A Systematic Study of Galactic Star-Forming Regions

Ava Webber

On Behalf of the LAT Collaboration:

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Star-Forming Regions

WHAT? These are Galactic objects, and we are interested in massive star clusters

WHERE? In molecular clouds; opaque clumps of cold (~10K) and dense (~100-1000 particles/cc) gas and dust

WHEN? cloud mass > Jean's mass

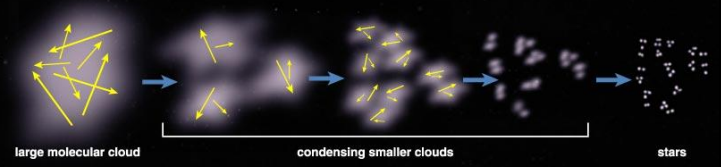
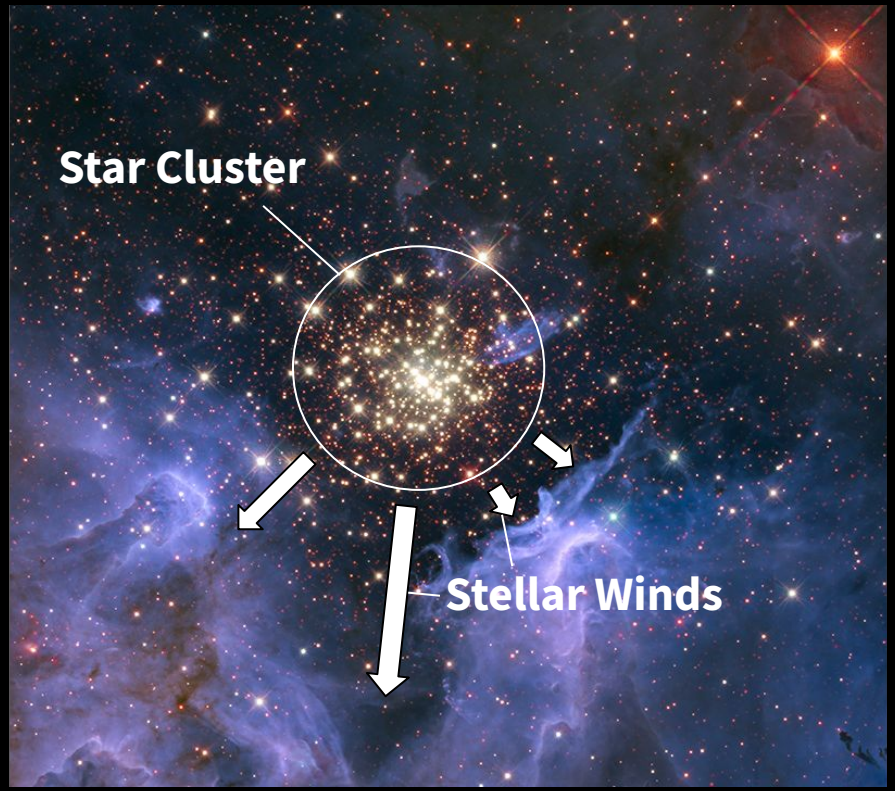


