

Highlights from the Southern VHE gamma-ray sky with H.E.S.S.

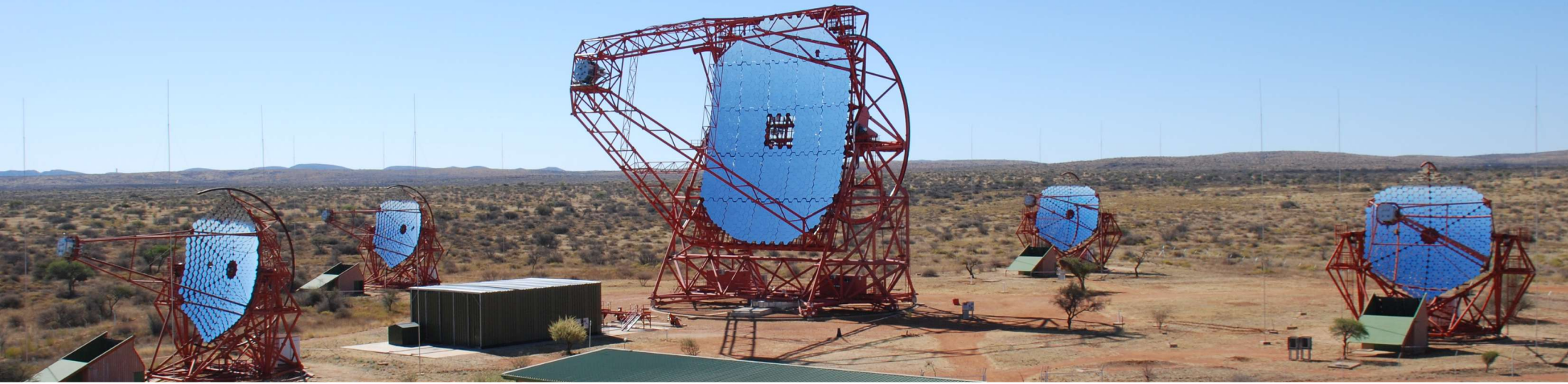
for the H.E.S.S. collaboration:

Stefan J. Wagner

HESS observatory
LSW, ZAH, U. Heidelberg
DZA, Germany



High Energy Stereoscopic System



Five telescope array in Namibia, $> 1000 \text{ m}^2$ mirror area
Telescopes operational since 2003, 2012, camera upgrades 2017, 2019
Operation in moderate moonlight, $> 97 \%$ efficiency, $> 1400 \text{ h/a}$

Cosmic Ray Measurements

Primary objective: VHE Gamma-ray studies.
VHE emission provides clues on CR.

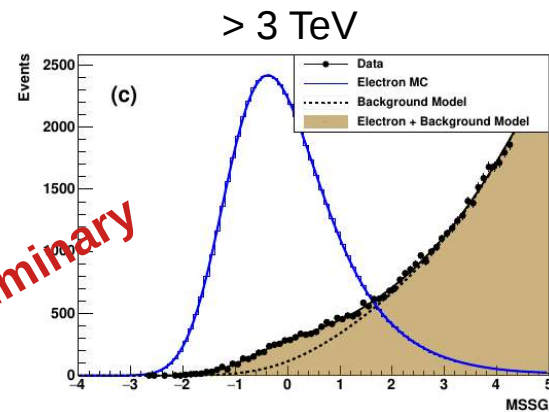
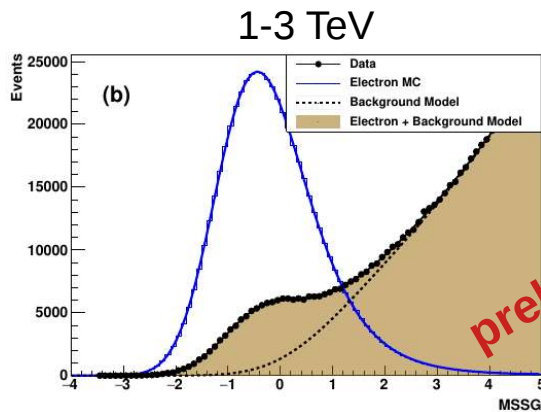
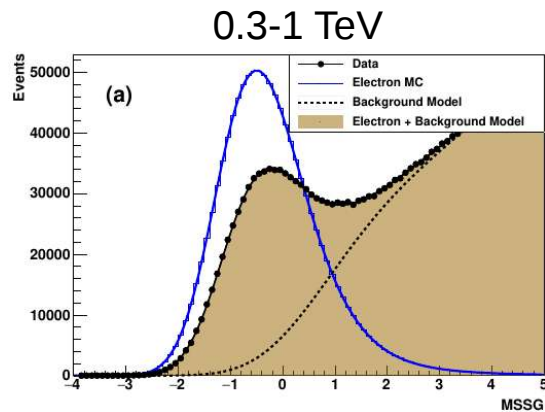
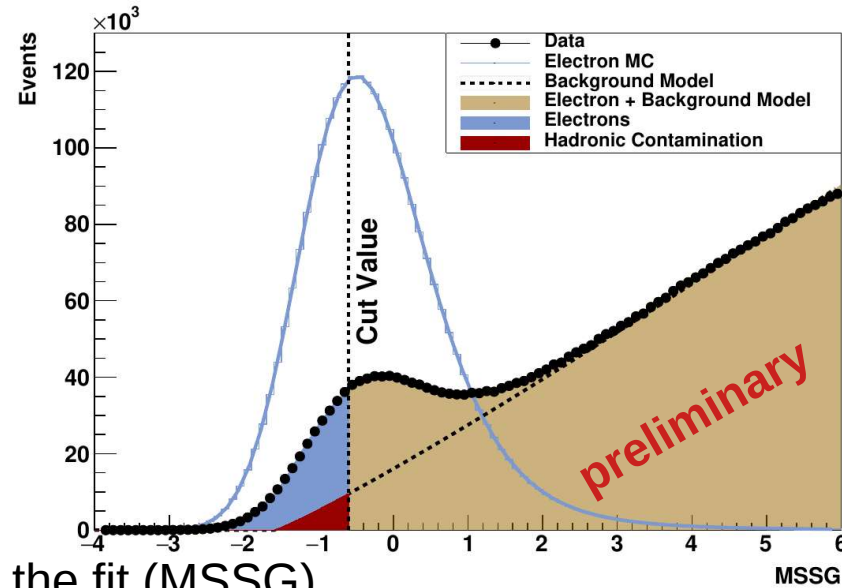
CR e^- and e^+ are an unavoidable contamination of gamma-ray showers.
They are hard to discriminate in terms of shower image parameters.
Studying 'background', HESS (2008, 2009) derived e^-/e^+ spectra < 4 TeV.
Break at ~ 1 TeV, later confirmed by MAGIC (2011), VERITAS (2018)
and direct detection experiments (AMS-02, DAMPE, CALET).

New study by HESS (submitted) towards higher energies.

CR Measurements

Analysis involves 'run-wise' simulations where each ~30 min data-set ('run') is simulated with actual pointing, NSB & calibration coefficients (px), dead-time, ATC, ..., involving ~200 000 e⁻ (hard spectrum ($\Gamma=1.3$)) showers.

The particle identification is derived using the quality of the fit (MSSG). Electron candidates are cut at $\text{MSSG} < -0.6$. The contamination by hadrons is derived from an analytic approximation to the MSSG distribution at each energy.



Conservative Data Selection

Only CT1-CT4 (CT5 has small fov)

Only 2003-2015 (homogeneity)

Standard quality cuts

$ZA < 45^\circ$ (threshold)

$|b| > 15^\circ$ (Galactic gammas)

