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

G. Principe[1,2,3], A. Mitchell[4,5], J. Hinton[5], R.D. Parsons[6], S. Caroff[7] and S. Funk[8]

[1]University of Trieste, Trieste, Italy; [2]INFN-Trieste, Trieste, Italy; [3]IRA-INAF, Bologna, Italy; [4]Physik-Institut, Zurich, Switzerland; [5]MPIK, Heidelberg, Germany; [6]Humboldt University, Berlin, Germany; [7]LPHNE-Jussieu, Paris, France; [8]ECAP, Erlangen University, Germany.

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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.

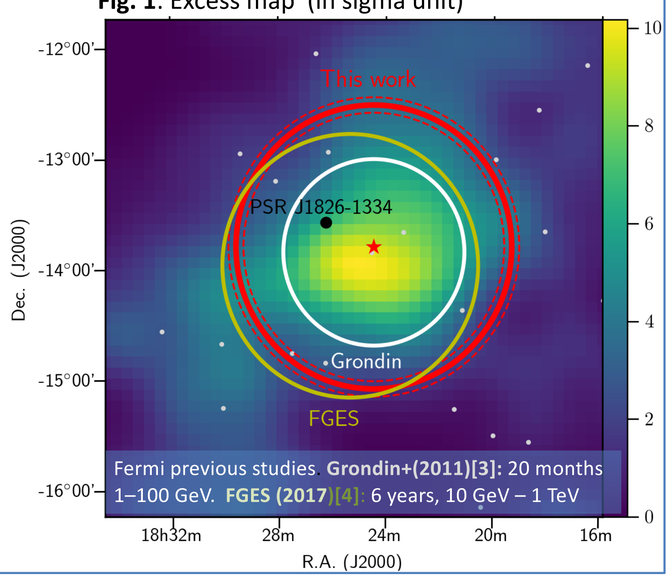
Overview of HESS J1825-137 and general results

HESS J1825-137, powered by the Pulsar PSR J1826-1334 (characteristic age = 21 kyr, period = 101 ms, distance = 4kpc) [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 (~30σ)

Fig. 1: Excess map (in sigma unit)

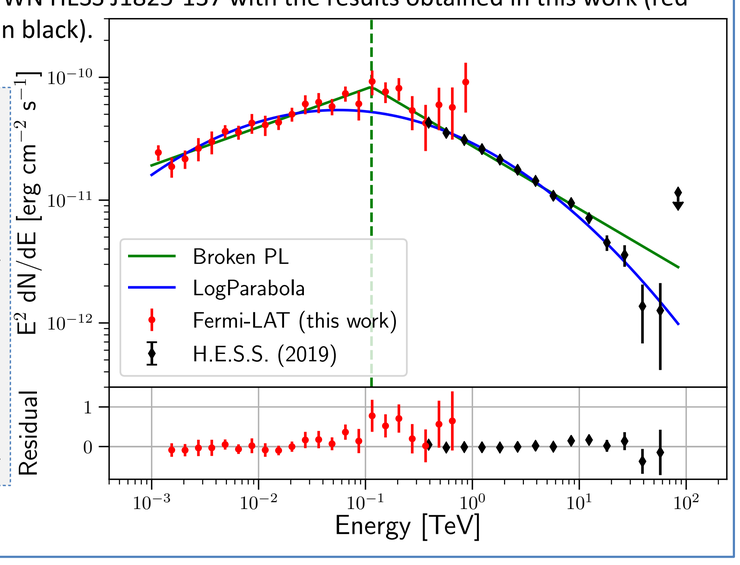


Spectral analysis

Fig. 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: 2.15±0.05
β: 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: 8.4 x10^{-11} erg cm^{-2} s^{-1}



