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# Energy dependent morphology of the PWN HESS J1825-137 in the GeV domain

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# Introducing HESS J1825-137

HESS J1825-137 : a bright PWN with strongly energy-dependent morphology

Large intrinsic extension > 100 pc from pulsar as seen by H.E.S.S.

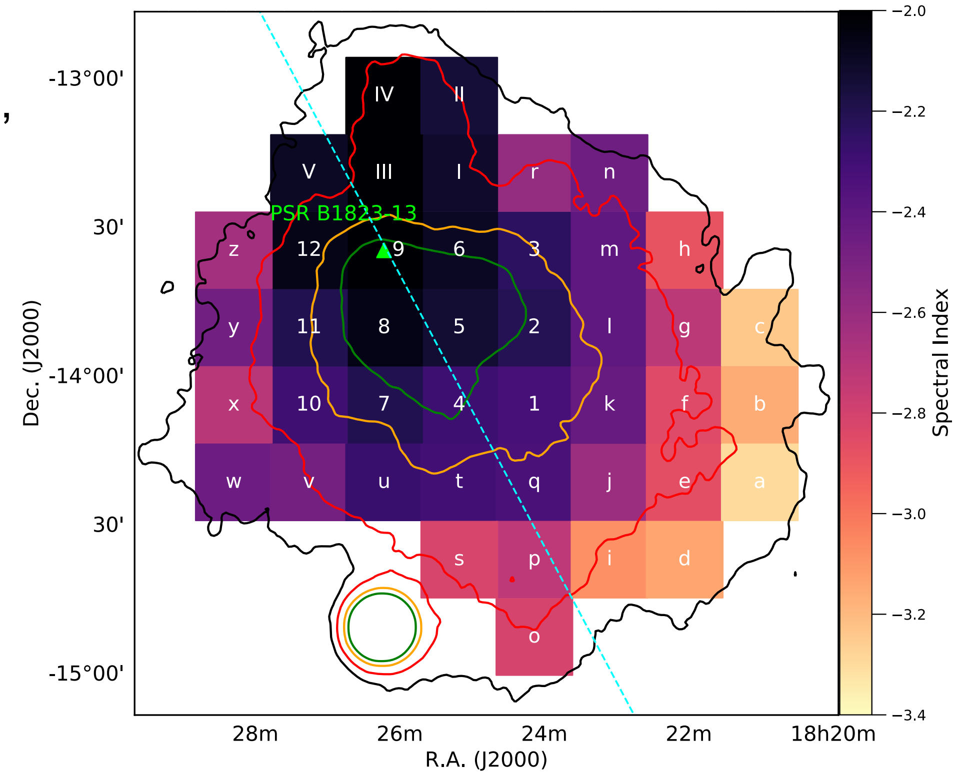
Powered by PSR J1826-1334 :
spin-down luminosity = $2.8 \times 10^{36}$ erg $s^{-1}$,

age = 21 kyr, period = 101 ms,

distance = 4 kpc

Associated with bright HAWC source

at E > 100 TeV




HESS Collaboration, A&A 621, A116 (2019)

# Previous Fermi-LAT Analyses

Grondin et al (2011):

- 20 months, 1-100 GeV
- Disk 0.67º radius, Gaussian 0.56º

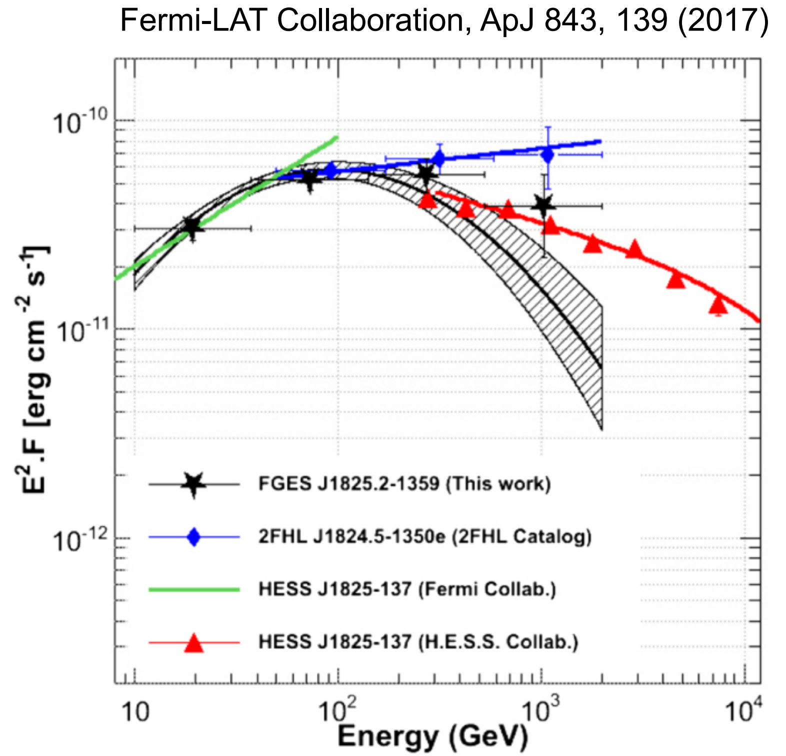
2FHL: 80 months, 50 GeV – 2 TeV

3FHL: 7 years 10 GeV – 2 TeV

- 2D Gaussian 0.75º

FGES (2017):