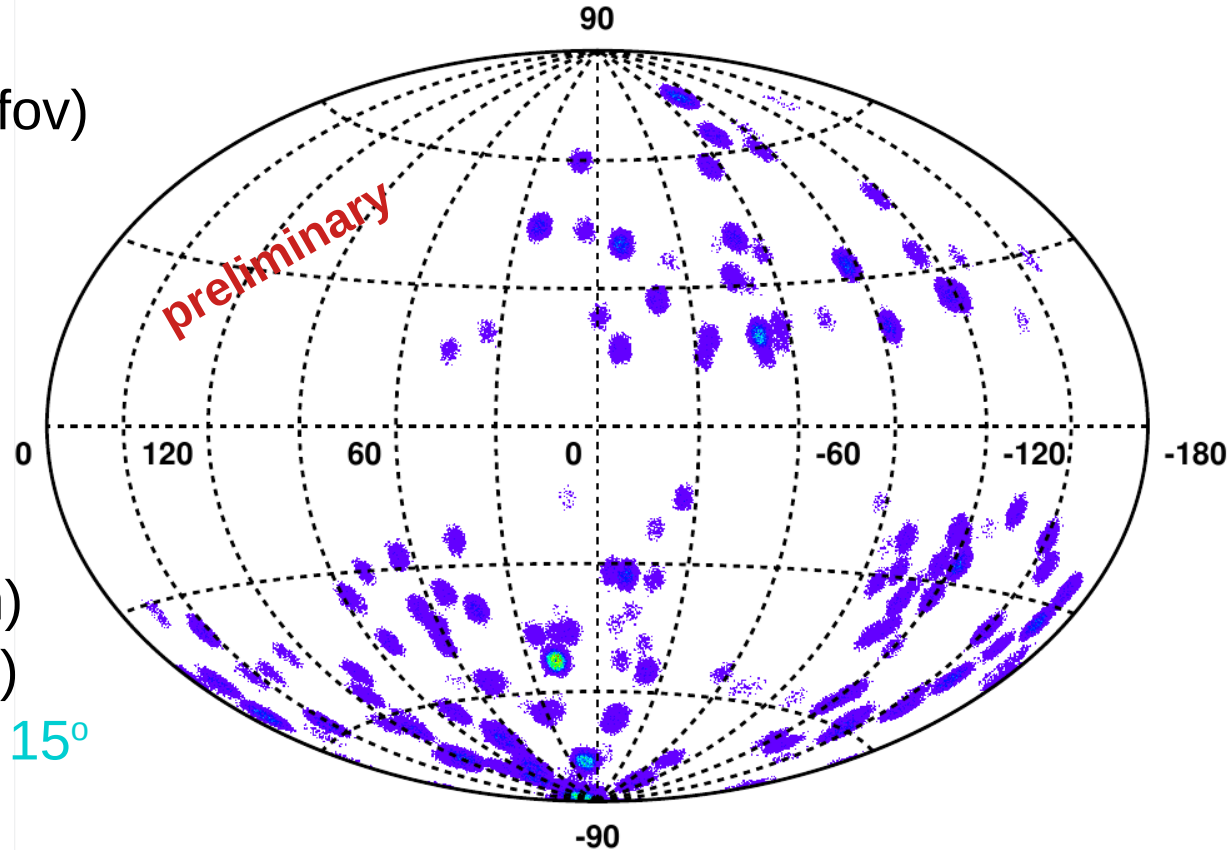
$d(\text{LMC, SMC}) > 5^\circ$

Four telescope events

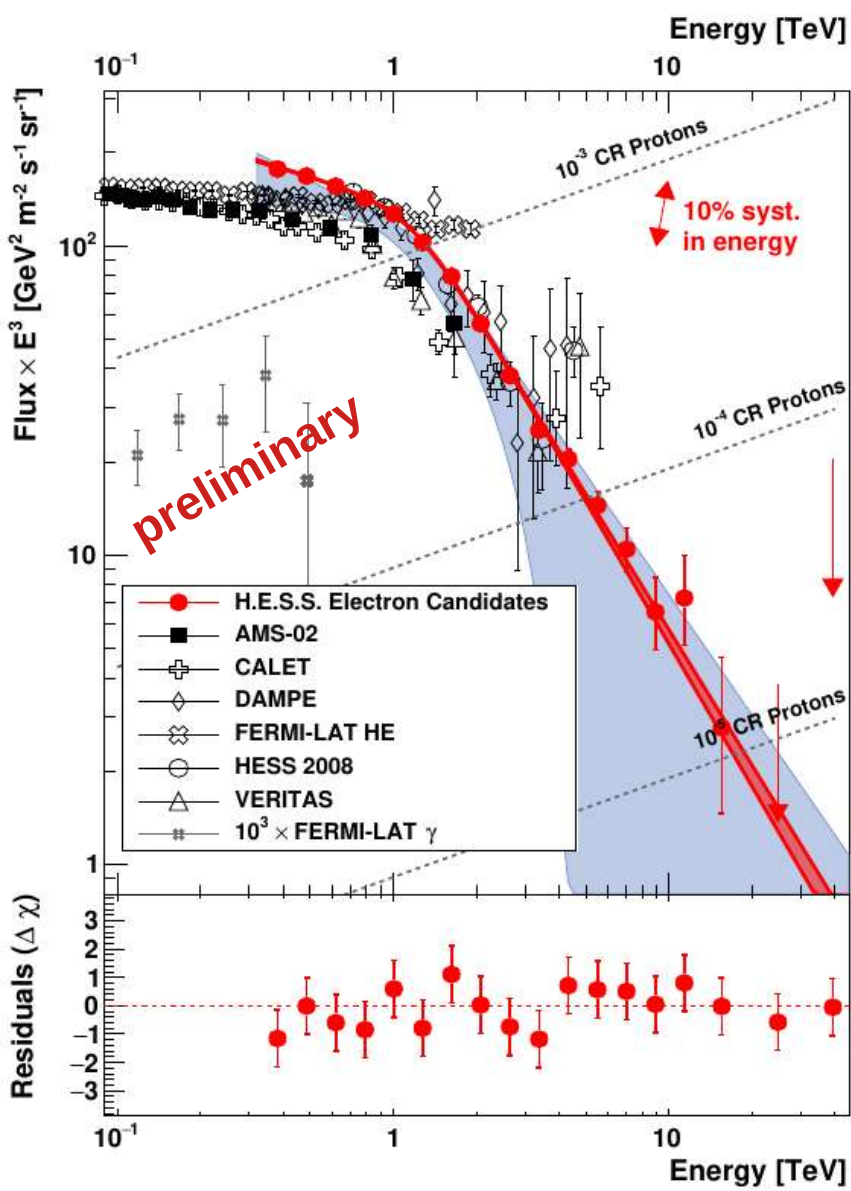
Central 4° of fov (reconstruction)

$d(\text{sources}) > 0.25^\circ$ (PSF: 0.06°)

Contamination: BG above $|b| > 15^\circ$



HESS CR $e^\pm$ Spectra



$$F(E) = F_0 \left(\frac{E}{1 \text{ TeV}} \right)^{-\Gamma_1} \left(1 + \left(\frac{E}{E_b} \right)^{\frac{1}{\alpha}} \right)^{-(\Gamma_2 - \Gamma_1)\alpha}$$

No significant deviations from broken PL

$$F_0 = (126.1 \pm 0.5_{\text{stat}} \pm 13_{\text{sys}}) \text{ GeV}^2 \text{m}^{-2} \text{sr}^{-1} \text{s}^{-1}$$

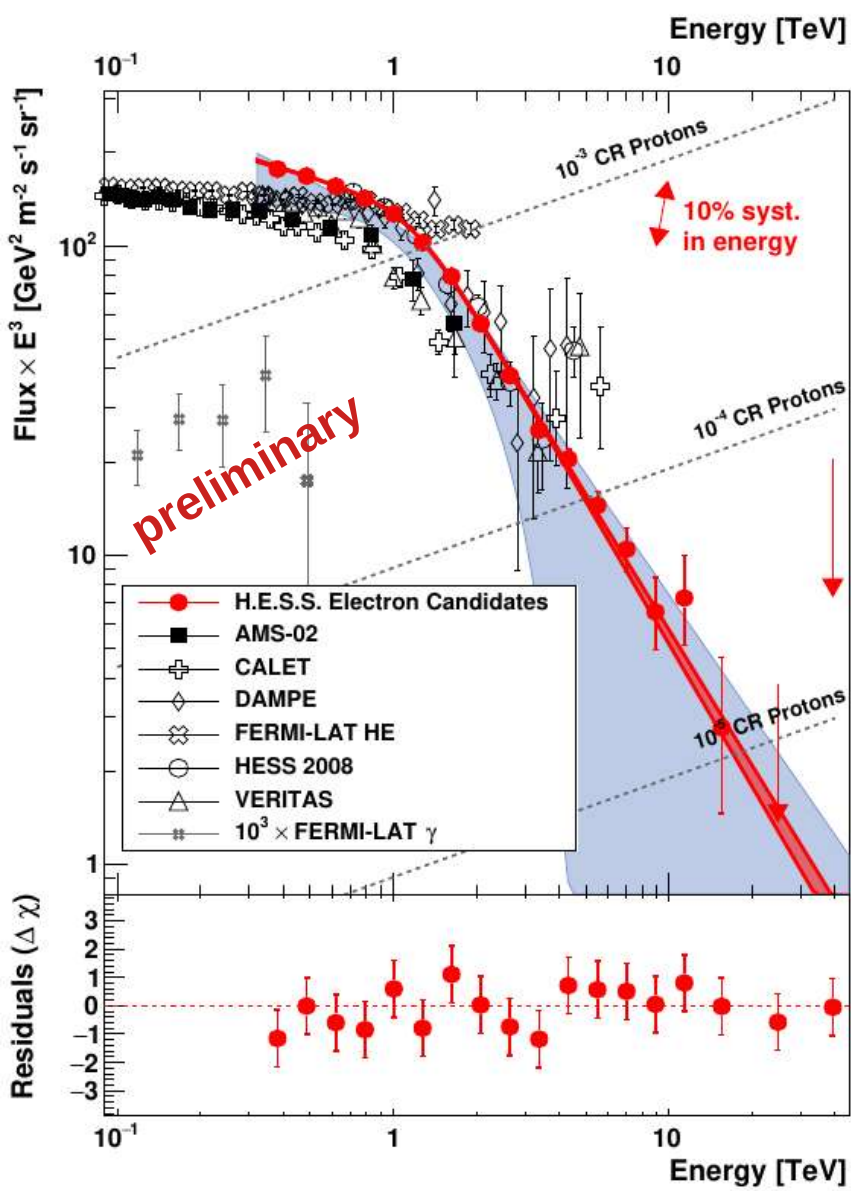
$$\Gamma_1 = 3.25 \pm 0.02_{\text{stat}} \pm 0.2_{\text{sys}}$$

$$\Gamma_2 = 4.49 \pm 0.04_{\text{stat}} \pm 0.2_{\text{sys}}$$

$$E_b = (1.17 \pm 0.04_{\text{stat}} \pm 0.12_{\text{sys}}) \text{ TeV}$$

$$\alpha = 0.21 \pm 0.02_{\text{stat}} {}^{+0.10_{\text{sys}}}_{-0.06_{\text{sys}}}$$

