Highlights from H.E.S.S.

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

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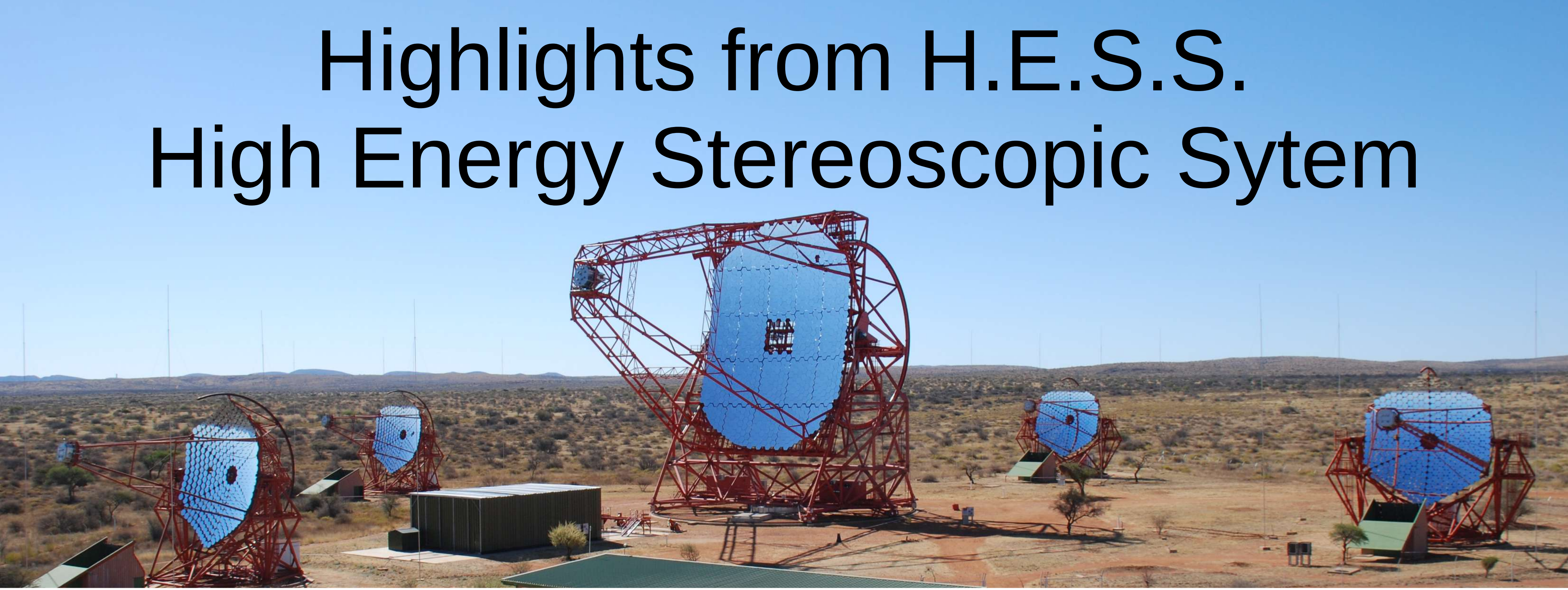
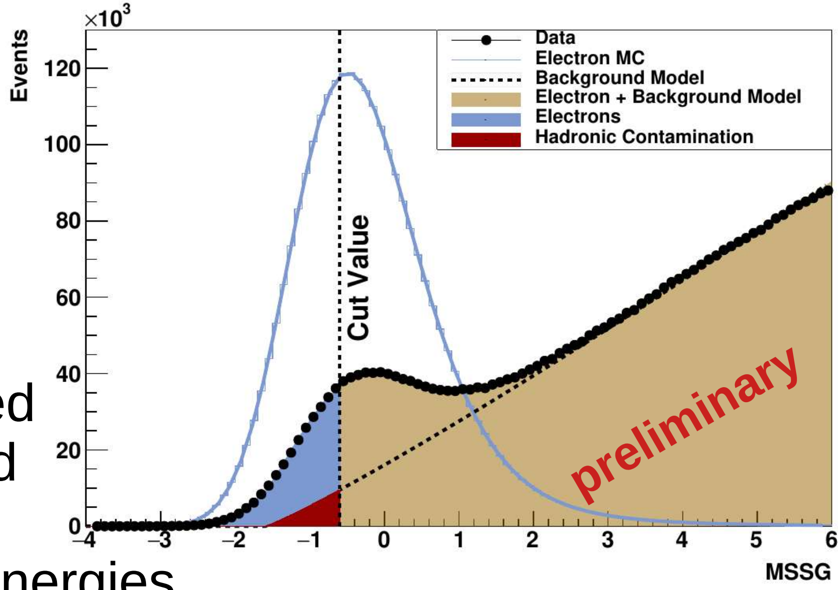
Highlights from H.E.S.S.
High Energy Stereoscopic Sytem



Five telescope array in Namibia, > 1000 m^2 mirror area
Telescopes operational since 2003, 2012, camera upgrades 2017, 2019
Past five years operation with > 97 % efficiency, > 1400 h/a

CR Measurements



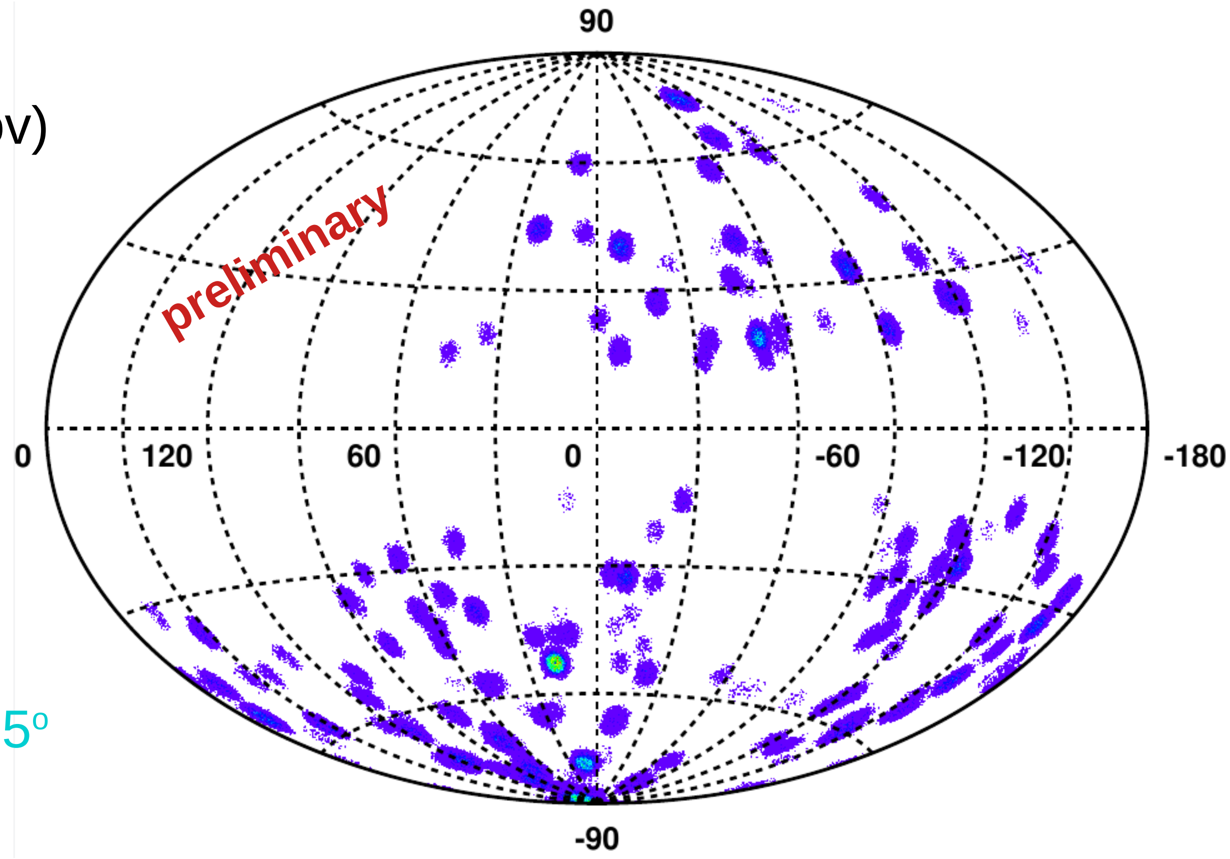
Primary objective: VHE Gamma-ray studies.
CR e- and e+ are an unavoidable contamination.
Studying ‘background’, HESS (2008, 2009) derived e-/e+ spectra < 4 TeV. Break at ~ 1TeV, confirmed by MAGIC, VERITAS, AMS-02, DAMPE, CALET.
New study by HESS (submitted) towards higher energies.

