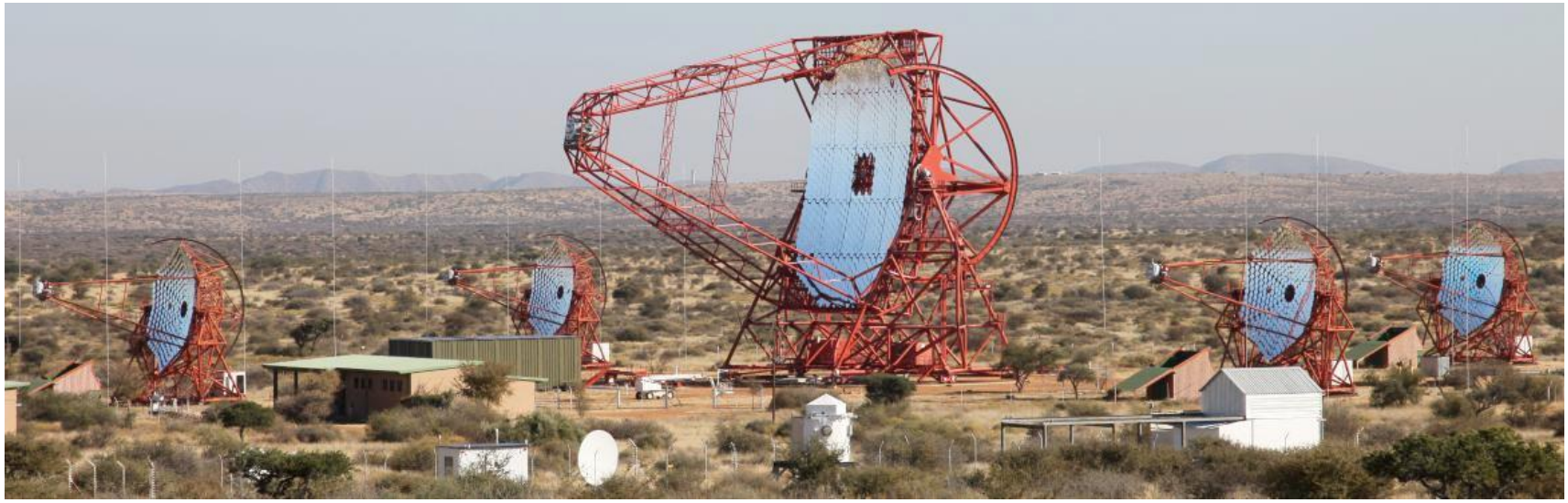
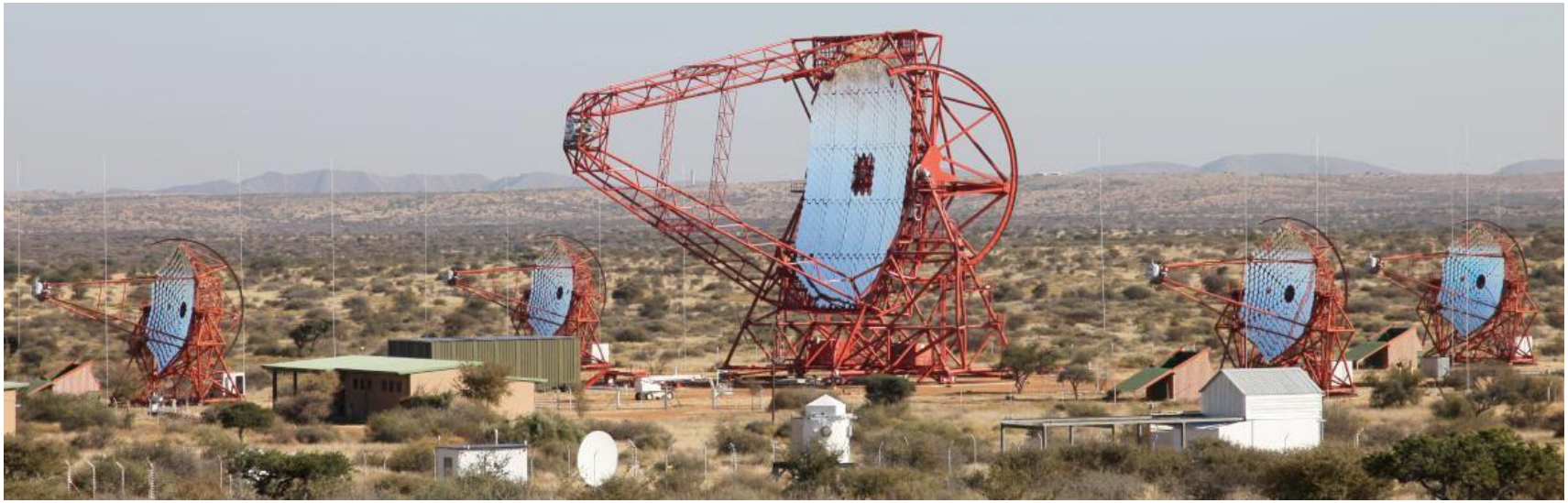
Highlights from H.E.S.S.



Mathieu de Naurois

LLR – Ecole Polytechnique – IN2P3/CNRS

H.E.S.S.

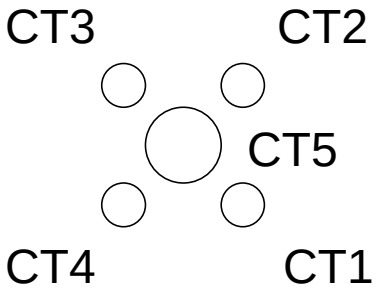


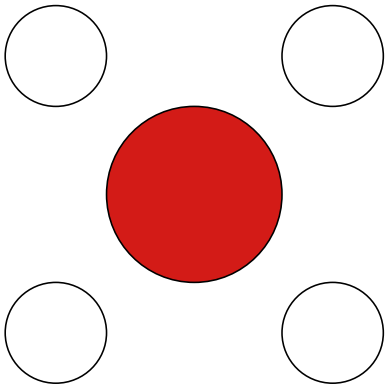
- H.E.S.S. phase 1 (09-2002):
  - 4 telescopes: Ø 12 m,107 m^2
  - Stereoscopic reconstruction
  - 960 PMTs/camera, Field of view : 5°
  - Observations : ~1000h/year
  - Source position : ~ 10”
- H.E.S.S. phase 2 (09-2012):
  - a 5th telescope, Ø 28 m, 600 m^2 (largest IACT in the world)
  - 2048 PMTs, Field of view : 3.5°

