



Energy-dependent morphology of the Pulsar Wind Nebula HESS J1825-137 in the GeV domain: investigating its PWN / γ -ray halo nature

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*on behalf of the Fermi-LAT collaboration

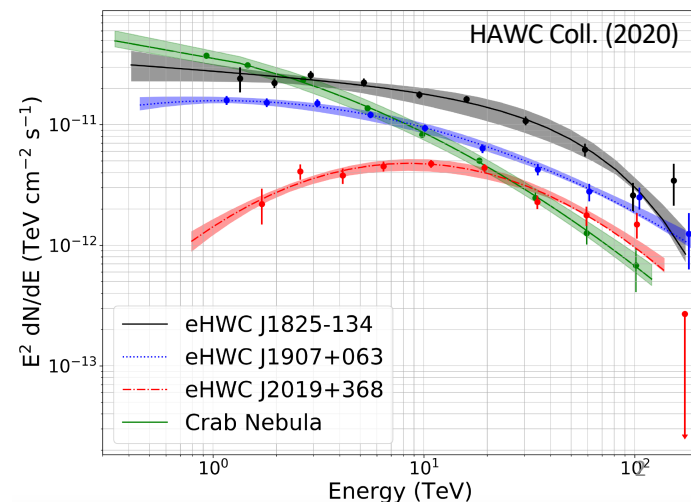
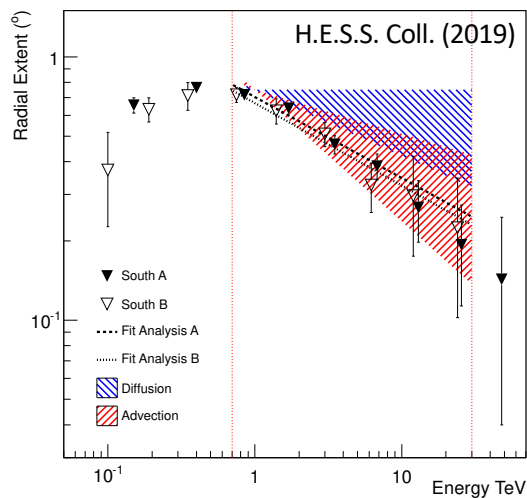
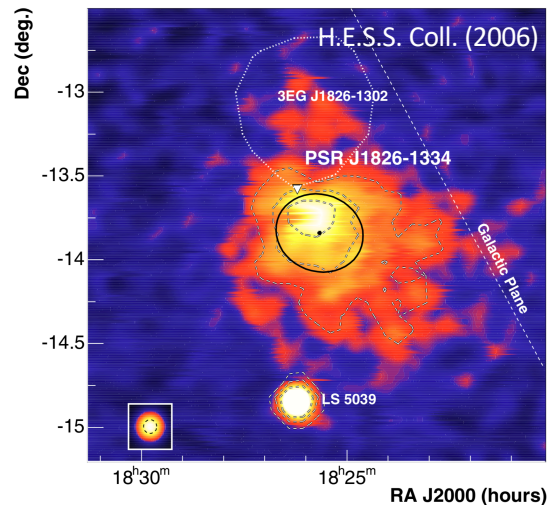
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The PWN HESS J1825-137

- First detected in the H.E.S.S. Galactic Plane Survey (2005)
- XMM-Newton/Suzaku: reveal diffuse x-ray emission size $\sim 0.1^\circ$
- Recent H.E.S.S. results (2019):
 - with a size >100 pc is the largest PWN currently known
 - TeV energy dependent morphology
- HESS J1825-137 is one of the three sources detected above 100 TeV by HAWC (2020), making it a promising Pevatron candidate.

Powered by the pulsar PSR J1826-1334 (PSR B1823-13):

- Characteristic age = 21 kyr
- Period = 101 ms
- Distance = 4kpc



We performed the *first energy dependent extension* and spectral analysis of HESS J1825-137 in the GeV domain using **11.6 years** of *Fermi-LAT* data.

