# The $\gamma$-ray binaries as a primary scientific target for the ASTRI Mini-Array

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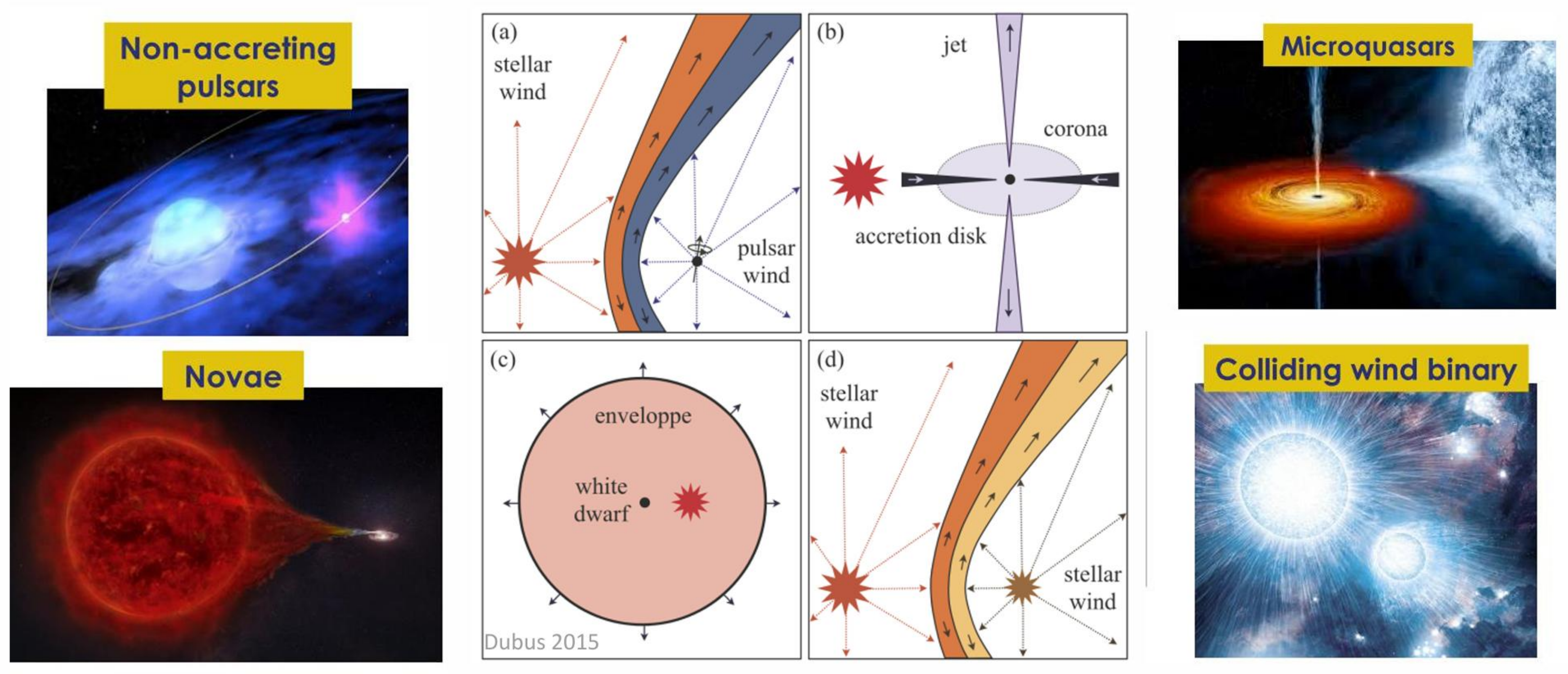
for the ASTRI Project

From 9 to 40: the SST Telescopes and Gamma-Ray Science with ASTRI and CTAO

# γ-ray binaries with ASTRI Mini-Array

## Binary VHE sources – 1




From: VHE overview of gamma-loud binaries, Alicia López Oramas (Gamma 2024)

# γ-ray binaries with ASTRI Mini-Array

## Binary VHE sources – 2

### γ-ray loud binaries

| Name | Star spectral type | Pspin | Porb (days) | Lat (°) | ZA (°) |
|---|---|---|---|---|---|
| **PSR B1259-63** | O9.5 Ve | 48 ms | 1236.72 | -63.8 | 92.1 |
| **PSR J2032+4127** | B0 Ve | 143 ms | ~ 50 years | 41.5 | 13.2 |
| **LS I +61°303** | B0 Ve | 270 ms | 26.49 | 61.2 | 32.9 |
| **LS 5039** | O6.5 V | 8.96 s (?) | 3.91 | -14.8 | 43.1 |
| **HESS J0632+057** | B0 Ve | - | 315.5 | 5.8 | 22.5 |
| **1FGL J1018.6-5856** | O6 V | - | 16.58 | -58.9 | 87.2 |
| **LMC P-3** | O5 III | - | 10.2 | -67.6 | 95.9 |
| **HESS J1832-093** | O6 V | - | 86.3 | -9.4 | 37.7 |

# γ-ray binaries with ASTRI Mini-Array

## Binary VHE sources – 3

### μQSOs

| Name | Star spectral type | Companion object | Porb (days) | Lat (°) | ZA (°) |
|---|---|---|---|---|---|
| **SS433** | A | BH | 13.08 | 5.0 | 23.3 |
| **V4641 Sgr** | B9 III | BH | 2.8 | -25.4 | 53.7 |
| **GRS 1915+105** | - | BH | 26.49 | 10.9 | 17.4 |
| **MAXI J1820+070** | - | BH | 3.91 | 7.2 | 21.1 |
| **Cyg X-1** | O9.7 I | BH | 315.5 | 35.2 | 6.9 |
| **Cyg X-3** | WN4-6 | ? | 0.2 | 41.0 | 12.7 |

### Colliding Wind Binaries

| | | | | | |
|---|---|---|---|---|---|
| **Eta Carinae** | LBV | O/B star | 5.5 years | -59.7 | 88 |

### Novae

| | | | | | |
|---|---|---|---|---|---|
| **RS Oph** | RG | WD | 454 | -6.7 | 35 |

Mini-Array

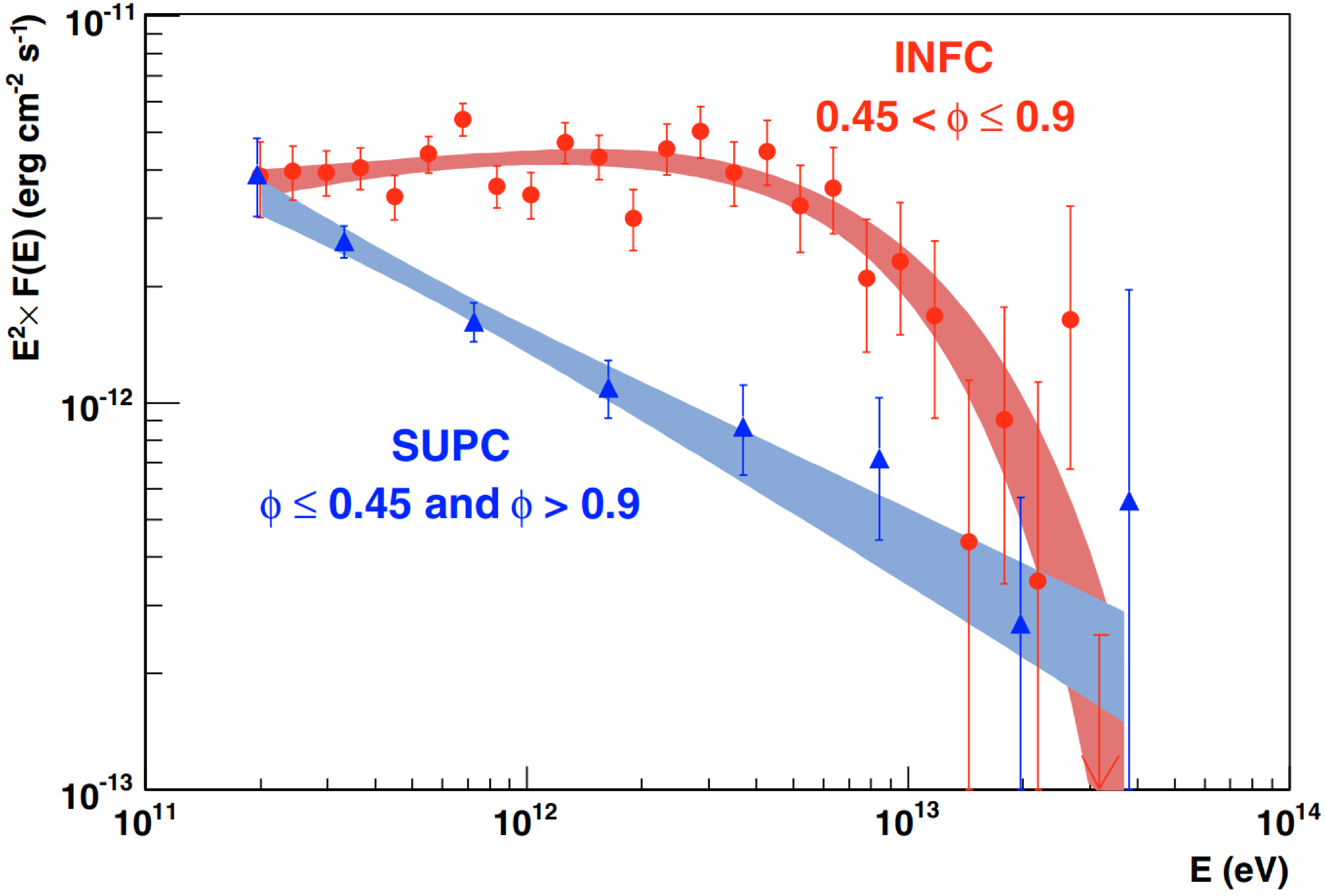
# LS 5039: main results

| Parameter | HESS | HAWC | LHAASO |
|---|---|---|---|
| Detection | > 40 σ | 11 σ | 4.1 σ (WCDA),<br>7.0 σ (KM2A) |
| Energy range (TeV) | 0.2-30 | 2-200 | 4-100 |
| Flux variability | YES | YES | NO |
| Spectral variability | YES | YES | NO |
| Spectrum | PL @ SC,<br>CPL @ IC | PL | PL |

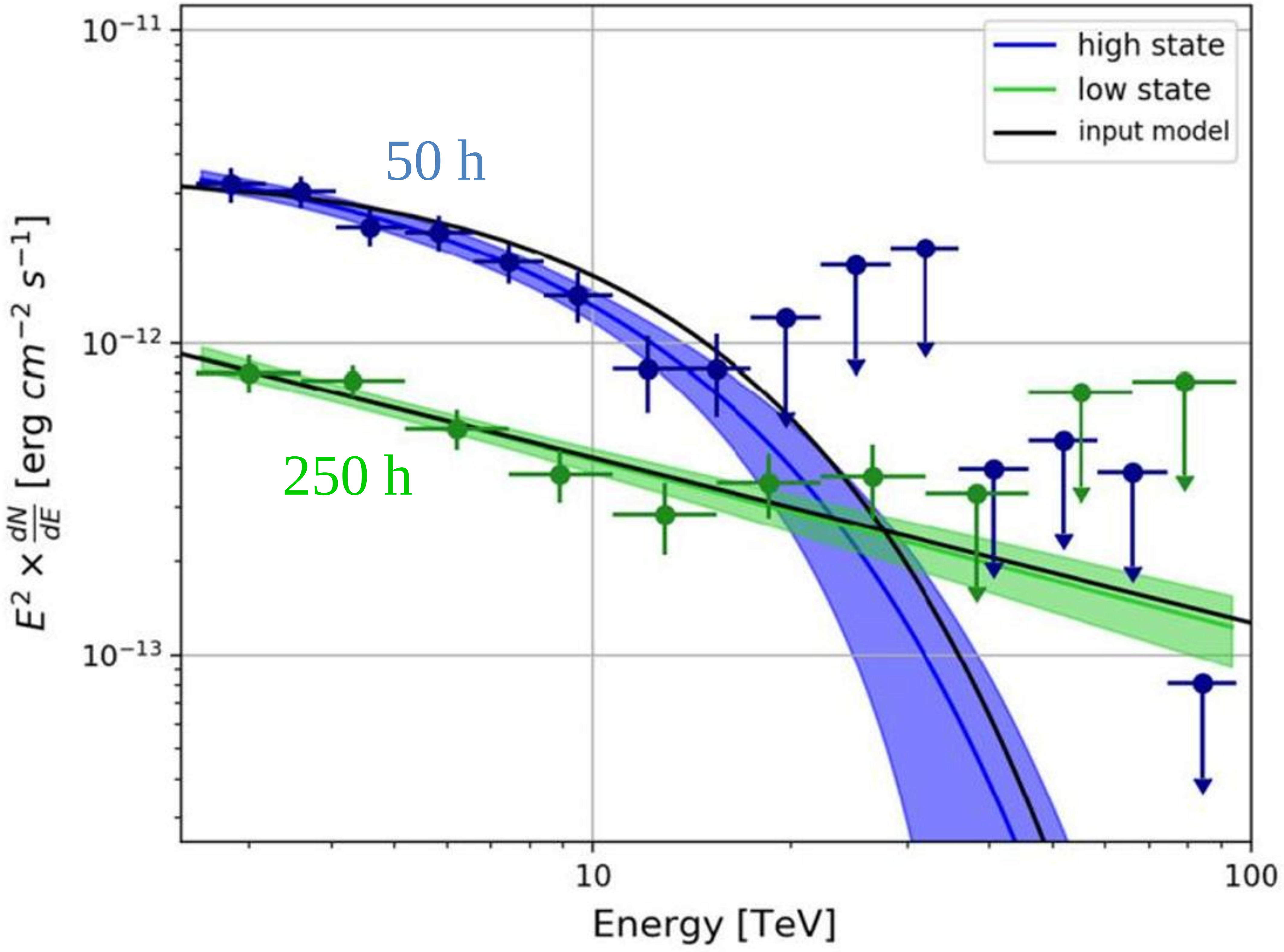
# LS 5039: analysis of the 2 spectral states

**Source visibility** (in moonless conditions): **130** h (ZA = 0-45°), **280** h (ZA = 45-60°)

HESS (Aharonian et al. 2006, A&A 460, 743)




ASTRI simulation (D'Aì et al. 2022, JHEAp 35)

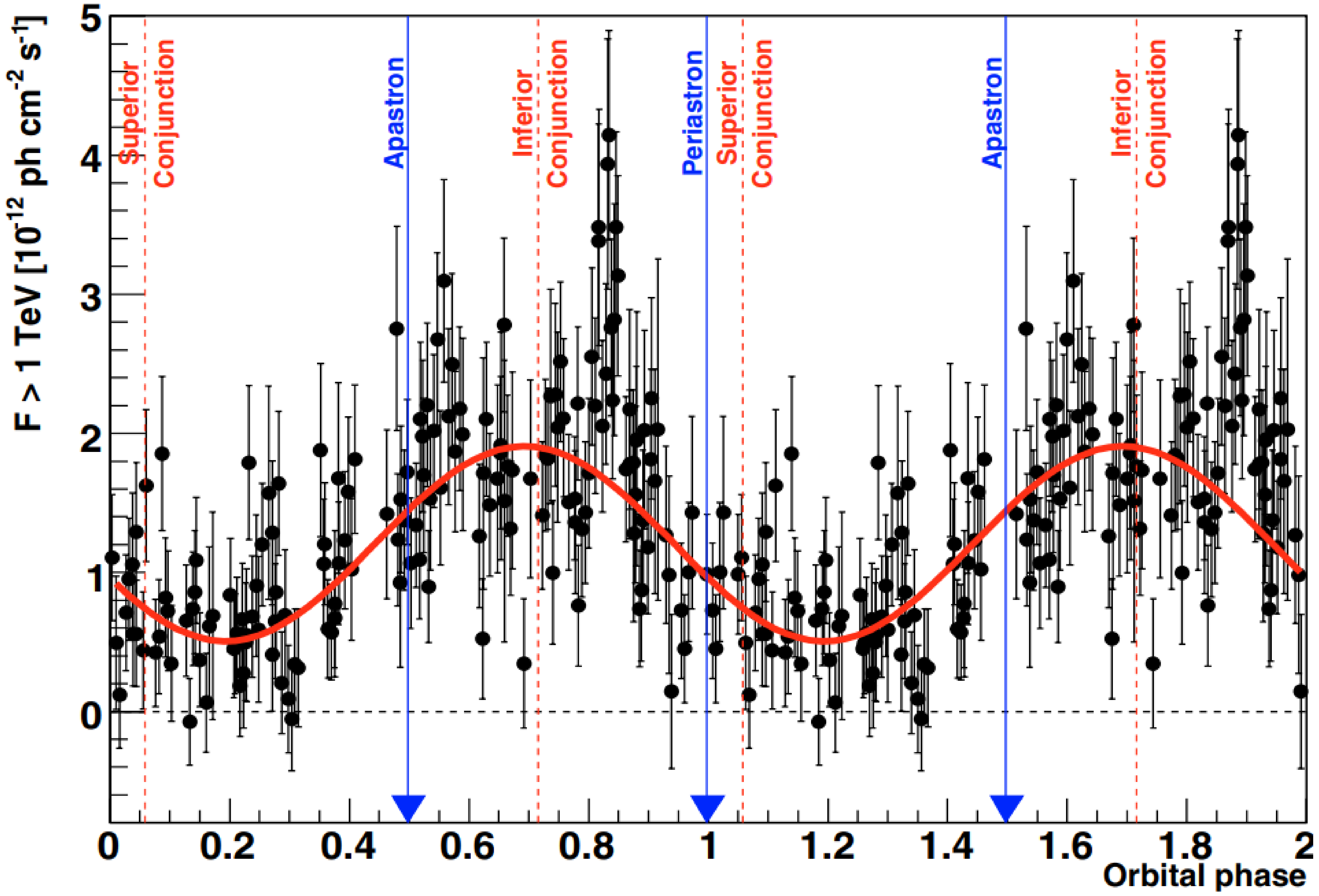


# γ-ray loud binaries

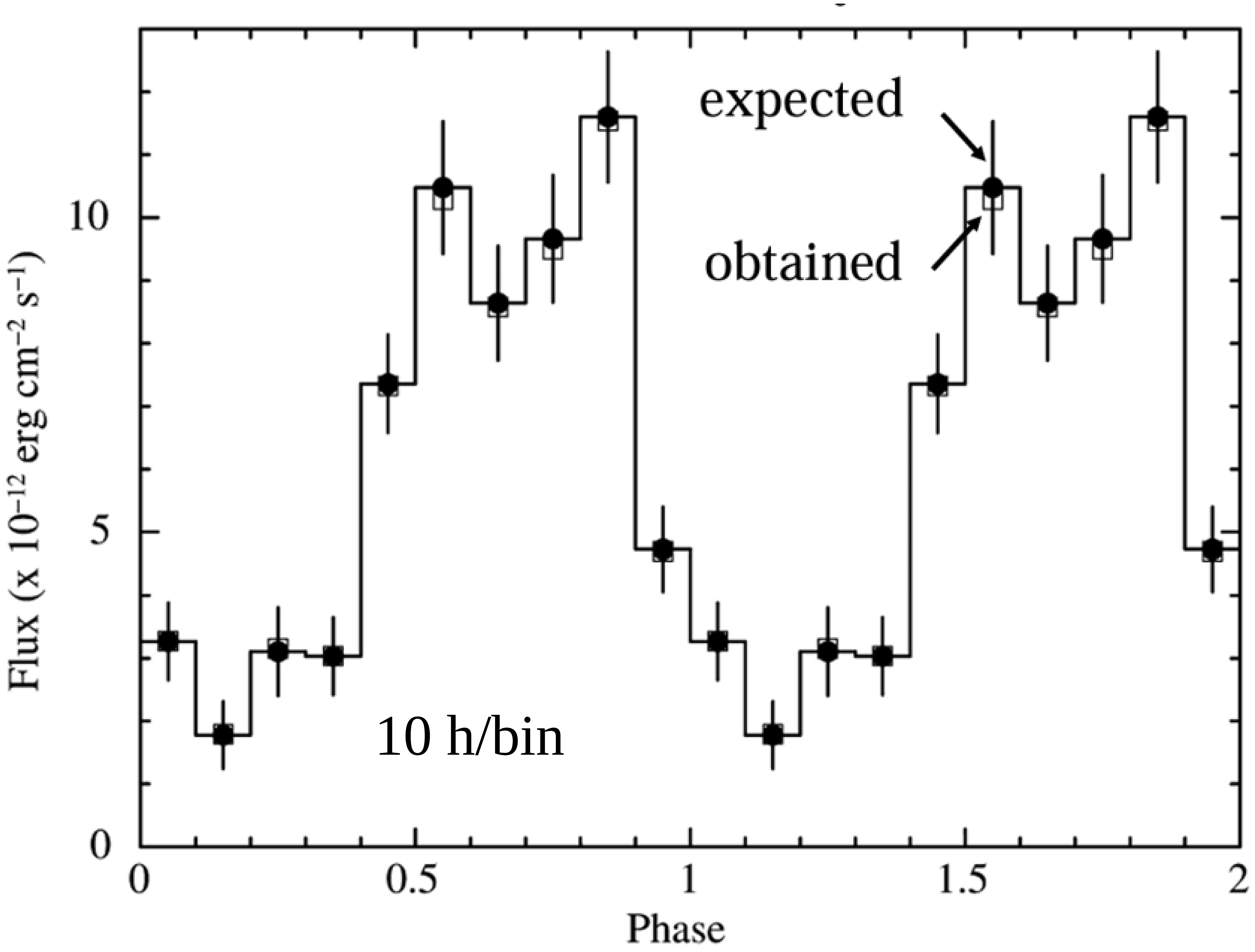
## LS 5039: analysis of the orbital modulation

**Source visibility** (in moonless conditions): **130** h (ZA = 0-45°), **280** h (ZA = 45-60°)

HESS (Aharonian et al. 2006, A&A 460, 743)




ASTRI simulation (D'Aì et al. 2022, JHEAp 35)



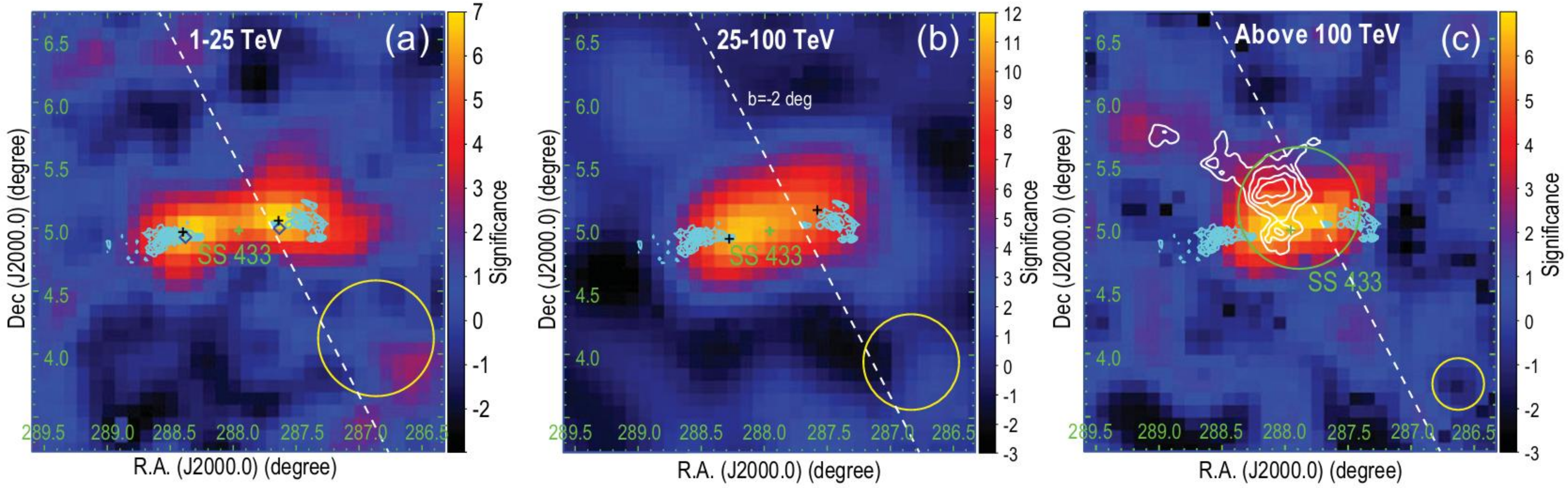
# SS433: main results

| Parameter | HESS | VERITAS | HAWC | LHAASO |
|---|---|---|---|---|
| Detection | 7.8 σ (E)<br>6.8 σ (W) | 5.5 σ (E)<br>6.1 σ (W) | 8.2 σ (E)<br>6.6 σ (W) | 9.9 σ (E)<br>6.3 σ (W)<br>8.0 σ (C) |
| Energy range (TeV) | 1-50 | 0.8-25 | 5-56 (E)<br>4-123 (W) | 25-100 (E, W)<br>100-630 (C) |
| Morphology | extended | extended | pointlike | pointlike (E, W)<br>extended (C) |
| E-dependent morphology | YES | NO | YES | YES |
| Spectrum | PL | PL | PL | PL |
| Emission origin | leptonic | leptonic | leptonic | leptonic (E, W)<br>hadronic (C) |

# µQSOs

## SS433: LHAASO results

(LHAASO Collaboration, 2025, NSR, 496)



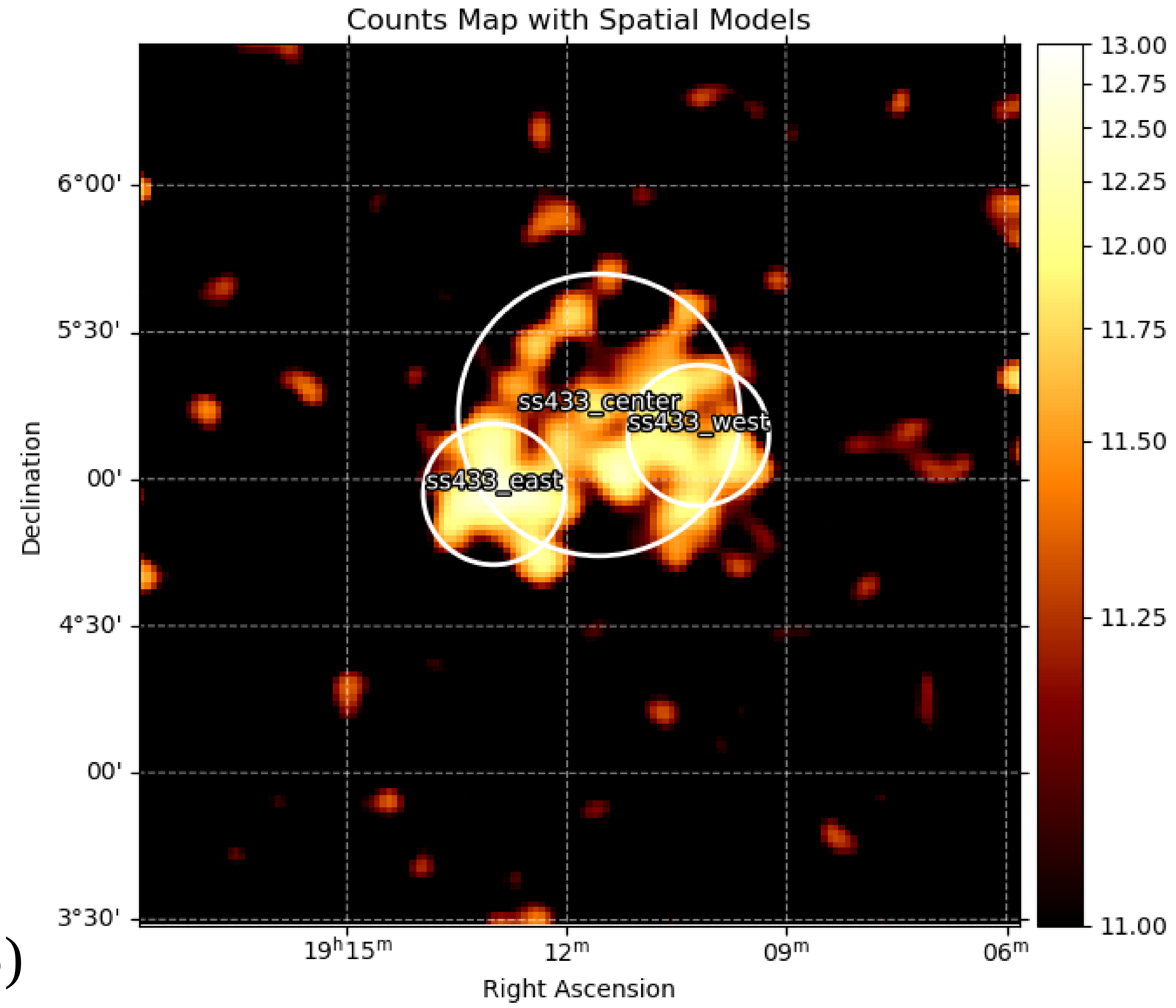

2 point-like sources associated with X-ray lobes

1 extended source associated with a giant molecolar cloud

## SS433: spatial analysis

**Source visibility** (Moonless + Dark conditions): **410** h (ZA = 0-40°), **280** h (ZA = 40-60°)

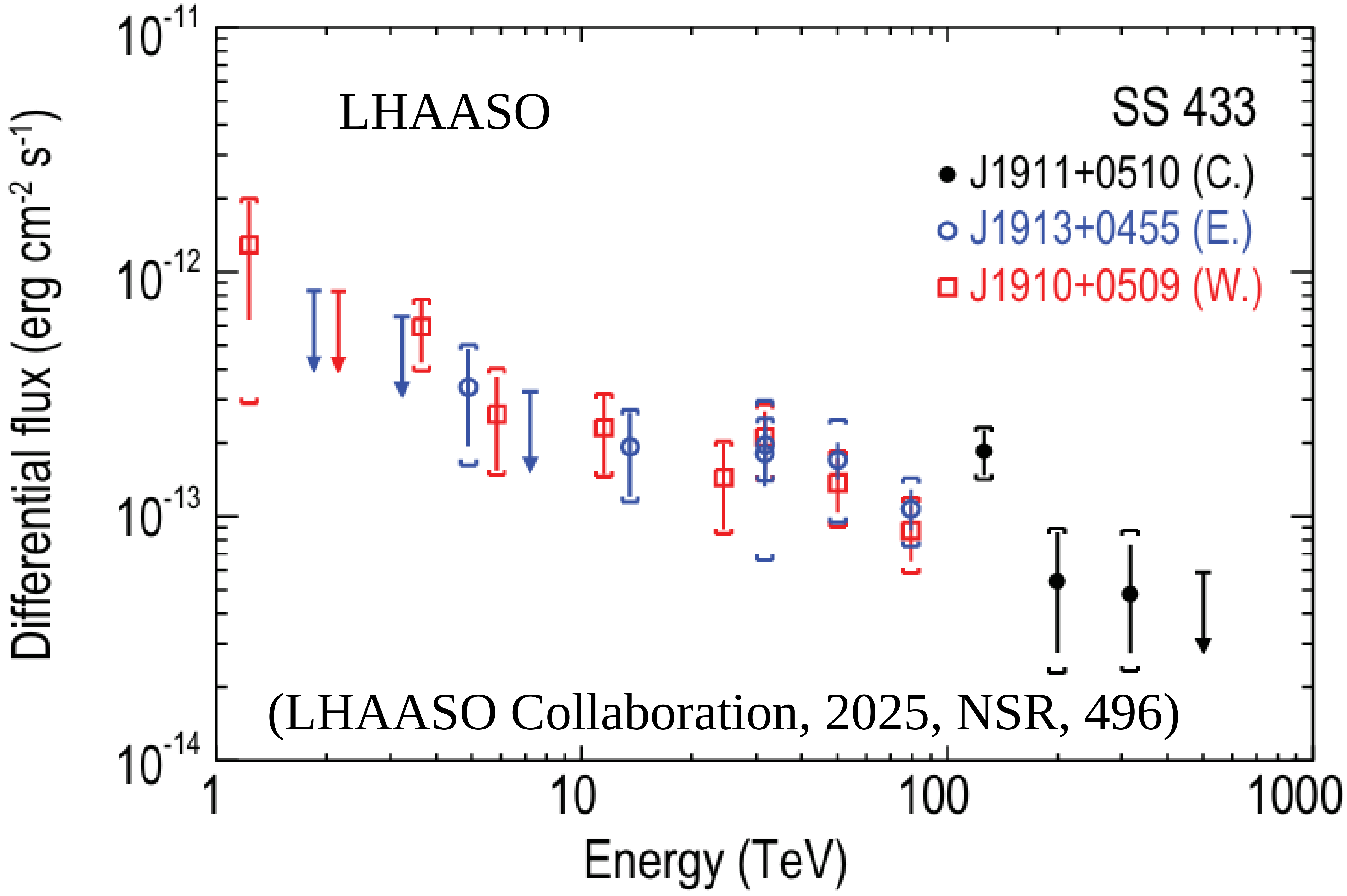
Simulation of 300 h of observation with ASTRI-MA:
- Central source: 0.32° σ Gaussian spatial model
- Extended E/W lobes: 0.16° Gaussian spatial model

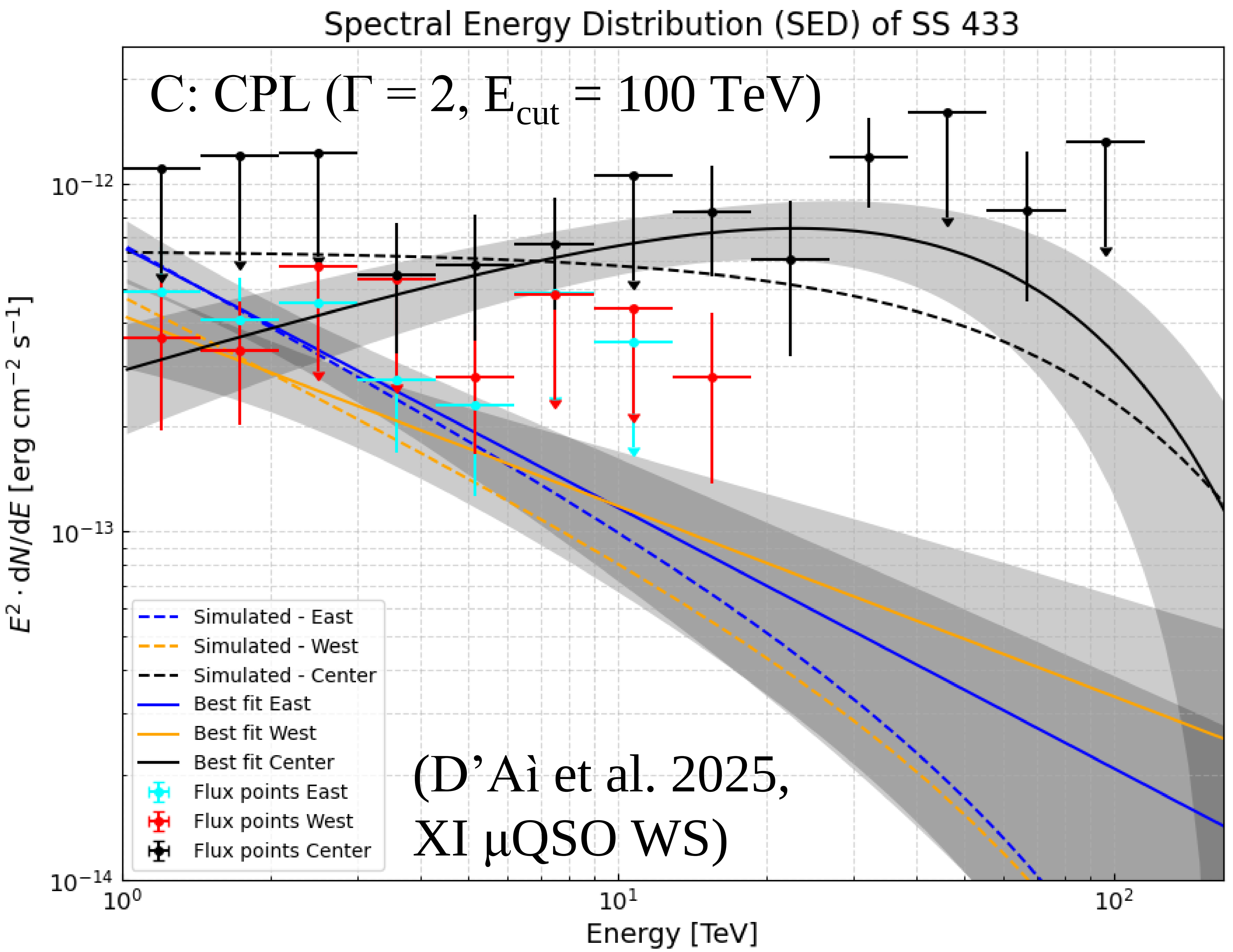



(D'Aì et al. 2025, XI µQSO WS)

