Max-Planck-Institut für Kernphysik Heidelberg

HAWC High Altitude Water Cherenkov Gamma-Ray Observatory

Energy-dependent Morphology of J1825-137 with HAWC

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TeVPA

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Introduction

- PWN are likely the dominant source population at TeV photon energies
- HESS J1825-137: Among the **most luminous & powerful** PWN
    - The brightest source in HAWC's FOV with energy >56 TeV
    - Powered by PSR J1826-1334 with distance ~4 kpc, $\dot{E} = 2.8 \times 10^{36}$ erg s^{-1}
    - Flux above 1 TeV = ~1.12×10^{-11} cm^{-2} s^{-1} ~64% of Crab nebula[1]

- **Leptonic models** predict energy dependent morphology
    - Rapid cooling of highest energy electrons
    - Can provide constraints on **particle transport mechanism**
- HESS J1825-137 discovered to have energy dependent morphology using H.E.S.S.
    - What about **with HAWC?**

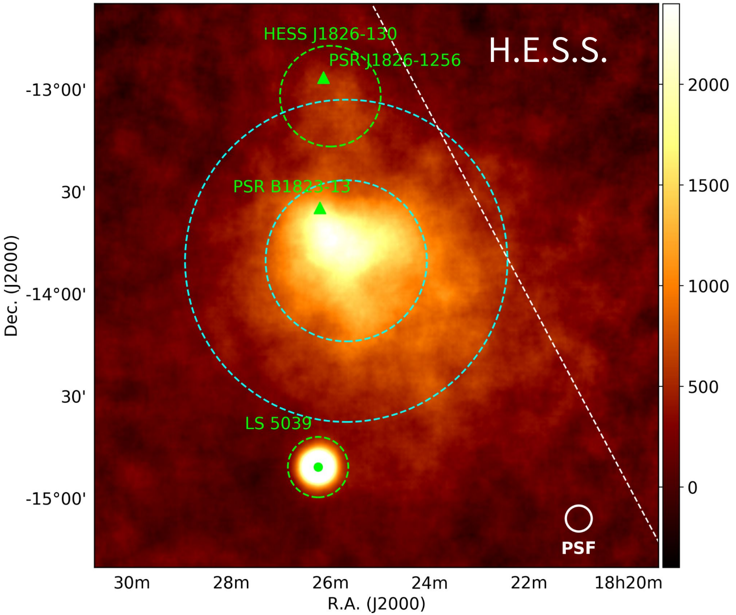
[1] H.E.S.S. Coll (2019)

High Altitude Water Cherenkov (HAWC) Observatory

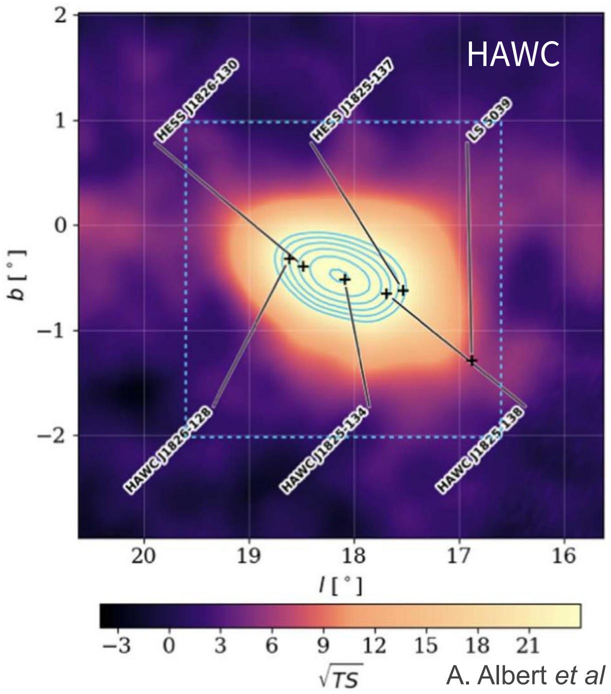
- 4100 m altitude at Sierra Negra, Mexico
- Wide FOV (~2 sr) → Extended sources
- High duty cycle
- Energy range: few TeV to >100 TeV
- Angular resolution ~ 0.1 degrees

HESS J1825-137 Region

- Complex region in HAWC FOV with multiple sources:
  PSR J1826-1334 & PSR J1826-1256 || LS 5039 binary system || PWN 1826-130 & **PWN 1825-137**



H. Abdalla et al *A&A*, 2019, 621



A. Albert *et al* 2021 *ApJL* **907** L30

Two Analysis Chains

- **Multi-Mission Maximum likelihood (3ML)**
  - Common framework for multiwavelength studies
  - Allows different tools of instruments to interface
  - Default tool for HAWC analysis

- **Gammapy**
  - Python package used by CTA, H.E.S.S.
  - Uses the common gamma-astro-data-format (GDAF)
  - Aims to provide a common tool for all gamma-ray data analysis
  - Parallel analysis to 3ML