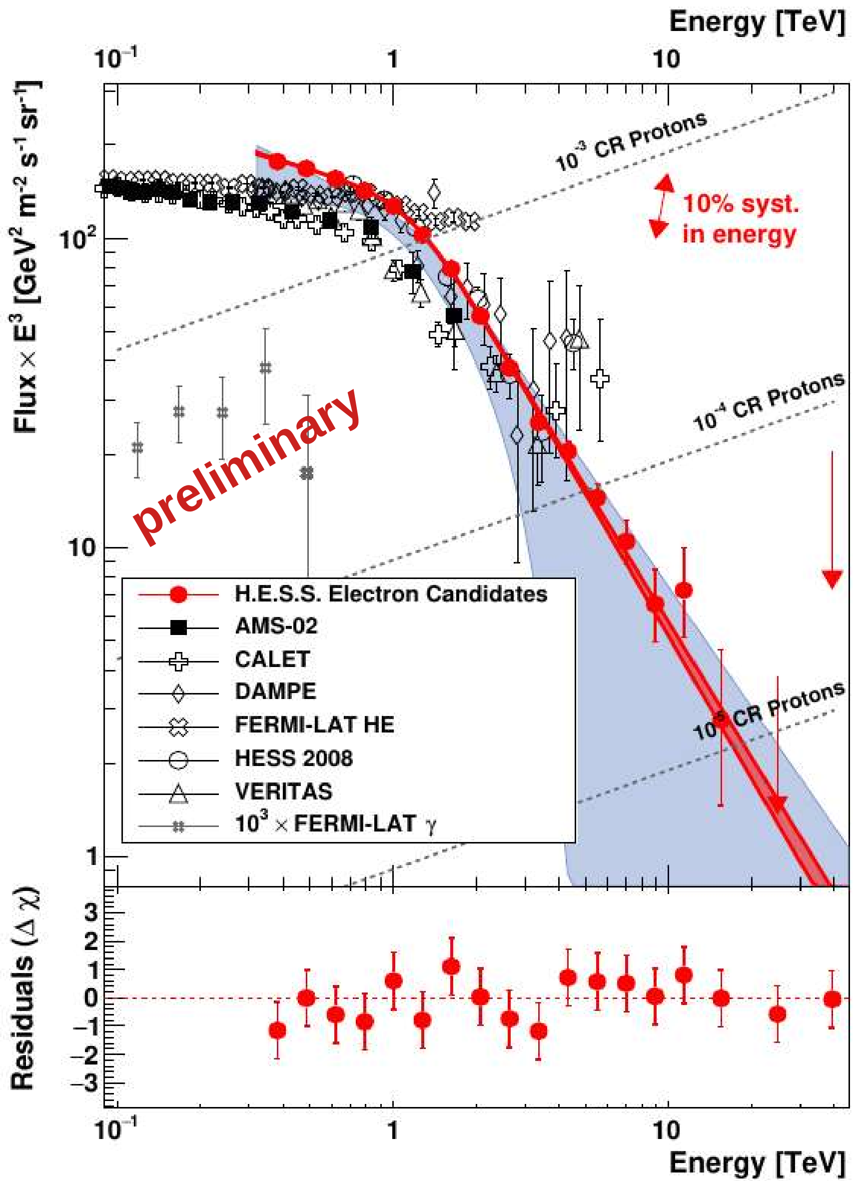
Analysis involves ‘run-wise’ simulations where each ~30 min data-set (‘run’) is simulated with actual pointing, NSB & calibration coefficients (px), dead-time, ATC, …, involving ~200 000 e- (hard spectrum (Γ=1.3)) showers.

The particle identification is derived using the quality of the fit (MSSG).
Electron candidates are cut at 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° (threshold)
|b| > 15° (Galactic gammas)
d (LMC, SMC) > 5°
Four telescope events
Central 4° of fov (reconstruction)
d (sources) > 0.25° (PSF: 0.06°)
Contamination: BG above |b| > 15°





HESS CR e± Spectra

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

No significant deviations from broken PL

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

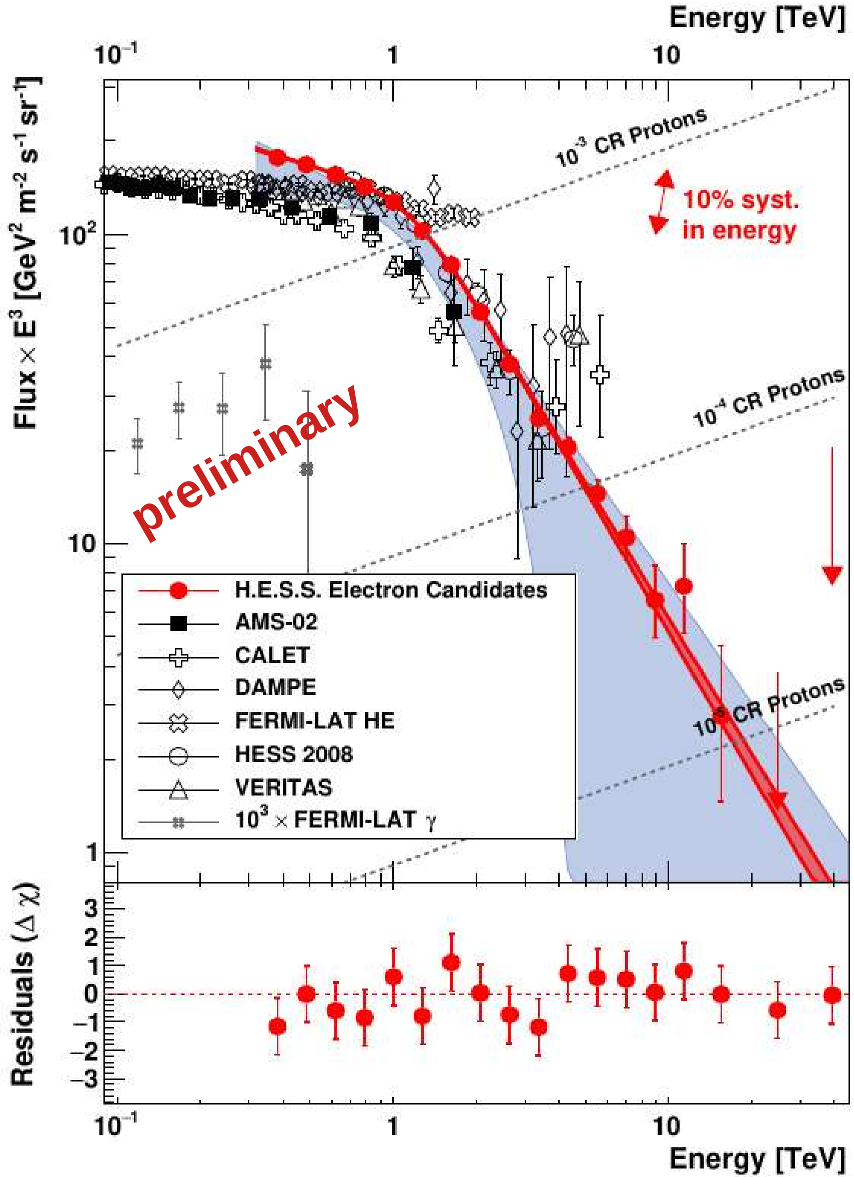
$$\Gamma_1 = 3.25 \pm 0.02_{\,\mathrm{stat}} \pm 0.2_{\,\mathrm{sys}}$$