- 6 years, E > 10 GeV
- Disk 1.05º radius, 2D Gaussian 0.79º




Motivation:

Energy-dependent extension and spectral analysis with 10 years, 1 GeV – 1 TeV

# Fermi-LAT Analysis

Analysis using Fermipy (0.17.4) and Fermi Science Tools (11-07-00)

Diffuse models: standard LAT (Acero et al. 2016) and optimised Galactic plane (Malyshev 2017)

Catalogue FL8Y list and Extended_archive_v18 for other sources in FoV

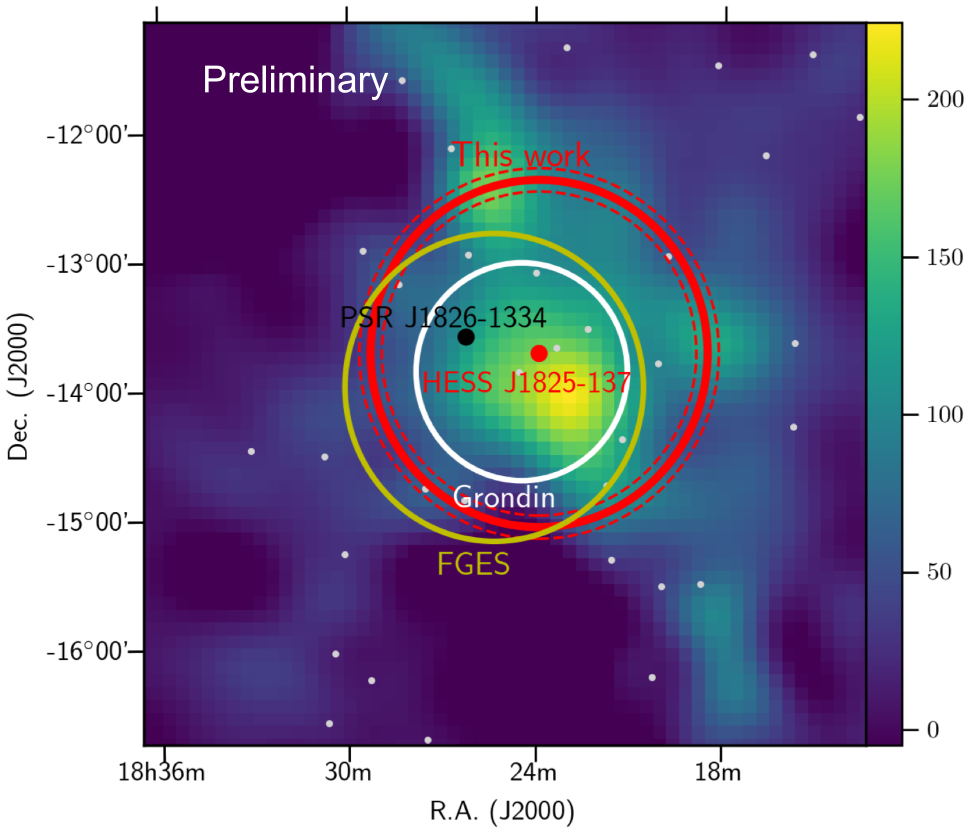
Procedure:

- Spectral analysis and localisation with free background, free sources in 2º radius
- Extension analysis in energy resolved bands (free background)
- Spectral analysis using template from energy-resolved morphology

For energy dependent extension analysis:

- 5 energy bands used: 1-3 GeV, 3-10 GeV, 10-30 GeV, 30-100 GeV, 100 GeV – 1 TeV
- Start using model from full range; re-fit localisation; extension analysis