HESS CR $e^\pm$ Spectra



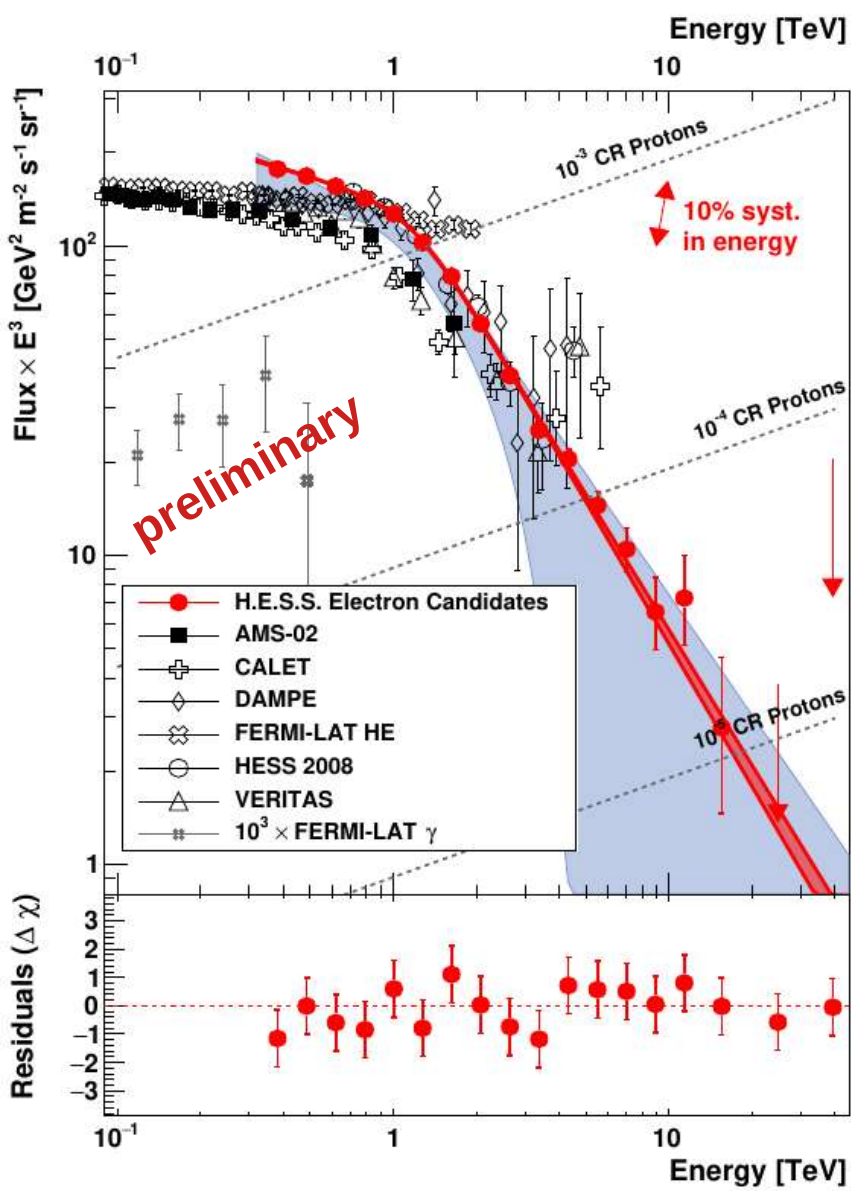
$$F(E) = F_0 \left(\frac{E}{1 \text{ TeV}} \right)^{-\Gamma_1} \left(1 + \left(\frac{E}{E_b} \right)^{\frac{1}{\alpha}} \right)^{-(\Gamma_2 - \Gamma_1)\alpha}$$

No significant deviations from broken PL

No confirmation of 1.4 TeV break (potential DM signal), Yuan et al.

No rise (hardening) above 5 TeV

HESS CR $e^\pm$ Spectra



$$F(E) = F_0 \left(\frac{E}{1 \text{ TeV}} \right)^{-\Gamma_1} \left(1 + \left(\frac{E}{E_b} \right)^{\frac{1}{\alpha}} \right)^{-(\Gamma_2 - \Gamma_1)\alpha}$$

No significant deviations from broken PL

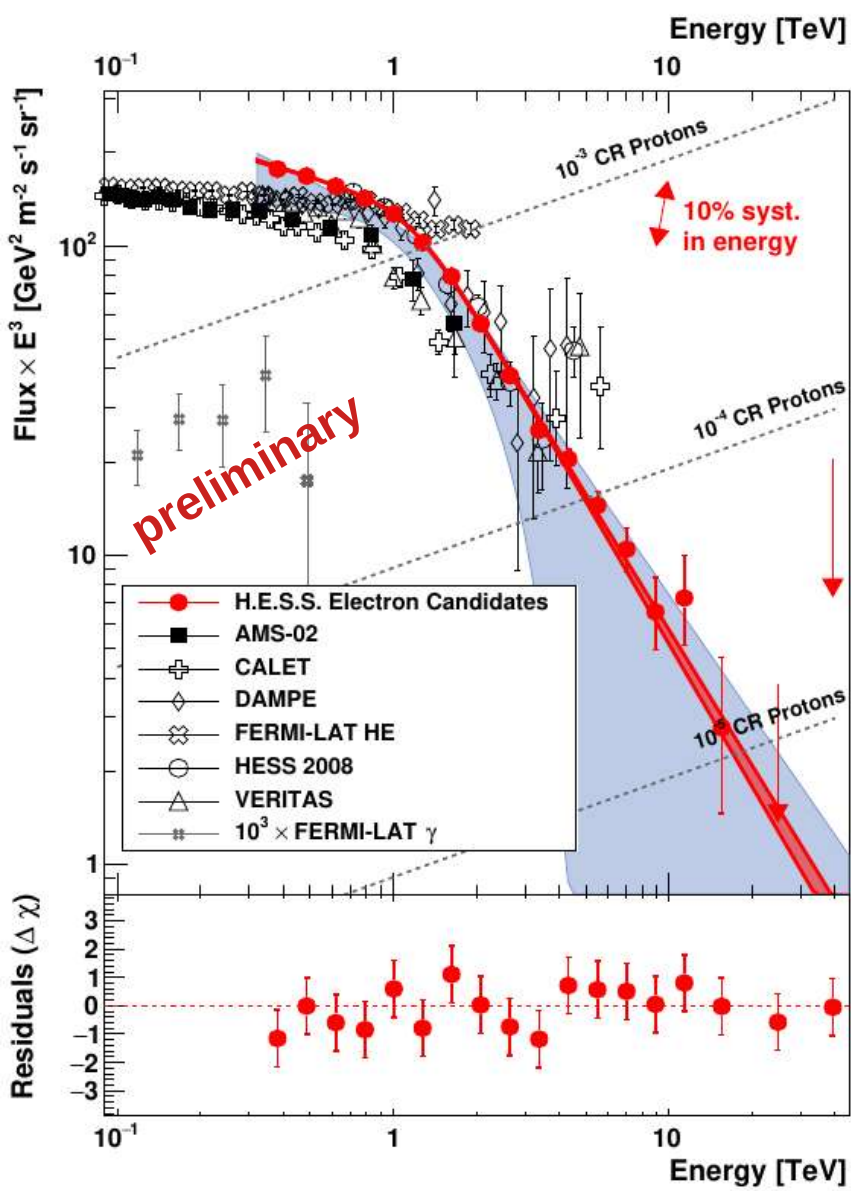
$$\Gamma_1 = 3.25 \pm 0.02_{\text{stat}} \pm 0.2_{\text{sys}}$$

larger but compatible with 3.2 (AMS)
and 3.1 (DAMPE, LAT)

$$\Gamma_2 = 4.49 \pm 0.04_{\text{stat}} \pm 0.2_{\text{sys}}$$

larger than DAMPE and VERITAS

HESS CR $e^\pm$ Spectra



$$F(E) = F_0 \left(\frac{E}{1 \text{ TeV}} \right)^{-\Gamma_1} \left(1 + \left(\frac{E}{E_b} \right)^{\frac{1}{\alpha}} \right)^{-(\Gamma_2 - \Gamma_1)\alpha}$$