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

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

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

HESS CR e± Spectra

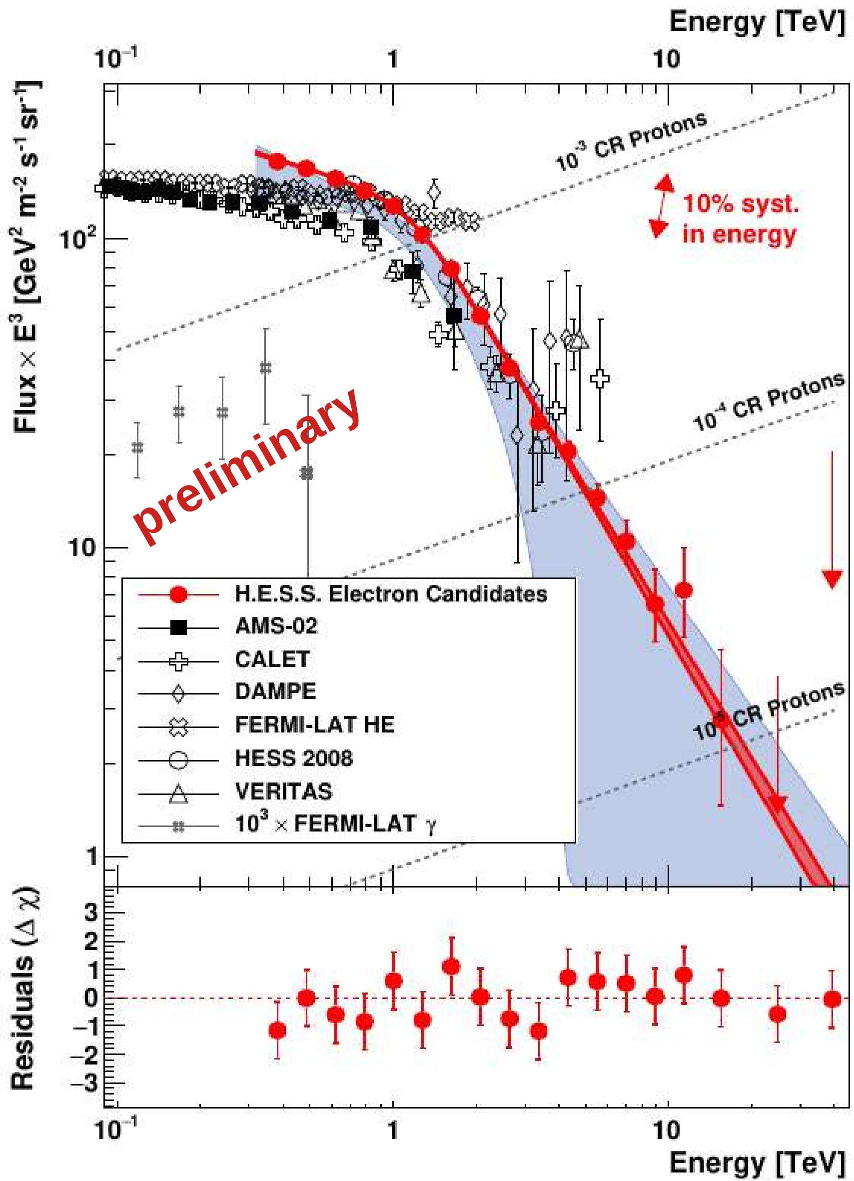


$$F(E) = F_0 \left(\frac{E}{1\ \mathrm{TeV}}\right)^{-\Gamma_1} \left(1 + \left(\frac{E}{E_b}\right)^{\frac{1}{\alpha}}\right)^{-(\Gamma_2-\Gamma_1)\alpha}$$

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

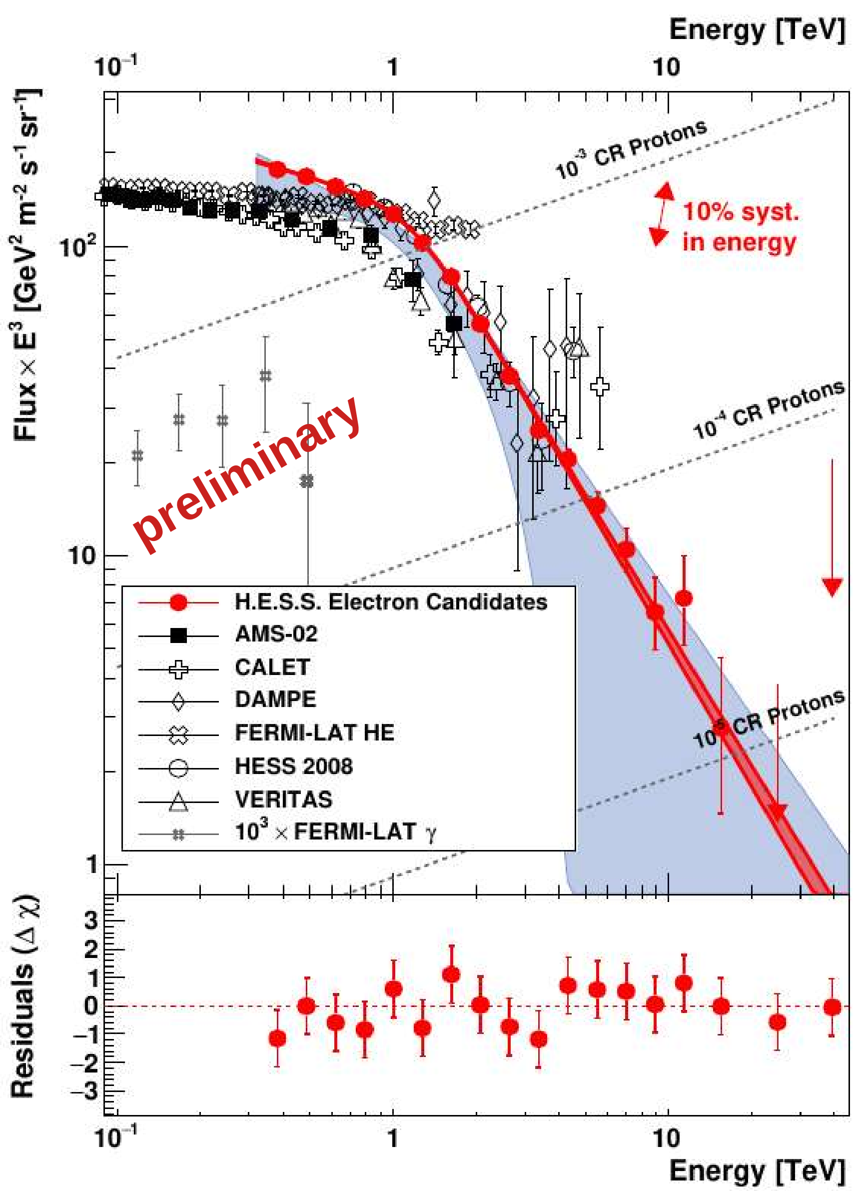
$$F(E) = F_0 \left(\frac{E}{1\ \mathrm{TeV}}\right)^{-\Gamma_1} \left(1 + \left(\frac{E}{E_b}\right)^{\frac{1}{\alpha}}\right)^{-(\Gamma_2-\Gamma_1)\alpha}$$

No significant deviations from broken PL

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

30% higher than other measurements
Systematic uncertainties
< 15% due to hadronic contamination
Compatible with other data

HESS CR e$^{\pm}$ Spectra



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

No significant deviations from broken PL

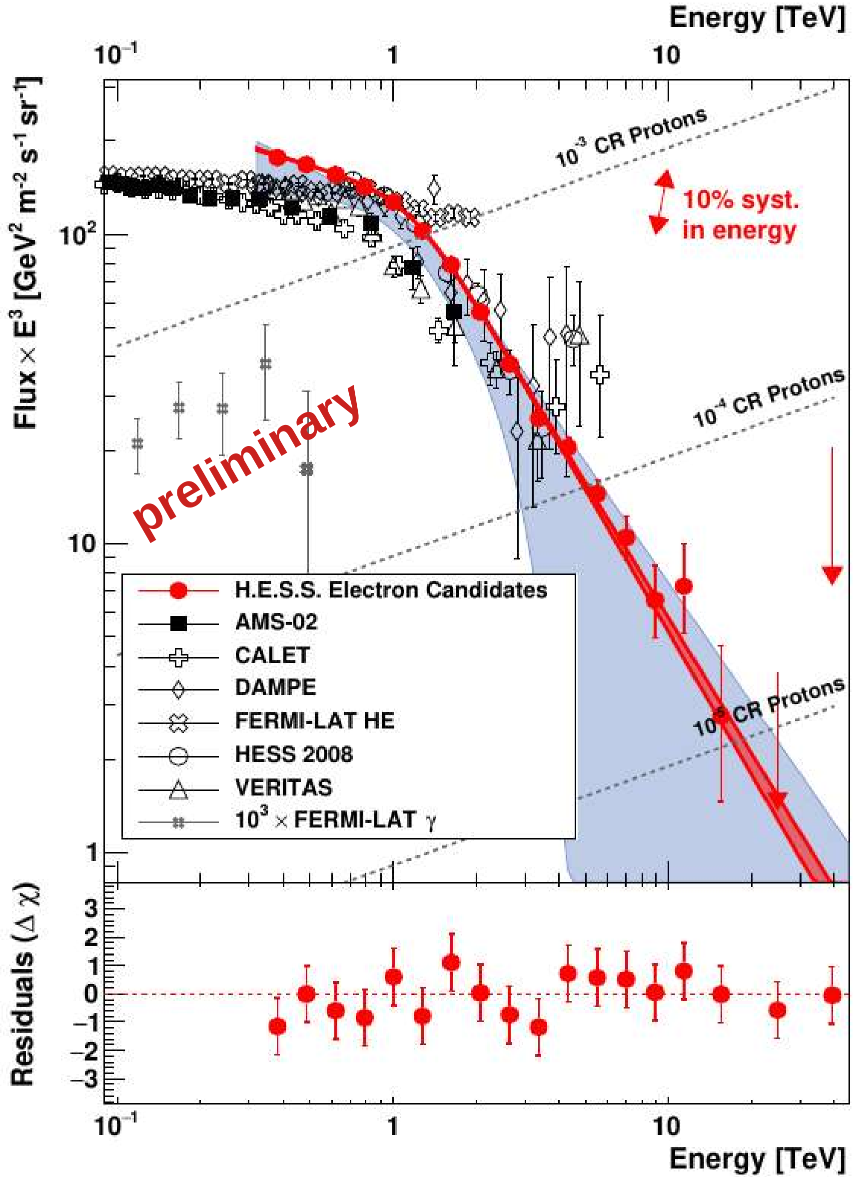
$$\Gamma_1 = 3.25 \pm 0.02_{\,\mathrm{stat}} \pm 0.2_{\,\mathrm{sys}}$$

