Understanding the extended gamma-ray source HESS J1841-055 with MAGIC observations

David Green

On behalf of the MAGIC collaboration

Lead contributors: Lab Saha, Alicia Lopez Oramas

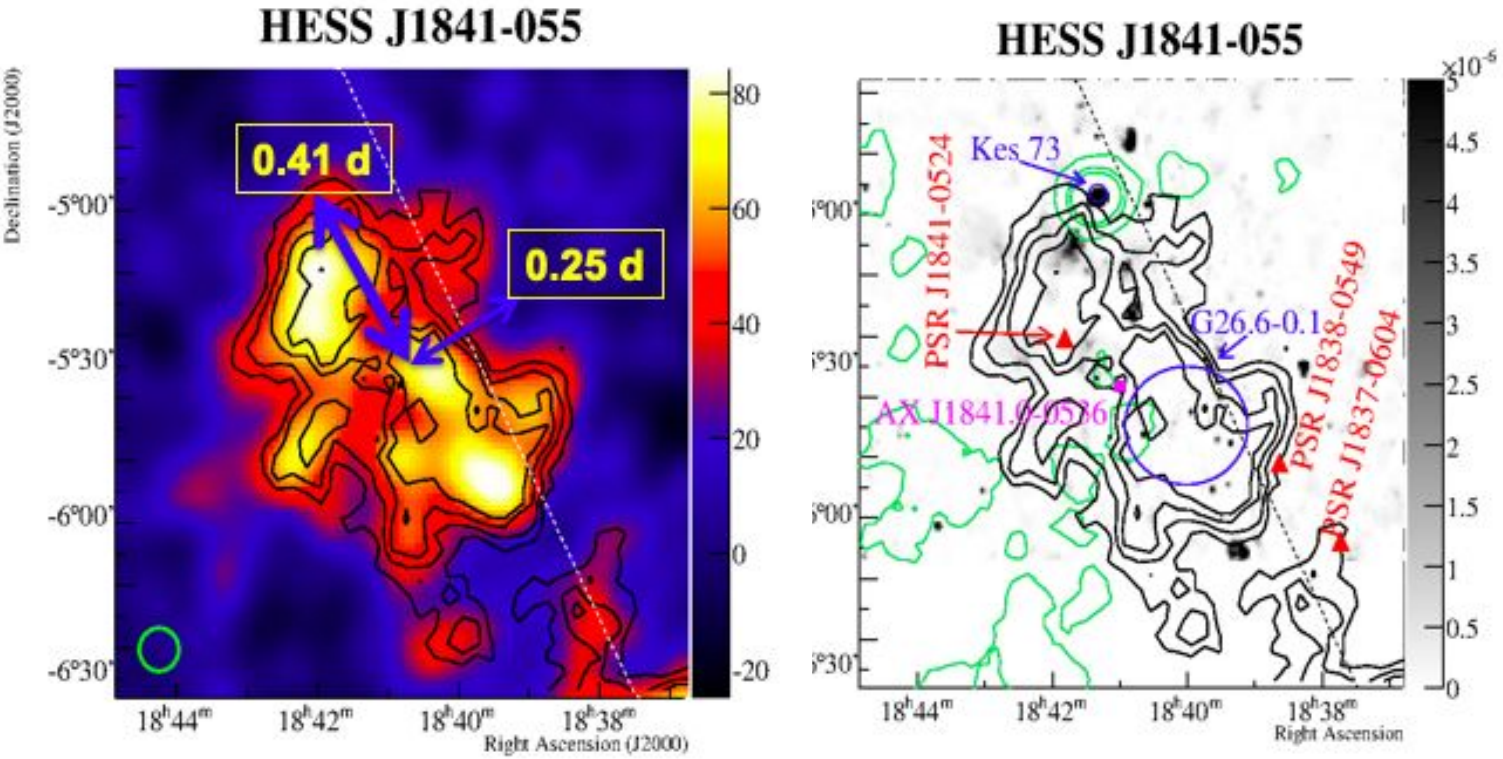
About the extended UID source: HESS J1841-055

First discovered at TeV energies in 2007 by H.E.S.S. (Aharonian et al 2006)

RA = 18h40m55s Dec = -05d55m
Obs Time = 26. h Significance ~

An elliptical extension

ARRO-YBJ, HAWC and most recent HAWC publication confirmed such extension



Several sources are present in the extended region: SNRs, Pulsars, XRB

Abeysekara et al 2016,2017; Bartoli et al. 2013, Abdalla et al 2018

Spectrum fit by a power-law index $2.4 \pm 0.1_{stat} \pm 0.2_{sys}$

Motivations

MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

- Unveiling the nature of the source
- Energy dependent morphology
- Counterparts
- Dominant emission mechanism