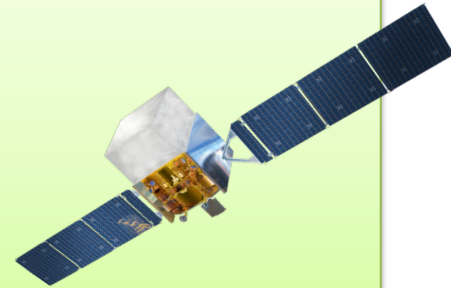
Analysis procedure:

1) General analysis (on the entire energy range 1 GeV - 1 TeV):

- Optimization, localization, and spectral analysis

2) Energy-resolved morphological study (2DGaussian, Radial profile)

Extension analysis in 5 energy bins (4 bins in 1-100 GeV, 1 bin in 100 GeV – 1TeV)



The initial model taken from the FGES paper (Ackermann et al. 2018):

Spatial Model: **2DGaussian**

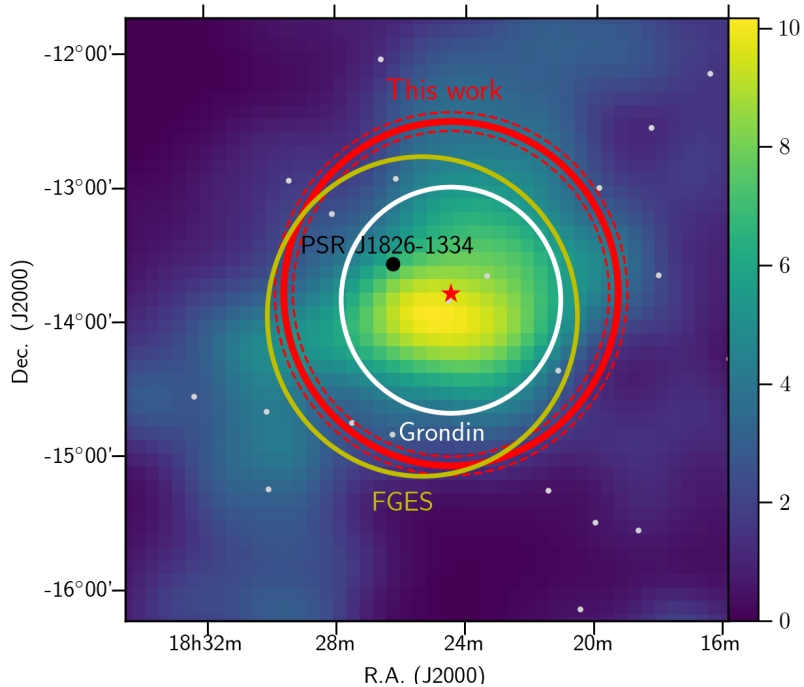
- $\Sigma = 0.79^\circ$
- $RA = 276.296^\circ$
- $DEC = -13.992^\circ$

Spectrum Type: **LogParabola**

Models: 4FGL, standard LAT diffuse model, and optimized model for the Galactic plane (Ackermann et al. 2017)

Data Selection	Values
IRFs	P8R3v2
Time Interval	11.6 years
Energy Range	1 GeV – 1 TeV
Energy Bins	8 per decade (for spectra)
Zenith angle	105°
ROI (pixel) size	15° (0.1°)