Figure credit: Linda Huff

Research Motivation

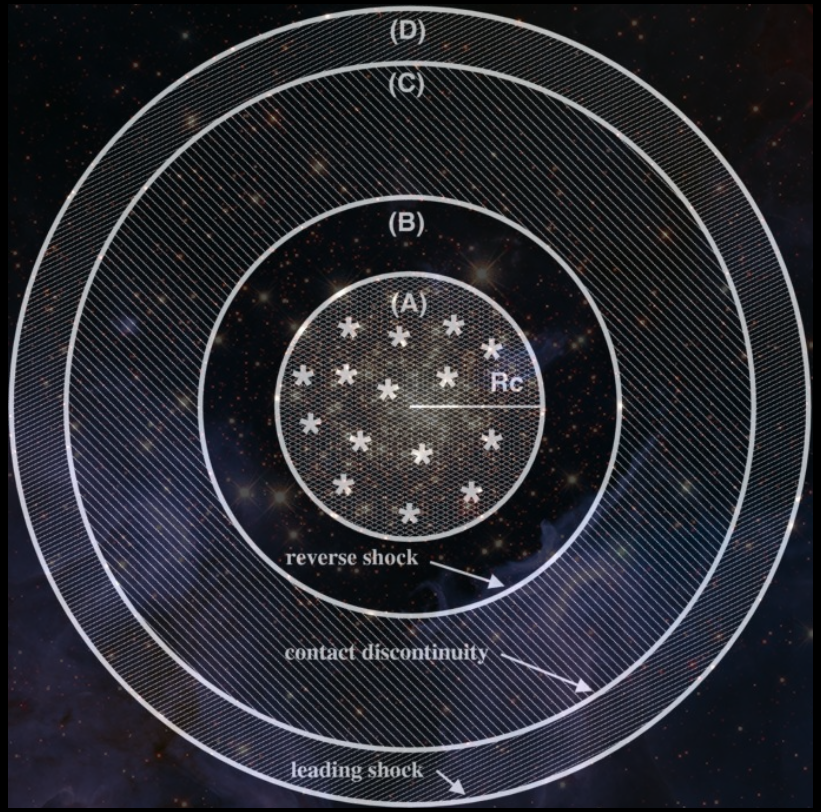
- ★ Galactic star-forming regions (SFRs) are potential CR accelerators and sources of γ-ray emission
- ★ SFRs may play an important role in the diffuse galactic emission and CR acceleration in the Galaxy
- ★ Only a few instances where associations with SFRs have been realized, while many more SFRs have not been detected

SFRs as CR Accelerators

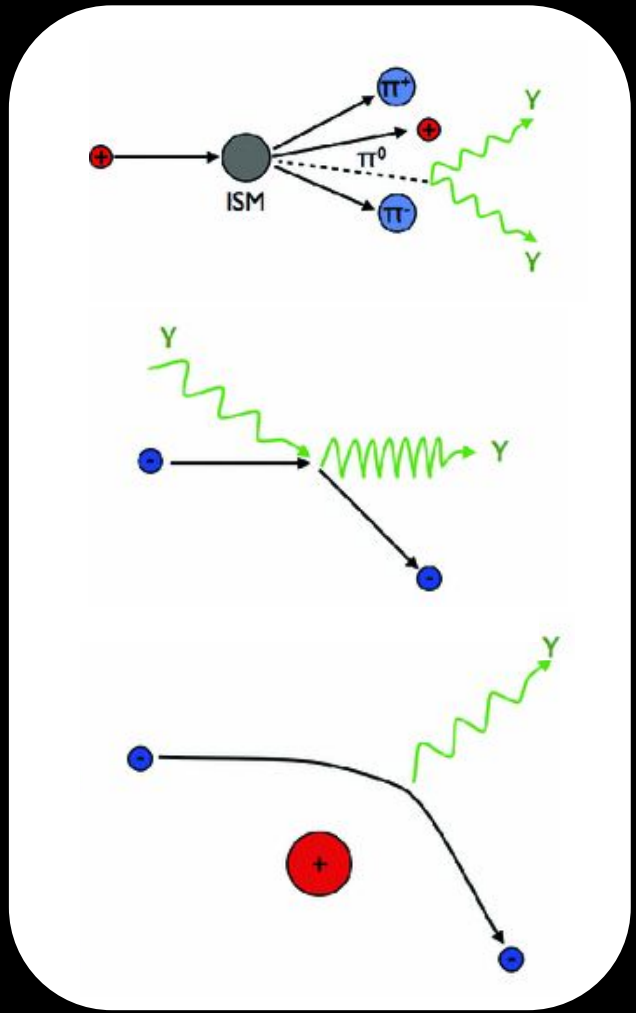


- Host known cosmic ray (CR) accelerators (pulsars & SNRs)
- Collective stellar winds
  - Expected CR accelerators are young massive clusters (OB stars greatly contribute to collective winds)
  - High velocity winds interacting with ISM give rise to shocks and superbubble (SB) formation
  - Diffusive shock acceleration (DSA) effectively accelerates particles to CR energies