# SS433: spectral analysis

**Source visibility** (Moonless + Dark conditions): **410** h (ZA = 0-40°), **280** h (ZA = 40-60°)

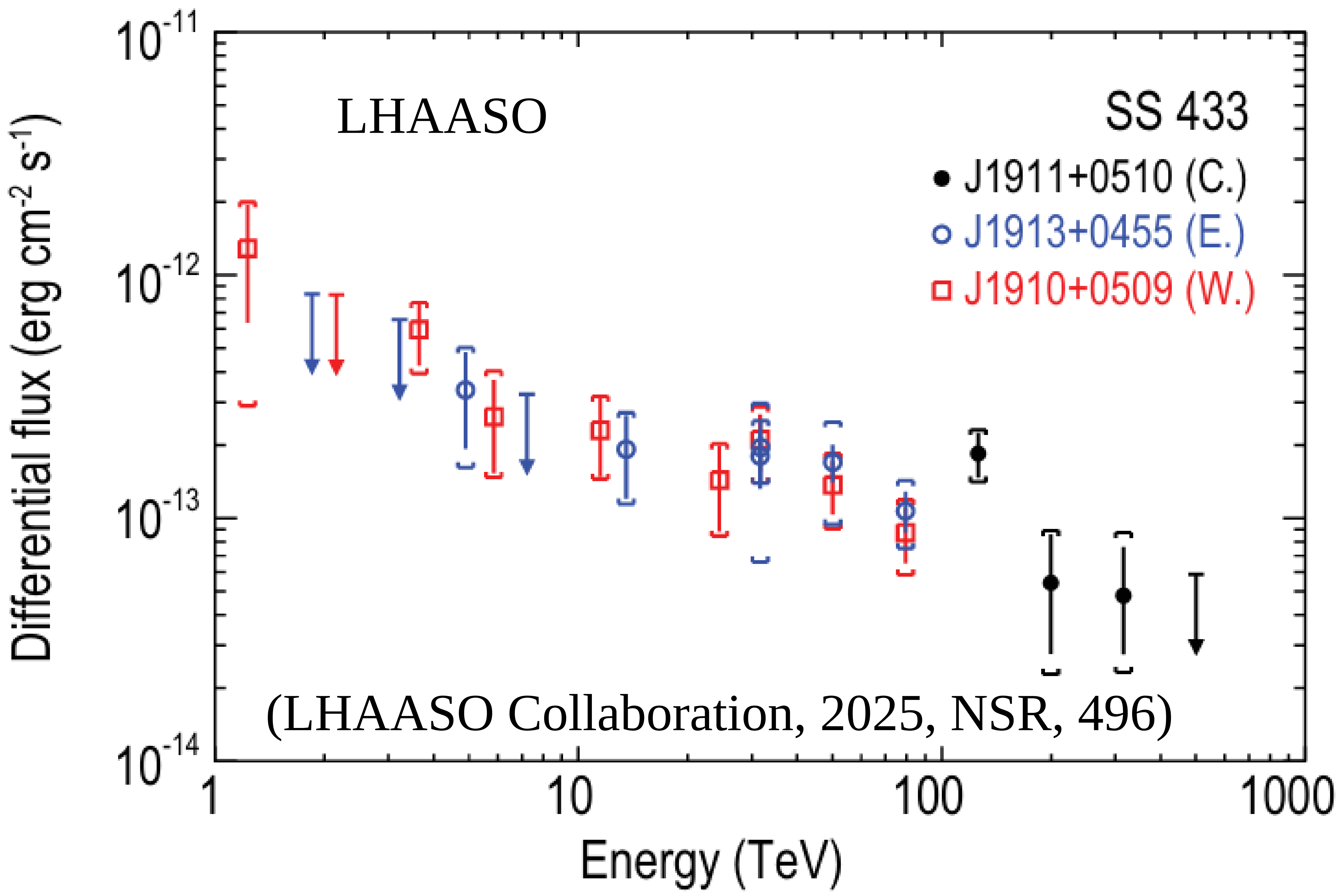


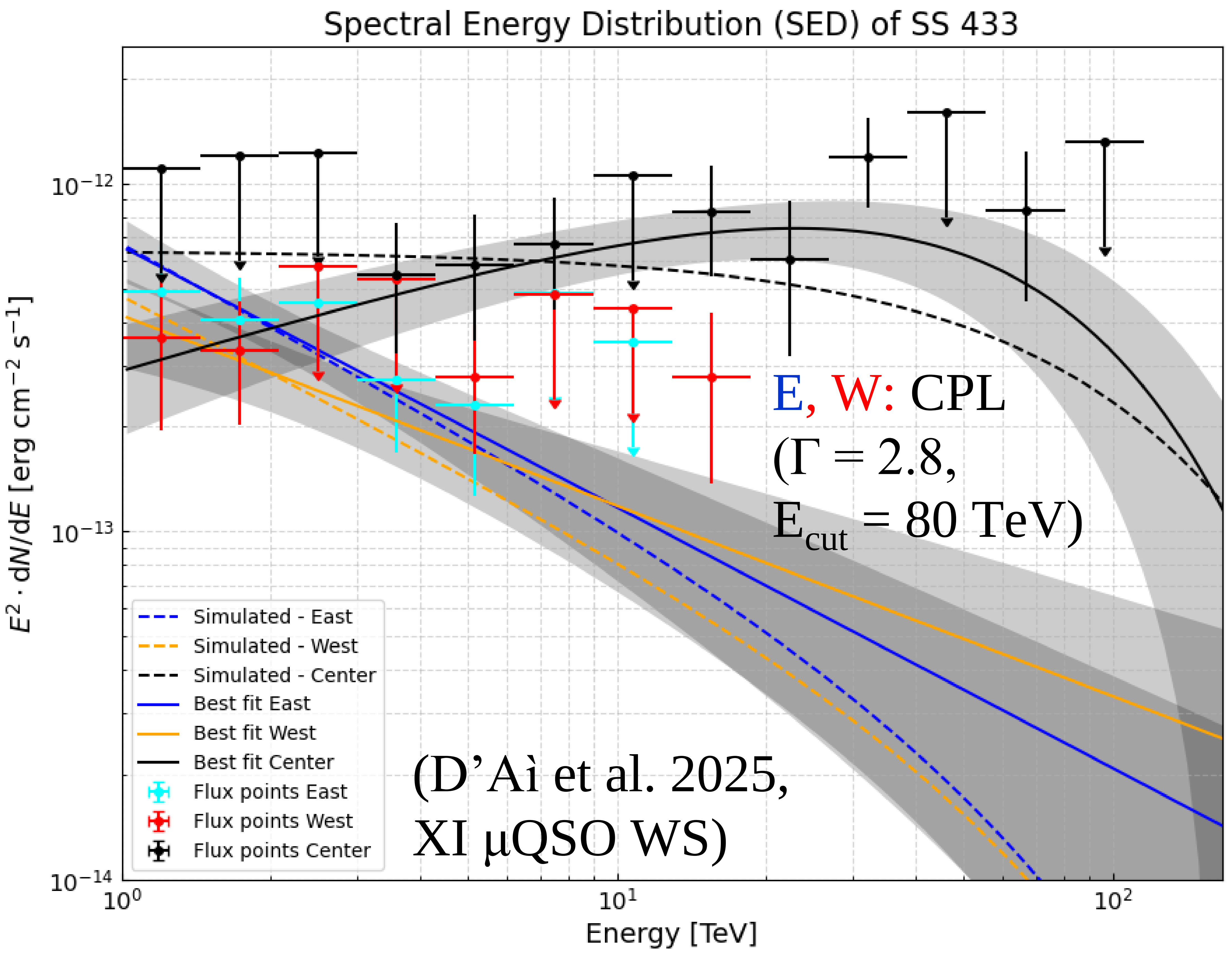



# μQSOs

## SS433: spectral analysis

**Source visibility** (Moonless + Dark conditions): **410** h (ZA = 0-40°), **280** h (ZA = 40-60°)



# μQSOs

## V4641 Sgr: main results

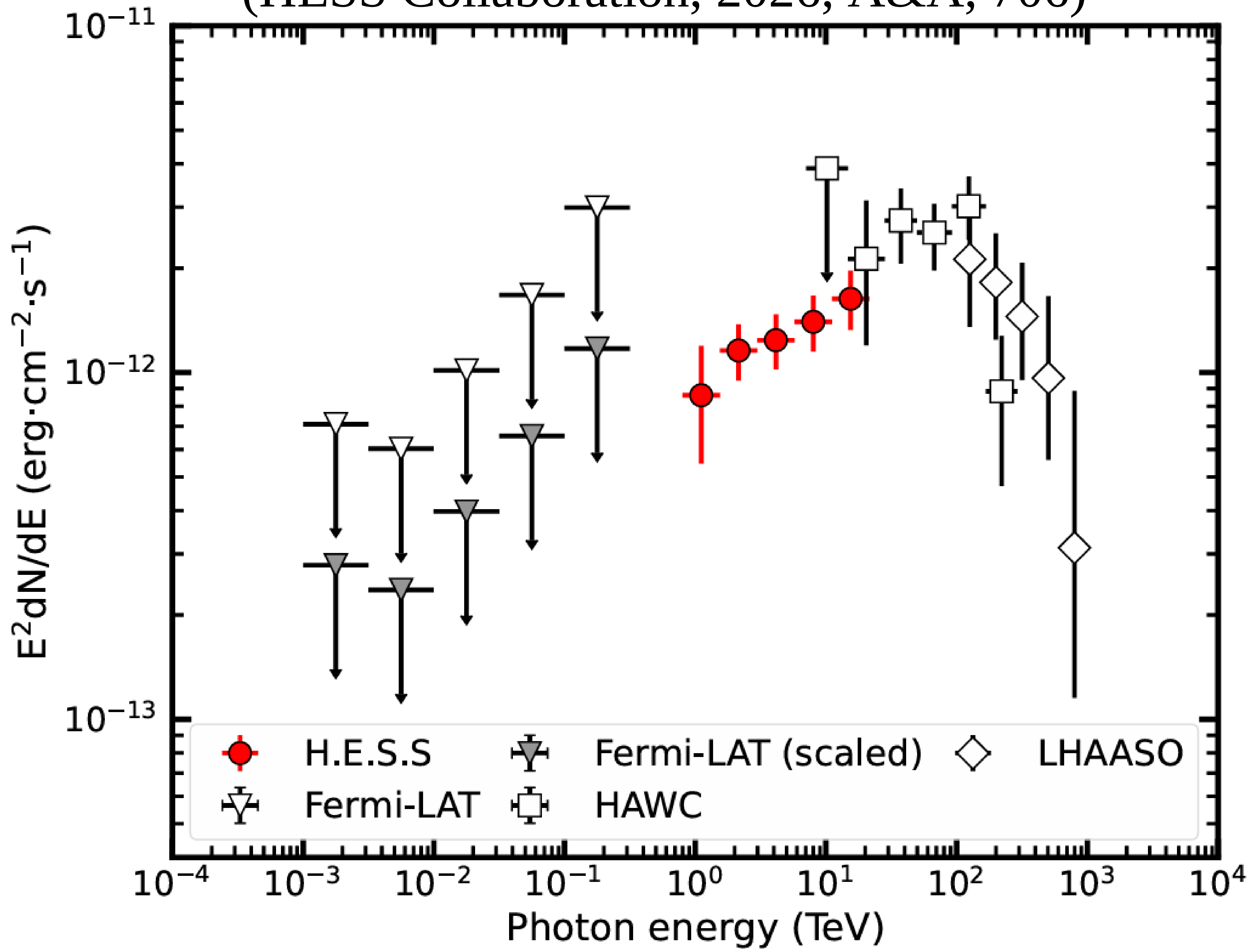
| Parameter | HESS | HAWC | LHAASO |
|---|---|---|---|
| Detection | 9.5 σ | 8.1 σ (S)<br>6.7 σ (N) | 10.5 σ |
| Energy range (TeV) | 1-20 | 20-220 (S)<br>20-150 (N) | 90-800 |
| Morphology | extended | pointlike | extended |
| E-dependent morphology | NO | NO | NO |
| Spectrum | PL | PL | PL |
| Emission origin | leptonic | leptonic | hadronic |

# μQSOs

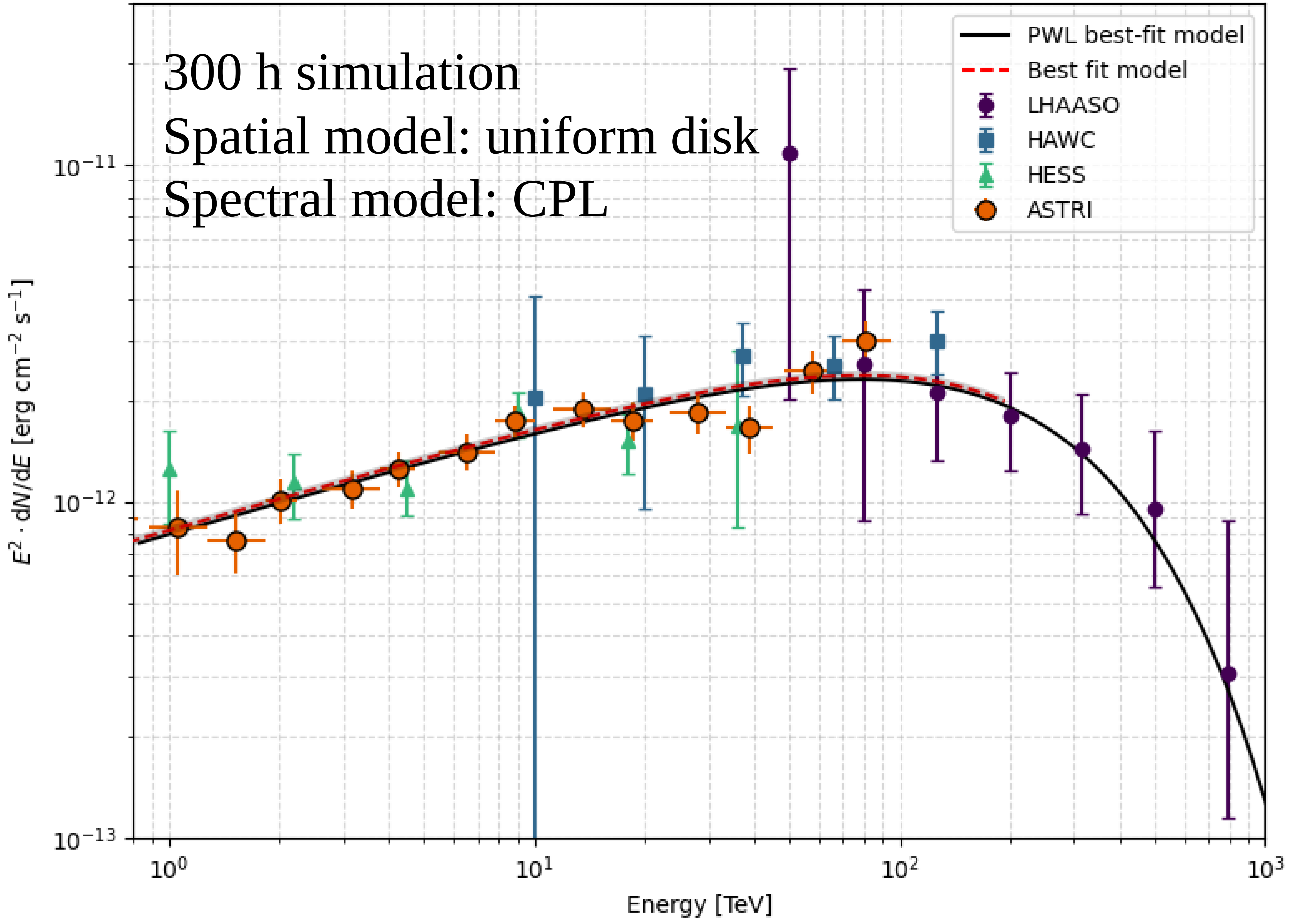
## V4641 Sgr: spectral analysis

**Source visibility** (Moonless + Dark conditions): **290** h (ZA = 40-60°)

(HESS Collaboration, 2026, A&A, 706)




(D'Aì et al. 2025, XI μQSO WS)



# µQSOs

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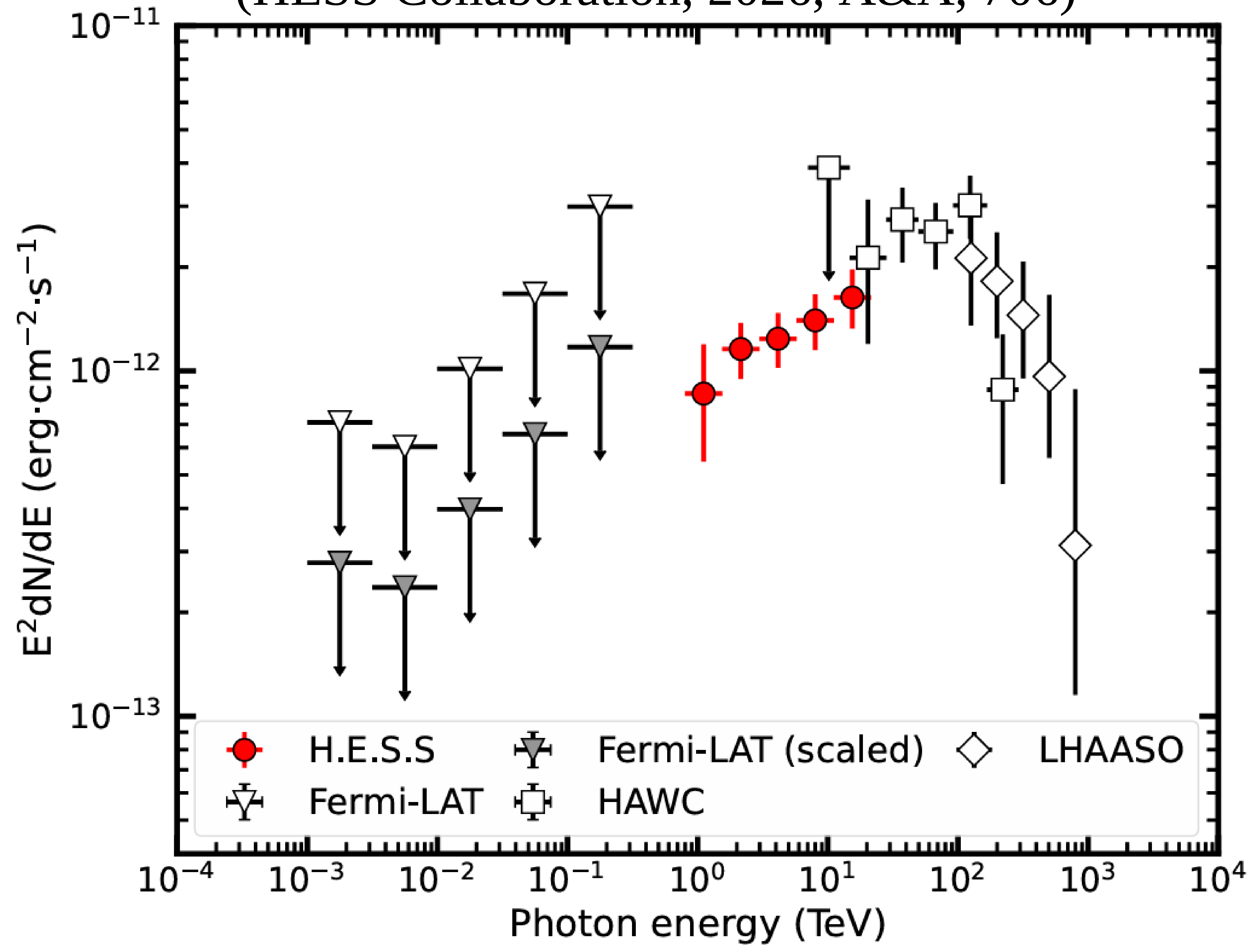
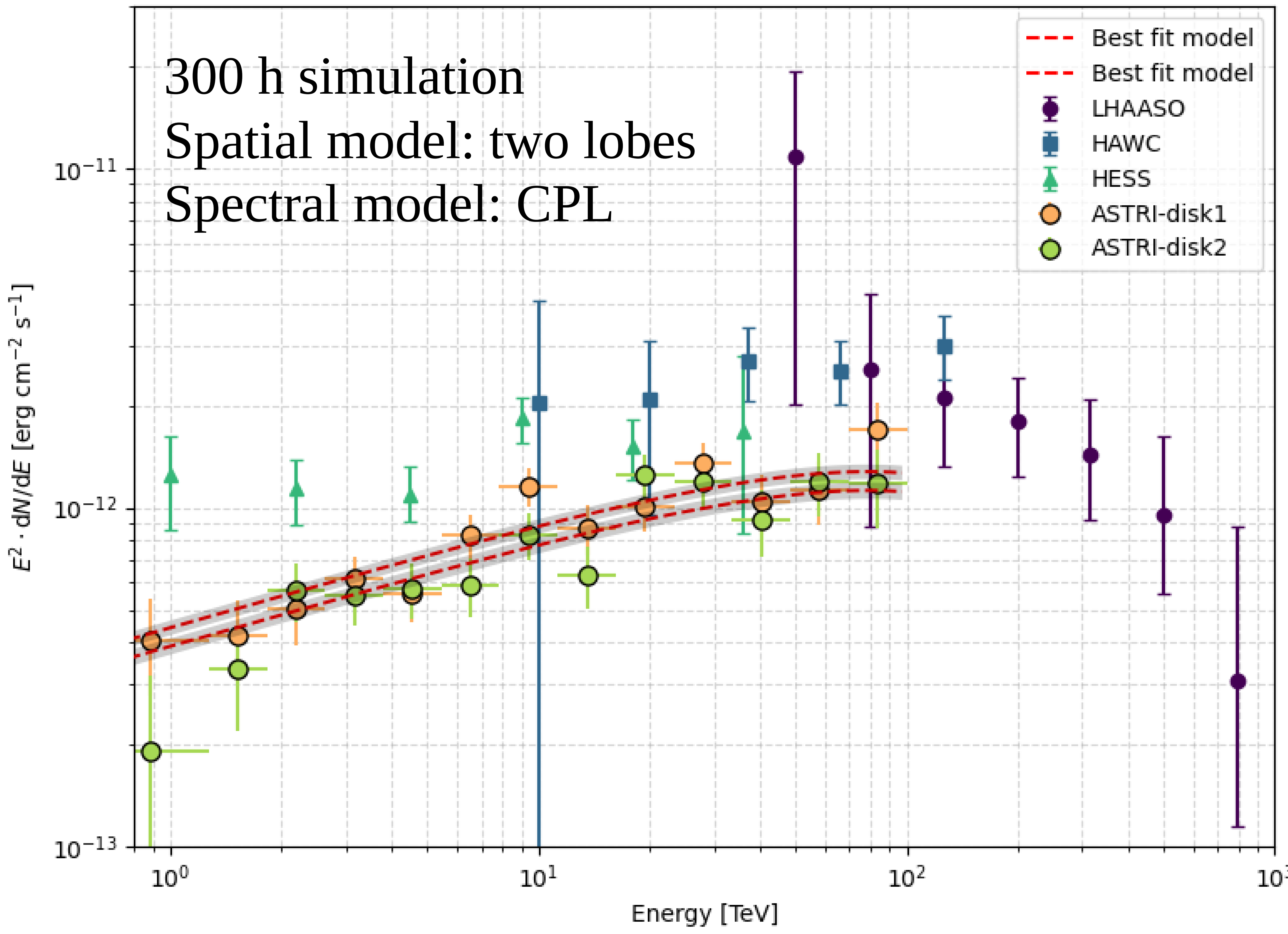
**Source visibility** (Moonless + Dark conditions): **290** h (ZA = 40-60°)

(HESS Collaboration, 2026, A&A, 706)

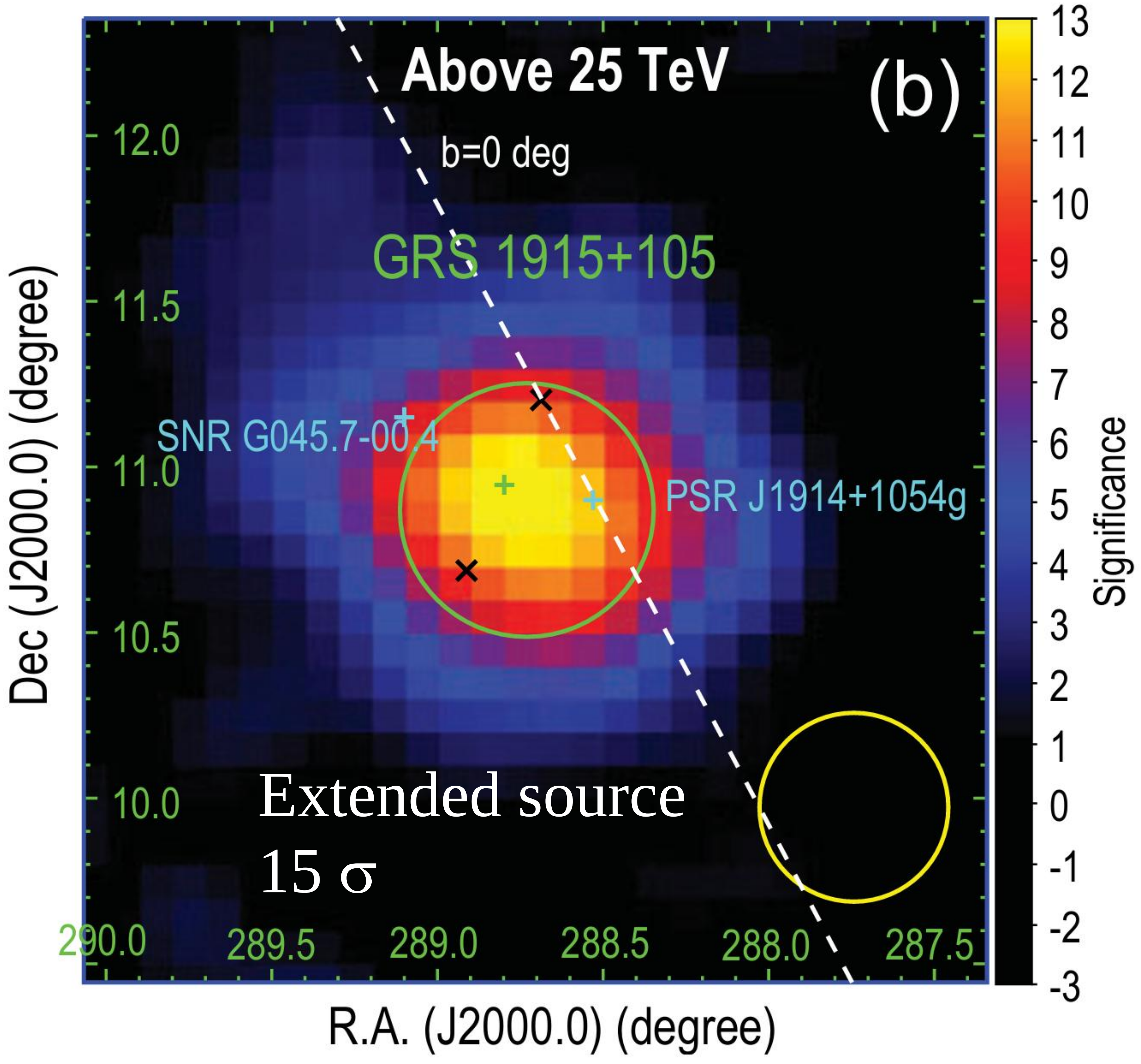



(D'Aì et al. 2025, XI µQSO WS)

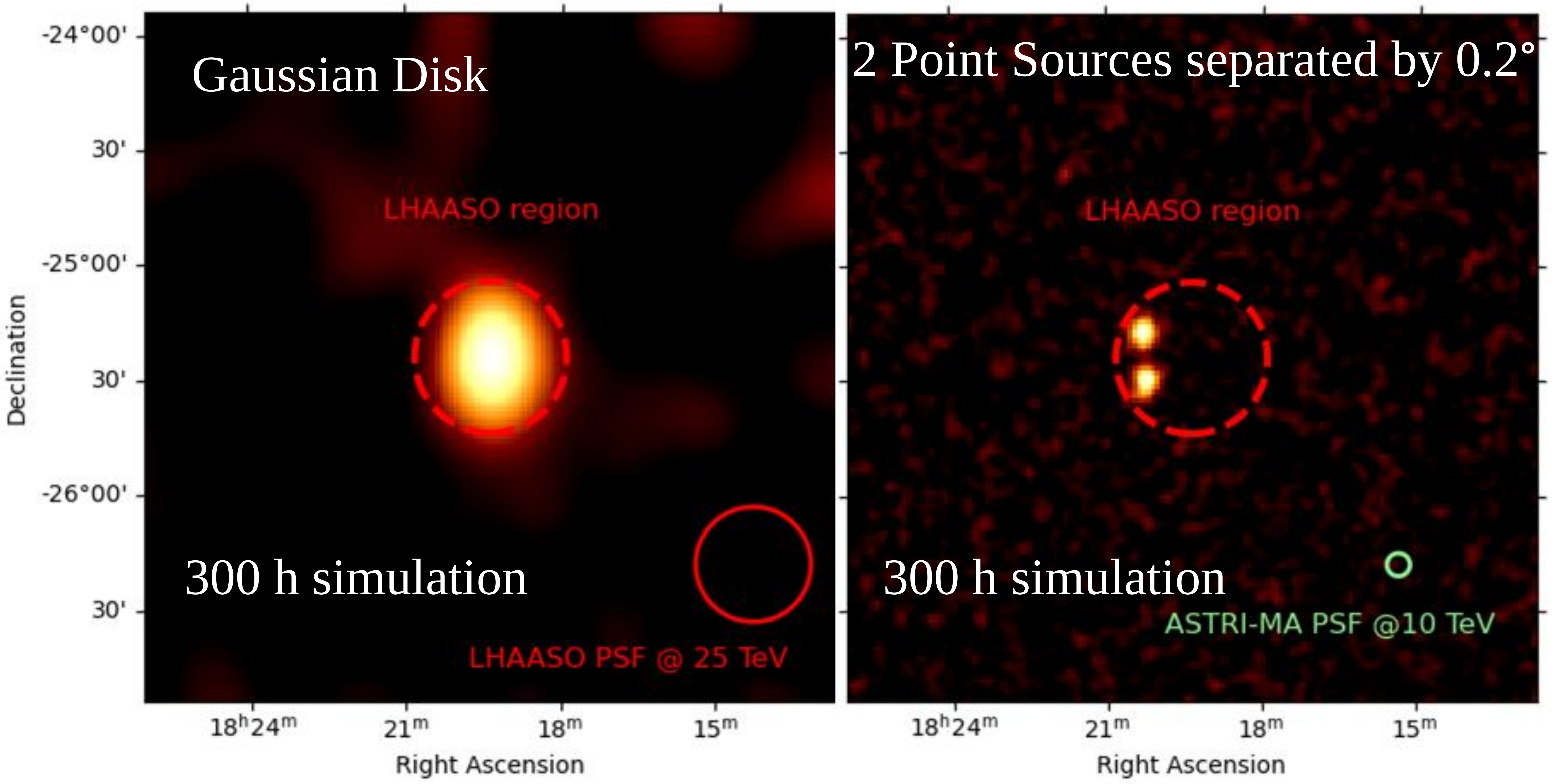


# GRS 1915+105: spatial analysis

**Source visibility** (Moonless + Dark conditions): **470** h (ZA = 0-40°), **270** h (ZA = 40-60°)




(LHAASO Collaboration, 2025, NSR, 496)




(D'Aì et al. 2025, XI µQSO WS)

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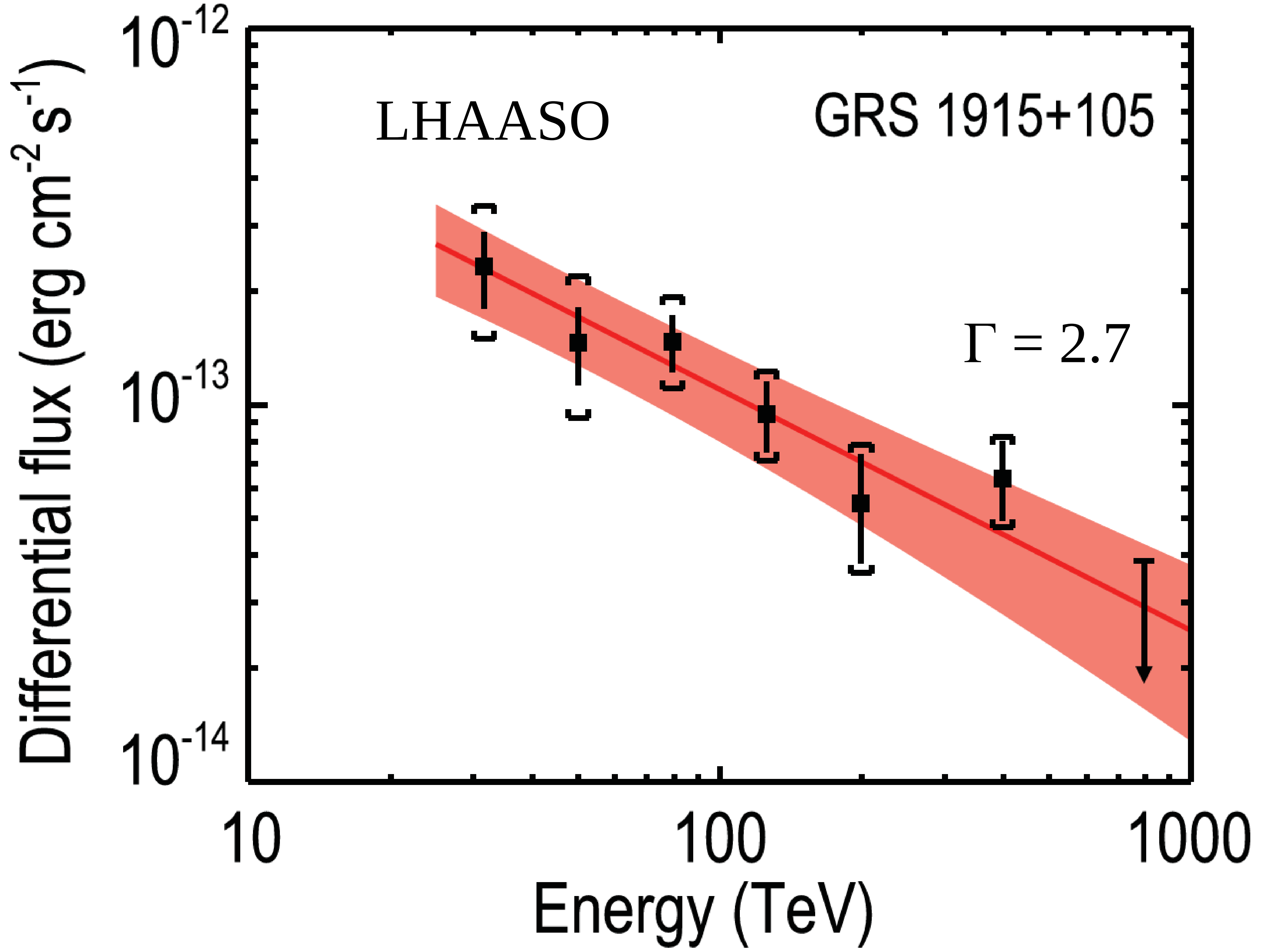
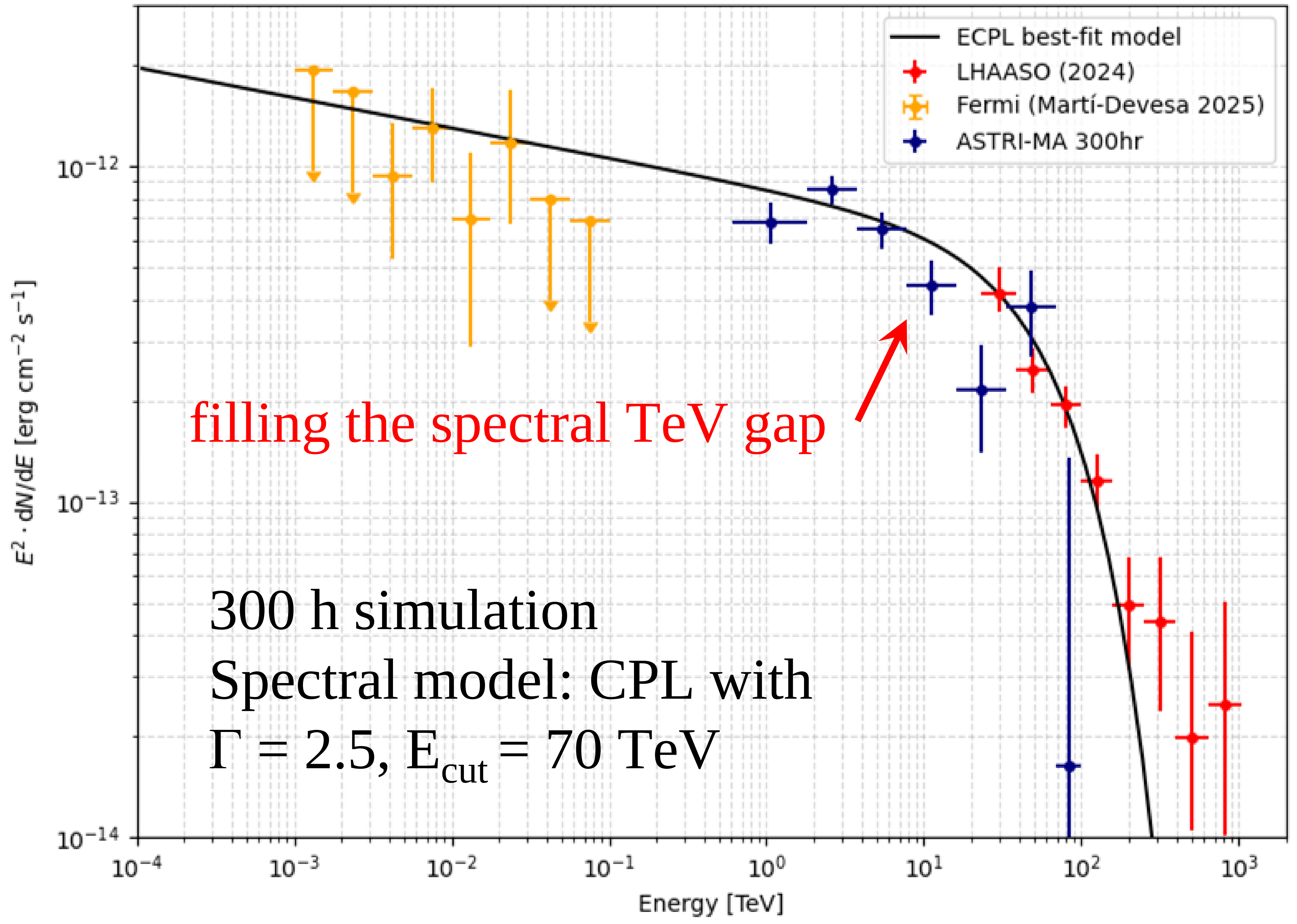
**Source visibility** (Moonless + Dark conditions): **470** h (ZA = 0-40°), **270** h (ZA = 40-60°)



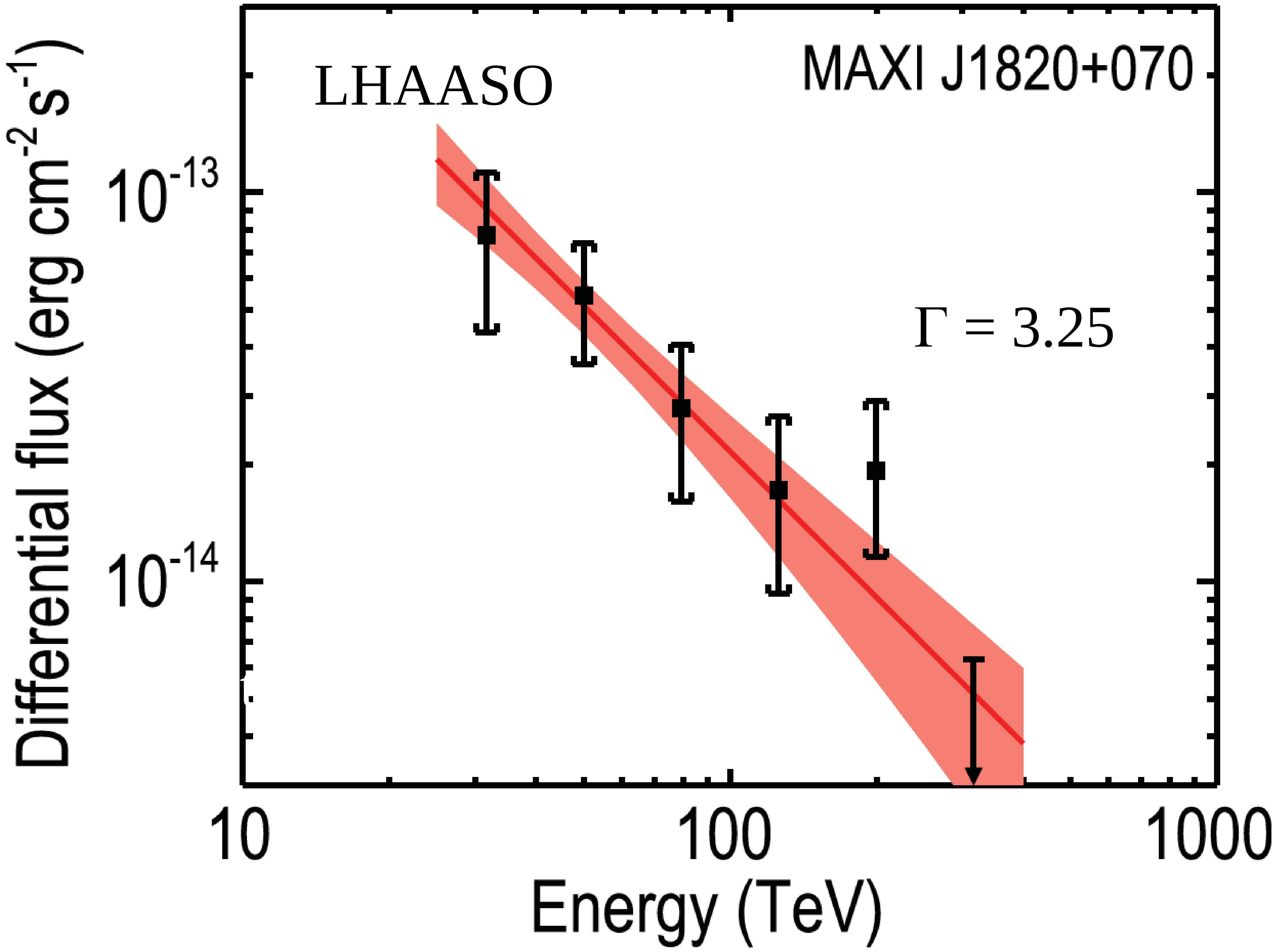

(LHAASO Collaboration, 2025, NSR, 496)



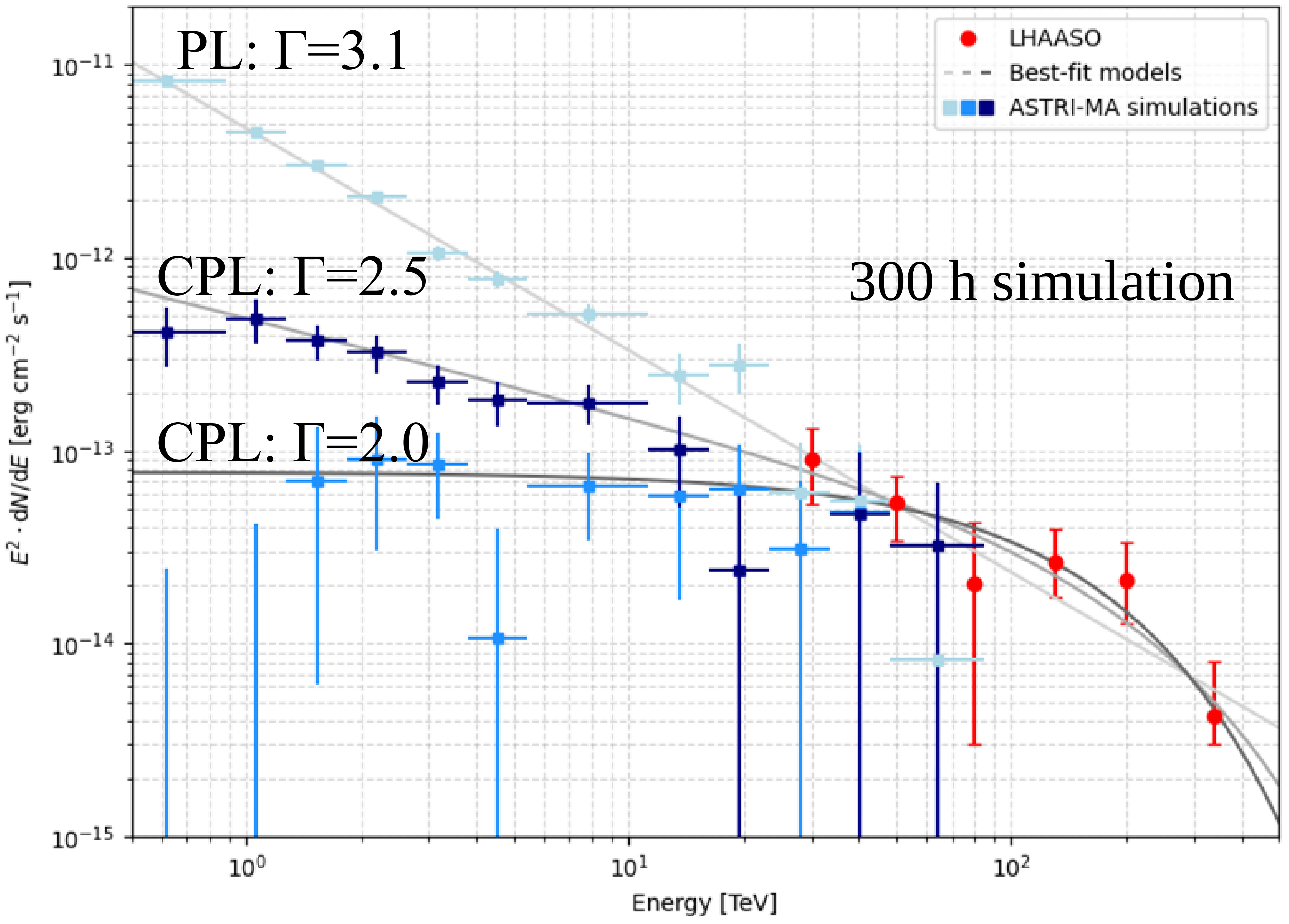

(D'Aì et al. 2025, XI µQSO WS)

# MAXI J1820+070: spectral analysis

**Source visibility** (Moonless + Dark conditions): **380** h (ZA = 0-40°), **250** h (ZA = 40-60°)




(LHAASO Collaboration, 2025, NSR, 496)