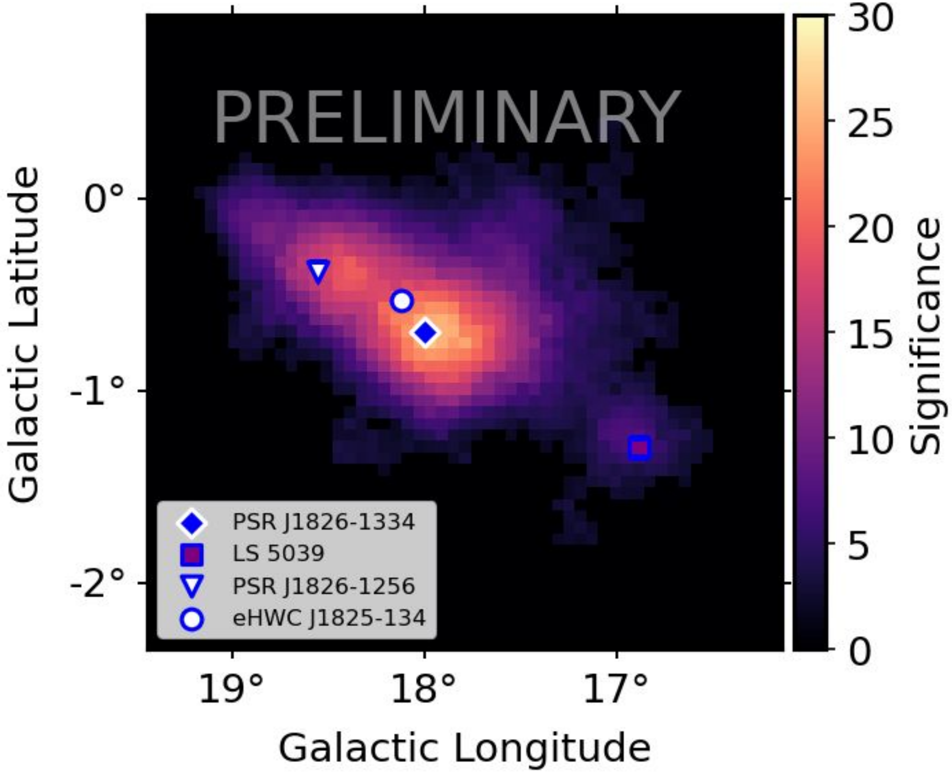
Dezhi Huang,
PoS (ICRC2023) 796

Analysis pipeline with Gammapy and dl3 Data

- Rescale background, add diffuse emission
- Find structures in excess significance map, rank candidates
- Fit generalized Gaussian & log parabola
- Test alternative shapes

Data

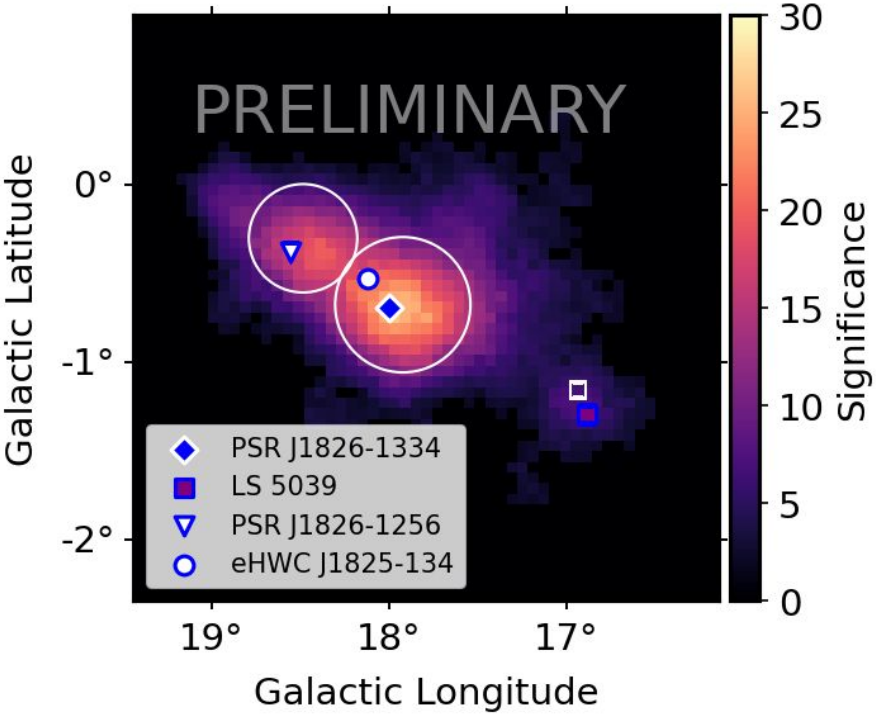
- Recent revision of data reconstruction "Pass5"
  - Better PSF
  - 1825 region can be resolved much better → individual structures
- Using dl3 format
- Neural Network (NN) energy estimator[1]
- Modified Background model for dl3 data[2]
- Quality cuts based on IRFs
  - Focus on higher energy bands
- 1849 days of data



