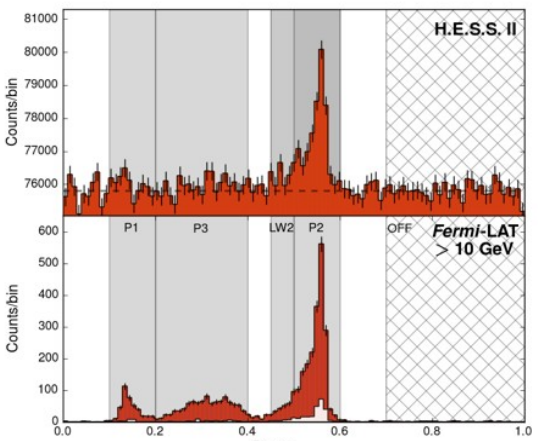
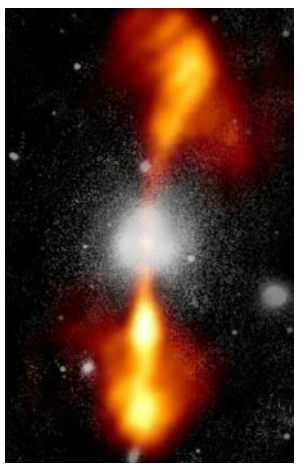
20 years on the austral sky with H.E.S.S.

M. de Naurois for the H.E.S.S. collaboration





High Energy Stereoscopic System (H.E.S.S.)

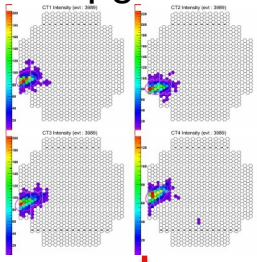
- Array of 4+1 Cherenkov telescopes located on Khomas Highland, Namibia (1800 m)
  - H.E.S.S. phase 1 (09-2002):
  - 4 telescopes: Ø 12 m,107 m^2
  - Stereoscopic reconstruction
  - 960 PMTs/camera, Field of view : 5°
  - Observations : ~1400 h/year
  - Source position : ~ 10”
  - H.E.S.S. phase 2 (09-2012):
  - 5^{th} telescope, Ø 28 m, 600 m^2 (largest IACT in the world)
  - 2048 PMTs, Field of view : 3.5°

    → Energy threshold (zenith) ~ 30 GeV

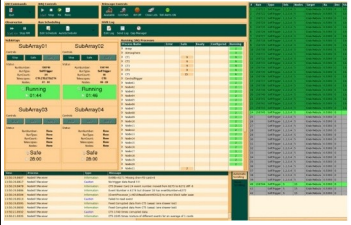
Evolution of H.E.S.S.

CT5 1st light

CT2-4 camera upgrade



DAQ & cluster upgrade



2002 2004 2008 2010 2012 2014 2016 2018 2020 2022

CT1-4 mirror refurbishment

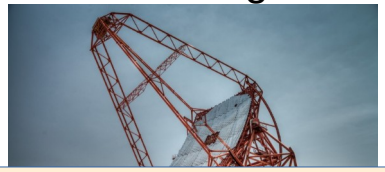
CT1 camera upgrade

CT3 mirror refurbishment

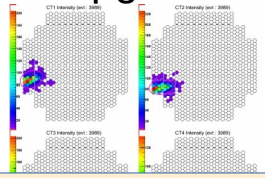
CT5 camera upgrade

Evolution of H.E.S.S.

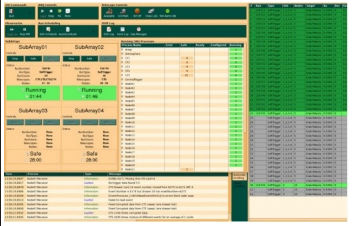
CT5 1st light



CT2-4 camera upgrade



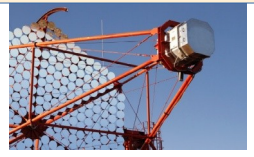
DAQ & cluster upgrade



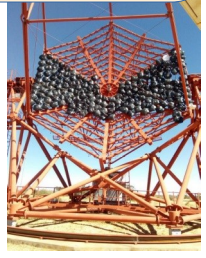
Operation until 2025 ⇒ 2028
currently under discussions