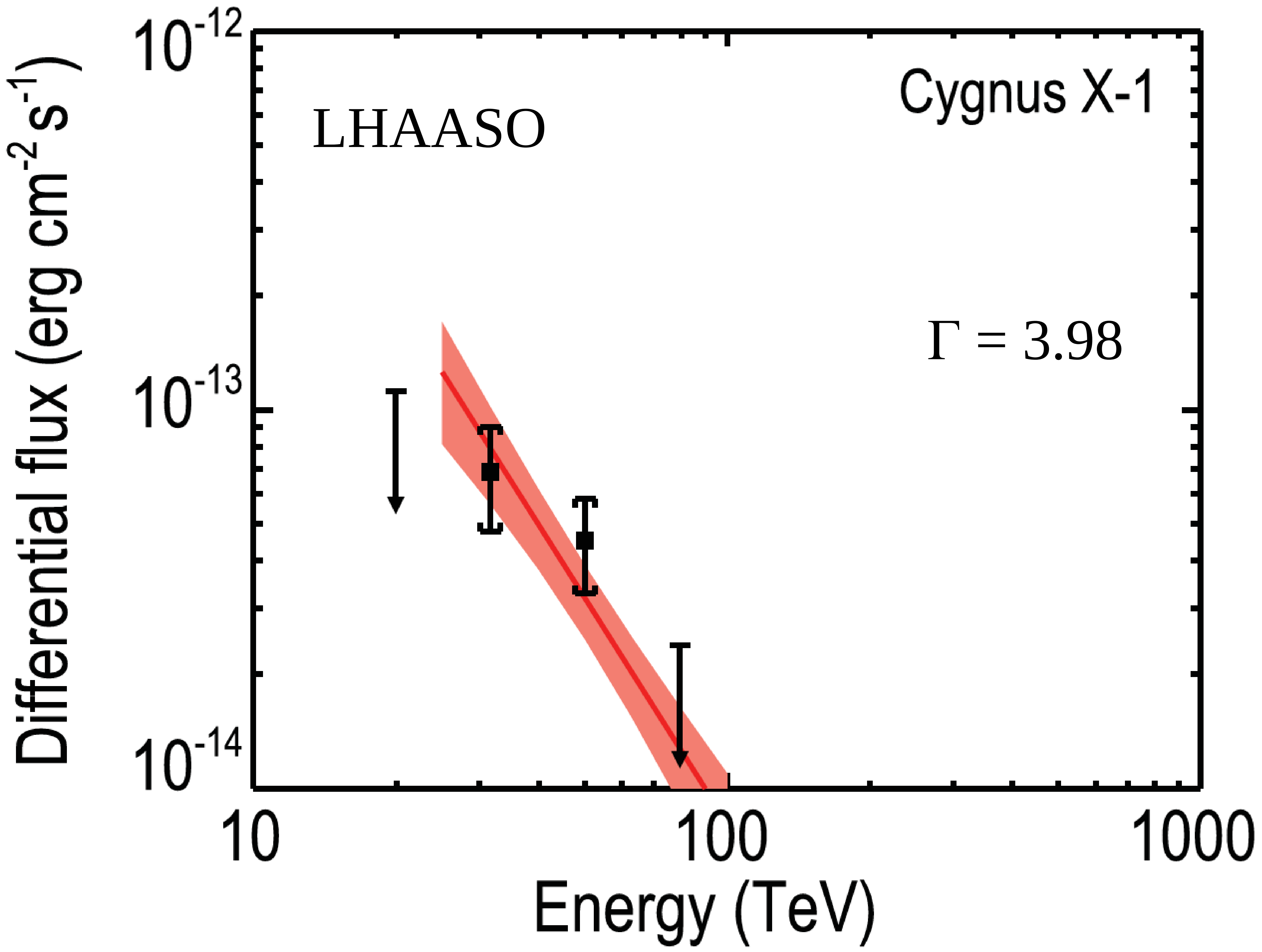



(D'Aì et al. 2025, XI μQSO WS)

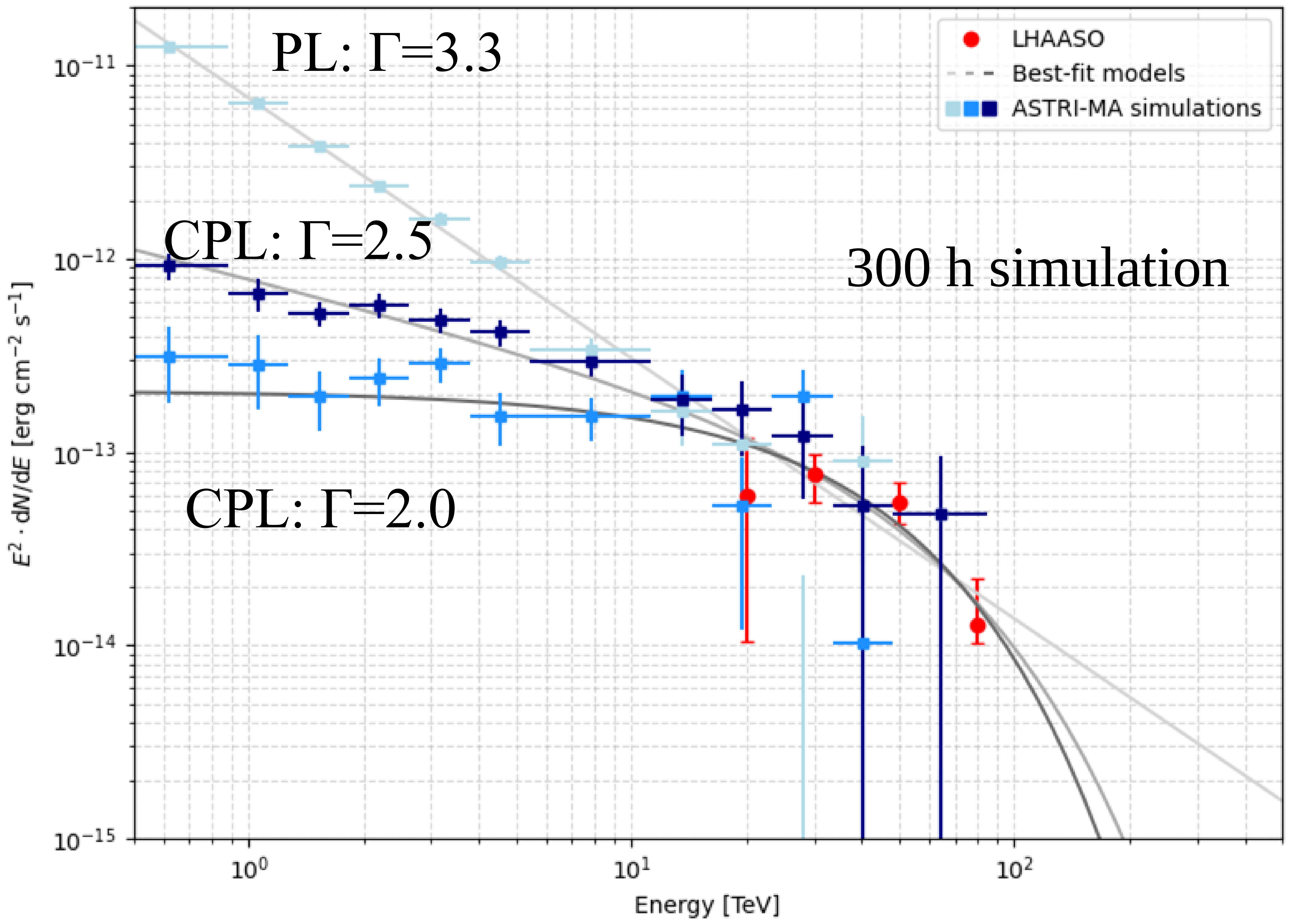
# μQSOs

## Cyg X-1: spectral analysis

**Source visibility** (Moonless + Dark conditions): **490** h (ZA = 0-40°), **260** h (ZA = 40-60°)




(LHAASO Collaboration, 2025, NSR, 496)




(D'Aì et al. 2025, XI μQSO WS)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# Summary

## (Personal view of) possible topics for ASTRI

**γ-ray binaries:**

- LS 5039: 1) orbital modulation; 2) orbital phased-resolved spectra; 3) light-curve shape in the high state
- LSI +61° 303: 1) orbital modulation; 2) spectrum; 3) TeV flares
- HESS J0632+057: 1) flux variability; 2) spectrum (possibly phase resolved?)
- HESS J1832-093: 1) spectrum

**μQSOs:**

- SS433: 1) morphological and spectral analysis of both lobes; 2) energy-dependent morphology
- V4641 Sgr: 1) morphological and spectral analysis; 2) energy-dependent morphology
- MAXI J1820+070 and Cyg X-1: 1) morphological and spectral analysis; 2) (time variability)
- Cyg X-3: 1) spectral analysis; 2) time variability

# Conclusions

## Concluding remarks

- The ASTRI Mini-Array will provide key coverage (especially in the 10-100 TeV band) to spectrally constrain the VHE emission of binary γ-ray sources
- ASTRI Mini-Array data will be able to disentangle the morphological shapes and provide spectral properties for selected spatial regions
- Coordinated observations with other facilities (e.g. LST, CTAO-N, and LHAASO) will offer a comprehensive view of the spectrum, thus distinguishing contributions from the core and outer regions of μQSOs

# Conclusions

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- The ASTRI Mini-Array will provide key coverage (especially in the 10-100 TeV band) to spectrally constrain the VHE emission of binary $\gamma$-ray sources
- ASTRI Mini-Array data will be able to disentangle the morphological shapes and provide spectral properties for selected spatial regions
- Coordinated observations with other facilities (e.g. LST, CTAO-N, and LHAASO) will offer a comprehensive view of the spectrum, thus distinguishing contributions from the core and outer regions of $\mu$QSOs

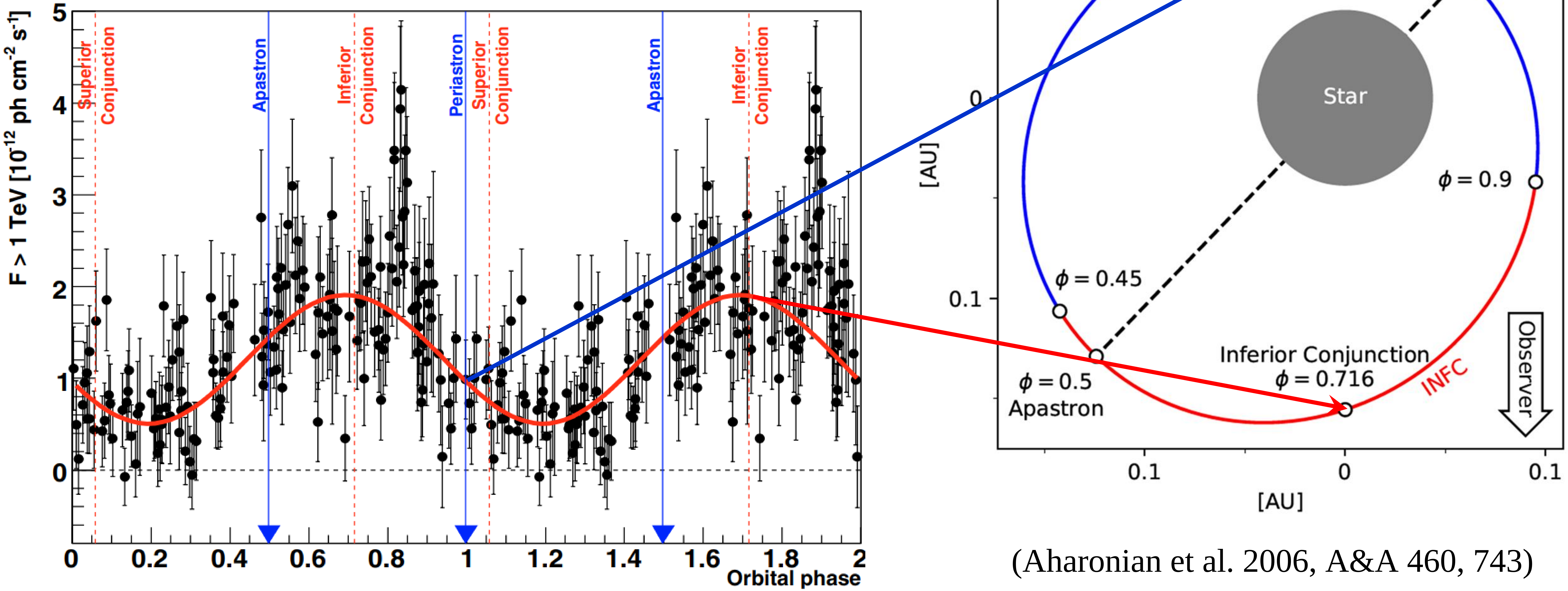
# Thanks for your attention

# BACK-UP SLIDES

# γ-ray loud binaries

## LS 5039: HESS results

Orbital modulation of the VHE flux



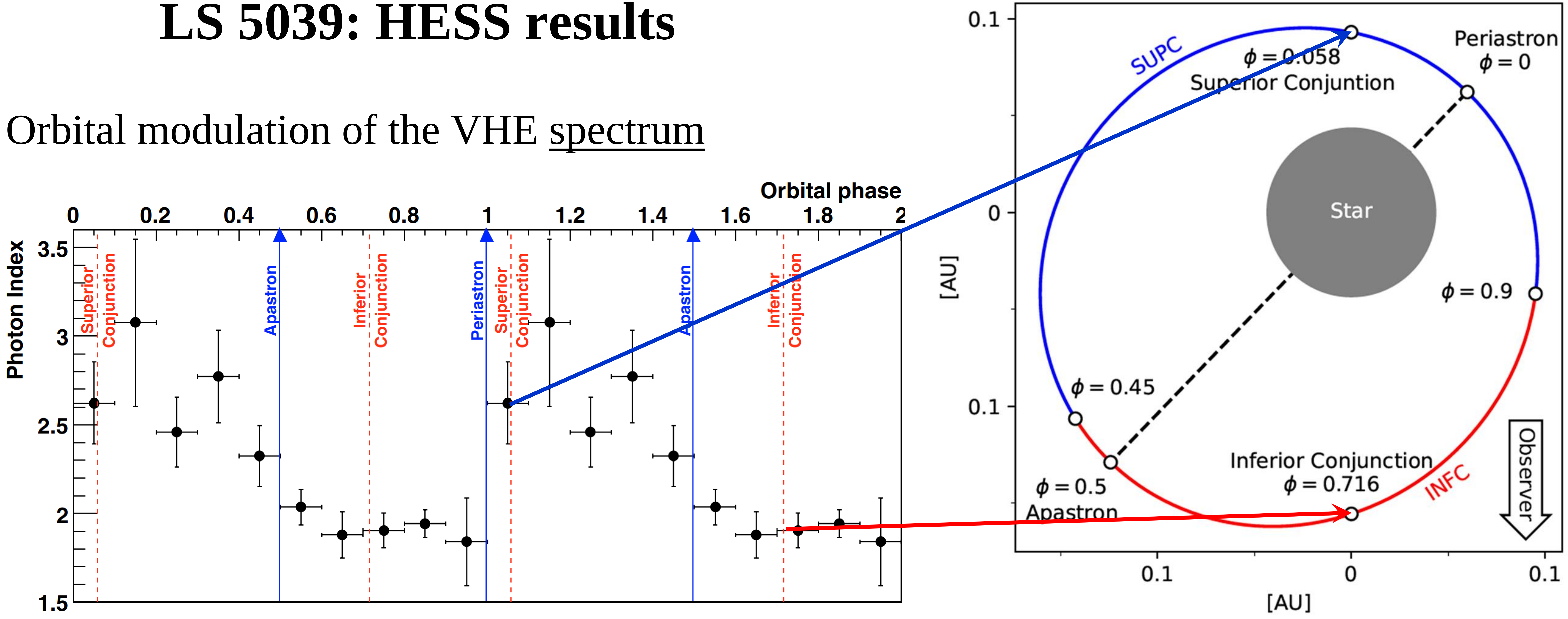

(Aharonian et al. 2006, A&A 460, 743)

# γ-ray loud binaries

Mini-Array

## LS 5039: HESS results

Orbital modulation of the VHE spectrum



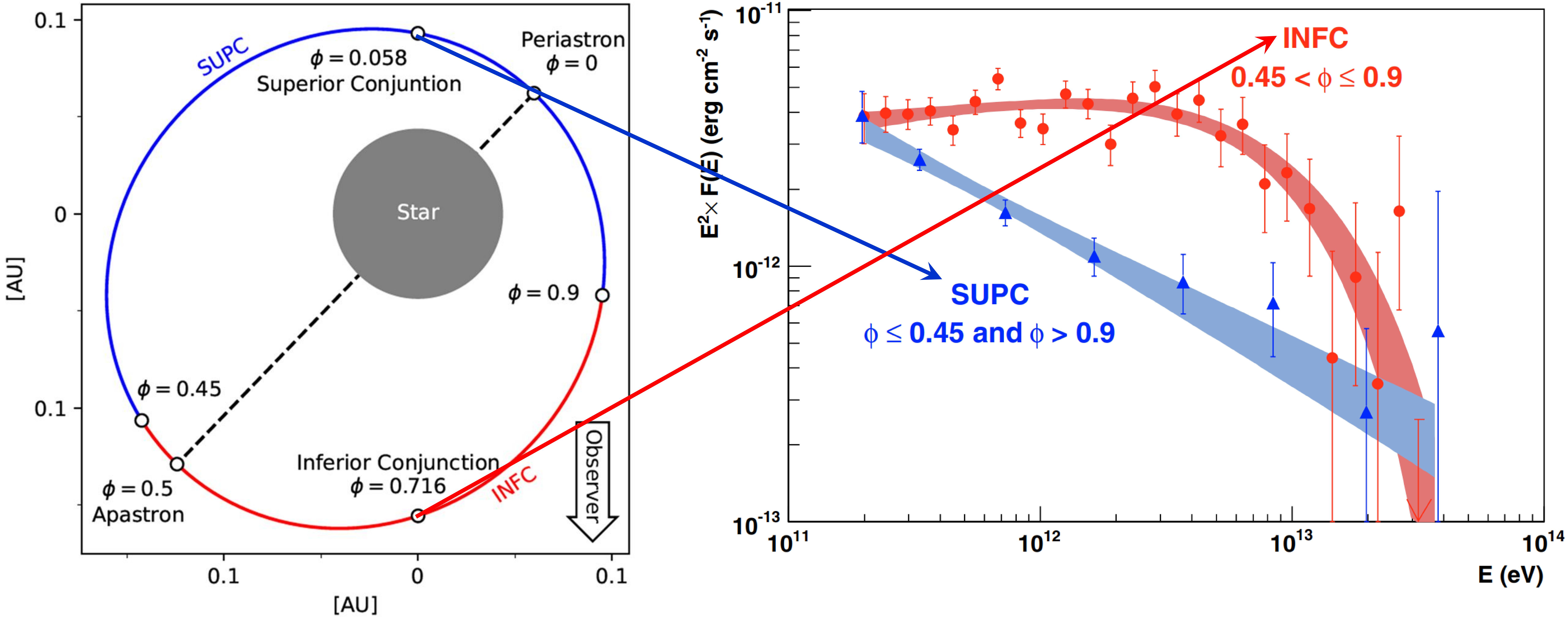

(Aharonian et al. 2006, A&A 460, 743)

# γ-ray loud binaries

## LS 5039: HESS results

Orbital modulation of the VHE spectrum

(Aharonian et al. 2006, A&A 460, 743)



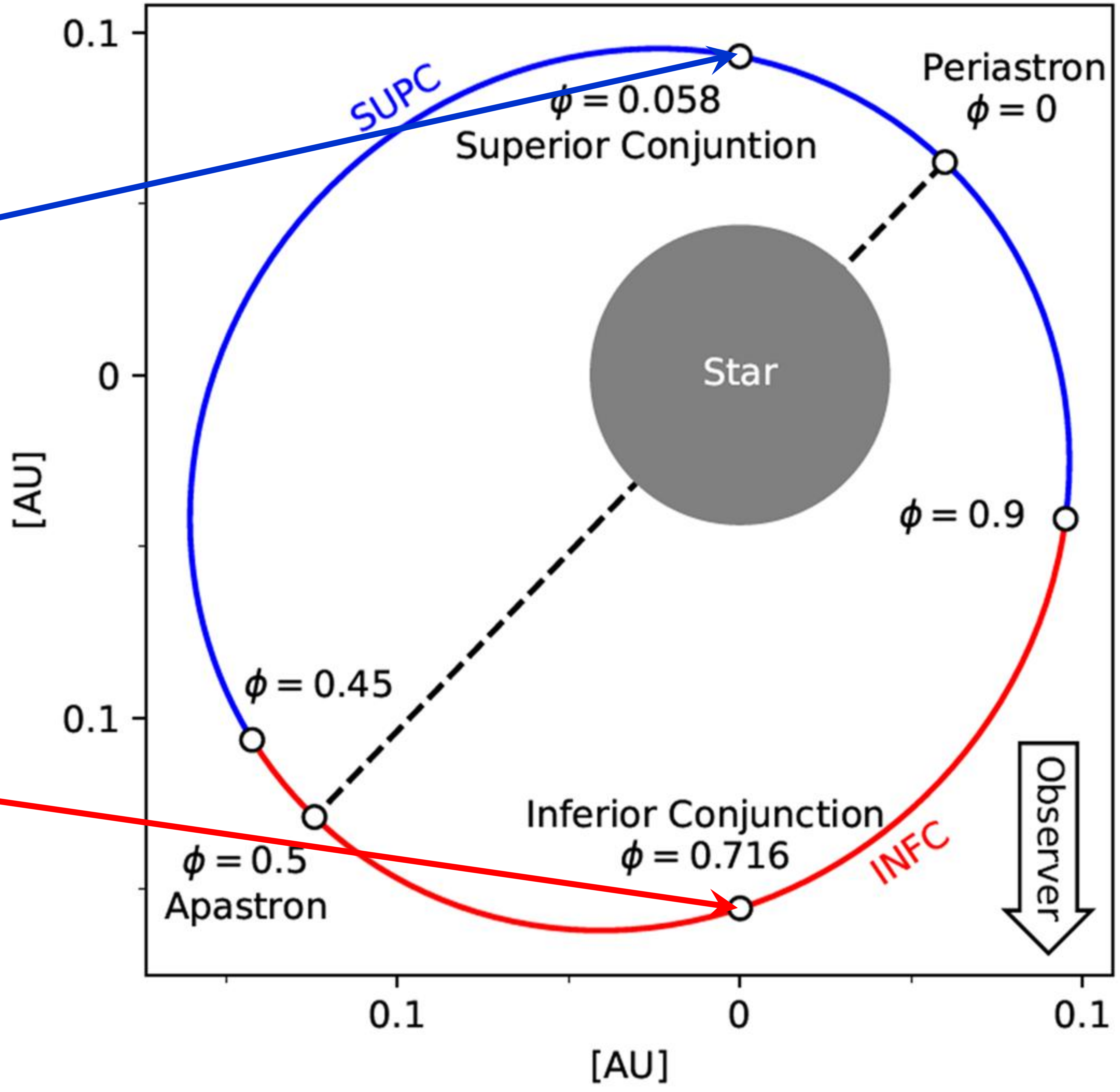
# γ-ray loud binaries

## LS 5039: HESS results

Assuming d = 2.5 kpc:

- **Low state @ SC**: simple PL,
  **$\Gamma = 2.53 \pm 0.07_{stat} \pm 0.1_{sys}$**,
  L(0.2-10 TeV) = $4.2 \times 10^{33}$ erg $s^{-1}$

- **High state @ IC**: cut-off PL,
  **$\Gamma = 1.85 \pm 0.06_{stat} \pm 0.1_{sys}$**,
  **$E_{cut} = 8.7 \pm 2.0$ TeV**,
  L(0.2-10 TeV) = $1.1 \times 10^{34}$ erg $s^{-1}$



# $\gamma$-ray loud binaries

## LS 5039: simulation of the 2 spectral states

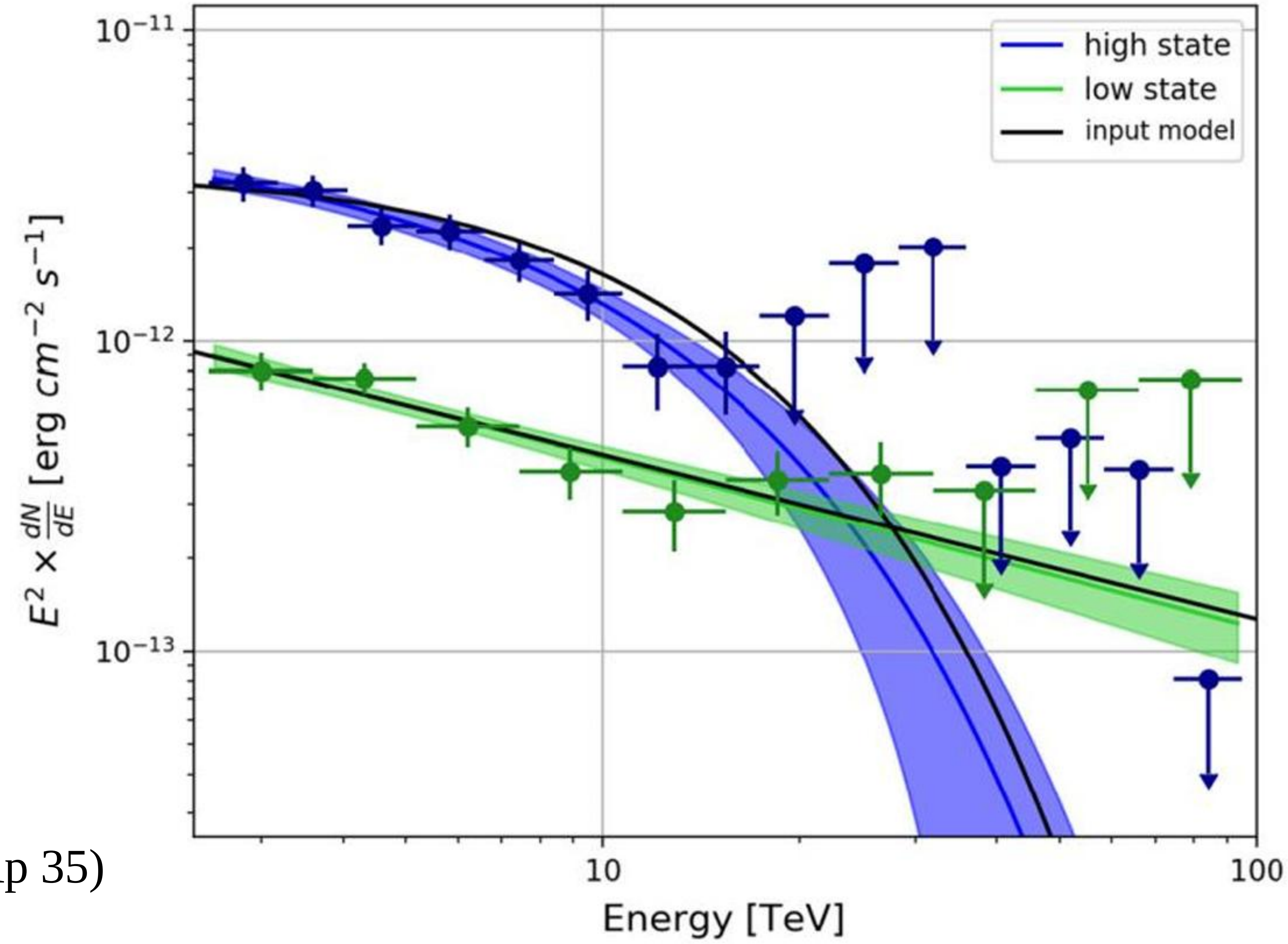
Results of ASTRI simulations (D'Aì et al. 2022, JHEAp 35):

- **Low state** (250 h): ~ 18 $\sigma$, **$\Gamma$ = 2.55 ± 0.08**, N = (0.9 ± 0.1)x10$^{-12}$ ph cm$^{-2}$ s$^{-1}$ TeV$^{-1}$ (compared with 0.91x10$^{-12}$ ph cm$^{-2}$ s$^{-1}$ TeV$^{-1}$); LL on Ecut ($E_{cut}$ > 46 TeV) if PL parameters are freezed

- **High state** (50 h): ~ 25 $\sigma$, **$\Gamma$ = 2.1 ± 0.3, $E_{cut}$ = 8.7 ± 4.0 TeV**, N = (2.9 ± 0.6)x10$^{-12}$ ph cm$^{-2}$ s$^{-1}$ TeV$^{-1}$ (compared with 2.28x10$^{-12}$ ph cm$^{-2}$ s$^{-1}$ TeV$^{-1}$)

# γ-ray loud binaries

## LS 5039: simulation of the 2 spectral states




(D’Aì et al. 2022, JHEAp 35)

# $\gamma$-ray loud binaries

## LS 5039: simulation of the orbital modulation

HESS results (Aharonian et al. 2006, A&A 460, 743):

- Orbit-averaged spectrum: cut-off PL, $\mathbf{\Gamma = 2.06 \pm 0.05_{stat}, E_{cut} = 13 \pm 4}$ **TeV**

$\Downarrow$

Simulation of the orbital modulation:

- 10 phase intervals
- exposure time of 10 h for each phase bin
- constant spectrum

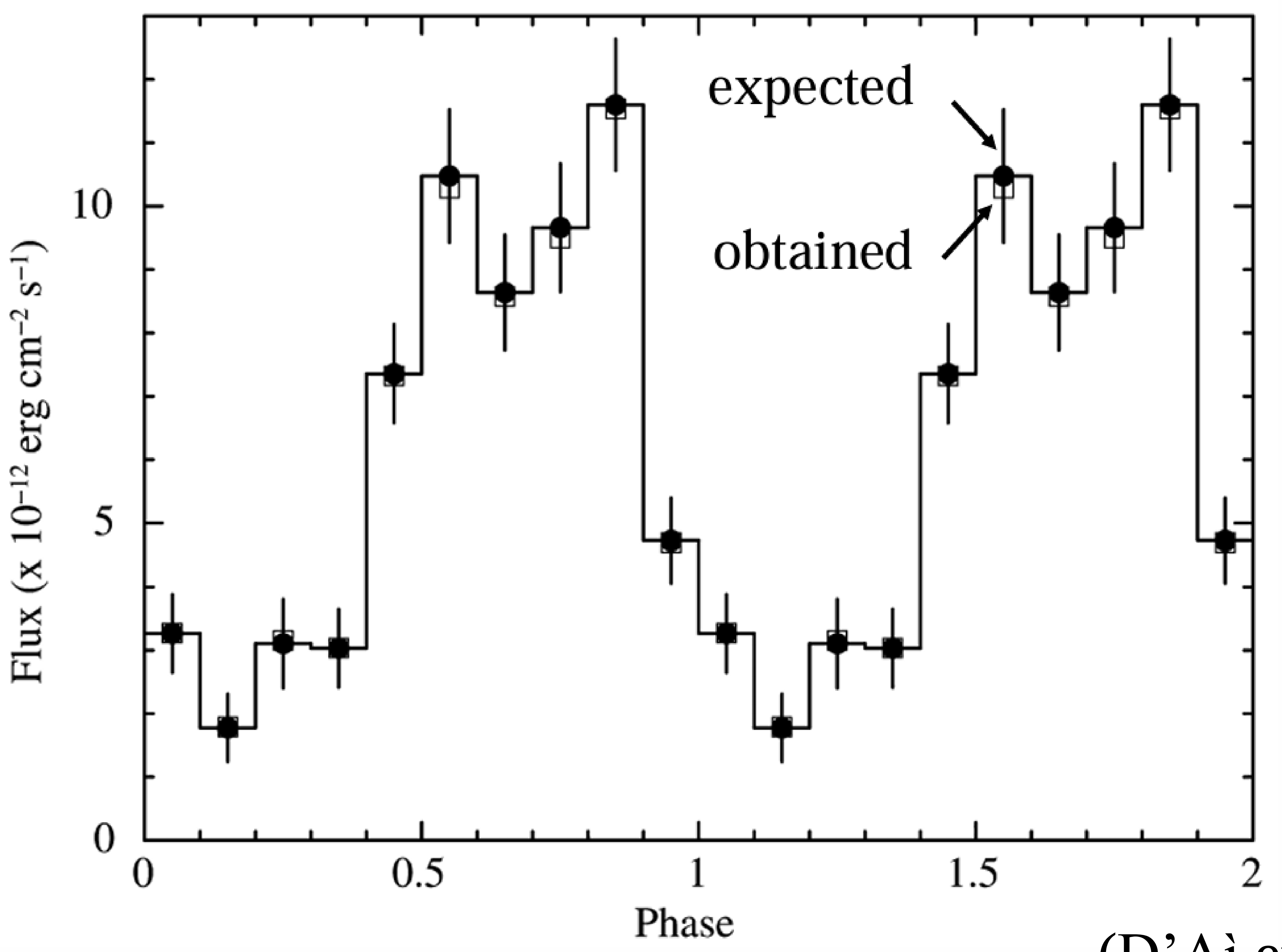
$\Downarrow$

evaluation of flux variability (0.8-200 TeV) and index uncertainty

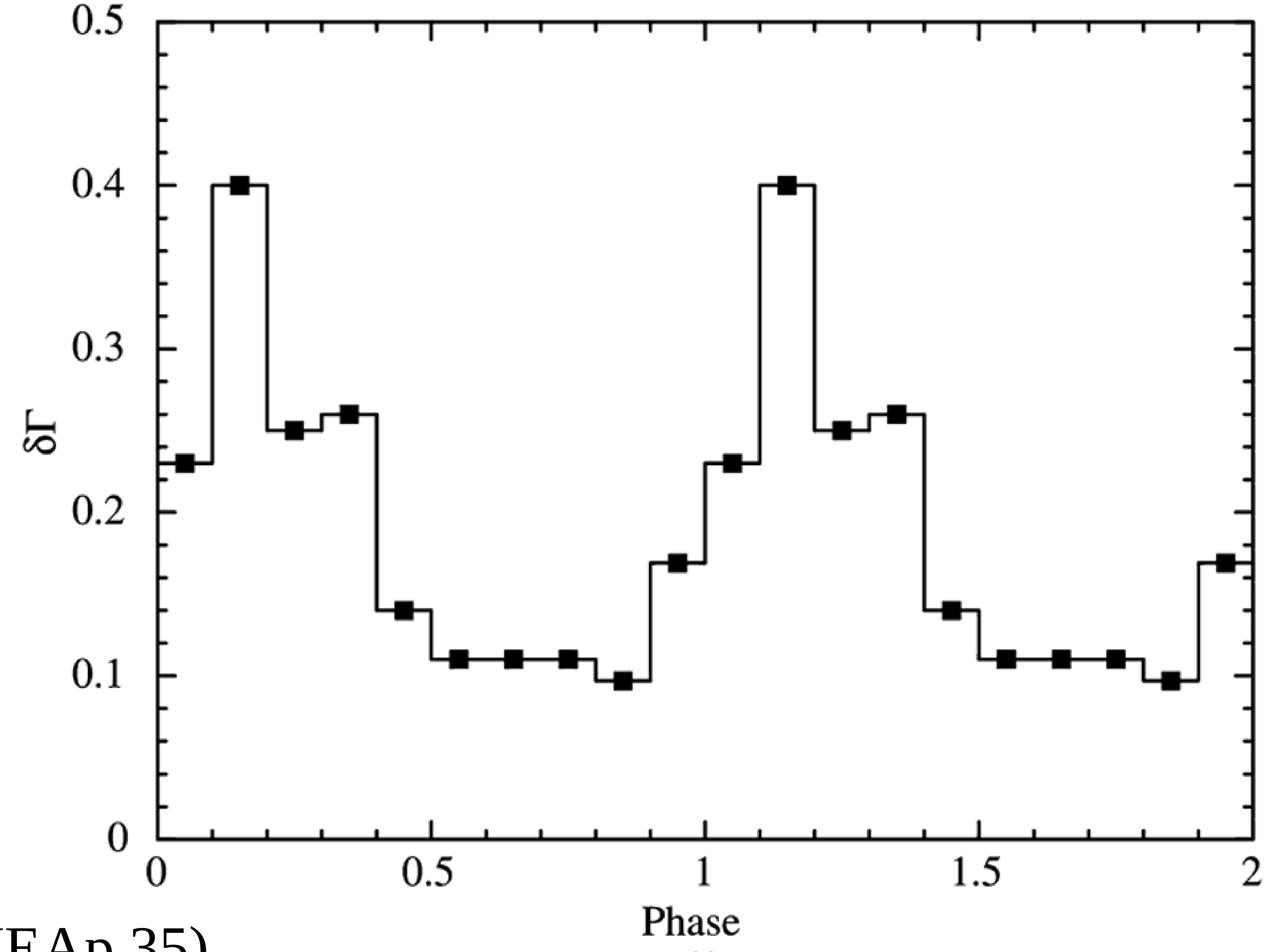
# γ-ray loud binaries

## LS 5039: simulation of the orbital modulation

Flux variability




Index uncertainty




(D’Aì et al. 2022, JHEAp 35)

⇓

estimated flux fully consistent with simulated model

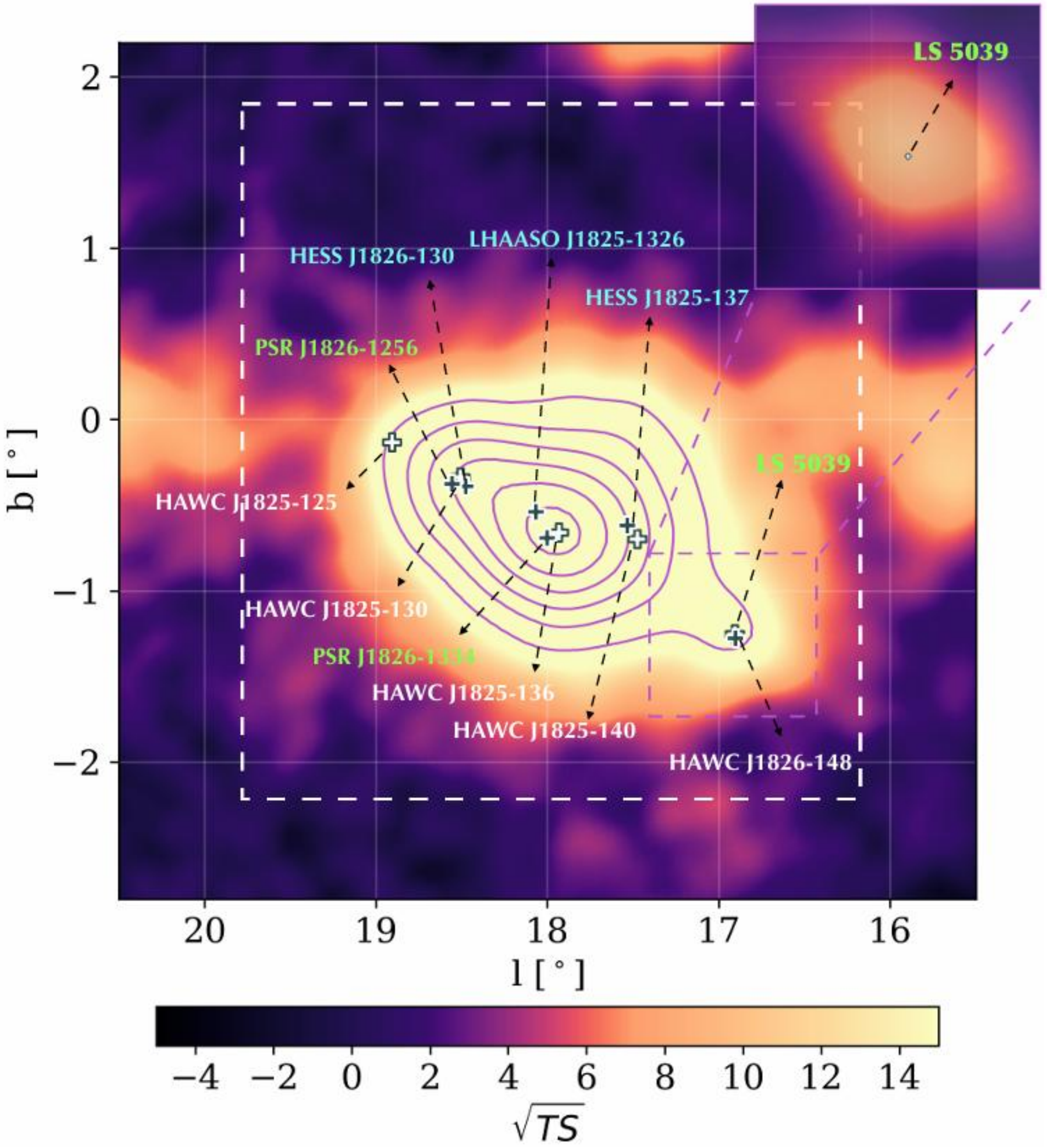
⇓

$\delta\Gamma > 0.25$ only in the lowest-flux bin

# γ-ray loud binaries

## LS 5039: HAWC results

Source detected at ~ 11 σ c.l.