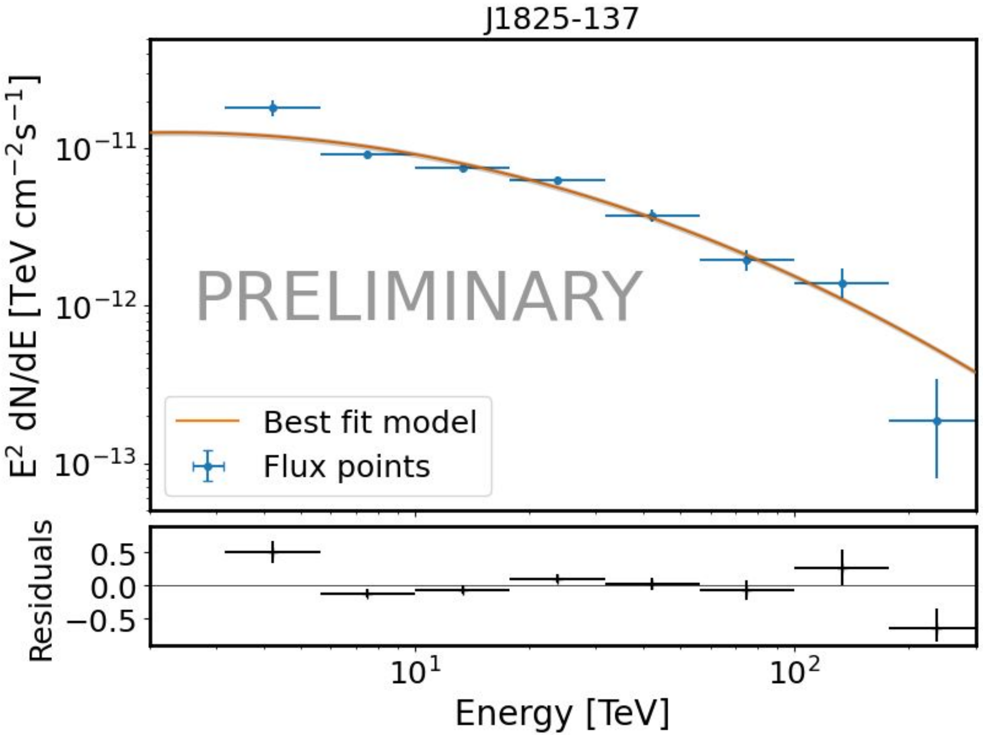
[1] A. U. Abeysekara *et al* 2019 *ApJ* **881** 134
[2] A. Albert et al. A&A, 667 (2022) A36

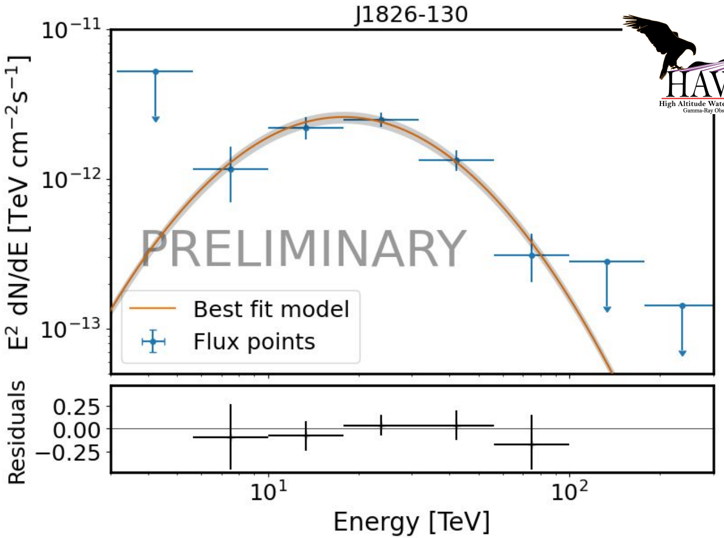
Modeling

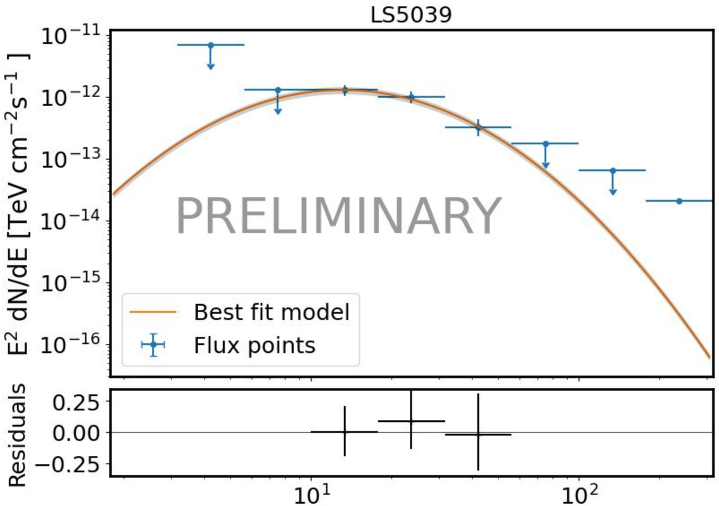
- Using automated pipeline to provide an unbiased starting point
- J1826-130
  - Log parabola spectral model
  - Generalized Gaussian
- J1825-137
  - Log parabola spectral model
  - Generalized Gaussian
- LS 5039
  - Log parabola spectral model
  - Point source