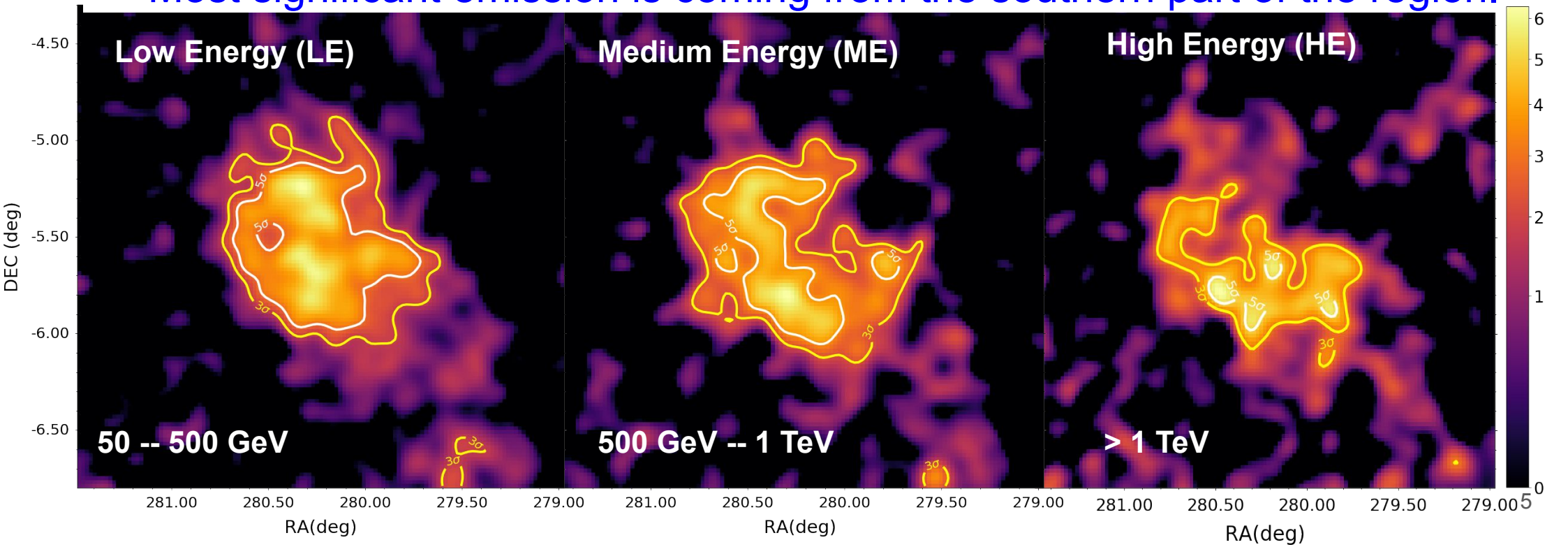
MAGIC Observations

- Observation period: April 2012 and August 2013
- Observation duration: 43 hours (before cuts)
- Observation duration: 34 hours (after cuts)
- Zenith angles: 5 -- 50 deg
- Energy threshold: 150 GeV
- Wobble offset: 0.55 deg

- **Data reduction using standard MAGIC Mars software.**
  Moralejo A., et al., 2009, Zanin R. et al., 2013
- **High level data analysis with Skyprism (a software package)** Vovk I., Strzys M., Fruck C., 2018
- **It performs 2D fitting suitable for extended sources and sources with arbitrary morphology.**

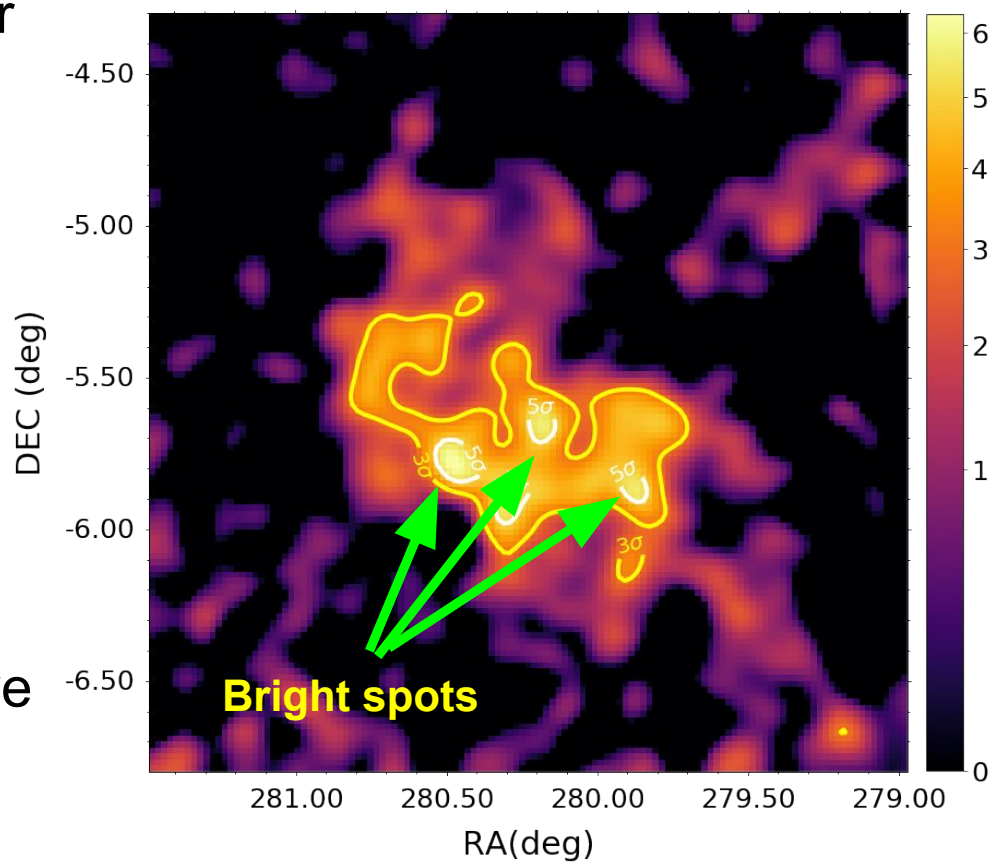
Energy dependent morphology

- A radially symmetrical 2D Gaussian shape as the model.
- Many bright spots are at **low** and **medium** energies; disappear at **high** energies.
- Most significant emission is coming from the southern part of the region.



Energy dependent morphology

- 2D gaussian model for likelihood method for extension
- The extension of the source at LE, ME, HE appears to be the same (~0.4 deg).
- The overall detection significance of the extended emission reduces at higher energies.
- The major contribution of gamma rays above 1 TeV arises from the southern part of the source



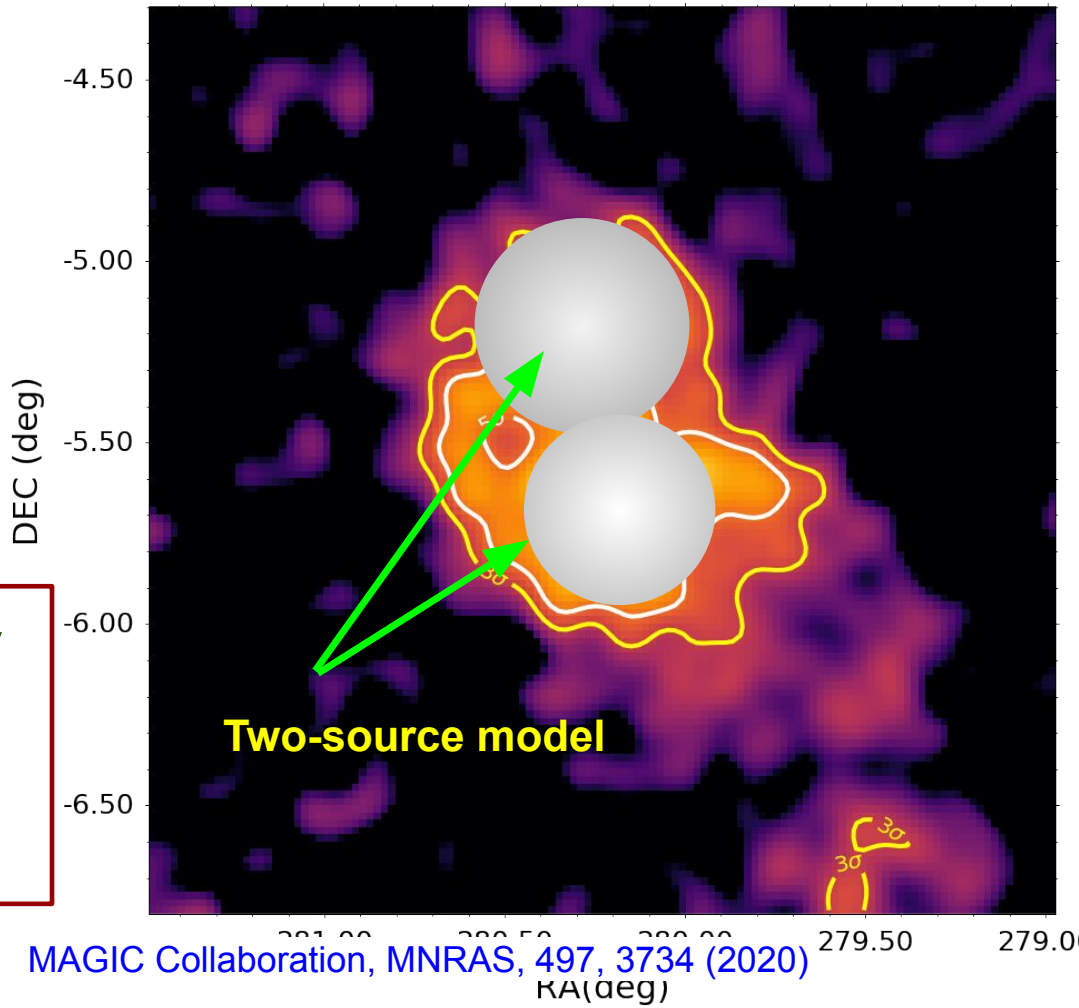
MAGIC Collaboration, MNRAS, 497, 3734 (2020)