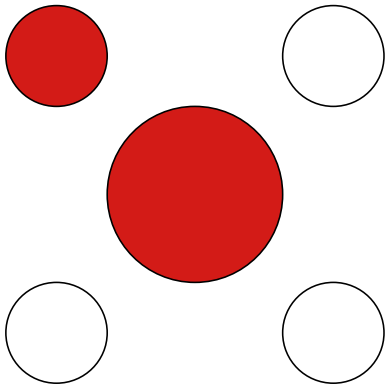
→ Energy threshold (zenith) ~ 30 GeV

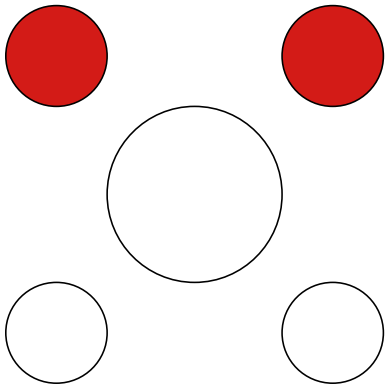
Hybrid Array - Trigger

Only Hybrid Array so far









CT5 mono

65%

CT5 + ≥ 1 CT1-4

30%

≥ 2 CT1-4

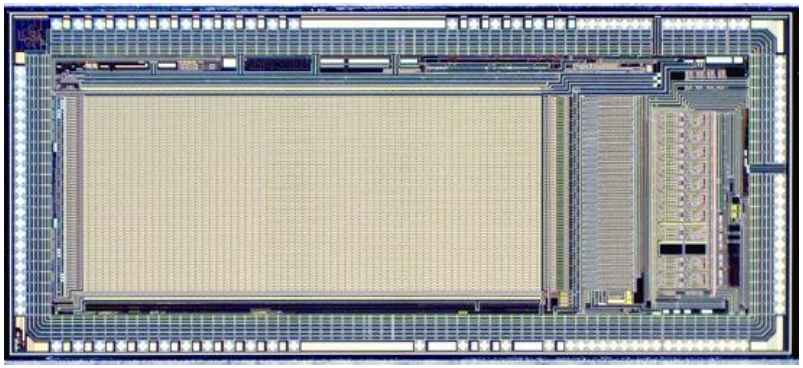
5%

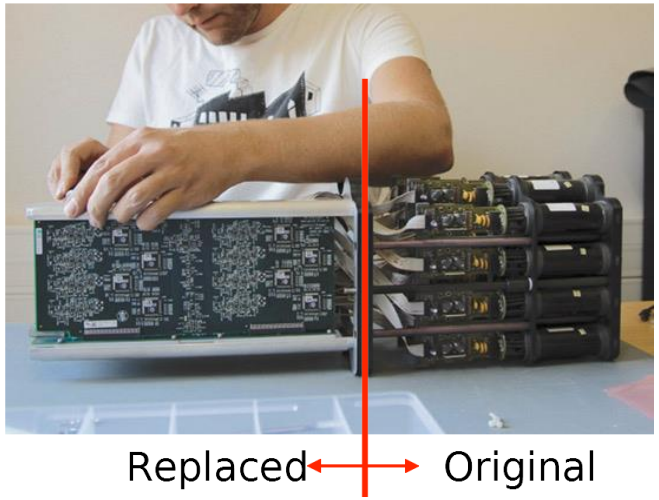
Systematics limited

Statistics limited

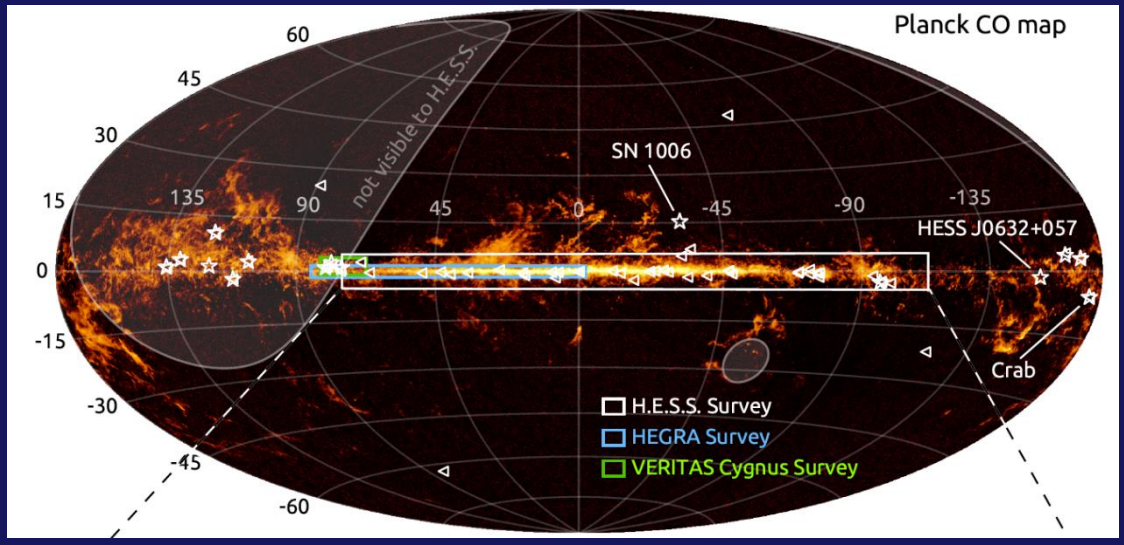
HESS-I Camera Upgrade

- Major upgrade campaign performed on the now 15 year old phase I camera over 2017
- Backend electronics replaced, using CTA NectarCam technology
  - Deadtime reduced to ~0
  - Readout of waveform now possible
  - Could be used to improve both low and high energy performances