Flux Points and Models



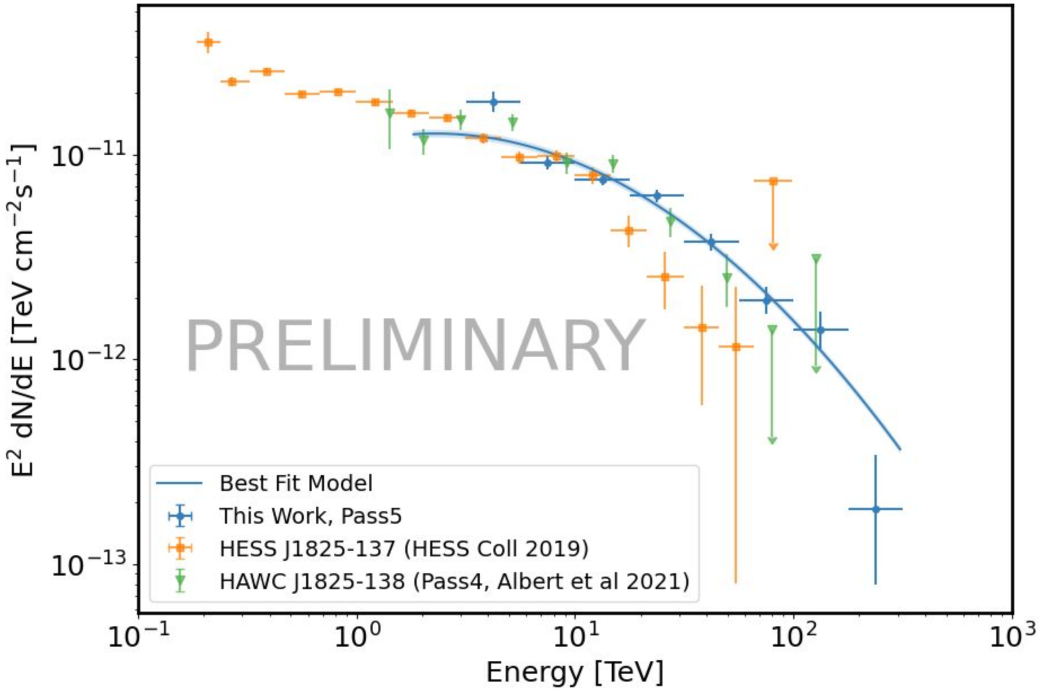




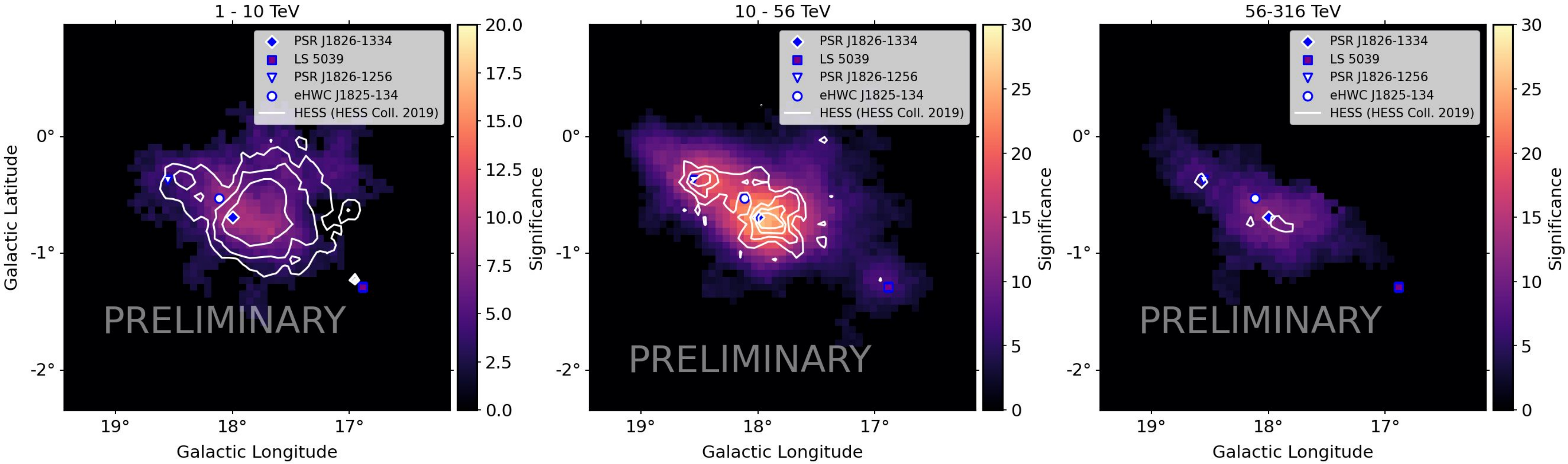
Comparison with Previous Work

- Flux points are consistent with previous HAWC publication and H.E.S.S. publication

Analysis	ϕ (10 cm^{-2} s^{-1} TeV)	α	β
This work (HAWC Pass5)	14.8 ± 0.405	2.43	0.15
H.E.S.S. Coll (2019)	19.3 ± 0.3 ± 0.2	2.31± 0.01 ± 0.01	0.076 ± 0.009 ± 0.008