2002 2004 20 2020 2022

CT1-4 mirror refurbishment



CT1 camera upgrade



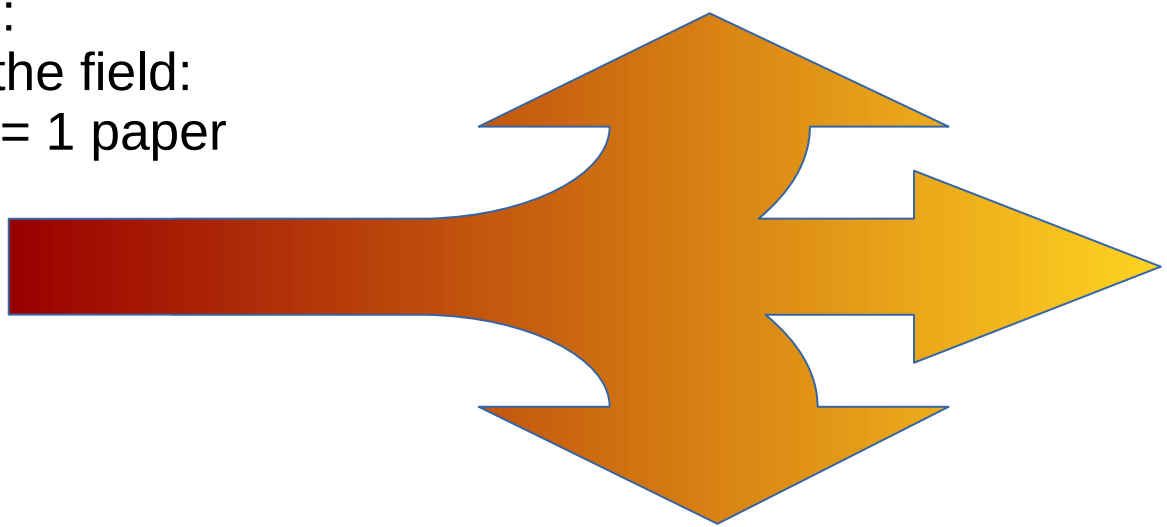
CT3 mirror refurbishment

CT5 camera upgrade

Evolution of the Field

Surveys, populations studies

~2000-2010:
Opening of the field:
1 discovery = 1 paper

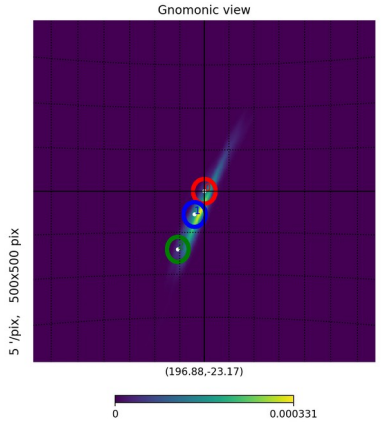


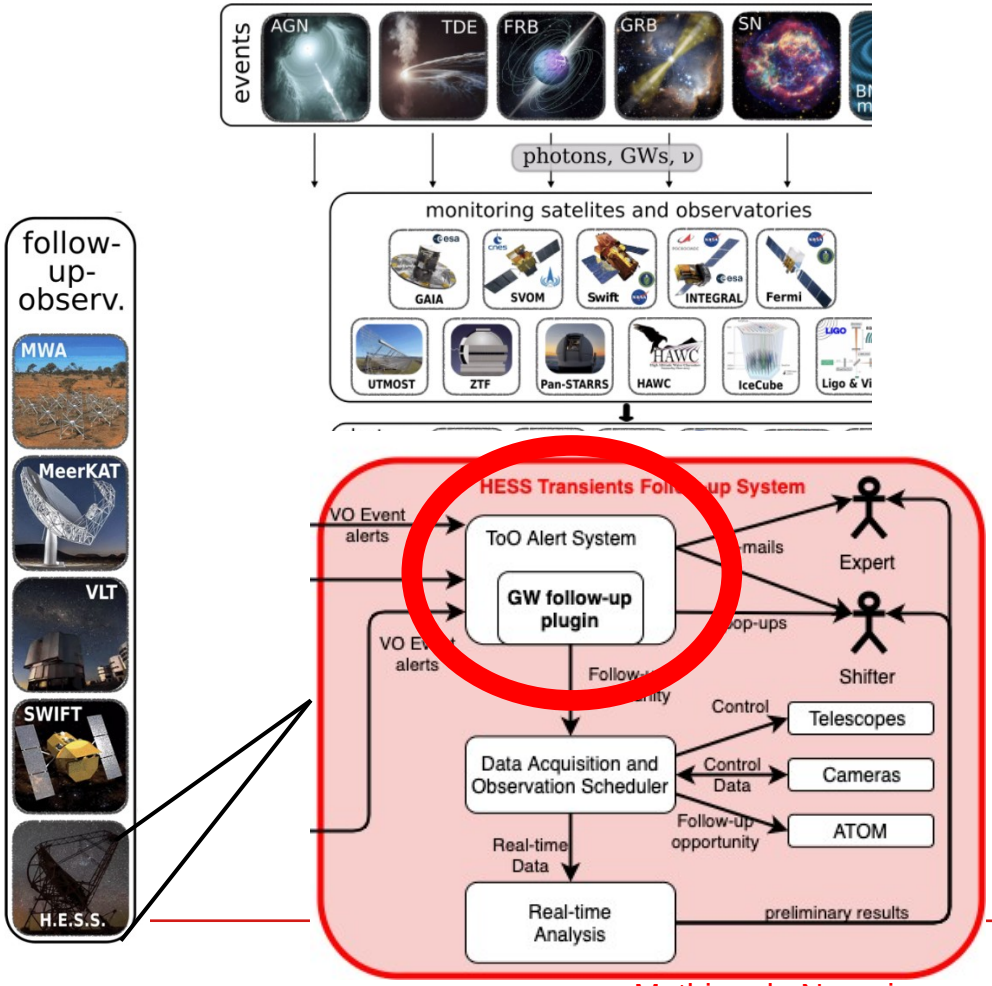
- Key Science projects,
- Deep investigation of specific objects
- Transients Sky

The Unknown, still searching for
- Dark Matter
- Exotic Physics

H.E.S.S. Transients Follow-up systems

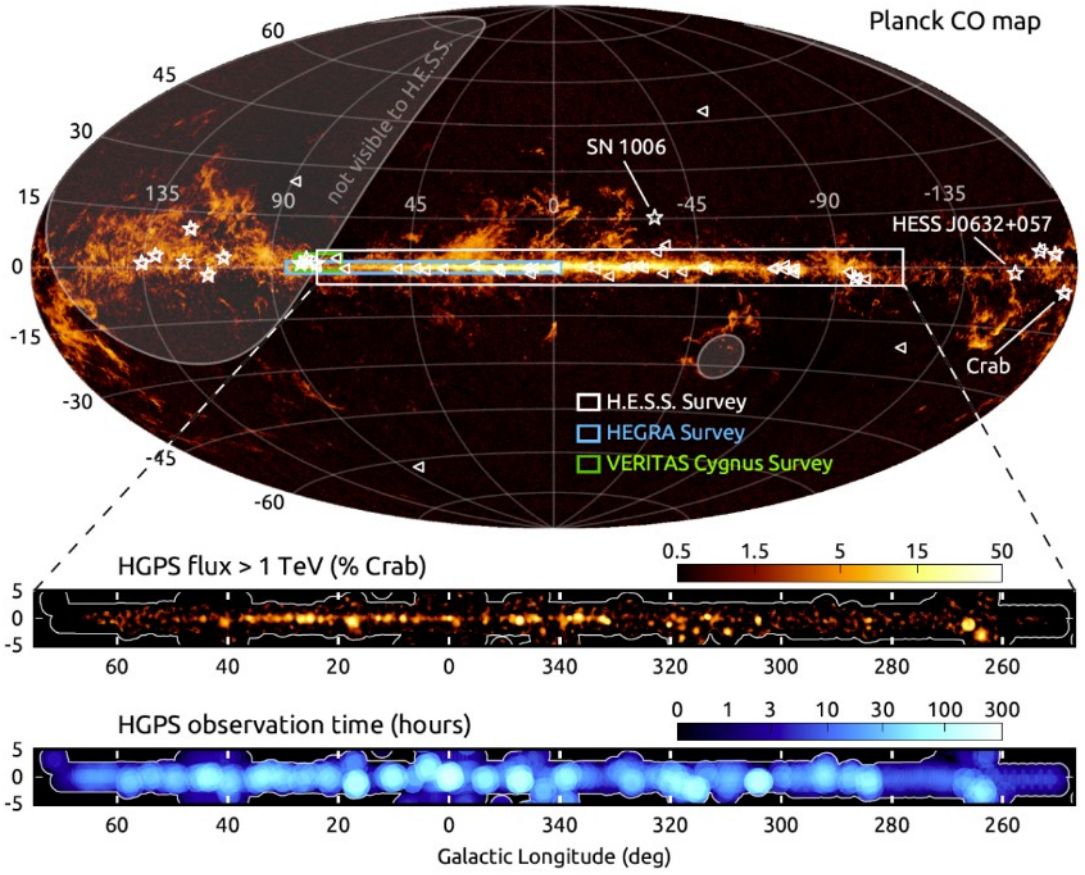
- Automatic response to selected transients (GRBs, GW, …)
- Automatic decision on follow-up
- Optimization of pointing using tilepy
- Response time < 1 minute for most cases and < 2 minutes for all cases, inclu. relescope slewing time