Energy-resolved morphological study

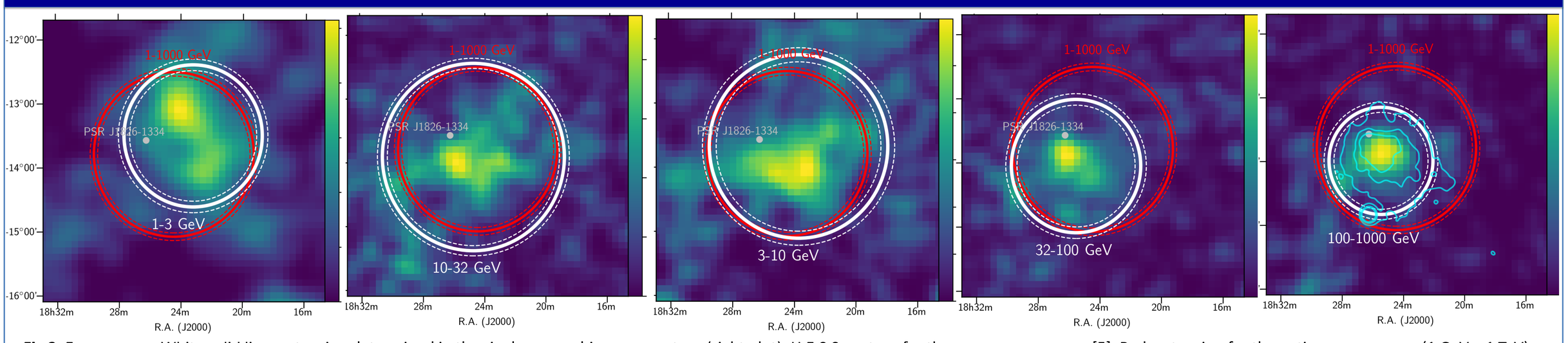


Fig 3. Excess maps. White solid line: extension determined in the single energy bin, cyan contour (right plot): H.E.S.S contour for the same energy range [5]. Red: extension for the entire energy range (1 GeV – 1 TeV).

Nebula modelling: investigating its PWN / γ-ray halo nature

1. **Single zone model,** NAIMA package (Zabalza 2015):
   IC from leptonic population, radiation fields from Popescu (2017), from X-ray observations the max B-field is 4 muG
2. **Multi-zone modelling,** GAMERA package (Hahn 2016):
   Summation of 20 zones treated as expanding shells (initially spherically sym.), 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

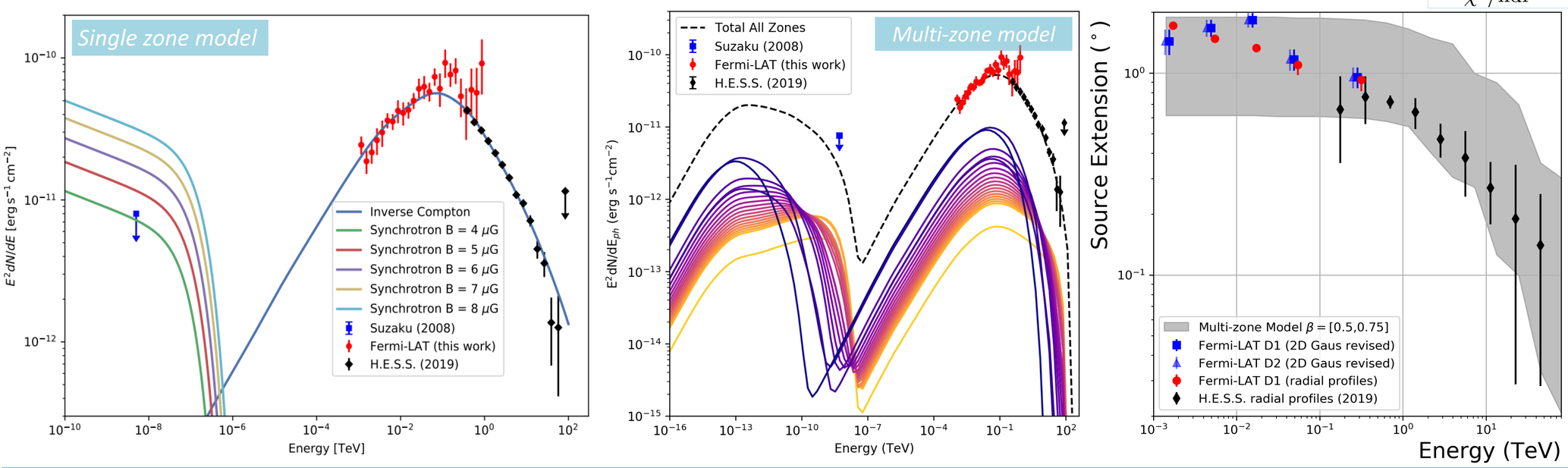


Fig 4.
Left: Results of the fitted IC NAIMA SED to the Fermi-LAT and H.E.S.S. data.
Middle: Total SED of the nebula with GAMERA, combining X-ray and gamma-ray data, described by the summation of 20 zones of particles of different ages.
Right: GAMERA model of the radial extent of the nebula as a function of energy.

Following the definition of TeV halo given by Giacinti et al. (2019)[6], as the area where En. Density$_{e-}$ << En. Density$_{ISM}$ (0.1 eV cm^{-3}), we investigate the nature of this source. 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**. Future detailed spectral and morphological studies may enable variation in energy density through the emission region to be determined, which will help to study the PWN-halo transition.

Conclusions

We performed a new and deep analysis of the PWN HESS J1825-137 using 11.6 years of *Fermi*-LAT data between 1 GeV - 1 TeV:

- We performed the *first energy-resolved morphological study* of the PWN HESS J1825-137 in the GeV domain.
- We model both the SED and the combined SED-morphology evolution using the NAIMA and GAMERA modelling packages.
- 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)[7]

References

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