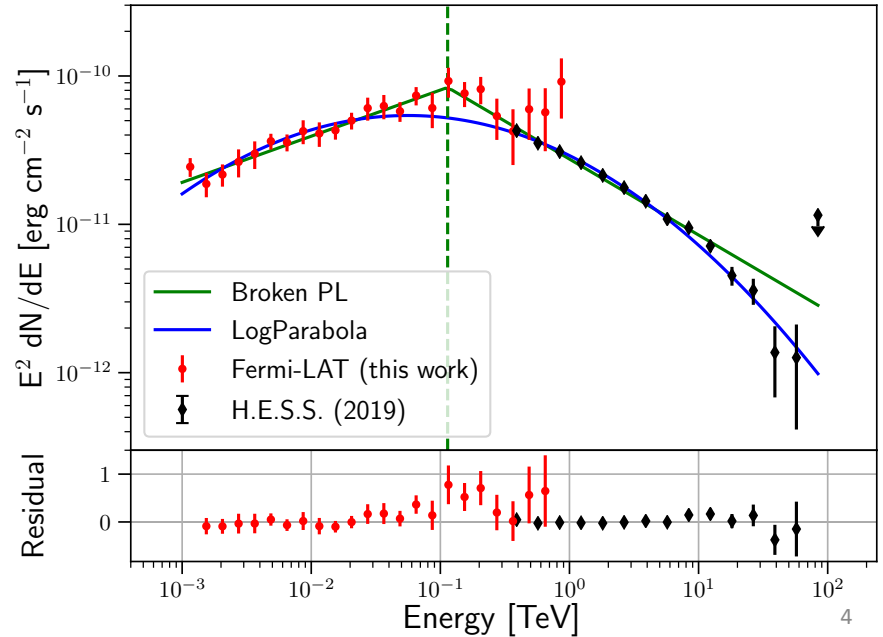
RA, DEC: (276.11, -13.80)
Extension: $1.30^\circ \pm 0.06^\circ$ (~150 pc)
 ($TS_{\text{ext}}=1040, \sim 30\sigma$)



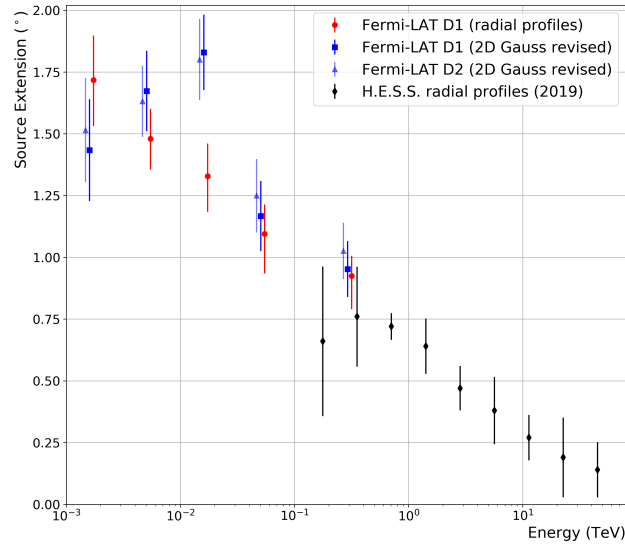
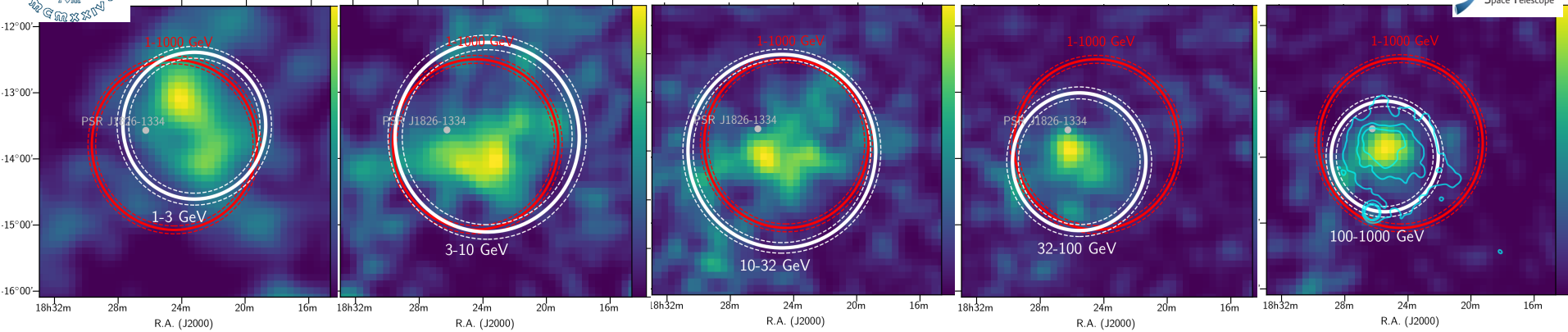
Fermi-LAT previous studies. **Grondin+(2011)**: 20 months 1 – 100 GeV.
FGES (2017): 6 years, 10 GeV – 1 TeV