Energy dependent morphology

Multi-source model

- 2D Gaussian, Disk templates are used to model the extended emission.
- More than one sources are used for likelihood fitting

Extended emission is best described by **more than one-source model**, i.e. either by a two-source or three-source model.

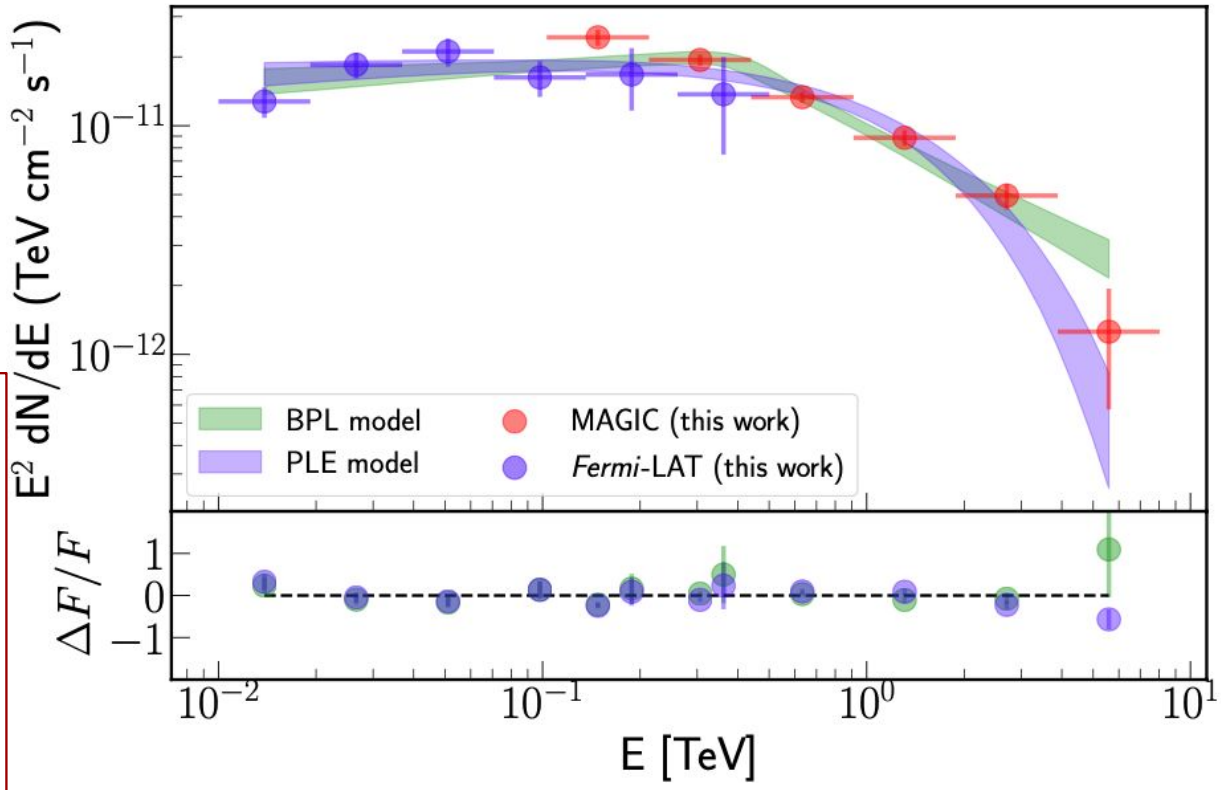


MAGIC Collaboration, MNRAS, 497, 3734 (2020)

Spectral energy distribution

MAGIC data: Energy range: **10 GeV -- 1 TeV**

SED points are extracted using best-fit one-source model obtained with morphological studies



Best-fit PL model parameters:

