

# HAWC's View on Supernova Remnants

**Henrike Fleischhack**  
For the HAWC Collaboration

October 16, 2018



**Michigan  
Technological  
University**



- High-Altitude Water Cherenkov Observatory.
- Located in Sierra Negra, Mexico (4400 m a.s.l).
- Energy range: sub-TeV to  $>100$  TeV.
- Angular resolution:  $0.1^\circ - 1^\circ$ .
- See talks by H. Zhou, A. Smith, C. Brisbois and poster by B. Hona.
- Results shown here use 1128 days of HAWC data.
- High-level analysis: 3ML [Vianello et al., 2015].
- Hadronic modeling: `naima` [Zabalza, 2015].

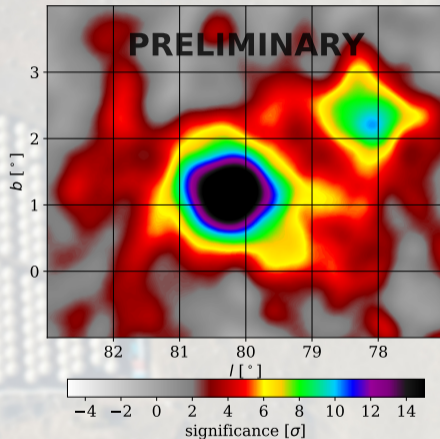
# SNR Intro

- Shock from SN explosion propagates into ISM for many kyr.
- Particle acceleration via diffusive shock acceleration mechanism.
- Gamma rays from leptonic and/or hadronic processes.
- Leptonic:
  - Inverse Compton scattering
  - Bremsstrahlung.
- Hadronic:
  - CR interactions inside remnant
  - CR interactions with nearby molecular clouds.
- Responsible for significant population of Galactic CRs?



# G78.2+2.1 ( $\gamma$ Cygni SNR)

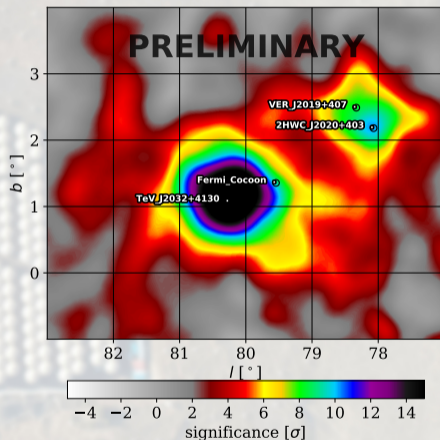
- Middle-aged SNR,  $\sim 6000$  yrs [Lozinskaya et al., 2000]).
- Located in Cygnus region, overlaps with Cygnus Cocoon.
- Distance:  $\sim 1.7$  kpc [Lozinskaya et al., 2000].
- X-ray/radio shell, enhanced emission at northern/southern edge.
- Seen up to TeV energies.
- Leptonic or hadronic emission?
- Connection to Cygnus Cocoon?





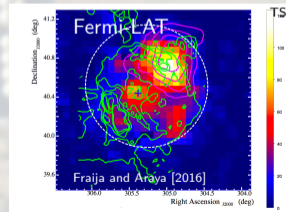
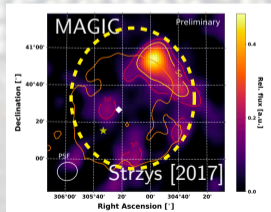
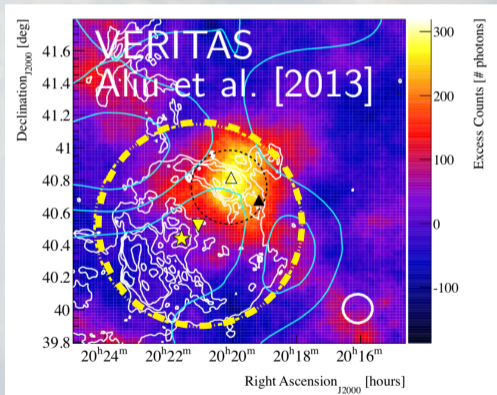
# G78.2+2.1 ( $\gamma$ Cygni SNR)

- Middle-aged SNR,  $\sim 6000$  yrs [Lozinskaya et al., 2000]).
- Located in Cygnus region, overlaps with Cygnus Cocoon.
- Distance:  $\sim 1.7$  kpc [Lozinskaya et al., 2000].
- X-ray/radio shell, enhanced emission at northern/southern edge.
- Seen up to TeV energies.
- Leptonic or hadronic emission?
- Connection to Cygnus Cocoon?