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

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

larger than DAMPE and VERITAS

HESS CR e± Spectra



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

No significant deviations from broken PL

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

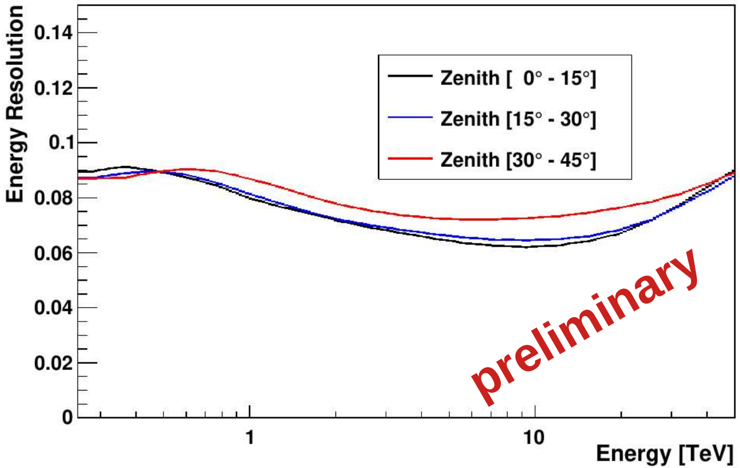
marginally compatible with DAMPE
significantly higher than VERITAS
incompatible with 95% lower limit (LAT)
$\alpha \rightarrow 0$, $E_b \rightarrow 1.09$ TeV