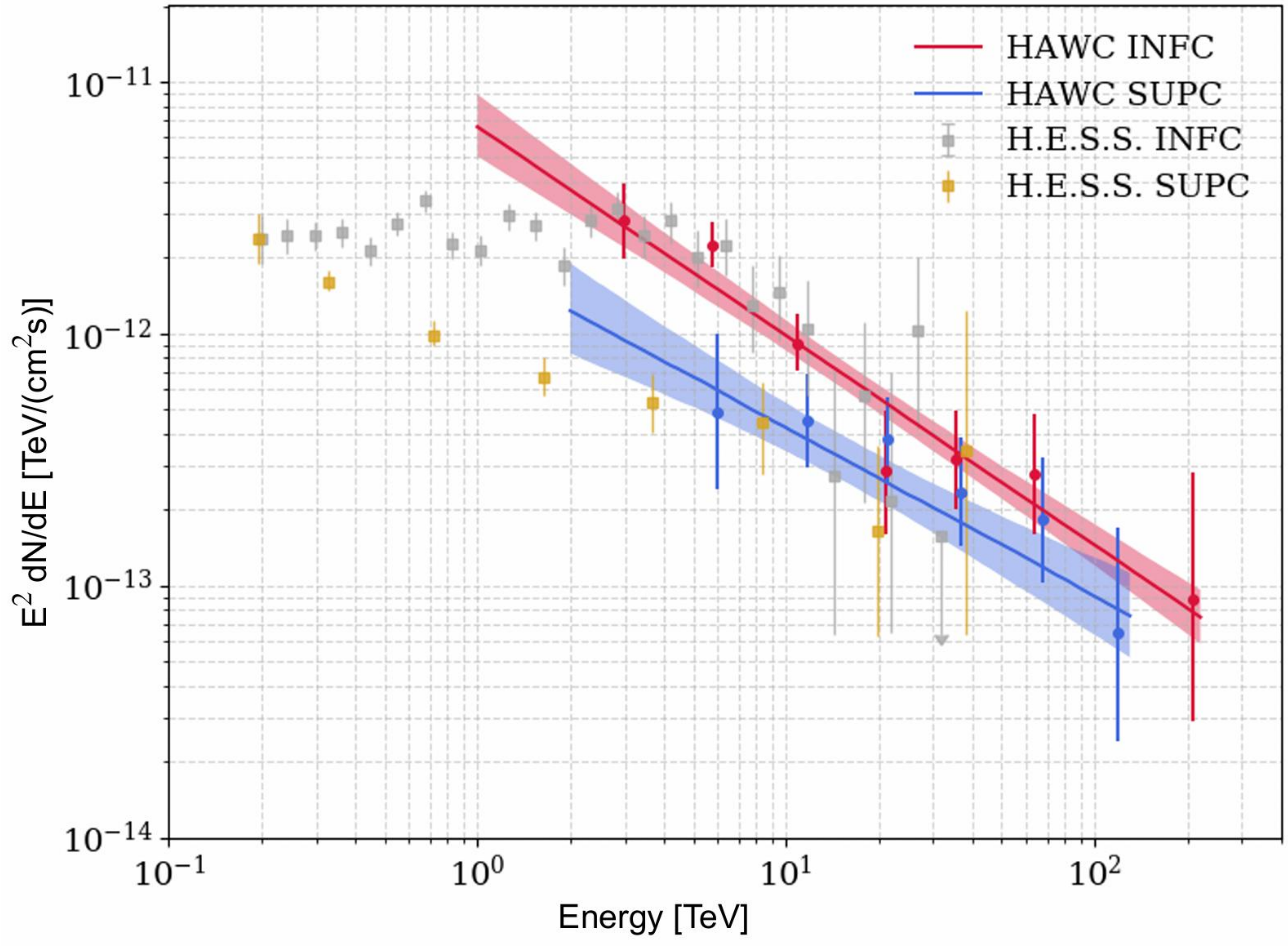

(HAWC Collaboration, 2025, ApJ 987, L42)

# γ-ray loud binaries

## LS 5039: HAWC results

Spectrum @ INFC extends up to 200 TeV with no apparent spectral cutoff

(HAWC Collaboration, 2025, ApJ 987, L42)



# $\gamma$-ray loud binaries

## LS 5039: HAWC results

(HAWC Collaboration, 2025, ApJ 987, L42)

| | Time Integrated | SUPC | INFC |
|---|---|---|---|
| R.A. (deg) | $276.54 \pm 0.004^{+0.003}_{-0.001}$ | $276.56 \pm 0.04^{+0.001}_{-0.000}$ | $276.52 \pm 0.04^{+0.003}_{-0.002}$ |
| Decl. (deg) | $-14.81 \pm 0.02 \pm 0.002$ | $-14.82 \pm 0.04^{+0.002}_{-0.001}$ | $-14.82 \pm 0.027 \pm 0.002$ |
| $K$ (TeV$^{-1}$ cm$^{-2}$ s$^{-1}$) | $(1.54^{+0.20}_{-0.18}{}^{+0.24}_{-0.22}) \times 10^{-15}$ | $(1.06^{+0.24}_{-0.2}{}^{+0.04}_{-0.14}) \times 10^{-15}$ | $(2.27^{+0.30}_{-0.26}{}^{+0.14}_{-0.29}) \times 10^{-15}$ |
| $\gamma$ | $2.76 \pm 0.10^{+0.03}_{-0.02}$ | $2.67 \pm 0.16^{+0.03}_{-0.00}$ | $2.83 \pm 0.09^{+0.02}_{-0.05}$ |
| $E_{min}$ (TeV) | 0.4 | 2.1 | 1.0 |
| $E_{max}$ (TeV) | 130 | 118 | 208 |
| TS (Equation (B1)) | 123 | 36 | 103 |

<u>Flux (2-120 TeV) modulated by the orbital motion of the system at 4.7 $\sigma$ c.l.</u>
(2.2 $\sigma$ @ E > 100 TeV)

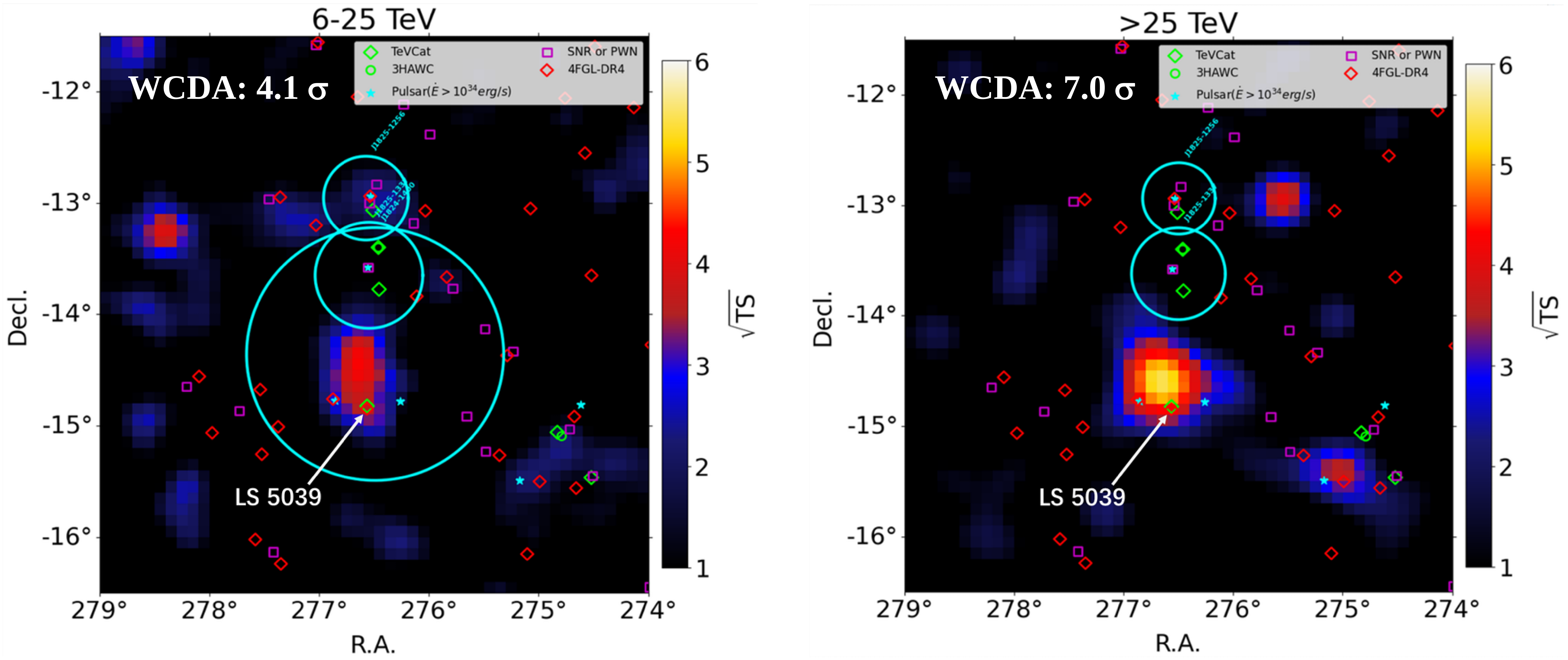
$\Downarrow$

**photons likely produced within or near the binary orbit**

# γ-ray loud binaries

## LS 5039: LHAASO results

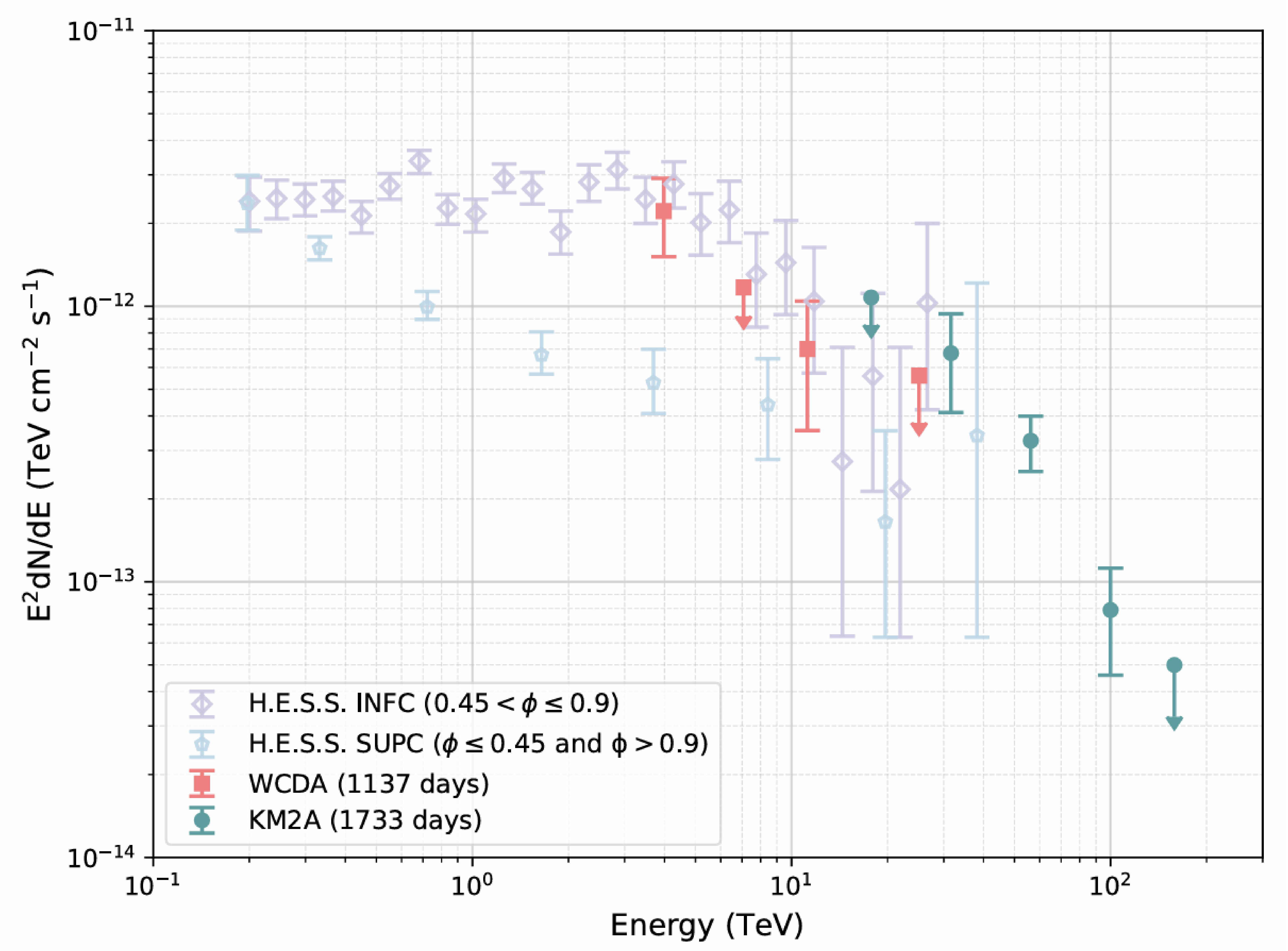
(LHAASO Collaboration, 2025, ICRC39, PoS 740)



# γ-ray loud binaries

## LS 5039: LHAASO results

Detection of VHE γ-ray emission up to 100 TeV, with no observed spectral cutoff




(LHAASO Collaboration, 2025, ICRC39, PoS 740)

# LS 5039: perspectives with ASTRI MA

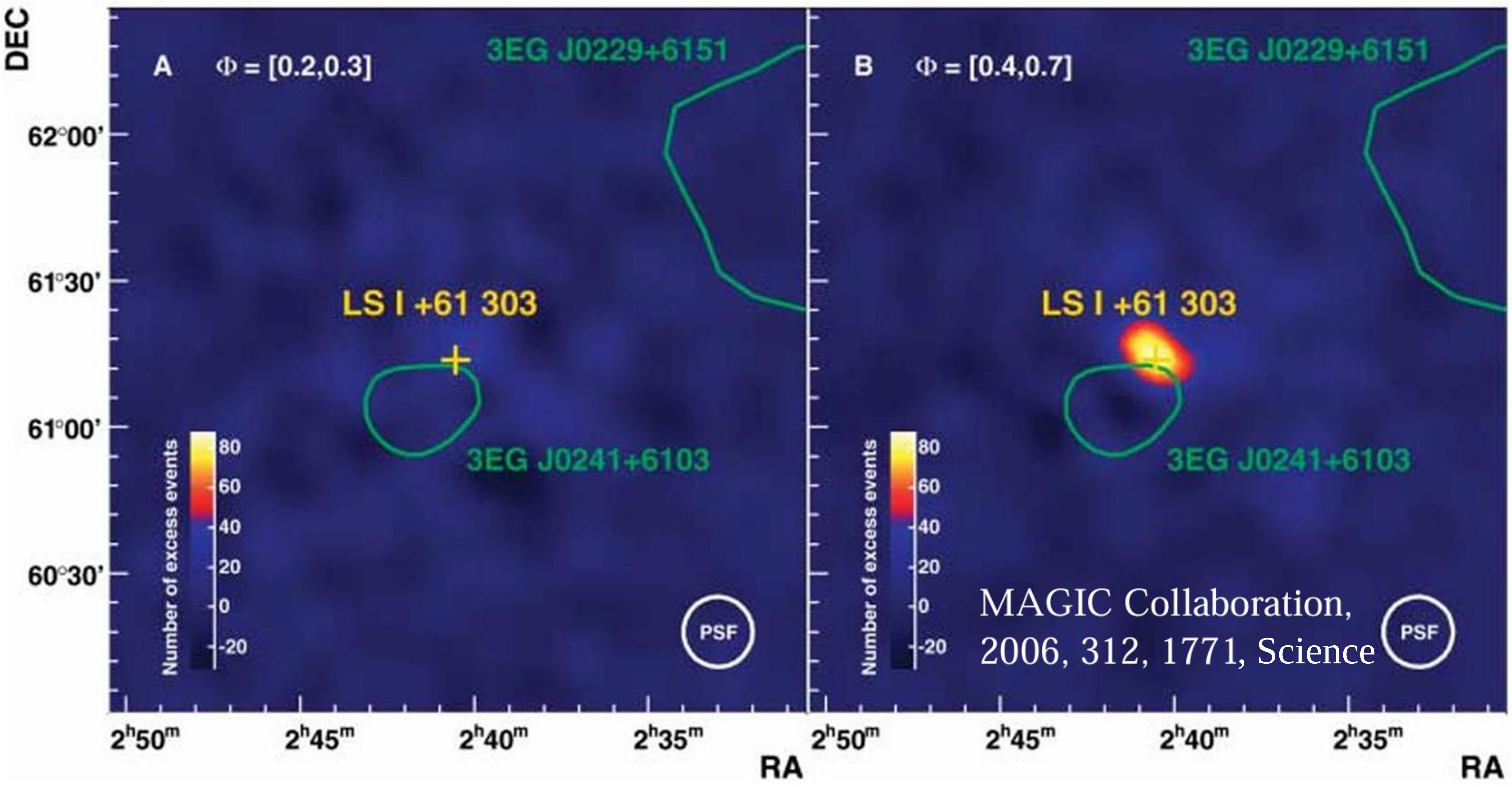
**Source visibility** (in moonless conditions): **130** h (ZA = 0-45°), **280** h (ZA = 45-60°)

- Phase-resolved spectral analysis (@ both IC and SC) up to (at least) a few tens of TeV
- Investigation of orbital modulation
- Need for deeper observations (> 50 h) of the lowest state to reach 10 % accuracy on Γ
- Investigation of the 2-peak modulation in the high state to study the emission geometry

# γ-ray loud binaries

## LS I +61° 303: MAGIC results

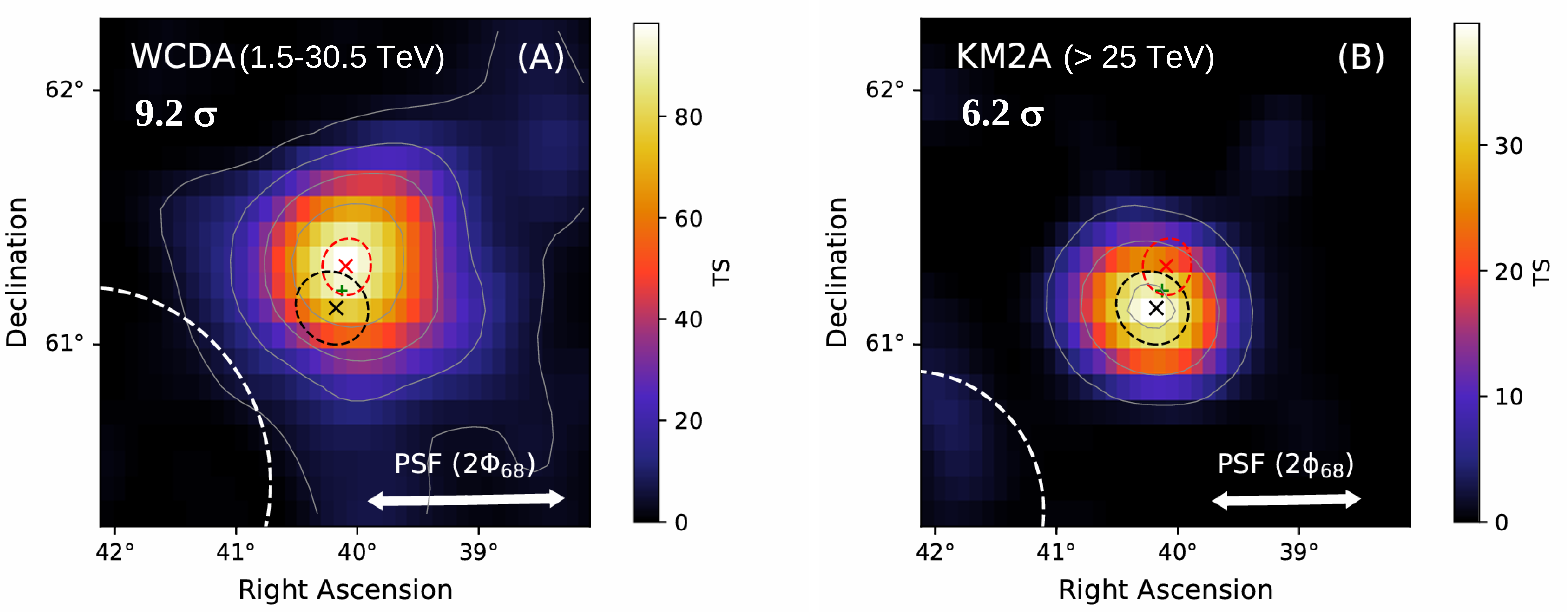
Orbital modulation of the source flux




MAGIC Collaboration, 2006, 312, 1771, Science

# γ-ray loud binaries

## LS I +61° 303: LHAASO results




(LHAASO Collaboration, 2026, PRL, arXiv:2510.23345)

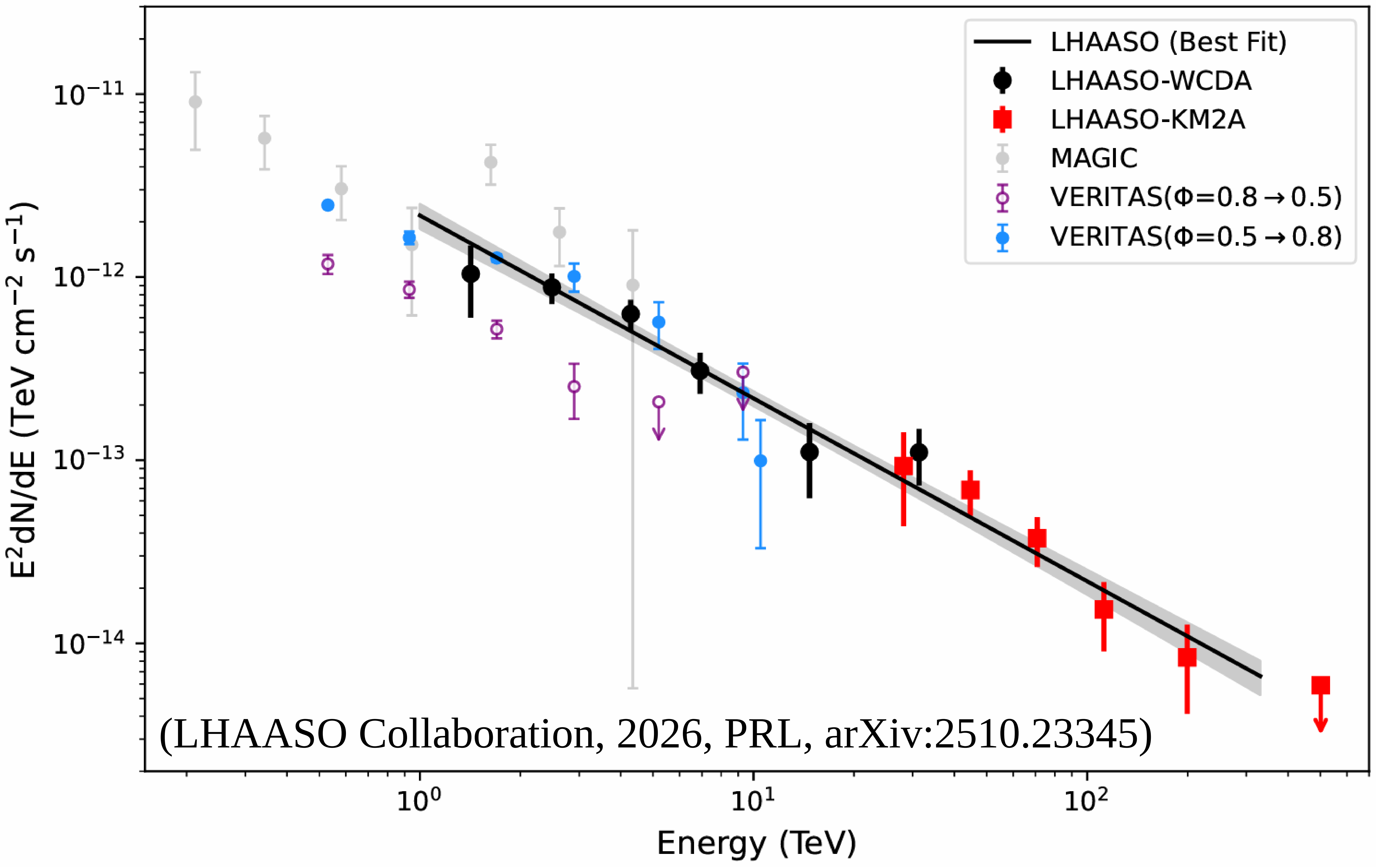
# γ-ray loud binaries

## LS I +61° 303: LHAASO results

- Emission up to 200 TeV with no apparent spectral cutoff
- Spectrum well-described with a <u>single PL model</u>:
  - N0 = (2.2±0.2)x10$^{-15}$ TeV$^{-1}$ cm$^{-2}$ s$^{-1}$
  - Γ = 3.00±0.05
  - F(> 1 TeV) = 1.1x10$^{-12}$ cm$^{-2}$ s$^{-1}$

⇓

**consistent with previous measurements by MAGIC and VERITAS**

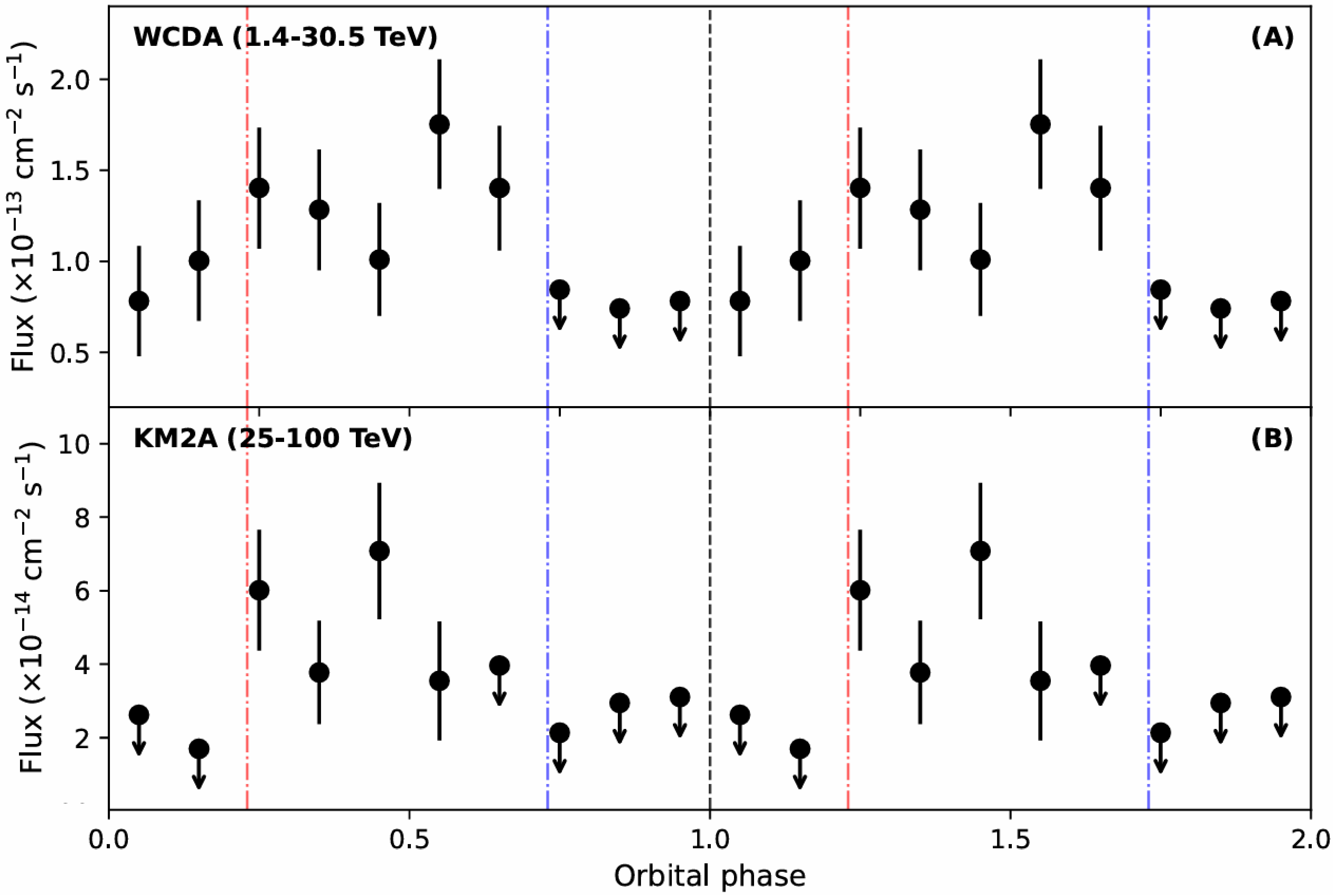


# γ-ray loud binaries

Mini-Array

## LS I +61° 303: LHAASO results

orbital modulation at 3.9 σ c.l.




(LHAASO Collaboration, 2026, PRL, arXiv:2510.23345)

# γ-ray loud binaries

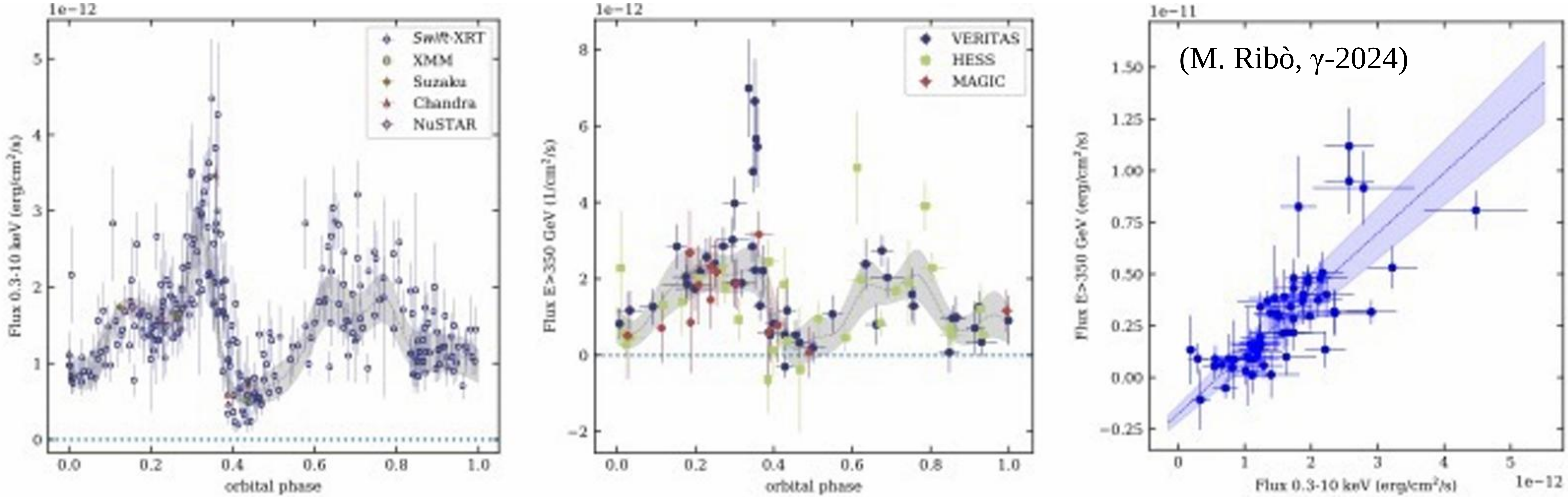
## LS I +61° 303: perspectives with ASTRI MA

**Source visibility** (in moonless conditions): **440** h (ZA = 0-45°), **310** h (ZA = 45-60°)

- Flux variability along the orbital phase
- Spectral analysis up to ~ tens of TeV
- Investigation of TeV flares (Archambault et al. 2016, ApJ 817, L7)

# γ-ray loud binaries

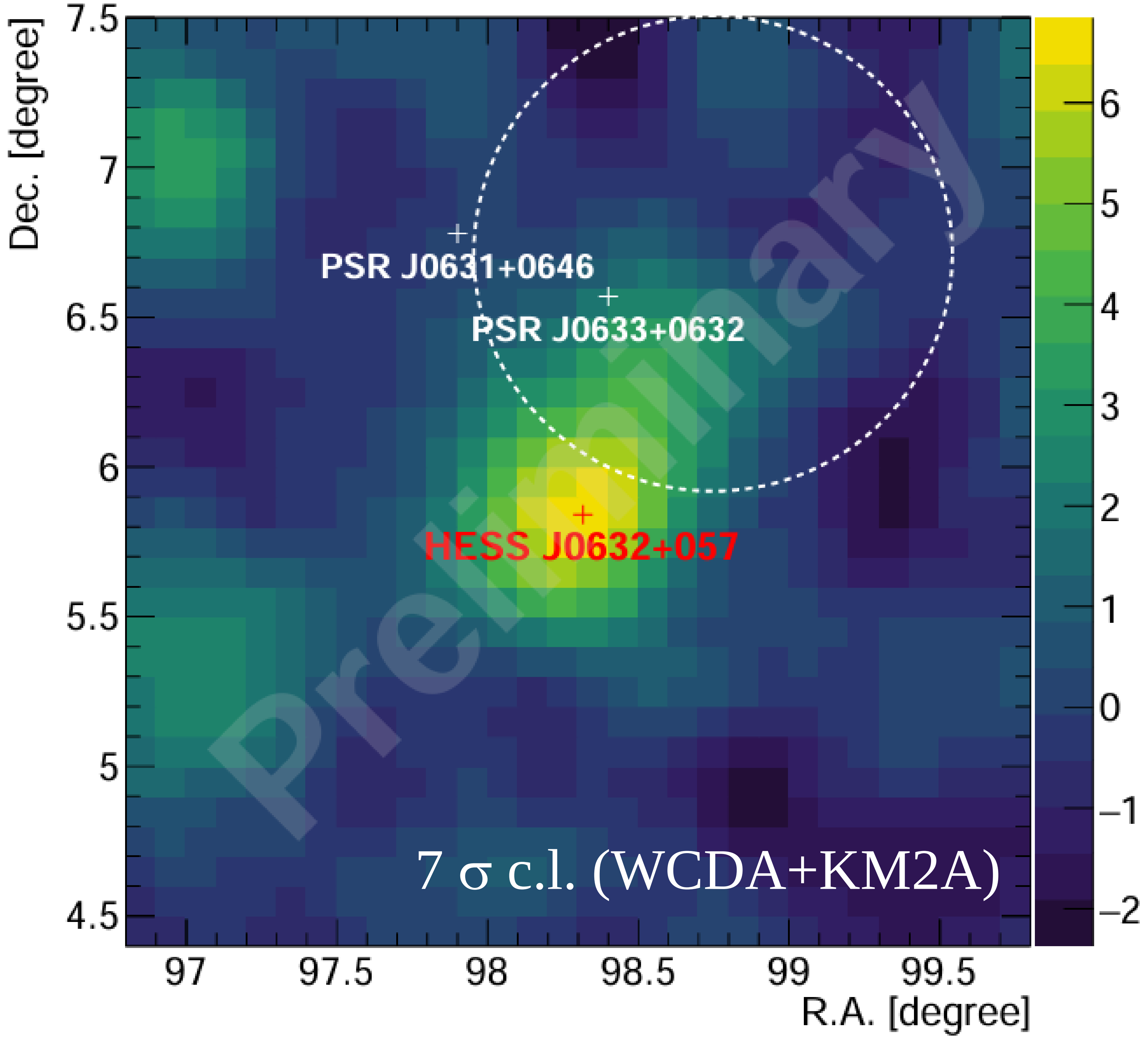
## HESS J0632+057: MAGIC/VERITAS/HESS results

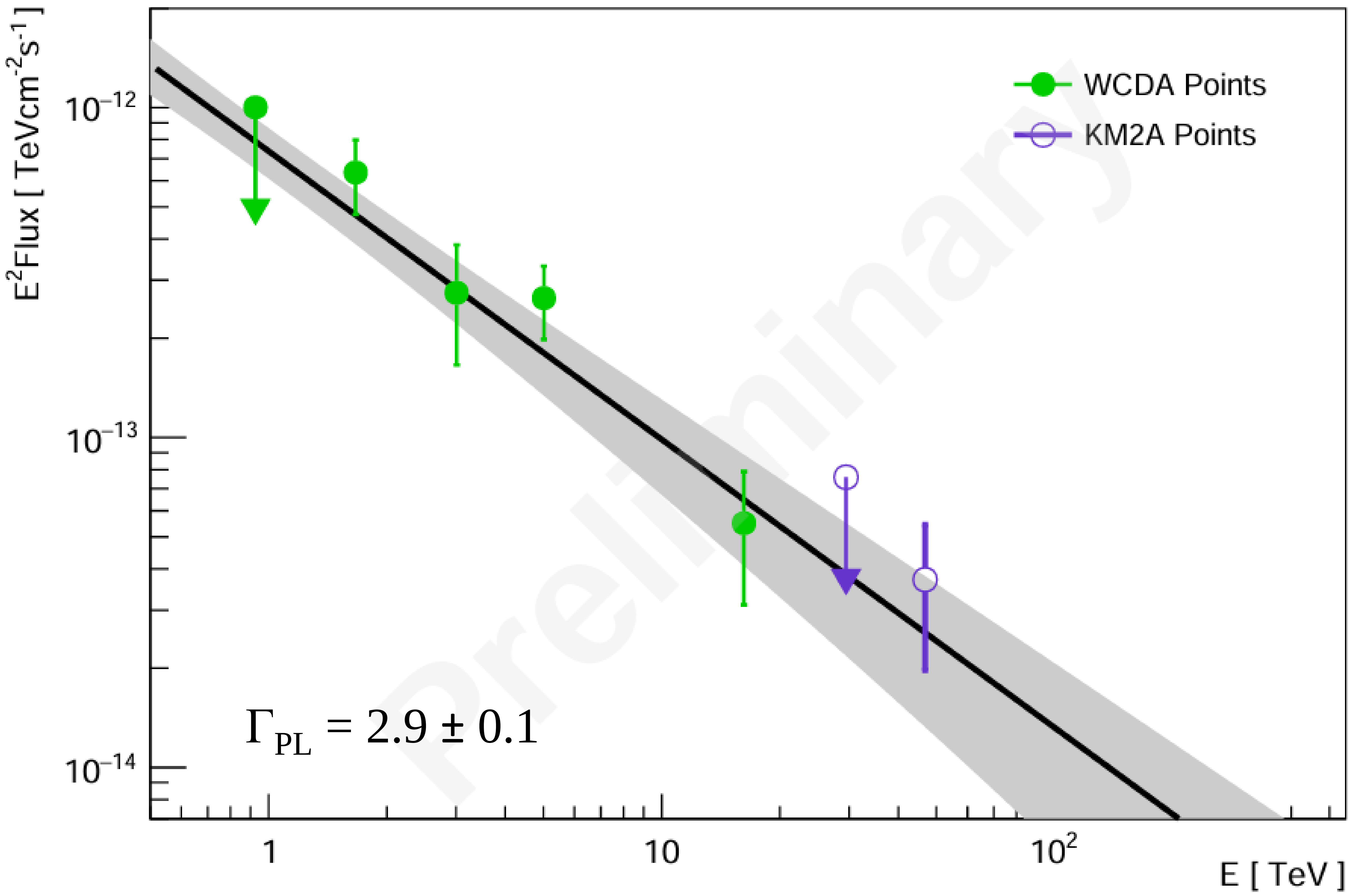



- **Orbital periodicity** of VHE emission
- **Spectra compatible with PL model** (with cut-off for orbital phases 0.2-0.4)
- Clear **X-ray/TeV correlation** with non-zero X-ray flux when TeV emission disappears

# γ-ray loud binaries

## HESS J0632+057: LHAASO results




(LHAASO Collaboration, 2025, ICRC39, PoS 761)

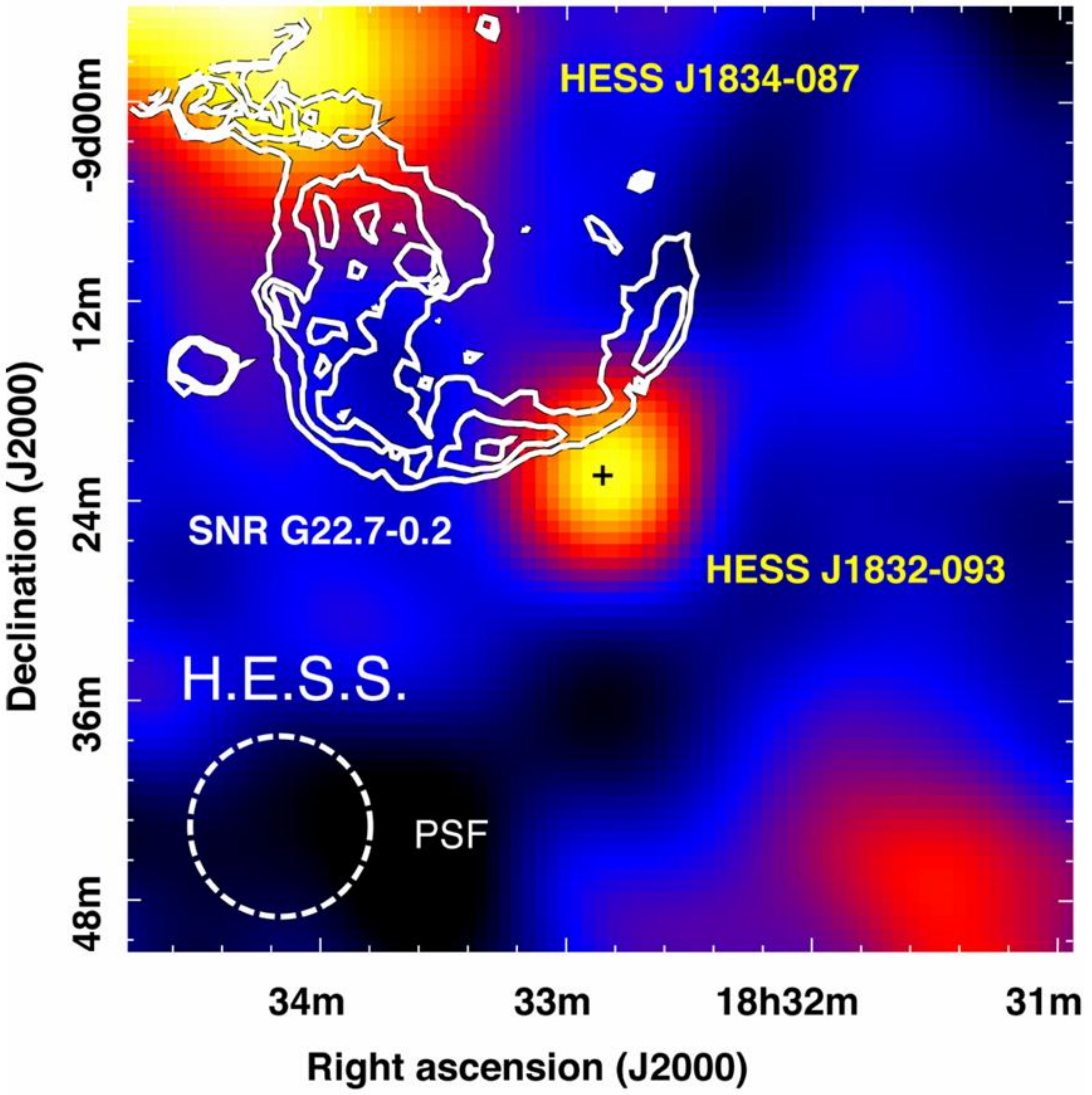
# HESS J0632+057: perspectives with ASTRI MA

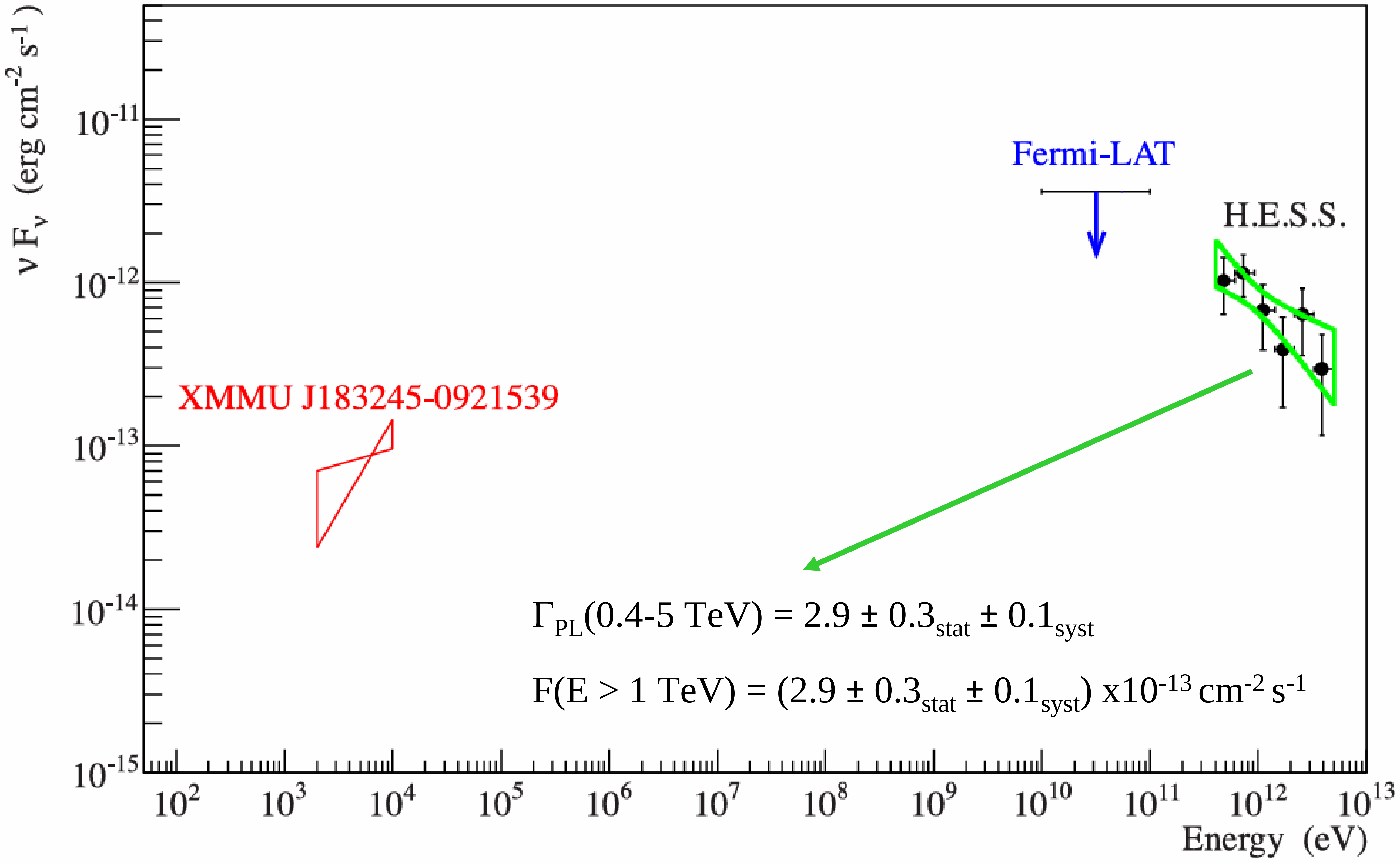
**Source visibility** (in moonless conditions): **400** h (ZA = 0-45°), **170** h (ZA = 45-60°)

- <u>Flux variability</u> along the orbital phase
- <u>Spectral analysis</u> (possibly phase resolved?)