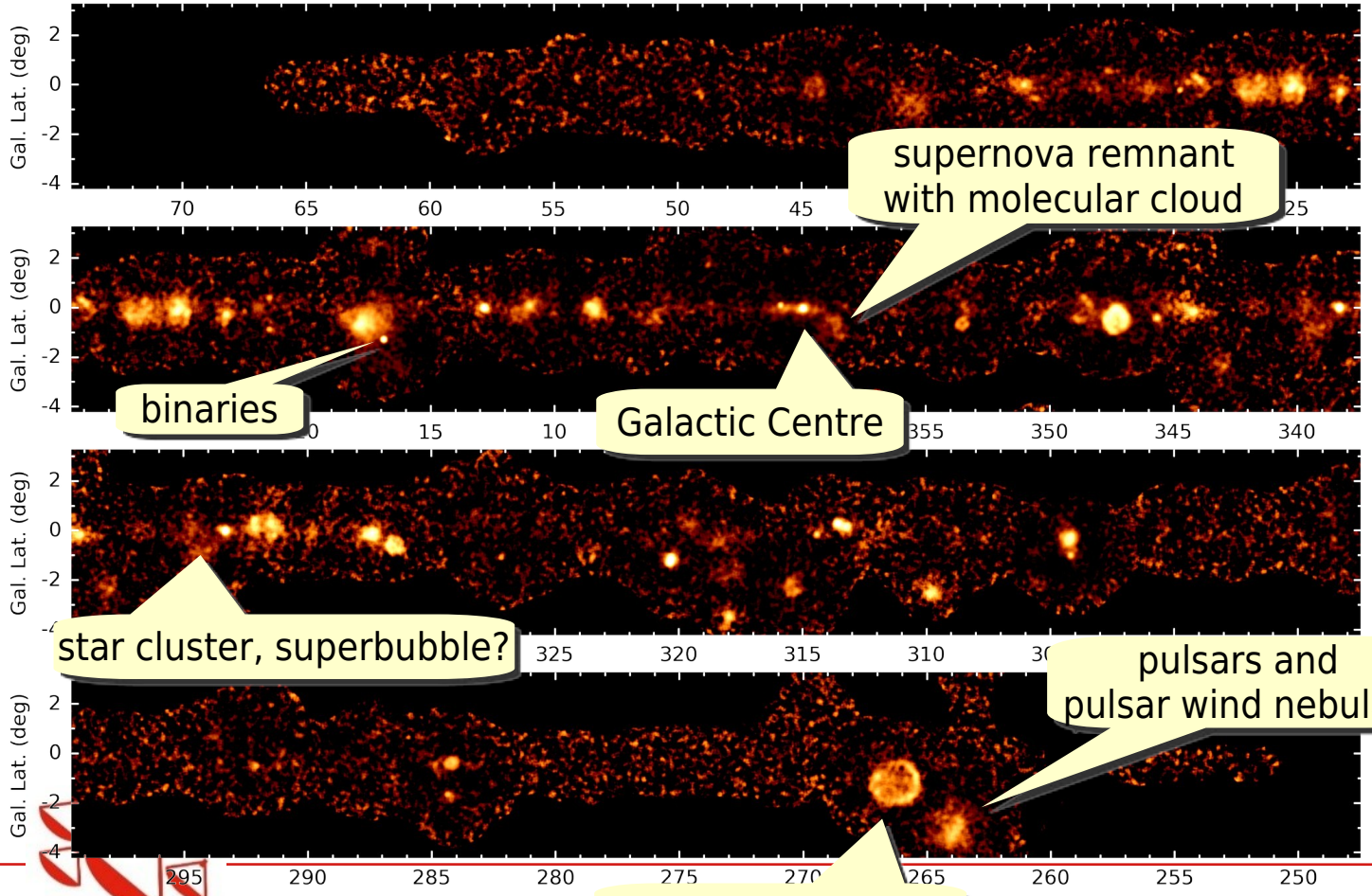
H.E.S.S Legacy Survey

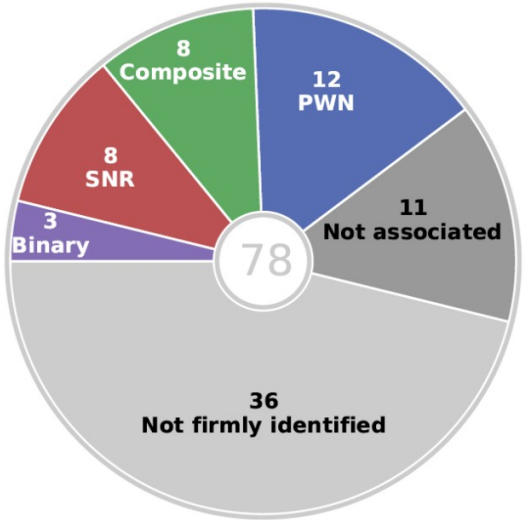
- Major H.E.S.S. project
- Data collected 2004 – 2013
  - 2673 h after quality selection
  - l in [-110°, 70°]
  - b in [-5°, 5°]
  - Inhomogeneous exposure (sources of particular interest)
- Largest VHE survey so far done by IACTs
- Maps released in FITS format
- Allows population studies

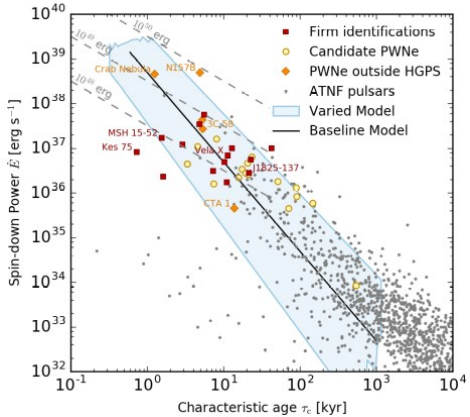


H.E.S.S. Collaboration - A&A 612 (2018)