SFRs as γ-ray Emitters



P. Velazquez et. al 2013



Cygnus Cocoon
spatial width ~ 3.6°

X. Astiasarain et al. 2022

Westerlund 2
spatial width ~ 0.24°

E. Mestre et al. 2021

Westerlund 1
spatial width ~ 2.0°

F. Aharonian et al. 2022

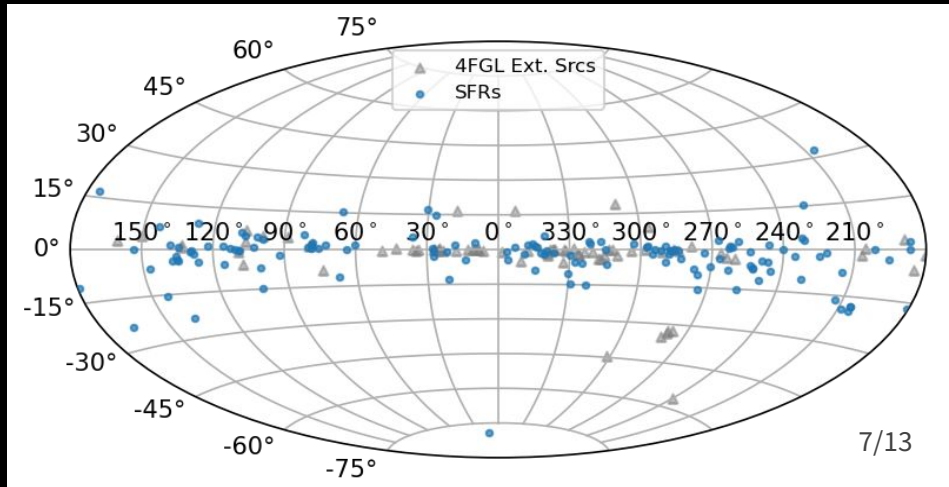
NGC 3603
spatial width ~ 0.16°

L. Saha et al. 2020

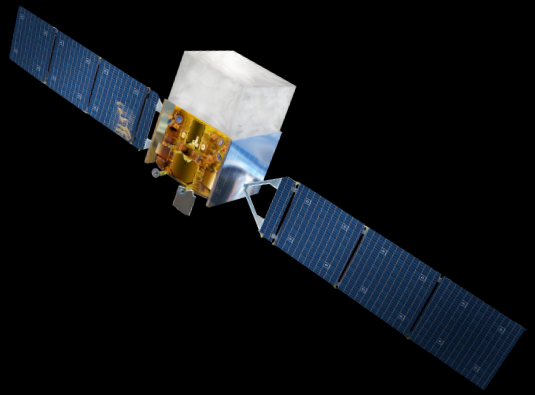
SFRs Sample Selection

- Majority from Cantat-Gaudin+2020 analysis of Gaia data
- Manageable sample: keep only optically bright (dereddened mG < 5.5) clusters
  - Diverse sampling of intrinsic properties (age, distances, stellar membership)
  - Majority of stellar clusters with OB stars
  - All previously known γ-ray detections of SFRs
- Added to sample: Fermi γ-ray sources (e.g. Cyg-OB2, Westerlund 1, Westerlund 2, NGC 3603)

