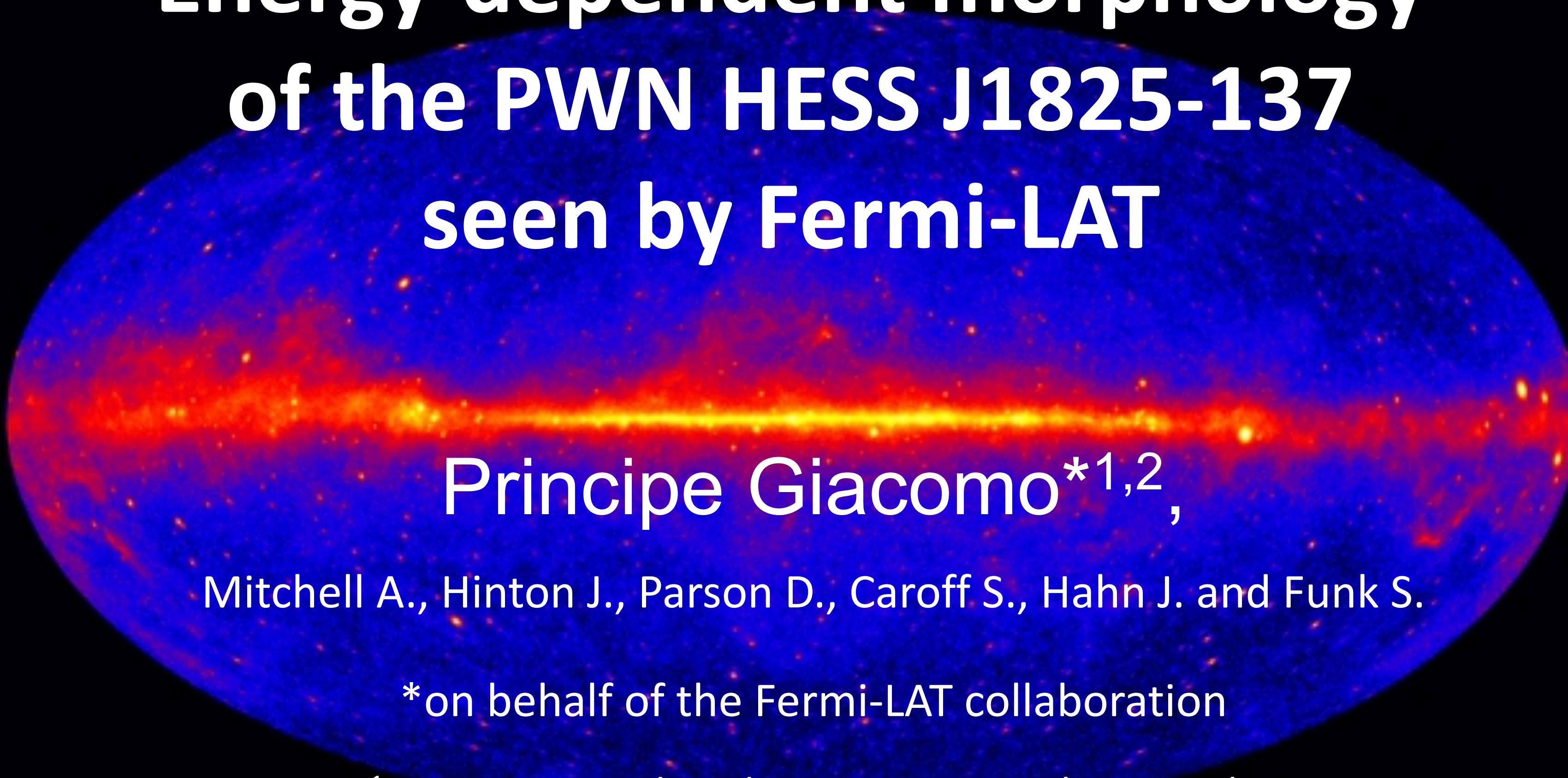
Energy-dependent morphology of the PWN HESS J1825-137 seen by Fermi-LAT



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Content

Energy-dependent morphology of the PWN HESS J1825-137 seen by Fermi-LAT

0. **Motivation (new H.E.S.S. results 2019)**

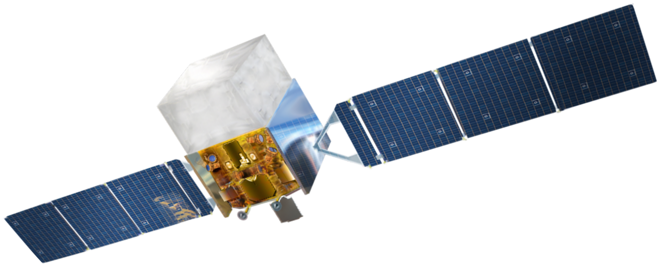
1. **Data and model selection**

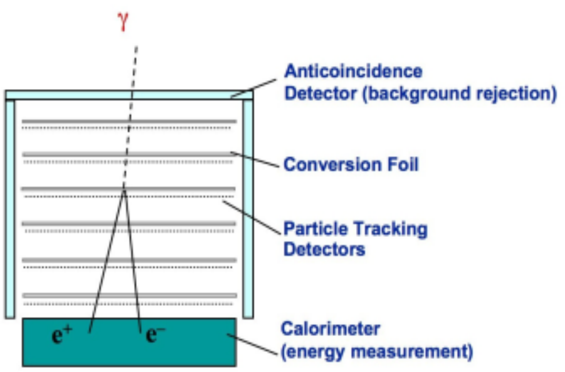
1. **Analysis description**

2. **Results:**
    - *Localization, Extension, SED*
    - *Energy resolved morphology*