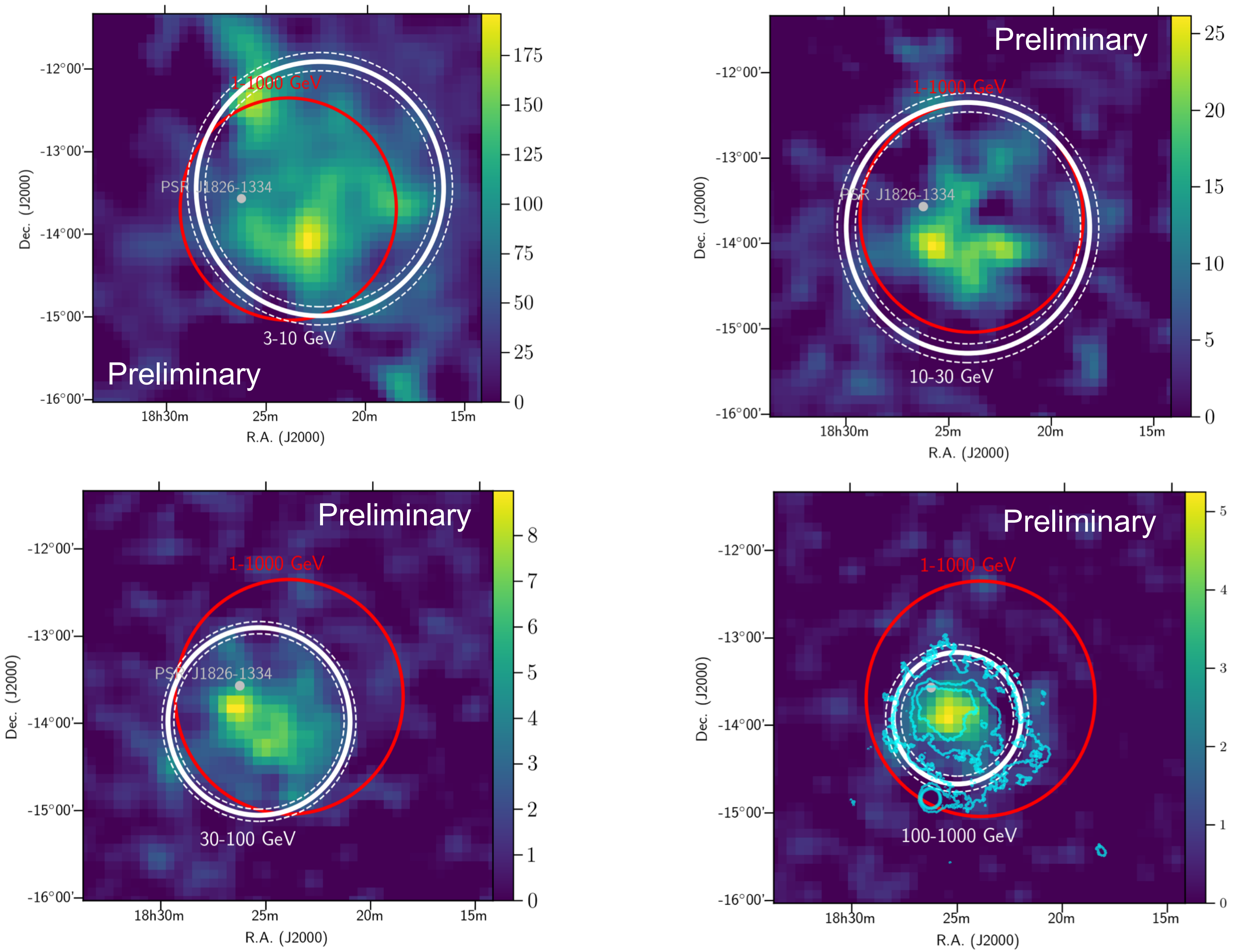
# Results from 3 GeV to 1 TeV




RA = 275.97° ± 0.03°
Dec = -13.71° ±0.04°

Extension R68 = 1.35° ±0.09°
TS = 992

# Energy Dependent Morphology – Excess Maps



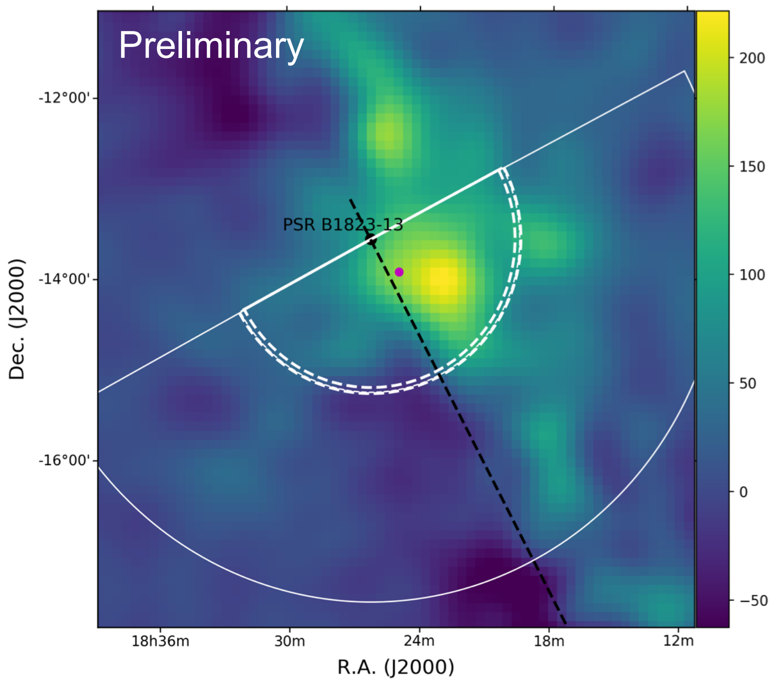
# Energy Dependent Morphology – Radial Profile

