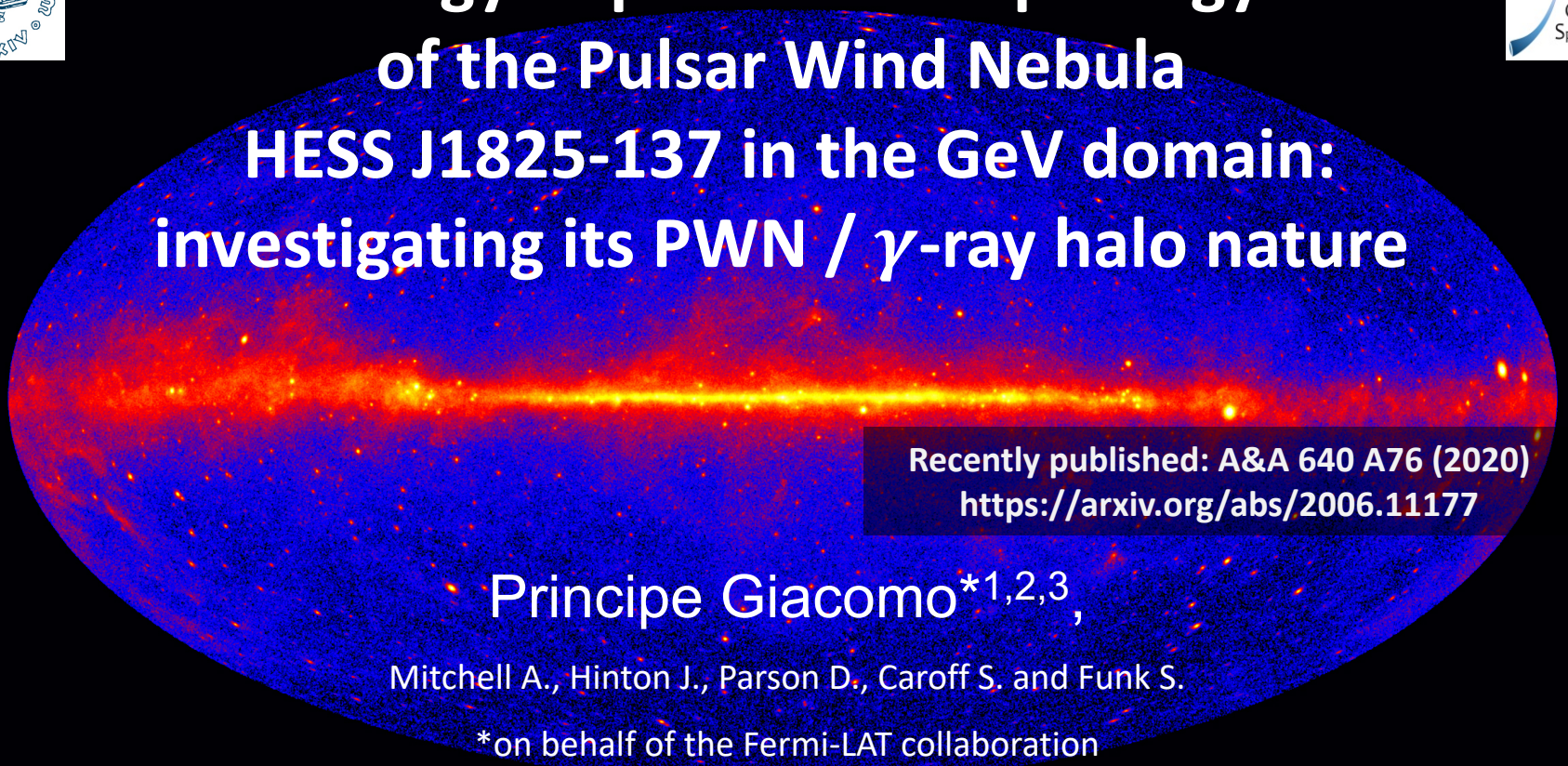
Energy-dependent morphology of the Pulsar Wind Nebula HESS J1825-137 in the GeV domain: investigating its PWN / γ-ray halo nature