3. **PWN modelling**

4. **Conclusion**



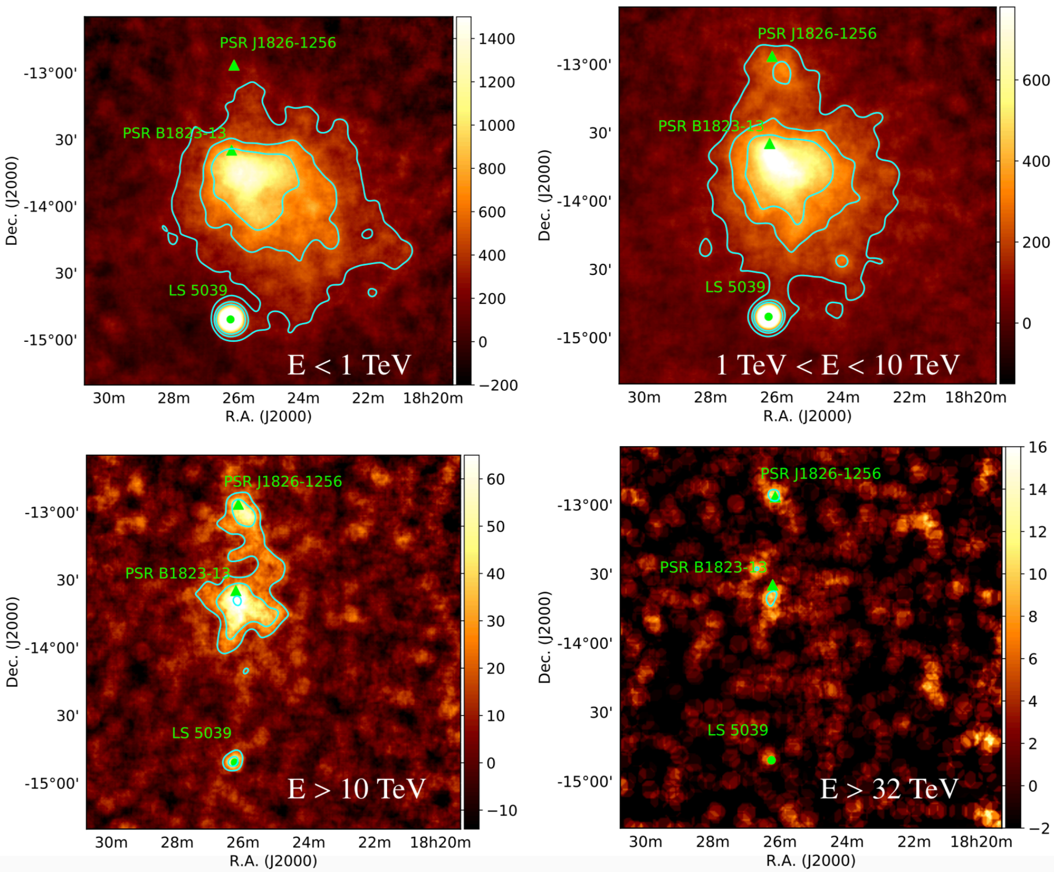


Fermi-LAT energy range: 20 MeV – 2 TeV

PWN evolution of HESS J1825-137

HESS J1825-137: *"with a size >100 pc is the largest PWN currently known."*

H.E.S.S. results at TeV energies

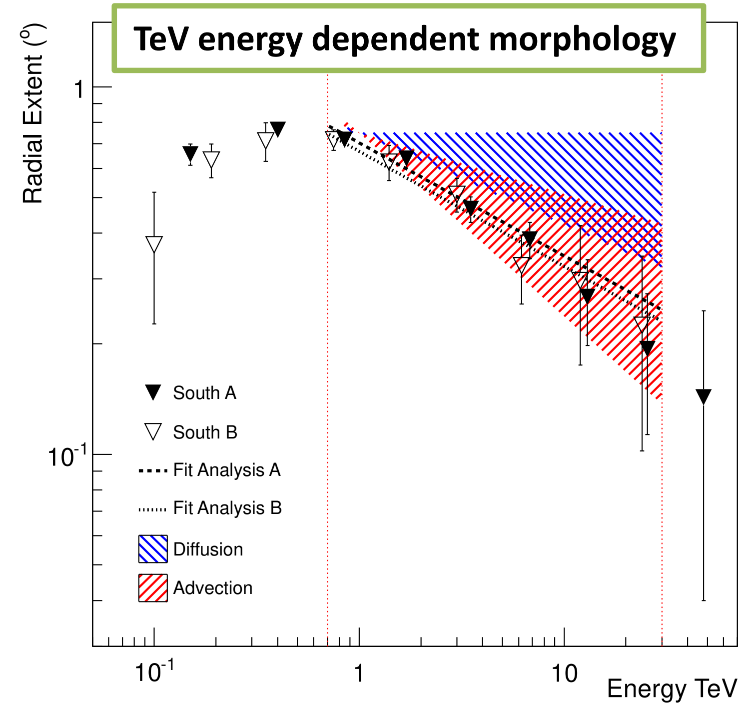


H.E.S.S. Coll. (2019)

Pulsar PSR J1826-1334:

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

TeV energy dependent morphology



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

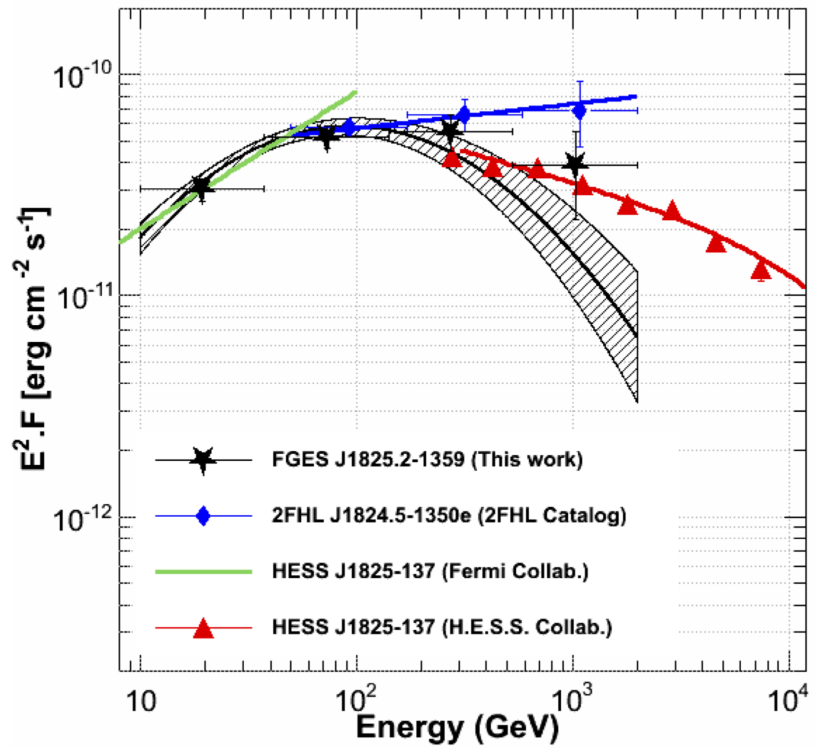
Previous LAT analysis

Grondin et. al. (2011):
- 20 months
- 1 – 100 GeV energy band
- Spatial Model: Gaussian (0.56 deg)

2FHL (and similarly in 3FHL):
- 80 months
- 50 GeV – 1 TeV energy band
- Spatial Model: 2D Gaussian (0.75 deg)

FGES (2017):
- 6 years
- 10 GeV – 1 TeV energy band
- Spatial Model: 2D Gaussian (0.79 deg)

Ackermann *et al.* (2017)



We are interested in performing a new extension and spectral analysis of HESS J1825-137 using **10 years** of LAT data in the energy range between **1 GeV and 1 TeV.**

Source model from FGES paper

The initial spatial and spectral models used for the analysis are taken from the FGES paper (Ackermann et al. 2018):

Spatial Model: **2DGaussian**

- Sigma = 0.79°
- RA = 276.296°
- DEC = -13.992°

Spectrum Type: **LogParabola**

Diffuse models:

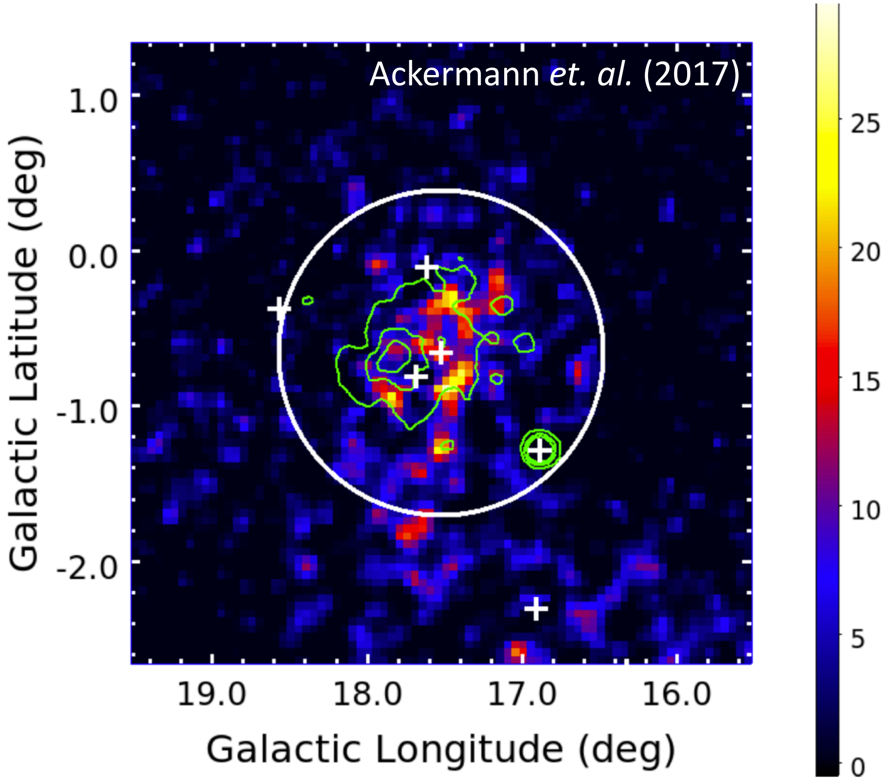
- standard LAT diffuse emission model: Acero *et al.* 2016
- optimized model for the Galactic plane: *Fermi GC excess study (Malyshev 2017)*

Model for the other Fermi-LAT extend sources:

- Extended_archive_v18

Catalog:

- latest version of **FL8Y list** (preliminary 4FGL)



Background-subtracted TS maps of HESS J1825−137.
Contour: H.E.S.S. in green, FGES in white.

Analysis

We performed the analysis using a recent version of Fermipy (0.17.4) and the Fermi Science Tools version 11-07-00.