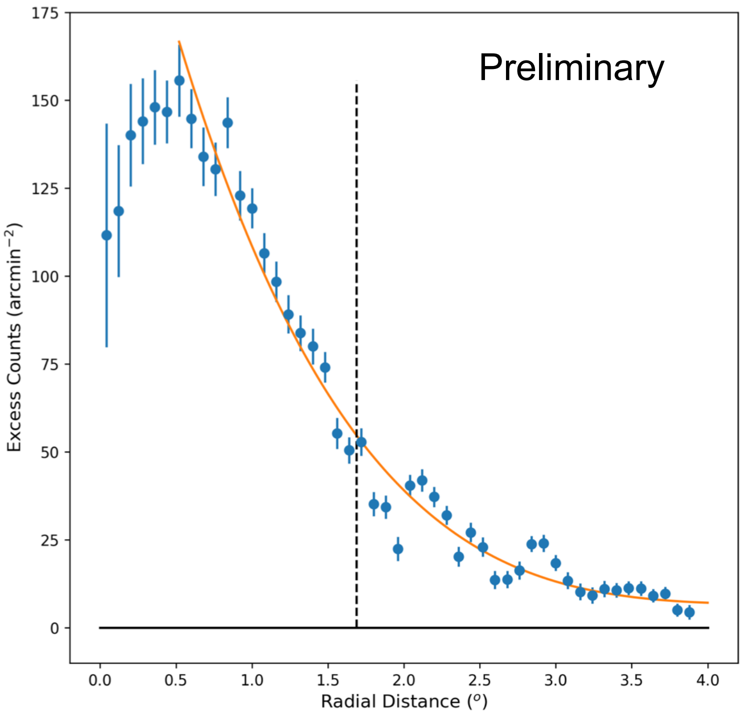
Radial profile method for consistency with H.E.S.S. coll. (2019)

Use the same semi-circular region to construct a 1D profile

Find radius from pulsar at which flux drops to 1/e of the peak

$$y(x) = \begin{cases} a(r - r_0)^n + c, & (x < r_0) \\ c, & (x \geq r_0) \end{cases}$$



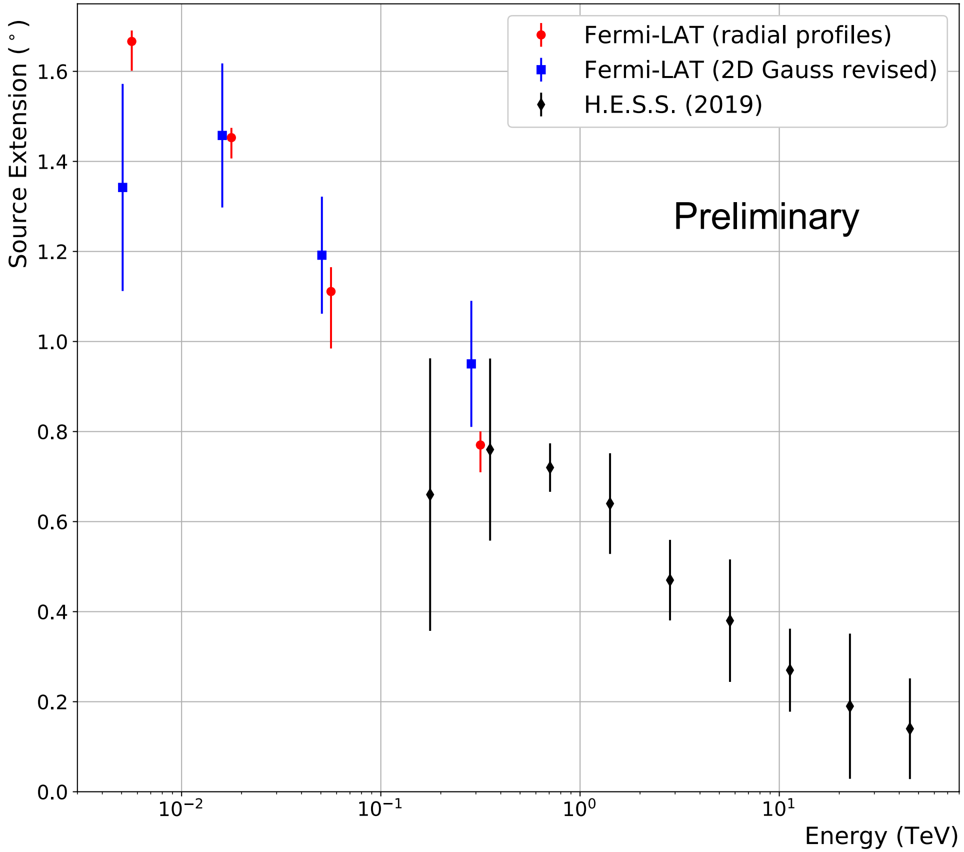
# Energy Dependent Morphology – Comparison