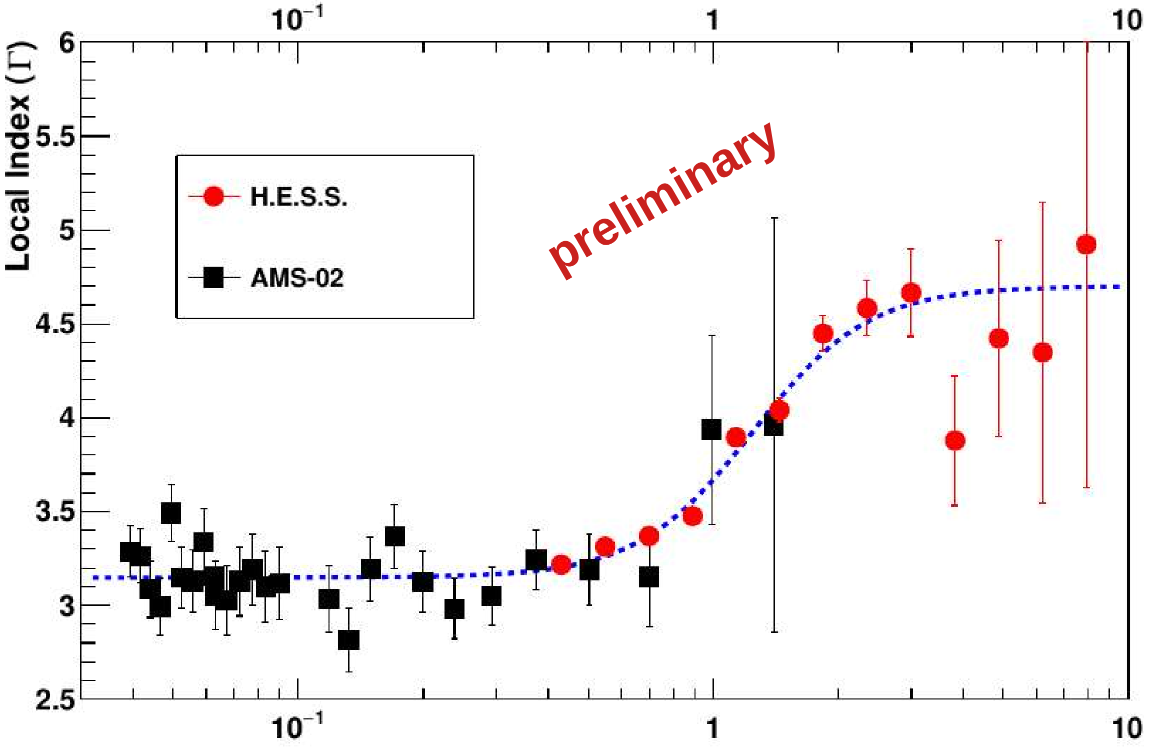
Cosmic Ray e$^{\pm}$ Spectra

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

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

α = 0 ruled out
ΔΓ/(ΔE/E) ~ 1/3
Energy resolution ~ 9%



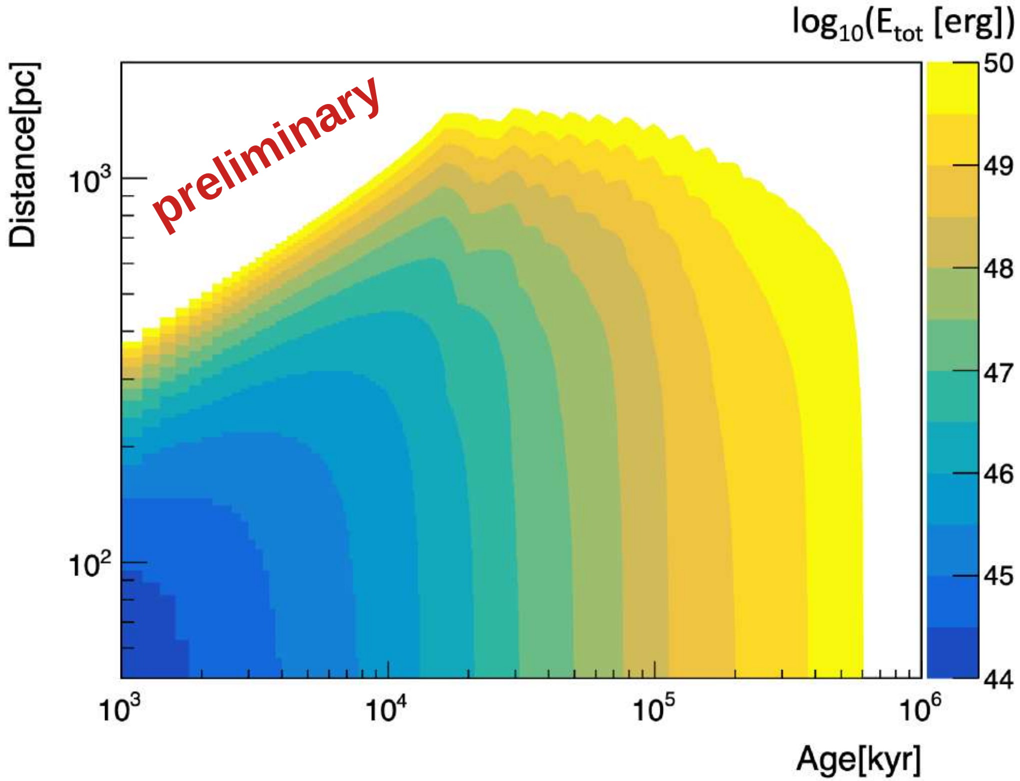


Cosmic Ray Measurements

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

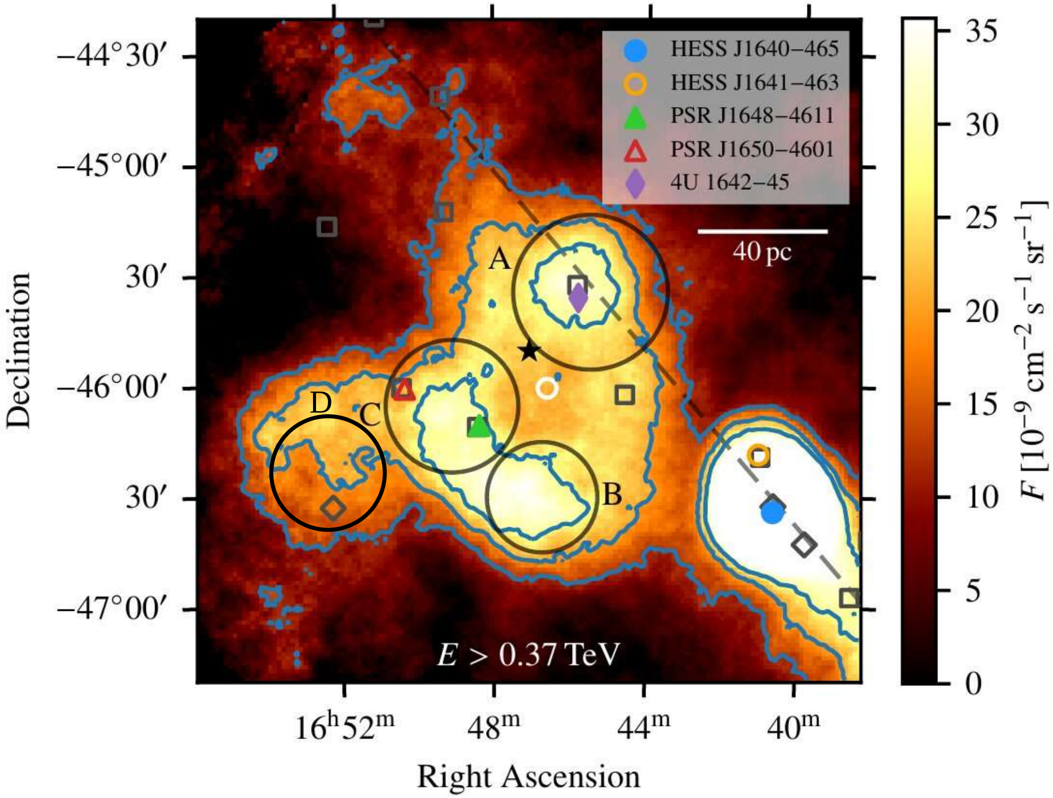
No strong local source; e.g. burst of Vela-type (300 pc, 11 kyr): E < 2 10^{46} erg but fairly sharp break disfavors distributed ensemble of sources with spectrum of propagation times.

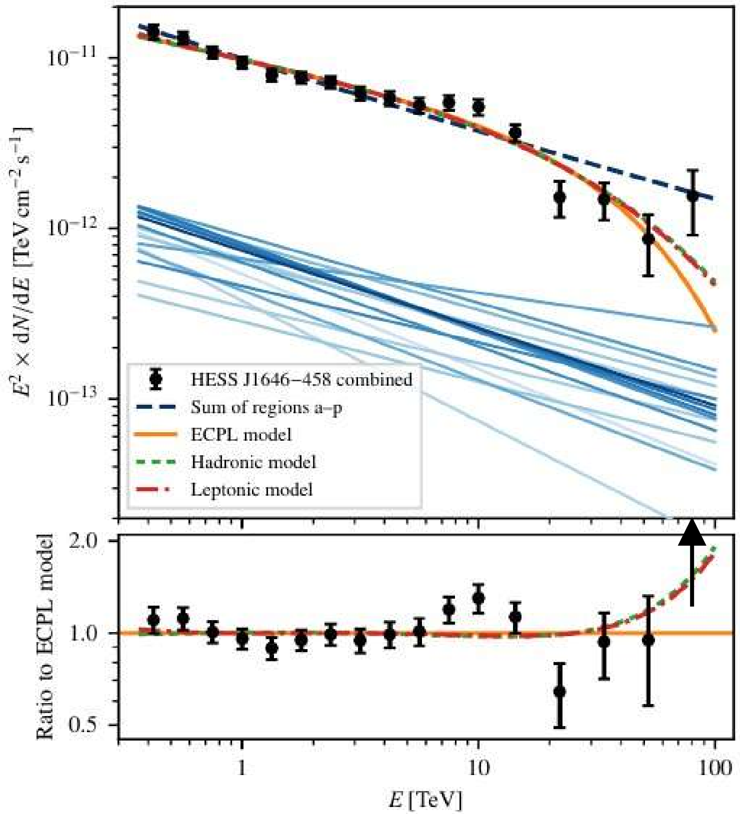
e.g. Mauro+ 14, Recchia+ 19, Drury 11



Stellar Clusters

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

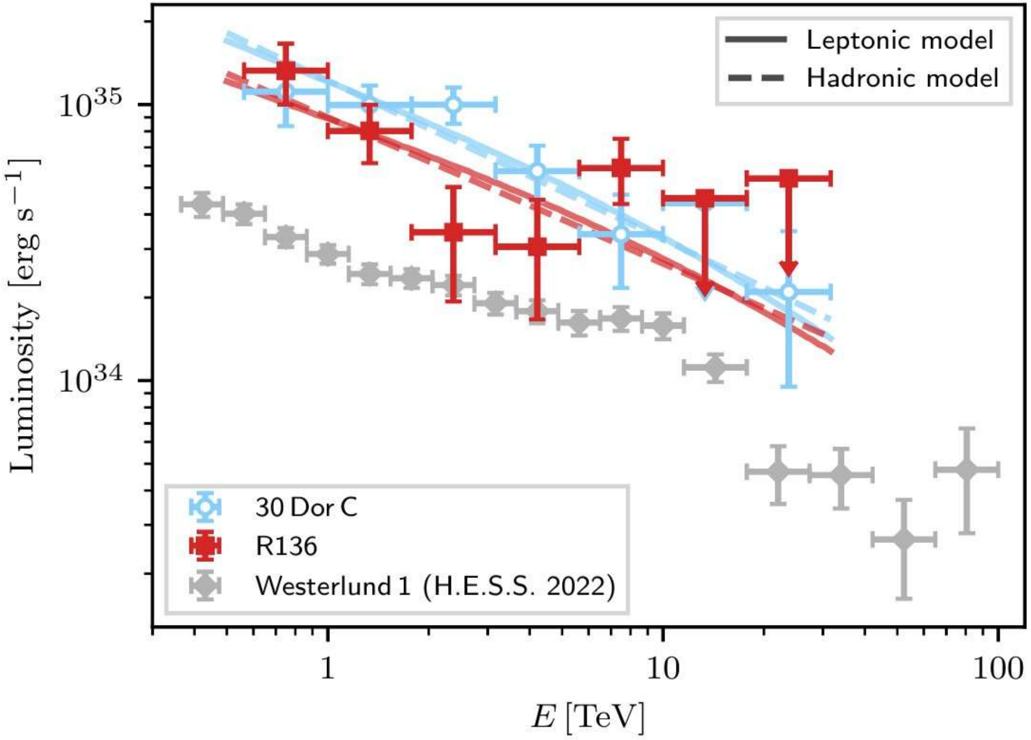




The most massive stellar cluster
$W_e \sim 10^{49}$ erg, a potential pevatron?

Stellar Clusters

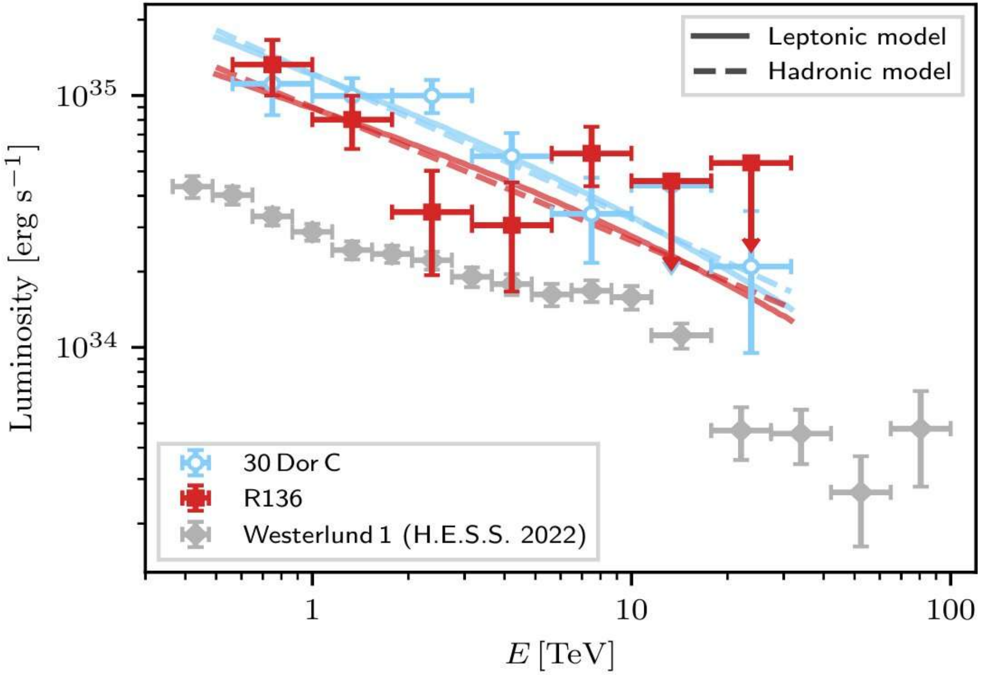
Westerlund 1 (HESS, AA 666, 124, 2022)
New: R 136, 30 Dor C (LMC), HESS, 2024