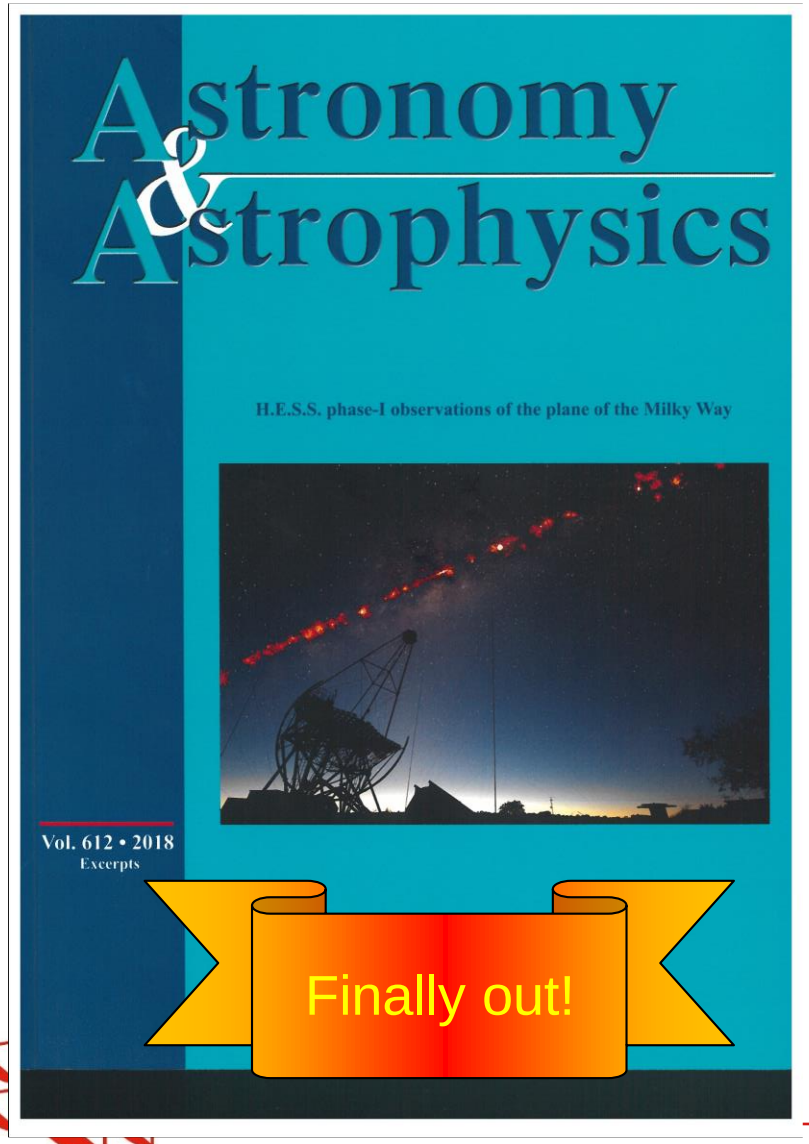


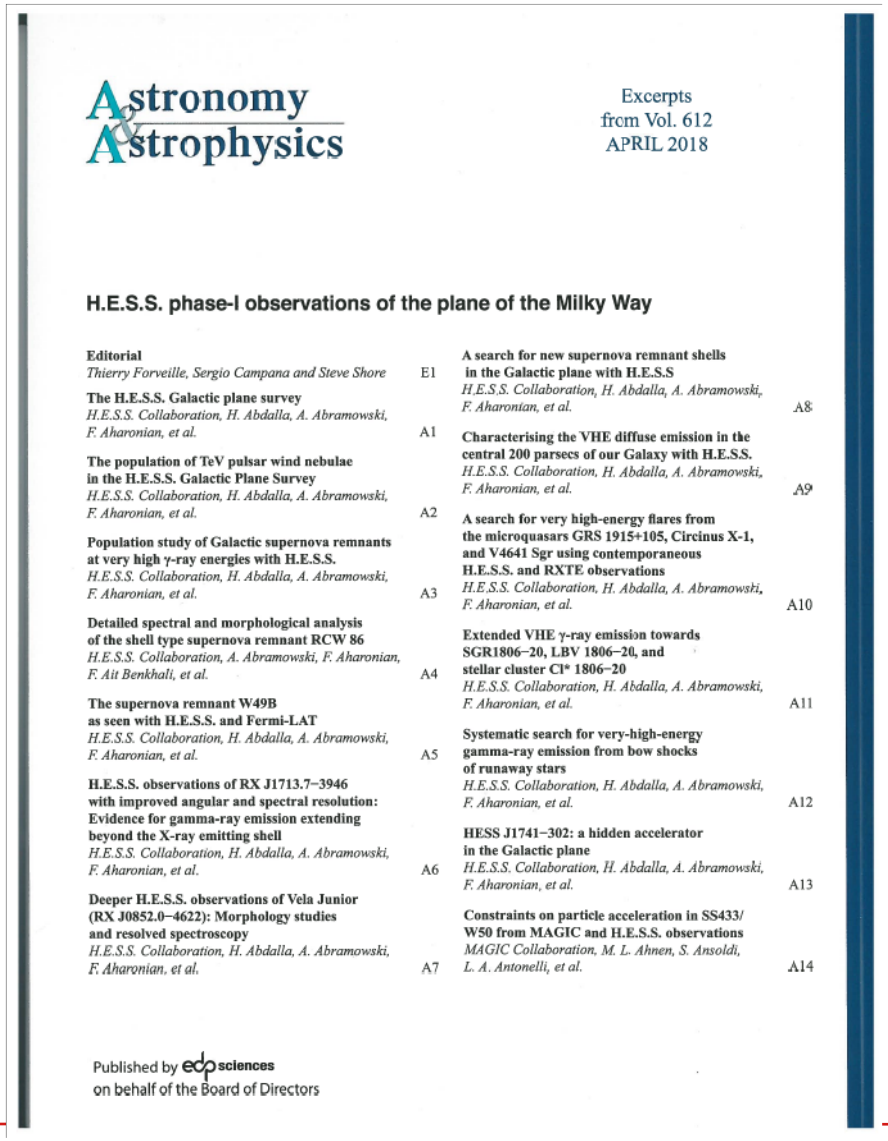


H.E.S.S. I Legacy
A new view on the Milky Way



H.E.S.S. observations of the inner galaxy





Astronomy & Astrophysics

Excerpts
from Vol. 612
APRIL 2018

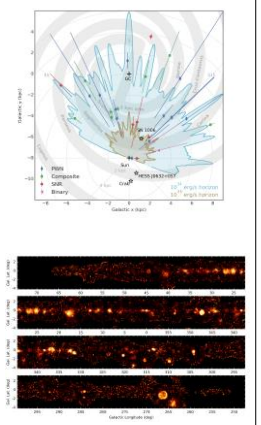
H.E.S.S. phase-I observations of the plane of the Milky Way

Published by edp sciences
on behalf of the Board of Directors

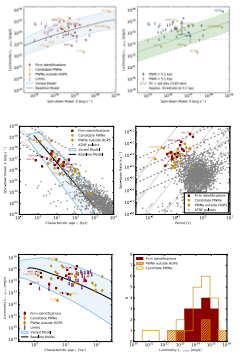
H.E.S.S. observations of the inner galaxy

- 14 publications bundled in A&A special issue (A&A 612) https://www.aanda.org/articles/aa/abs/2018/04/contents/contents.html

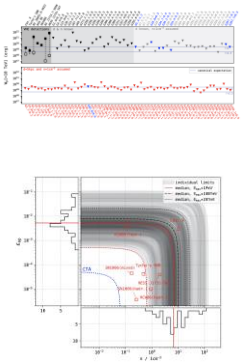
The H.E.S.S. Galactic plane survey



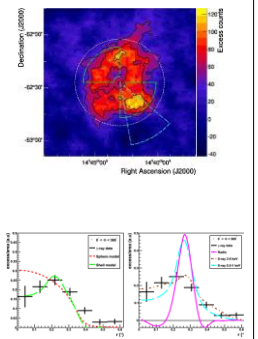
The population of TeV pulsar wind nebulae in the H.E.S.S. Galactic Plane Survey



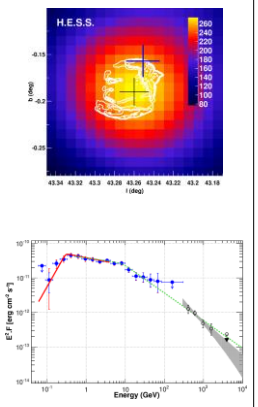
Population study of Galactic supernova remnants at very high γ-ray energies with H.E.S.S.