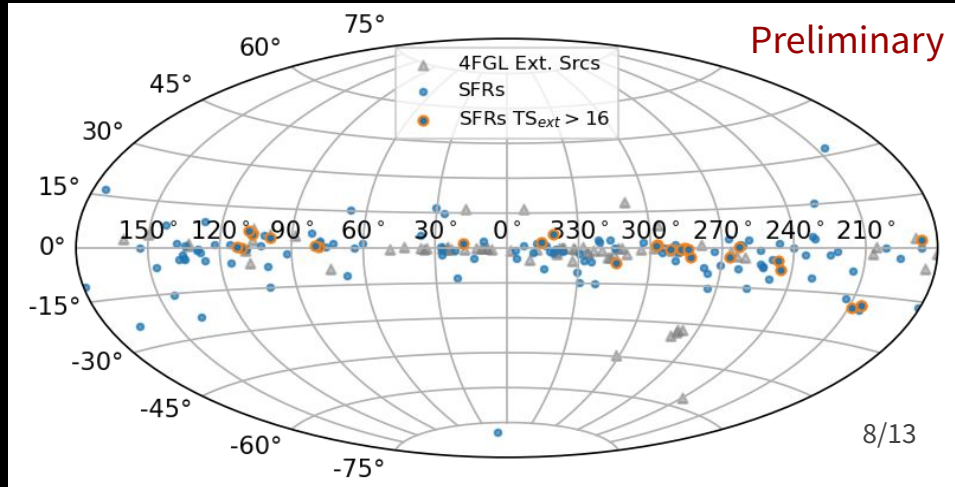
➡ **Total sample: 139 targets**



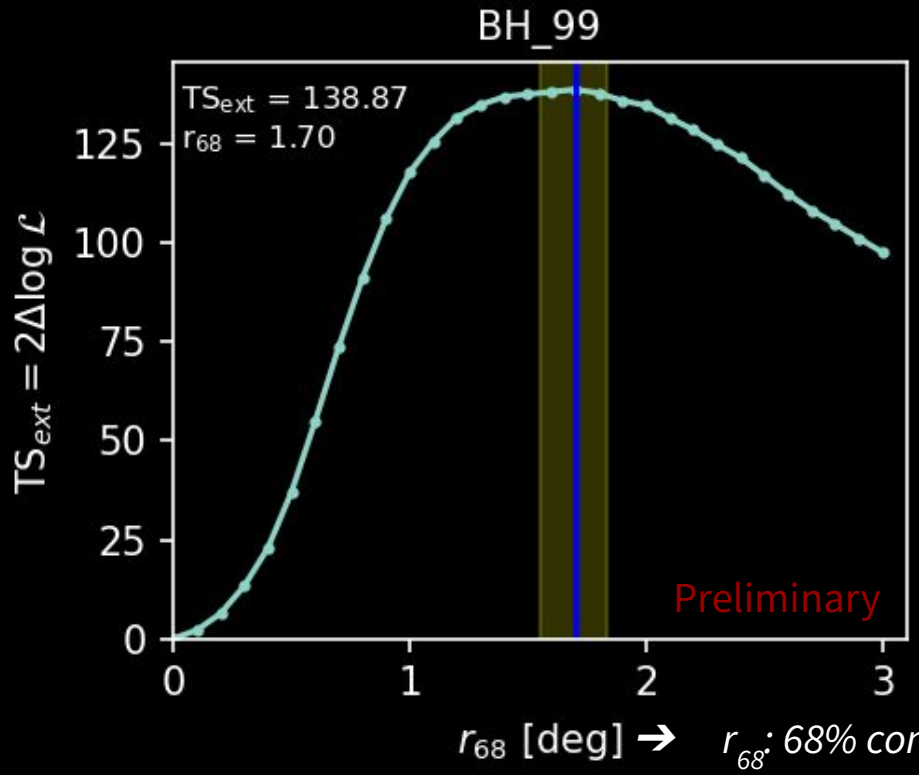
Fermi Data & Analysis



- ~15 years of data, 1 GeV - 1 TeV range, ROI 10x10 deg.
- Binned joint likelihood analysis
- Preprocessing steps
  - All targets modeled as point sources
  - Only one detection for SFRs
- Extension fitting with Fermipy
  - Perform likelihood scan in spatial extension
    - Fermipy's gta.extension( ) with free parameters for BG sources
  - 19 *new* targets detected showing significant (S ≥ 4σ) extension