No significant deviations from broken PL

$$E_b = (1.17 \pm 0.04_{\text{stat}} \pm 0.12_{\text{sys}}) \text{ TeV}$$

marginally compatible with DAMPE
 significantly higher than VERITAS
 incompatible with 95% lower limit (LAT)
 $\alpha \rightarrow 0, E_b \rightarrow 1.09 \text{ TeV}$

Cosmic Ray $e^\pm$ Spectra

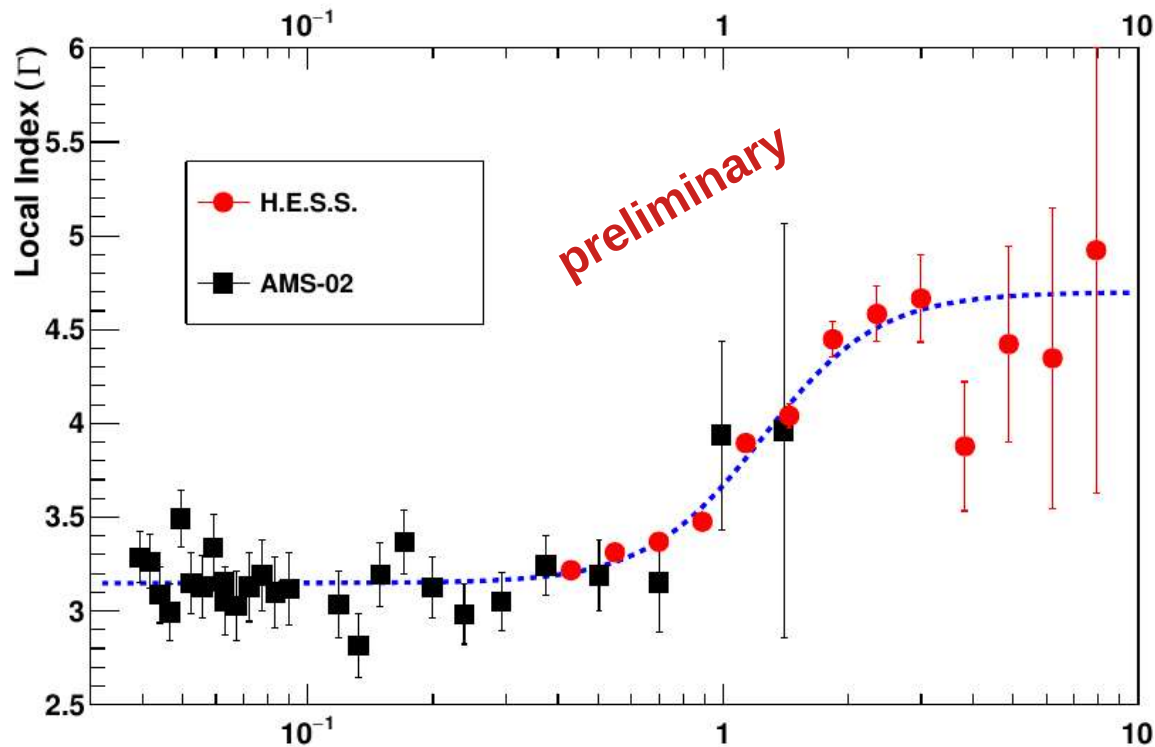
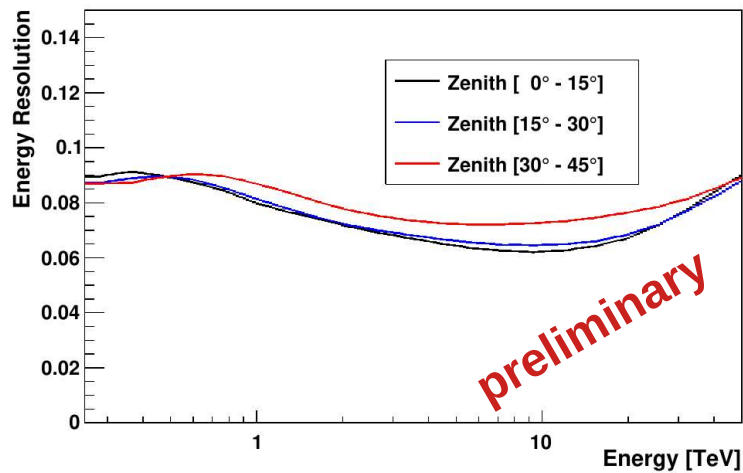
Spectral break at $E_b = (1.17 \pm 0.04_{\text{stat}} \pm 0.12_{\text{sys}}) \text{ TeV}$
with

$$\alpha = 0.21 \pm 0.02_{\text{stat}} \pm 0.10_{\text{sys}} \quad +0.10_{\text{sys}} \quad -0.06_{\text{sys}}$$