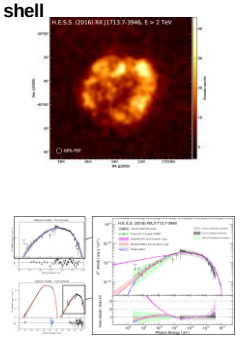
Detailed spectral and morphological analysis of the shell type supernova remnant RCW 86



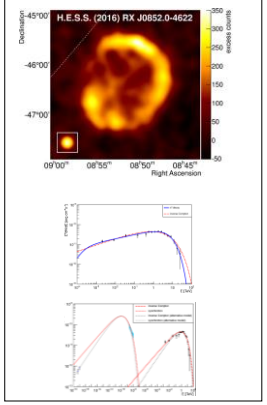
The supernova remnant W49B as seen with H.E.S.S. and Fermi-LAT



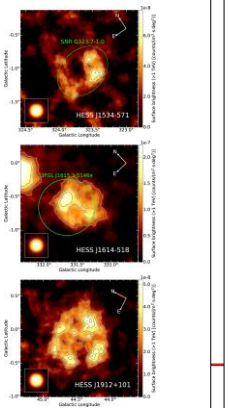
H.E.S.S. observations of RX J1713.7−3946 with improved angular and spectral resolution: Evidence for gamma-ray emission extending beyond the X-ray emitting shell



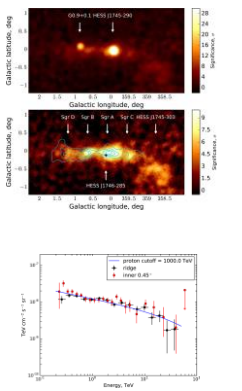
Deeper H.E.S.S. observations of Vela Junior (RX J0852.0−4622): Morphology studies and resolved spectroscopy



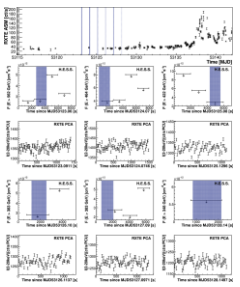
A search for new supernova remnant shells in the Galactic plane with H.E.S.S.



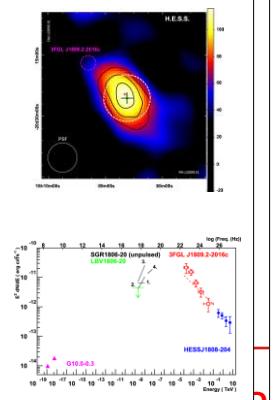
Characterising the VHE diffuse emission in the central 200 parsecs of our Galaxy with H.E.S.S.



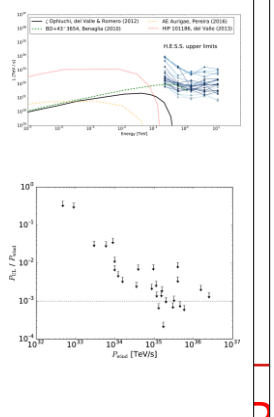
A search for very high-energy flares from the microquasars GRS 1915+105, Circinus X-1, and V4641 Sgr using contemporaneous H.E.S.S. and RXTE observations



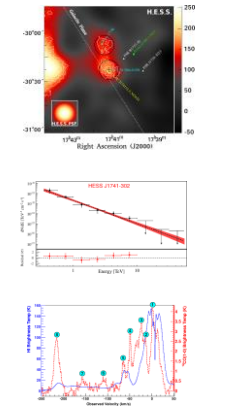
Extended VHE γ-ray emission towards SGR1806−20, LBV 1806−20, and stellar cluster Cl* 1806−20



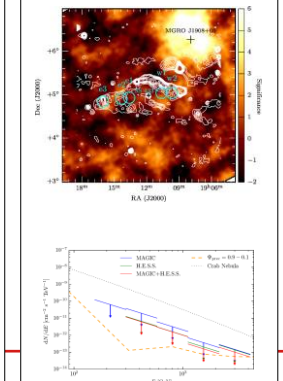
Systematic search for very-high-energy gamma-ray emission from bow shocks of runaway stars



HESS J1741−302: a hidden accelerator in the Galactic plane



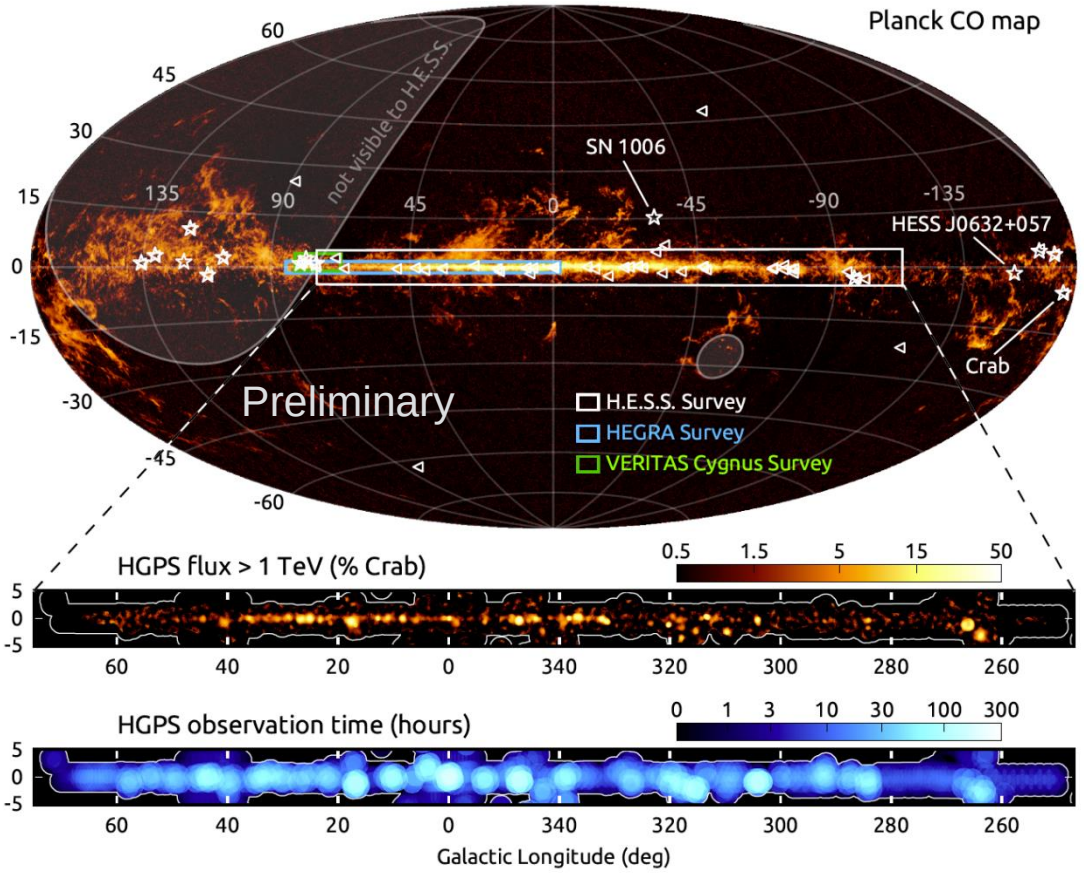
Constraints on particle acceleration in SS433/W50 from MAGIC and H.E.S.S. observations