Extension Fitting



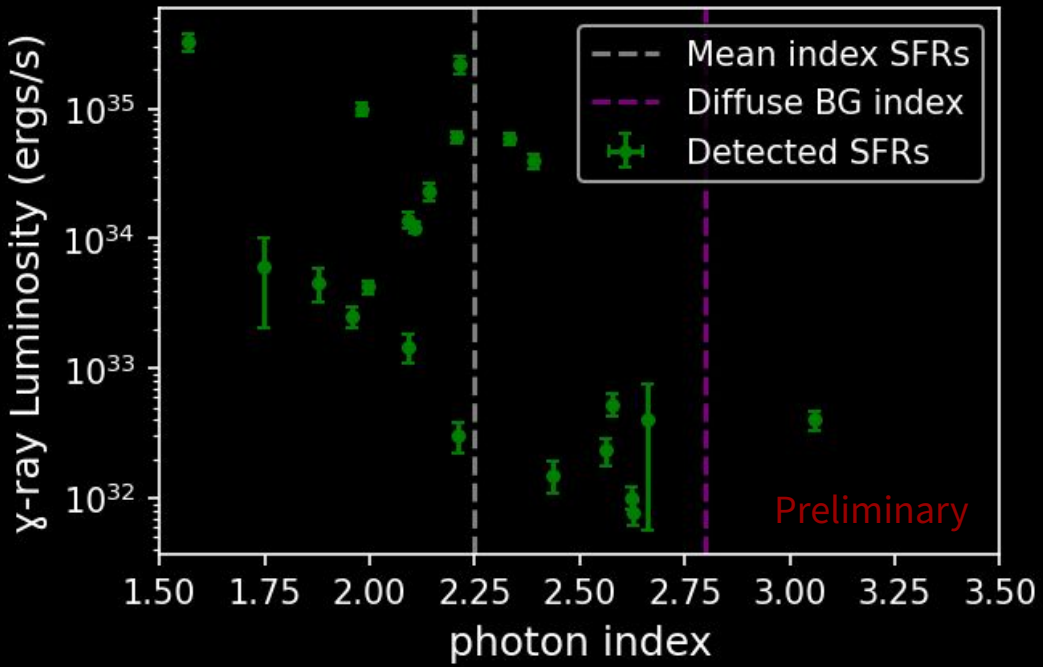
➔ *Radial Gaussian model*

$$TS_{ext} = 2ln\left(\frac{L_{ext}}{L_{ps}}\right)$$

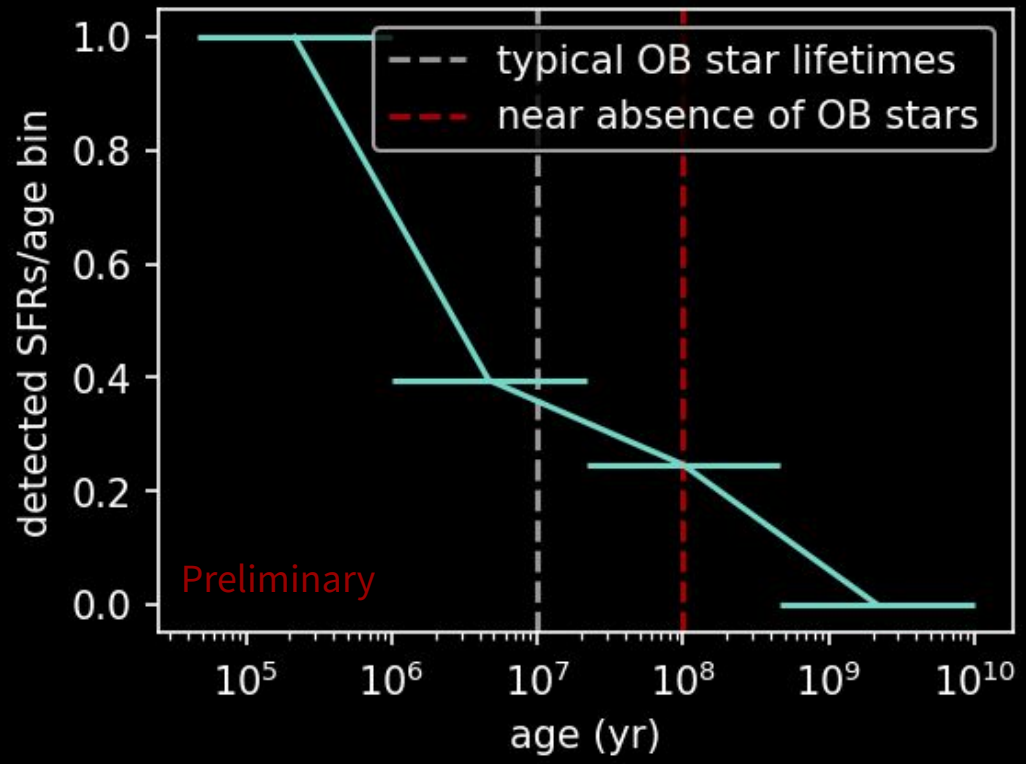
$$S \geq 4\sigma : 16\% \ or \ \frac{22}{139}$$