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https://arxiv.org/abs/2006.11177

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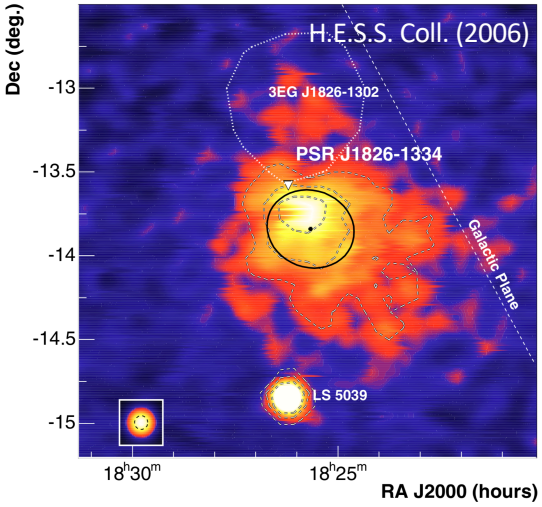
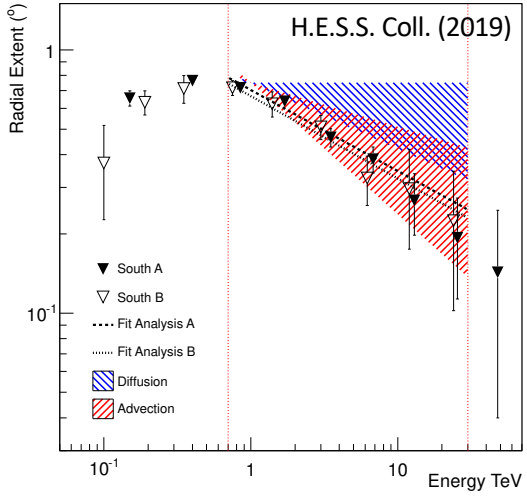
The PWN HESS J1825-137

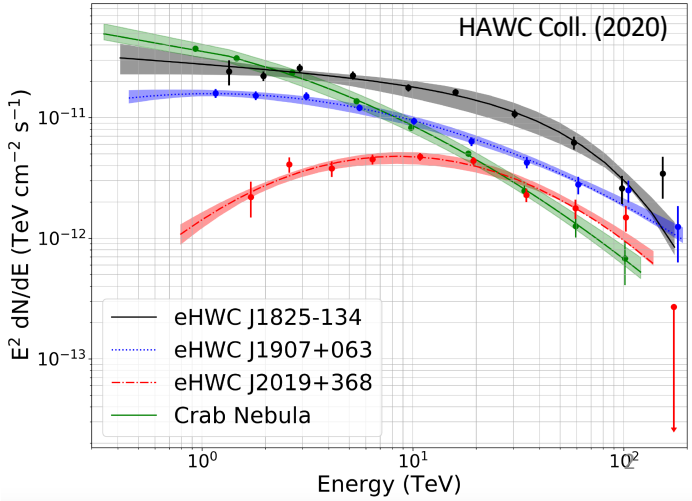
- First detected in the H.E.S.S. Galactic Plane Survey (2005)
- XMM-Newton/Suzaku: reveal diffuse x-ray emission size~0.1°
- Recent H.E.S.S. results (2019):
  - *with a size >100 pc is the largest PWN currently known*
  - TeV energy dependent morphology
- HESS J1825-137 is one of the three sources detected 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*







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.

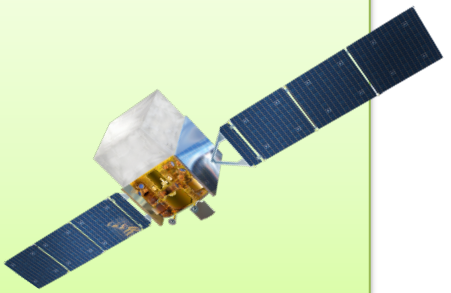
Analysis procedure:

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°
- RA = 276.296°
- DEC = -13.992°

