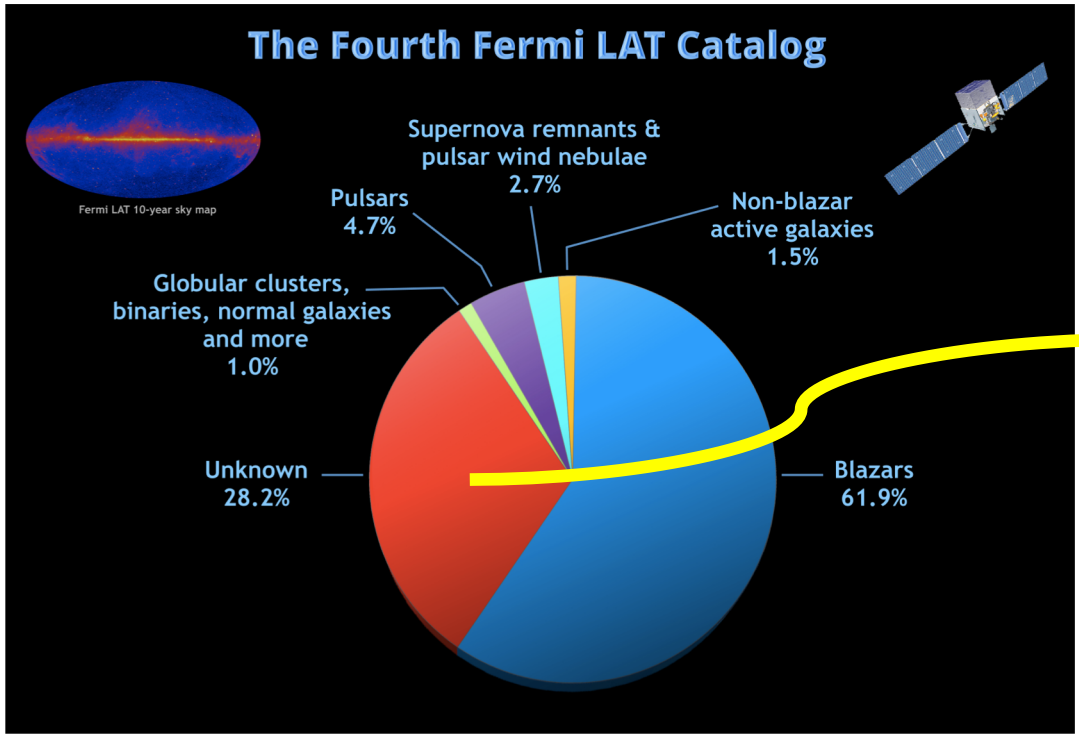
- The rich star forming region NGC 3603
- This stellar "jewel box" is one of the most massive young star clusters in the Milky Way Galaxy
- NGC 3603 is a prominent star-forming region in the Carina spiral arm of the Milky Way, about 20,000 light-years away.
- This image shows a young star cluster surrounded by a vast region of dust and gas. The image reveals stages in the life cycle of stars. The nebula was first discovered by Sir John Herschel in 1834.



3.24 x 3.26 arcminutes

# Search for gamma rays from NGC 3603

## Fermi-LAT observations




- An unidentified gamma-ray source in the 3FHL catalog (>10 GeV): **3FHL J1115-6117**.
- **3FHL J1115-6118** was positionally coincident with **NGC 3603**
- This source was also present in the 4$^{th}$ Fermi-LAT Catalog: **4FGL J1115.1-6118**

Making an association with NGC 3603 requires detailed morphological and spectral analysis.