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

- Optimization – Fit
- Spectral analysis (free bkg, free sources in 2° radius)
- Localization (free bkg, free sources in 2° radius)
- Extension analysis (free bkg)
- Spectral analysis (using the template from the energy-resolved morphology)

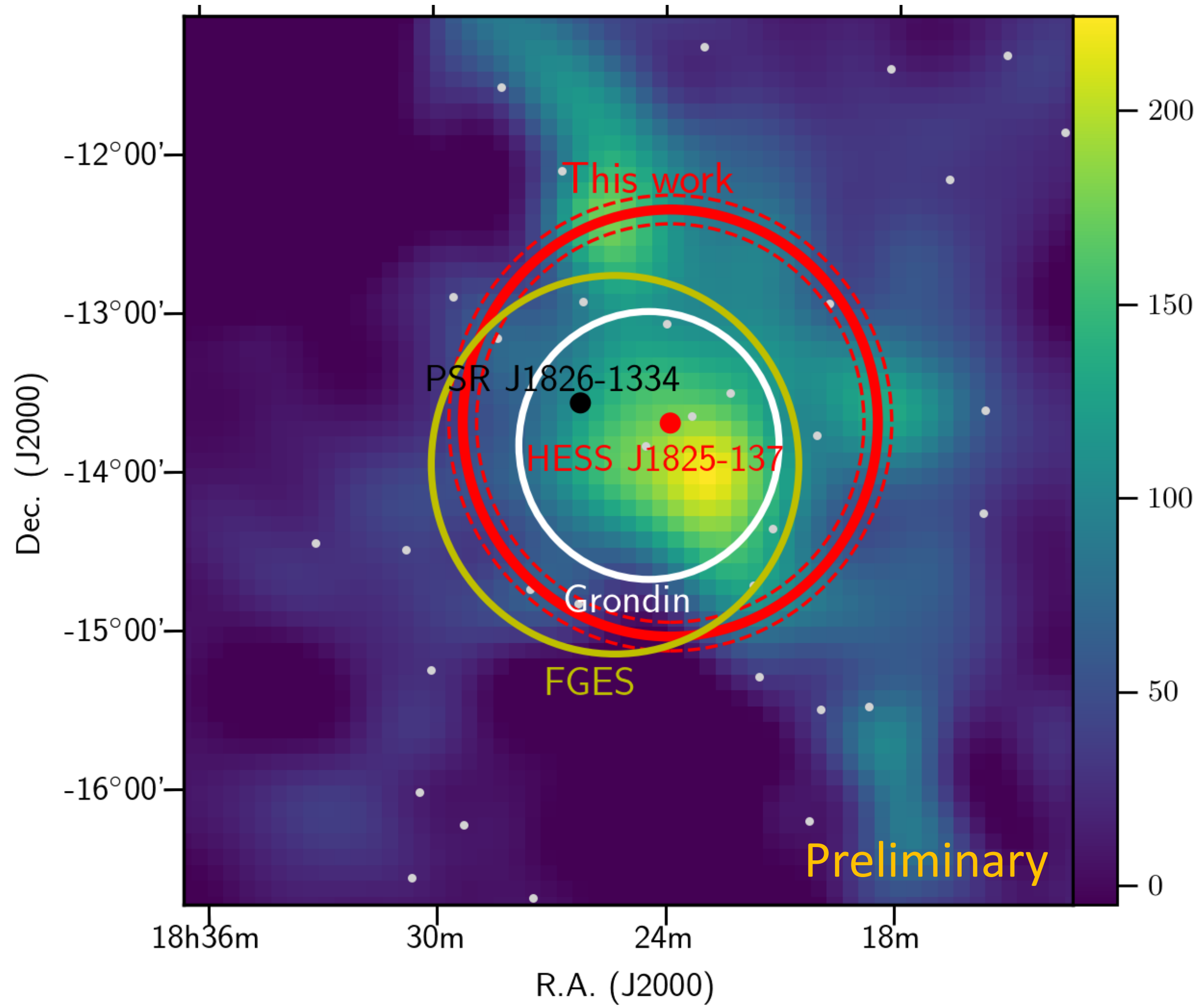
Energy-resolved morphological study

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

- In input it is given the model derived in the general analysis
- The localization is refitted in each energy bin (free bkg)
- Extension analysis (free bkg, fixed center)

General results - Comparison

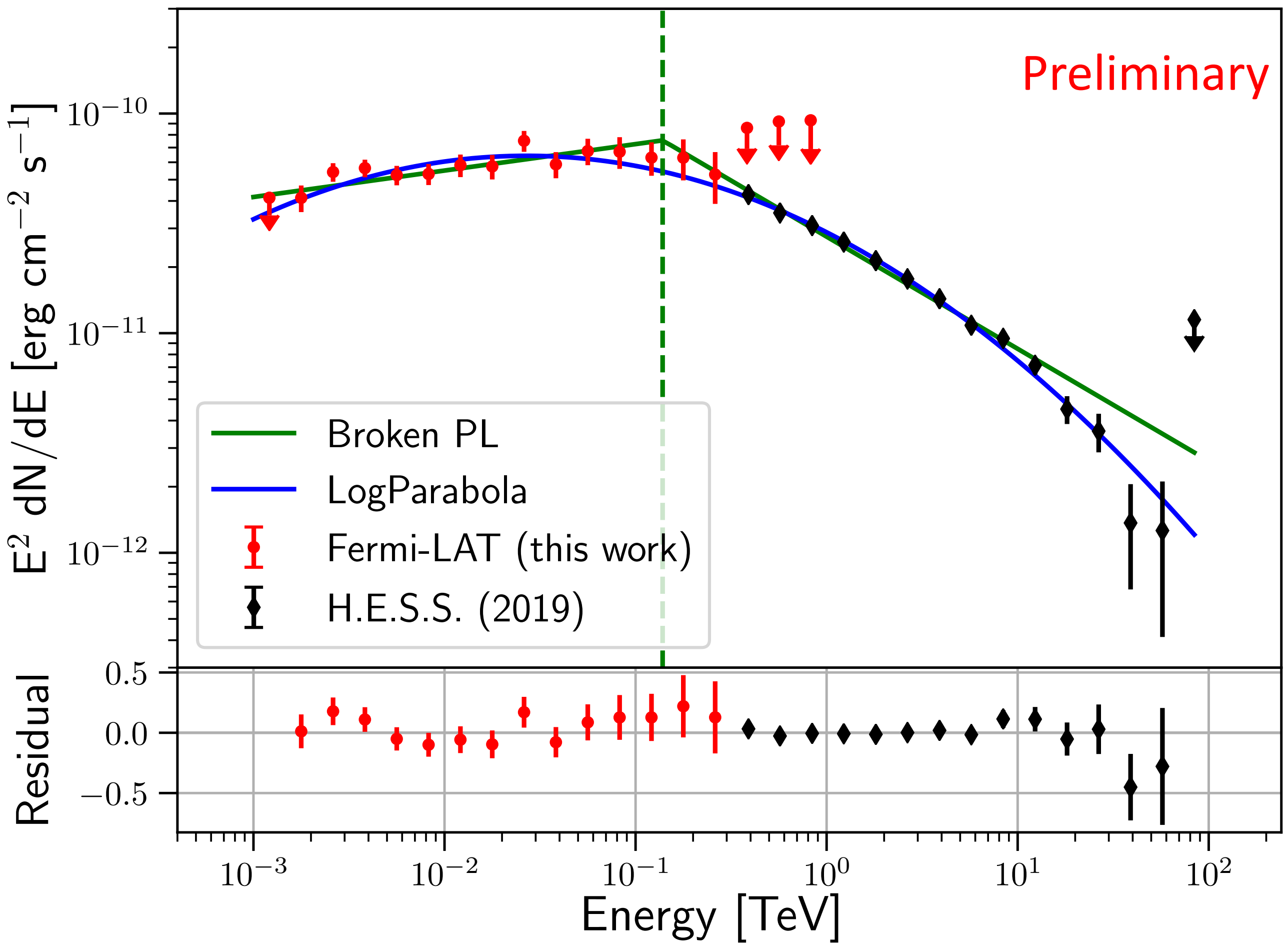
Excess map between
3 GeV and 1 TeV
(Gauss smooth 0.1 deg)



Position:
RA: 275.97 ±0.03°
DEC: -13.70±0.04°
Extension (R_68%):
1.35±0.09°
(TS_ext=992)