Spectrum Type: **LogParabola**

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

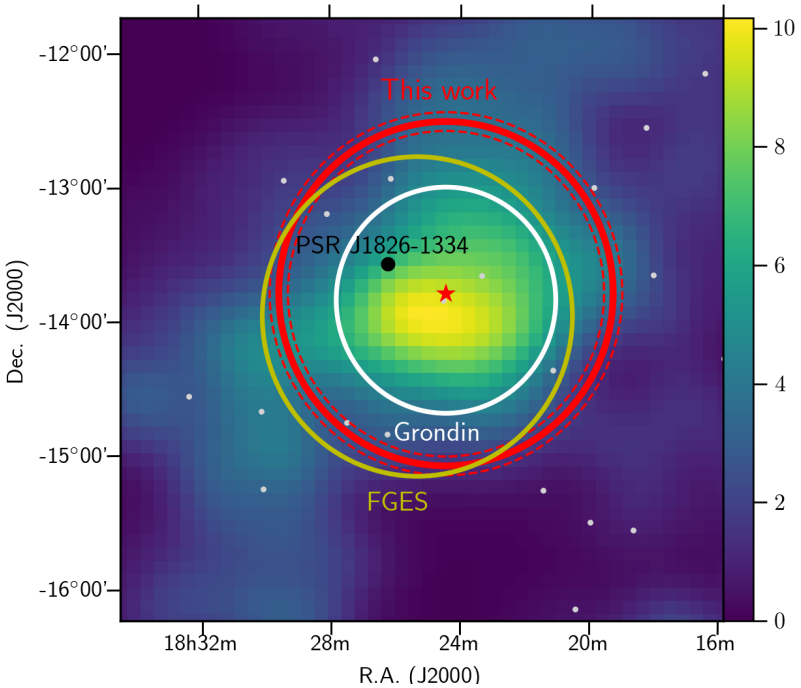
Data Selection	Values
IRFs	P8R3v2
Time Interval	11.6 years
Energy Range	1 GeV – 1 TeV
Energy Bins	8 per decade (for spectra)
Zenith angle	105°
ROI (pixel) size	15° (0.1°)

General results - Comparison

RA, DEC: (276.11, -13.80)

Extension: 1.30 ° ± 0.06° (~150 pc)

(TS_{ext}=1040, ~30σ)



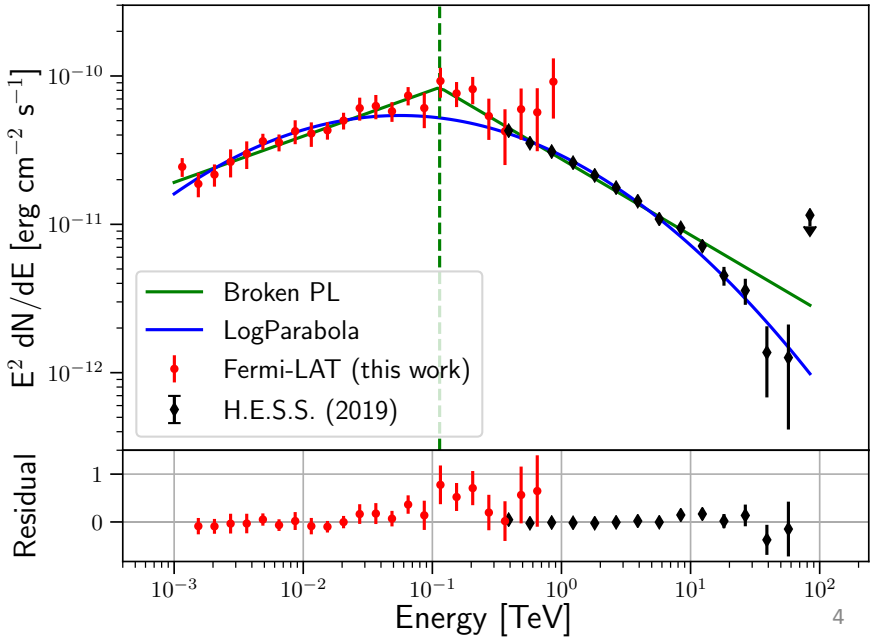
Fermi-LAT previous studies. **Grondin+(2011):** 20 months 1 – 100 GeV.
FGES (2017): 6 years, 10 GeV – 1 TeV