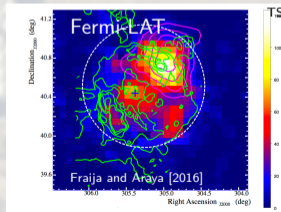
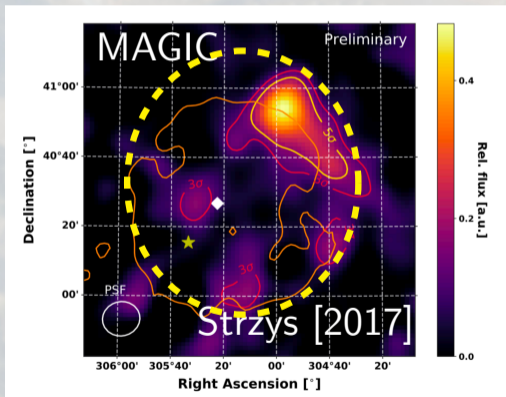
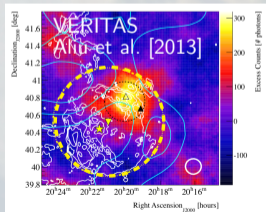
# $\gamma$ Cygni in $\gamma$ rays

- Two components:
  - Hotspot (NW quadrant): VERITAS [Aliu et al., 2013], MAGIC [Strzys, 2017], Fermi-LAT [Fraija and Araya, 2016].
  - Extended disk ( $r \approx 0.6^\circ$ ): MAGIC, Fermi-LAT [Ackermann et al., 2017].



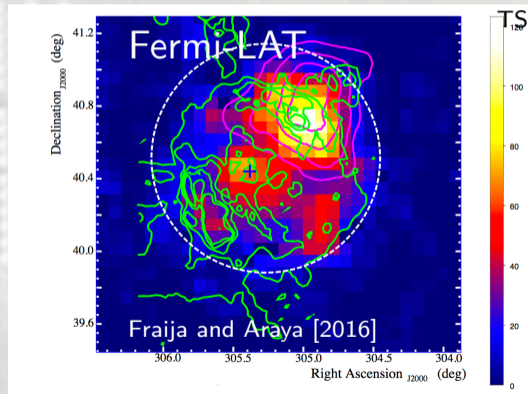
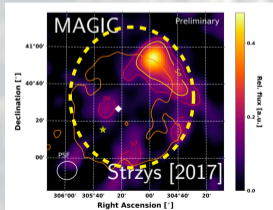
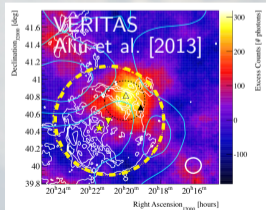
# $\gamma$ Cygni in $\gamma$ rays

- Two components:
  - Hotspot (NW quadrant): VERITAS [Aliu et al., 2013], MAGIC [Strzys, 2017], Fermi-LAT [Fraija and Araya, 2016].
  - Extended disk ( $r \approx 0.6^\circ$ ): MAGIC, Fermi-LAT [Ackermann et al., 2017].