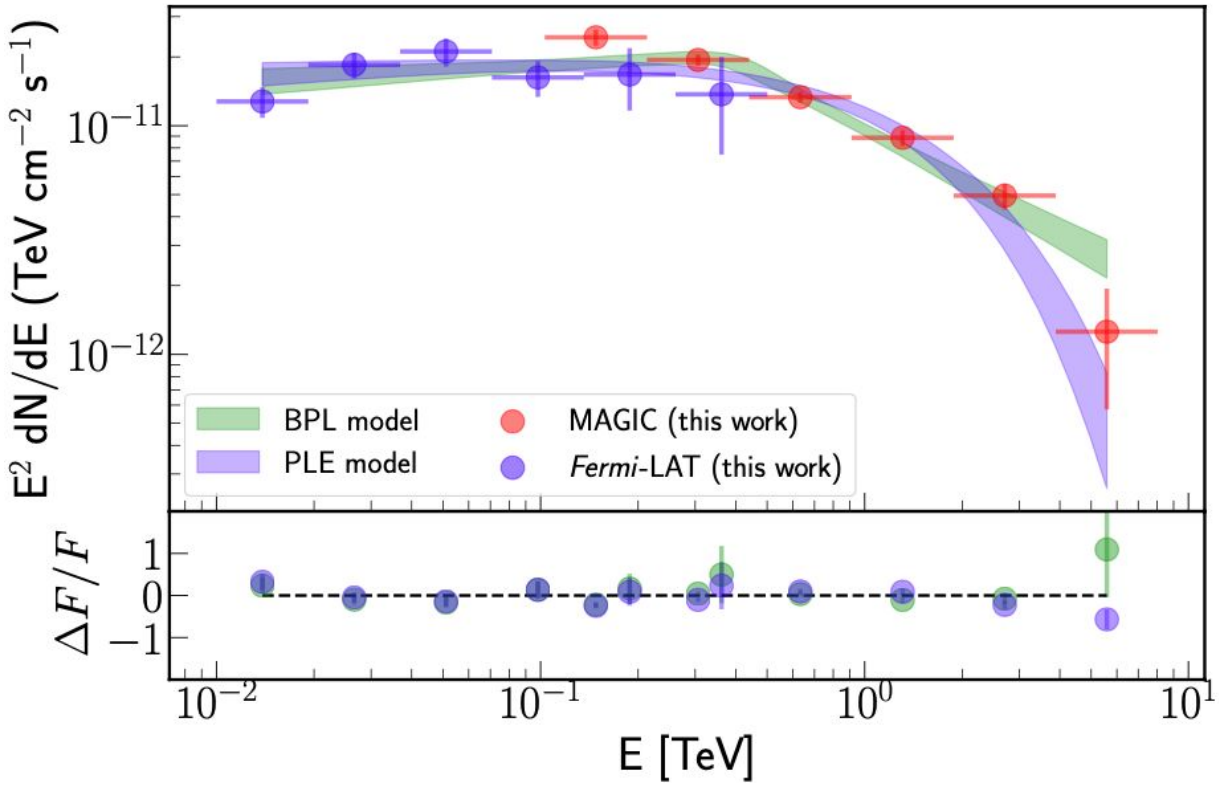
N0 = (1.71 ± 0.41) x 10^{-14} MeV^{-1} cm^{-2} s^{-1}
α = 2.30 ± 0.03
F(>10 GeV) = (1.2 ± 0.1)x 10^{-8} photons cm^{-2} s^{-1}

Spectral energy distribution

Joint likelihood fit of MAGIC and Fermi-LAT data

Both broken powerlaw (BPL) and powerlaw with exponential cutoff (PLE) models explain the data compared to a powerlaw (PL) model

A significant curvature is present in the combined observed spectrum of MAGIC and Fermi-LAT.



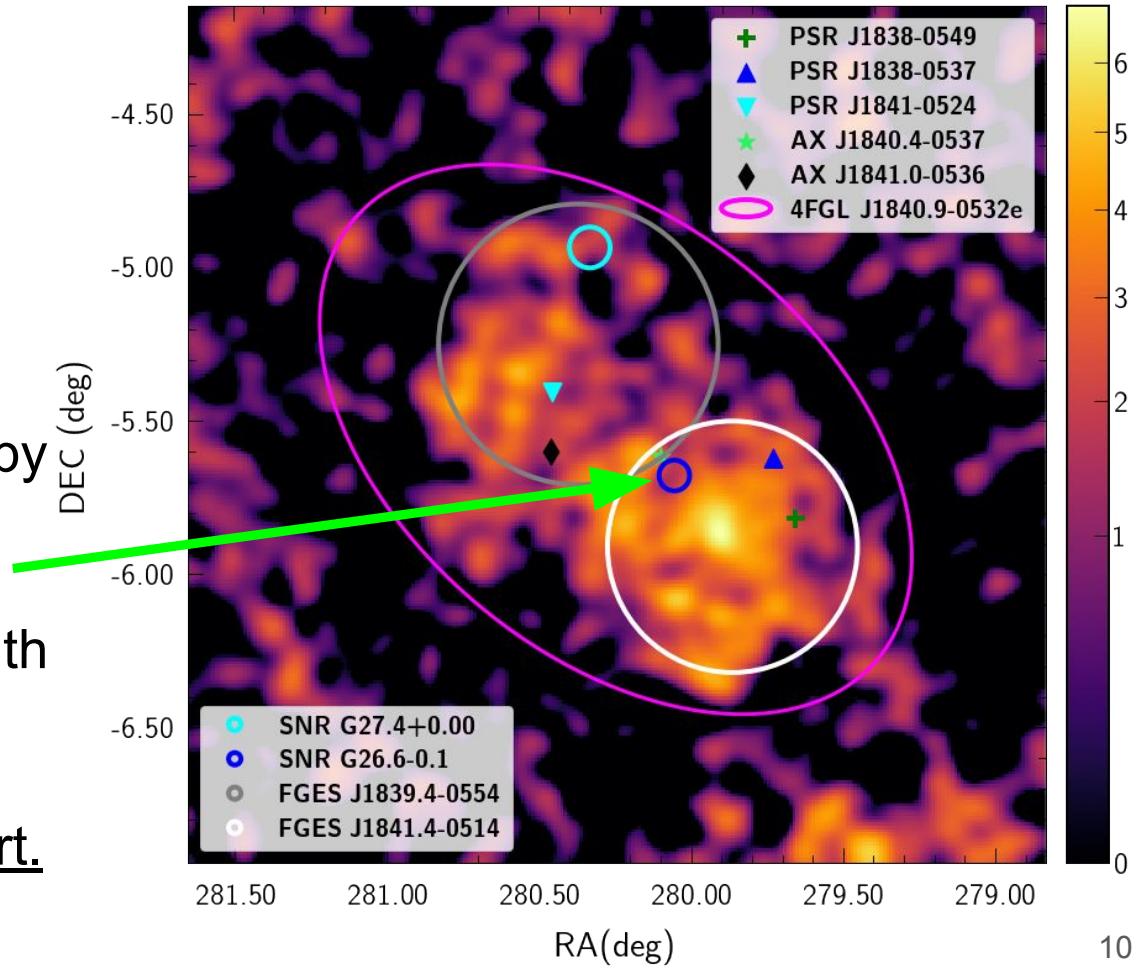
Potential counterparts

Several point-like sources in the FoV

Some are likely to contribute to the VHE emission.

G26.6 - 0.1

- Diffuse hard X-ray source; detected by ASCA (Bamba et al. 2003).
- Featureless X-ray spectrum; fitted with a PL spectrum with index 1.3
- Considered as a potential counterpart.