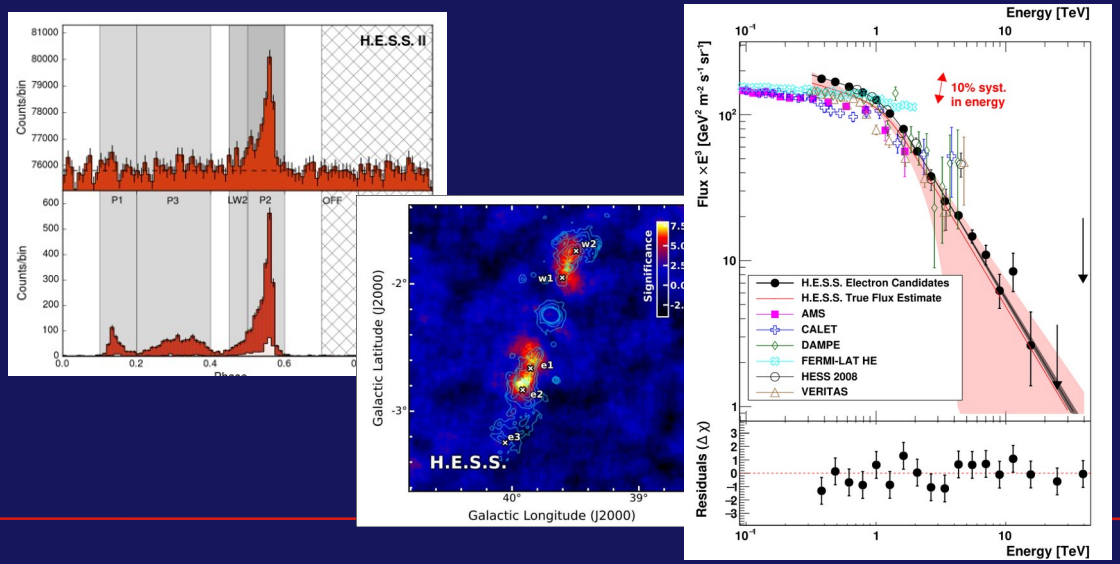
H.E.S.S Legacy Survey







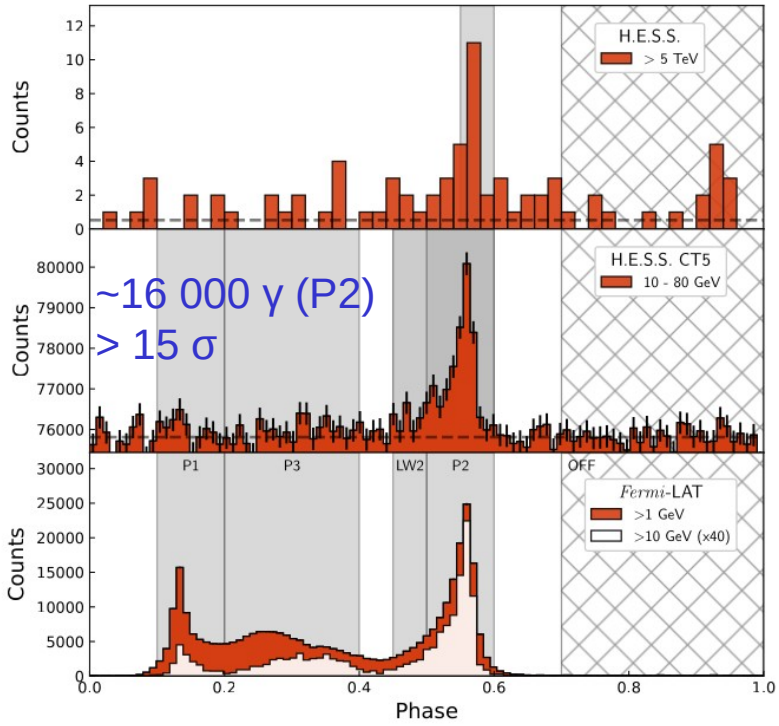
Selected recent highlight



Vela Pulsar – H.E.S.S. II

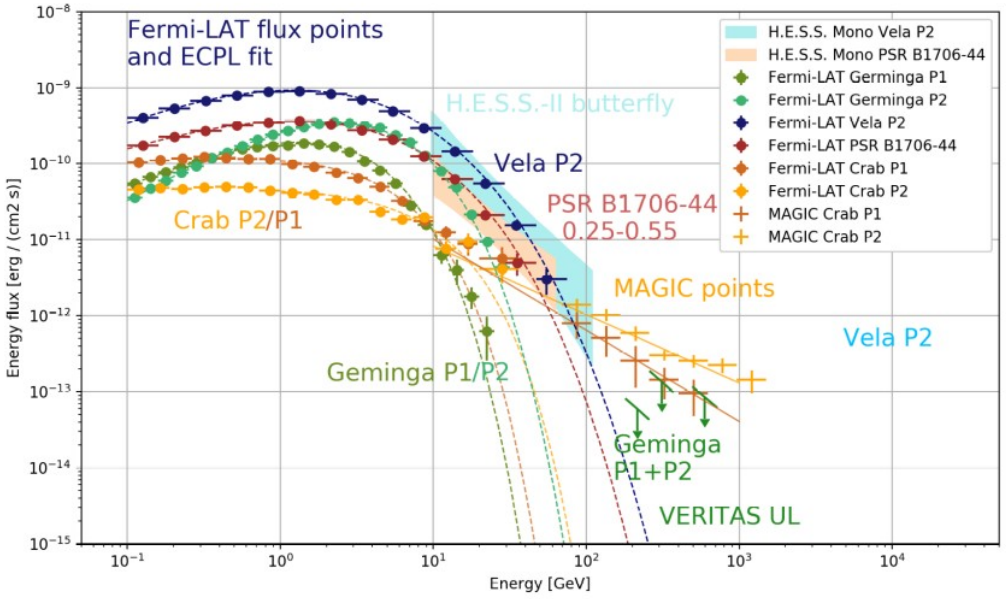
Nature Astronomy
October 5th 2023!