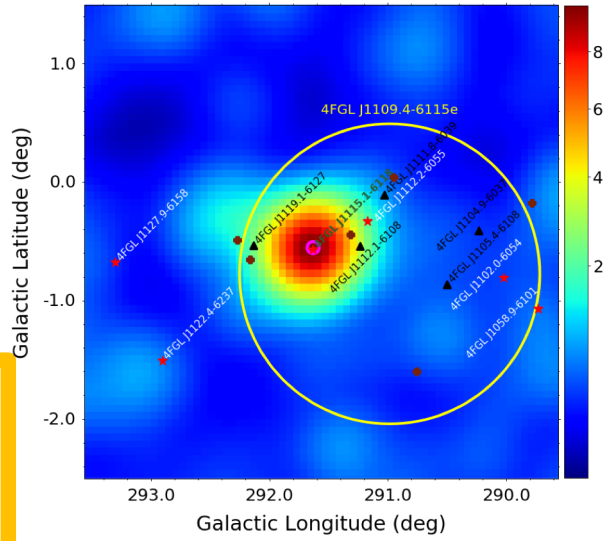
# Morphology of 4FGL J1115.1-6118

## Why morphological analysis?

To check the extension: Radially symmetric Gaussian model

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**




Energy range: **10 GeV to 1 TeV**

- **The source is not extended**
- **No diffuse emission**

**Saha et al, ApJ, 897, 2020**

# Spectral analysis of 4FGL J1115.1-6118

**Energy range: 300 MeV to 1 TeV**

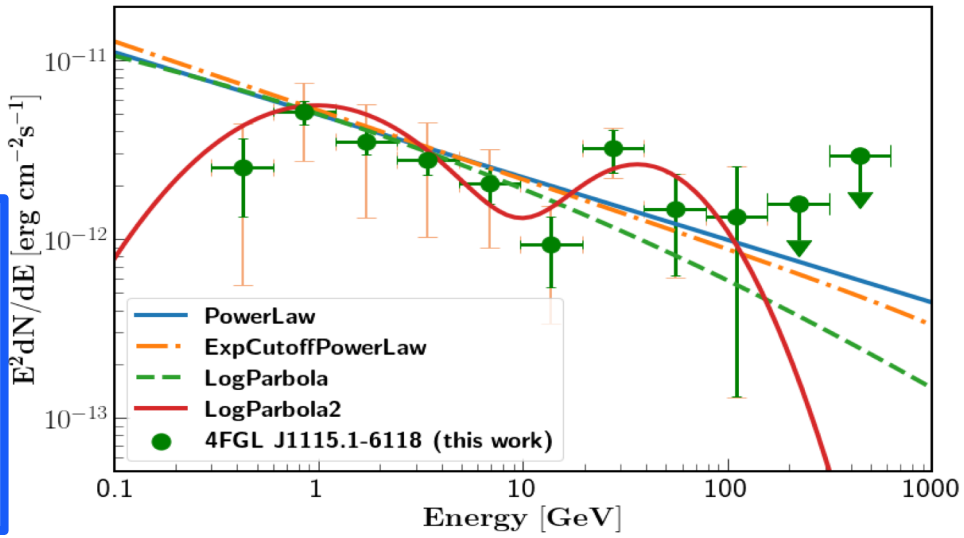
Spectral fit with power-law spectral shape.

The SED may suggest that the **emission has two components**, one **below 10 GeV** and the other **above 10 GeV**.

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

| Spectral model | $\Delta \log \mathcal{L}^{a}$ | d.o.f | $\Delta$ AIC$^{a}$ |
|---|---|---|---|
| Powerlaw | 0.0 | 22 | 0.0 |
| ExpCutoffPowerlaw | 0.6 | 23 | 0.8 |
| Logparabola | 1.0 | 23 | 0.0 |
| Logparabola2 | 7.1 | 26 | -6.2 |