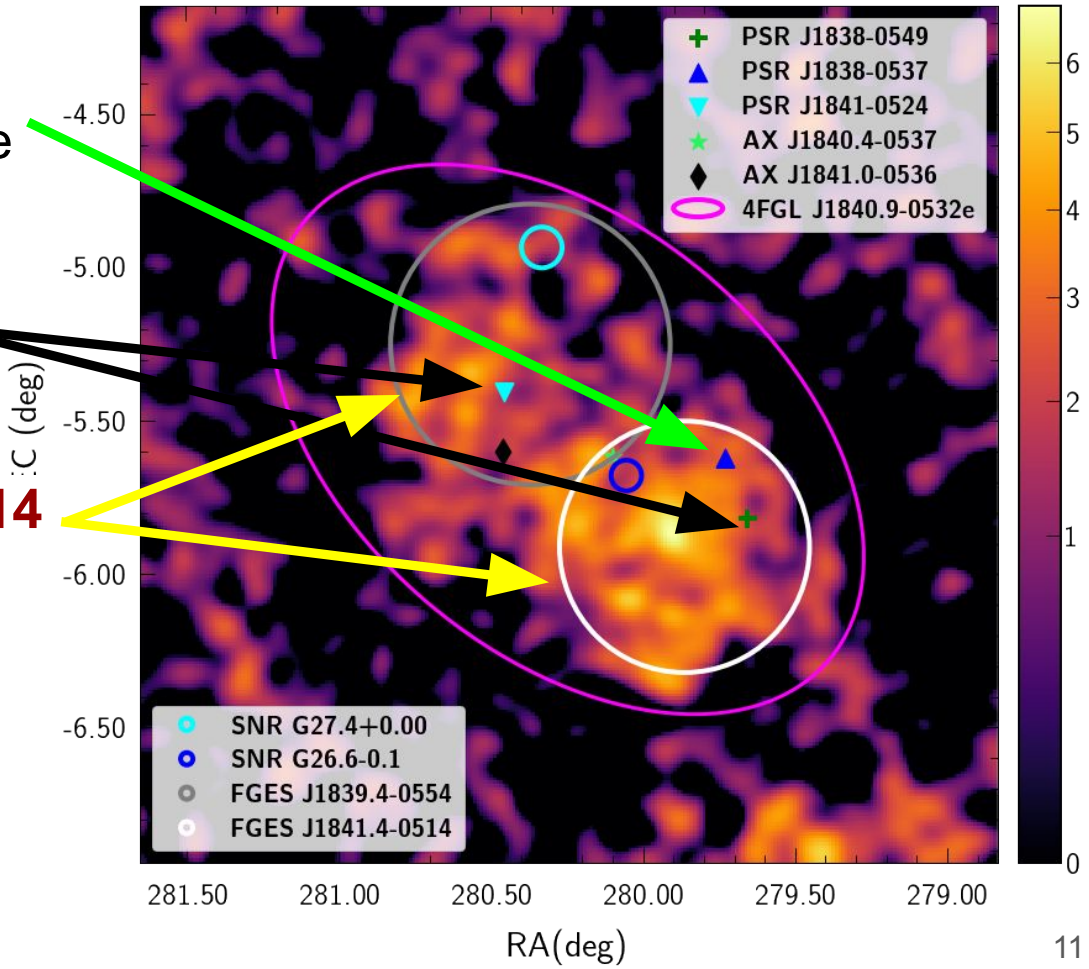
Potential counterparts

PSR J1838–0537
The pulsar's energetic (10^{36} erg/s) is likely to power a PWN producing part of the TeV emission.

PSR J1841-0524 and PSR J1838-0549
Energetically not efficient (10^{33} erg/s).

FGES J1839.4-0554 & FGES J1841.4-0514

- Two Fermi-LAT extended sources.
- GeV emission is overlapping with the extension found at TeV energies.
- <u>Considered as potential counterparts</u>



Potential counterparts

G27.4+0.00 (Kes 73)

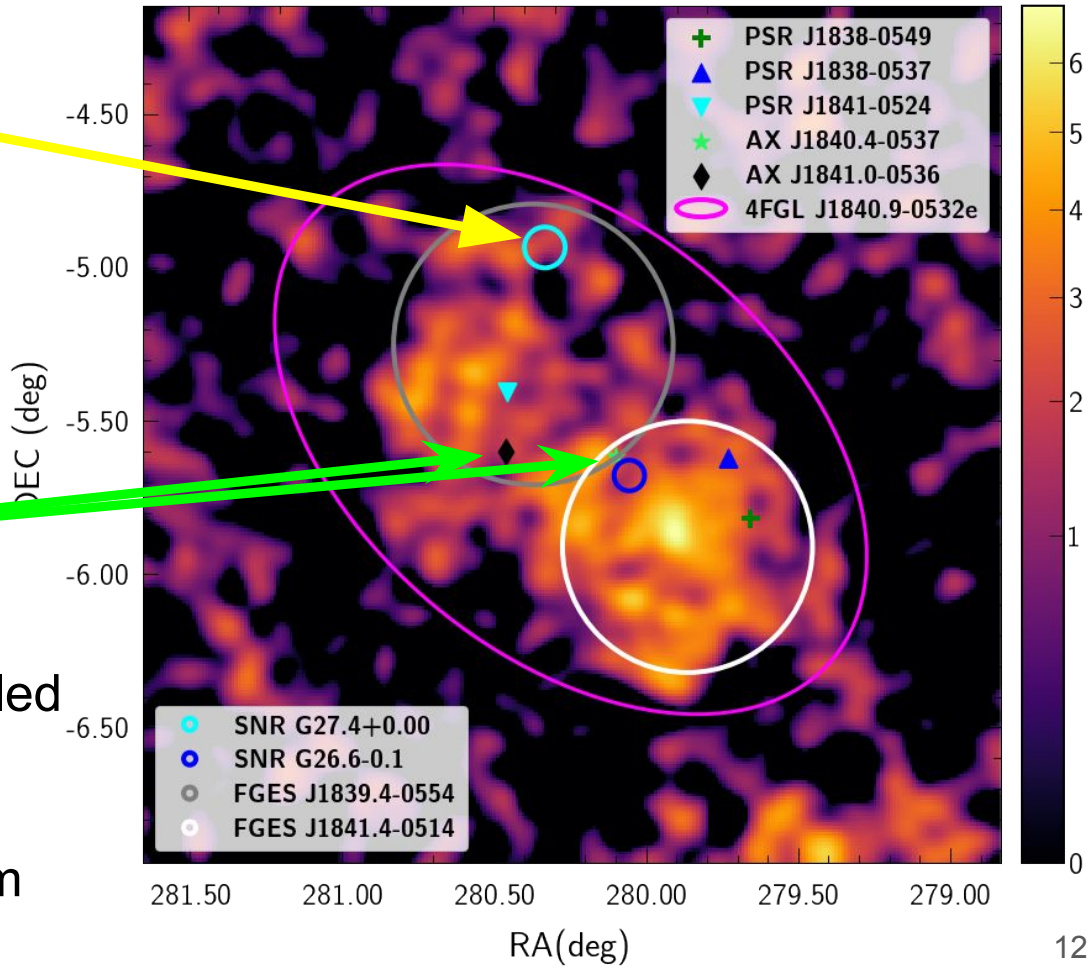
unlikely counterpart due to

- the very small angular size of 5′ in radio
- its location on the edge of the extended emission

AX J1840.4–0537 & AX J1841.4–0536

unlikely counterparts due to

- Observed X-ray fluxes are well below scaled X-ray flux of other X-ray source.
- Also no X-ray nebula associated with them is found.