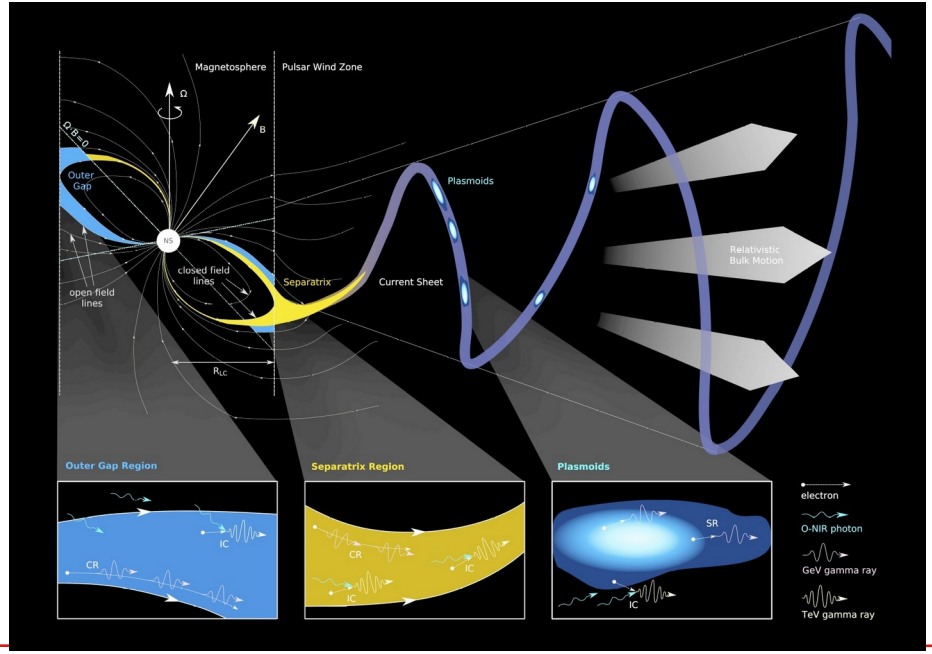
- Second VHE pulsar (H.E.S.S.)
  - At the threshold in standard observation mode
  - Deep observation campaign
  - VHE emission up to 20 TeV
    → new component?
- Crab vs Vela:
  - Crab:
    - P1 and P2 observed from the GeV to the TeV, bridge also detected from the ground (MAGIC)
    - Power-Law Spectrum from GeV to TeV
  - Vela:
    - P1/P2 changing a lot with energy, only P2 detected at TeV
    - Curvature / cutoff at few GeV with > 3σ for both Fermi and HESS
    - Very hard VHE spectrum: distinct spectral component



Pulsars from ground

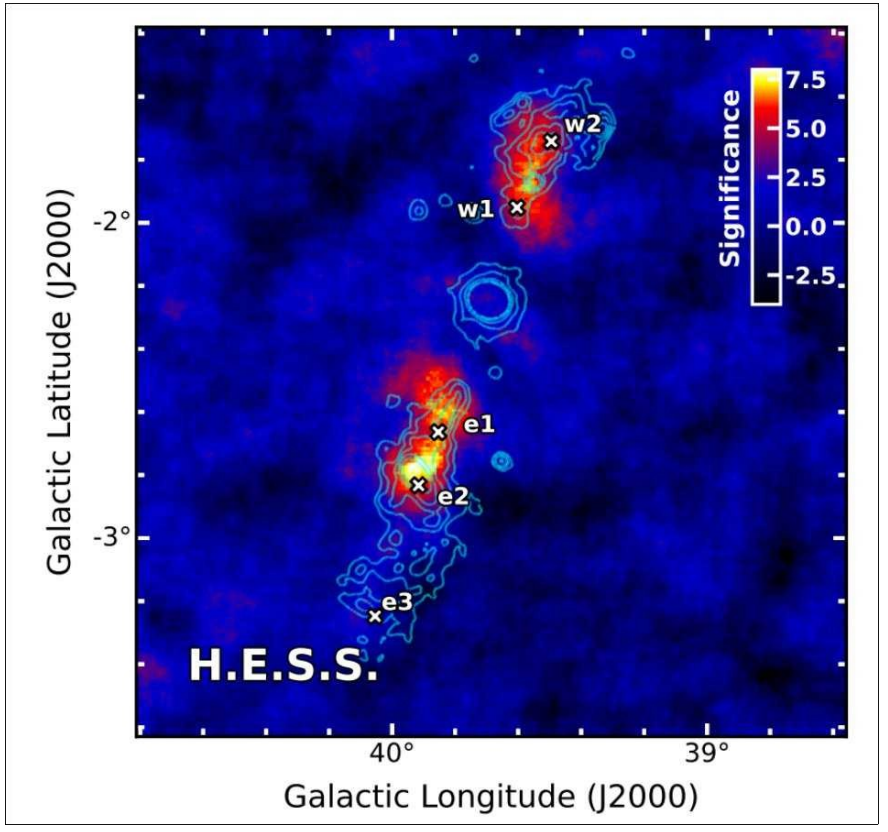
- With PSR B1706-44, 3 VHE pulsars
- Amongst brightest pulsars in Fermi 2PC catalogue
- Emission far from the light-cylinder (avoid sync. cooling)





Microquasars – SS 433

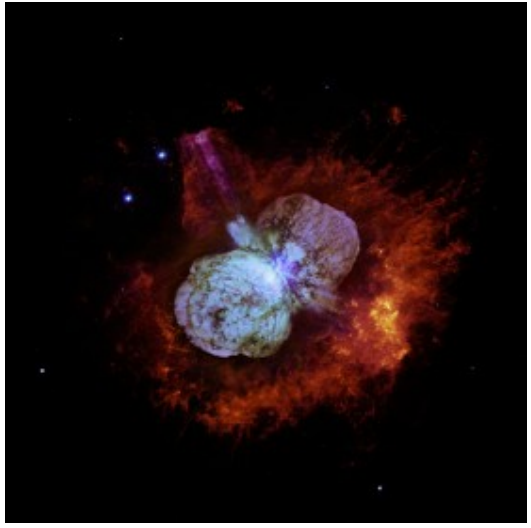
- VHE upper limits with MAGIC (2018) based on ~18h of data
- HAWC detection of emission from both jets (2018)
- Deep H.E.S.S. observations (300 h)
  - Extended emission along jet direction (both sides)
  - Spectrum up to 40 TeV
  - Highest energies at e1/w1
  - Central BH not detected
  - Science 383, 402-406 (2024)
- First VHE microquasar !

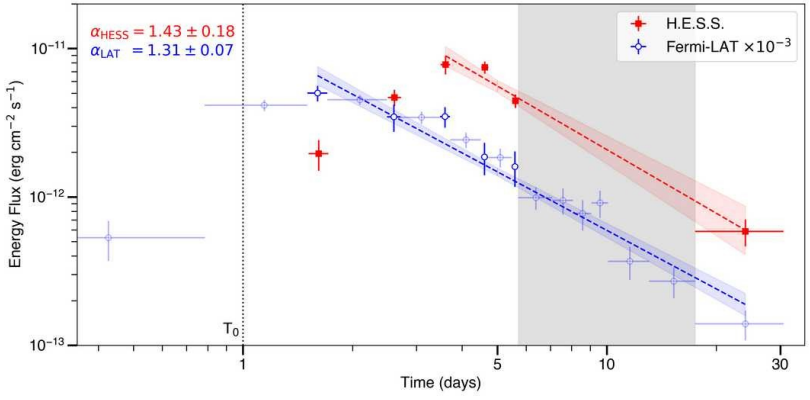


Other recent news from the Milky Way

- Recurrent Nova RS Ophiuchi
  - First Galactic transient observed in VHE (2021 flare)
  - VHE emission detected during 40 days
  - Hadronic emission scenario preferred