LogParabola

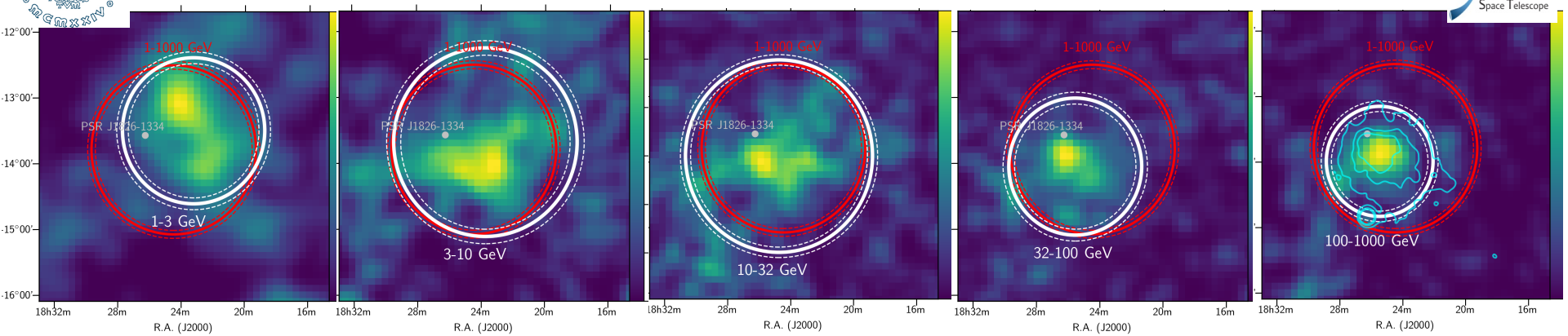
Alpha: 2.15±0.05, Beta: 0.075±0.02, E_0: 154 GeV, N_0: 6.0 x10^{-11} erg cm^{-2} s^{-1}

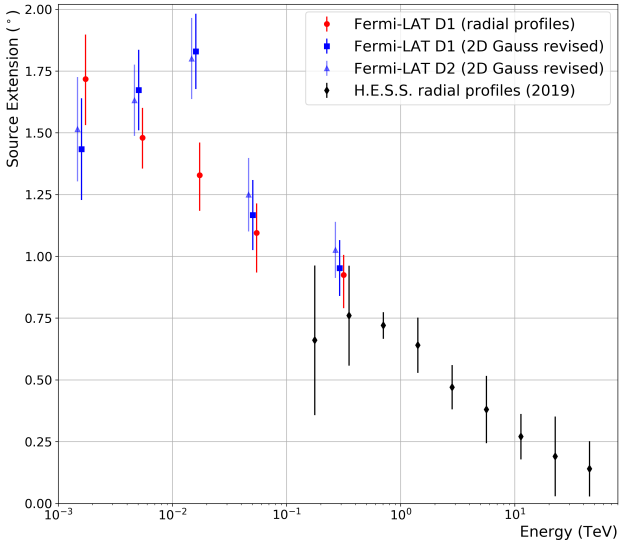
Broken PL

Γ_1: 1.69±0.03, Γ_2: 2.51±0.01, **E_0: 114 GeV,** N_0: 8.37 x10^{-11} erg cm^{-2} 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).

Nebula Modelling

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

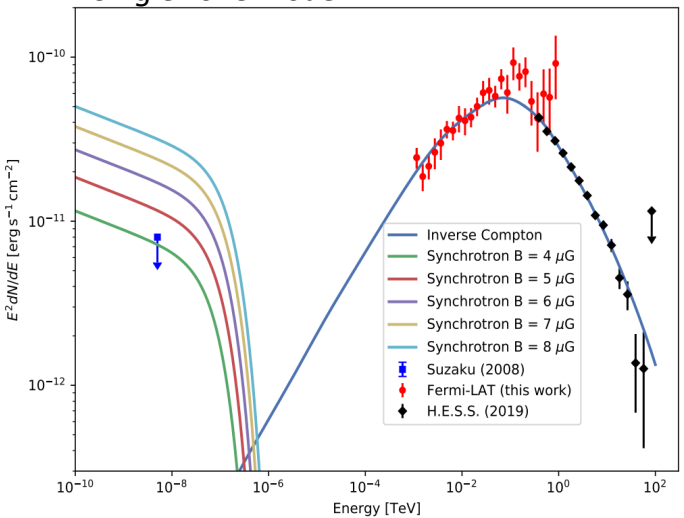
IC from leptonic population, Radiation fields parameter from Popescu (2017), From X-ray observations the max B-field is 4 muG