H.E.S.S.-I Legacy Survey

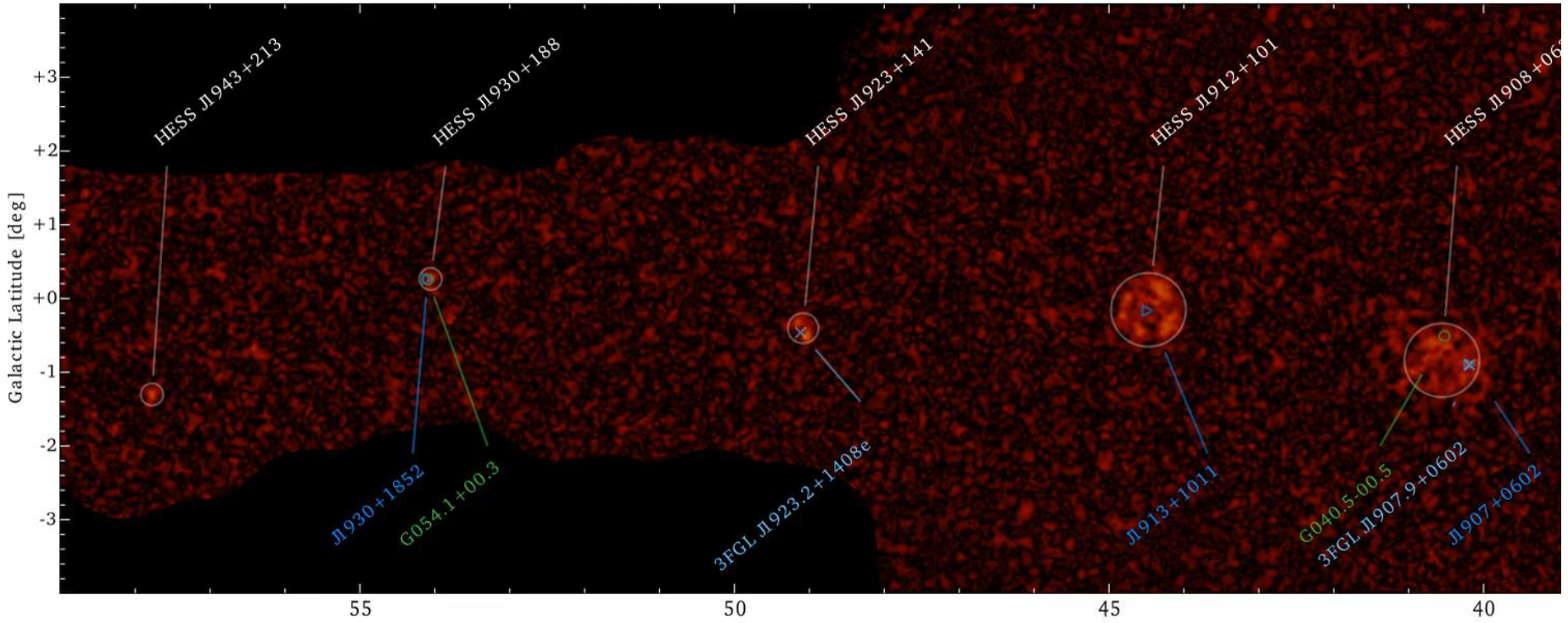
- Major H.E.S.S. project
- Data collected 2004 – 2013
  - 2673 h after quality selection
  - l in [-110°, 70°]
  - b in [-5°, 5°]
  - Inhomogeneous exposure (sources of particular interest)

- Paper in collaboration review
- Maps will be released in FITS format

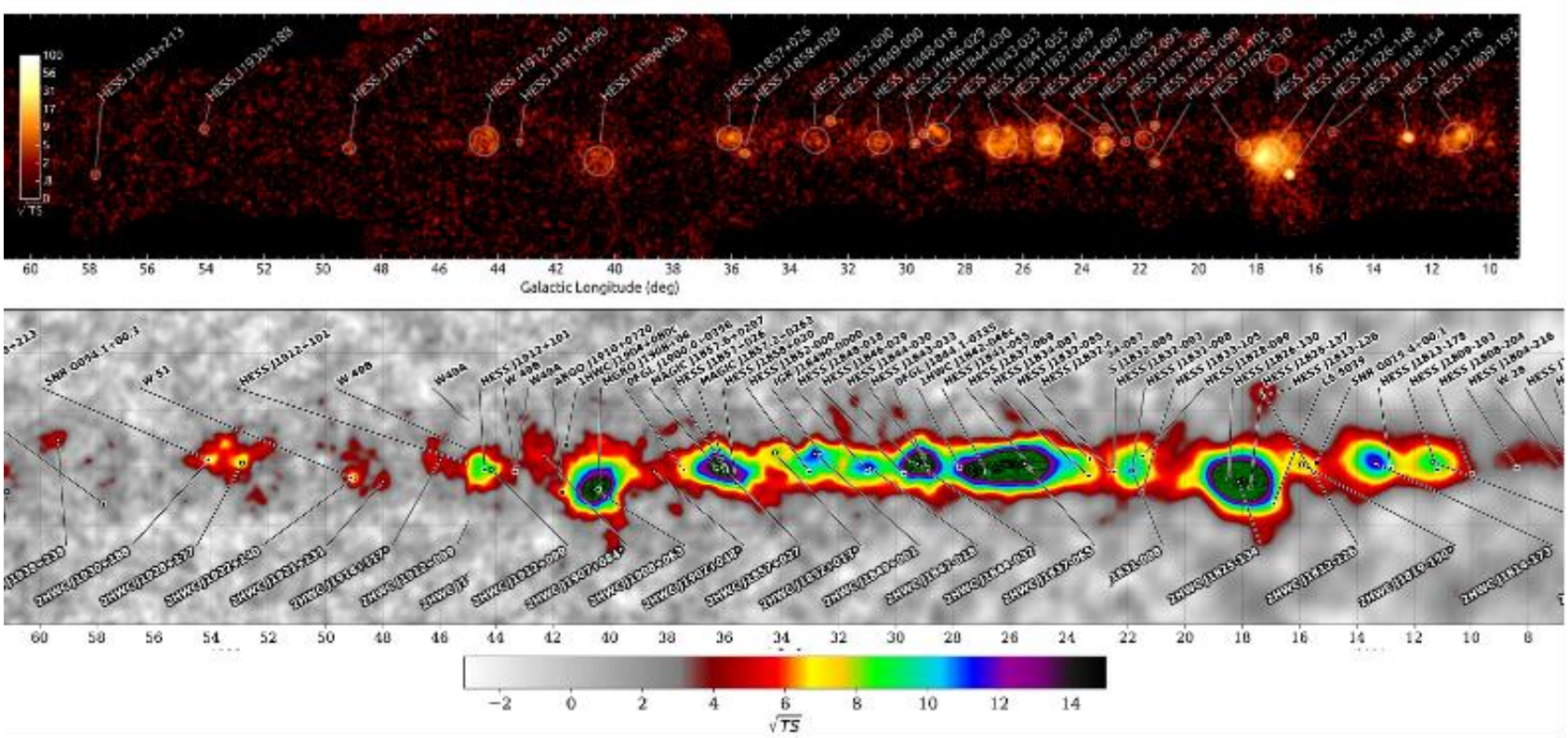


H.E.S.S. Collaboration (**A&A Special Issue**)