Extent measurement approaches are compatible

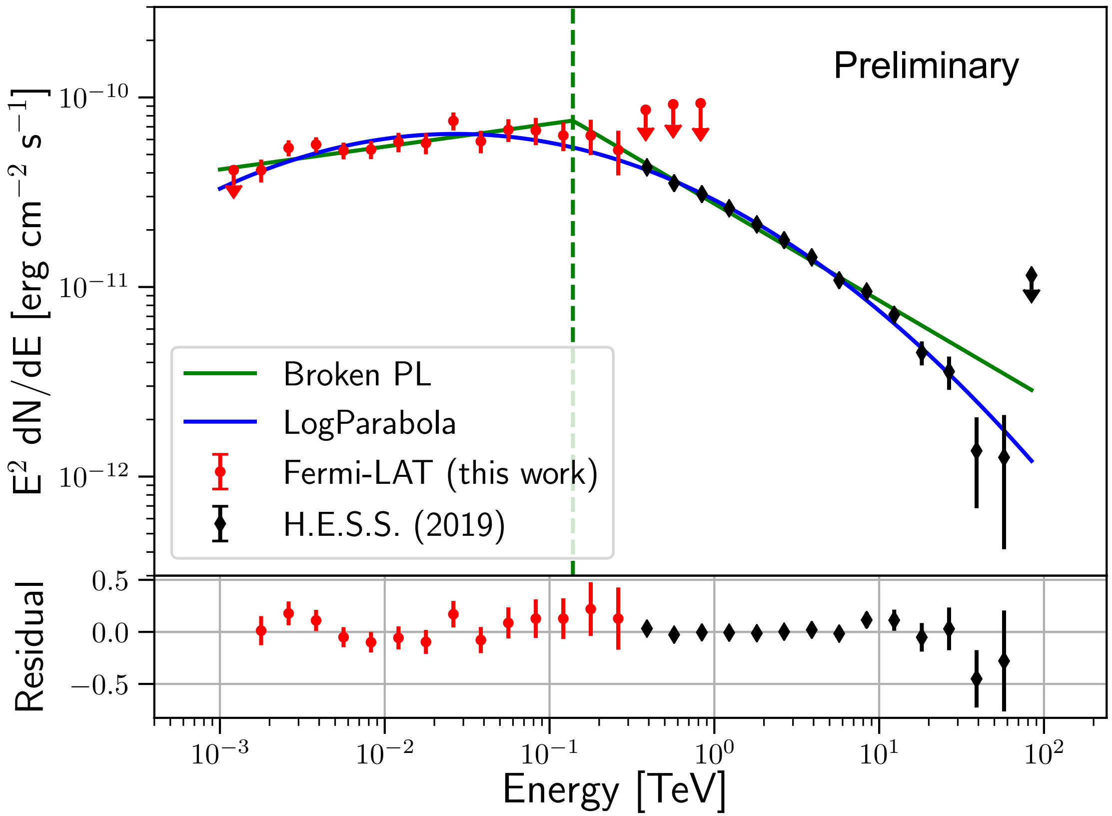
2D Gaussian extent is 68% containment – convert to radius at 1/e

$$R\left(\frac{1}{e}\right) = \sqrt{2}\frac{R_{68\%}}{\sqrt{-2\log(1-0.68)}} = 0.937R_{68\%}$$

Correct for orientation: distance along major axis from pulsar position



# Spectral Energy Distribution




BrokenPL:

Γ1 = 1.88±0.03
Γ2 = 2.51±0.01
$E_b$ = 139 GeV
$N_0 = 7.5\times10^{-11}$ erg cm$^{-2}$ s$^{-1}$

$$\frac{dN}{dE} = N_0 \times \begin{cases} \left(\frac{E}{E_b}\right)^{-\Gamma 1} & if E < E_b \\ \left(\frac{E}{E_b}\right)^{-\Gamma 2} & otherwise \end{cases}$$