# γ-ray loud binaries

## HESS J1832-093: HESS results




(HESS Collaboration, 2015, MNRAS, 446)

## HESS J1832-093: perspectives with ASTRI MA

- Spectral analysis

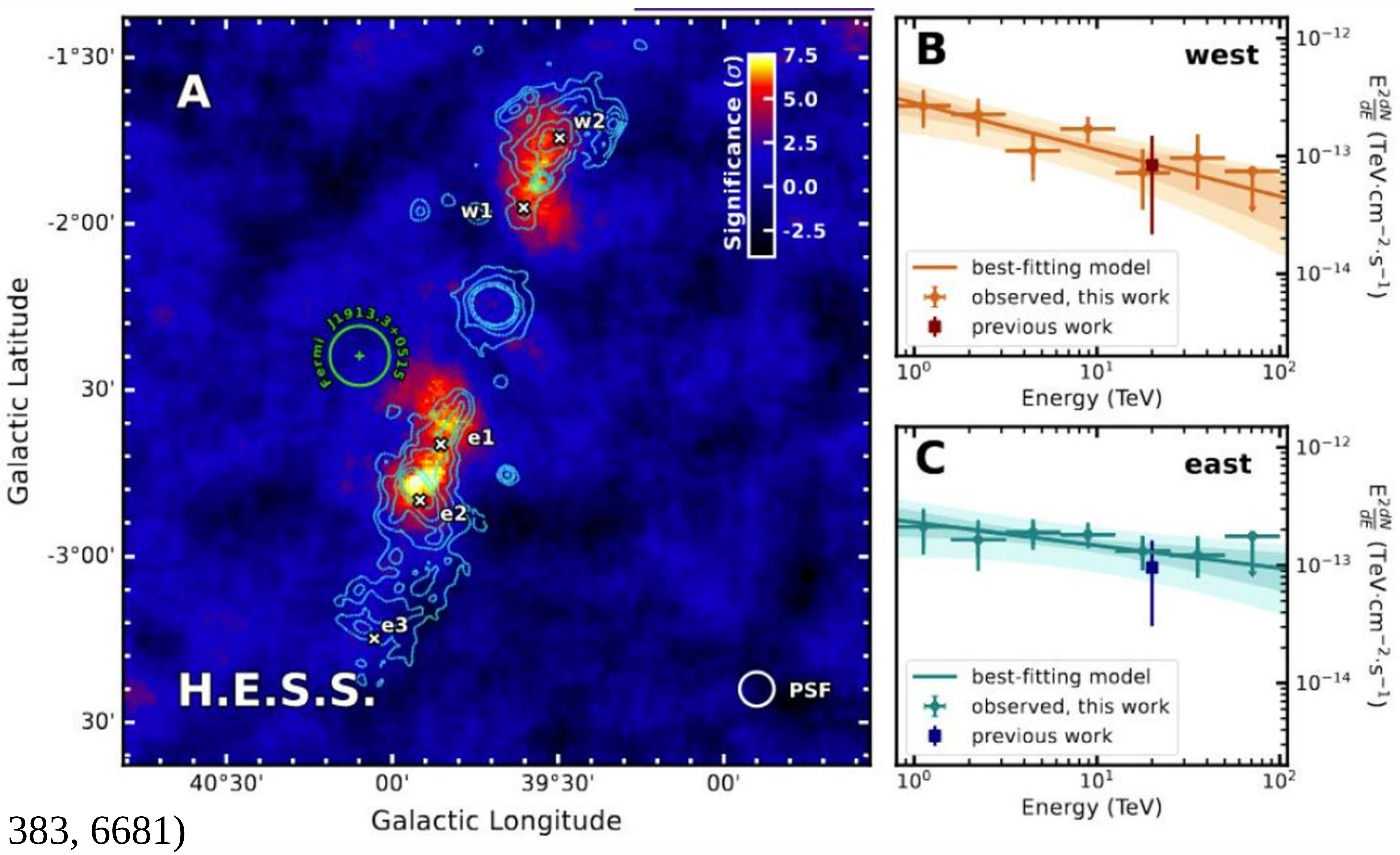
# μQSOs

## SS433: HESS results

Detection of VHE emission <u>up to ~ 50 TeV</u> @ ~ 30 pc from the central source, <u>on both E and W sides</u>, at the base of jets

Similar shape & spectrum in both cases

Emission consistent with the extended non-thermal X-ray jets.




(HESS Collaboration, 2024, Science, 383, 6681)

# SS433: HESS results

Morphology of the γ-ray emission:

- Elliptical description favoured compared with a point-like description
- In both jets spatial extension is significant (> 3σ) in both the major and minor axis directions of the ellipse

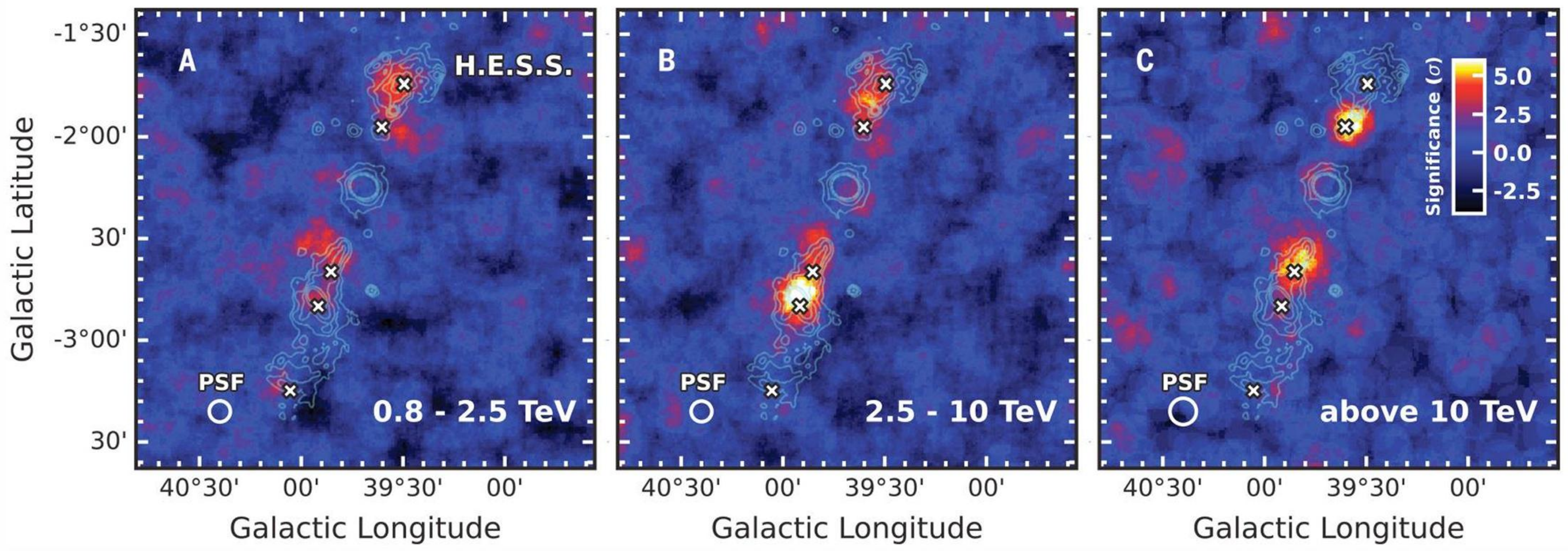
| | unit | $l$ | $b$ | $r_{\rm maj}$ | $r_{\rm min}$ | $\theta$ |
|---|---|---|---|---|---|---|
| east | deg | $39.875 \pm 0.018$ | $-2.687 \pm 0.027$ | $0.205 \pm 0.035$ | $0.044 \pm 0.014$ | -19 |
| | pc | | | $19.68 \pm 3.36$ | $4.22 \pm 1.35$ | |
| west | deg | $39.564 \pm 0.013$ | $-1.853 \pm 0.027$ | $0.134 \pm 0.036$ | $0.046 \pm 0.015$ | -19 |
| | pc | | | $12.86 \pm 3.46$ | $5.37 \pm 1.44$ | |

(HESS Collaboration, 2024, Science, 383, 6681)

# SS433: HESS results

Energy dependent morphology:

(HESS Collaboration, 2024, Science, 383, 6681)



## SS433: HESS results

Energy dependent morphology:

$\Downarrow$

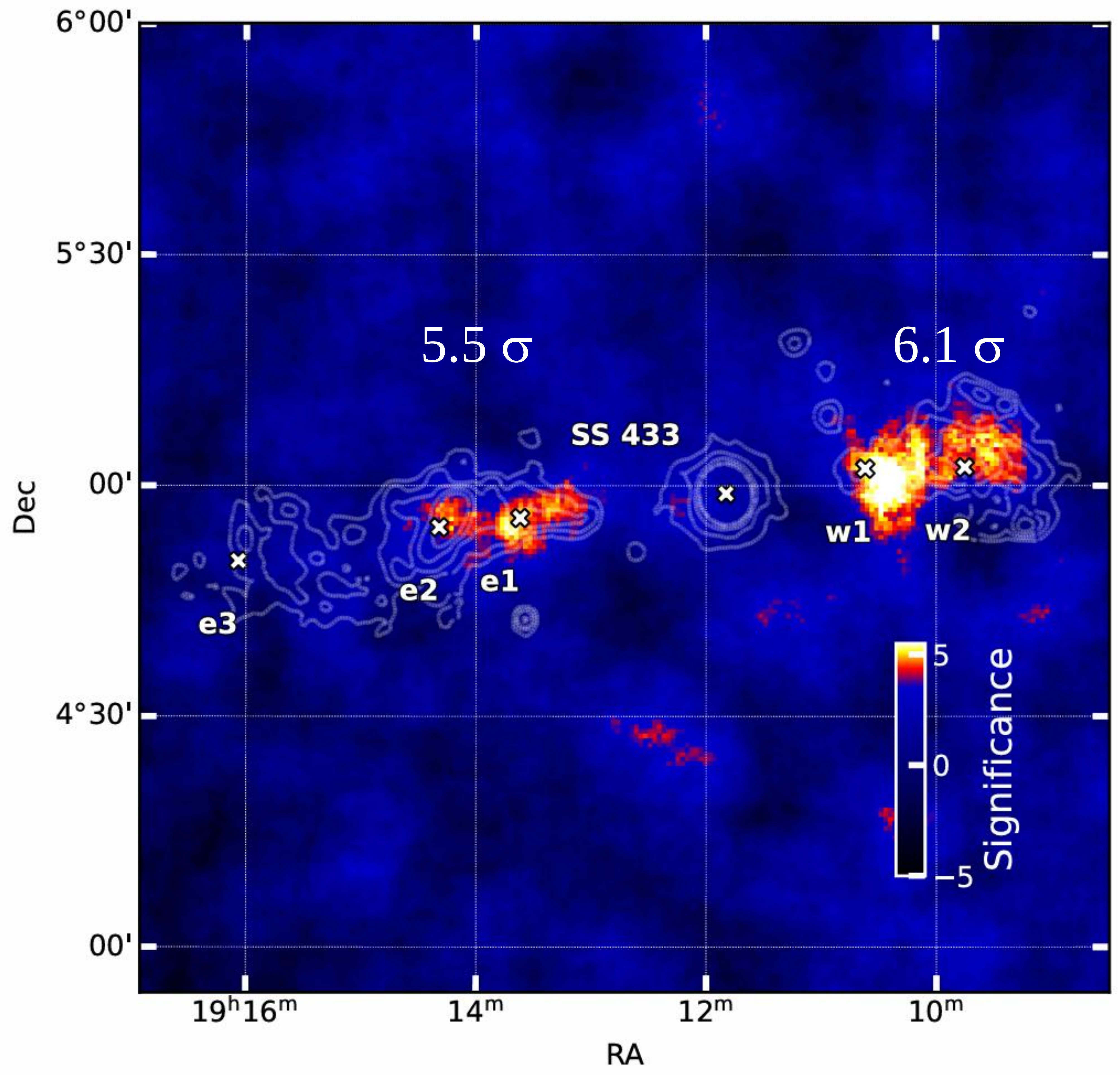
- Energy dependent energy-loss timescale for particles $\Rightarrow$ leptonic origin for TeV emission
- IC of synchrotron photons due to relativistic electrons with E up to 200 TeV
- shocks where flow velocity decreases to 0.08c

| | $\phi_0$ ($10^{-13}$ TeV$^{-1}$ cm$^{-2}$ s$^{-1}$) | $E_0$ (TeV) | $\Gamma$ |
|---|---|---|---|
| east | $2.30 \pm 0.58_{\mathrm{stat.}} \pm 0.32_{\mathrm{syst.}}$ | 1 | $2.19 \pm 0.12_{\mathrm{stat.}} \pm 0.12_{\mathrm{syst.}}$ |
| west | $2.83 \pm 0.70_{\mathrm{stat.}} \pm 0.39_{\mathrm{syst.}}$ | 1 | $2.40 \pm 0.15_{\mathrm{stat.}} \pm 0.13_{\mathrm{syst.}}$ |

# SS433: VERITAS results

150 h of observation:

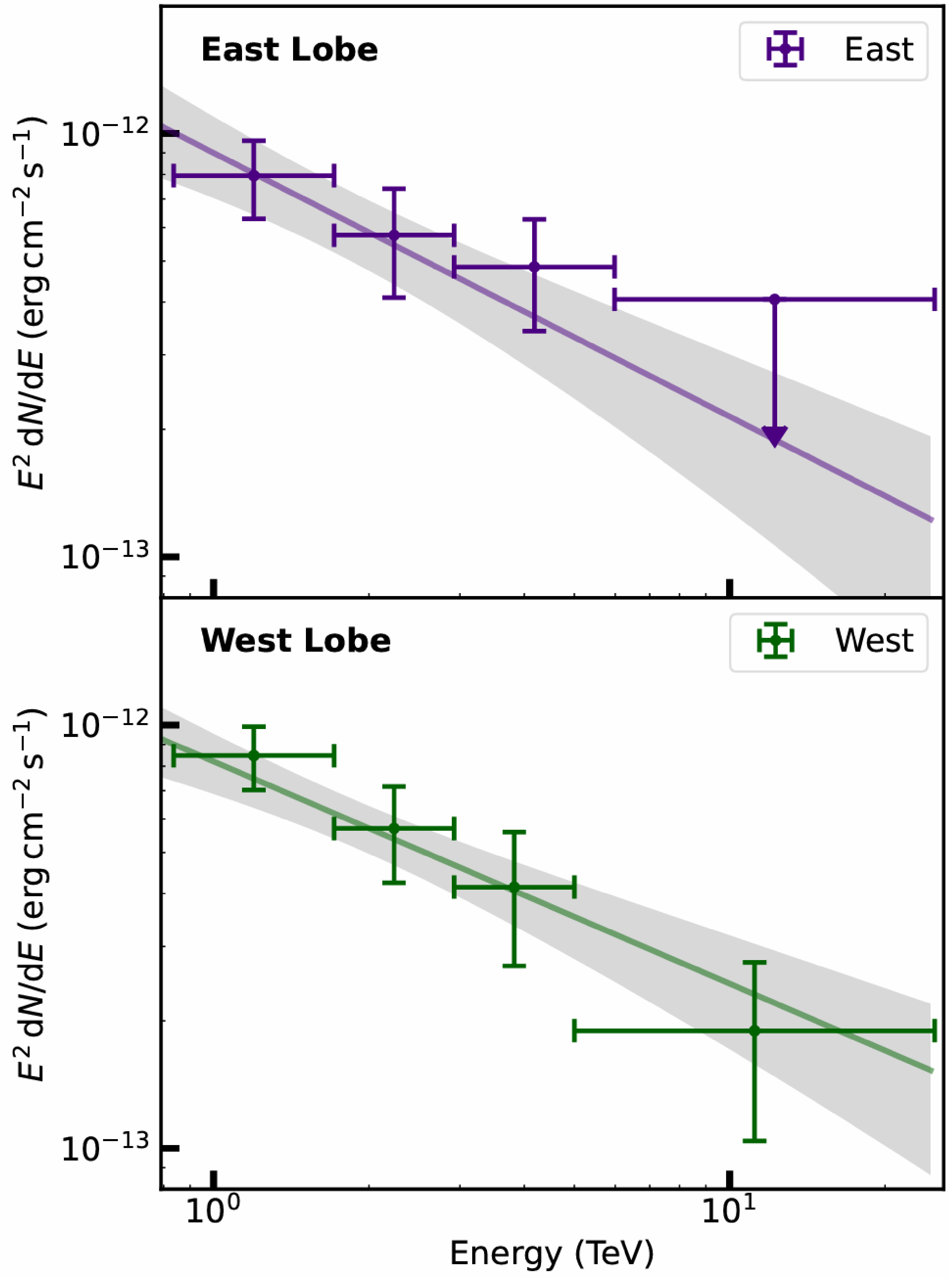
- 2 distinct emission regions corresponding to E and W jet lobes
- elongated Gaussian spatial models
- power-law spectral models
- no emission detected from the central source
- no energy-dependent morphology
- no variability (either orbital or precessional)




(VERITAS Collaboration, 2026, ApJ, 1002)

# SS433: VERITAS results

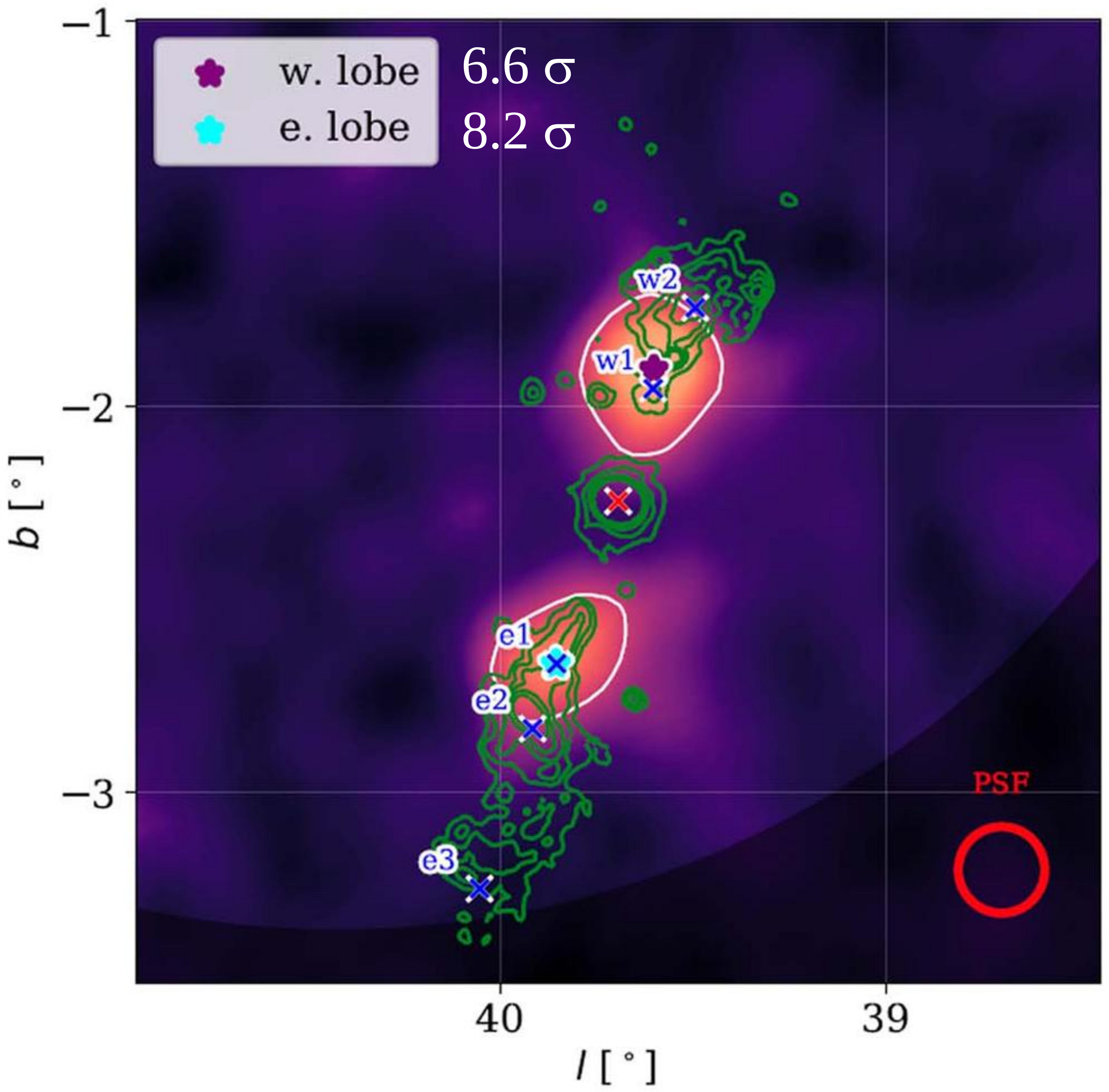
| Lobe | $\Gamma$ | $dN/dE$ $[10^{-14}]$ $[\mathrm{TeV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}]$ | $F(E \geq 0.8\,\mathrm{TeV})$ $[10^{-13}]$ $[\mathrm{cm}^{-2}\,\mathrm{s}^{-1}]$ |
|---|---|---|---|
| East | $2.62 \pm 0.20$ | $1.48 \pm 0.37$ | $4.53 \pm 1.60$ |
| West | $2.53 \pm 0.16$ | $1.55 \pm 0.28$ | $4.21 \pm 1.23$ |




- Leptonic origin favoured for the observed emission in the VERITAS energy range
- Hadronic emission subdominant

(VERITAS Collaboration, 2026, ApJ, 1002)

## SS433: HAWC results




2565 days of observation

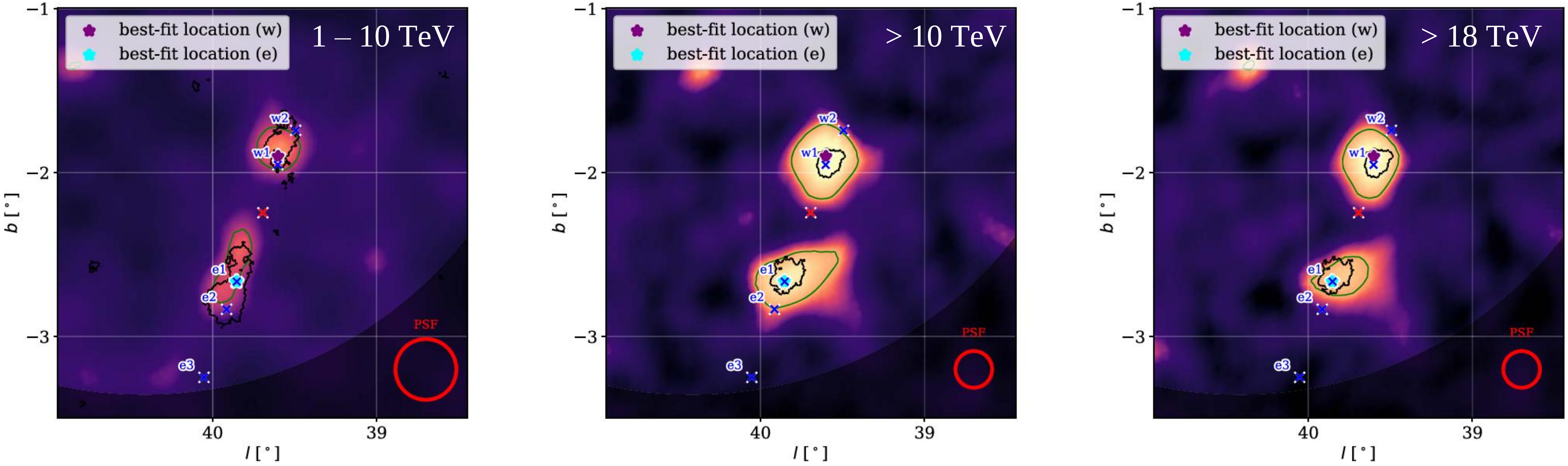
⇓

- 2 point-like sources, coincident with the E and W jet lobes
- power-law spectrum with no cutoff
- no emission from the central source

| Source | R.A., Decl. (deg, deg) | $K$ ($\mathrm{TeV^{-1}\ cm^{-2}\ s^{-1}}$) | $\alpha$ | TS |
|---|---|---|---|---|
| West lobe | $287.61^{+0.02}_{-0.02}$, $5.06^{+0.02}_{-0.02}$ | $2.02^{+0.32}_{-0.31} \times 10^{-15}$ | $-2.35^{+0.12}_{-0.11}$ | 79.5 |
| East lobe | $288.41^{+0.02}_{-0.02}$, $4.93^{+0.02}_{-0.02}$ | $1.65^{+0.28}_{-0.28} \times 10^{-15}$ | $-2.44^{+0.13}_{-0.12}$ | 53.9 |

(HAWC Collaboration, 2024, ApJ, 976)

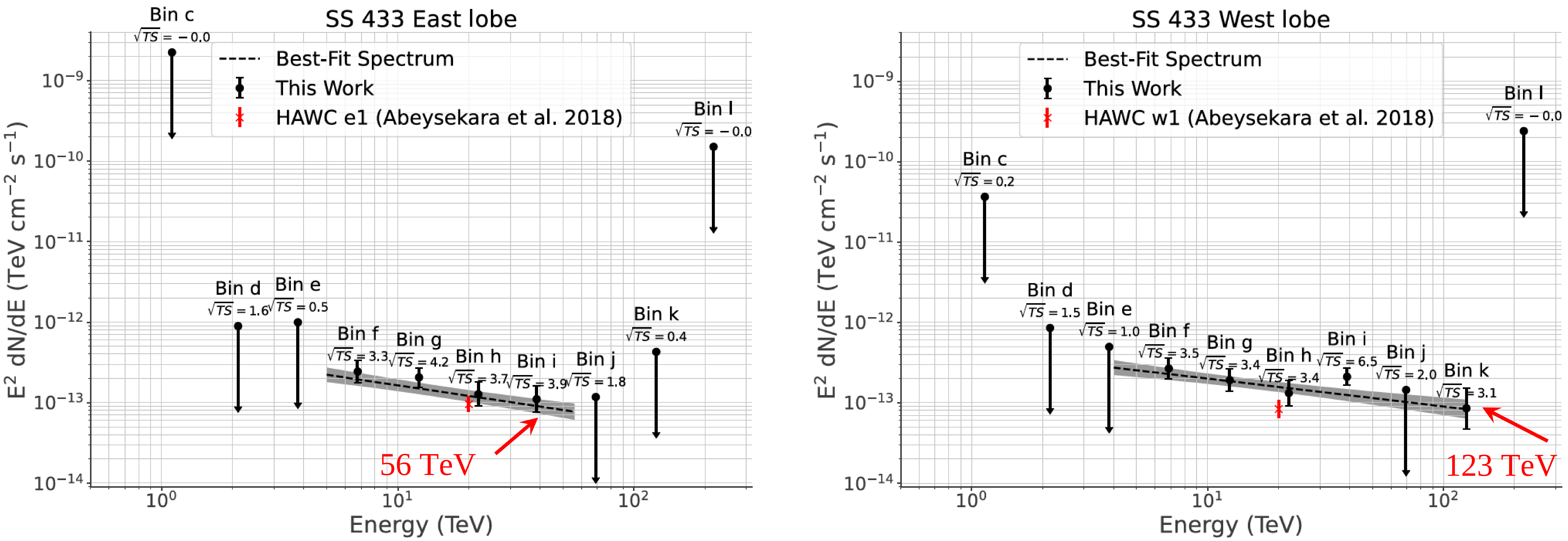
# SS433: HAWC results




- Energy-dependent morphology
- Positions consistent with HESS results

(HAWC Collaboration, 2024, ApJ, 976)

# SS433: HAWC results



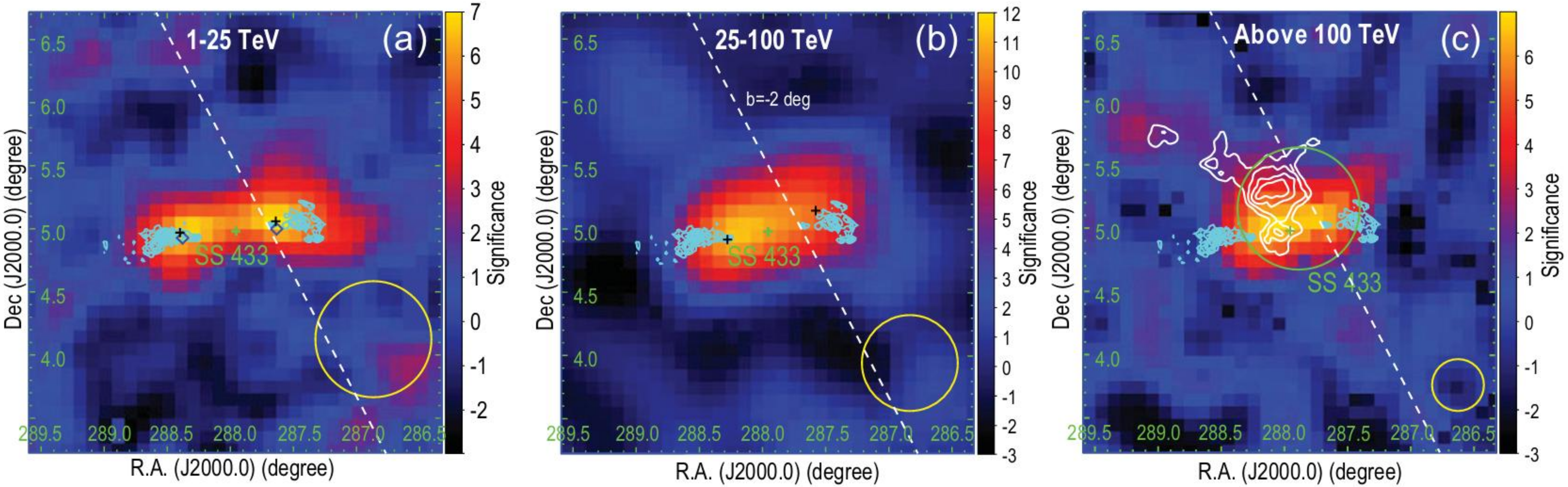

(HAWC Collaboration, 2024, ApJ, 976)

VHE emission due to a population of efficiently accelerated electrons

# µQSOs

## SS433: LHAASO results

(LHAASO Collaboration, 2025, NSR, 496)

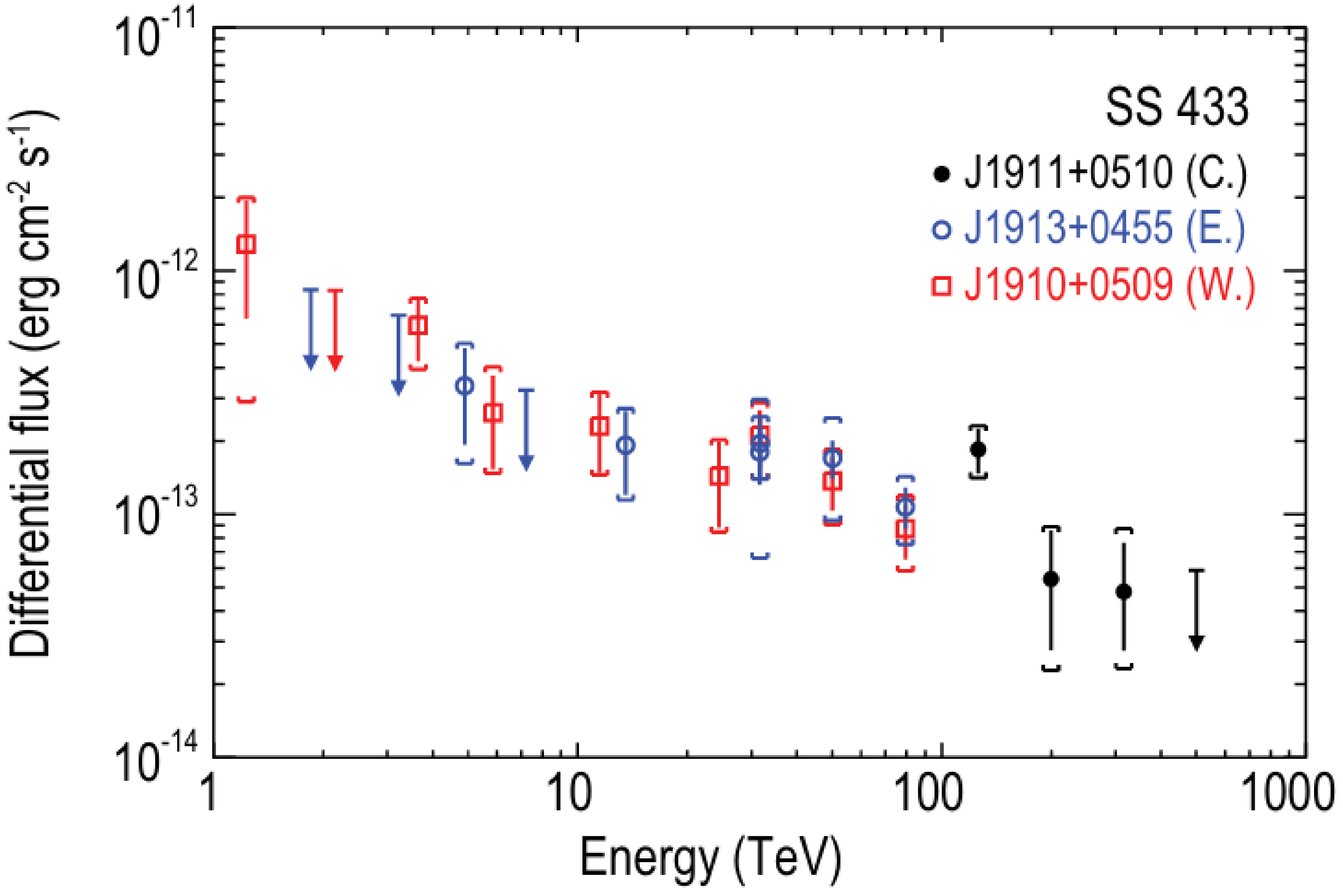



2 point-like sources associated with X-ray lobes

1 extended source associated with a giant molecolar cloud

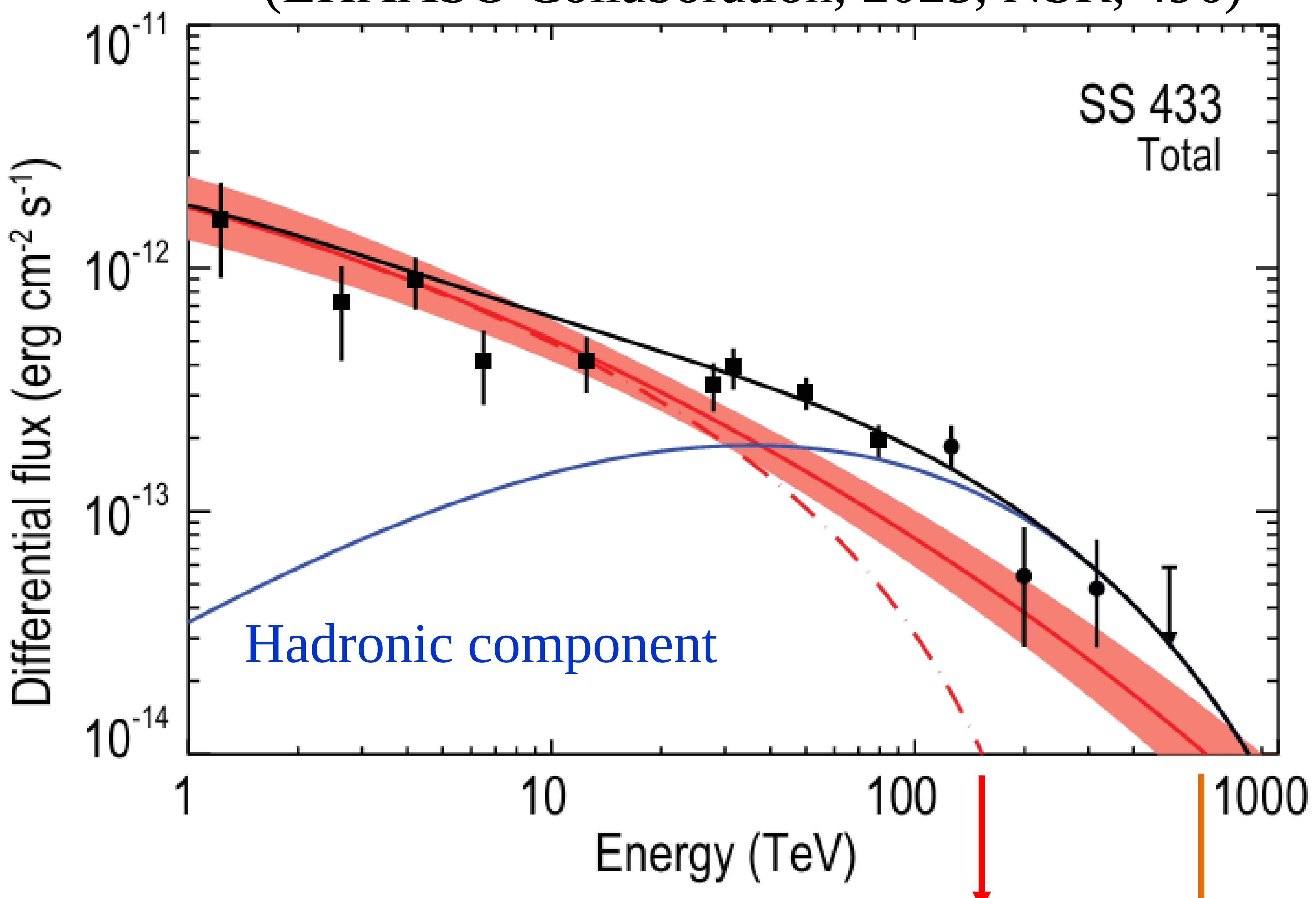
# μQSOs

## SS433: LHAASO results




(LHAASO Collaboration, 2025, NSR, 496)

(LHAASO Collaboration, 2025, NSR, 496)




Leptonic component ($E_{e\text{-}cut}$ = 0.2 PeV)

Leptonic component ($E_{e\text{-}cut}$ = 10 PeV)

# μQSOs

## SS433: LHAASO results

(LHAASO Collaboration, 2025, NSR, 496)

| Microquasar | Distance (kpc) | LHAASO Source | Significance ($\sigma$) | Photon index | Energy range (TeV) | Extension[a] | Flux[b] (Crab unit) |
|---|---|---|---|---|---|---|---|
| SS 433 E. | $4.9 \pm 0.4$ [31] | J1913+0455 | 9.9[c] | $2.82 \pm 0.16$ | 25-100 | $0.73^\circ \pm 0.07^\circ$ | 0.10 |
| SS 433 W. | | J1910+0509 | 6.3[c] | $2.94 \pm 0.38$ | 25–100 | | 0.082 |
| SS 433 central | | J1911+0510 | 8.0 | $3.96 \pm 0.25$ | 100–630 | $0.32^\circ \pm 0.04^\circ$ | 0.32 |

3 distinct sources:

- **E > 100 TeV:** 1 extended source ~ 0.25° North of the BH, spatially coincident with a giant atomic cloud ⇒ hadronic origin via the p-p collision between accelerated protons and H nuclei in the cloud
- **E < 100 TeV:** 2 point-like sources (expecially at E < 25 TeV), associated with E and W X-ray lobes, spatially consistent with HESS and HAWC sources ⇒ mainly leptonic origin