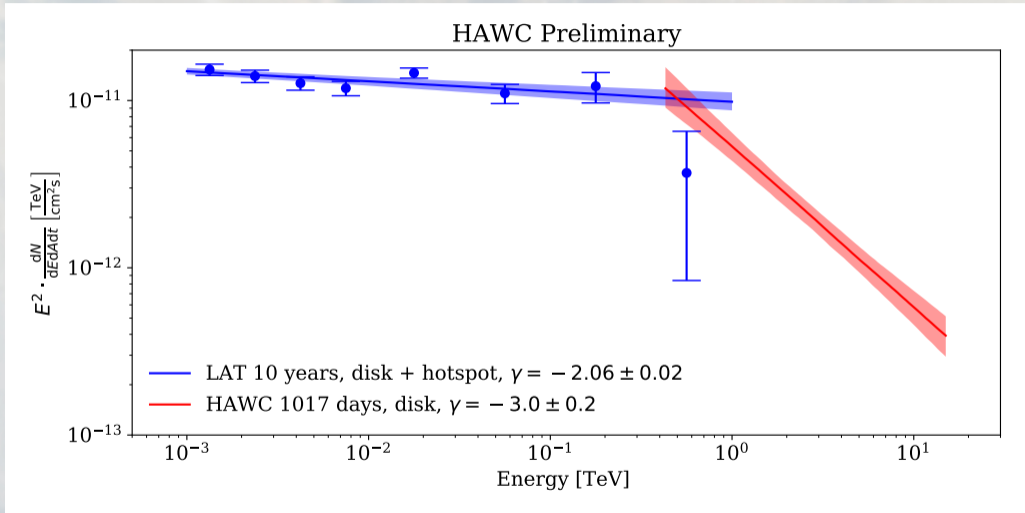


# $\gamma$ Cygni in $\gamma$ rays

- Two components:
  - Hotspot (NW quadrant): VERITAS [Aliu et al., 2013], MAGIC [Strzys, 2017], Fermi-LAT [Fraija and Araya, 2016].
  - Extended disk ( $r \approx 0.6^\circ$ ): MAGIC, Fermi-LAT [Ackermann et al., 2017].

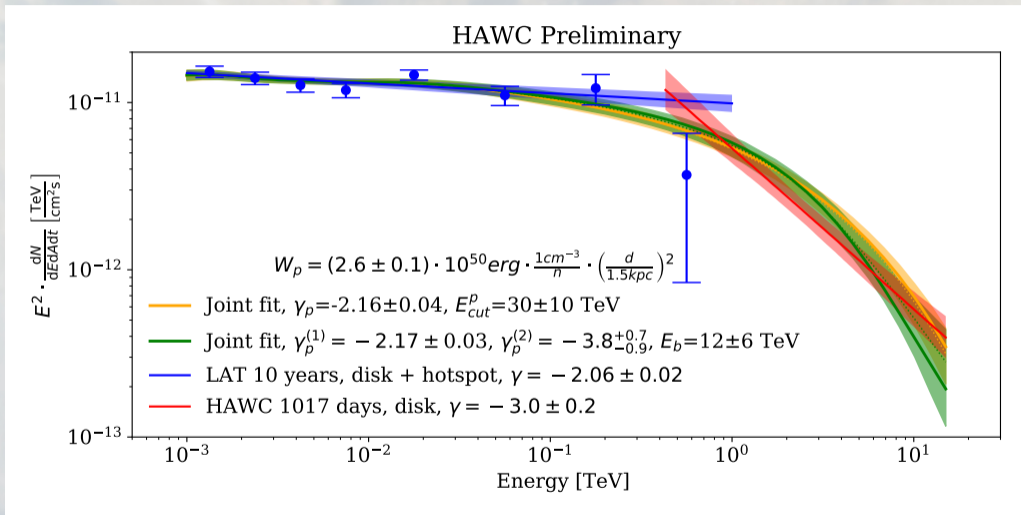


# Energy Spectra and Modeling



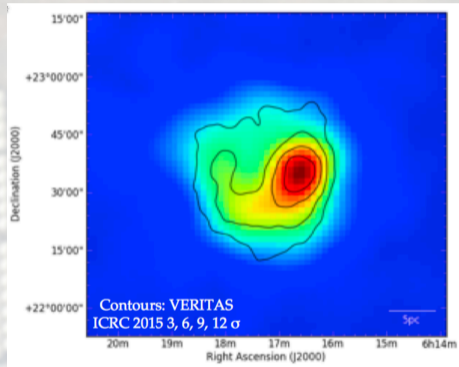


# Energy Spectra and Modeling



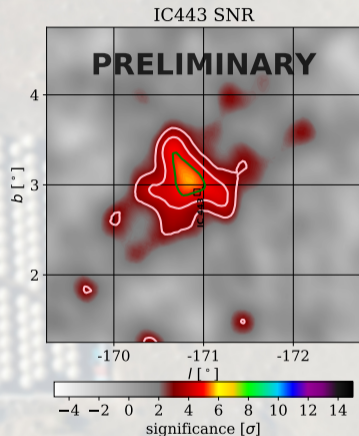
# IC 443 (G189.1+03.0)

- Middle-aged/old SNR, 3-30 kyr [Olbert et al., 2001], interacting with nearby ISM.
- Distance: 1.5 kpc [Olbert et al., 2001; Petre et al., 1988], near Galactic anti-center.
- GeV-TeV emission seen by Fermi-LAT [Ackermann et al., 2013], MAGIC [Albert et al., 2007] and VERITAS [Humensky, 2016] correlated with gas distribution.
- Evidence for 'pion bump' in gamma-ray data [Ackermann et al., 2013].
- HAWC detects significant emission, not sensitive to substructure.