- Massive stellar cluster
  - Westerlund 1: Potential Pevatron (HESS, AA 666, 124, 2022)
  - New: R 136, 30 Dor C (LMC), HESS, 2024



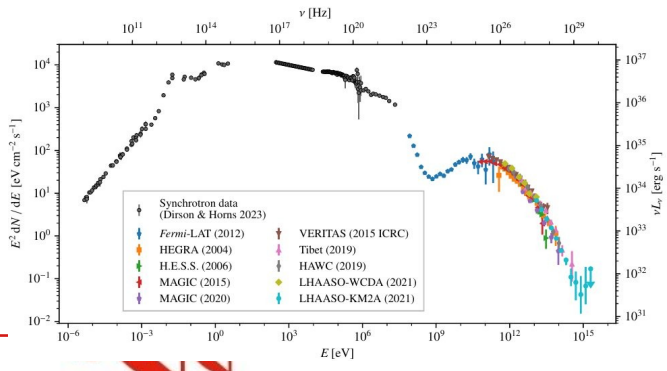


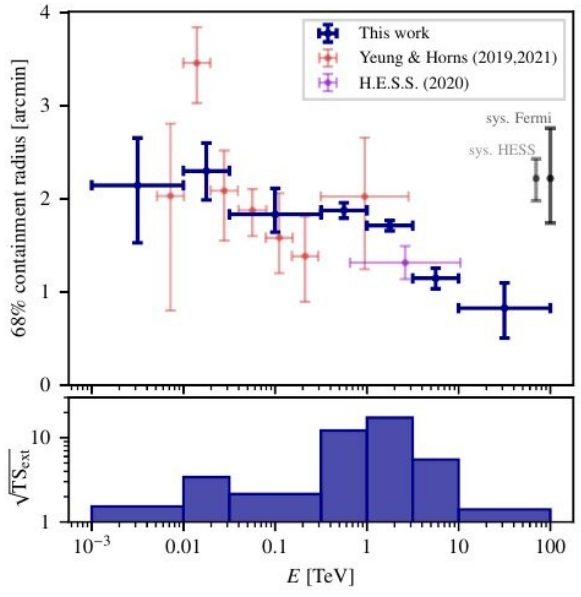
Size of Crab PWN

- 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.





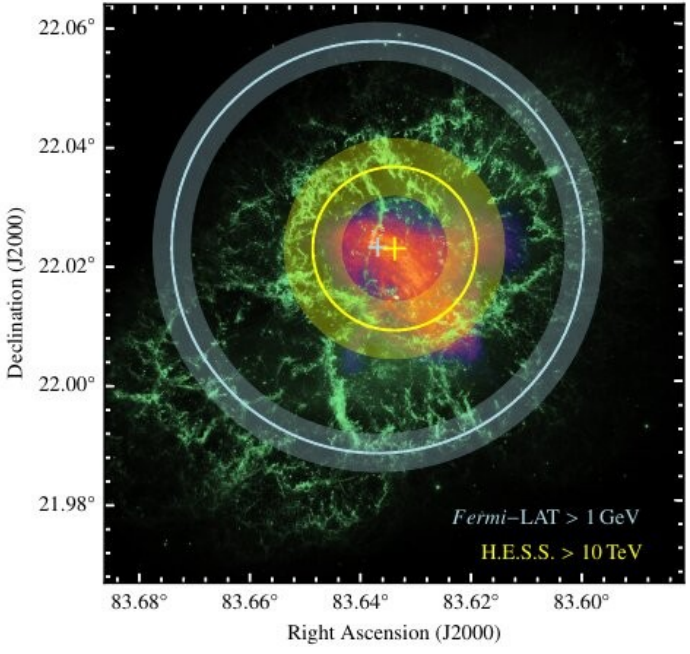
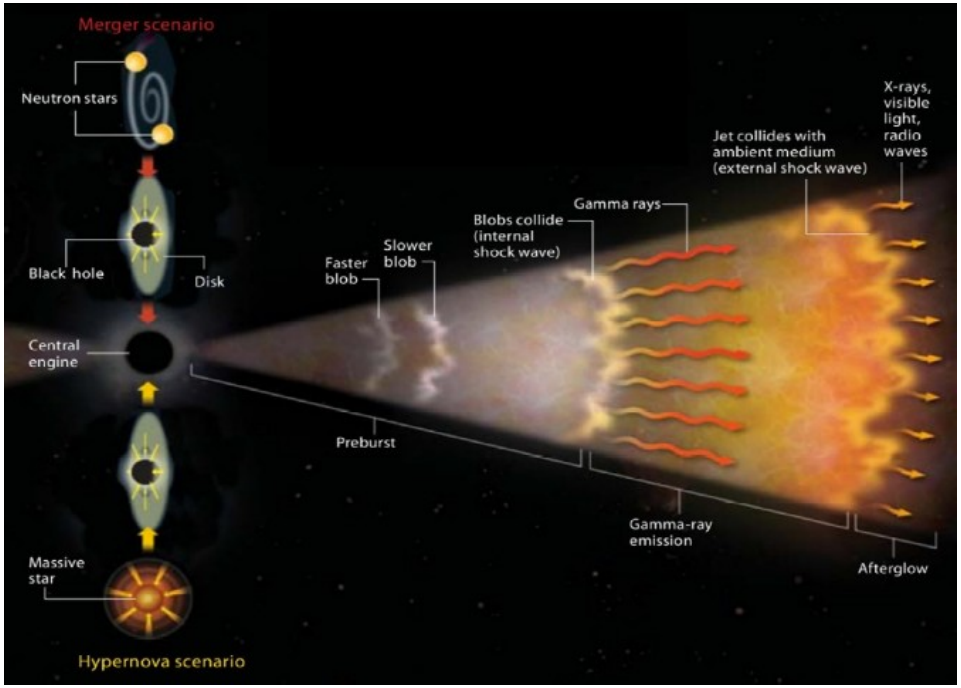


Fig. 7. Optical image of the Crab Nebula in green (credit: NAS.