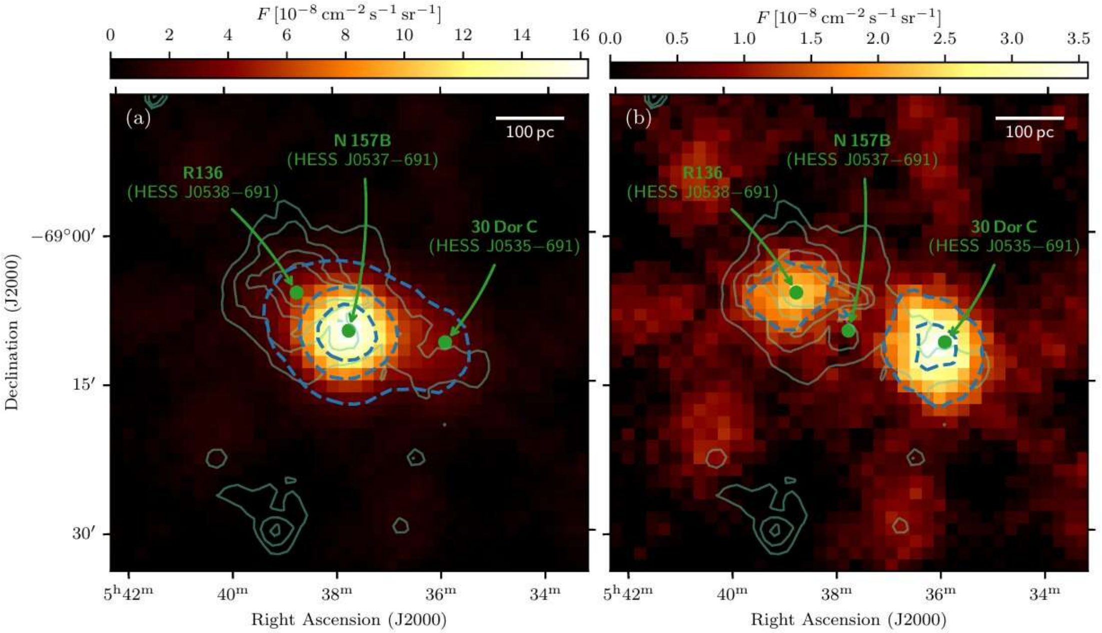


The heart of the Tarantula nebula
(next to superbubble 30 Dor C)

Stellar Clusters

New: R 136 (LMC), HESS, 2024

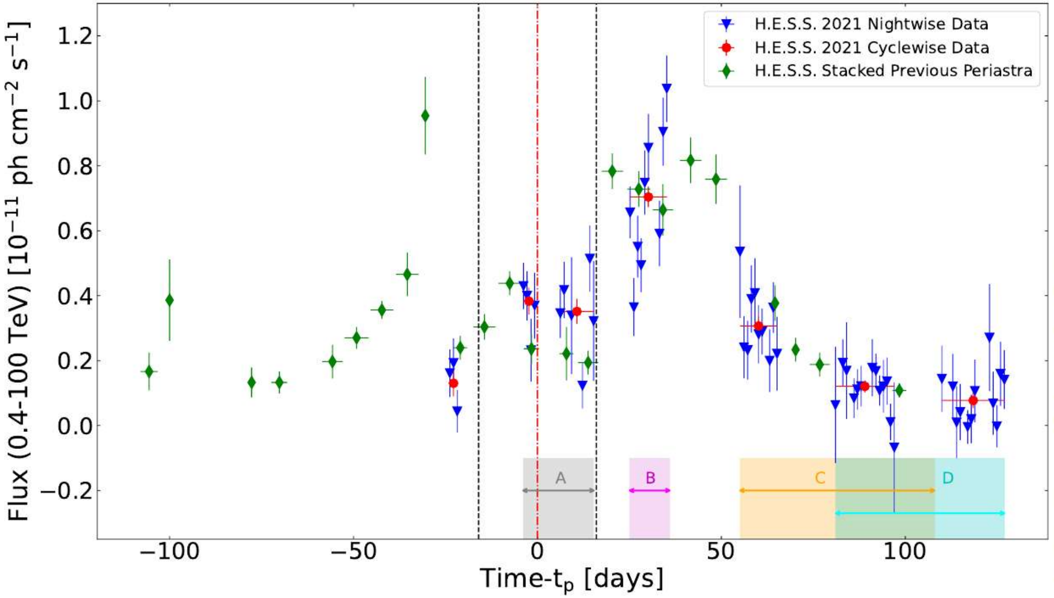


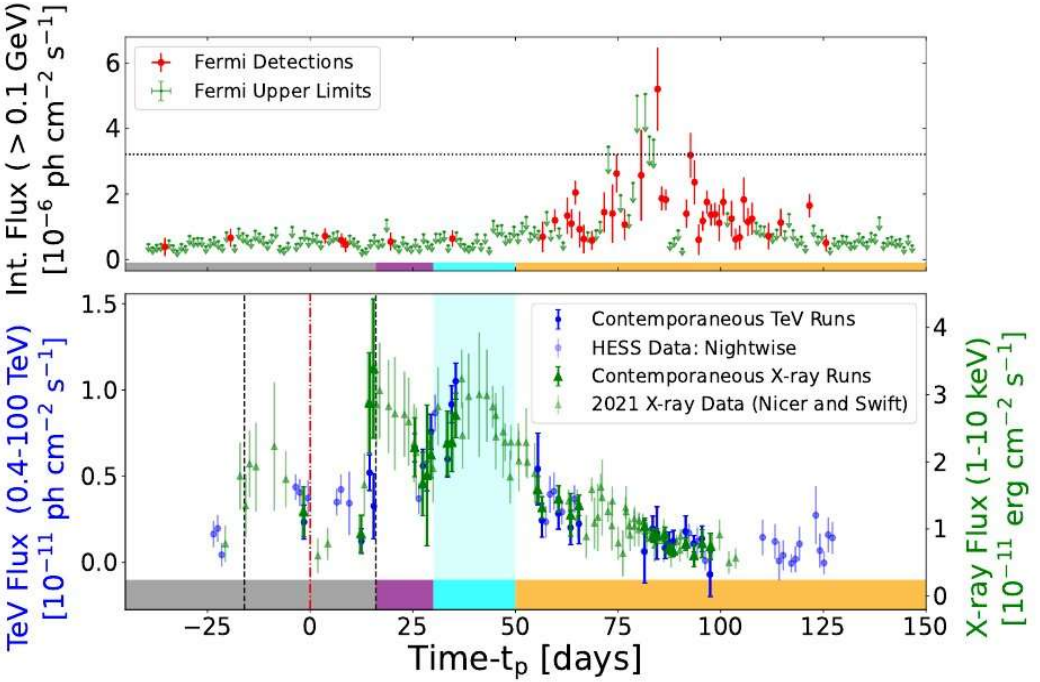


30 Dor C extended
indicate both SB **and** enclosed OBA

Monitoring GR Binaries

e.g. PSR 1259-63 (HESS, arXiv:2406.18167 plus current periastron)
Secular variation in VHE band, good overall match VHE-X but significant deviations from linear correlation. Significant spectral GeV/TeV evolution.