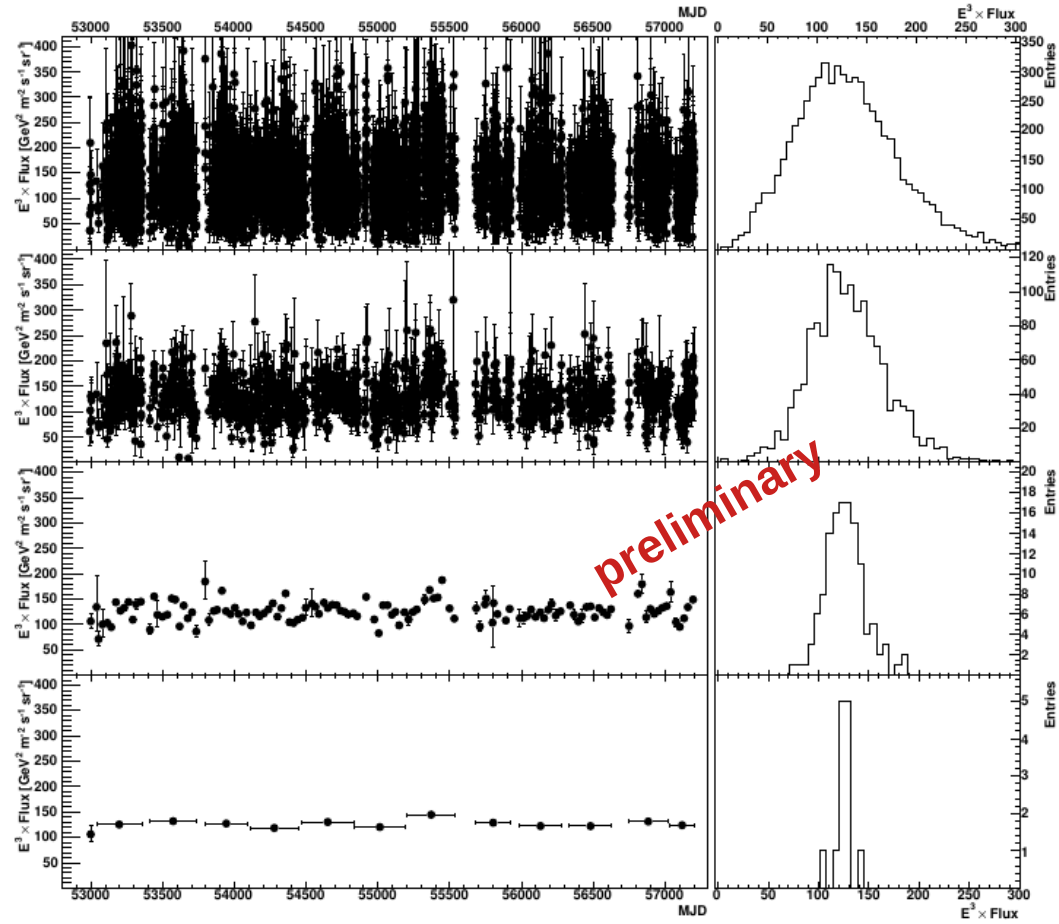
$\alpha = 0$ ruled out

$$\Delta\Gamma/(\Delta E/E) \sim 1/3$$

Energy resolution $\sim 9\%$



Time resolved data



Diffusive propagation
→ no changes over ~ decades

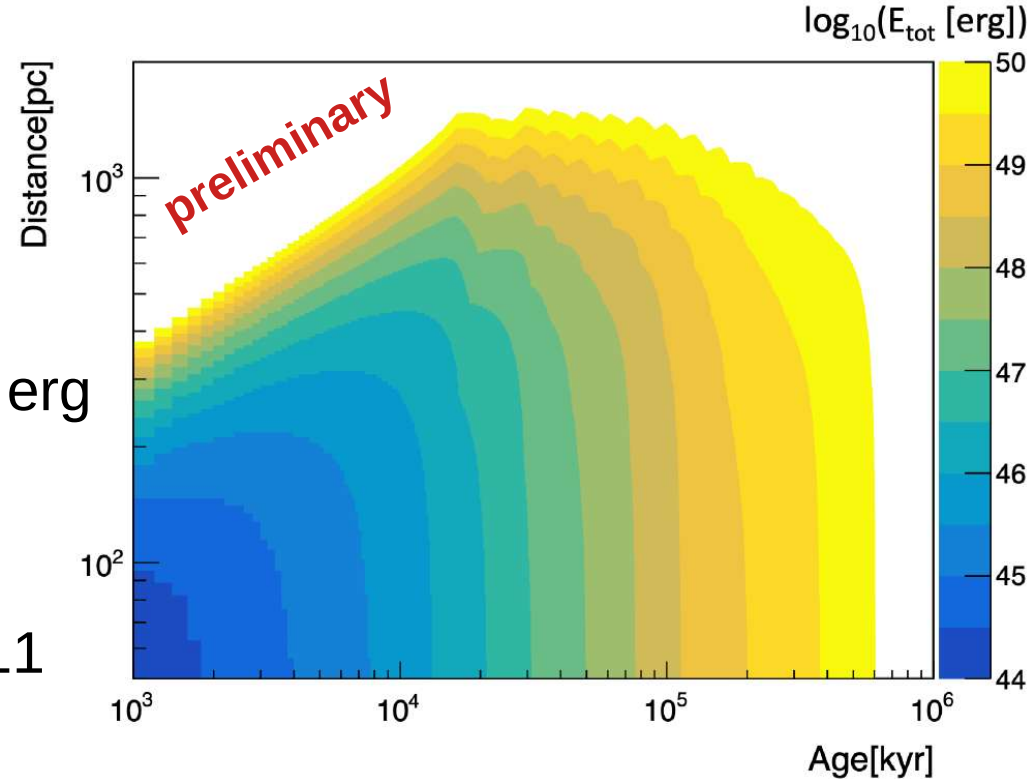
Testing stability and uncertainties

E.g.: Fixed spectral shape and
free normalization on runs, nights,
months and years timescales vary,
all are consistent with statistical
and systematic errors.

Cosmic Ray Measurements

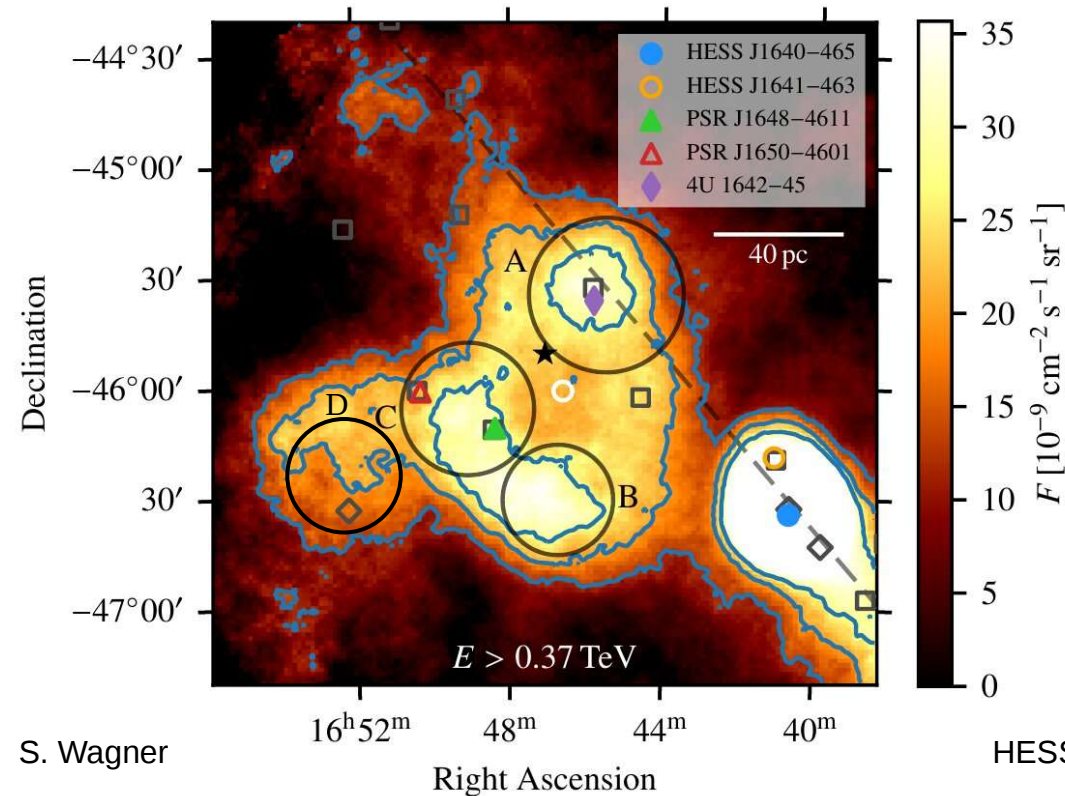
>10 TeV electrons and break impose limitations on cooling time (~ 100 kyr) and propagation ($\sim$ few 100 pc).

No strong local source; e.g. burst of Vela-type (300 pc, 11 kyr): $E < 2 \cdot 10^{46}$ erg but fairly sharp break disfavors distributed ensemble of sources with spectrum of propagation times.
e.g. Mauro+ 14, Recchia+ 19, Drury 11

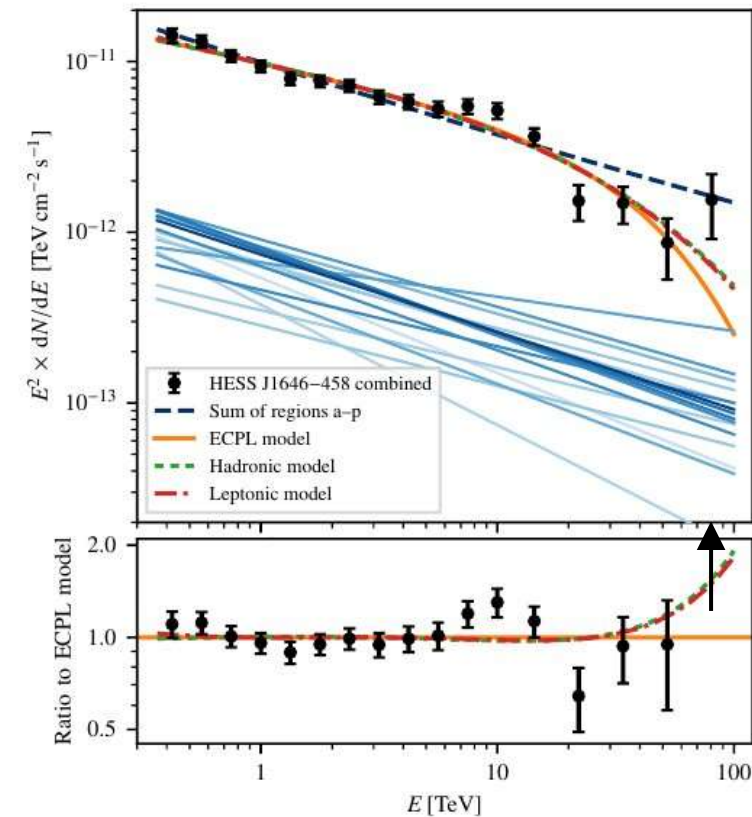


Stellar Clusters

Westerlund 1 (HESS, AA 666, 124, 2022)