# SS433: perspectives with ASTRI MA

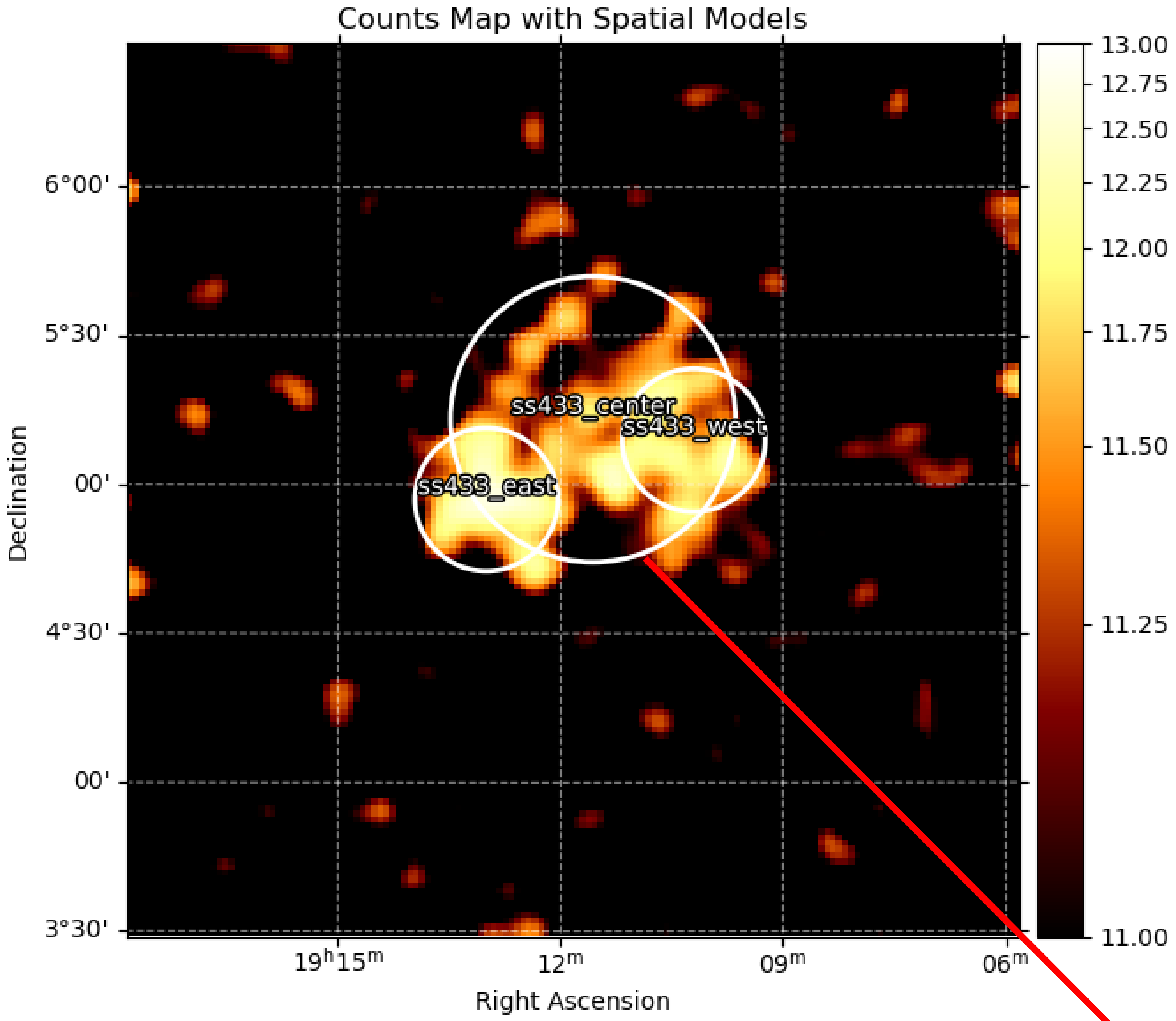
**Source visibility** (Moonless + Dark conditions): **410** h (ZA = 0-40°), **280** h (ZA = 40-60°)

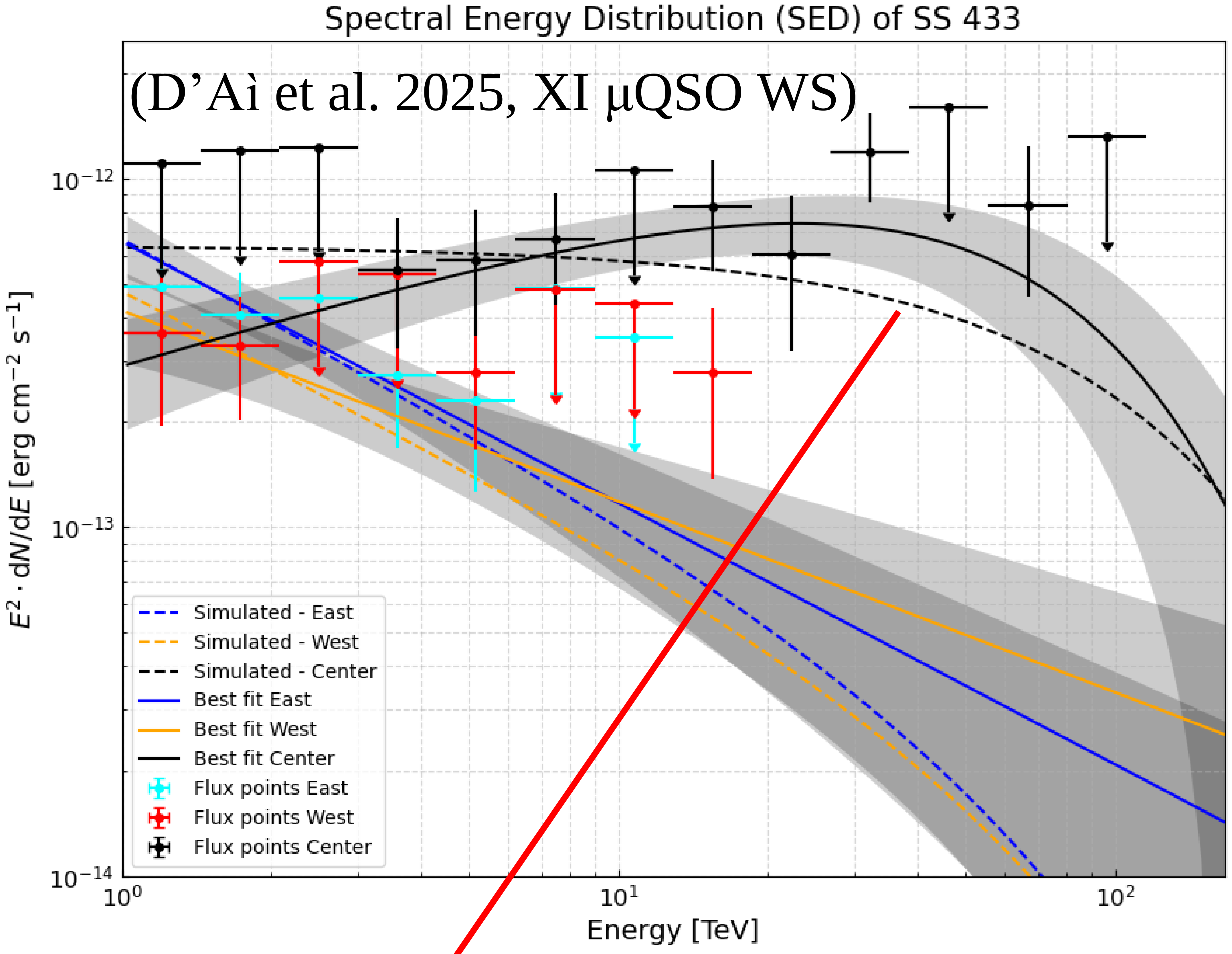
$\Downarrow$

- morphological analysis of both central source and external lobes with spatial models
- spectral analysis of both central source and external lobes with new models
- (energy dependent) morphology (ASTRI MA angular resolution)

# μQSOs

## SS433: perspectives with ASTRI MA

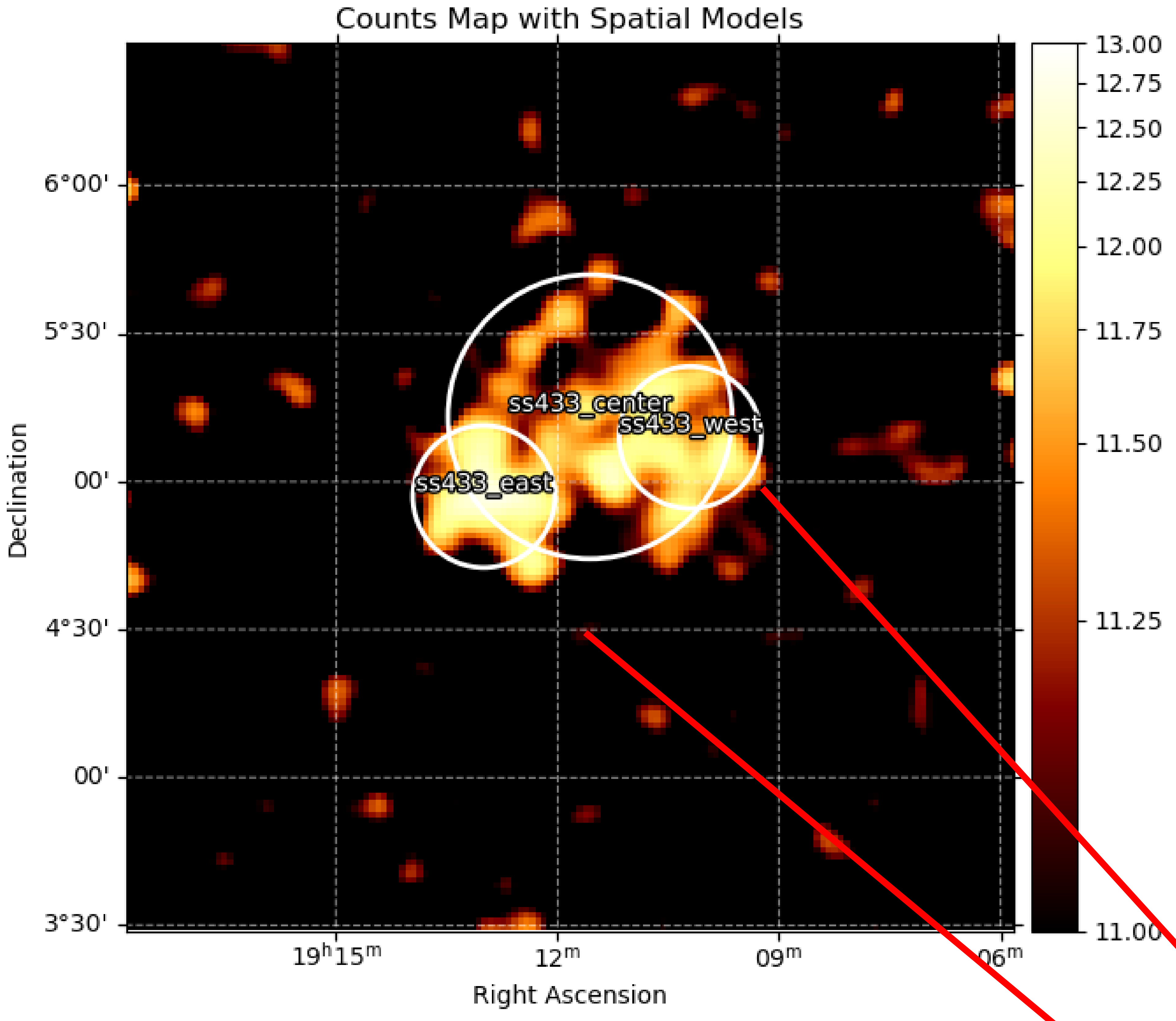


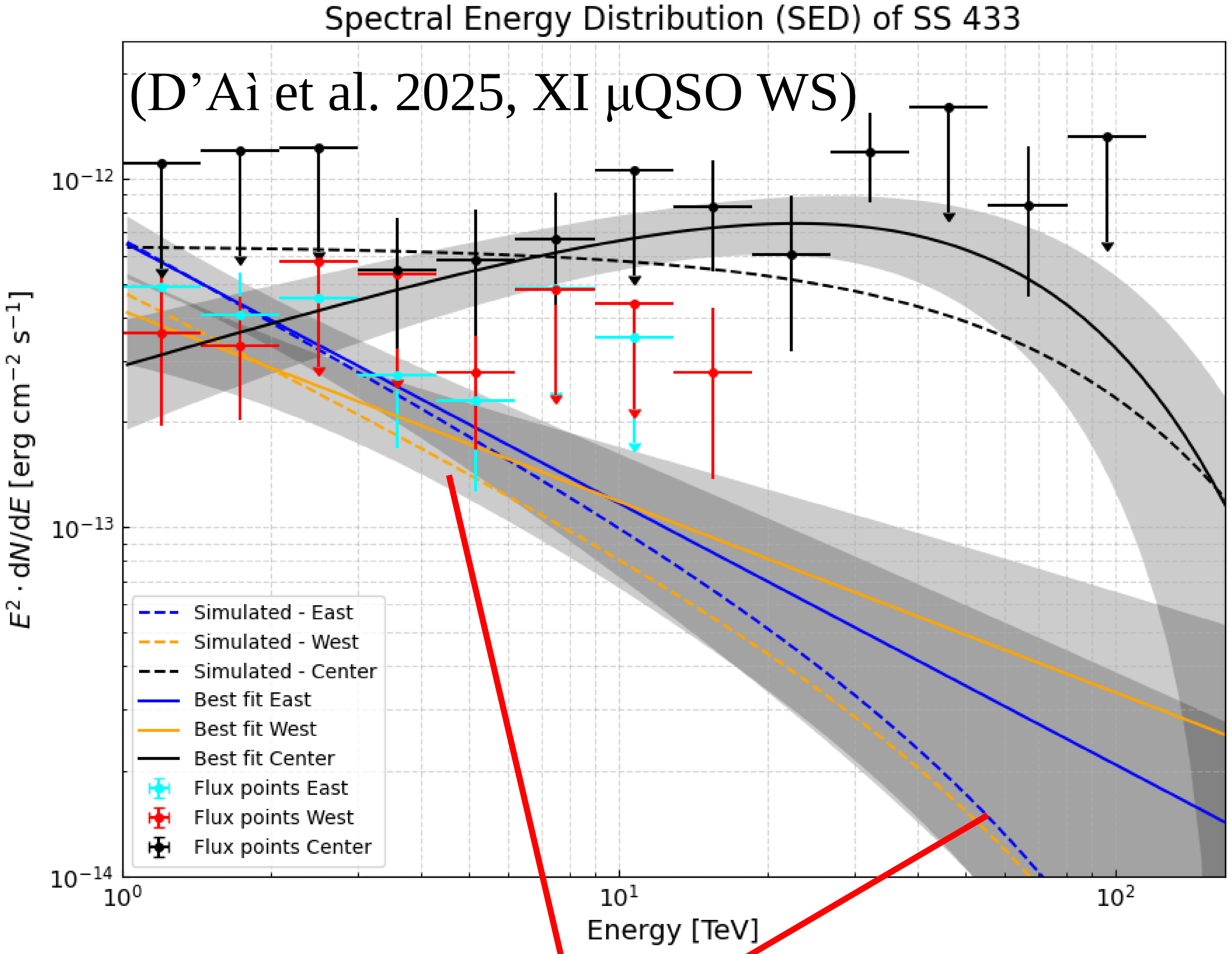




<u>Central source</u>: 300 h, 0.32° σ Gaussian spatial model, CPL (Γ = 2, $E_{cut}$ = 100 TeV)

# μQSOs

## SS433: perspectives with ASTRI MA



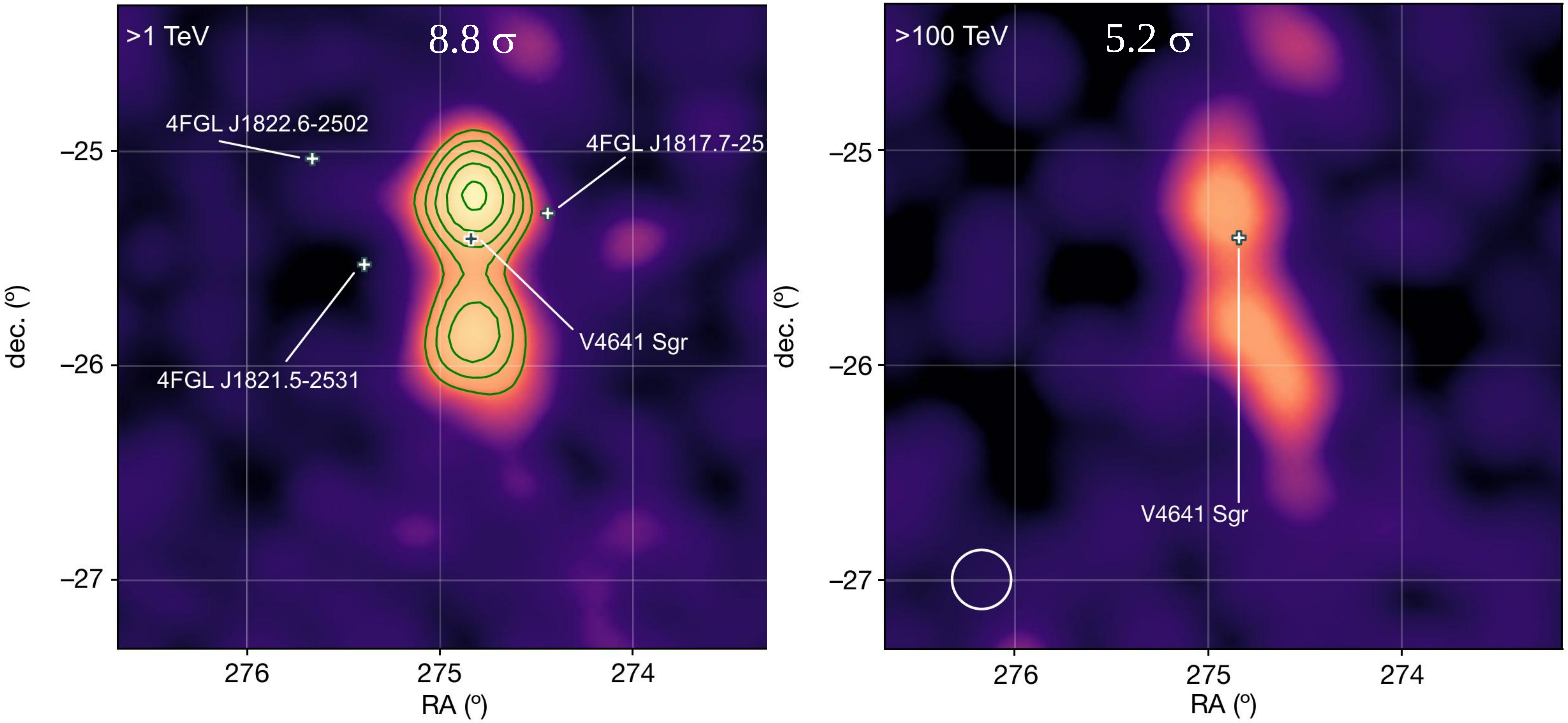




Extended E/W lobes: 300 h, 0.16° σ Gaussian spatial model, CPL ($\Gamma = 2.8$, $E_{cut} = 80$ TeV)

# μQSOs

## V4641 Sgr: HAWC results

~ 2400 days of observation
⇓
detection of extended emission up to > 100 TeV
⇓
either
2 point-like sources
or
1 extended source




(HAWC Collaboration, 2024, Nature, 634)

# μQSOs

ASTRI Mini-Array

## V4641 Sgr: HAWC results

(HAWC Collaboration, 2024, Nature, 634)

| Source name | RA (°) | dec. (°) | $N_0$ (×$10^{-16}$cm$^{-2}$TeV$^{-1}$s$^{-1}$) | Index ($\alpha$) | Extension upper limit at 95% confidence level (°) | Physical distance to the black hole (distance: 6.6 kpc) | |
|---|---|---|---|---|---|---|---|
| Southern | 274.82 ± 0.04 | −25.87 ± 0.03 | $2.4^{+0.6}_{-0.5}$(stat.)$^{+0.2}_{-0.5}$(syst.) | −2.2 ± 0.2(stat.)$^{+0.07}_{-0.02}$(syst.) | 0.23 | 0.46° ≈ 55 pc | 8.1 σ |
| Northern | 274.82 ± 0.03 | −25.18 ± 0.02 | $2.6^{+0.5}_{-0.4}$(stat.)±0.4(syst.) | −2.2 ± 0.2(stat.)$^{+0.07}_{-0.05}$(syst.) | 0.17 | 0.23° ≈ 30 pc | 6.7 σ |

The optimal pivot energy, $E_0$, is 47 TeV for both sources.

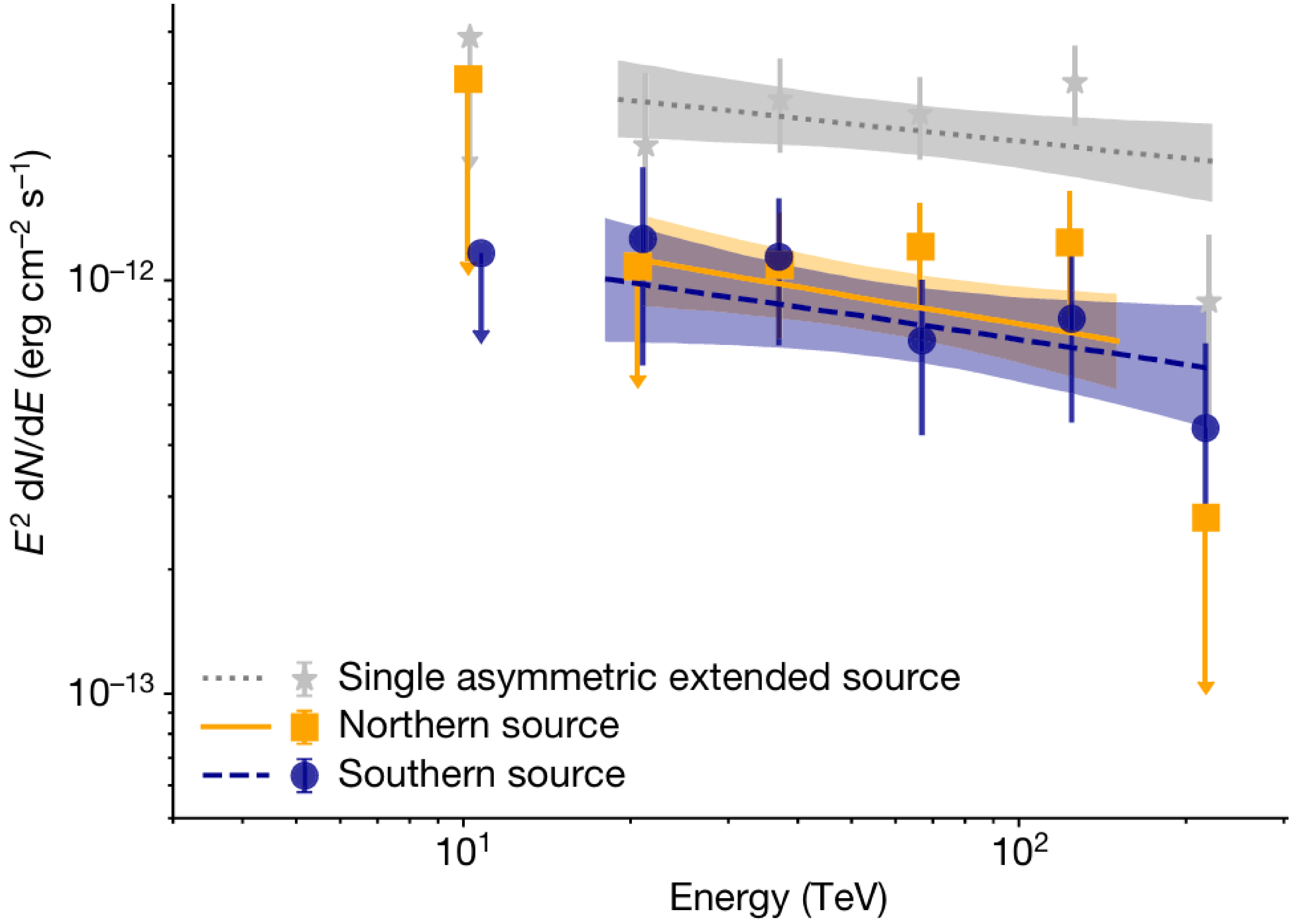
very hard spectrum

# μQSOs

## V4641 Sgr: HAWC results

almost identical flux amplitudes
and spectral indices
⇓
common origin

PL spectrum (Γ = 2.2) up to 220
TeV without cutoff
⇓
leptonic scenario challenging



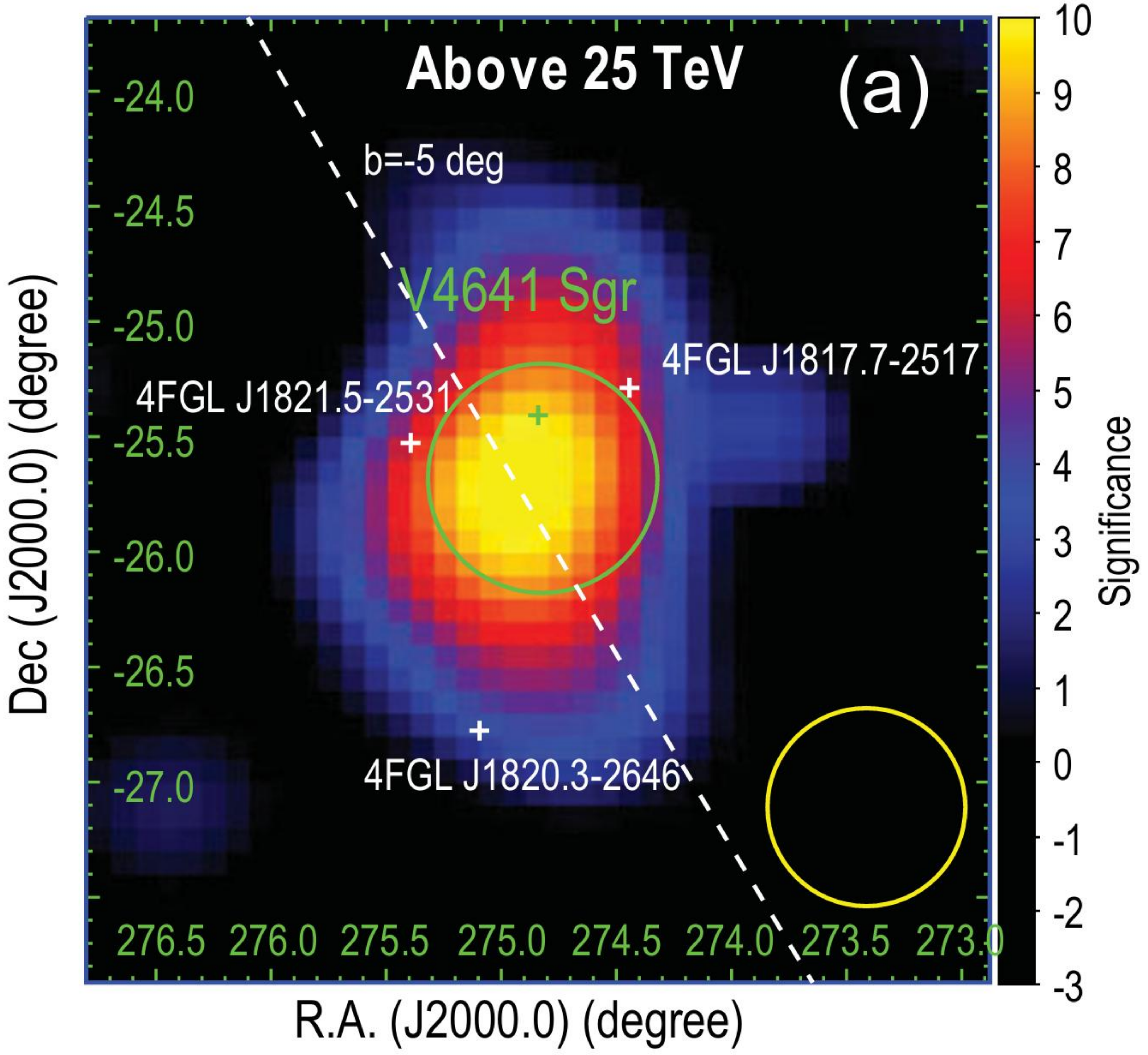

(HAWC Collaboration, 2024, Nature, 634)

# V4641 Sgr: LHAASO results

LHAASO-KM2A observing time: 290 days with ½ array + 216 days with ¾ array + 1228 days with full array

⇓

Extended source LHAASO J1819-2541 (0.33°) detected @ 10.5 σ c.l., offset from V4641 Sgr by ~ 0.19°




(LHAASO Collaboration, 2025, NSR, 496)

# μQSOs

## V4641 Sgr: LHAASO results

- PL spectrum:
  $\Gamma = 2.84$
  $E_{max} = 0.8$ PeV

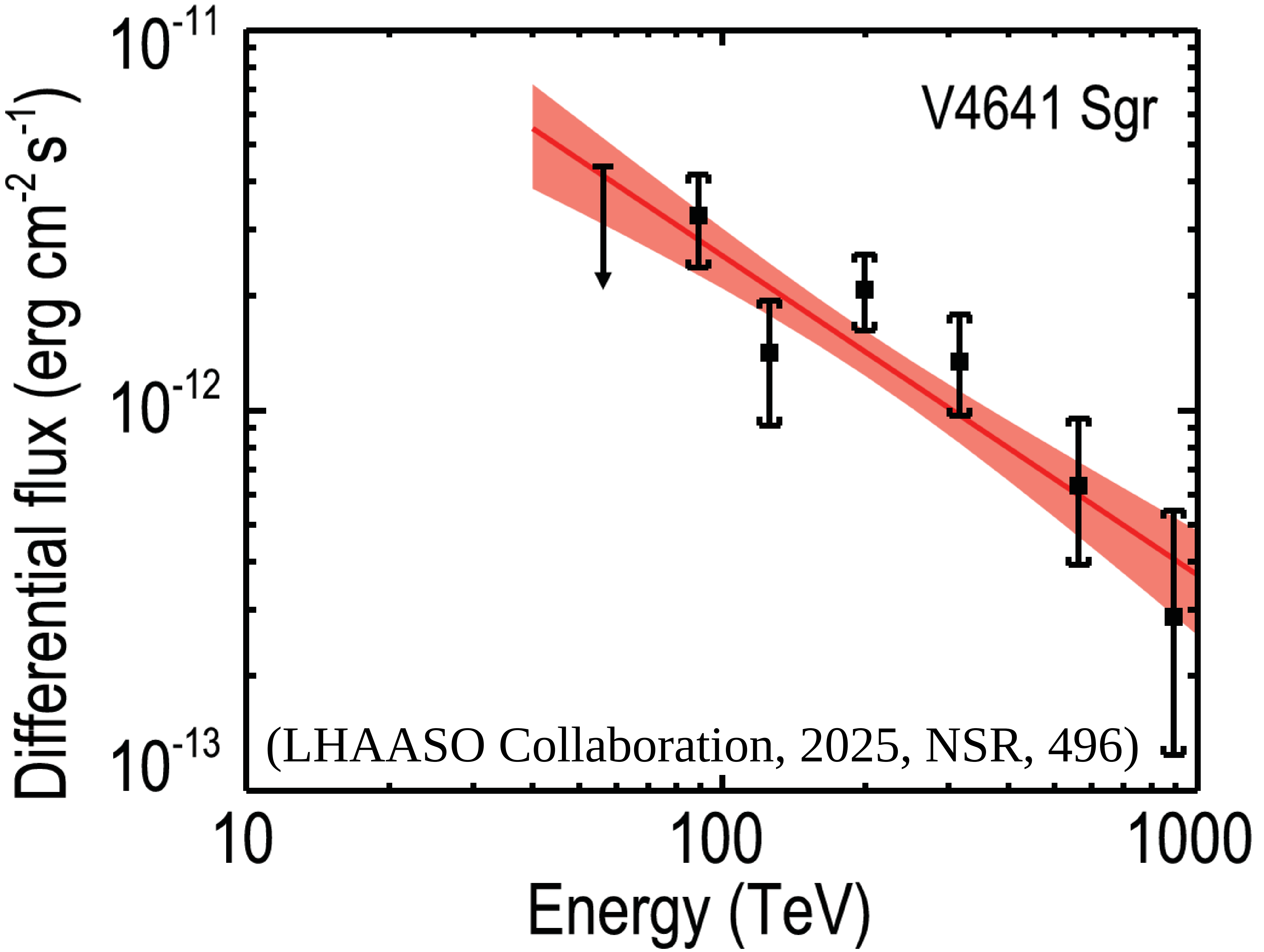
$\Downarrow$

IC radiation from leptons unlikely, hadronic origin favoured

- No cutoff

$\Downarrow$

possible super-PeVatron with proton acceleration up to 10 PeV

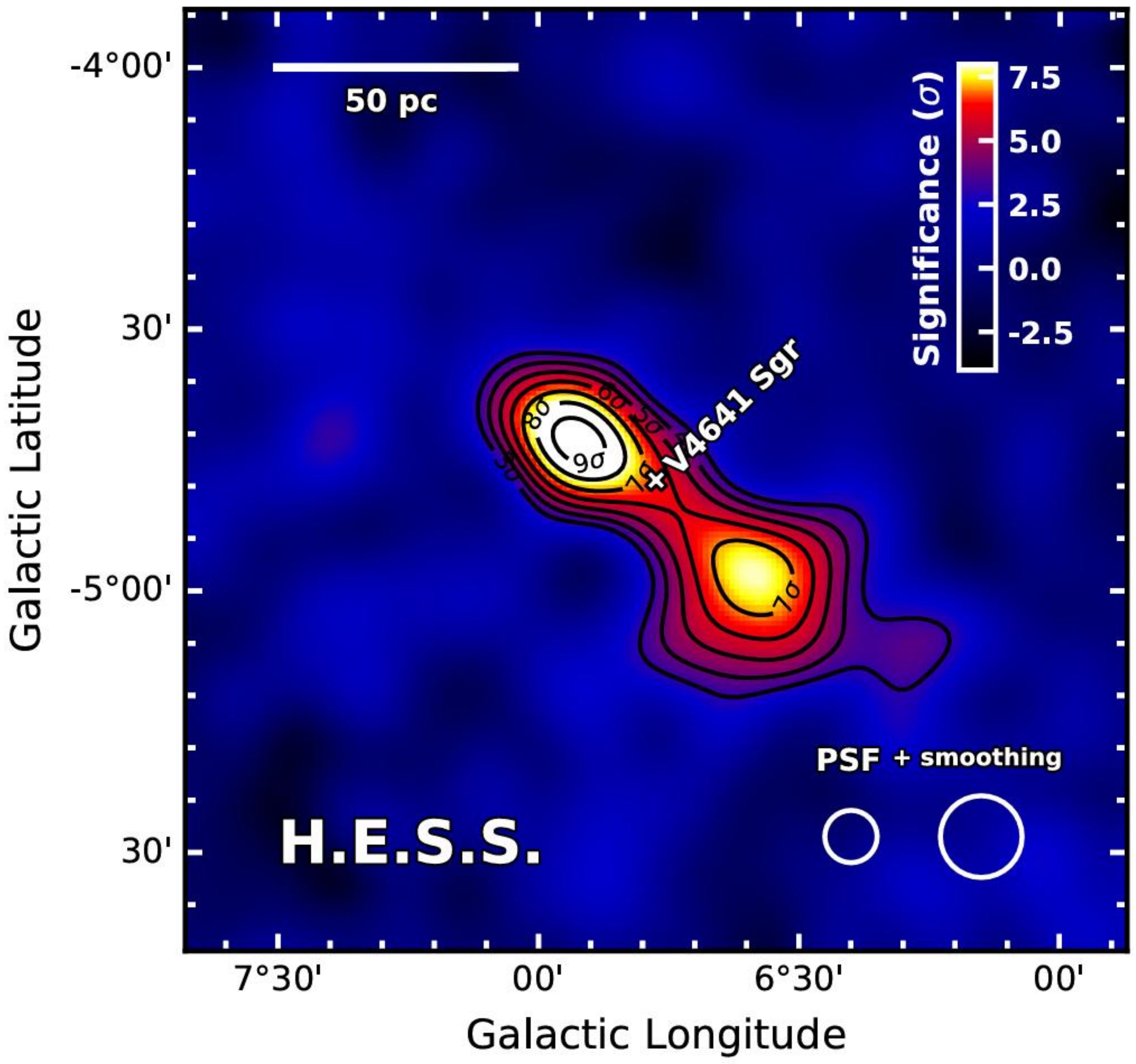


# V4641 Sgr: HESS results

~ 100 hours of observation

⇓

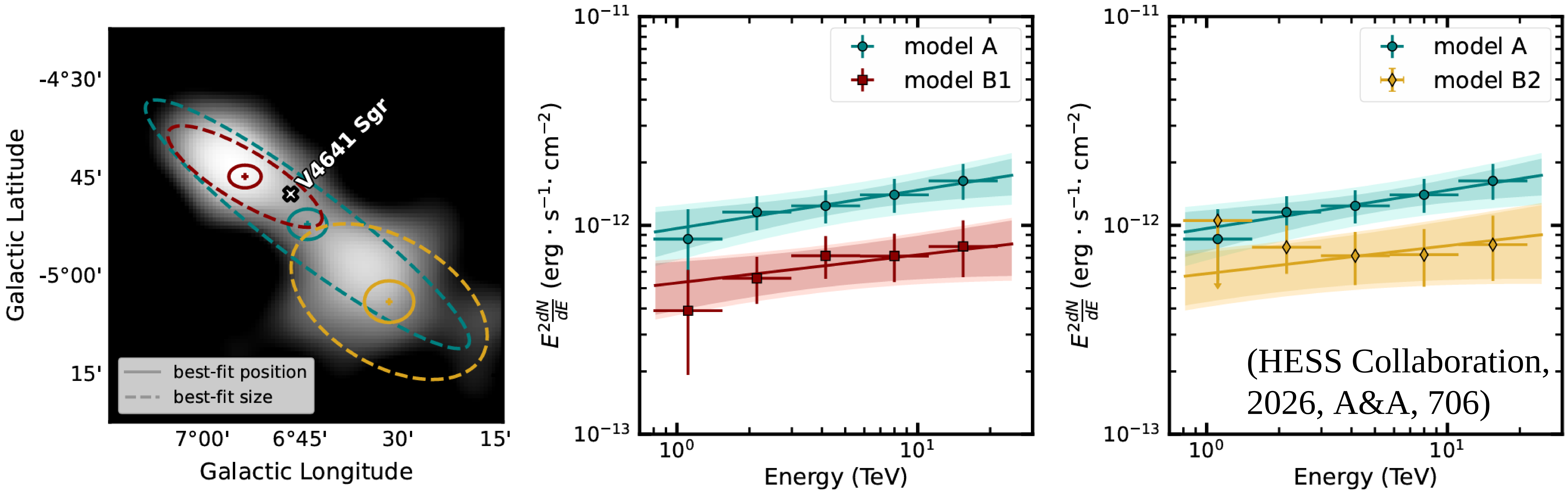
detection of an elongated excess @ 9.5 σ c.l.




(HESS Collaboration, 2026, A&A, 706)

# µQSOs

## V4641 Sgr: HESS results



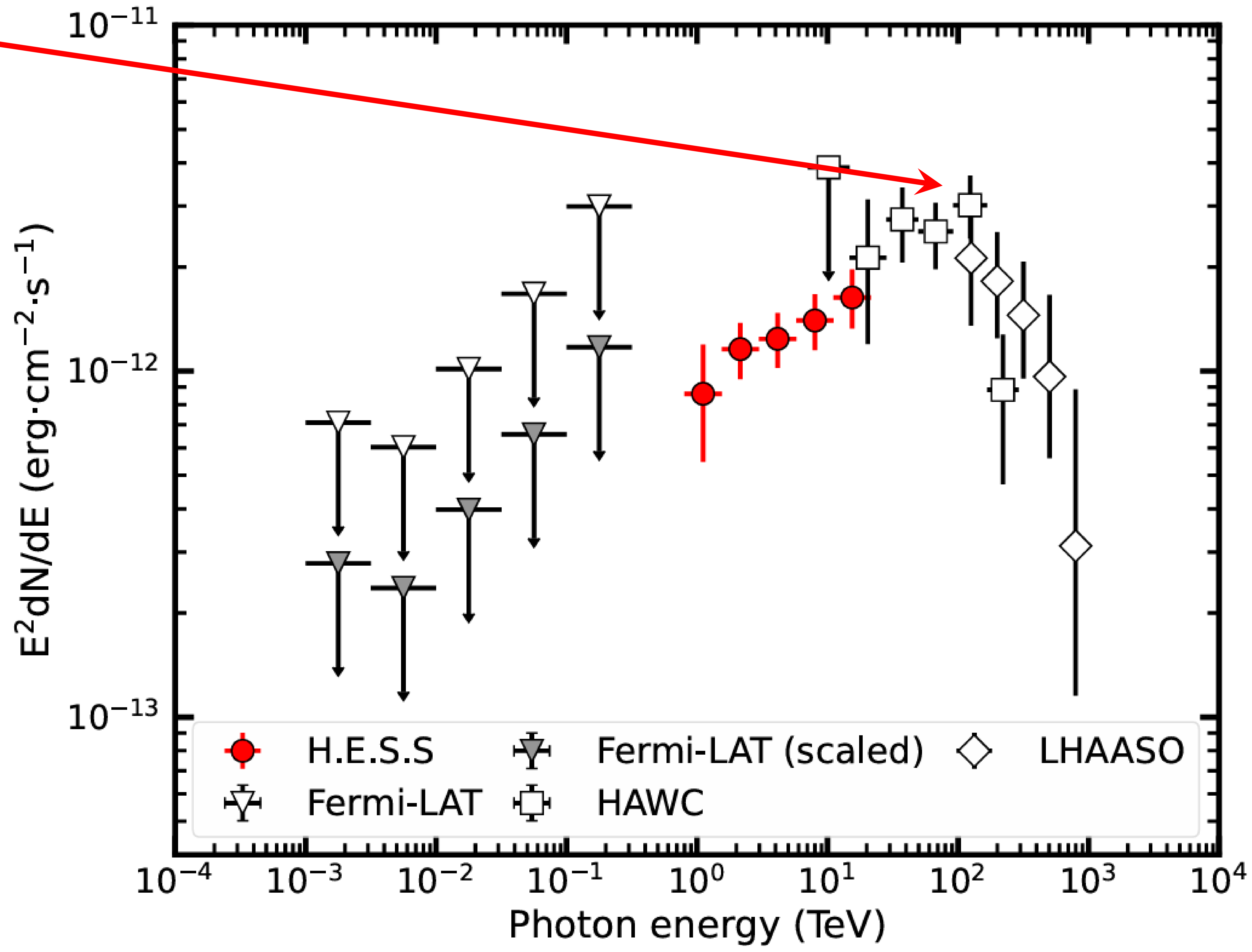

(HESS Collaboration, 2026, A&A, 706)

- Best-fit model: 2 extended sources with same spectral index and orientation angle
- 2 point-like sources rejected
- Position of V4641 Sgr much closer to the centroid of one of the two sources

# μQSOs

## V4641 Sgr: HESS results

- source spectrum peaks at E > 100 TeV
- no evidence of energy-dependent morphology
- no evidence of flux variability on timescales of months-years
- no evidence of dense target gas ⇒ leptonic origin favoured?
- no bright X-ray emission ⇒ B < 3 μG
- hadronic scenario possible with a hard ($\Gamma_p$ = 1.5) proton spectrum




(HESS Collaboration, 2026, A&A, 706)

# V4641 Sgr: perspectives with ASTRI MA

**Source visibility** (Moonless + Dark conditions): **290** h (ZA = 40-60°)

Open issues:

- Leptonic or hadronic origin
- Site of γ-ray emission
- Cause of particle acceleration

⇓

Potential target for ASTRI MA?