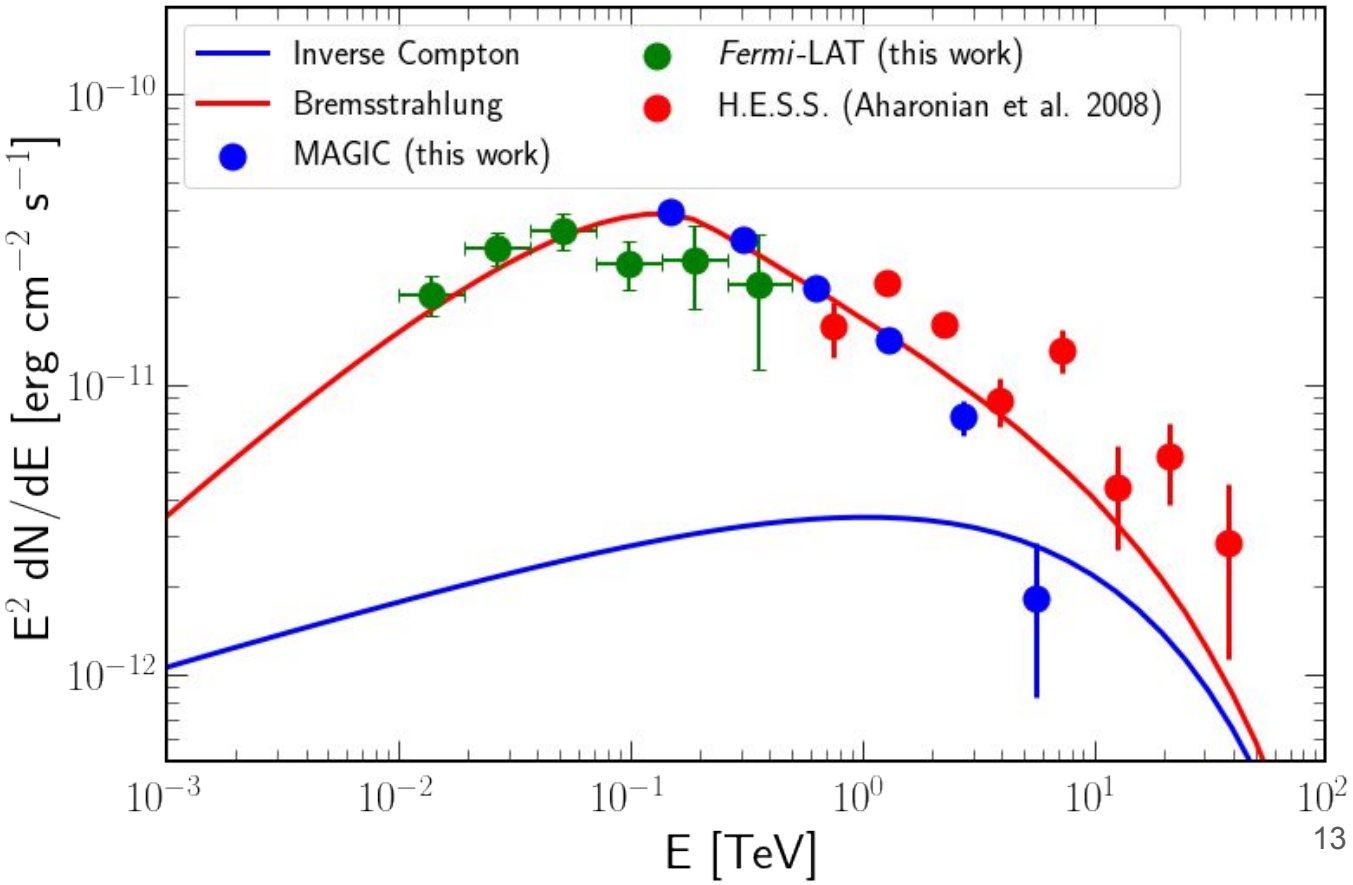


Spectral modelling: Leptonic

Best described by BPL type input spectrum

MAGIC Collaboration, MNRAS, 497, 3734 (2020)

Parameters	Leptonic
Spectral index (α_1)	$1.06^{+0.10}_{-0.05}$
Spectral index (α_2)	$2.52^{+0.06}_{-0.05}$
Energy at spectral break, E_b (TeV)	$0.18^{+0.03}_{-0.02}$
Ambient matter density, n_0 (cm^{-3})	100
Total energy (10^{48} erg)	$5.82^{+0.11}_{-0.19}$