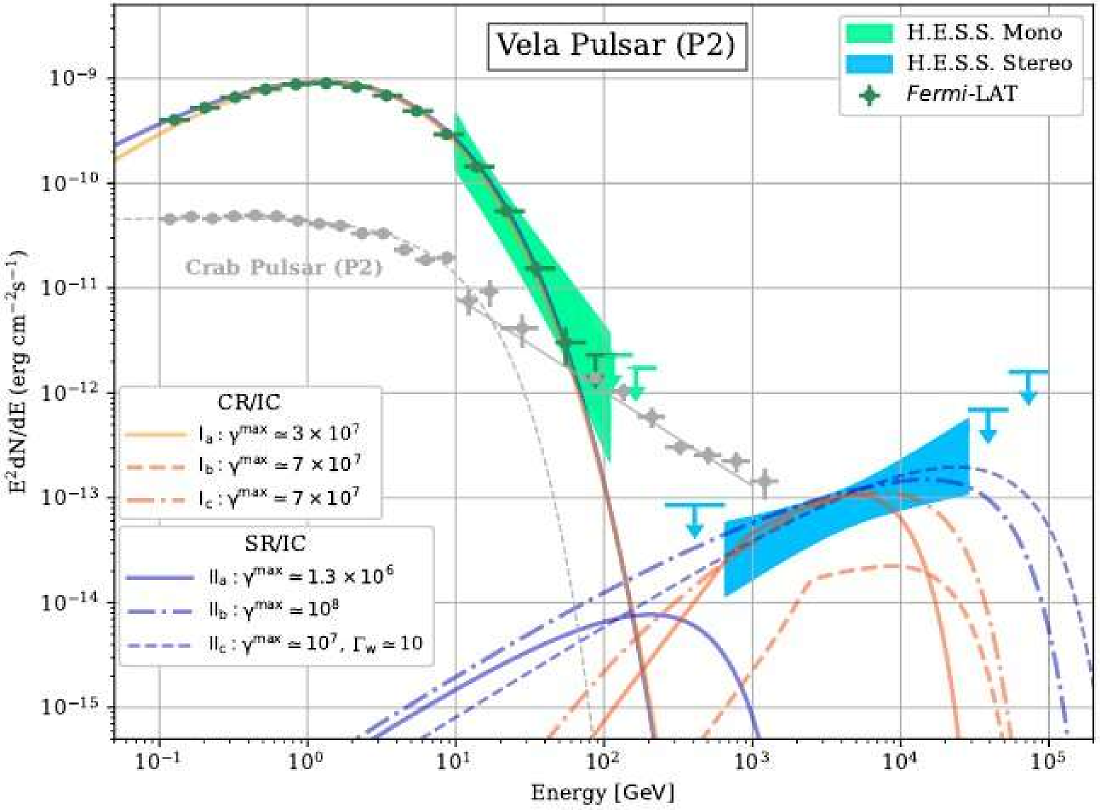




Pulsed VHE component in Vela

Pulsed VHE emission
from Vela pulsar
Nature Astronomy, 2024
arXiv: 2310.06181

20 – 100 GeV spectra
of pulsed emission(P2)
differ significantly from
1 – 20 TeV spectra

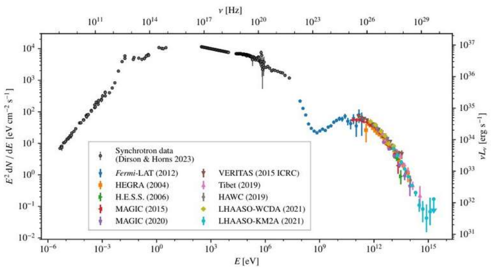


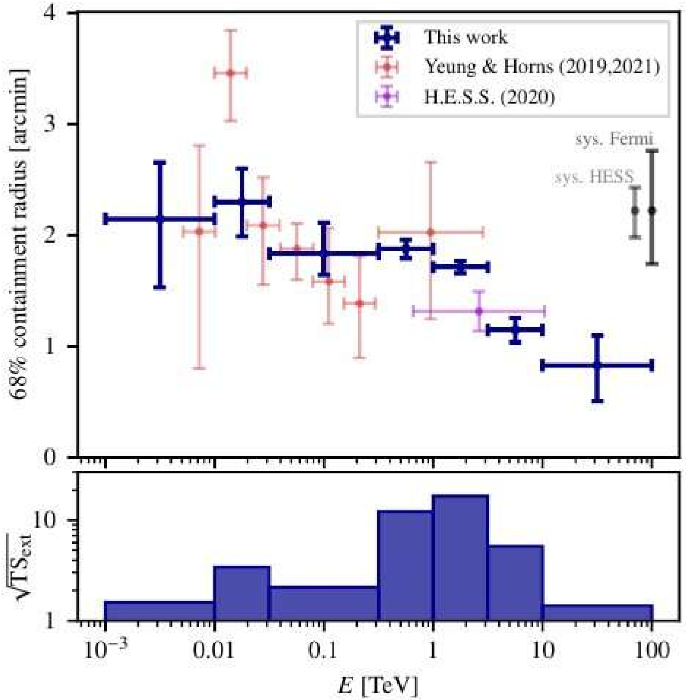
Size of Crab PWN

Energy dependent morphology of Crab, A&A 686, A308 (2024)
Self-consistent analysis over 5 orders of magnitude.

Size shrinks with E.

Strength of B field decreases outwards.