LogParabola
Alpha: 2.15 ± 0.05 , *Beta*: 0.075 ± 0.02 , E_0 : 154 GeV, N_0 : 6.0×10^{-11} erg $\text{cm}^{-2} \text{s}^{-1}$

Broken PL
 Γ_1 : 1.69 ± 0.03 , Γ_2 : 2.51 ± 0.01 , E_0 : **114 GeV**, N_0 : 8.37×10^{-11} erg $\text{cm}^{-2} \text{s}^{-1}$



Energy dependent morphology



Radial profile method: radial distance at which the emission drops to $1/e$ relative to the maximum *starting from the PSR position* (only in one hemisphere due to the asymmetry of the PWN).

1. Single zone model, NAIMA package (Zabalza 2015)

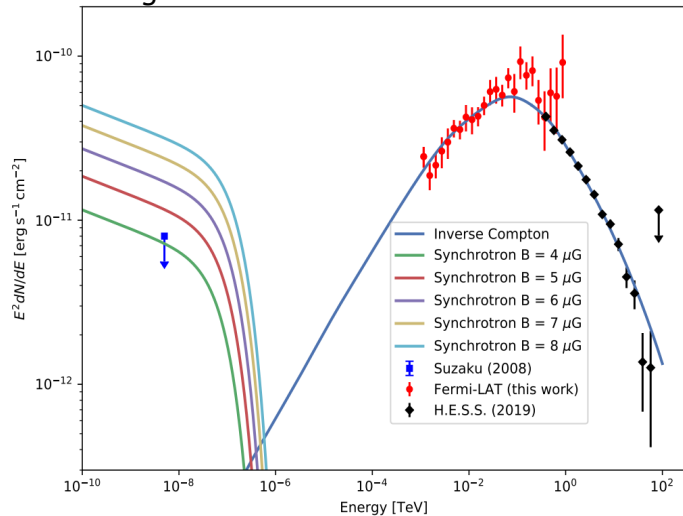
IC from leptonic population, Radiation fields parameter from Popescu (2017), From X-ray observations the max B-field is 4 μG

1. Multi-zone modelling, GAMERA package (Hahn 2016)

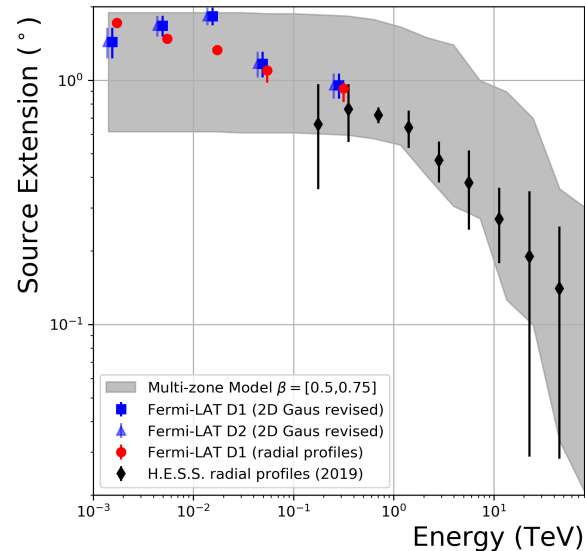
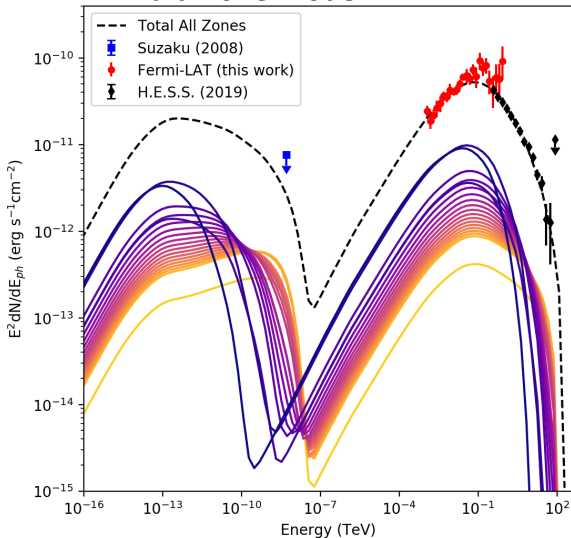
Summation of 20 zones treated as expanding shells in space (initially spherically symmetric), Evolution in time until the system age (assumed as PSR characteristic age) is reached, Burst like injection in each shell