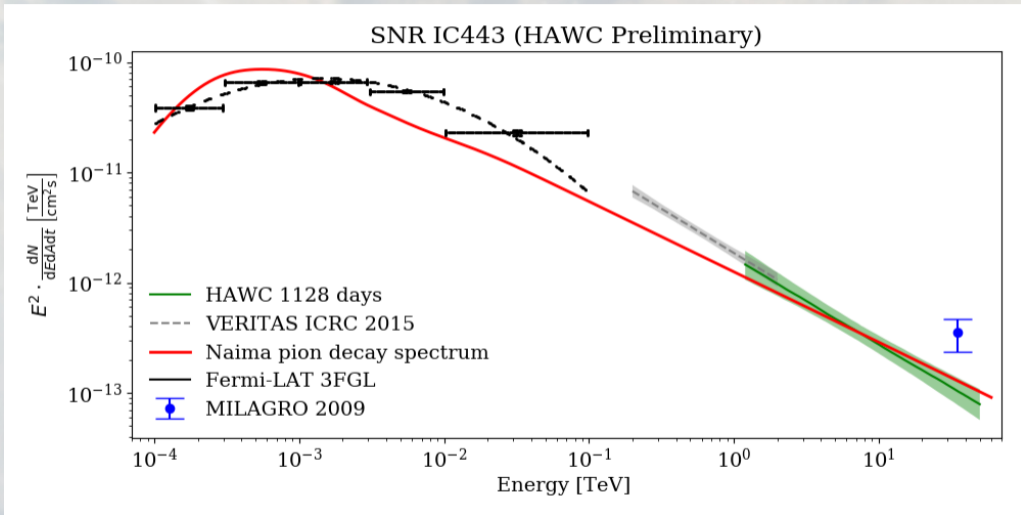


# IC 443 (G189.1+03.0)

- Middle-aged/old SNR, 3-30 kyr [Olbert et al., 2001], interacting with nearby ISM.
- Distance: 1.5 kpc [Olbert et al., 2001; Petre et al., 1988], near Galactic anti-center.
- GeV-TeV emission seen by Fermi-LAT [Ackermann et al., 2013], MAGIC [Albert et al., 2007] and VERITAS [Humensky, 2016] correlated with gas distribution.
- Evidence for 'pion bump' in gamma-ray data [Ackermann et al., 2013].
- HAWC detects significant emission, not sensitive to substructure.

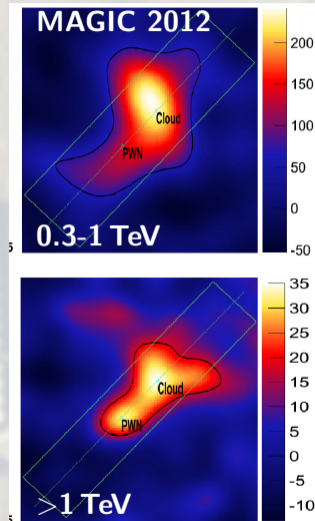


# Energy Spectra and Modeling



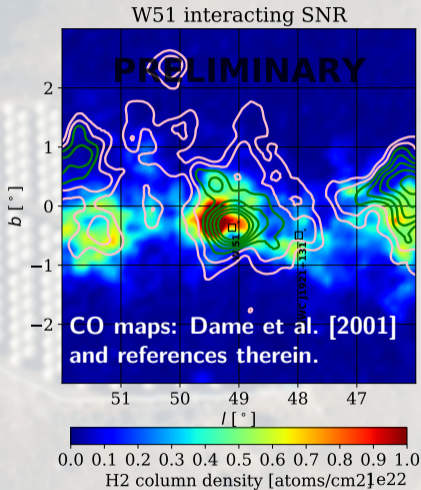
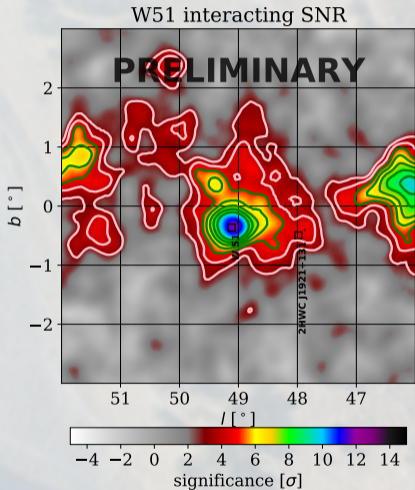
# W 51C (G049.2–00.7)