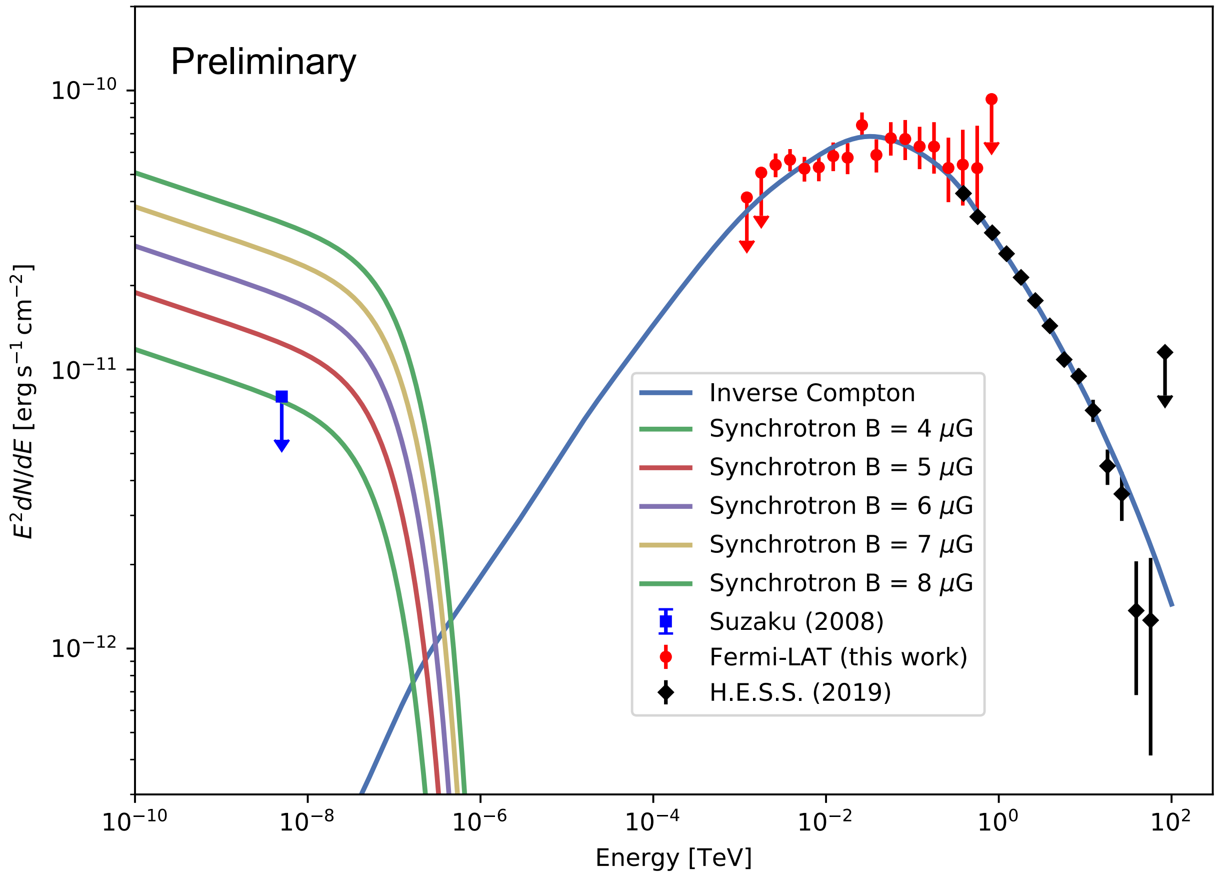
LogParabola:

α = 2.13±0.03
β = 0.061±0.02
$E_0$ = 80 GeV
$N_0 = 6.0\times10^{-11}$ erg cm$^{-2}$ s$^{-1}$

$$\frac{dN}{dE} = N_0 \left(\frac{E}{E_b}\right)^{-(\alpha+\beta\log(E/E_b))}$$

Fermi-LAT spectrum extracted using energy-dependent morphology templates in different energy bins.

# SED Modelling – single electron population




Naima (Zabalza 2015) one zone model
Leptonic population, max B-field 4 µG
Radiation fields approx. from Popescu (2017)

| Parameter | H.E.S.S. and *Fermi* |
|---|---|
| $W_e$ ($10^{49}$ erg) | $5.57^{+2.73}_{-2.78}$ |
| $\Gamma_1$ | $2.16^{+0.16}_{-0.40}$ |
| $\Gamma_2$ | $3.20^{+0.02}_{-0.01}$ |
| $E_b$ (TeV) | $0.50^{+0.14}_{-0.13}$ |
| $\chi^2$/ndf | 25.7/28 |