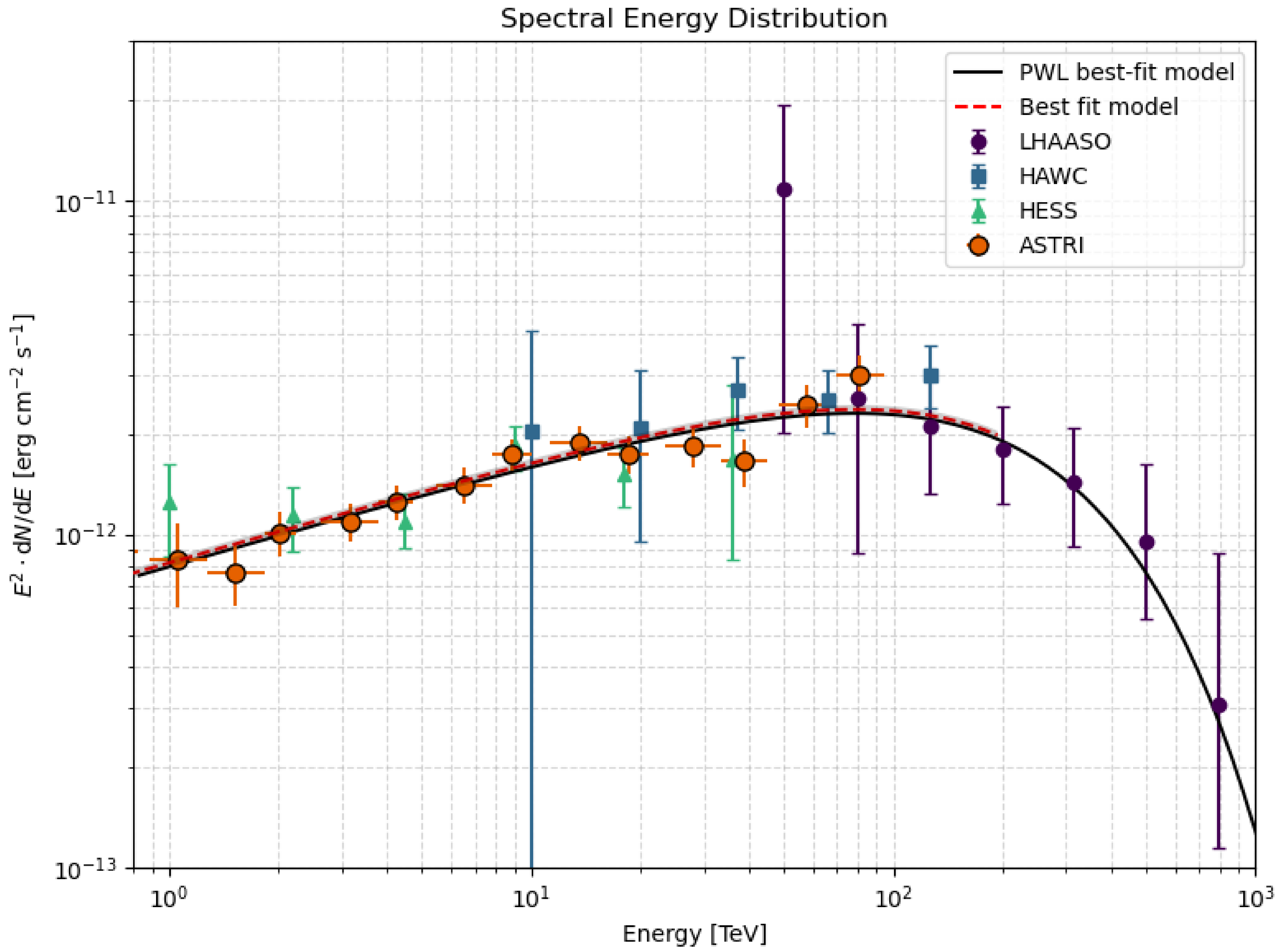
- Morphological analysis (bridge the gap between HESS and HAWC/LHAASO)
- Investigation of possible energy-dependent morphology
- Spectral analysis

but low latitude (Lat = -25.4° ⇒ ZA = 53.7°)

# V4641 Sgr: perspectives with ASTRI MA

- 300 hr simulation
- Spatial model: uniform disk (major axis = 0.45°, e = 0.95)
- Spectral model: CPL from the best-fitting model of LHAASO + HAWC + HESS data

(D'Aì et al. 2025, XI μQSO WS)

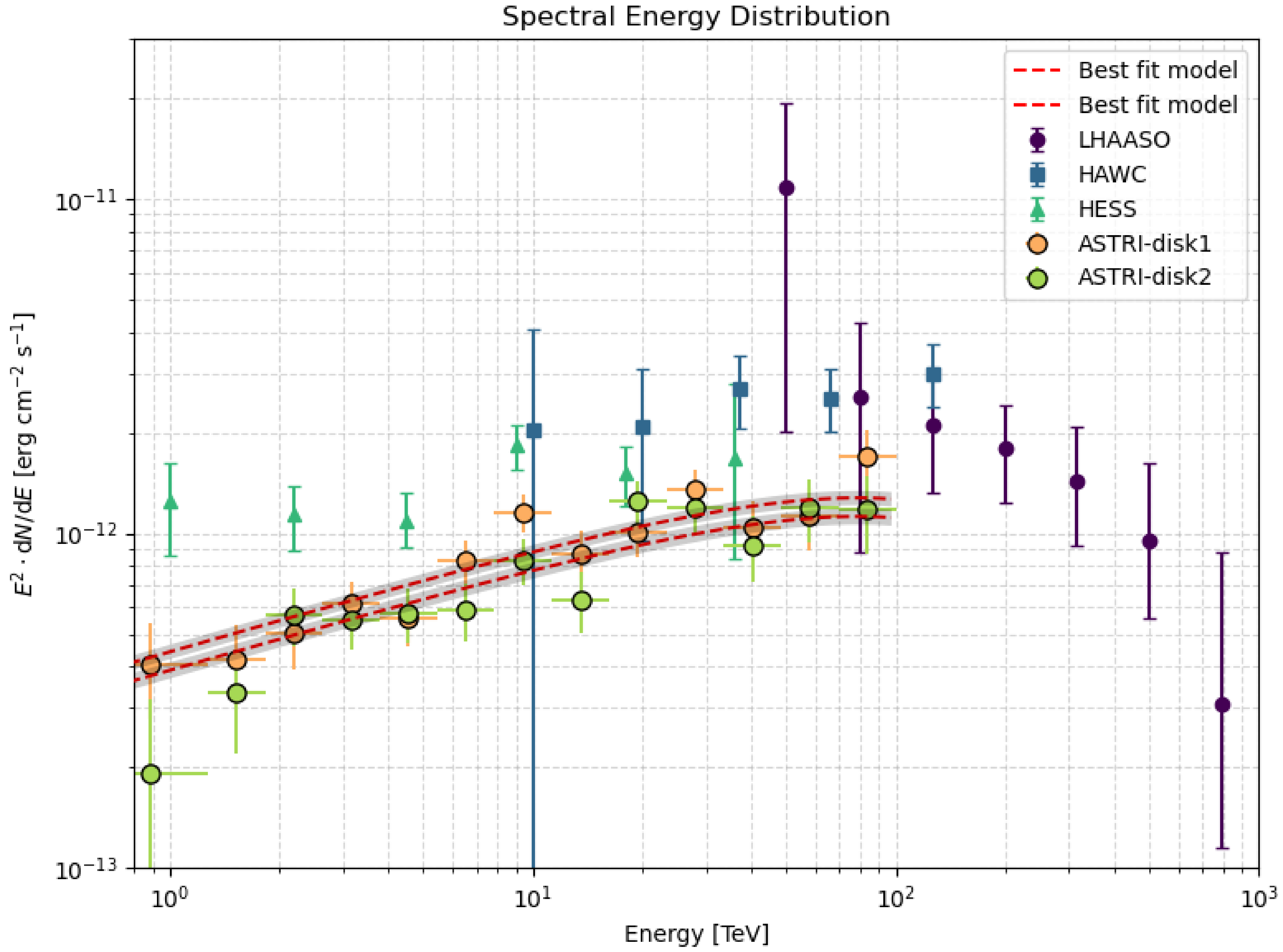


# µQSOs

## V4641 Sgr: perspectives with ASTRI MA

- 300 hr simulation
- Spatial model: two spatially-resolved extended lobes (major axis = 0.25°, e = 0.95)
- Each lobe contributing half of the total flux (as HAWC data suggest)
- Spectral model: CPL from the best-fitting model of LHAASO + HAWC + HESS data

(D’Aì et al. 2025, XI µQSO WS)

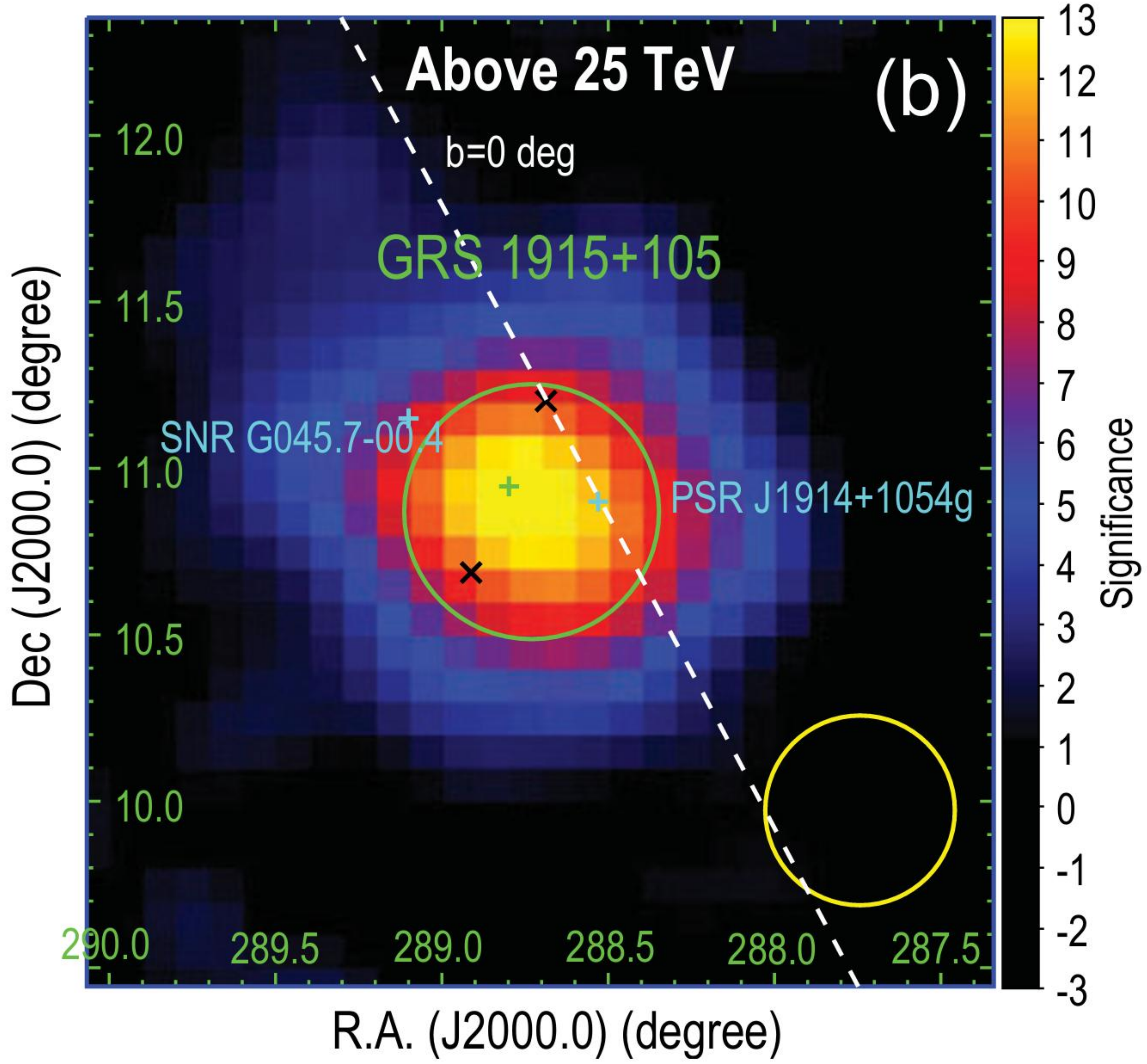


## GRS 1915+105: LHAASO results

LHAASO-KM2A observing time: 290 days with ½ array + 216 days with ¾ array + 1228 days with full array

⇓

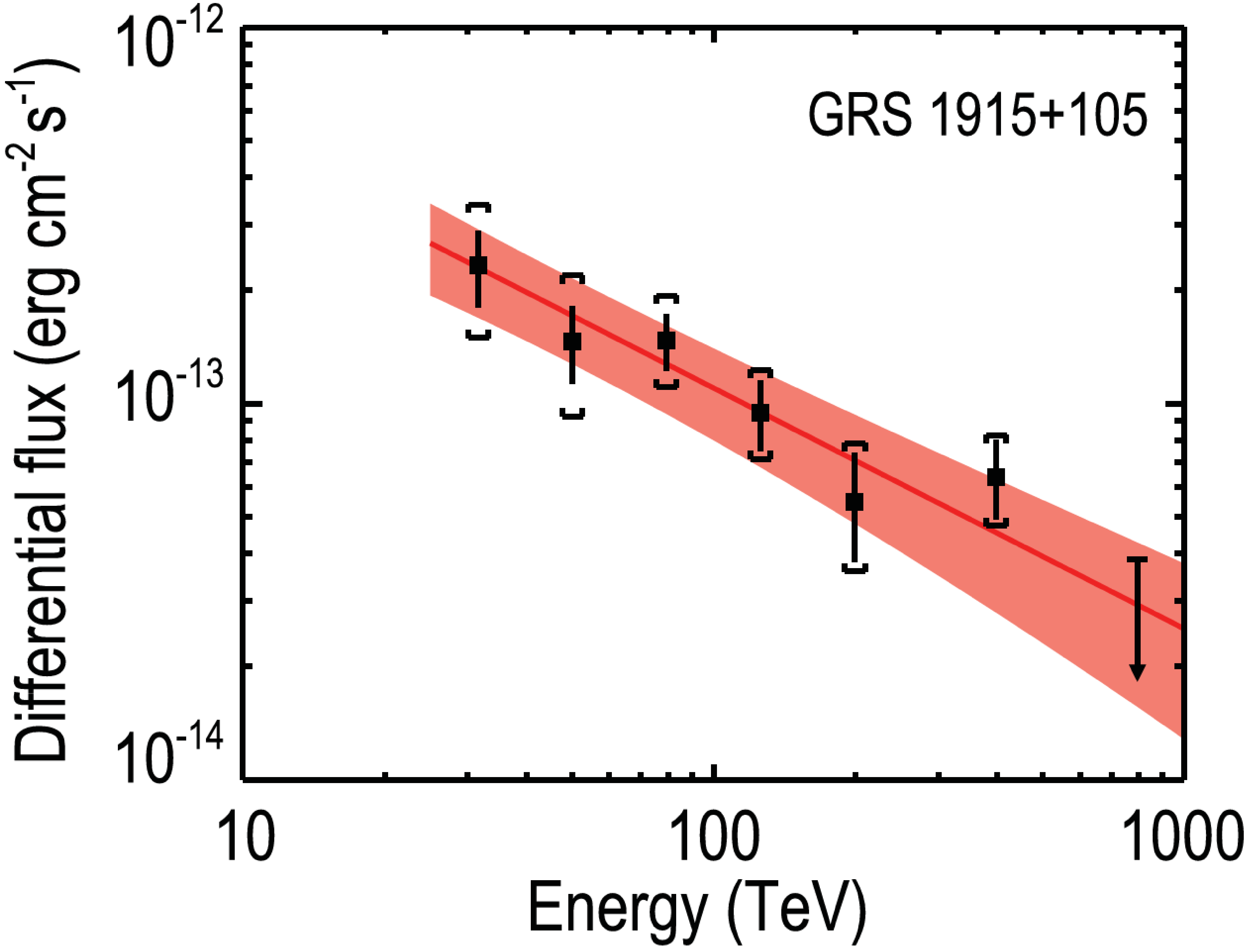
- Extended source LHAASO 1915+1053 (0.28°) detected @ 15 σ c.l., 0.1° SW of GRS 1915+105
- Angular extension of LHAASO source comparable with the angular separation between the two spots detected with ALMA




(LHAASO Collaboration, 2025, NSR, 496)

# GRS 1915+105: LHAASO results

PL spectrum up to 400 TeV, with Γ = 2.7




(LHAASO Collaboration, 2025, NSR, 496)

# μQSOs

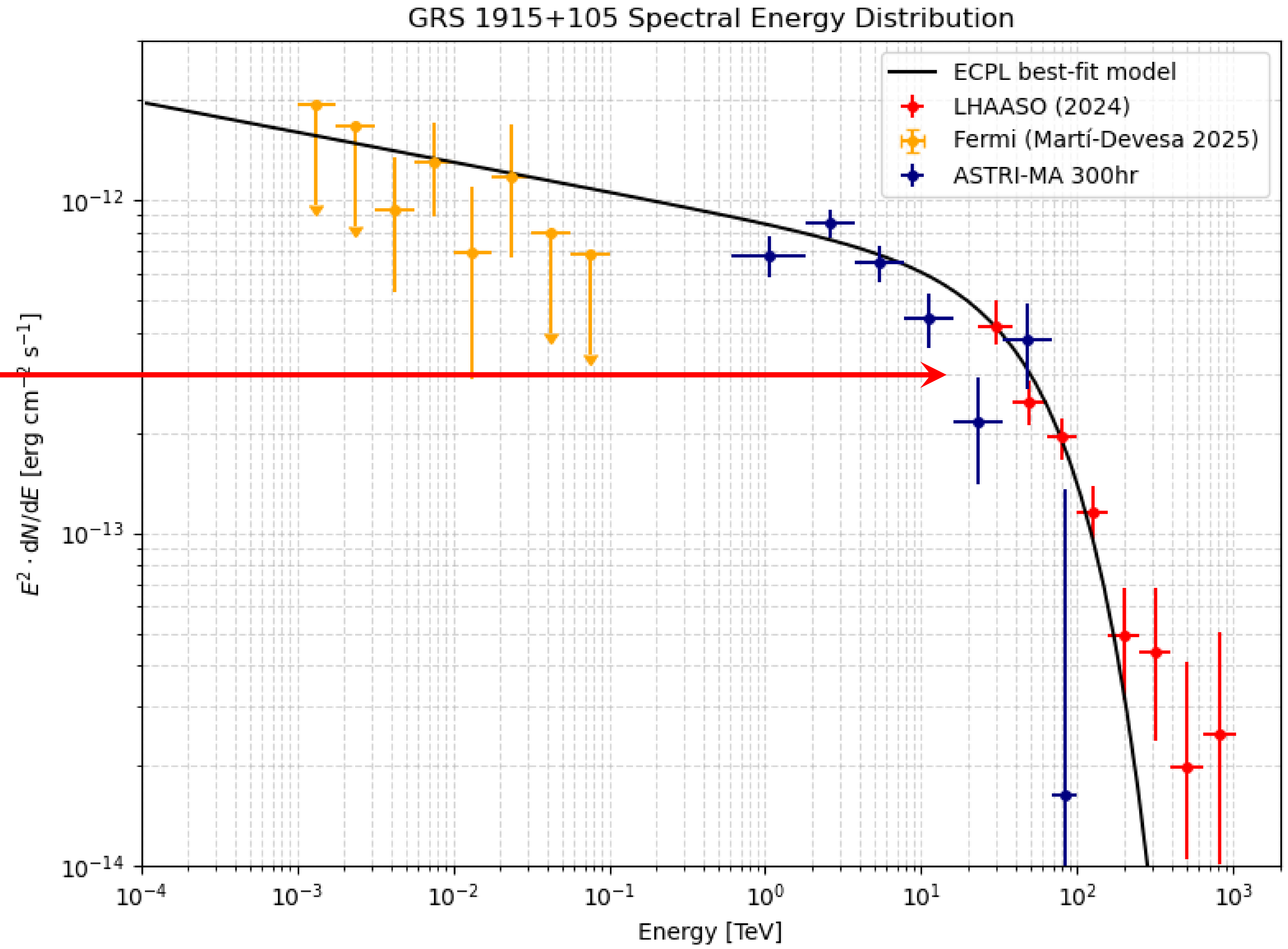
## GRS 1915+105: perspectives with ASTRI MA

**Source visibility** (Moonless + Dark conditions): **470** h (ZA = 0-40°), **270** h (ZA = 40-60°)

⇓

- filling the spectral TeV gap
- 300 hr simulation
- Spectral model: CPL with Γ = 2.5, $E_{cut}$ = 70 TeV

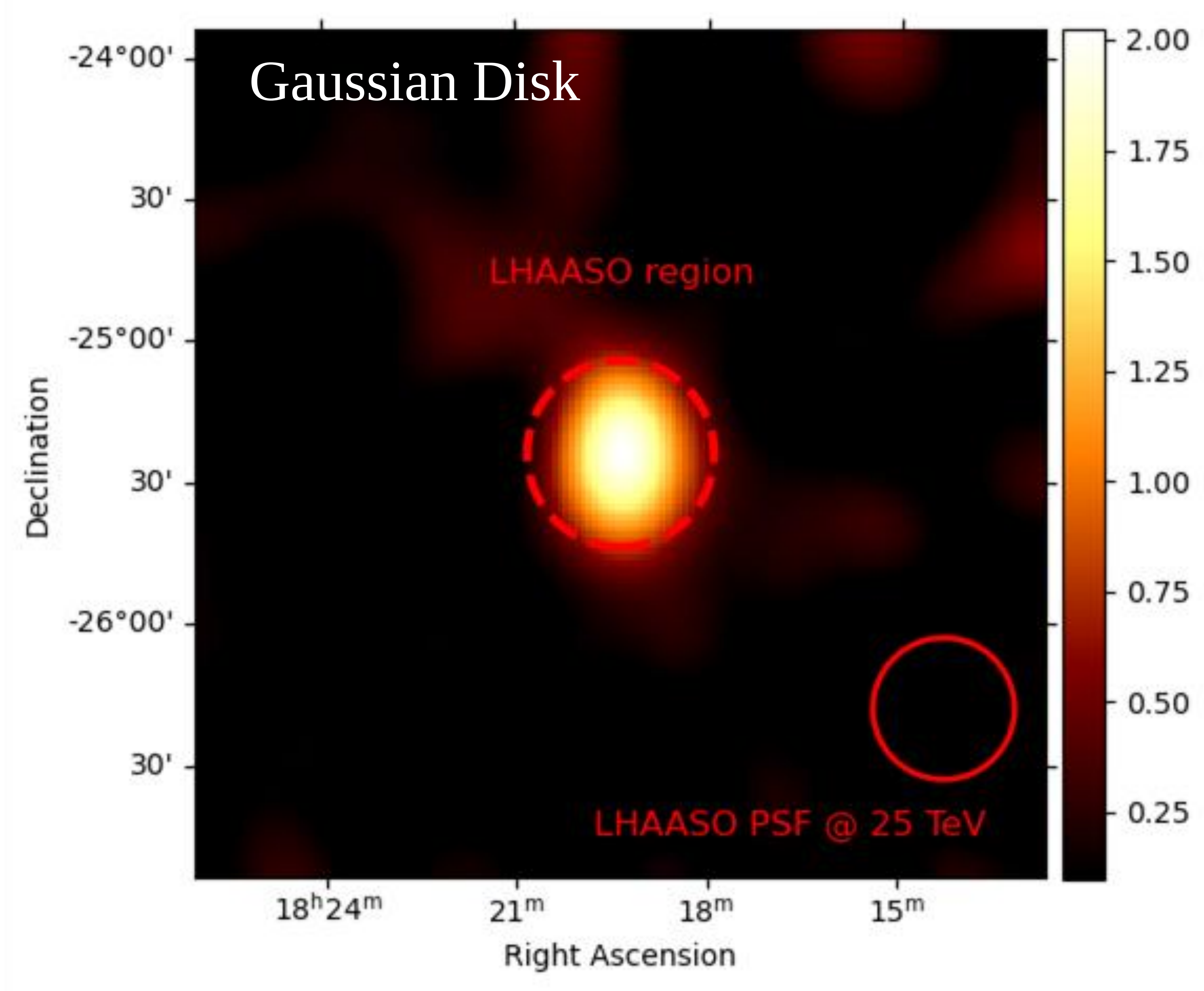
(D'Aì et al. 2025, XI μQSO WS)

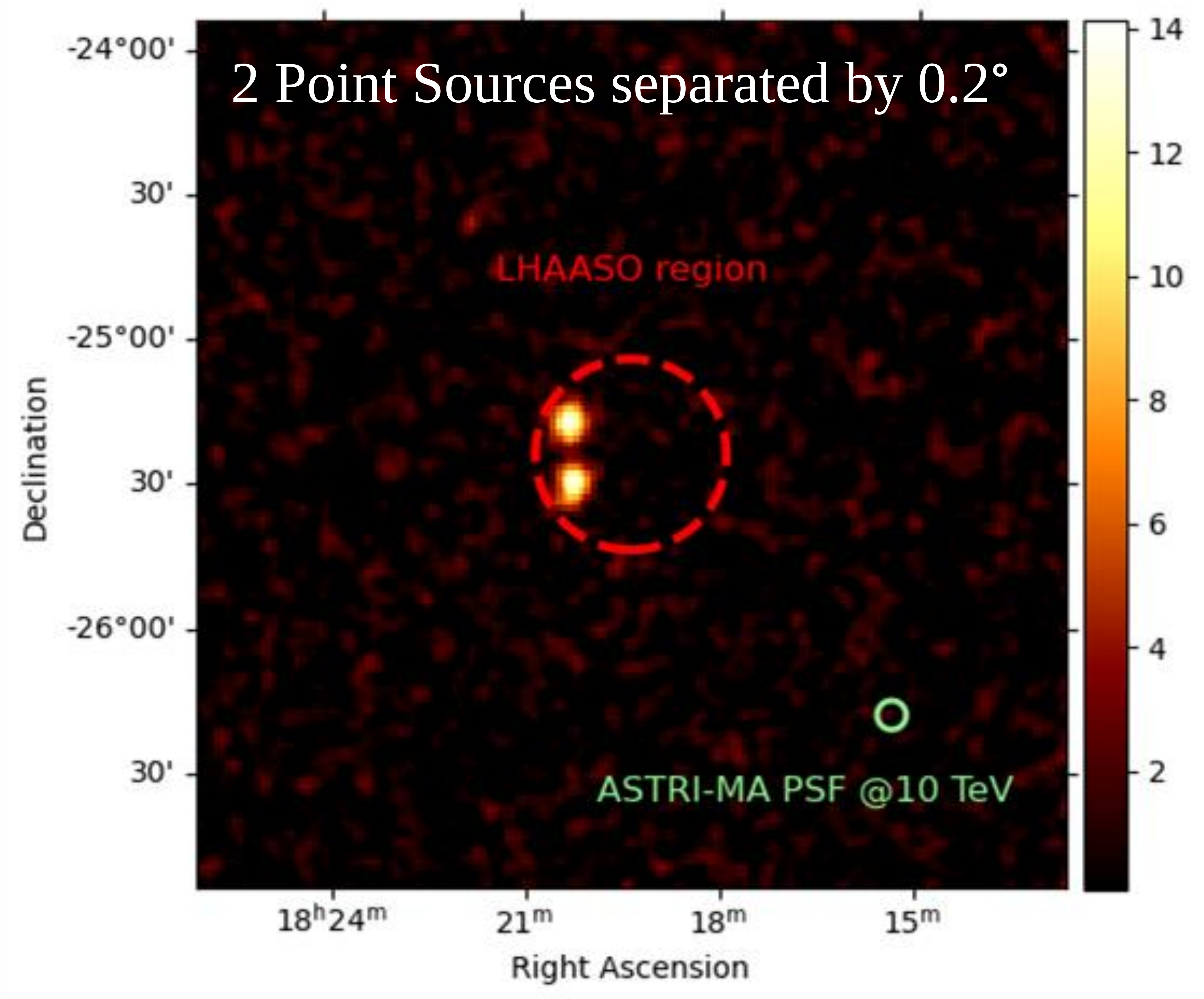


## µQSOs

# GRS 1915+105: perspectives with ASTRI MA

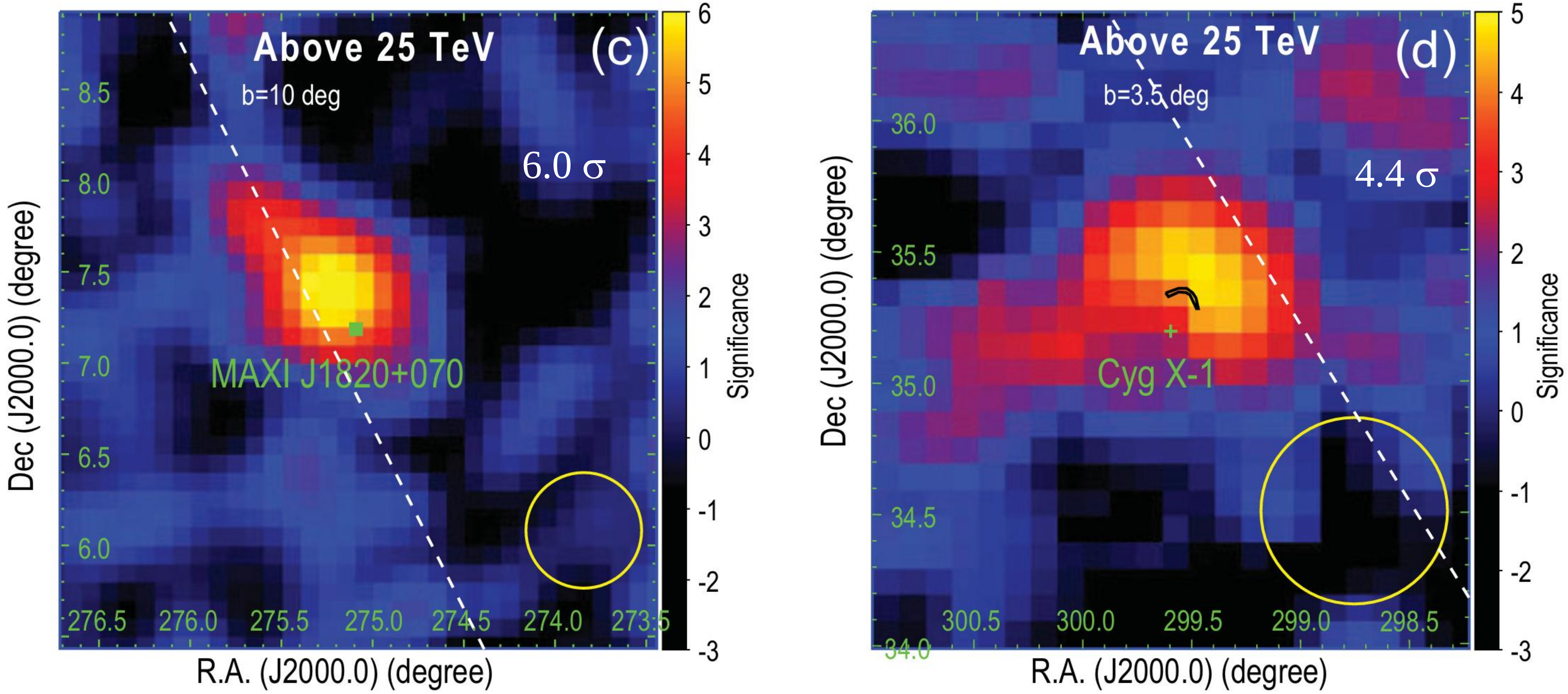
- Investigate the source morphology (300 hr of observation) (D'Aì et al. 2025)



# MAXI J1820+070 and Cyg X-1: LHAASO results

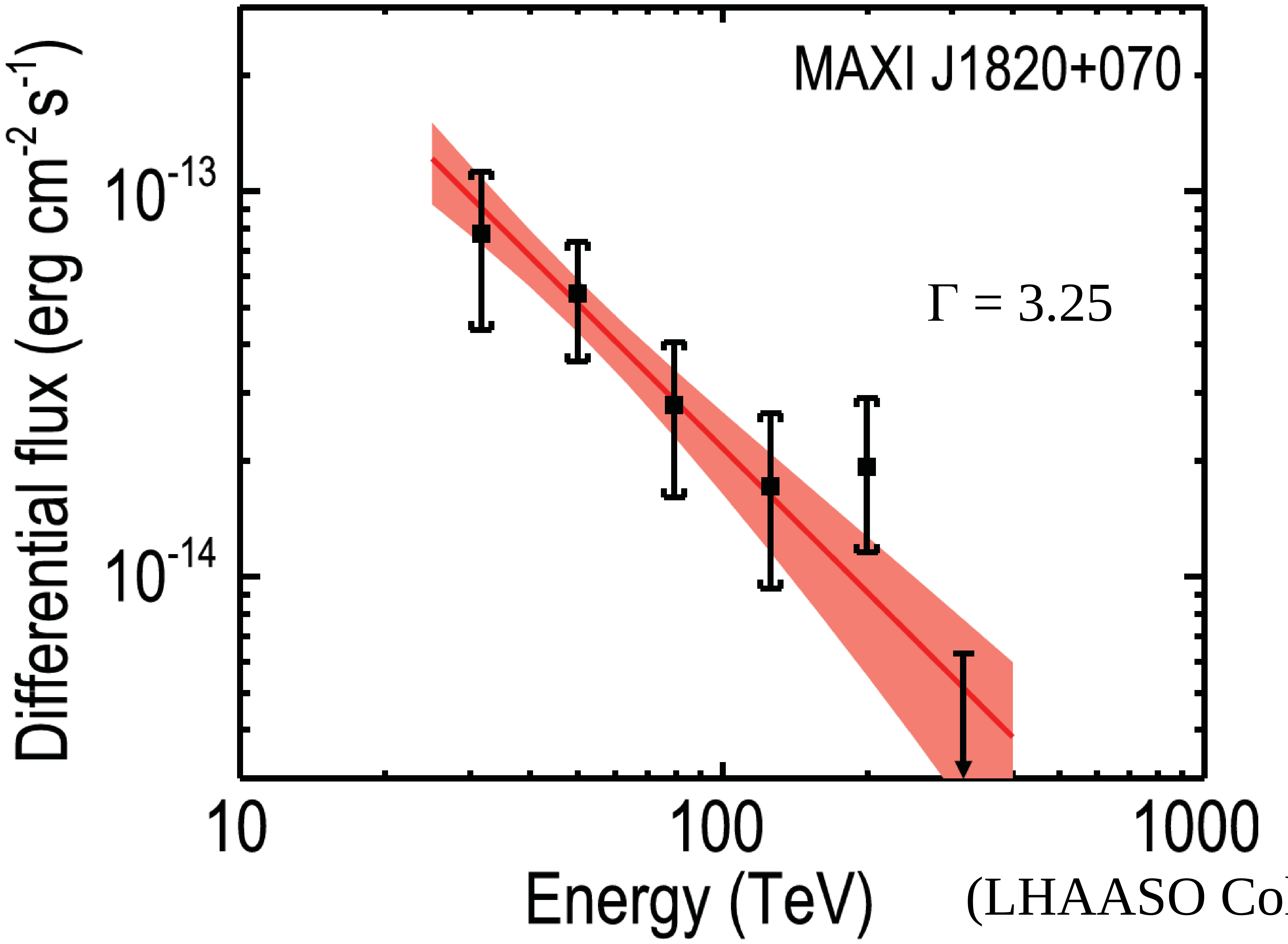
Both detected as point-like sources, offset of 0.2-0.3° from the counterpart

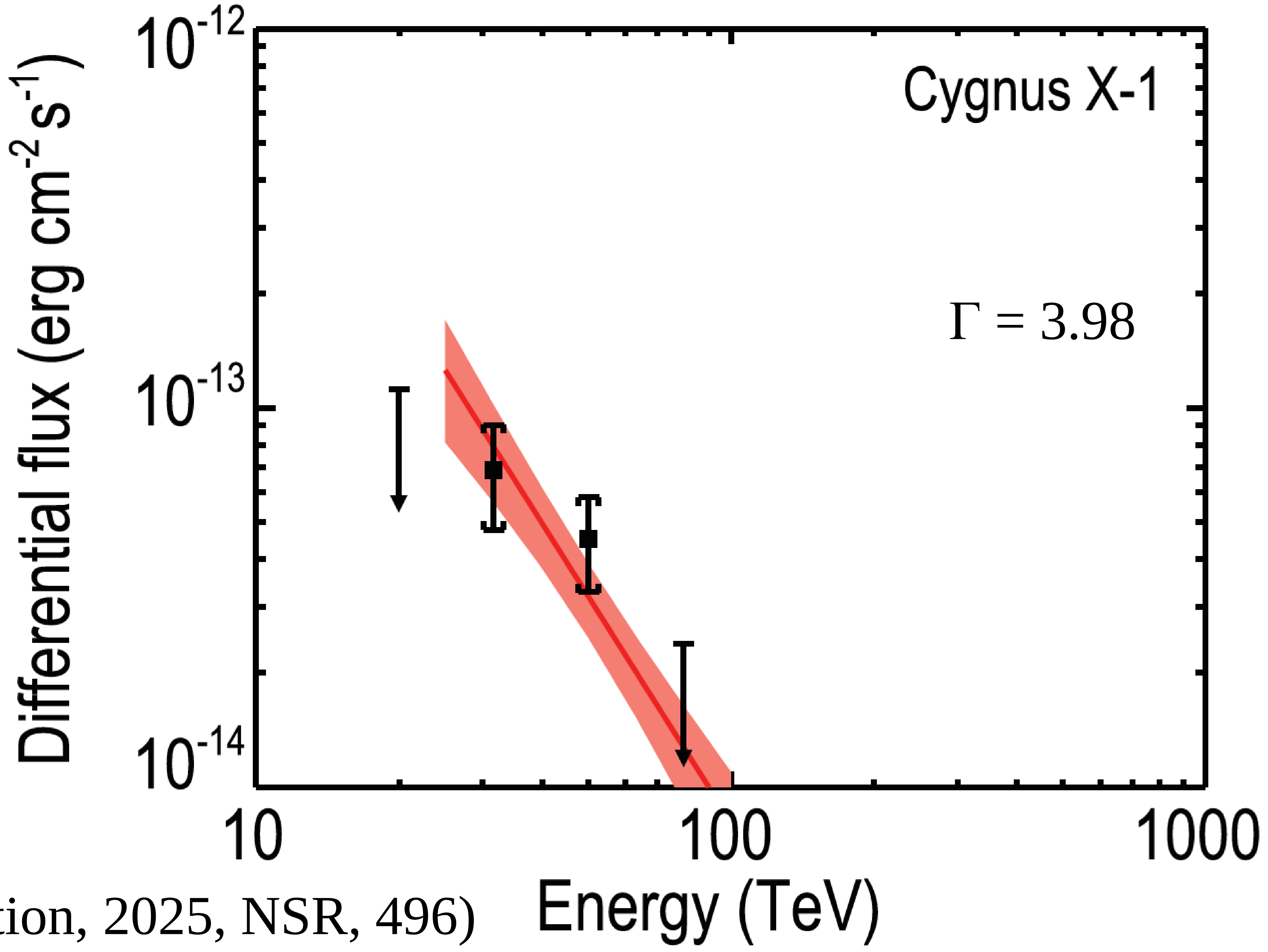



(LHAASO Collaboration, 2025, NSR, 496)

# MAXI J1820+070 and Cyg X-1: LHAASO results

For both sources power-law spectrum without evidence of spectral cut-off




(LHAASO Collaboration, 2025, NSR, 496)

## MAXI J1820+070 and Cyg X-1: perspectives with ASTRI MA

**Source visibility** (Moonless + Dark conditions):

- **MAXI J1820+070: 380** h (ZA = 0-40°), **250** h (ZA = 40-60°)
- **Cyg X-1: 490** h (ZA = 0-40°), **260** h (ZA = 40-60°)