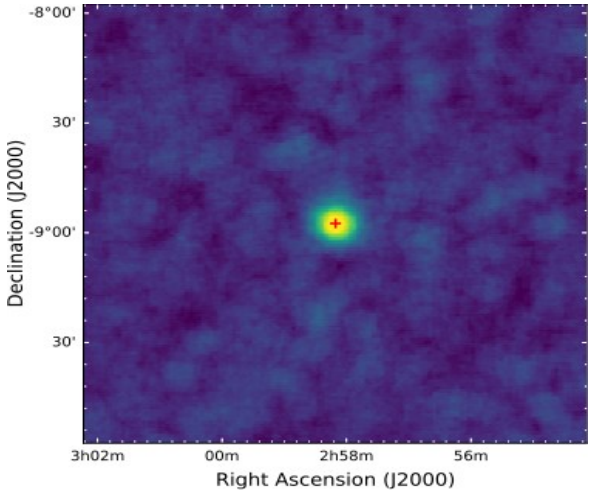
Gamma Ray Bursts

- Recent revolution in VHE astronomy
- Made possible by
  - Fast slewing
  - Aggressive observation strategies
  - Luck?
- Detections of long GRBs are recent:
  - GRB 180720B (HESS)
  - GRB 190114C (MAGIC)
  - GRB 190829A (HESS)
  - GRB 201216C (MAGIC)
  - GRB 221009A aka BOAT (LHAASO)
- Hint from short GRB
  - GRB 160821B (MAGIC, 3 σ)

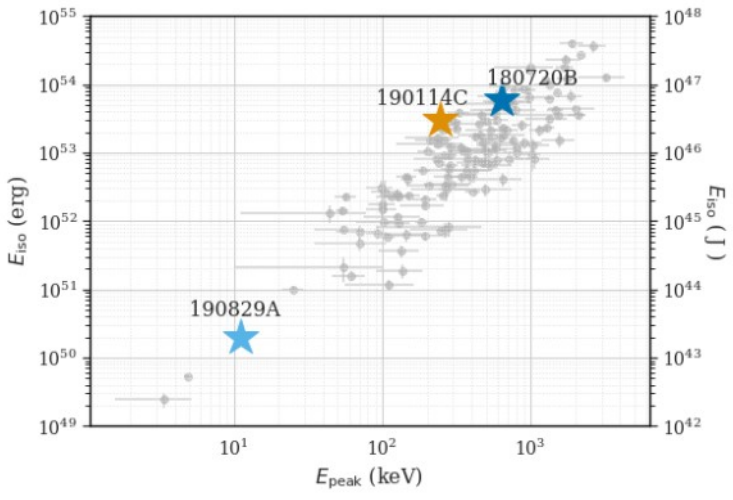


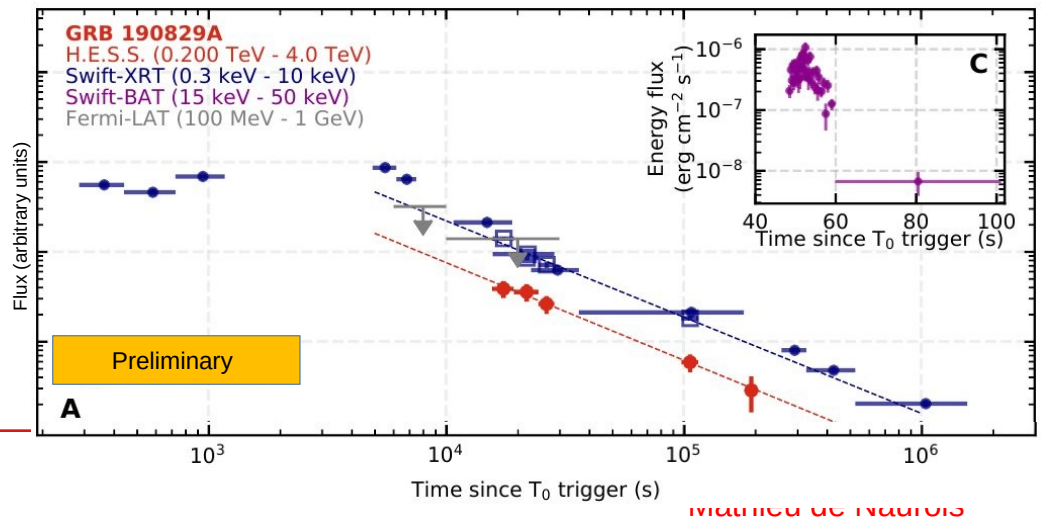
GRB 190829A

- Long GRB (t_{GBM90} ~ 60 s, t_{BAT90} ~ 60 s) @ z = 0.078
- Observation started at t_0 + 4h20 (ATel #13052)
- Followed during 3 nights (22, 6 and 3 σ)!
- Extending up to > 3 TeV
- Modest energy but one of the closest ever
- Similarly to GRB 180720B, afterglow falling at similar rate in all wavelength



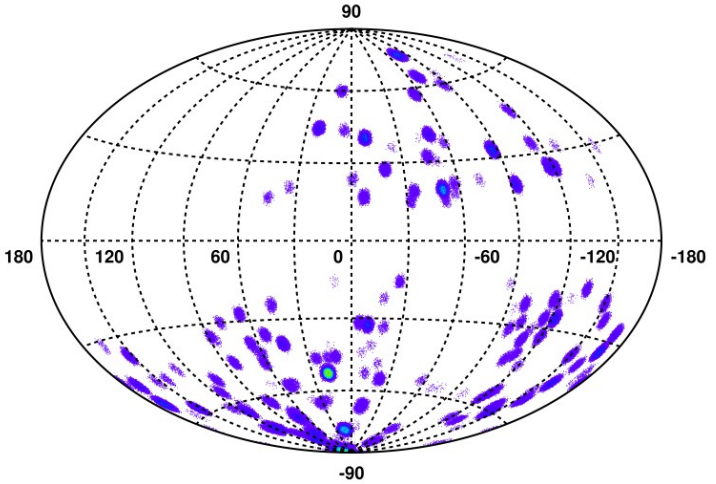
H.E.S.S. Collaboration - Science 372 (2021)

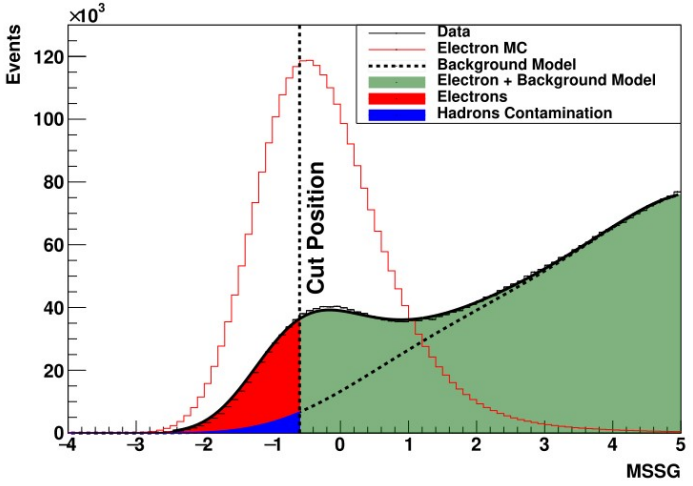




Beyond γ-rays: Cosmic Electron Spectrum

- Huge data set (> 3000 hr) excl. Gal. Plane (|l| > 15°)
- Specific analysis with hard cuts (limit hadronic contamination)
- Novel analysis technique & IRFs production (“Runwise simulations”)