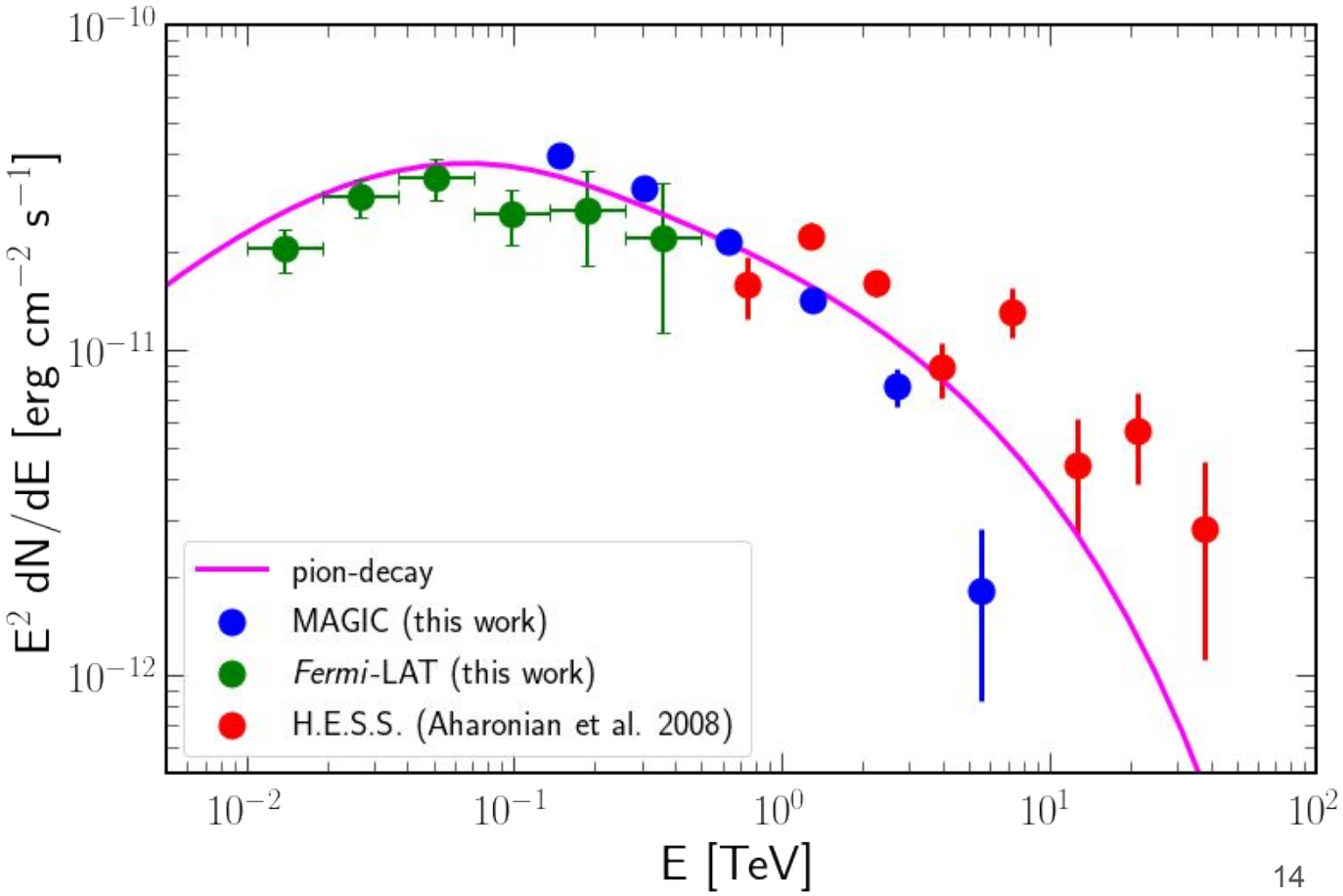


Spectral modelling: hadronic

Similar spectrum of BPL as used for leptonic model

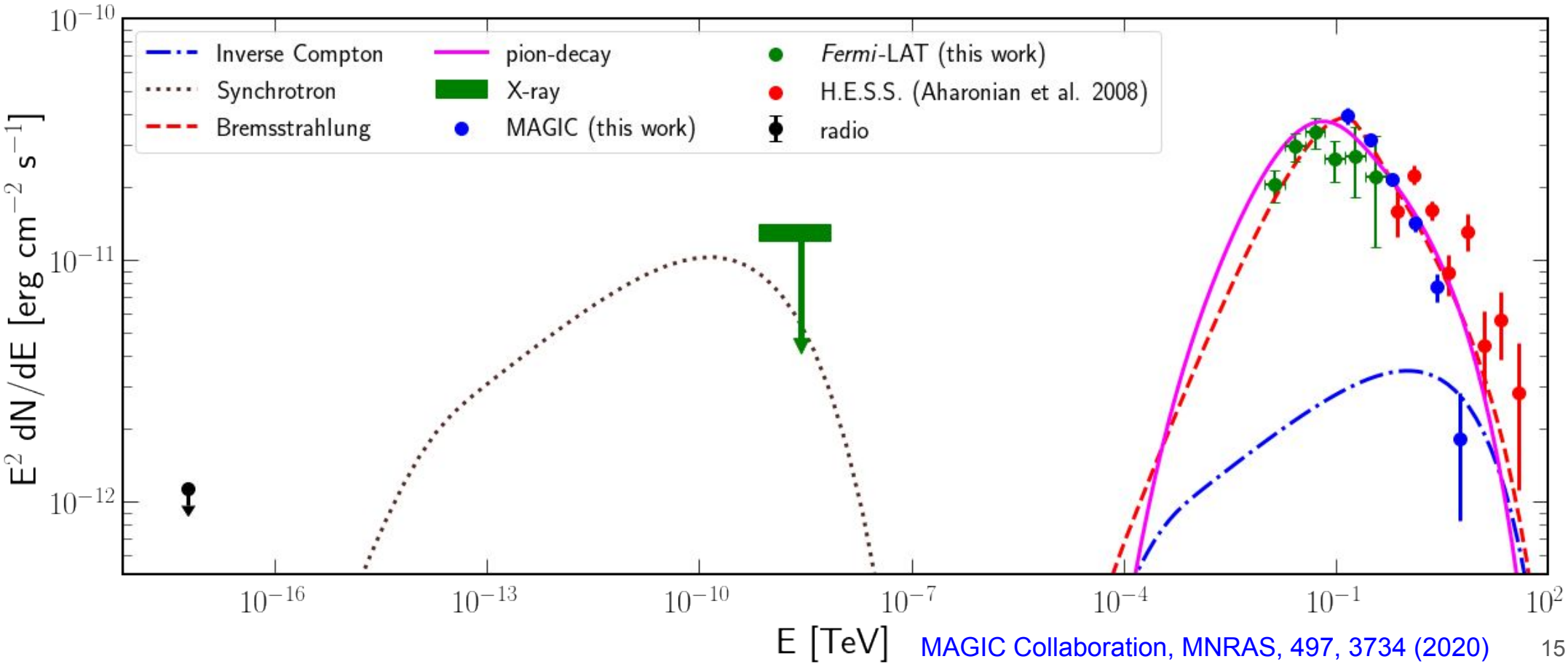
MAGIC Collaboration, MNRAS, 497, 3734 (2020)

Parameters	Hadronic
Spectral index (α_1)	$1.18^{+0.13}_{-0.11}$
Spectral index (α_2)	$2.02^{+0.05}_{-0.05}$
Energy at spectral break, E_b (TeV)	$0.22^{+0.07}_{-0.04}$
Ambient matter density, n_0 (cm^{-3})	100
Total energy (10^{48} erg)	$5.52^{+0.12}_{-0.13}$



Multiwaveband modelling

MWL is performed considering one source is responsible for the extended emission.