# SED Modelling

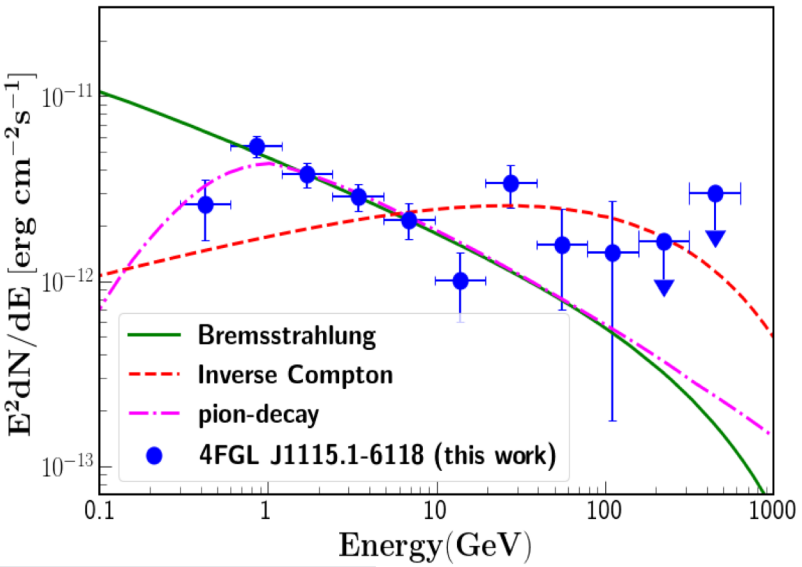
**Leptonic model:**

- 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:**

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

| Parameters | Leptonic | Hadronic |
|---|---|---|
| spectral index ($\alpha$) | 2.5 | 2.3 |
| Low energy cutoff, $E_{min}$ (GeV) | $10^{-3}$ | 1.0 |
| High energy cutoff, $E_{cutoff}$ (GeV) | $1.0 \times 10^2$ | $50 \times 10^3$ |
| 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.