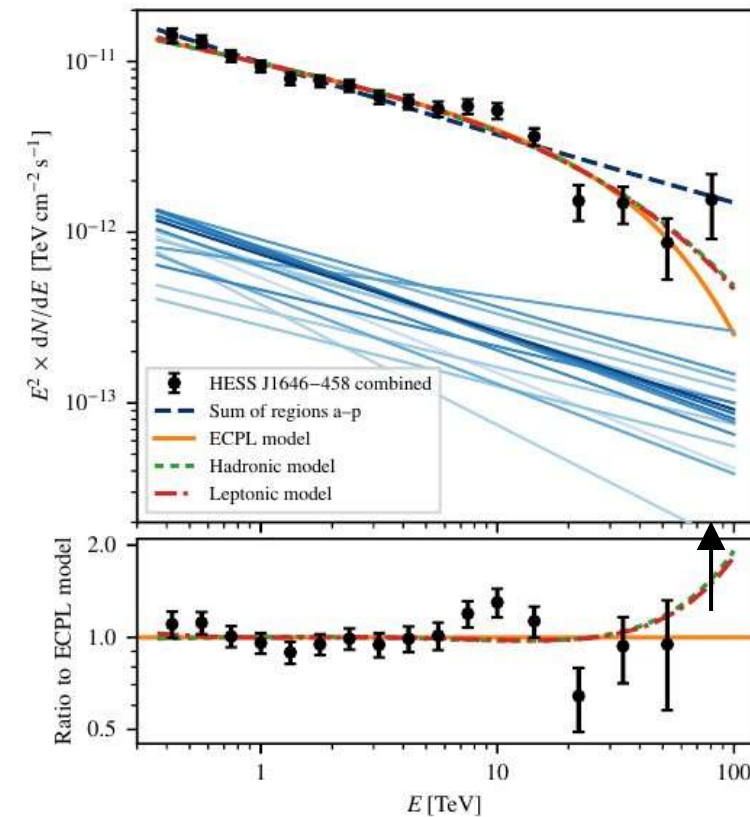
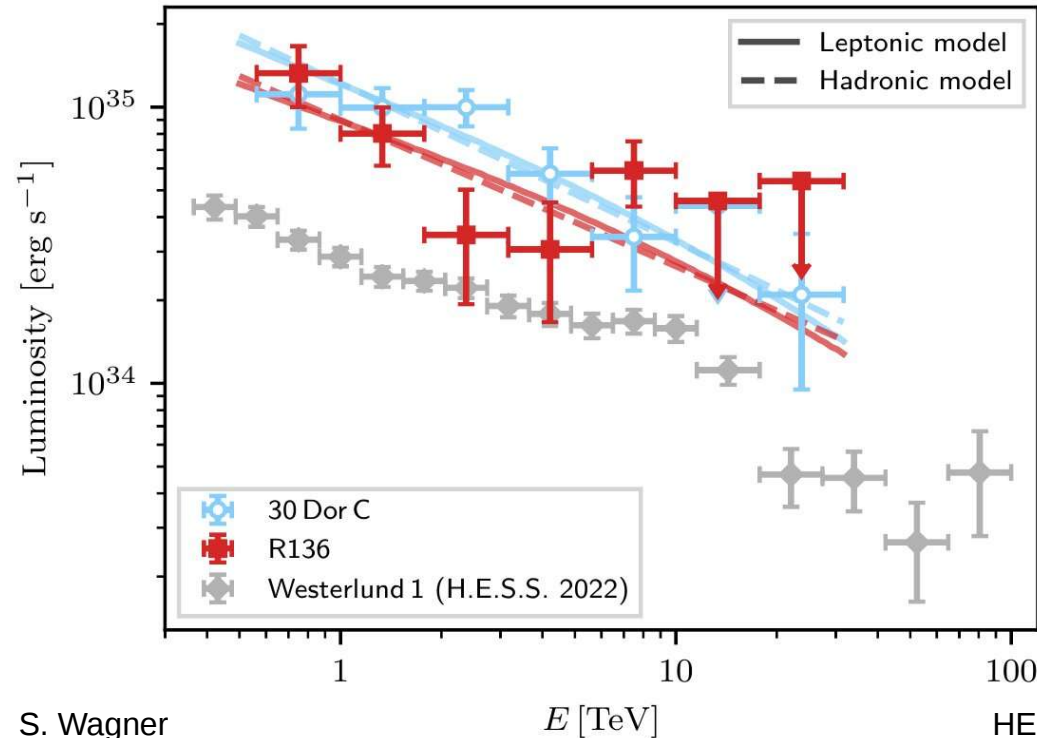
The most massive stellar cluster
 $W_e \sim 10^{49} \text{ erg}$, a potential pevatron?



Stellar Clusters

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New: 30 Dor C, R 136 (LMC), HESS, 2024

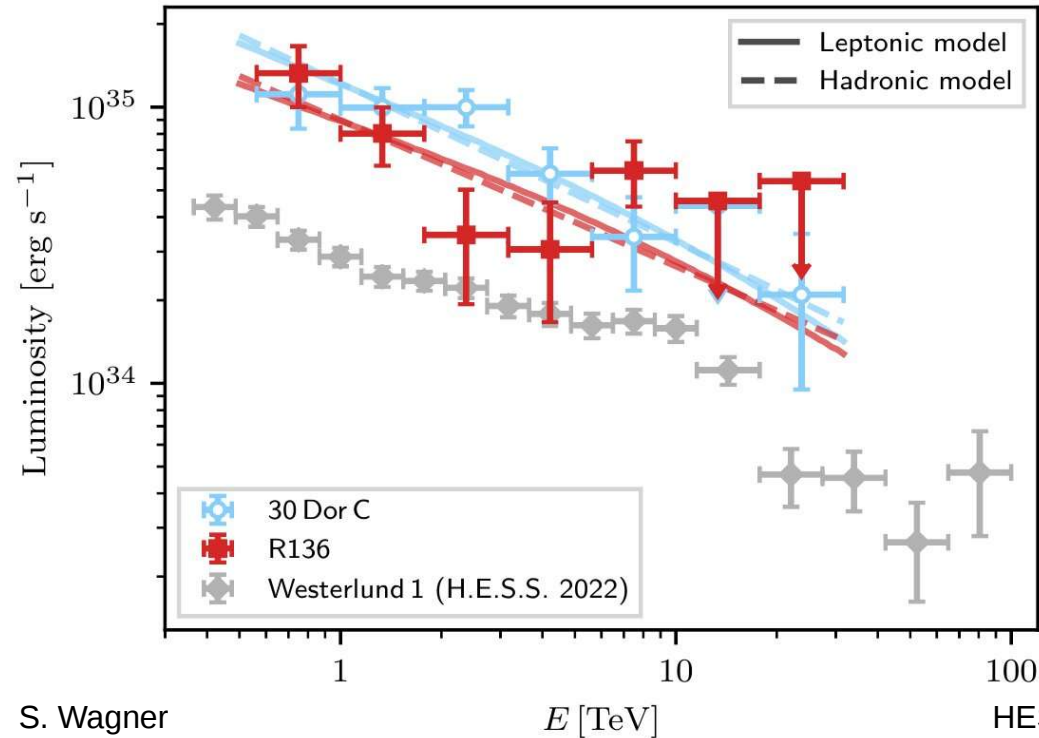


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Stellar Clusters

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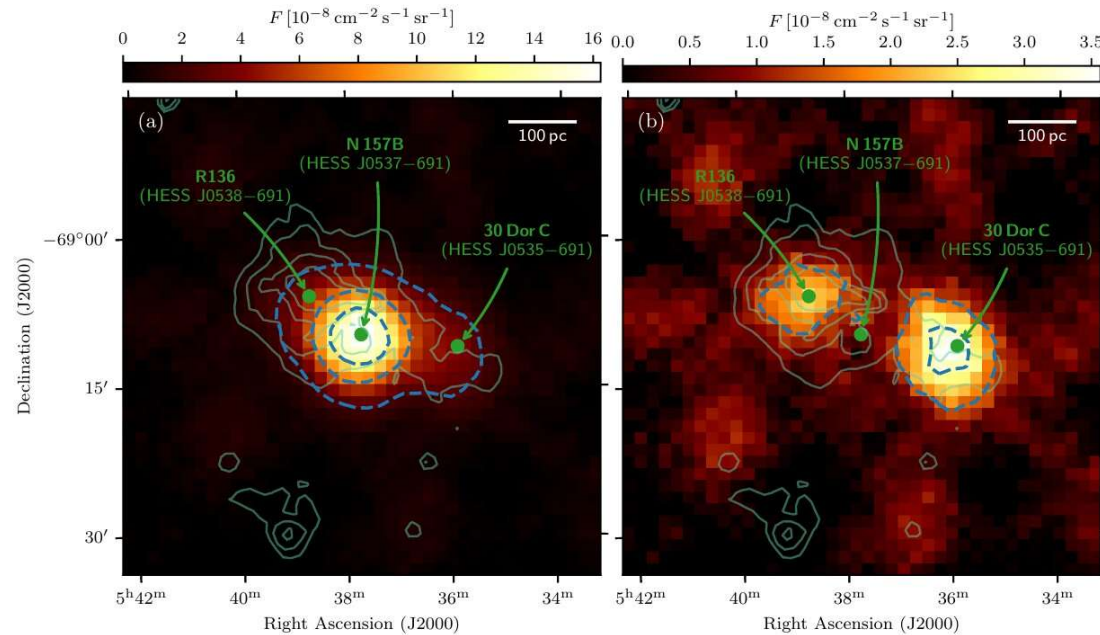
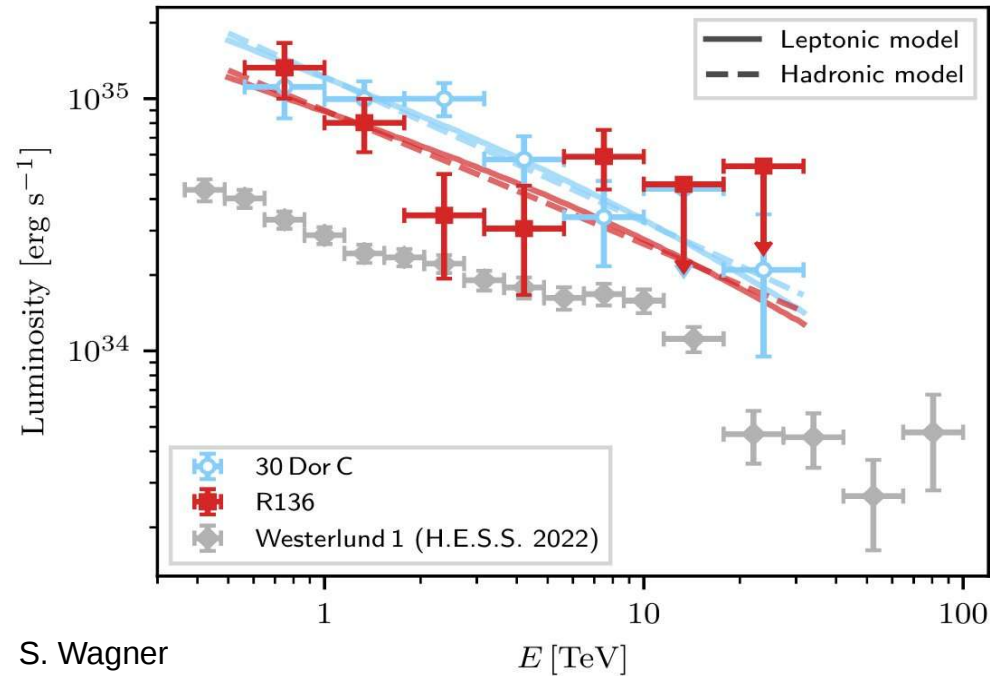
New: R 136, 30 Dor C (LMC), HESS, 2024