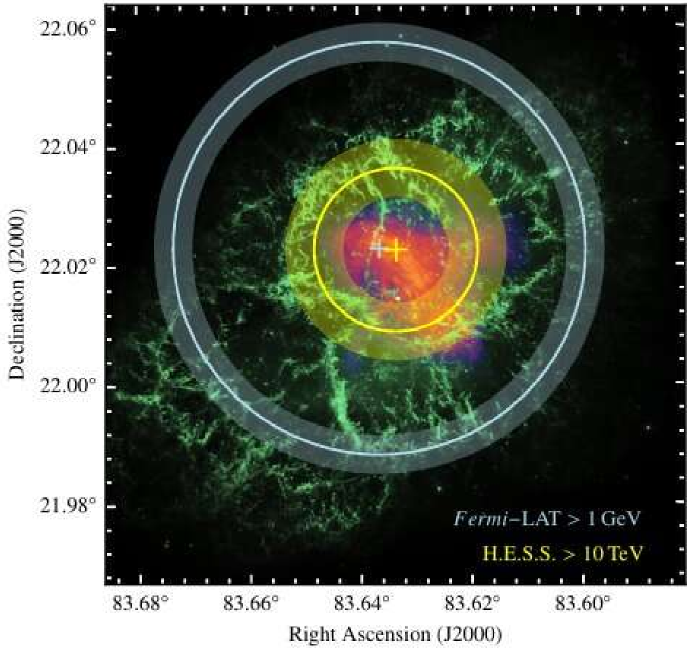


Fig. 7. Optical image of the Crab Nebula in green (credit: NAS

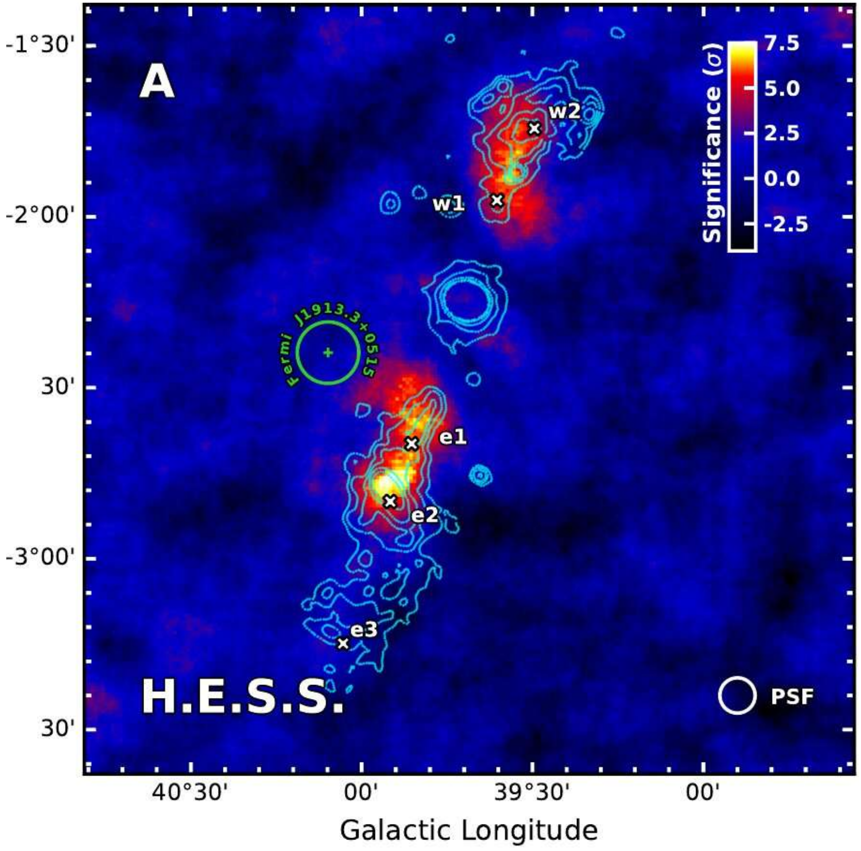
Resolved jets of SS 433

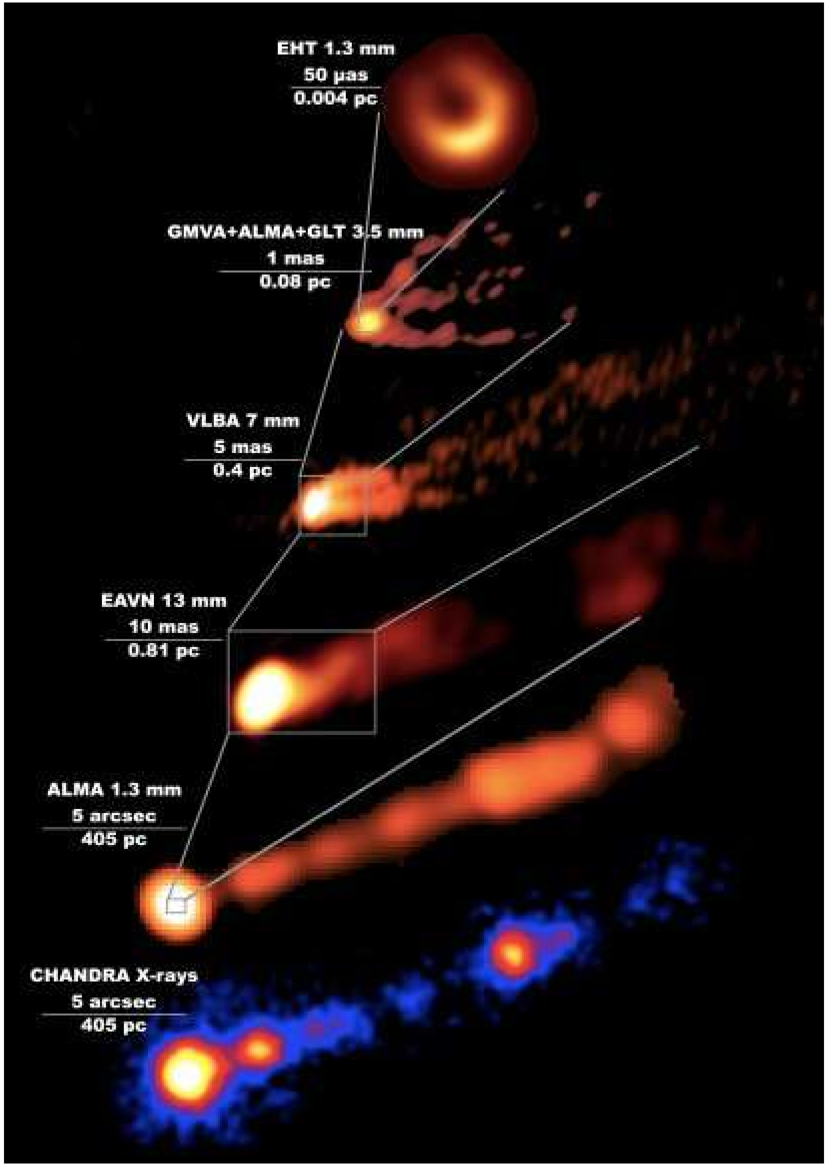
Resolved jets of microquasar SS433
Science 383, 402-406 (2024)

Multiple knots along jet on either side.
Energy dependent morphology.
Highest energies at e1/w1,
lower energies at larger radii.

Morphological similarity to V4146 Sgr

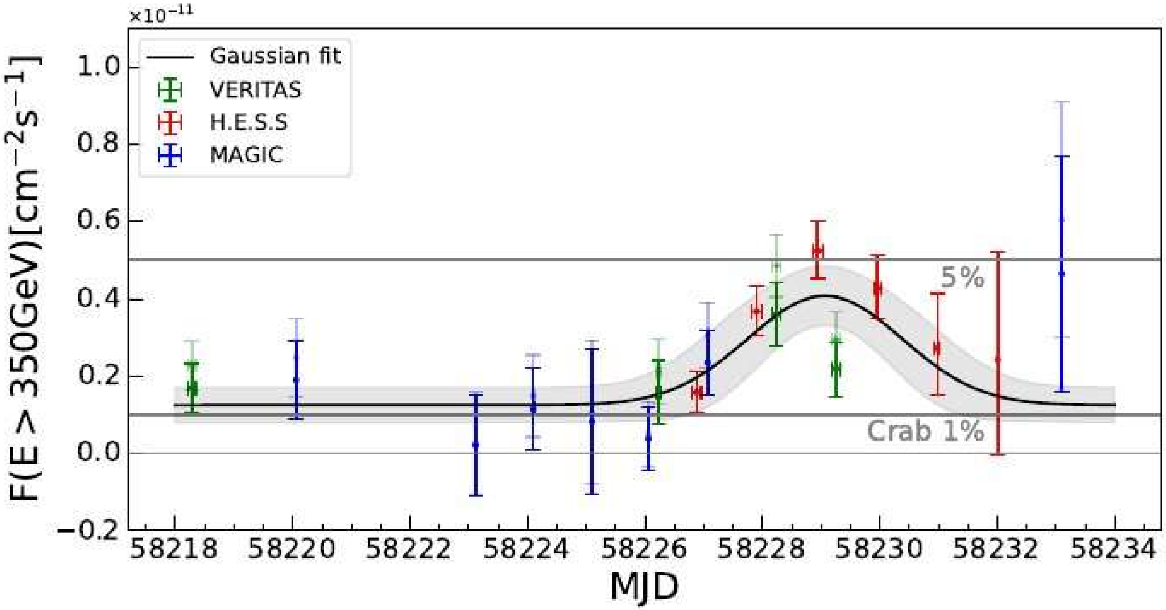
Implications for extended extragalactic jets.





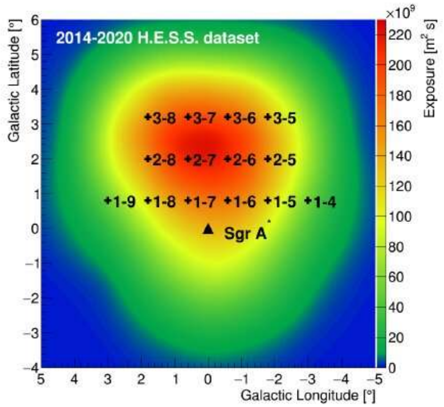
Probing SMBH

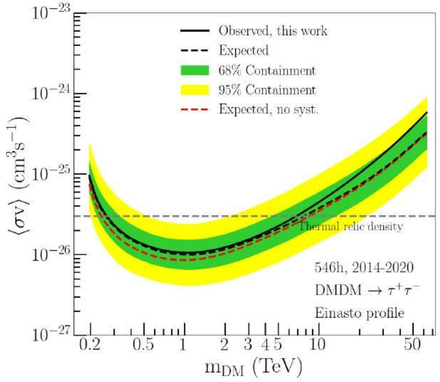
2005: t_{var} ~ 1 d → ~ SMBH diameter
2018: Joint campaign with EHT
A&A accepted (Aug 29, 2024), 2404.17623

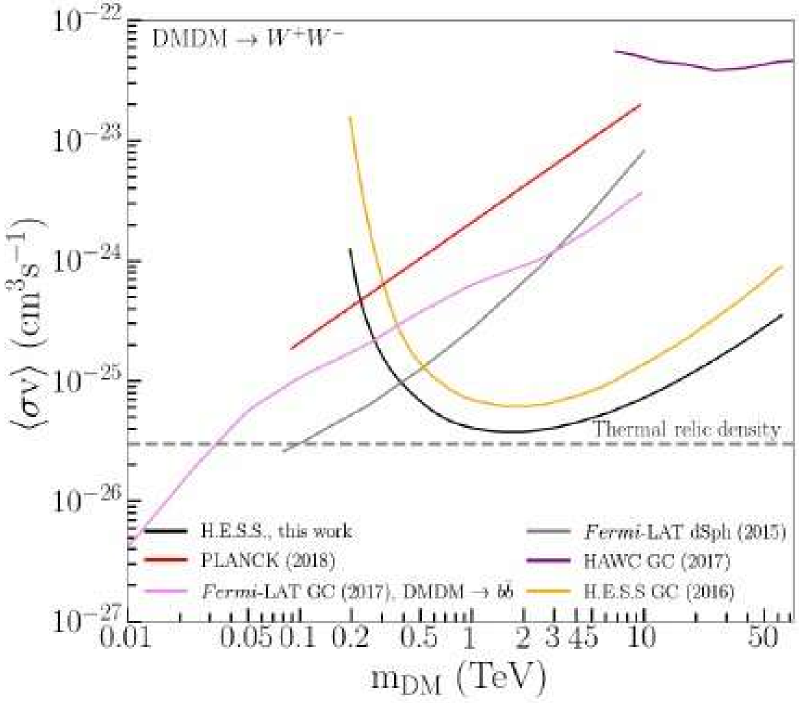


DM limits in GC

Inner Galaxy Survey:
Strongest limits on DM in this energy range
(down to thermal limit)
Phys. Rev. Lett. 129, 111101
→ further limits (lines)
→ further data exploitation (Devin)



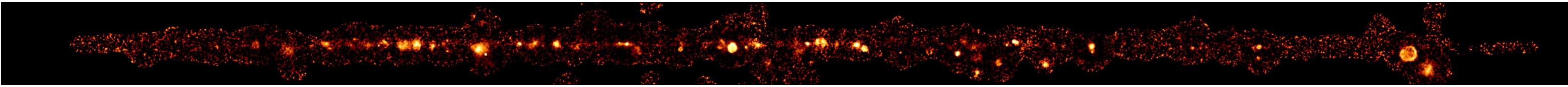




Surveys

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

The **H**ESS **G**alactic **P**lane **S**urvey (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 halos)

Monitoring (1259-63, M87)

New constraints on AGN

Further results I had not had the time to present….

New surveys

2025 – 2028: New legacy program to be launched

Thank you for your attention