# Multi-zone Modelling SED and Morphology

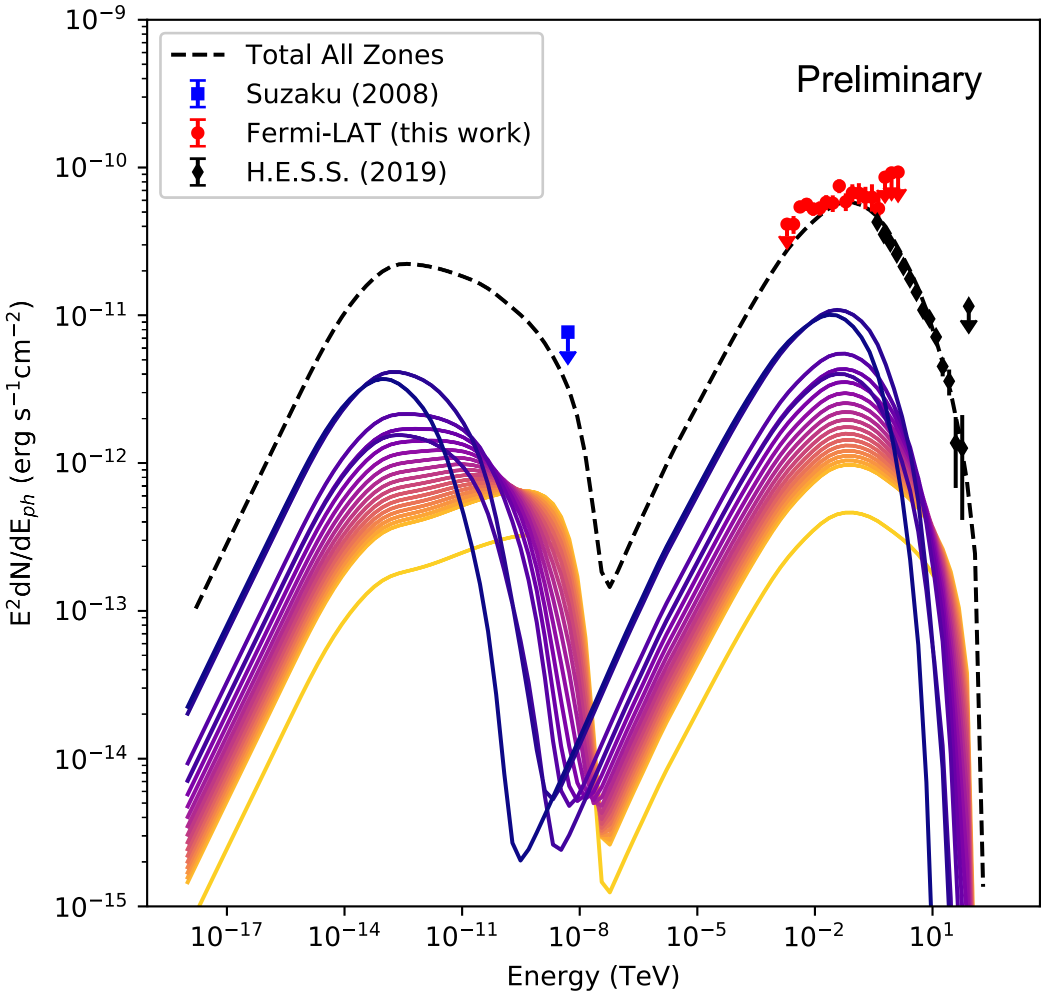
GAMERA (Hahn 2016) multi-zone model

Treat as sum of 20 zones as spherically symmetric shells expanding and evolving with time up to system age (pulsar age)

Burst-like injection

Parameters constrained to reach present values at age

$$L(t) = (1-\eta)\left(1+\frac{t}{\tau_0}\right)^{-\frac{n+1}{n-1}}$$




$$P = P_0\left(1+\frac{t}{\tau_0}\right)^{\frac{1}{n-1}}$$

$$B(t) \propto \left(1+\frac{t}{\tau_0}\right)^{-1}$$

# Multi-zone Modelling SED and Morphology

Project sum of zones along line of sight to form 1D radial profile

Line of sight depth:

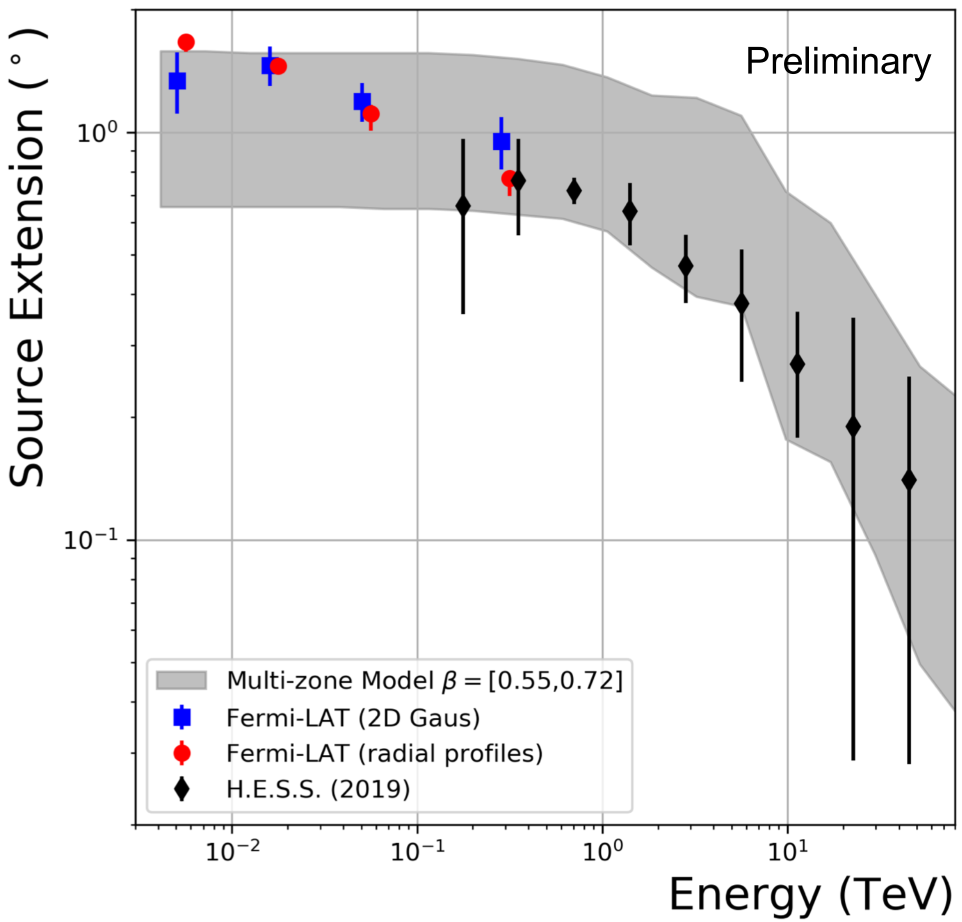
$$d_z = \begin{cases} 2\sqrt{R_z^2 - r^2} & (r < R_z) \\ 0 & \end{cases}$$