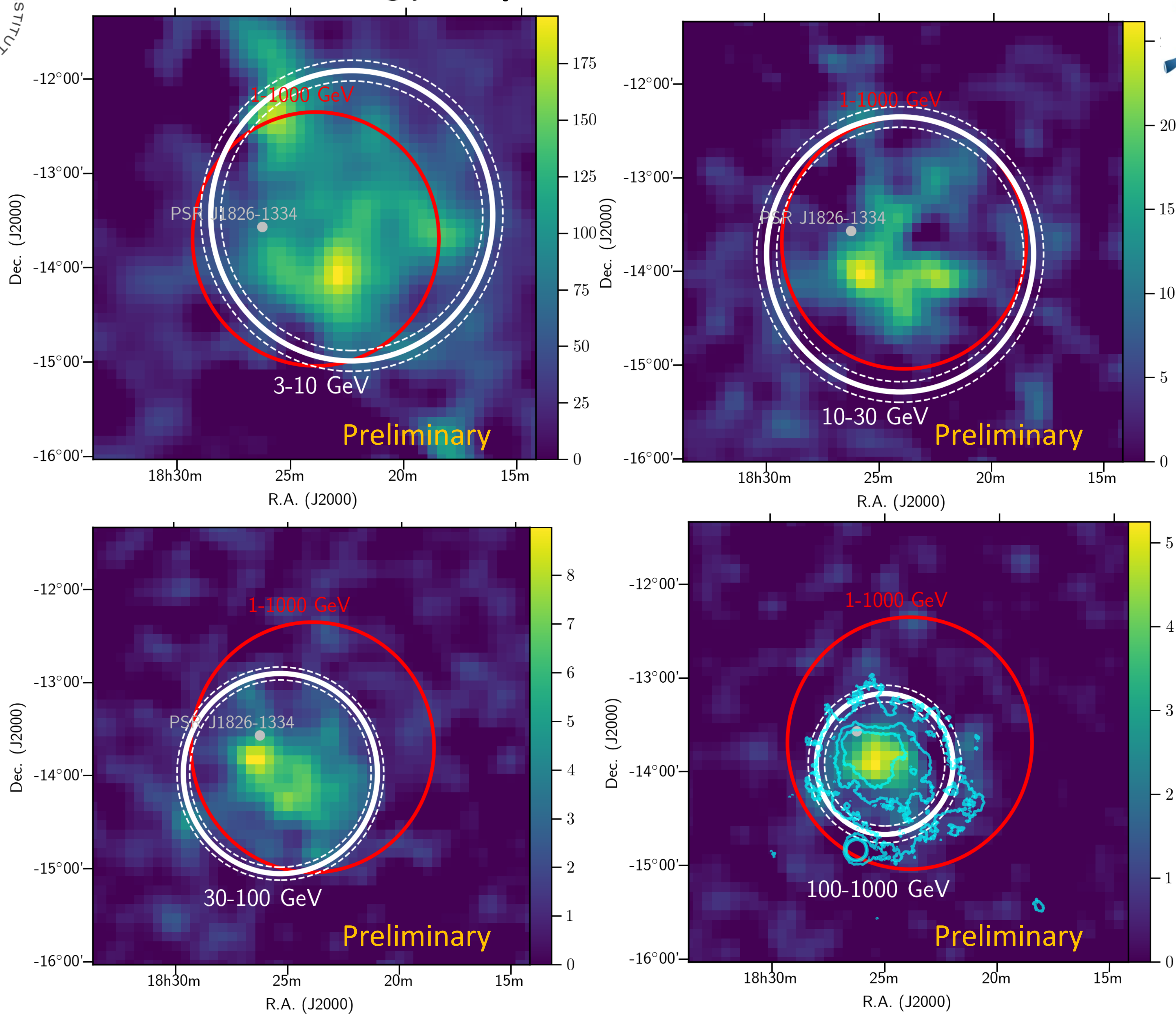
The Fermi extension is given as the 68% containment radius from the center of the PWN.

SED



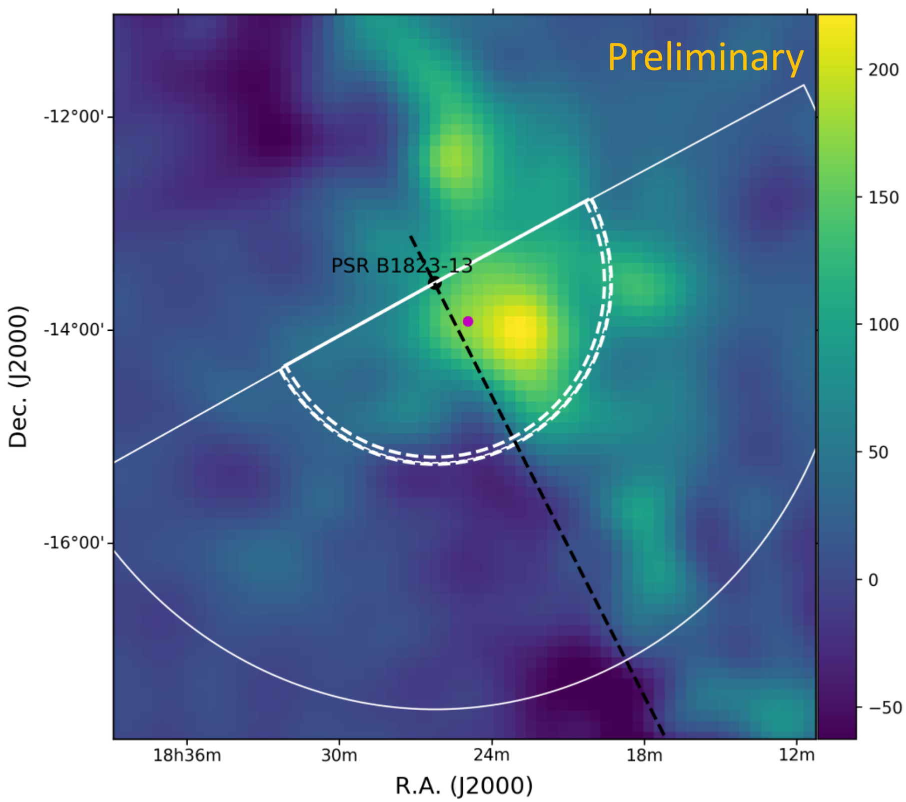
We use TS<10 as threshold for the upper limits on the flux points.