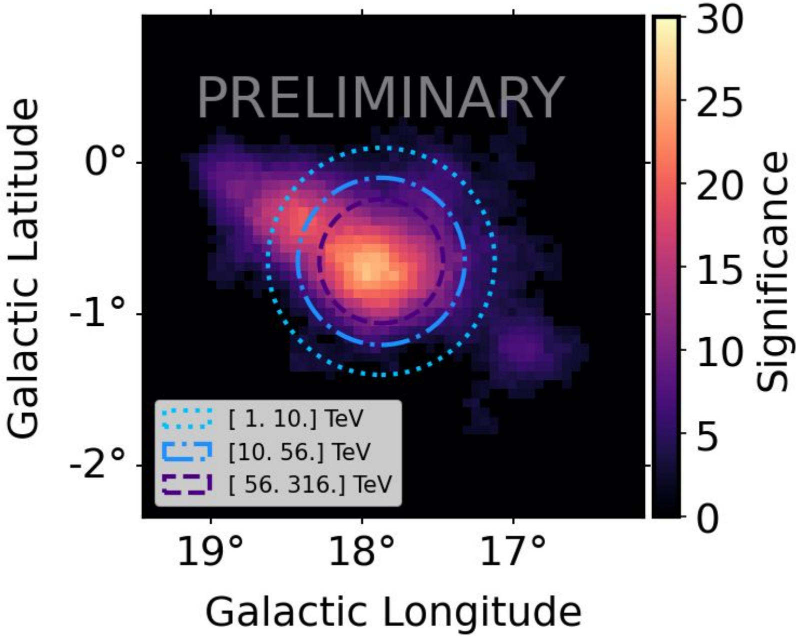


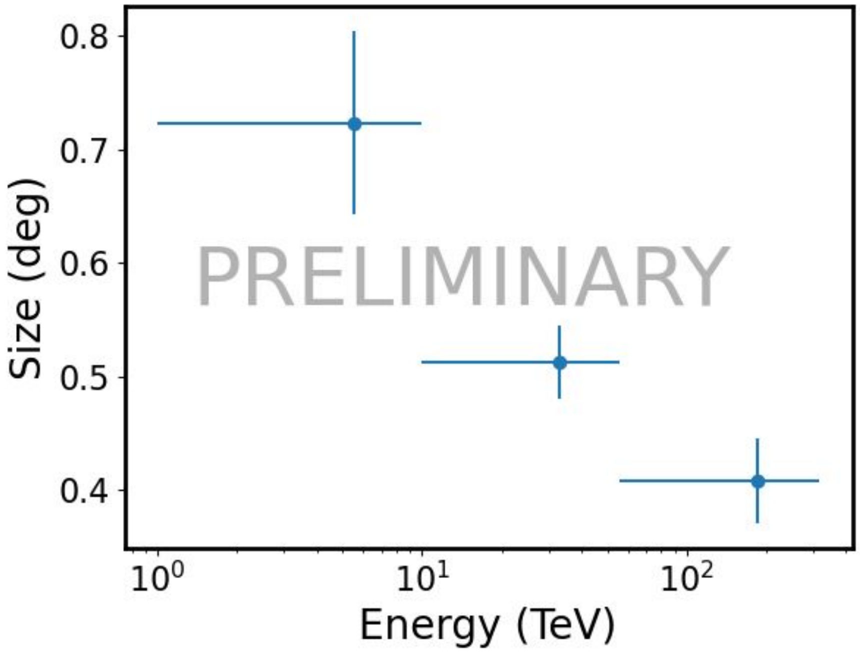
Energy Dependent Morphology



Energy Dependent Morphology

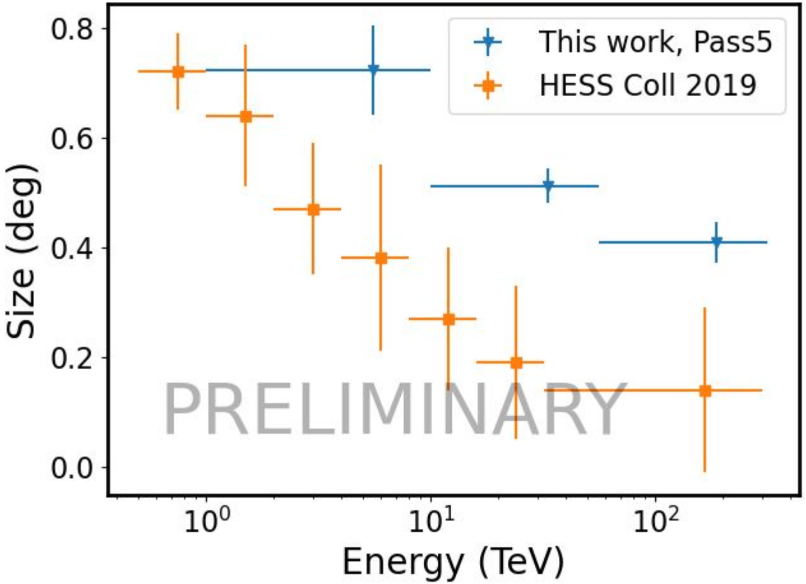
- Fit in three energy bands
  - [1, 10] , [10, 56] , [56, 316] TeV