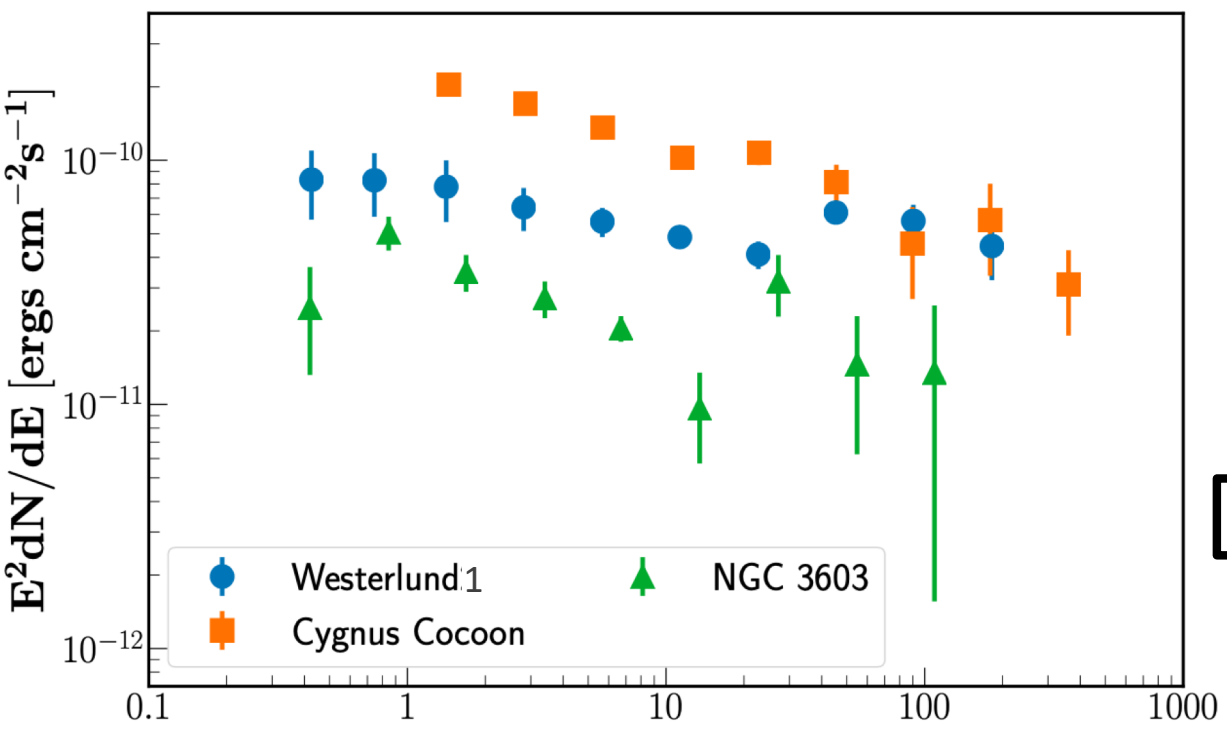
**Saha et al, ApJ, 897, 2020**

# Is it associated with a star-forming region?

- All other associations with the known classes of astrophysical objects are very less likely.
- The gamma-ray luminosity of the source is only 0.2% of the total mechanical power of the winds from the SFR ($8.5 \times 10^{31}$ W)
- Energetically the hypothesis that the source is powered by the SFR is also acceptable.

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

# Are these SFRs likely to be PeVatrons?




**No signature of spectral cut-off yet!!**

**Double-bump structure: Is it real?**

# Conclusions

1. Our detailed analysis show that the observed gamma-ray emission from the 4FGL J1115.1−6118 source is not significantly extended.

2. The observed X-ray emission is expected to be associated with the point source 4FGL J1115.1−6118 and Galactic in origin.

3. The observed SED can be explained with both a leptonic and a hadronic model for an ambient matter density of 35 $cm^3$.

1. No firm evidence of association with any other classes of known gamma-ray emitters is found.

# Conclusions

1. Our detailed analysis show that the observed gamma-ray emission from the 4FGL J1115.1−6118 source is not significantly extended.

**It becomes a potential candidate for studying SFRs to understand the origin of cosmic rays using the next generation of gamma-ray telescopes.**

3. The observed SED can be explained with both a leptonic and a hadronic model for an ambient matter density of 35 $cm^3$.