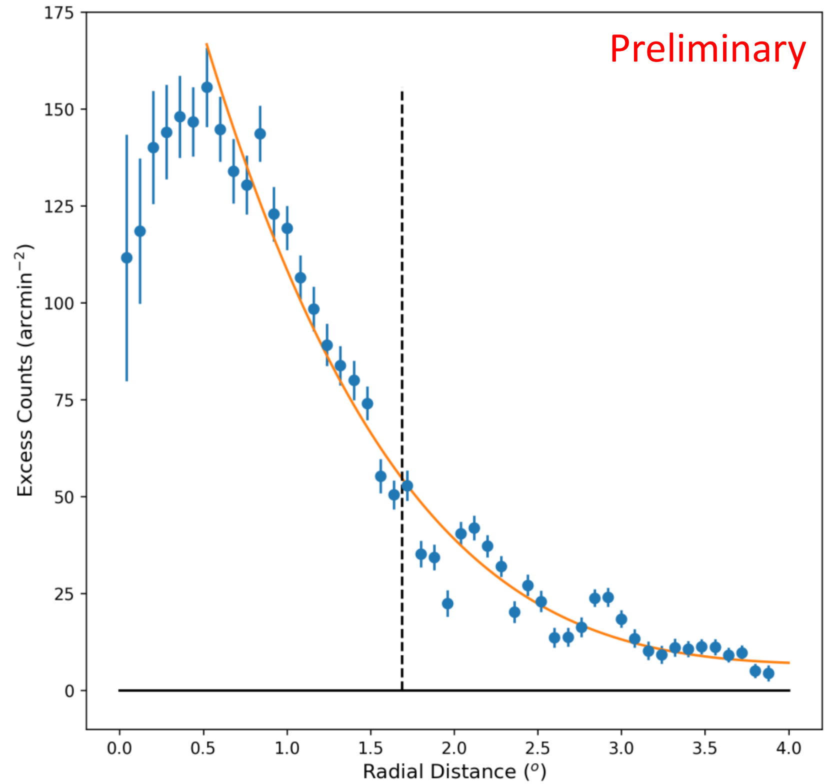
Energy dependent extension



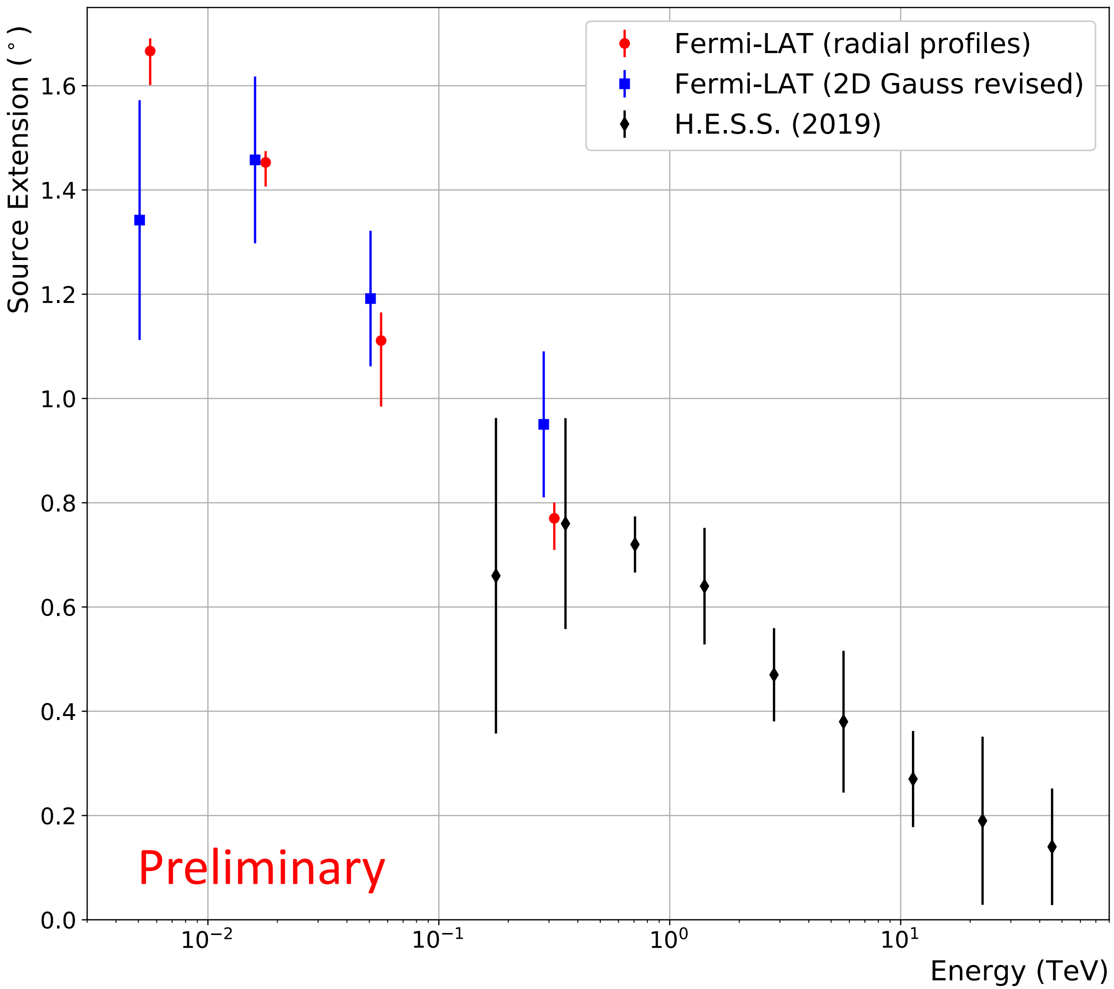
Extension / Radial profile (HESS method)

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).





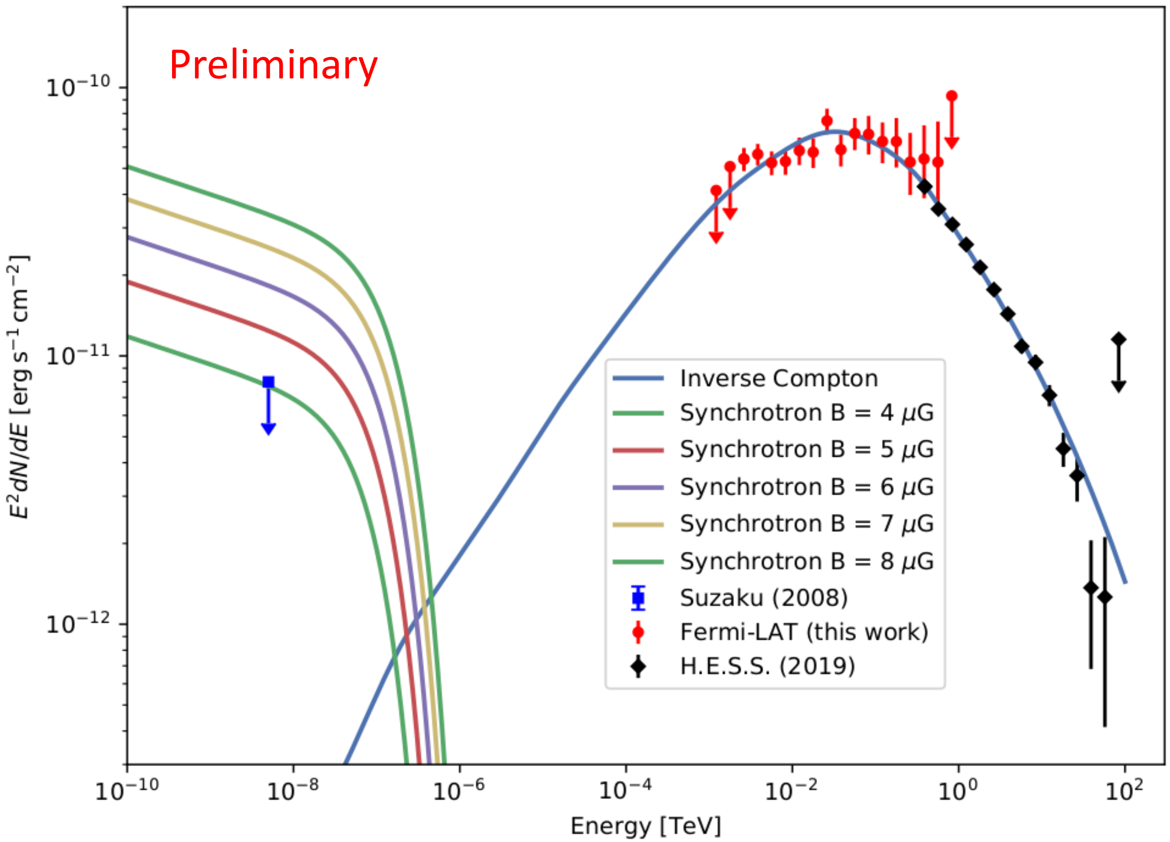
Energy dependent morphology



NAIMA SED Modelling

Naima SED modelling: single zone model (Zabalza 2015):
- IC from leptonic population
- Radiation fields parameter from Popescu (2017)
- From X-ray observations the max B-field is 4 muG

Parameter	H.E.S.S. and *Fermi*
W_e (10^{49} erg)	$5.57^{+2.73}_{-2.78}$
Γ_1	$2.16^{+0.16}_{-0.40}$
Γ_2	$3.20^{+0.02}_{-0.01}$
E_b (TeV)	$0.74^{+0.08}_{-0.09}$
χ^2/ndf	25.7/28



Combined spectra and extension modelling

Multi-zone modelling - GAMERA package (Hahn 2016):