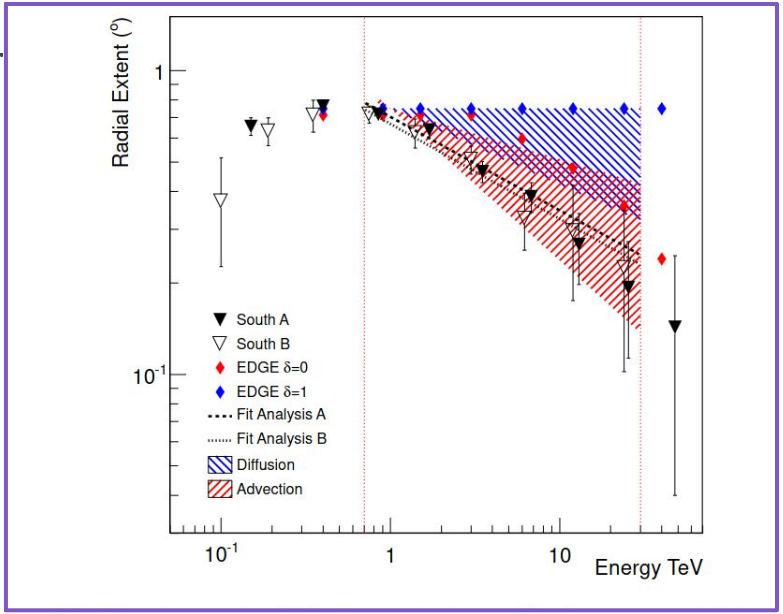




Energy Dependent Morphology: H.E.S.S.

- Different definition of size for H.E.S.S.
- But both H.E.S.S. and HAWC results have a similar trend of decreasing size with increasing energy



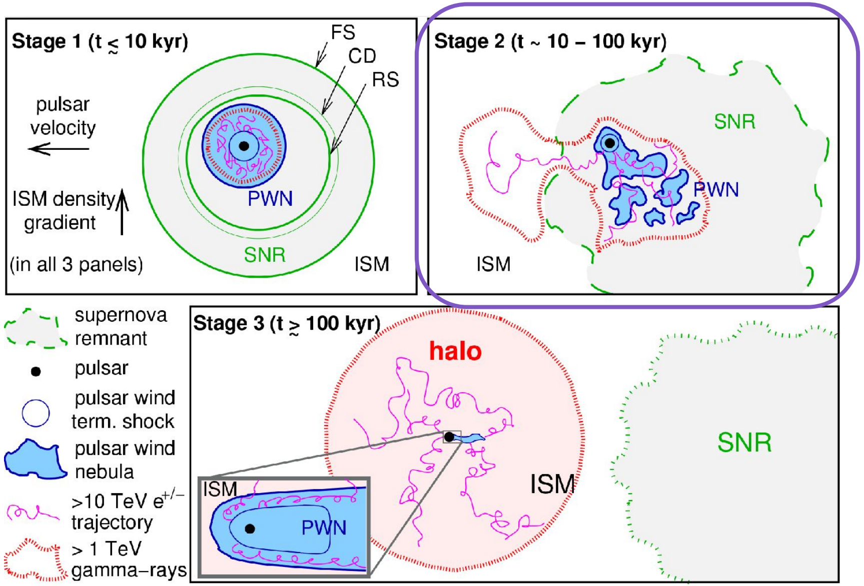


Radial extent: Fits a polynomial to the radial profile for each energy band

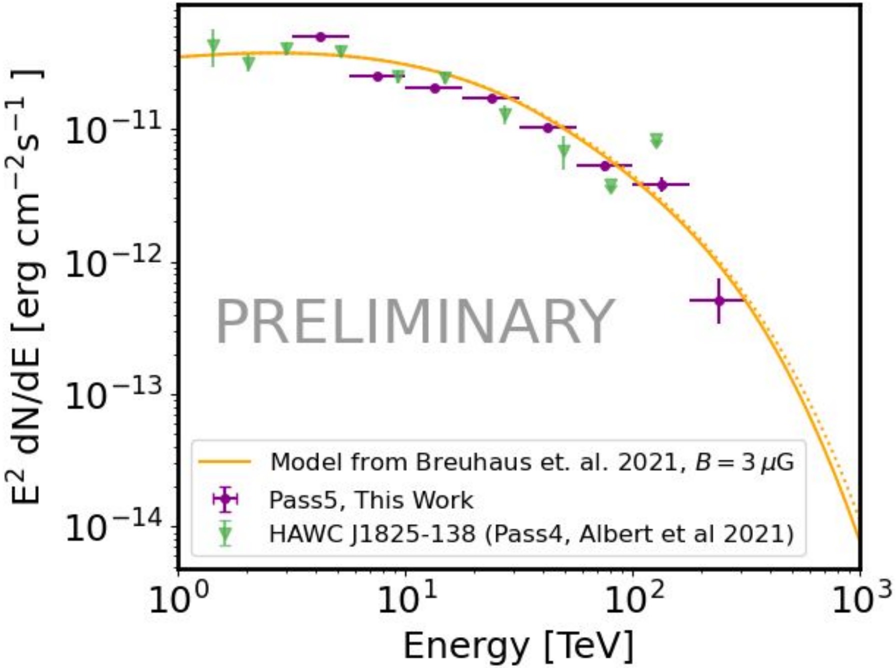
H.E.S.S. Coll (2019)

Where does high energy emission come from?