Parameter	H.E.S.S. and <i>Fermi</i> -LAT
W_e (10^{49} erg)	$2.33^{+1.00}_{-0.64}$
Γ_1	$2.02^{+0.15}_{-0.19}$
Γ_2	$3.23^{+0.02}_{-0.02}$
E_b (TeV)	$0.80^{+0.18}_{-0.14}$
χ^2/ndf	20.8/34

Single zone model

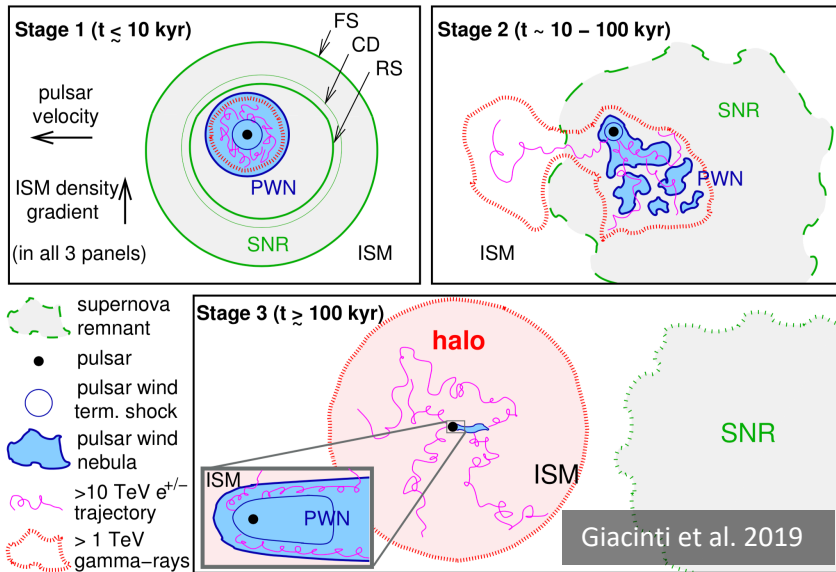


Multi-zone model



PWN vs TeV Halo

Def TeV Halo (Giacinti et al. 2019): area where $\text{En. Density}_{e^-} \ll \text{En. Density}_{\text{ISM}}$ (0.1 eV cm^{-3})



Giacinti et al. 2019

System	Crab	MSH 15-52	G21.5-0.9	G0.9+0.1	Vela X	G327.1-1.1	J1825-137
Age (kyr) ^a	0.94	1.56	4.85	5.31	11.3	18	21.4
PSR ^b	B0531+21	B1509-58	J1833-1034	J1747-2809	B0833-45	^c	B1823-13
$\log(\dot{E})$ (erg/s)	38.65	37.23	37.53	37.63	36.84	36.49	36.45
Distance (kpc)	2	4.4	4.1	8.5	0.28	9	3.93
R_{SNR} (pc)	? ^d	38.4	2.98	19.8	19.5	22	120
R_{PWN} (pc) ^e	2.8	19.2	0.8	2.5	12.2	10.5	?
$v \times t$ (pc) ^f	0.27	0.45	1.4	1.5	3.3	5.2	6.2
R_{TeV} (pc) ^g	< 3	11	< 4	< 7	2.9	3	50
$R_{\text{X-ray}}$ (pc)	0.24	10.2	0.8	4.9	3.08	13	9.1
Stage ^h	I	I	1b	1b	2	2	2b
Refs. ⁱ	I	II	III	IV	V	VI	VII