Fit model profiles in different energy bands to obtain R(1/e) extension from model

Velocity profile assumed:

$$v(r,t) = v_0 \left(\frac{r}{r_{max}}\right)^{\beta} \left(\frac{t}{T}\right)^{-\beta}$$

Data bracketed by
β = [0.55, 0.72]
(compatible with H.E.S.S.)



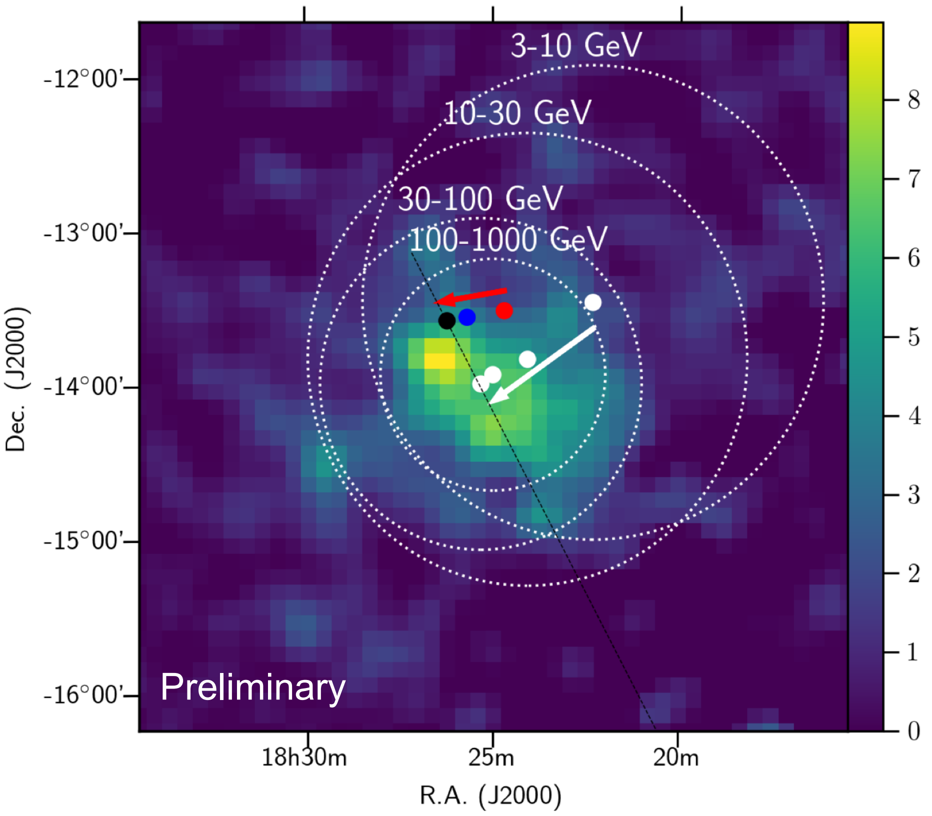
# System Evolution

Shift in centre of gravity (white) with increasing energy

Similar direction to pulsar proper motion (red arrow)

Cooled electron population originating from earlier in the systems history?

Black:
current pulsar position
Blue:
pulsar initial location for 21 kyr age
Red:
pulsar initial location assuming 60 kyr age



# Conclusions

First study of energy-dependent morphology of HESS J1825-137 in the GeV regime

Spectral and morphological analysis using 10 years of Fermi-LAT data from 1 GeV – 1 TeV

Results compatible with H.E.S.S. in overlapping energy range

Independent methods of estimating extension (2D Gaussian and profile) agree

Multi-zone model can simultaneously describe SED and energy dependent morphology, B-field constrained to low values

Trend in emission compatible with proper motion of pulsar and system evolution

Paper will soon be submitted

# Thank you for your attention