- IC scenarios with plausible parameters exist
- J1825-137 could be a hard-spectrum UHE IC emitter in intermediate evolutionary stage



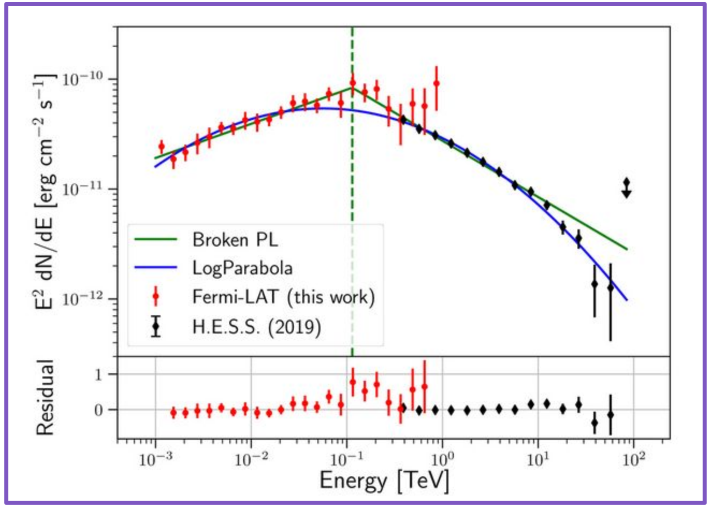
Giacinti et. al. 2020

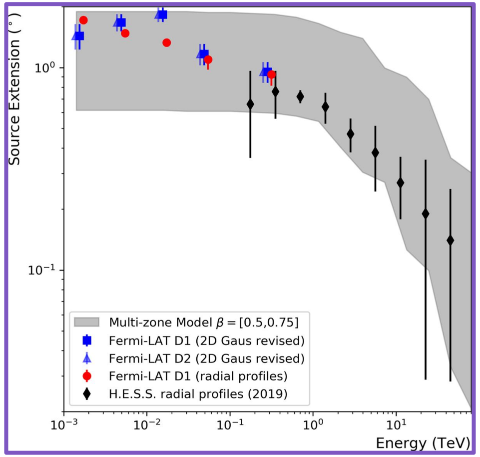


Breuhaus et. al. 2021

Outlook

- More comparisons
  - Repeat the H.E.S.S. method with HAWC data
  - Compare with LHAASO and Fermi-LAT
- Explore particle transport mechanism further with this HAWC addition
- Test new models: HAWC standard analysis & LHAASO have two components





Principe et al. 2020

backups

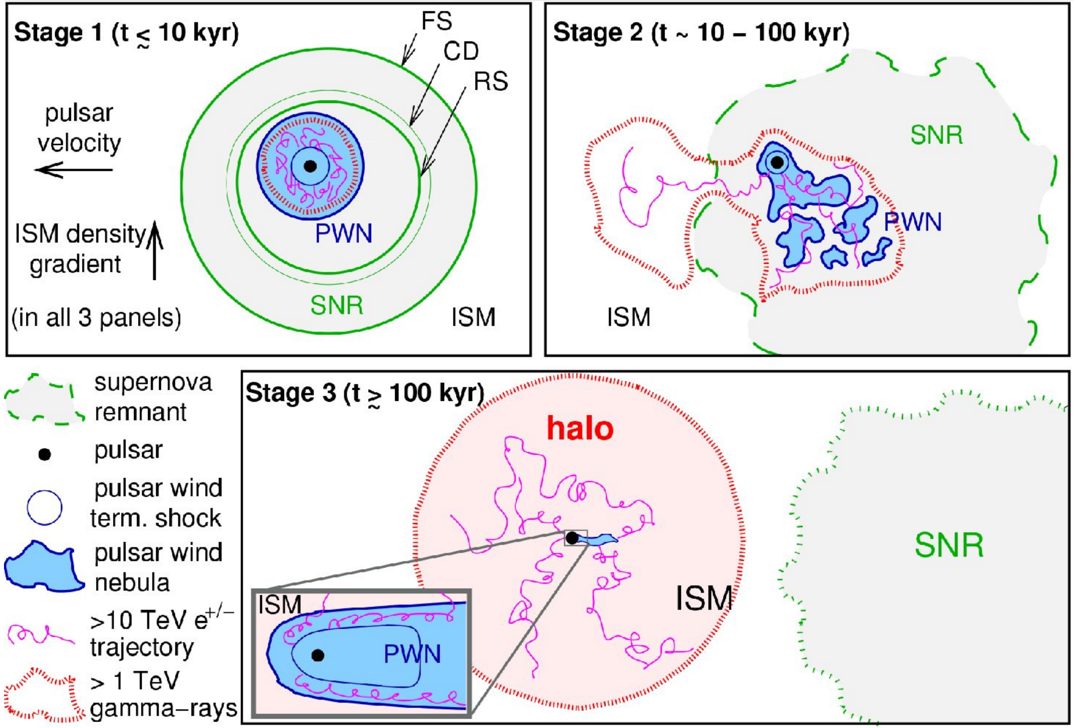
PWN vs Halo

Stage 1: PWN is contained inside the SNR, before the reverse shock (RS) interacts with it. The SNR forward shock (FS) and contact discontinuity (CD) are plotted with green lines. The electrons responsible for the TeV γ-ray emission of the nebula are thought to be confined within the nebula.