Sky maps with associations

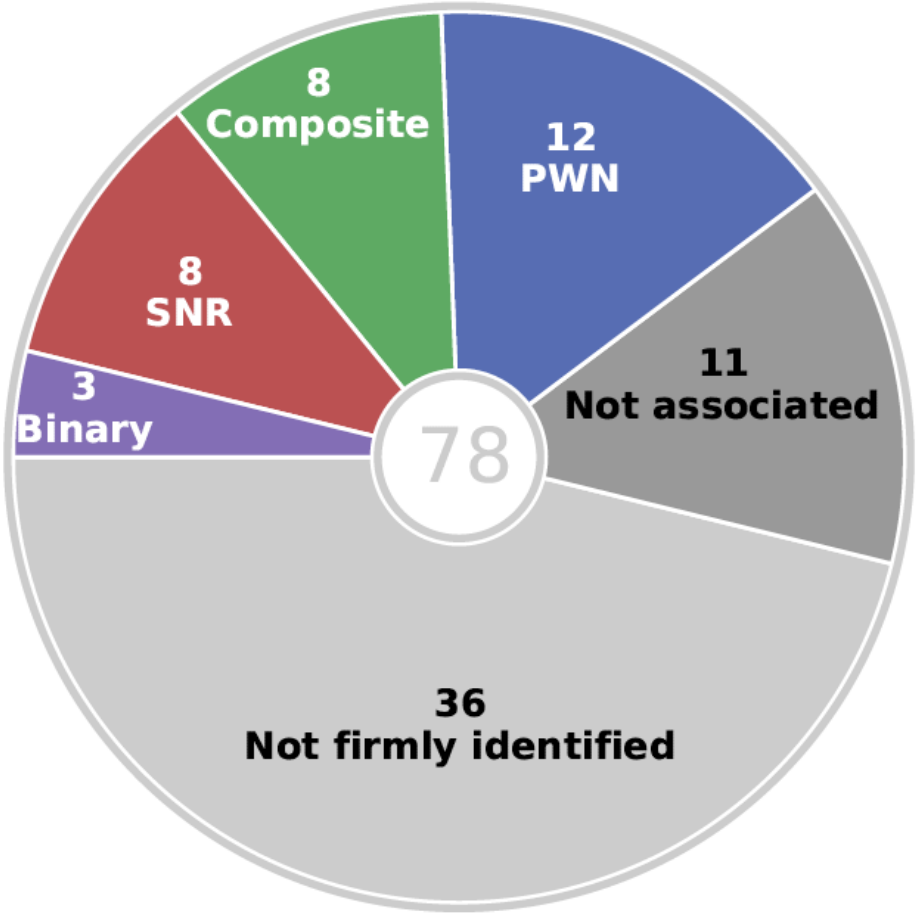


HAWC & H.E.S.S. Galactic Plane Surveys

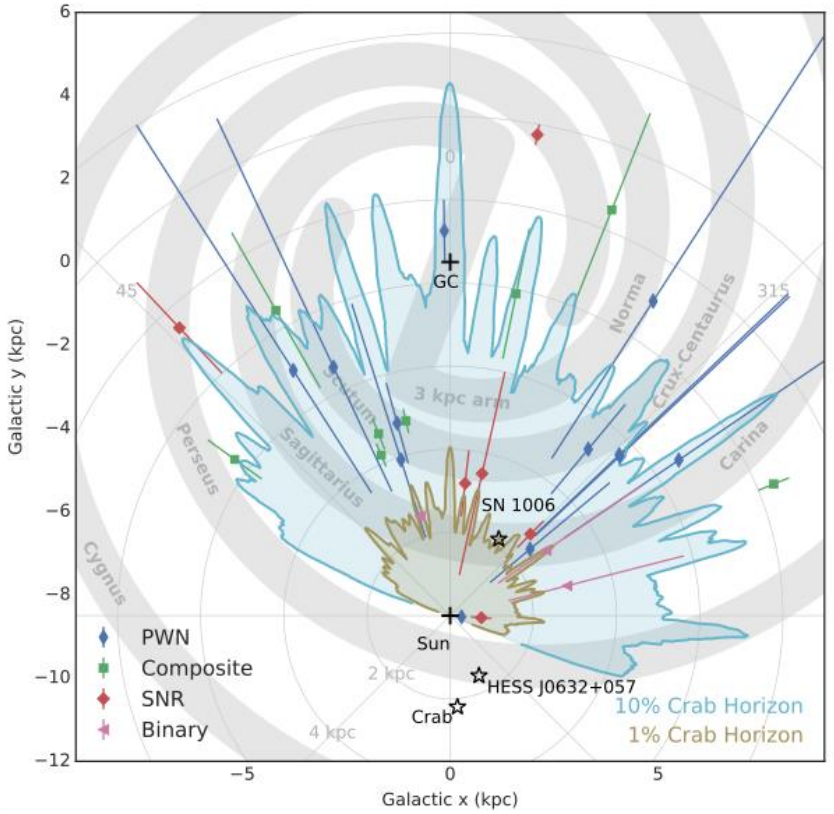


- 15 HAWC sources associated with H.E.S.S. sources
- 7 HAWC sources undetected by IACTs
  - lack of sensitivity to very extended sources?
  - energy-threshold effects?

Association and Identification



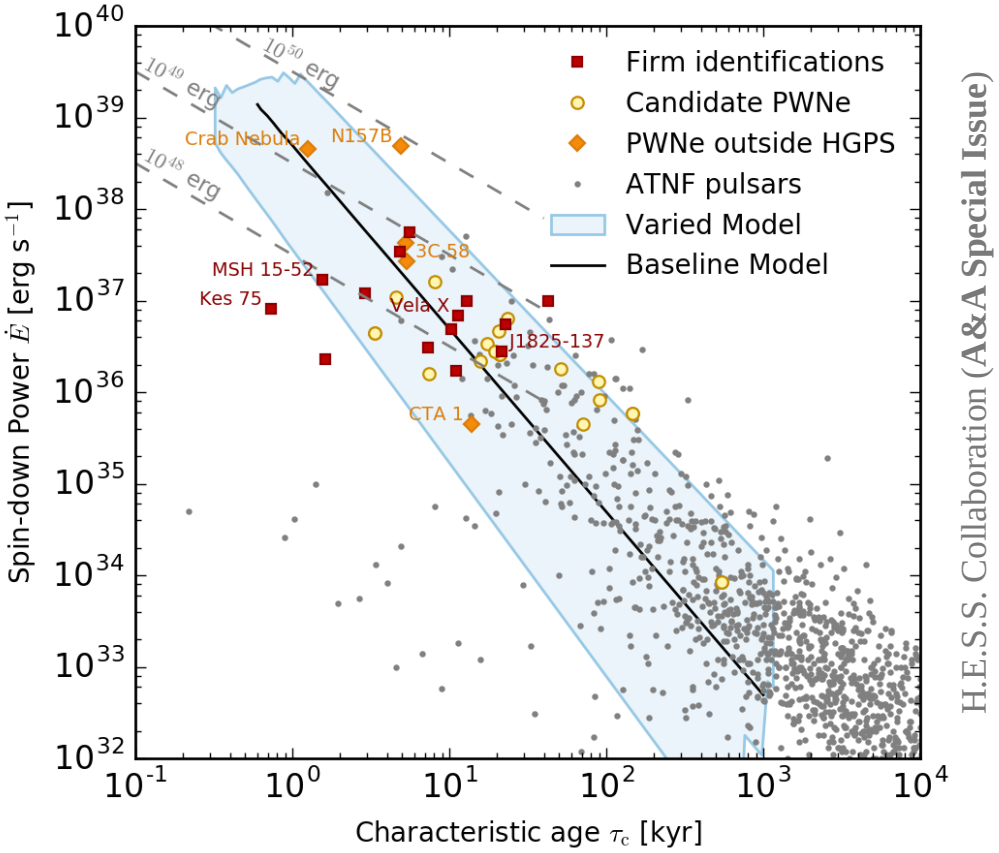
Horizon



What Surveys are good for? Population Studies – Pulsar Wind Nebulae

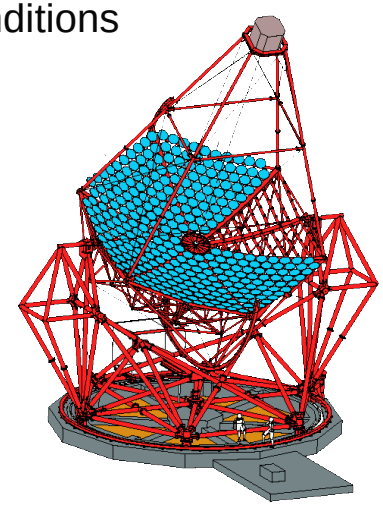
- Population of TeV Pulsar Wind Nebulae in the H.E.S.S. HGPS
  - ~2/3 of pulsars with $\dot{E} > 10^{37}\ \mathrm{erg.s^{-1}}$
  - ~50% of pulsar with $\dot{E} > 10^{36}\ \mathrm{erg.s^{-1}}$