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

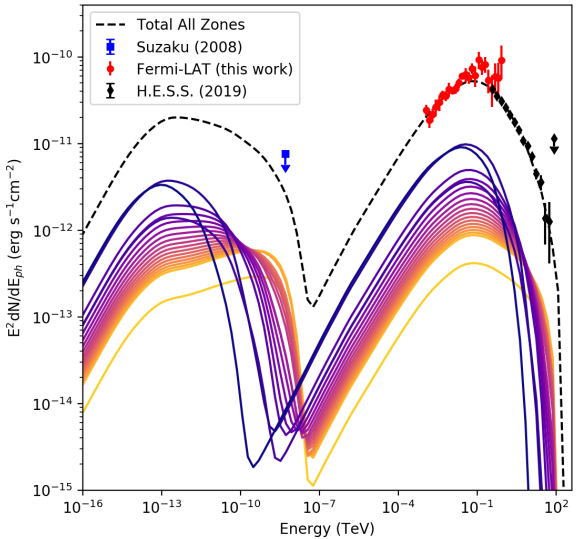
Summation of 20 zones treated as expanding shells in space (initially spherically symmetric), Evolution in time until the system age (assumed as PSR characteristic age) is reached, Burst like injection in each shell

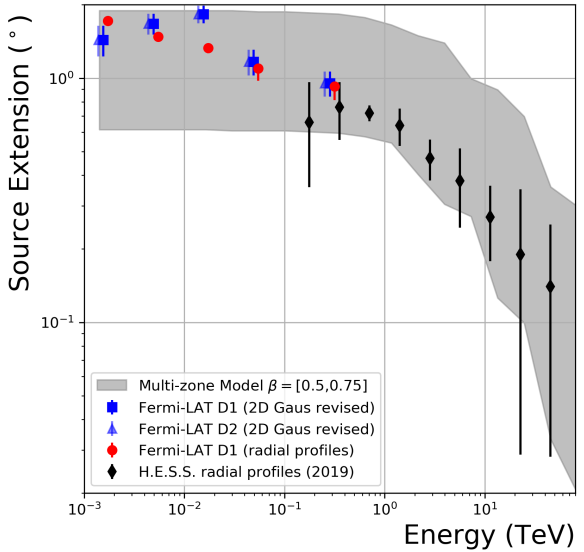
Parameter	H.E.S.S. and *Fermi*-LAT
W_e (10^{49} erg)	$2.33^{+1.00}_{-0.64}$
Γ_1	$2.02^{+0.15}_{-0.19}$
Γ_2	$3.23^{+0.02}_{-0.02}$
E_b (TeV)	$0.80^{+0.18}_{-0.14}$
χ^2/ndf	20.8/34