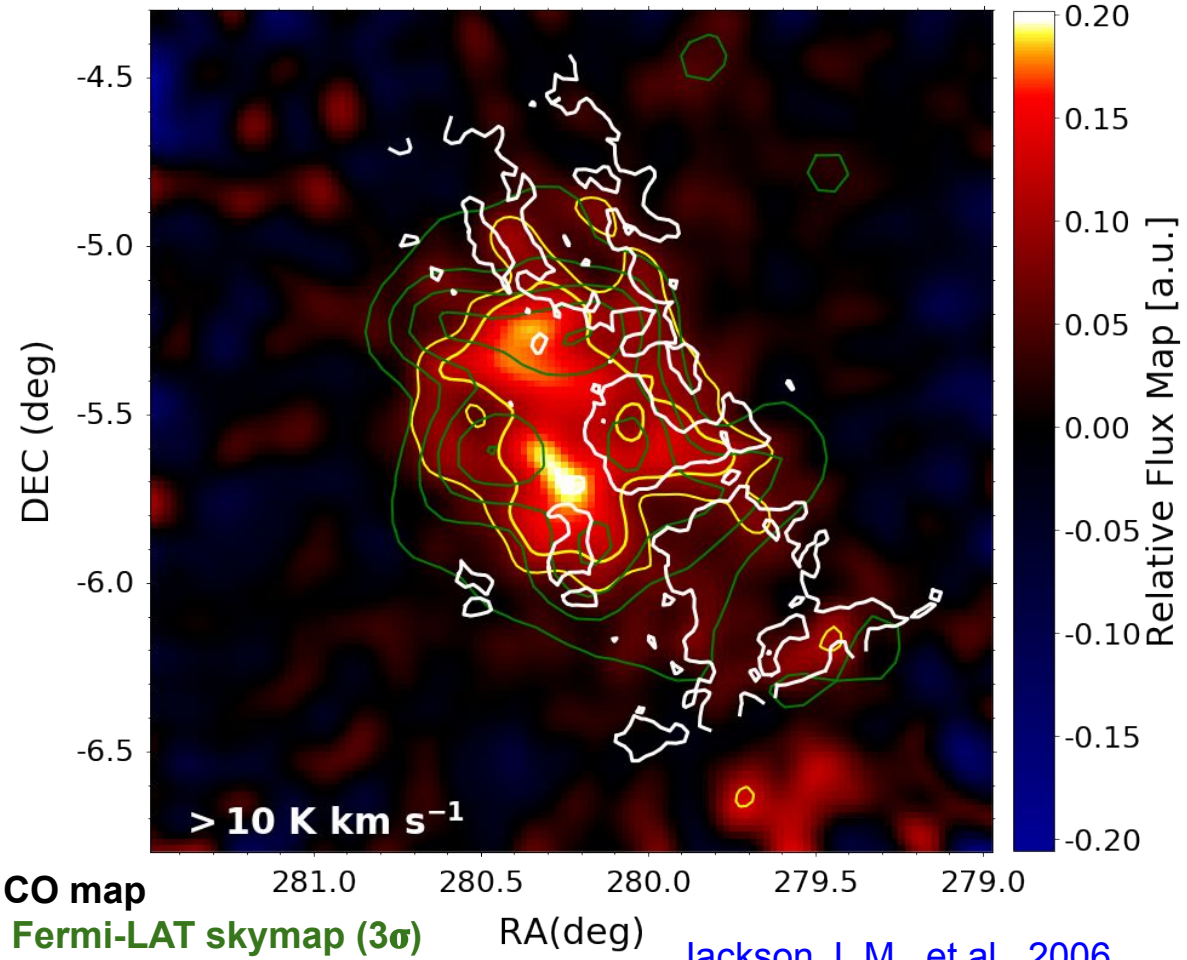


MAGIC Collaboration, MNRAS, 497, 3734 (2020)

Molecular environment

Molecular cloud along the extension of the source.

It supports the relatively high ambient matter density required for both leptonic and hadronic model.



White contours: **CO map**
Green contours: **Fermi-LAT skymap (3σ)**
Yellow contours: **MAGIC skymap (3σ)**

Jackson J. M., et al., 2006

Nature of HESS J1841-055

SNR scenario

- G26.6-0.1, a potential counterpart for the extended emission.
- No strong radio and X-ray nebulae associated with the extent of the emission which is the case for a typical SNR Scenario.
- One possibility: the particles that escaped the SNR shocks and are interacting with the molecular clouds.
- Diffusion timescale & the age of the SNR G26.6-0.1 as a middle-age SNR (~10^3 years; Bamba et al. 2003) may indicate it a possible candidate for at least part of the detected GeV-TeV emission.

Less likely scenario ★★☆☆☆

Nature of HESS J1841-055

MAGIC
Major Atmospheric
Gamma Imaging
Cerenkov Telescopes

PWN scenario

- Energetically the pulsar PSR J1838-0537 can account for the observed GeV–TeV energies
- No radio or X-ray nebula around PSR J1838-0537, might be an isolated pulsar
- TeV emission is an effective product of the IC mechanism for such isolated pulsars, with the injection of relativistic electrons in the interstellar B field of about 3 μG. In such a scenario, the bright X-ray and radio synchrotron nebula could be absent
- Molecular cloud along the observed GeV–TeV emission can support its extension but through bremsstrahlung processes
- With extension of 0.4 deg and n ~100/cm^3, Tdiff = 17 kyr and Tbrems = 400 kyr. It implies that the dominant emission through bremsstrahlung process is a viable solution for the observed extension of the source

A feasible scenario

Summary

- The detailed analysis show that the observed gamma-ray emission from HESS J1841-055 is significantly extended
- Several bright hot-spots are in the extension of the source which appears to be multiple sources contributing to the observed emission
- The extended emission is modelled better with a multi-source model
- The significant spectral curvature of the SED in the energy range from GeV--TeV can either be described by a BPL model or a PLE model
- The observed SED can be explained well with both a leptonic (bremsstrahlung) and a hadronic model for the density of ambient matter of 100/cm^3 assuming a BPL distribution of electrons and protons, respectively

Summary

- The detailed analysis show that the observed gamma-ray emission from HESS J1841-055 is significantly extended.

- Severa[illegible] ears to be mult[illegible]

- The e[illegible]

- The sig[illegible] om GeV--TeV can either be described by a BPL model or a PLE model.

- The observed SED can be explained well with both a leptonic (bremsstrahlung) and a hadronic model for the density of ambient matter of 100/cm^3 assuming a BPL distribution of electrons and protons, respectively.

Similar methodology can unveil the nature of several UID sources observed by both ground and space based gamma-ray telescopes