$$\dot{E}(t) = \frac{\dot{E}_0}{\left(1 + \frac{t}{\tau_0}\right)^2}$$



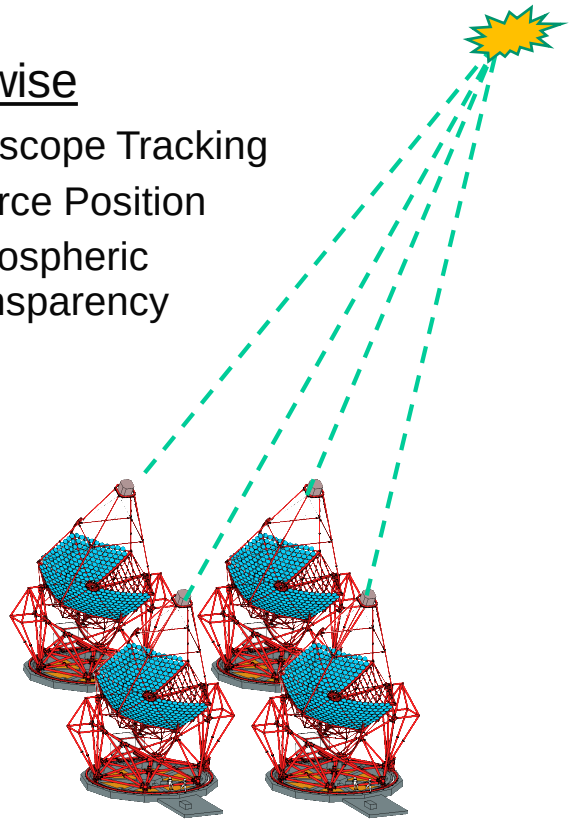
Advanced framework for simulations

- More realistic simulation approach (ICRC 2017)
  - Simulating each observation run of a data set
  - Using actual observation and instrument conditions

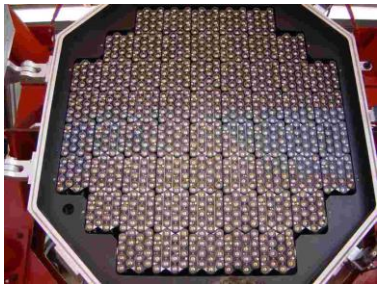


- Telescope-wise
  - Camera focus
  - Trigger Settings
  - Live-Time fraction

- Array-wise
  - Telescope Tracking
  - Source Position
  - Atmospheric Transparency

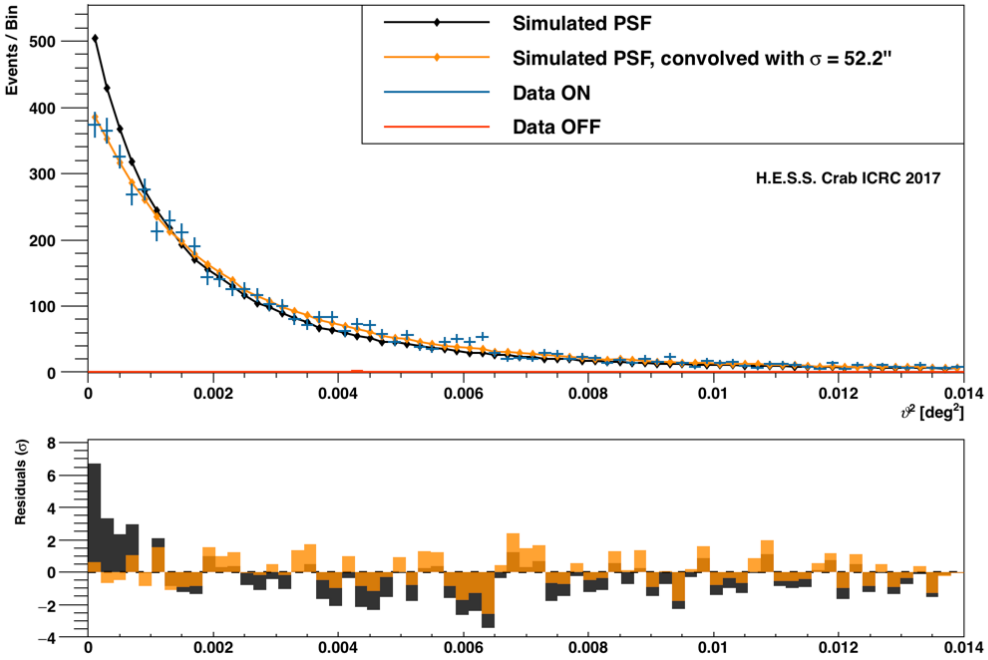


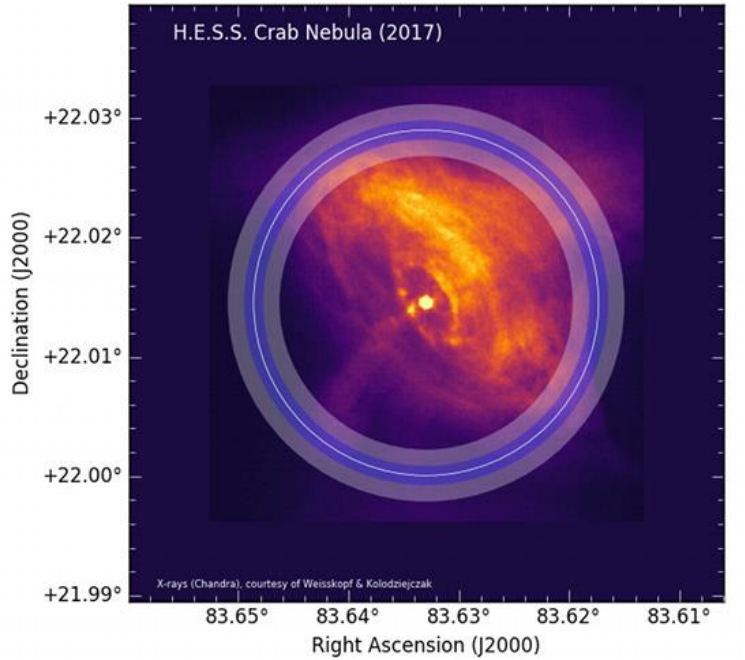
- Pixel-wise
  - Broken Pixels
  - PMT Gain
  - HI-Lo ratio
  - Flatfield Coefficient
  - Night Sky Background