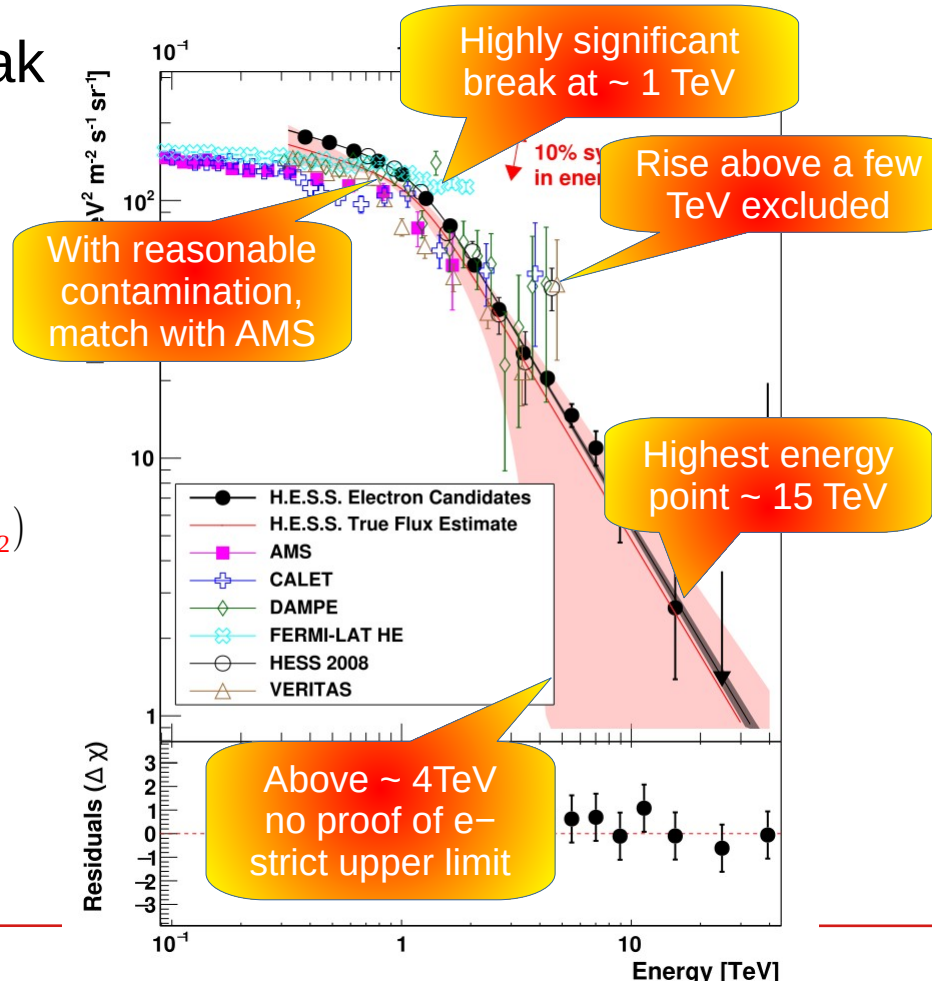




Beyond γ-rays: Cosmic Electron Spectrum

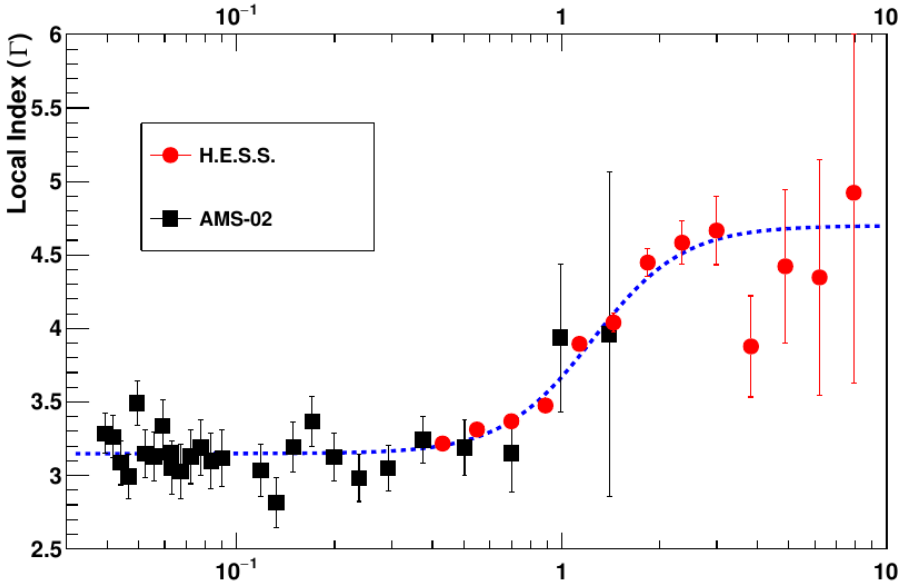
- Highly significant (> 100 σ) spectral break
- Best fit parameters:
  - $\Gamma_1 = 3.25 \pm 0.02_{stat} \pm 0.2_{syst}$
  - $\Gamma_2 = 4.49 \pm 0.04_{stat} \pm 0.2_{syst}$
  - $E_{break} = (1.17 \pm 0.04_{stat} \pm 0.1_{syst})$ TeV
  - Sharpness $s = 0.21 \pm 0.02_{stat}$

$$\frac{\mathrm{d}N}{\mathrm{d}E} = \Phi_0 \times \left(\frac{E}{E_0}\right)^{-\Gamma_1} \times \left(1 + \left(\frac{E}{E_{\mathrm{cut}}}\right)^{1/s}\right)^{s\times(\Gamma_1-\Gamma_2)}$$



Beyond γ-rays: Cosmic Electron Spectrum

- Contribution of a handful, nearby sources
- Steep spectrum very challenging for space instruments
- Accepted for publication in PRL



Outlook

- Many studies use very extended data sets (600h+), obtained over many years with changing camera/telescope combinations
- A lot of technical work to go beyond classical analyses and to reduce systematics
  - Looking for (very) extended features, beyond the FoV of the instrument
  - More reliable RunWise simulations (simulate every run)
  - Open source tools, 3D Analysis, using gammapy as high-level tool

- Many subjects not covered in this talk (Binaries, SNRs, LIV, Dark Matter, AGNs, …)

- H.E.S.S. will likely operate until 2028