- Middle aged/old SNR, 30 kyr [Koo et al., 1995], interacting with nearby molecular cloud.
- Distance:  $\sim 5.5$  kpc [Sato et al., 2010].
- GeV-TeV detection by Fermi-LAT [Acero et al., 2015, 2016], MAGIC [Aleksić et al., 2012], and H.E.S.S. [Abdalla et al., 2018].
- MAGIC sees evidence for two emission components (PWN and molecular cloud).
- HAWC sees more extended emission: Nearby sources?

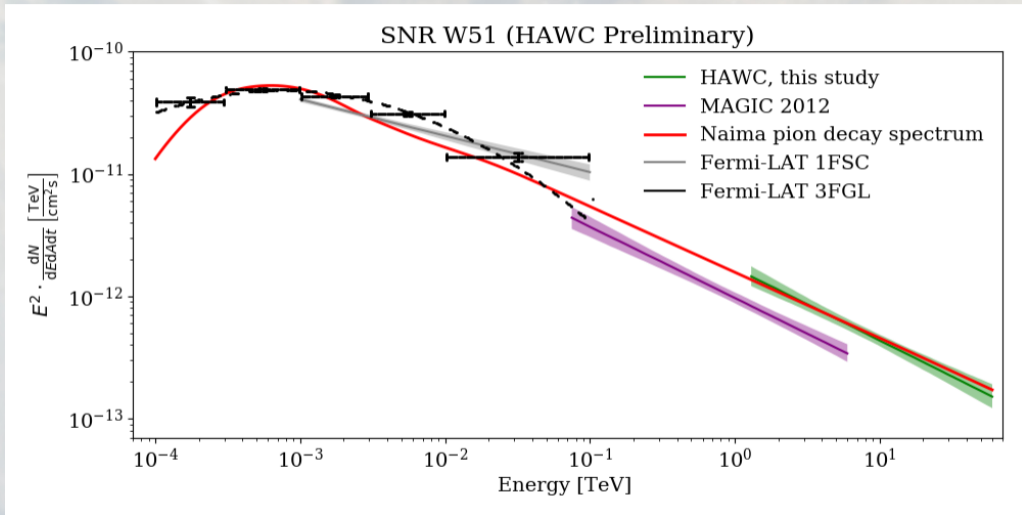




# HAWC morphology and gas distribution



# Energy Spectra and Modeling



# Outlook and Conclusions

## Conclusions:

- HAWC sees significant TeV  $\gamma$  ray emission from middle-aged SNRs  $\gamma$  Cygni, IC 433, and W51C.
- Currently not sensitive to  $\gamma$  Cygni and IC 433 substructure.
- W51C more extended than expected.
- $\gamma$  Cygni has a harder GeV and softer TeV spectrum compared to IC 433 and W51.
- Can describe GeV-TeV emission as a pion-decay spectrum.

## Future steps:

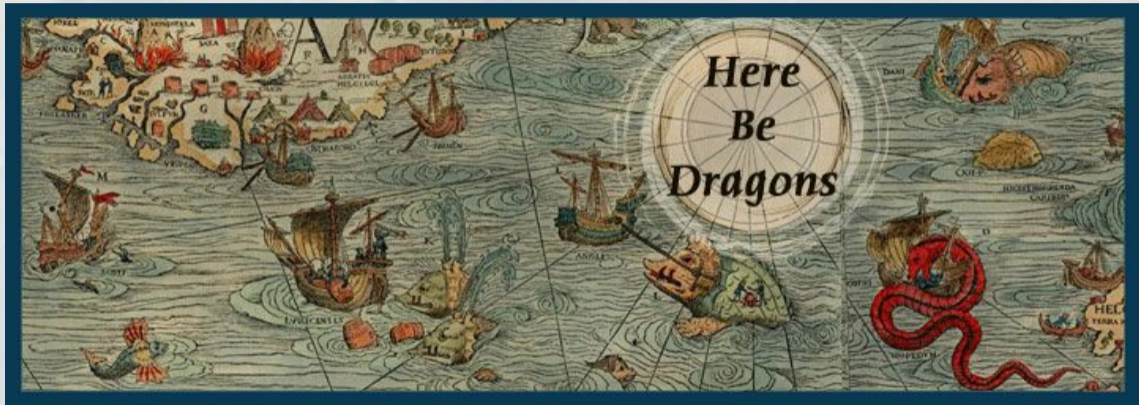
- Spectral modeling still in progress.
- Will look into leptonic models.
- Study of maximum energy in progress.