1. No firm evidence of association with any other classes of known gamma-ray emitters is found.


Thank you
Sarah A. Brands, 2018

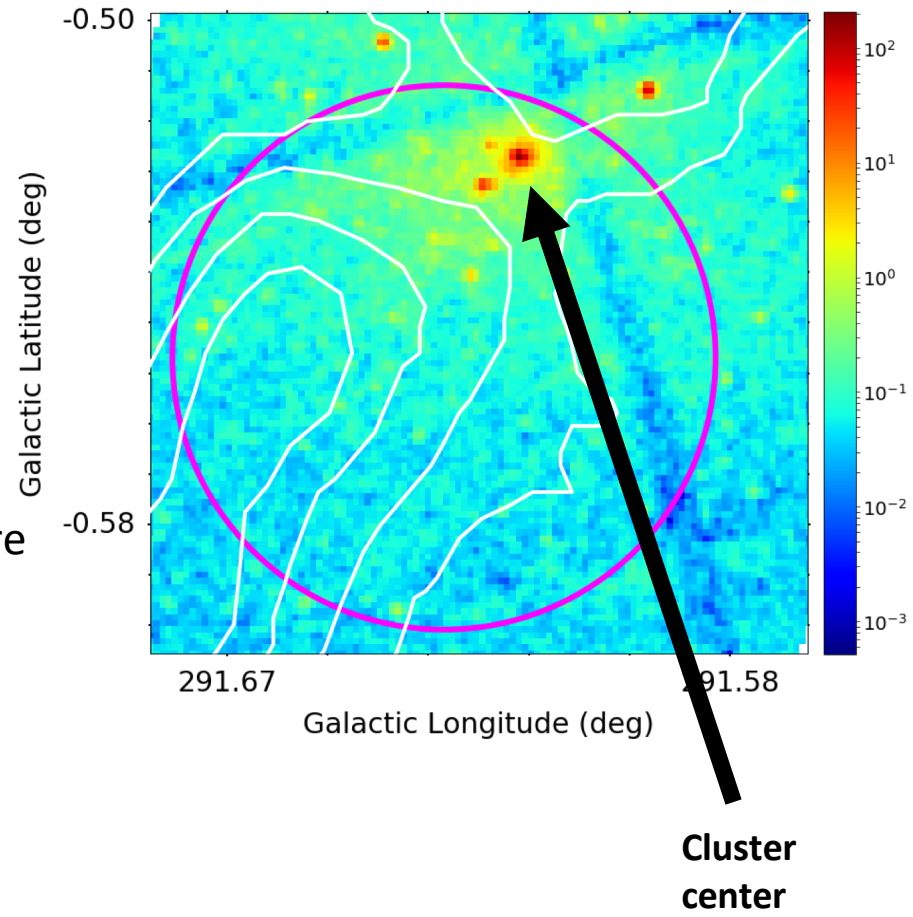
# Backup Slides

# NGC 3603: X-ray association

*Chandra data*

- Energy range: 0.5 - 7.0 keV
- ObsId: 12329 (October 2010, 150 ks long exposure)
- About 300 sources are detected. 38 of them are with net counts more than 70 counts.

Extragalactic association is less likely



# NGC 3603 Environments: HII regions and CO clouds

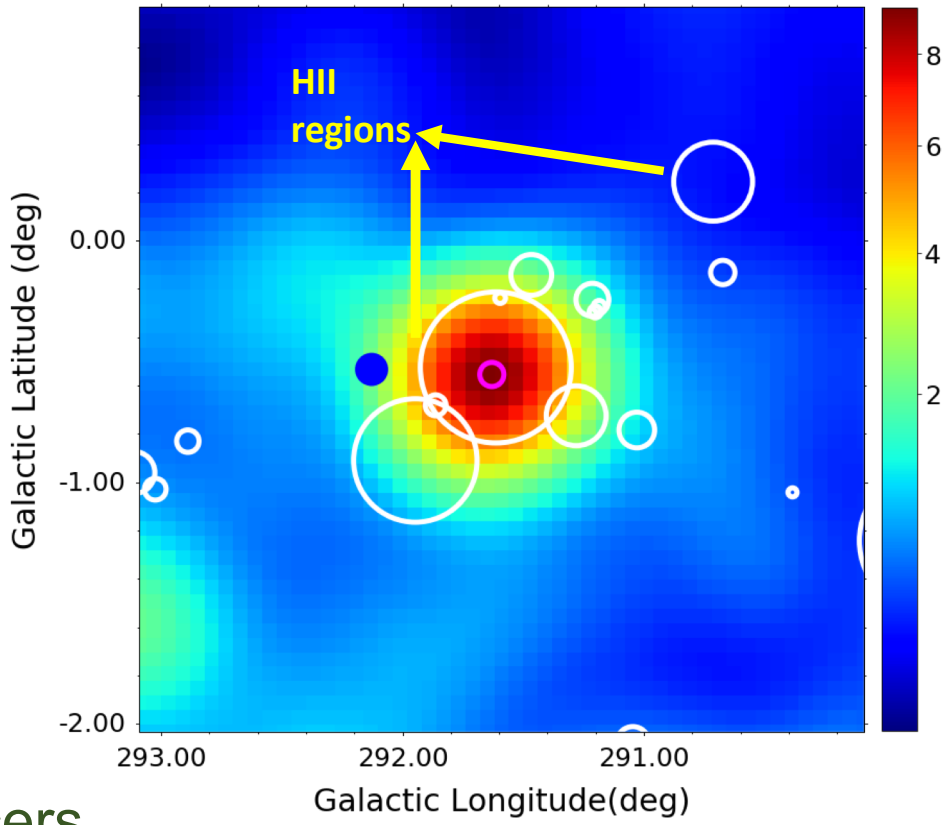
A HII region is well-known characteristics of an SFR.

Which emission mechanisms are active?

Leptonic or hadronic?

An estimate of the ambient matter density is very essential

- HII regions is positionally coincident with the source region
- CO molecular clouds are also present in this region




HII and CO molecular clouds are tracers.