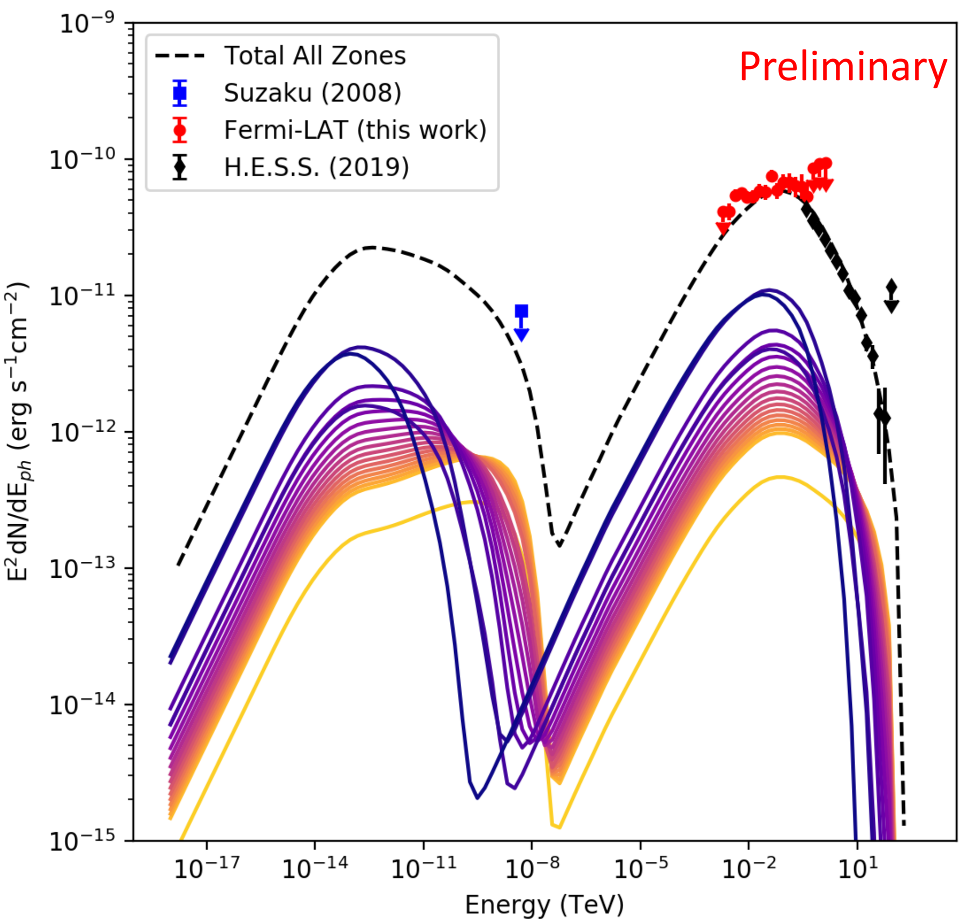
- Summation of 20 zones treated as expanding shells in space (initially spherically symmetric)
- Evolution in time until the system age is reached
- Burst like injection in each shell
- PSR characteristic age assumed to be the age of the nebula system

PSR spin-down luminosity:

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

PSR spin period:

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

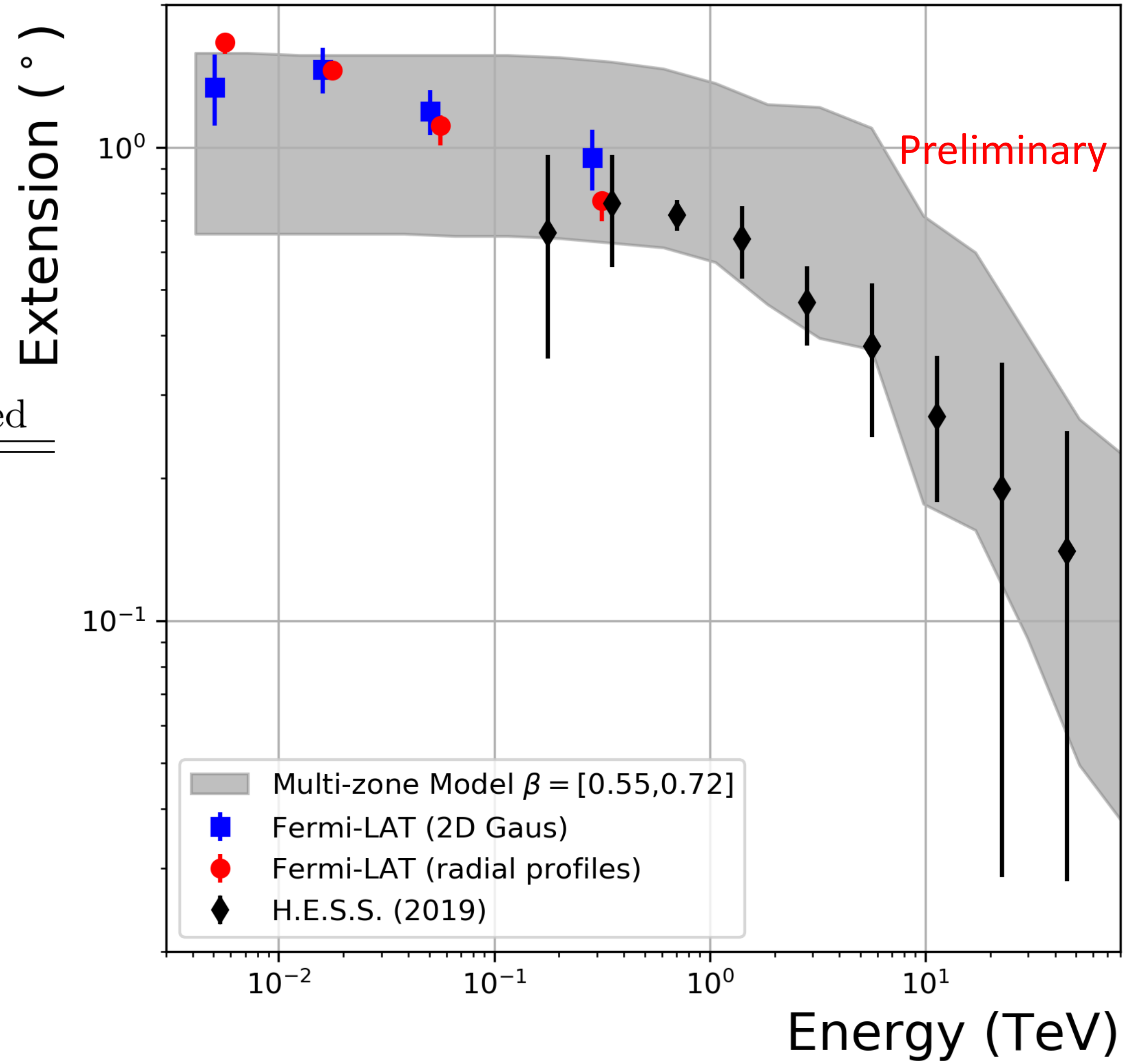


Combined spectra and extension modelling

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

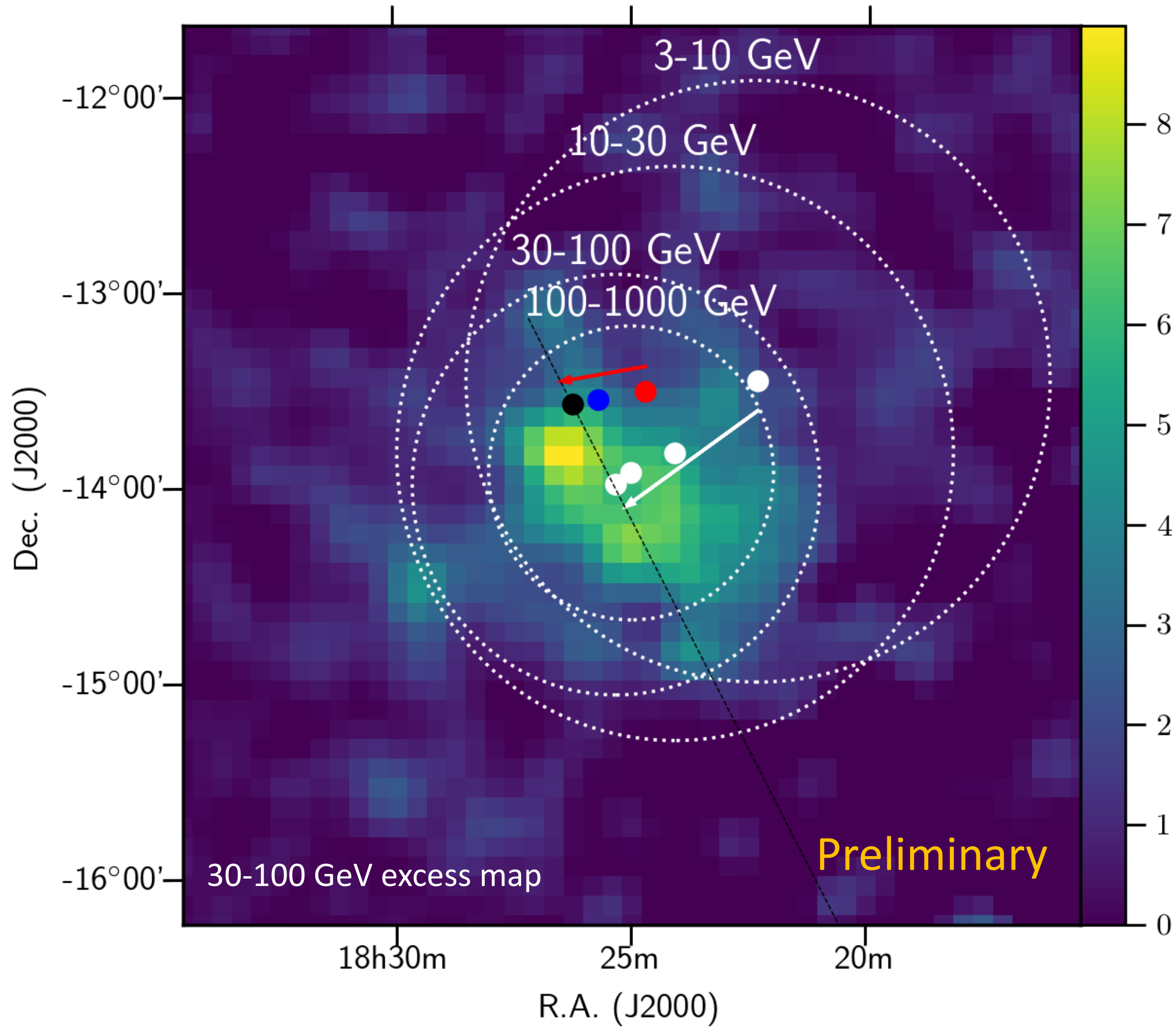
$$v(r,t) = v_0 \left(\frac{r}{r_{\max}}\right)^{\beta} \left(\frac{t}{T}\right)^{-\beta}$$