# Thank you for the Attention!



# Backup





# References I

- Abdalla, H. et al. (2018). The H.E.S.S. Galactic plane survey. *Astron. Astrophys.*, 612:A1.
- Acero, F. et al. (2015). Fermi Large Area Telescope Third Source Catalog. *Astrophys. J. Suppl.*, 218(2):23.
- Acero, F. et al. (2016). The First Fermi LAT Supernova Remnant Catalog. *Astrophys. J. Suppl.*, 224(1):8.
- Ackermann, M. et al. (2013). Detection of the Characteristic Pion-Decay Signature in Supernova Remnants. *Science*, 339:807.
- Ackermann, M. et al. (2017). Search for Extended Sources in the Galactic Plane Using Six Years of *Fermi*-Large Area Telescope Pass 8 Data above 10 GeV. *Astrophys. J.*, 843(2):139.
- Albert, J. et al. (2007). Discovery of VHE Gamma Radiation from IC443 with the MAGIC Telescope. *Astrophys. J.*, 664:L87–L90.
- Aleksić, J. et al. (2012). Morphological and spectral properties of the W51 region measured with the MAGIC telescopes. *Astronomy and Astrophysics*, 541:A13.
- Aliu, E. et al. (2013). Discovery of TeV Gamma-ray Emission Toward Supernova Remnant SNR G78.2+2.1. *Astrophys. J.*, 770:93.
- Dame, T. M., Hartmann, D., and Thaddeus, P. (2001). The Milky Way in Molecular Clouds: A New Complete CO Survey. *Astrpart. Phys. J.*, 547:792–813.
- Fraija, N. and Araya, M. (2016). The GeV counterpart of VER J2019+407 in the northern shell of the supernova remnant G78.2+2.1 ( $\gamma$  Cygni). *Astrophys. J.*, 826(1):31.
- Humensky, B. (2016). The TeV Morphology of the Interacting Supernova Remnant IC 443. *PoS, ICRC2015:875*. [34,875(2015)].
- Koo, B.-C., Kim, K.-T., and Seward, F. D. (1995). ROSAT Observations of the Supernova Remnant W51C. *Astrophys. J.*, 447:211.
- Lozinskaya, T. A., Pravdikova, V. V., and Finoguenov, A. V. (2000). The Supernova Remnant G78.2+2.1: New Optical and X-ray Observations. *Astronomy Letters*, 26:77–87.
- Olbert, C. M., Clearfield, C. R., Williams, N. E., Keohane, J. W., and Frail, D. A. (2001). A bow shock nebula around a compact x-ray source in the supernova remnant ic443. *Astrophys. J.*, 554:L205.
- Petre, R., Szymkowiak, A. E., Seward, F. D., and Willingale, R. (1988). A comprehensive study of the X-ray structure and spectrum of IC 443. *Astrophys. J.*, 335:215–238.
- Sato, M., Reid, M. J., Brunthaler, A., and Menten, K. M. (2010). Trigonometric Parallax of W51 Main/South. *Astrophys. J.*, 720:1055–1065.
- Strzys, M. (2017). Gamma-Cygni: the GeV to TeV morphology of an unique Sedov-phase SNR with MAGIC and Fermi-LAT. *PoS, ICRC2017*.
- Vianello, G., Lauer, R. J., Younk, P., Tibaldo, L., Burgess, J. M., Ayala, H., Harding, P., Hui, M., Omodei, N., and Zhou, H. (2015). The Multi-Mission Maximum Likelihood framework (3ML).
- Zabalza, V. (2015). naima: a python package for inference of relativistic particle energy distributions from observed nonthermal spectra. *Proc. of International Cosmic Ray Conference 2015*, page 922.