The heart of the Tarntula nebula
(next to superbubble 30 Dor C)

Stellar Clusters

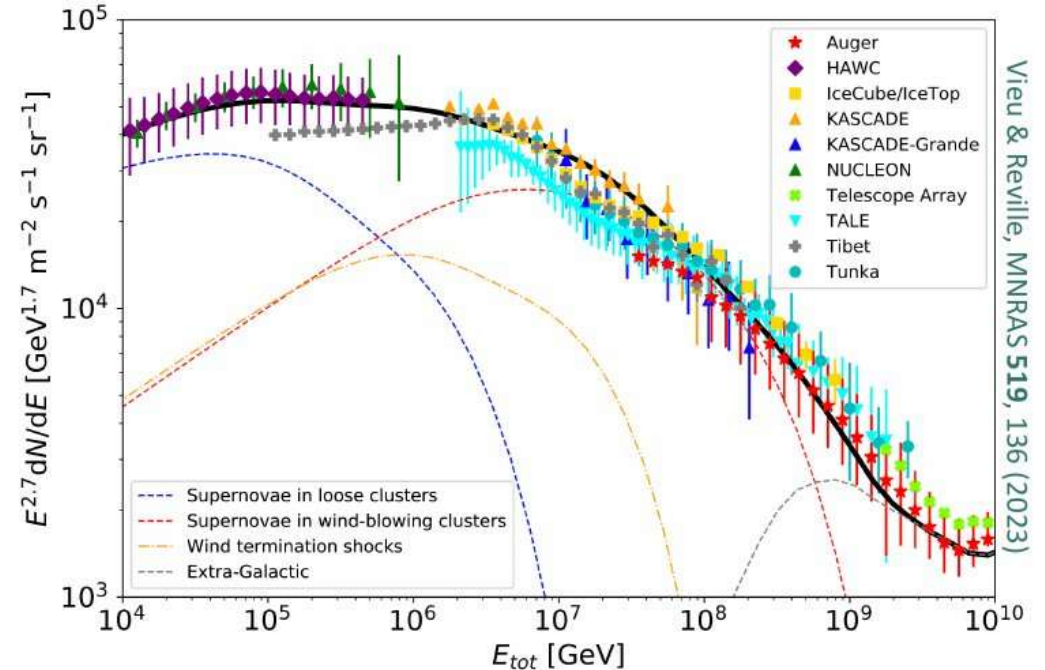
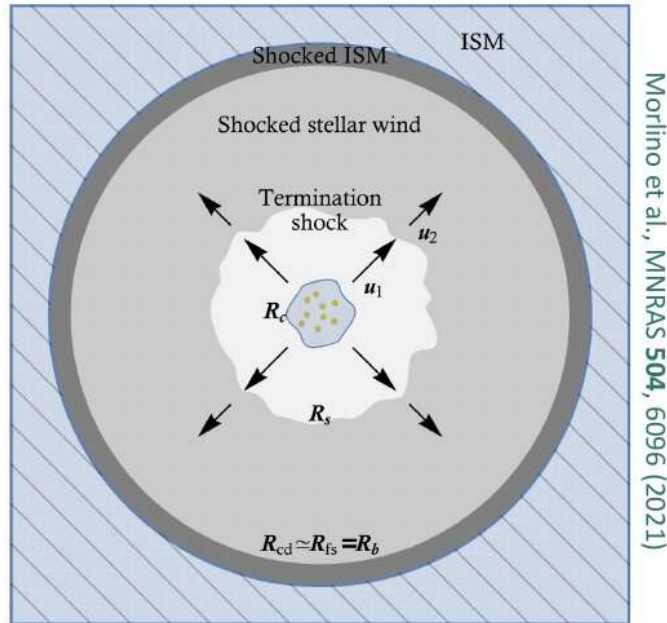
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30 Dor C extended
indicate both SB and enclosed OBA

Young Stellar Clusters

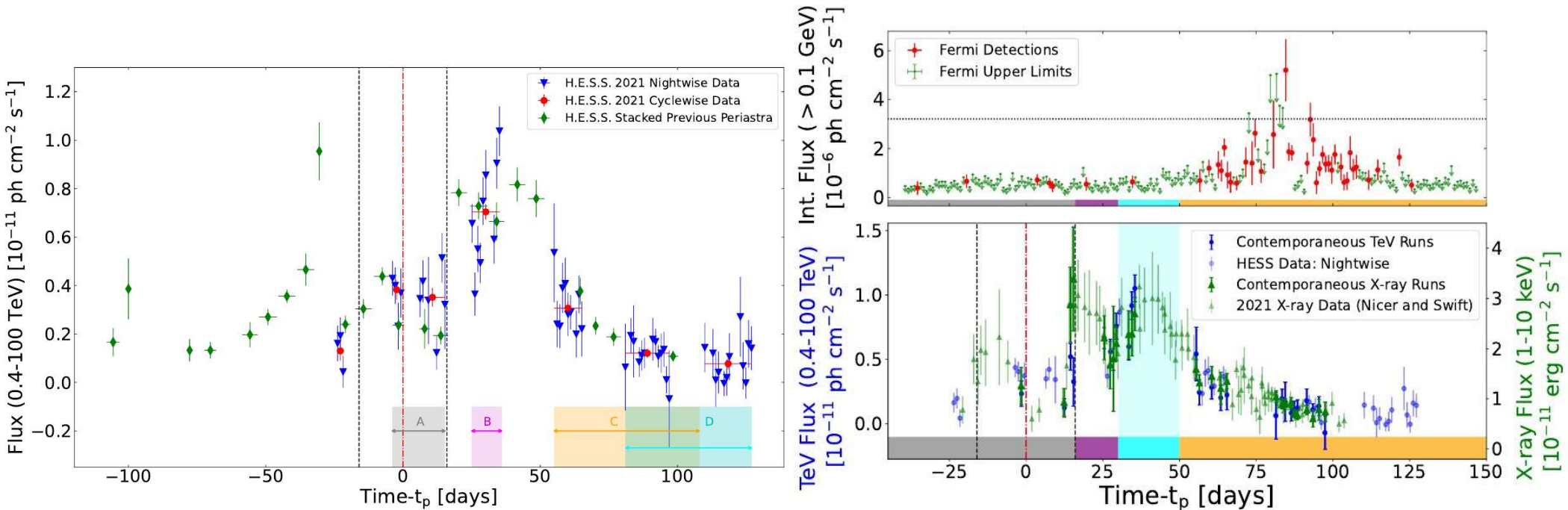
A potential contributor also to UHE CRs



Monitoring GR Binaries

Time domain program (GRB, Novae, AGN, GW, Neutrino, TDE, FRB, ...)