Parameter	Value	Constrained
T_c (kyr)	21	Y
$L(T)$ (erg/s)	2.8×10^{36}	Y
d (kpc)	4	Y
Γ_1	1.9	N
Γ_2	2.8	N
E_b (TeV)	0.3	N
$E_{\max}$ (TeV)	250	N
P_0 (ms)	15	N
$P(T)$ (ms)	101	Y
η	0.5	N
$B(T)$ (μG)	5	Y



PWN System evolution

The PWN-center position seems to move in the same direction as the PSR proper motion.

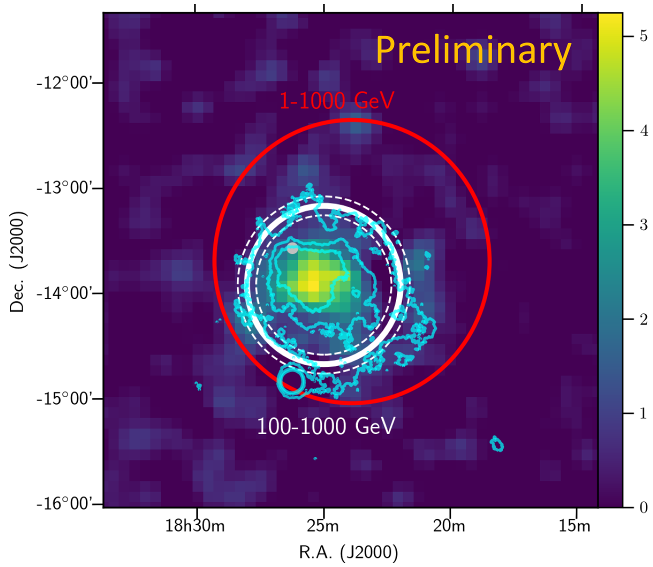


Black: PSR current pos.
Blue: est. initial PSR pos. for a characteristic age of 21 kyr
Red: est. initial PSR pos. for a characteristic age of 60 kyr

Conclusion

- We have analyzed 10 years of Fermi-LAT data between 1 GeV and 1 TeV performing a morphology and spectral analysis
- We have performed for the first time a study of the energy dependent morphology of the PWN HESS J1825-137 in the GeV regime
- We model the SED and the combined SED - morphology evolution using the NAIMA and GAMERA modelling packages.
- The paper will be submitted soon to A&A (stay tuned!)

Thank you very much for your attention!



Backup Slides

Data selection

Data Selection	Values
IRFs	P8R2_SOURCE_v6
Time Interval	10 years
Energy Range	1 GeV – 1 TeV
Energy Bins	6 per dec (only for spectra)
Zenith angle	105°
Pixel Size	0.1°
ROI dimension	15°
RA (ROI center)	276.296
DEC (ROI center)	-13.992

Comparison Fermi and H.E.S.S. extension

The **Fermipy** extension is given as the 68% containment radius (radius at which the integral of the normalized 2DGaussian is equal to 0.68):

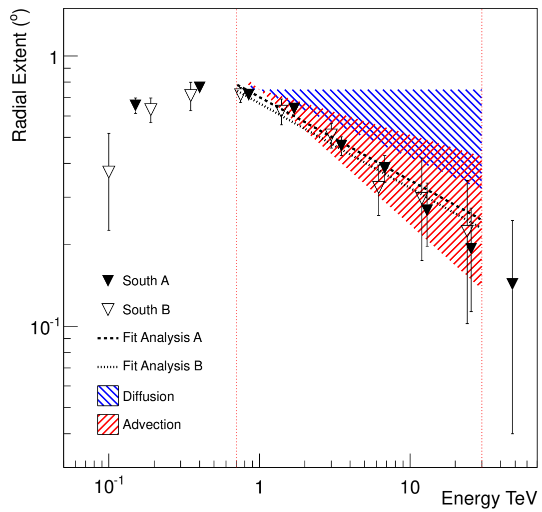
2DGaussian

$$f(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2+y^2}{2\sigma^2}}$$

68% containment radius:

$$\int_0^{R^\alpha} f(r)\, dr = \alpha \quad (\alpha = 68\% \; in \; our \; case)$$

$$\boldsymbol{R^\alpha = \sigma\sqrt{-2\log(1-\alpha)}} \;, \boldsymbol{\sigma = \frac{R^\alpha}{\sqrt{-2\,log(1-\alpha)}}}$$



H.E.S.S. extension (radial distance at which the emission drop to 1/e relative to the maximum starting from the PSR position).

Using our Gaussian approx.: $f(r) = \frac{1}{2\pi\sigma^2} e^{-\frac{r^2}{2\sigma^2}}, R^{1/e}$ so that $f(R^{1/e}) = \frac{1}{e} f_{max}$

$$\boldsymbol{R^{1/e} = \sqrt{2}\,\sigma}$$

Conversion Fermipy->HESS ext. : $\boldsymbol{R^{1/e} = \sqrt{2}\frac{R^\alpha}{\sqrt{-2\,log(1-\alpha)}}} = 0.93\boldsymbol{R^{68\%}}$ + offset?