Single zone model



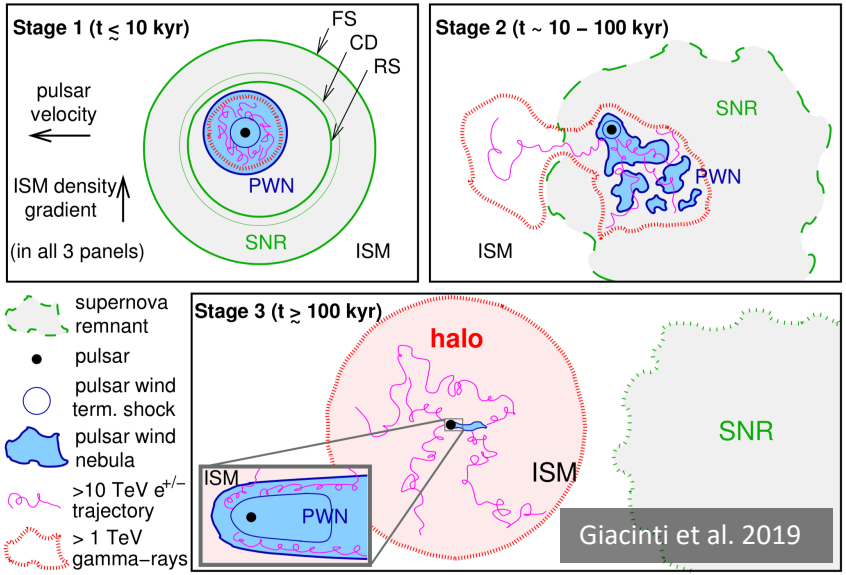
Multi-zone model





PWN vs TeV Halo

Def TeV Halo (Giacinti et al. 2019): **area where En. Density$_{e^-}$ << En. Density$_{ISM}$ (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_{X-ray} (pc)	0.24	10.2	0.8	4.9	3.08	13	9.1
Stage[h]	1	1	1b	1b	2	2	2b
Refs.[i]	I	II	III	IV	V	VI	VII

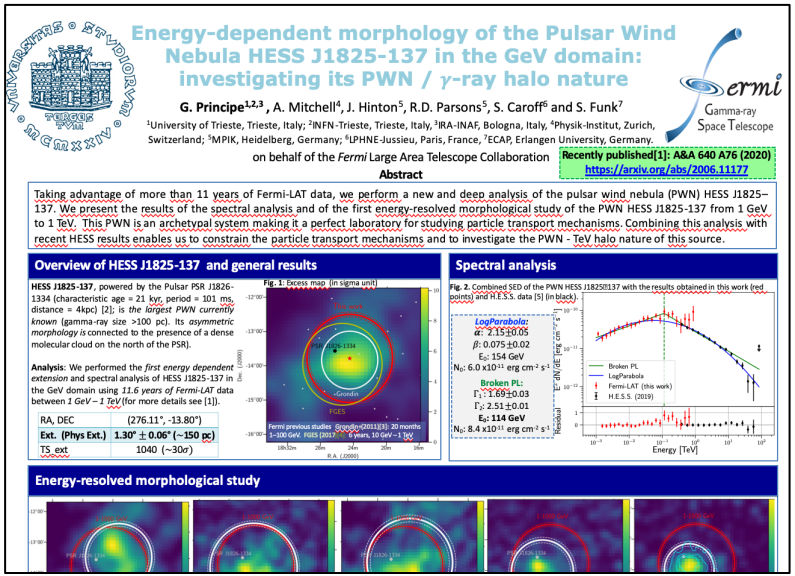
$\varepsilon_{e^-} = 0.1 \pm 0.3$ eV cm^{-3}

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

Conclusion

- 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



Paper published in A&A, 640 A76 (2020) :
Principe et al., 2020 (https://arxiv.org/abs/2006.11177)

Thank you very much for your attention!

Conclusion

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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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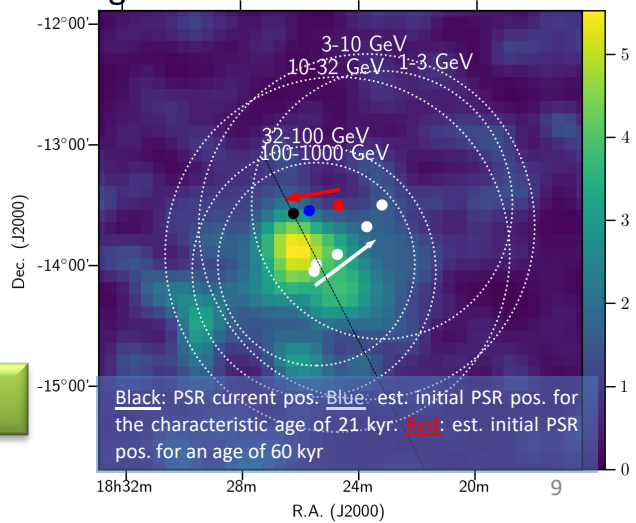

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