Binaries, e.g. 1259-63 (HESS, arXiv:2406.18167 plus current periastron)



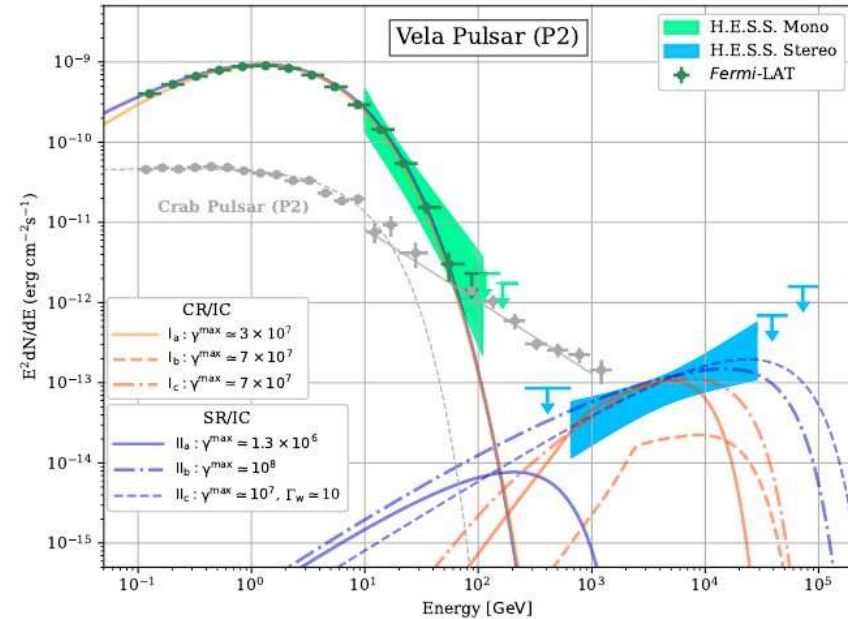
Other selected highlights

VHE pulsed emission from Vela
Nature Astronomy, arXiv:2310.06181

Energy dependent morphology of Crab
A&A 686, A308 (2024)

Resolved jets of microquasar SS433
Science383, 402-406 (2024)

Limits on DM down to thermal limit
Phys. Rev. Lett. 129, 111101



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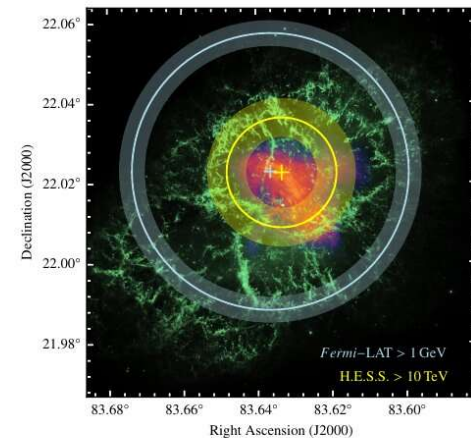
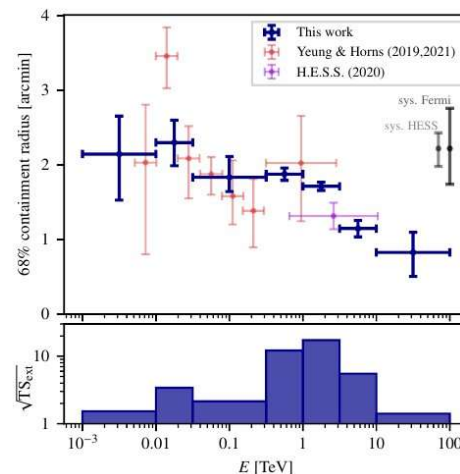


Fig. 7. Optical image of the Crab Nebula in green (credit: NAS).

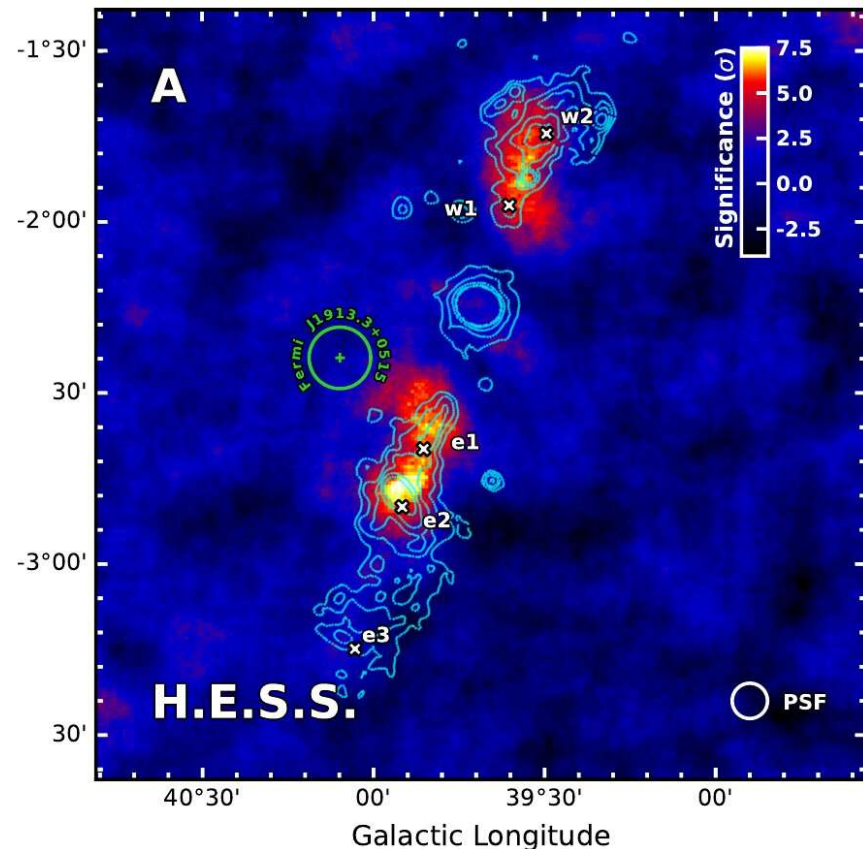
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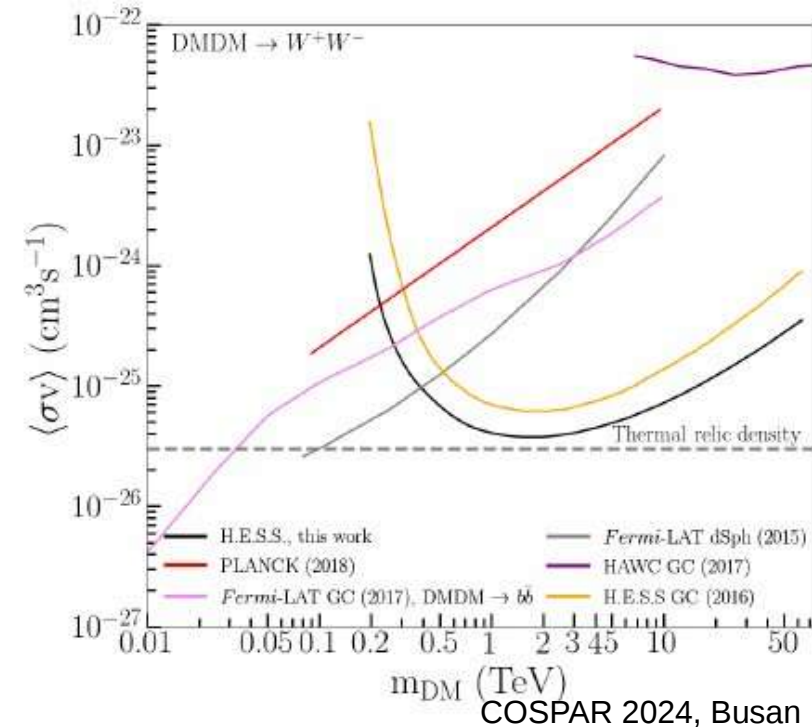
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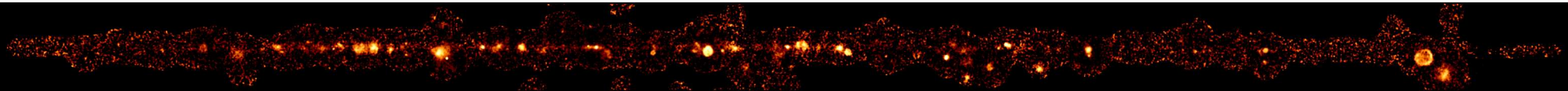
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Preview

A major emphasis of HESS has been on surveys in various domains:

The **HESS Galactic Plane Survey** (2018) has been a key enterprise during the first decade of HESS.



HGPS 2.0 is in preparation and will ~double the number of sources (caveat: what is a 'source' (vs. a 'component'))? → source confusion

HESS Extragalactic Gamma-ray Survey (HEGS)
Inner Galaxy Survey
HESS LMC Survey

Summary

HESS continues at high efficiency

Broad science portfolio:

New studies of CR e up to 40 TeV

New accelerators: Massive clusters

New diagnostics (Vela, Crab, Microquasars)

New studies on diffusion (PWN haloes)

Monitoring (1259-63, M87, quasars)

New surveys

2025 – 2028: New legacy program to be launched