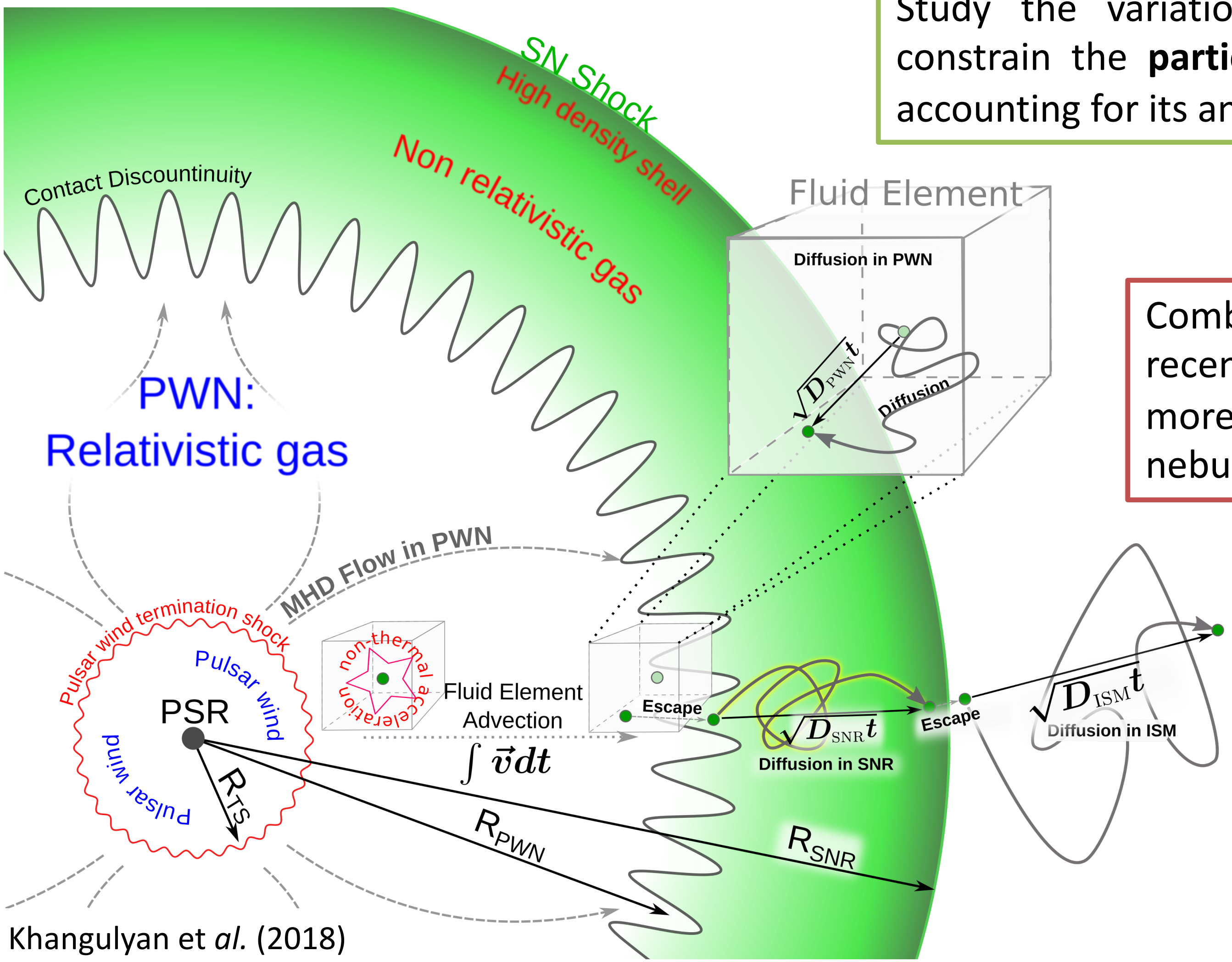
Goal of the analysis

Study the variation of PWN extension to constrain the **particle transport mechanisms** accounting for its anomalously large size.

Combining this analysis with recent H.E.S.S. results enables a more complete picture of the nebula to emerge.

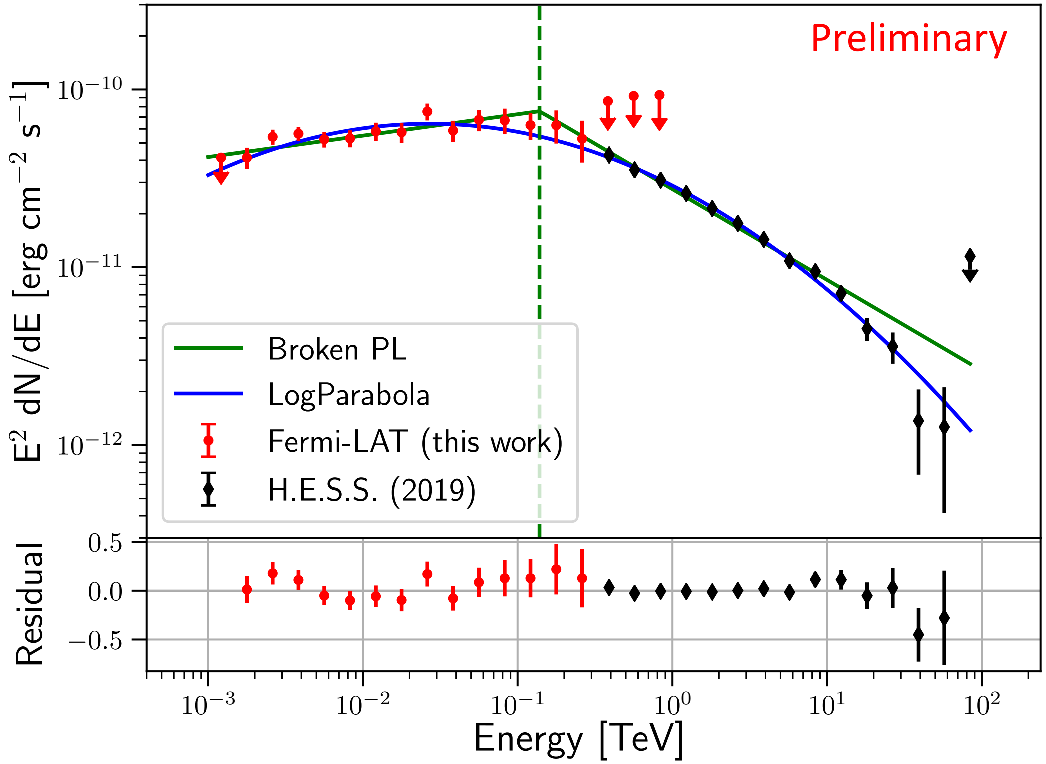
Two possible particle transport mechanisms:

- ***Advection***
- ***Diffusion***



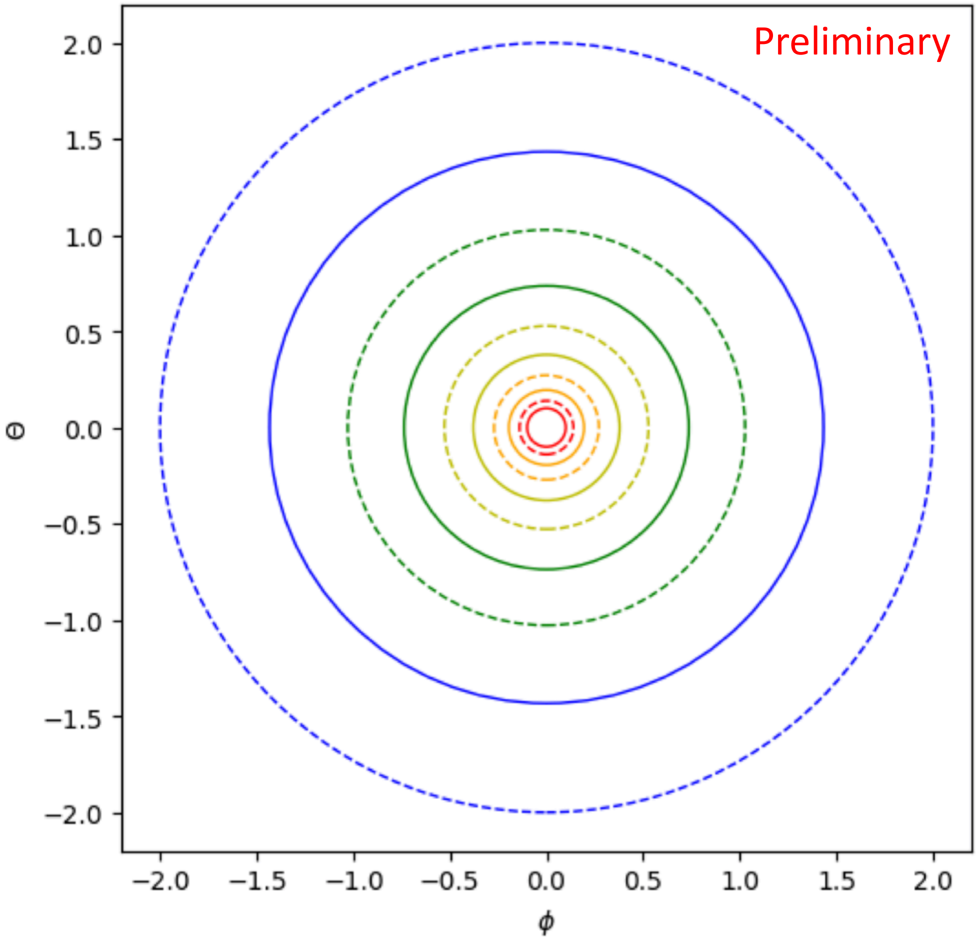
Khangulyan et *al.* (2018)

SED



We use 10 TS as threshold for the upper limits on the flux points.

LogParabola			Broken PL		
Parameter	*Fermi*	*Fermi* + H.E.S.S.	Parameter	*Fermi*	*Fermi* + H.E.S.S.
α	2.05 ± 0.18	2.13 ± 0.03	Γ_1	1.84 ± 0.04	1.88 ± 0.03
β	0.040 ± 0.013	0.061 ± 0.002	Γ_2	2.08 ± 0.06	2.51 ± 0.01
E_0 (GeV)	79 ± 18	78 ± 18	E_b (GeV)	26 ± 1	139 ± 17
N_0	6.41 ± 0.73	5.99 ± 0.21	N_0	6.79 ± 0.41	7.55 ± 0.46
χ^2/ndf	9/14	29/28	χ^2/ndf	10/14	81/28



Principe *et. al*. (in preparation)

- Form a spatial distribution of 20 zones (shells)
- 2D projection (angular space)
- Simple case: concentric logarithmically spaced shells

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