Stage 2: After the PWN is disrupted by the reverse shock, but before the pulsar escapes its SNR. TeV γ-ray emitting electrons start to escape from the PWN into the SNR and possibly into the ISM.

Stage 3: Pulsar has escaped from its currently fading parent SNR. High-energy electrons escape into the surrounding ISM, and may, only then, form a “halo” .

In all three panels, the ISM density gradient is upwards, and the pulsar “kick” velocity is towards the left.



Giacinti et. al. 2020

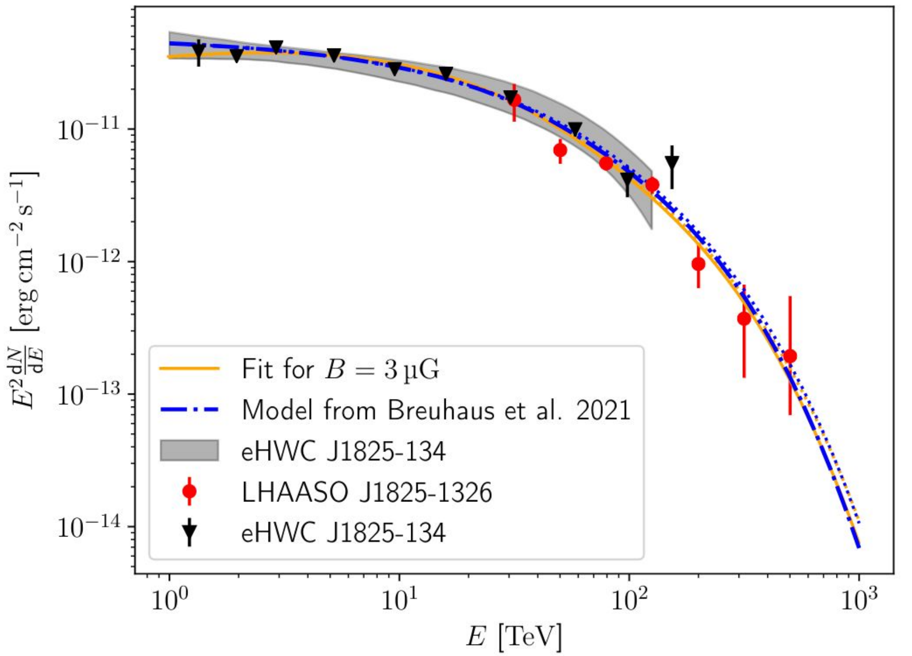
UHE IC Emitters

Breuhaus et. al. 2021

“Hard IC spectra up to and beyond 100 TeV are possible wherever IC losses dominate over synchrotron losses for sufficiently high energies

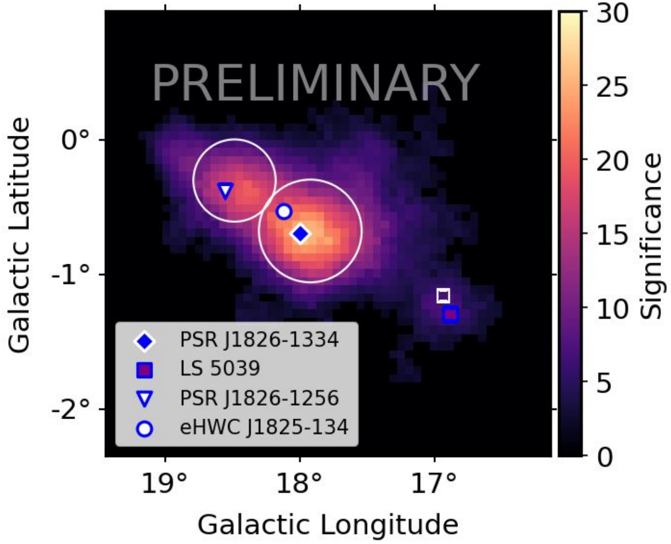
Sites of PeV electron acceleration are likely to sample significantly higher than galactocentric average radiation energy densities, located … in general associated with high-mass star formation; regions of intense FIR emission.
In such environments hard IC emission is possible if the region is able to confine the high-energy particles long enough, but also small enough to prevent strong γγ-absorption.
The HAWC observatory UHE sources at 100 TeV (Abeysekara et al. 2002) support such leptonic scenarios, with energy dissipation of the pulsar wind, for example via shocks, as the favored accelerator.

The combination of a powerful pulsar in an IR photon-dominated environment appear to be essential features of any leptonic model.”



Modeling

- Using automated pipeline as unbiased guide
- 3 sources
  - J1825-137 || LS5039 || J1826-130



- **Spectral:** Log Parabola Spectral model for 3 sources

$$\phi(E) = \phi_0 \left(\frac{E}{E_0}\right)^{-\alpha-\beta\log\left(\frac{E}{E_0}\right)}$$

- **Spatial:** Generalized Gaussian for J 1825 and J1826 ; point source for LS 5039

$$\phi(\mathrm{lon},\mathrm{lat}) = \phi(\mathrm{r}) = N \times \exp\left[-\left(\frac{r}{r_{\mathrm{eff}}}\right)^{(1/\eta)}\right]$$

$$N = \frac{1}{2\pi\sqrt{(1-e^2)}r_0^2\eta\Gamma(2\eta)}$$

Energy Dependent Morphology