r_{68}: *68% containment radius (within 1σ of the mean value)*

γ-ray Luminosity Dependence on Index



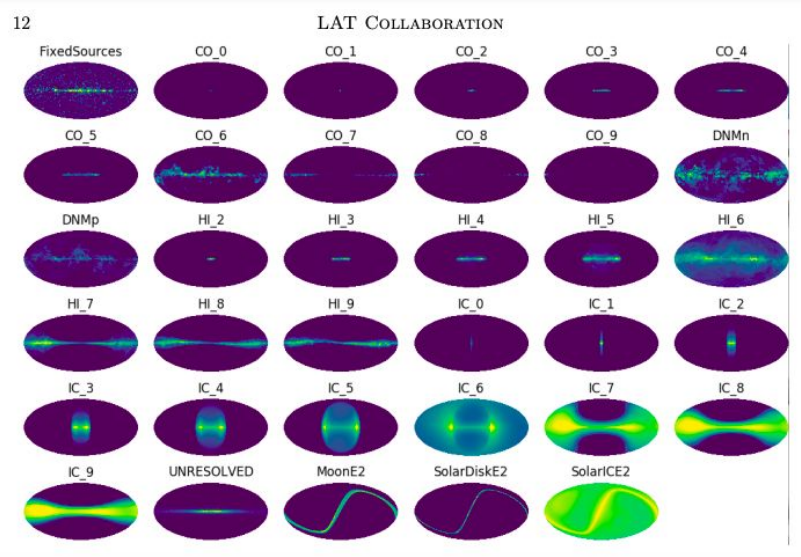
γ-ray Luminosity Dependence on Age



Robustness Tests of Analysis

Increase DOF in background model

- Multiple component modeling of Galactic diffuse emission



The *Fermi*-LAT Collaboration 2019

Control fields

- Spots within galactic plane distributed similarly to SFR sample
- Exclude regions spatially coincident with known γ-ray emitters (Fermi point and extended sources)
- Exclude other star clusters from Cantat-Gaudin analysis

Extension Fitting

- Refining our fits “recipe” for all 139 targets
- Ensure detections of extended sources are robust against changes of BG source parameters

Main Takeaways

- ★ Have Identified ~19 significant candidates for newly detected γ-ray emitting SFRs
- ★ γ-ray luminosity and detection rate as a function of age is consistent with expectation: younger clusters brighter and easier to detect!
- ★ **<u>Future work</u>:** multiwavelength studies of individual sources will be used to determine emission mechanisms, revealing the relation between physical features of Galactic SFRs and their emissions

THANK YOU

Acknowledgements:

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Image Credits:

Velazquez, Pablo & Rodríguez-González, Ary & Esquivel, Alejandro & Rosado, Margarita & reyes-iturbide, Jorge. (2013). Modeling the thermal diffuse soft and hard x-ray emission in M17. The Astrophysical Journal. 767. 69. 10.1088/0004-637X/767/1/69.

Cygnus X (NASA/JPL-Caltech/Harvard-Smithsonian CfA)

Westerlund 1 (NASA/ESA/Hubble)

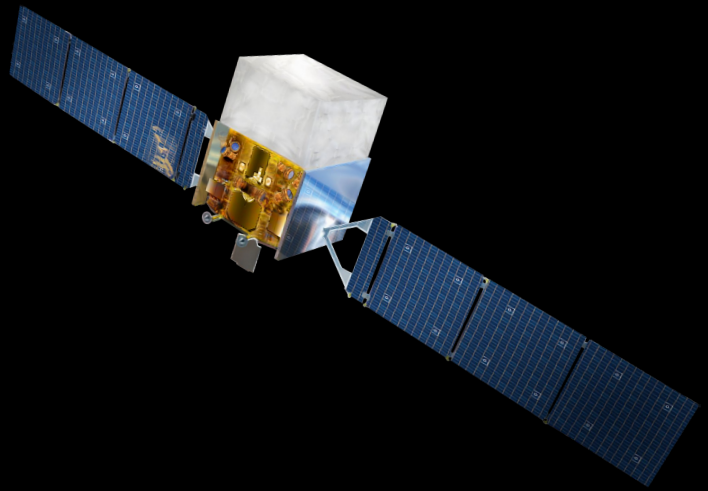
Westerlund 2 (NASA/ESA/Hubble)

NGC 3603 (NASA/ESA/Hubble)

The *Fermi*-LAT Collaboration. (2019). Galactic Interstellar Emission Model for the 4FGL Catalog Analysis.

Extra Slides

Fermi-LAT Data



- Joint-Likelihood Analysis using PSF 1,2,3
- ~15 years of data
- P8R3
- 1 GeV - 1 TeV
- z < 105
- 10 x 10 ROI (modeled as PS)
- 8 energy bins per decade
- Pix = 0.08 deg
- Point Source catalog: 4FGL-DR3
- Additional sources found with find_sources()