$\Downarrow$

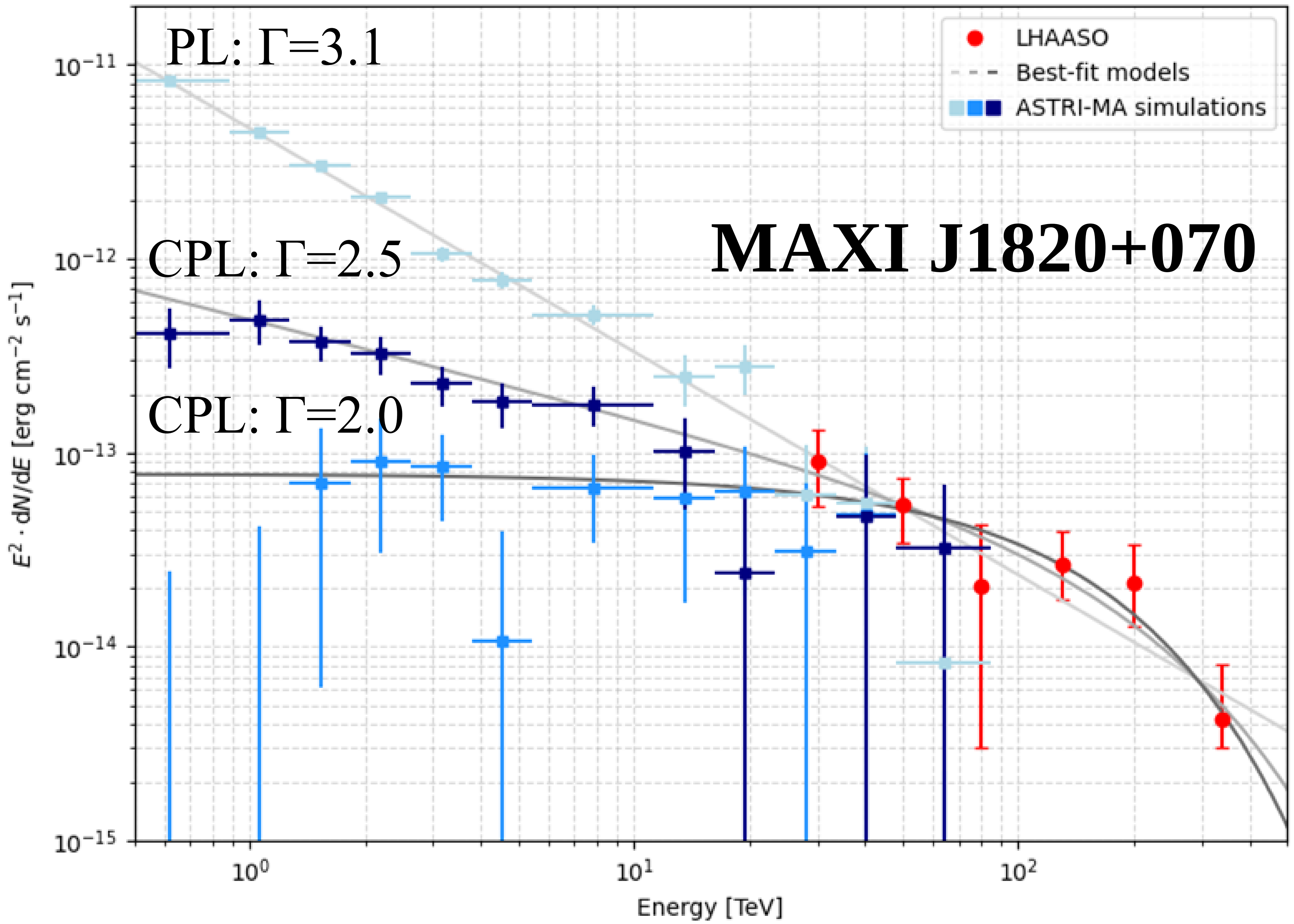
- Morphological analysis
- Spectral analysis
- If point-like sources $\Rightarrow$ investigation of possible time variability

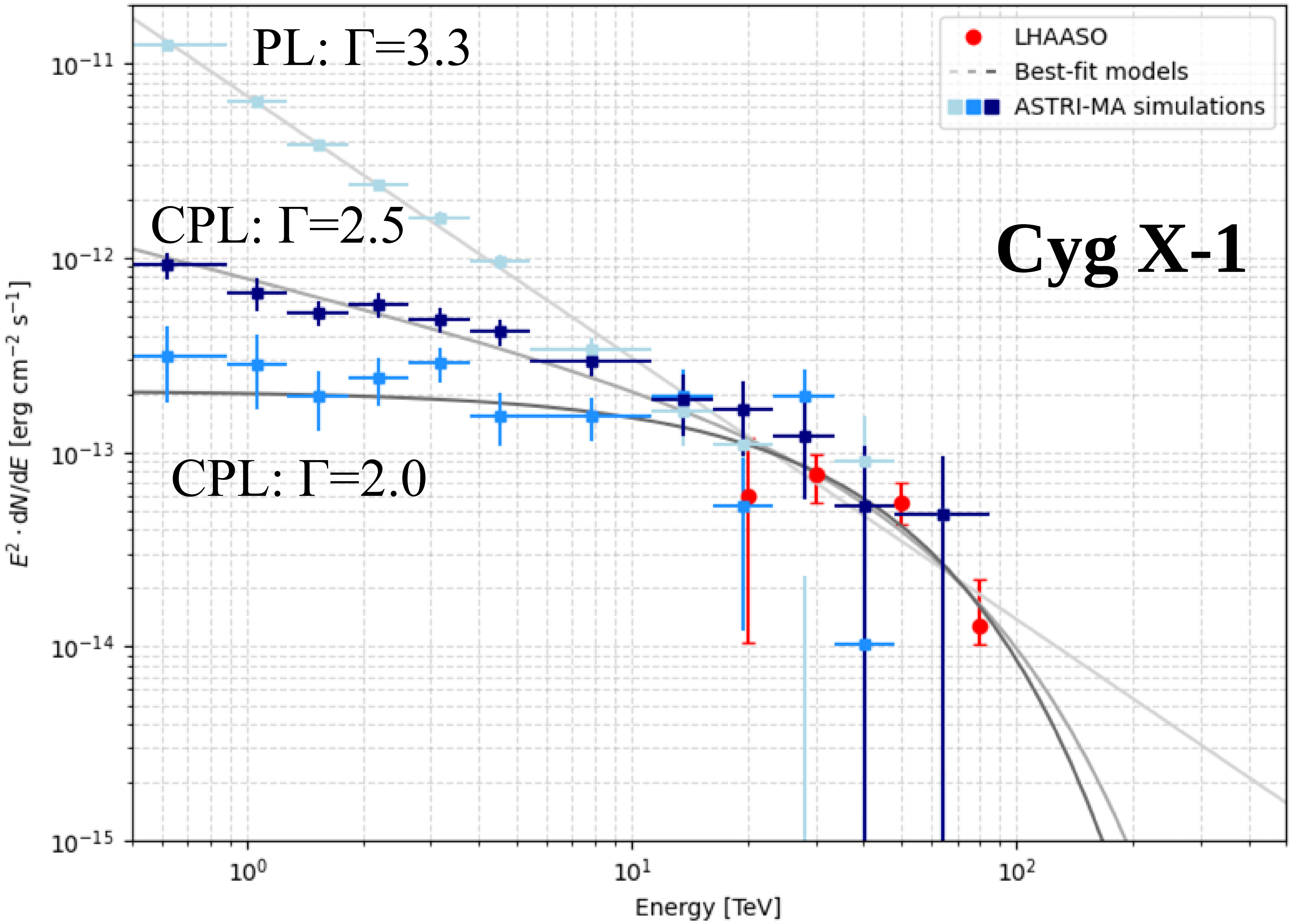
# μQSOs

# MAXI J1820+070 and Cyg X-1: perspectives with ASTRI MA

ASTRI-MA 300 h simulated observations

(D'Aì et al. 2025, XI μQSO WS)



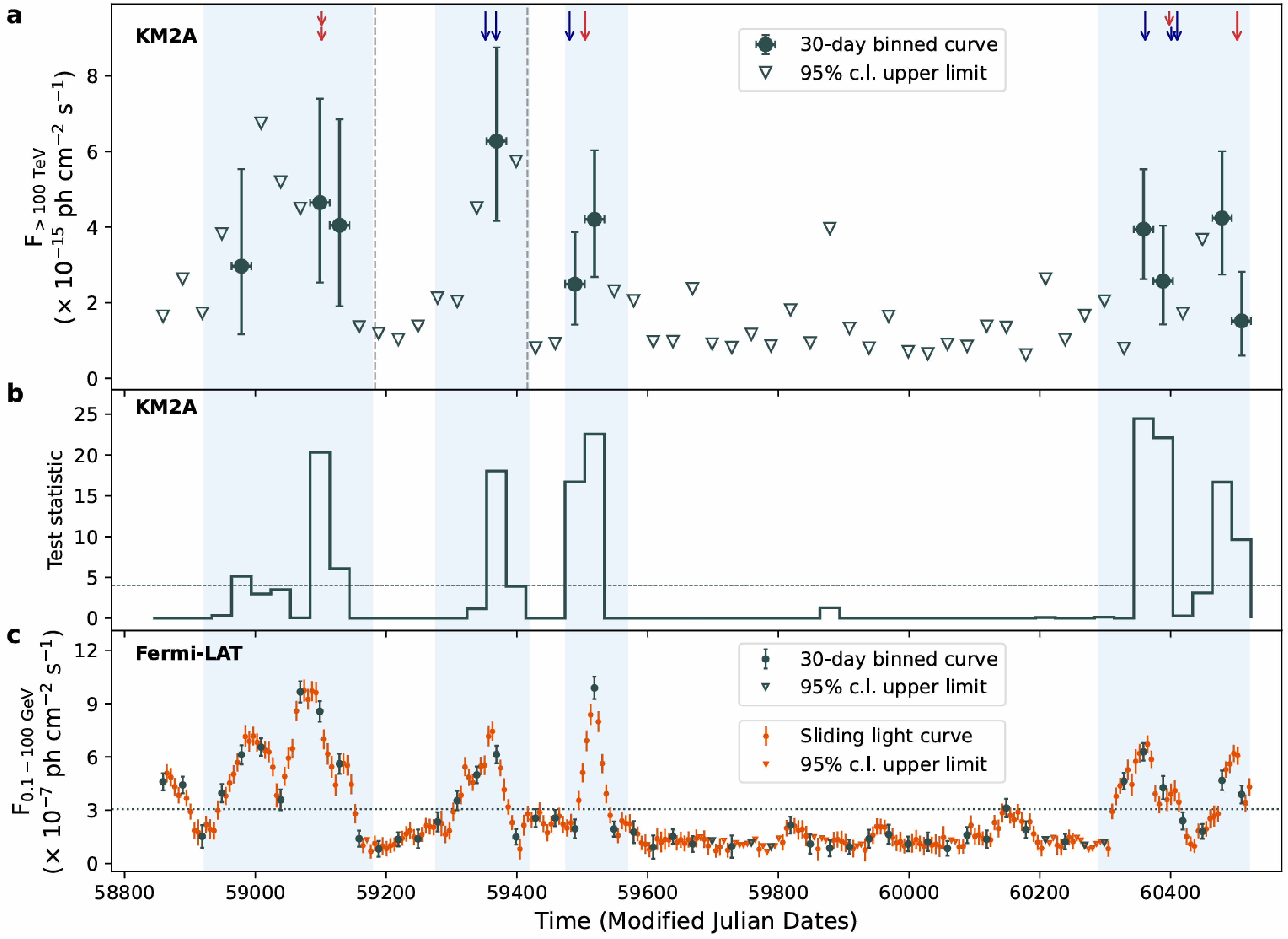
# µQSOs

## Cyg X-3 – *The Super PeVatron*: LHAASO results

Point-like source detected @ 9.6 σ c.l.

- only at E > 0.1 PeV
- only when in high state

Flux variability @ 8.6 σ c.l.



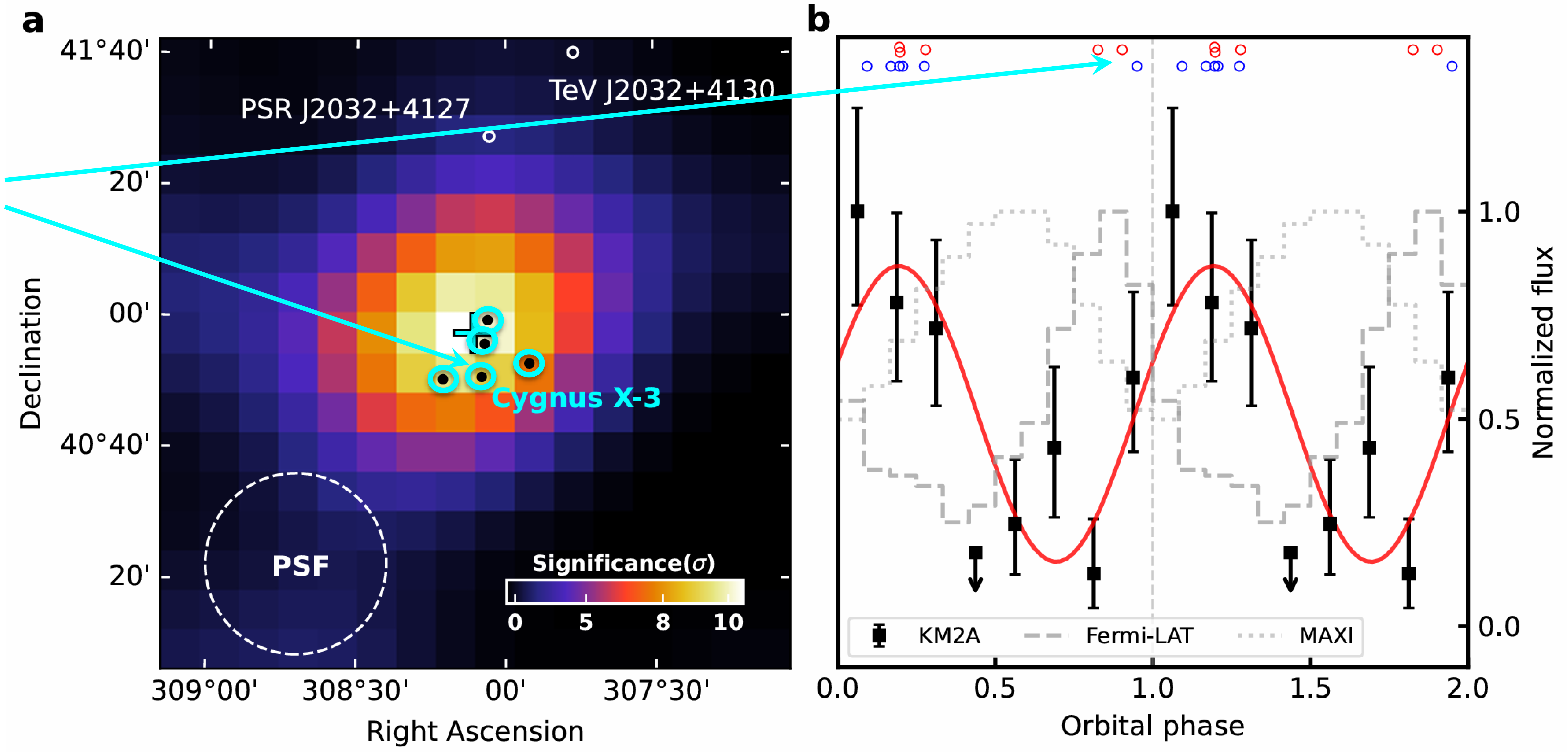

(LHAASO Collaboration, 2026, NSR)

# µQSOs

## Cyg X-3 – *The Super PeVatron*: LHAASO results

(LHAASO Collaboration, 2026, NSR)

- 5 photons with E > 1 PeV (up to 3.7 PeV)
- Evidence of orbital modulation @ 3.2 σ c.l.



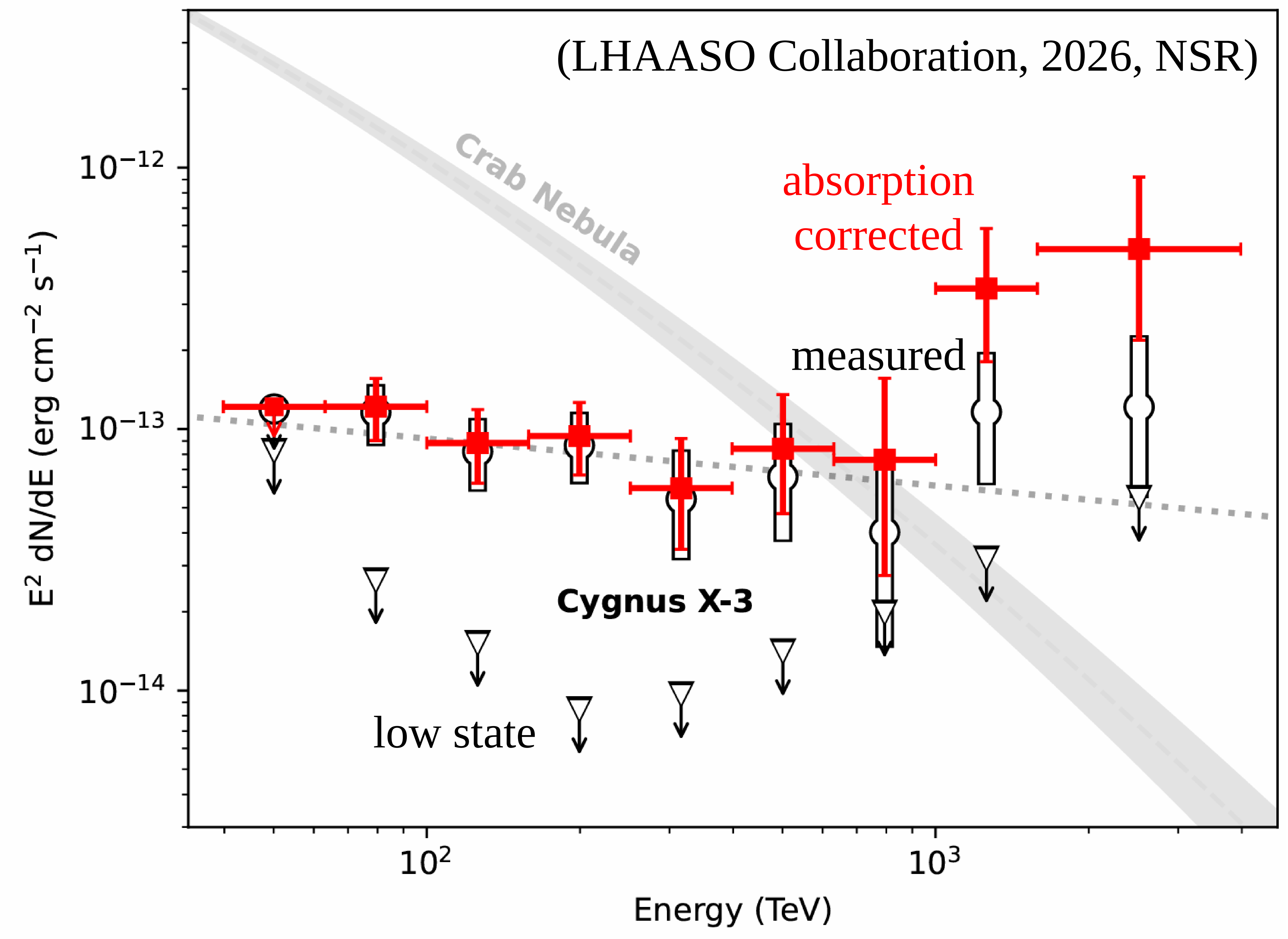
# μQSOs

## Cyg X-3 – *The Super PeVatron*: LHAASO results

- PL spectrum with $\Gamma = 2.18 \Rightarrow$ the hardest UHE source ever detected by LHAASO
- spectral hardening above 1 PeV, even more pronounced when accounting for absorption of UHE photons

$\Downarrow$

$\gamma$-ray production through hadronic processes in the innermost region of the relativistic jet



# Cyg X-3 – *The Super PeVatron*: perspectives with ASTRI MA

**Source visibility** (Moonless + Dark conditions): **> 400** h (ZA = 0-40°), > **200** h (ZA = 40-60°)

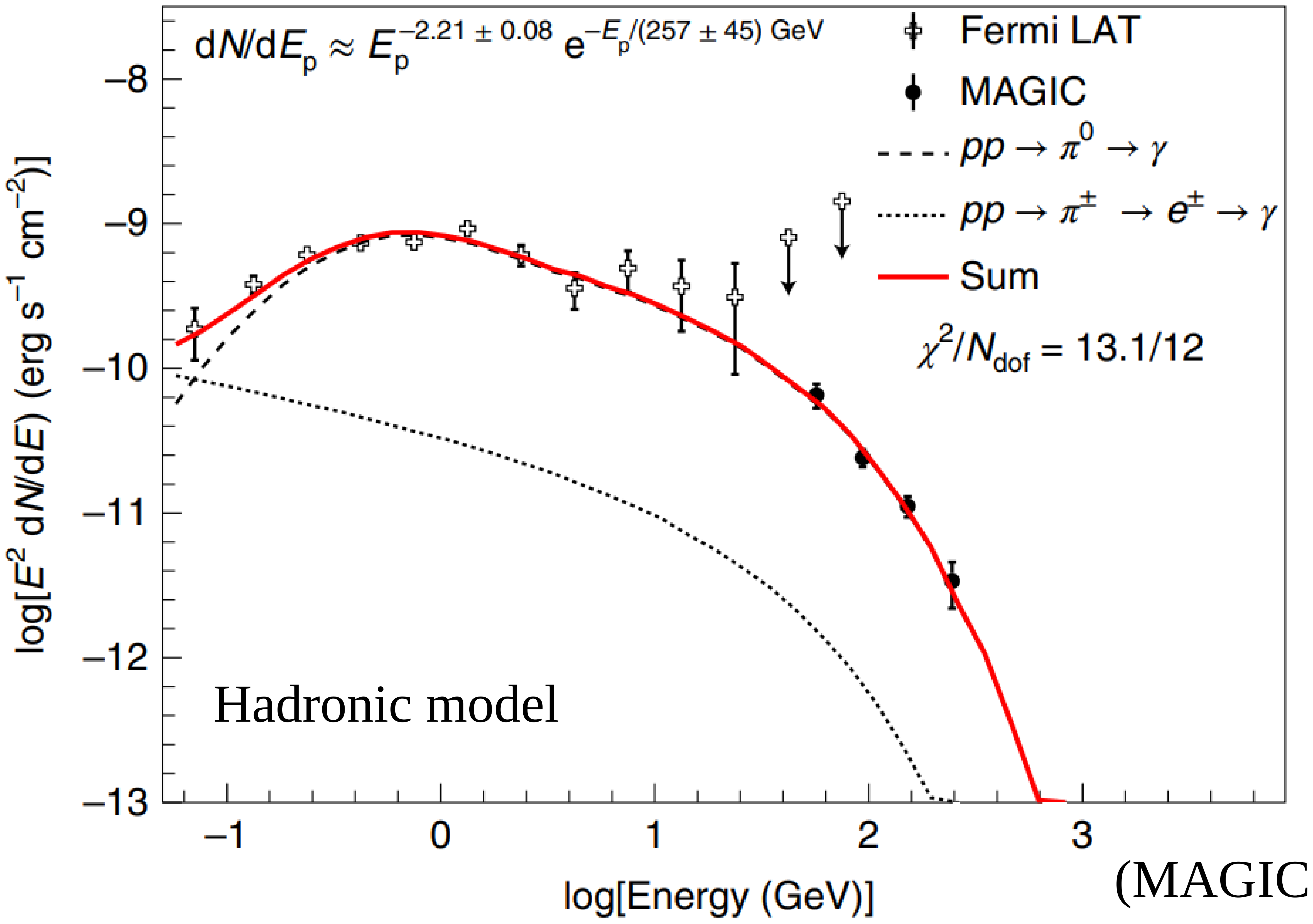
⇓

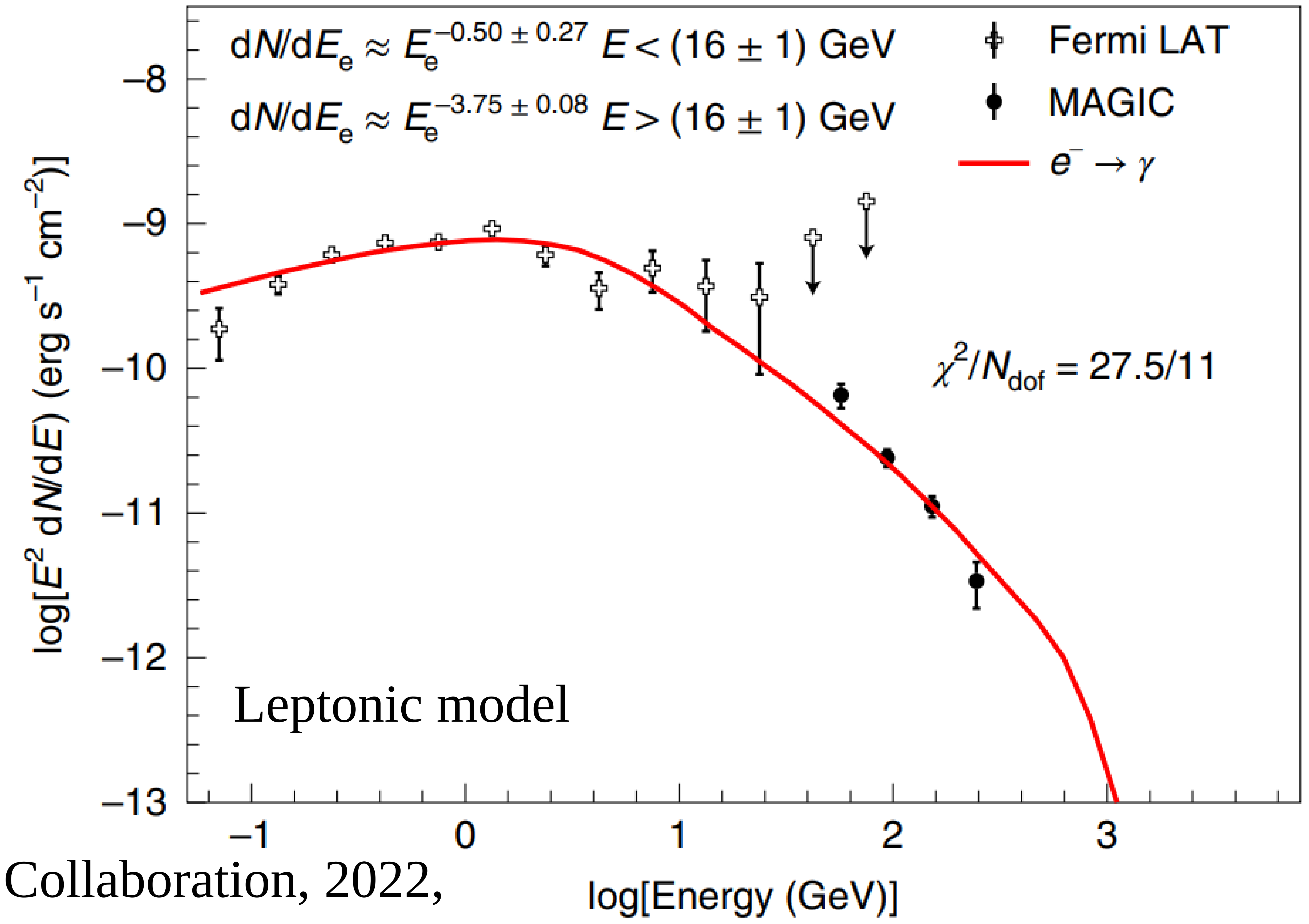
- Spectral analysis (extension towards low energies, bridge between HE and UHE)
- Deeper investigation of time variability

# Novae

## RS Oph: MAGIC results

Outburst observed in August 2021 ⇒ source detected in 60-250 GeV energy range



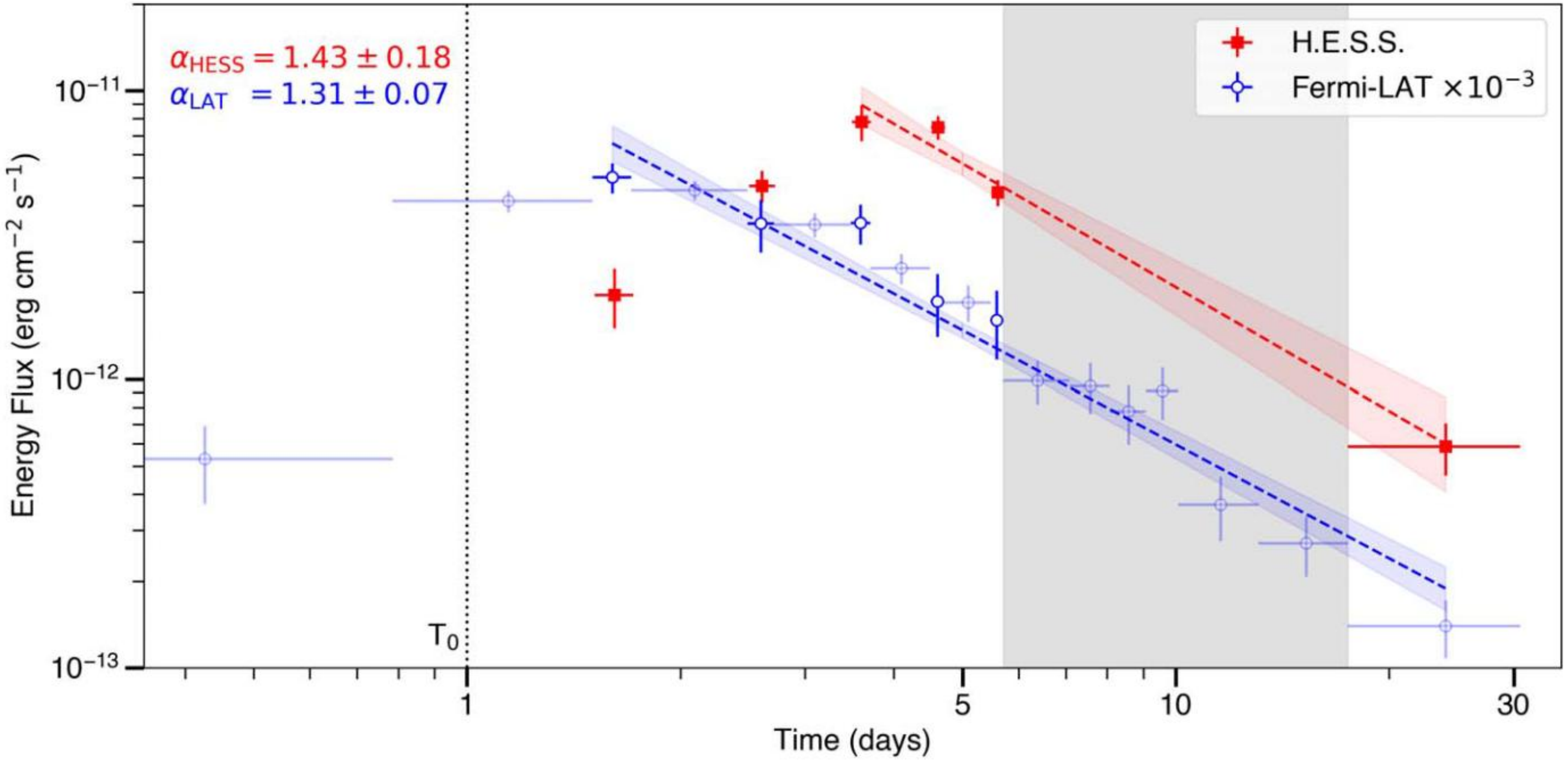



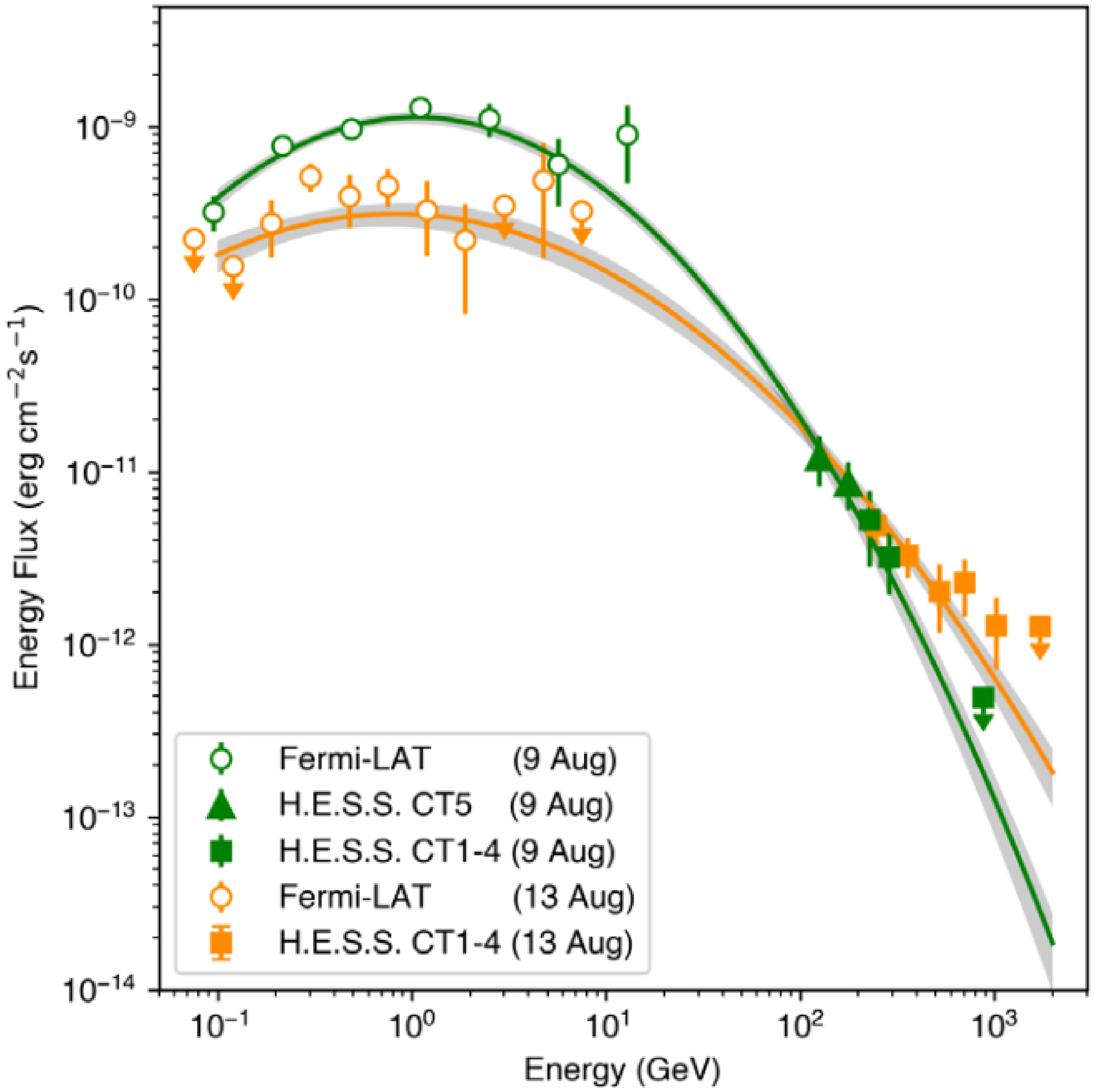

(MAGIC Collaboration, 2022, Nature Astronomy, 6)

# Novae

## RS Oph: HESS results

Outburst observed in August 2021 ⇒ source detected in 0.25-2.5 TeV energy range



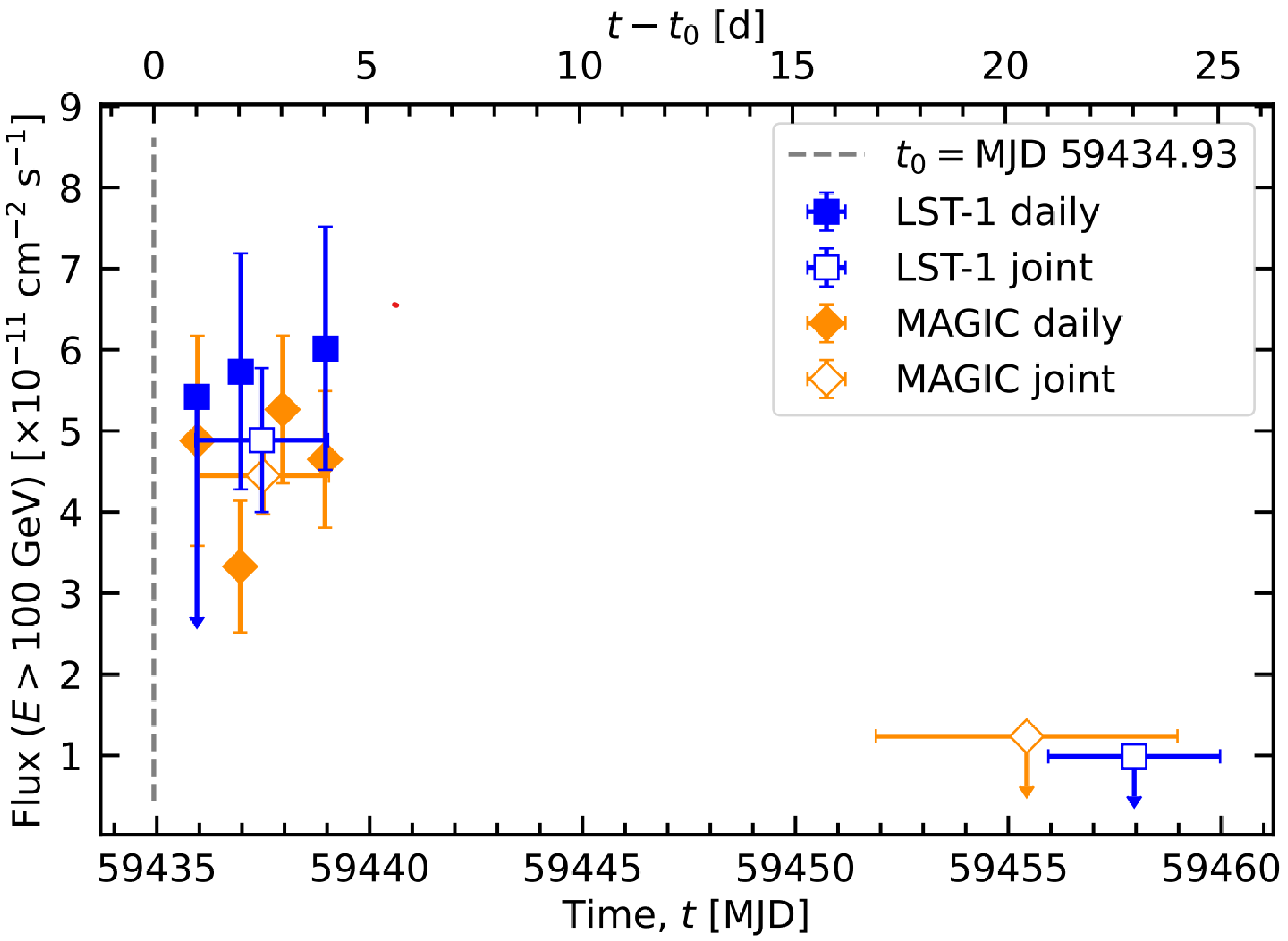

(HESS Collaboration, 2022, Science, 376)

# Novae

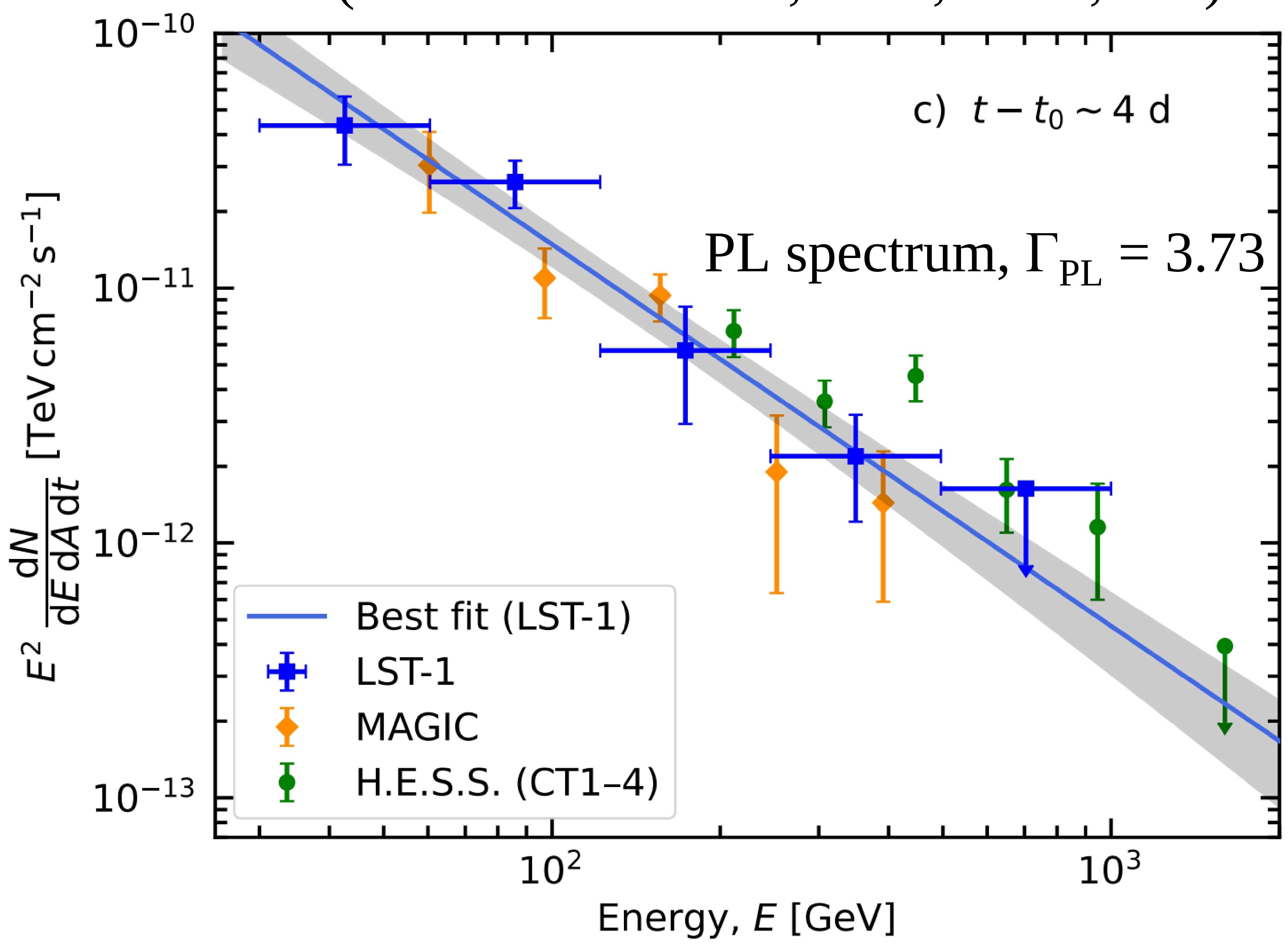


## RS Oph: LST results

Outburst observed in August 2021 ⇒ source detected @ 6.6 σ c.l. at E < 1 TeV




(LST Collaboration, 2025, A&A, 695)



# Novae

## RS Oph: perspectives with ASTRI MA

- Recurrence time ~ 15 years ⇒ next outburst in ~ 2036
- Too soft and faint for ASTRI MA?