$$\epsilon_{e^-} = 0.1 \pm 0.3 \text{ eV cm}^{-3}$$

In our work we obtain a compatible result ($\epsilon_{e^-} = 0.16 \text{ eV cm}^{-3}$), confirming the composite (**PWN-TeV halo**) nature of HESS J1825-137.

- We analyzed 11.6 years of Fermi-LAT data (1 GeV - 1 TeV) performing a morphology and spectral analysis
- We performed for the first time a study of the energy dependent morphology of the PWN in the GeV domain
- We modeled the SED and the combined SED/morphology evolution using the NAIMA and GAMERA modelling pack.
- We have estimated the electron's energy density in order to investigate the PWN – TeV halo nature.
- The improved sensitivity and resolution of CTA in the GeV and TeV domain, will allow the morphology and spectrum of this PWN to be more accurately resolved, further constraining the nature of its emission.. (poster at the 1st CTA symposium

Poster

Energy-dependent morphology of the Pulsar Wind Nebula HESS J1825-137 in the GeV domain: investigating its PWN / γ -ray halo nature

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on behalf of the *Fermi* Large Area Telescope Collaboration

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Abstract

Taking advantage of more than 11 years of Fermi-LAT data, we perform a new and deep analysis of the pulsar wind nebula (PWN) HESS J1825-137. We present the results of the spectral analysis and of the first energy-resolved morphological study of the PWN HESS J1825-137 from 1 GeV to 1 TeV. This PWN is an archetypal system making it a perfect laboratory for studying particle transport mechanisms. Combining this analysis with recent HESS results enables us to constrain the particle transport mechanisms and to investigate the PWN - TeV halo nature of this source.

Overview of HESS J1825-137 and general results

HESS J1825-137, powered by the Pulsar PSR J1826-1334 (characteristic age = 21 kyr, period = 301 ms, distance = 4 kpc) [2], is the largest PWN currently known (gamma-ray size >100 pc). Its asymmetric morphology is connected to the presence of a dense molecular cloud on the north of the PSR.

Analysis: We performed the first energy dependent extension and spectral analysis of HESS J1825-137 in the GeV domain using 11.6 years of Fermi-LAT data between 1 GeV - 1 TeV (for more details see [1]).

RA, DEC	(276.11°, -13.80°)
Ext. (Phys Ext.)	1.30' ± 0.06' (~150 pc)
TS_ext	1040 (~30 σ)

Spectral analysis

Figure 1: Excess map (in sigma unit)

Figure 2: Combined SED of the PWN HESS J1825-137 with the results obtained in this work (red points) and H.E.S.S. data [5] (in black)

LogParabola:
 α^{\pm} : 2.15 \pm 0.05
 β : 0.075 \pm 0.02
 E_c : 154 GeV
 N_e : 6.0 $\times 10^{11}$ erg cm $^{-2}$ s $^{-1}$

Broken PL:
 Γ_1 : 1.58 \pm 0.03
 Γ_2 : 2.51 \pm 0.01
 E_c : 114 GeV
 N_e : 8.4 $\times 10^{11}$ erg cm $^{-2}$ s $^{-1}$

Energy-resolved morphological study

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 Principe et al., 2020 (<https://arxiv.org/abs/2006.11177>)

Thank you very much for your attention!

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- We have performed for the first time a study of the energy dependent morphology of the PWN HESS J1825-137 in the GeV domain
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