The Crab Nebula

- Improved simulation techniques „aka run-wise simulation“ allow to push the limits of ground-based gamma-astronomy
- Major step in data analysis, important for CTA
- An „advanced search for the extension of unresolved TeV sources with H.E.S.S.“

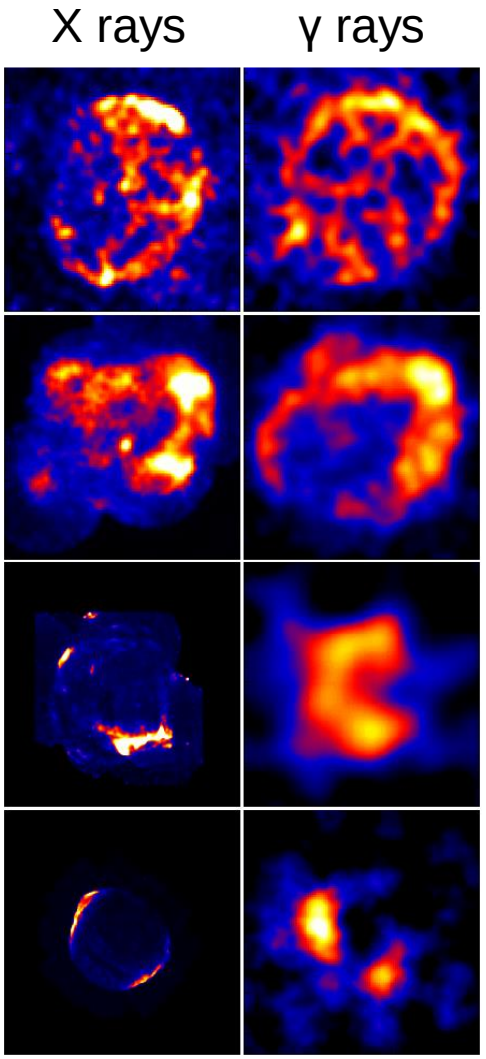




H.E.S.S. collaboration, ICRC 2017

Population Studies II – Supernova Remnants

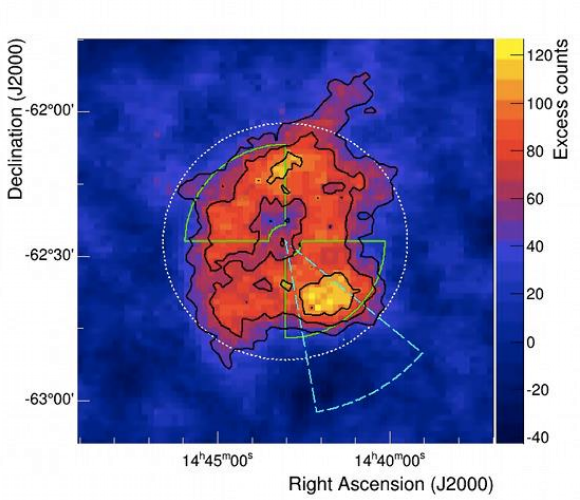
- Second population of VHE sources in Galaxy
- Young, historical supernova, in different evolution stages
  - High quality images, MWL data
- Olders SNRs proven to accelerate protons
  - In interaction with molecular clouds (W28)
  - π^0 bump in Fermi LAT (IC 433, W49A, W51C, W44 …)
- High energy can be dominated by leptonic processes
  - Due to different efficiency of radiation mechanisms
  - $e^{\pm}$ cannot travel invisibly (IC unavoidable)
  - Hadrons need target to be revealed
- SNRs can be pevatrons only during a (very) short time

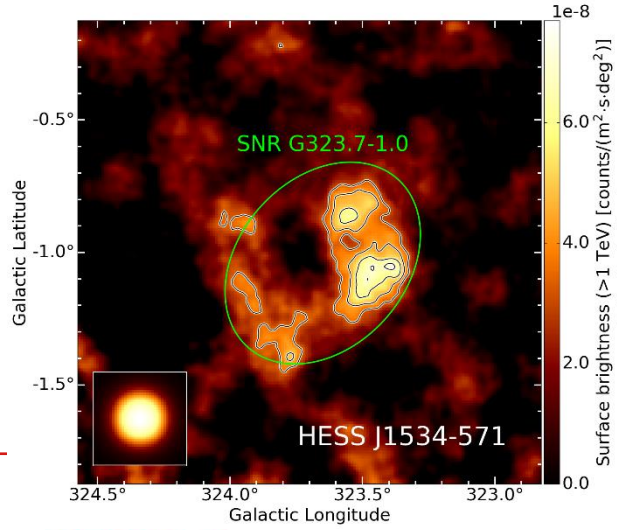


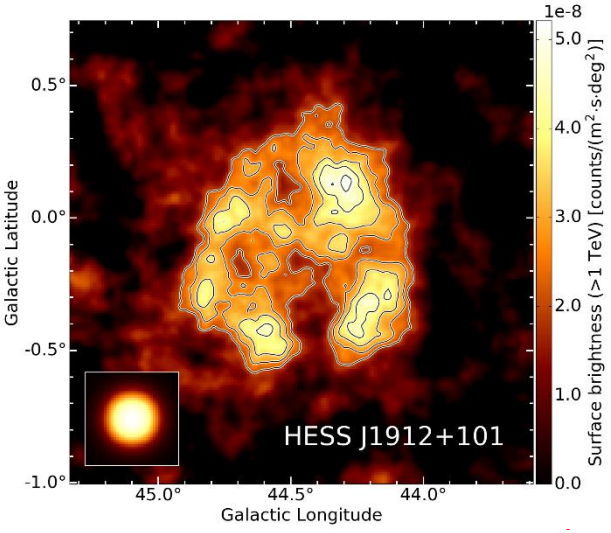
New TeV Shell-type SNRs

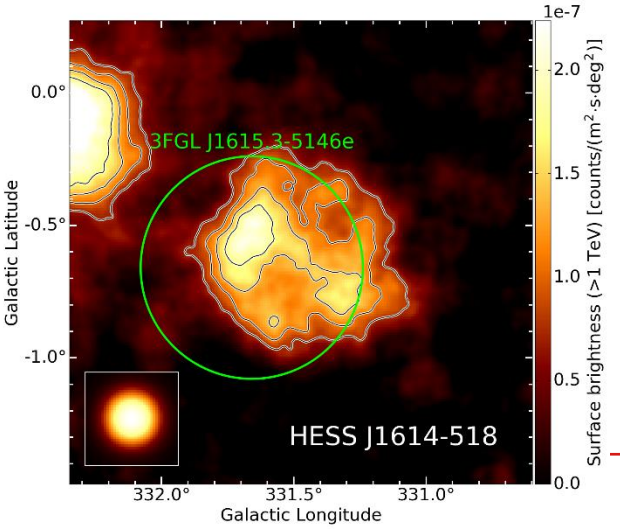
Increasing sample

- New shell-type SNRs resolved by H.E.S.S.
- RCW 86 from deep exposure
  - Good correlation between TeV and hard X-ray (IC vs synchrotron)
  - Likely leptonic dominated, B ~20 μG
  - Max energy ~ 3 TeV
- HESS J1534-471, HESS J1614-518 and HESS J1912+101 from HGPS
  - HESS J1912+101 only
    TeV SNR w/o counterparts in other wavebands



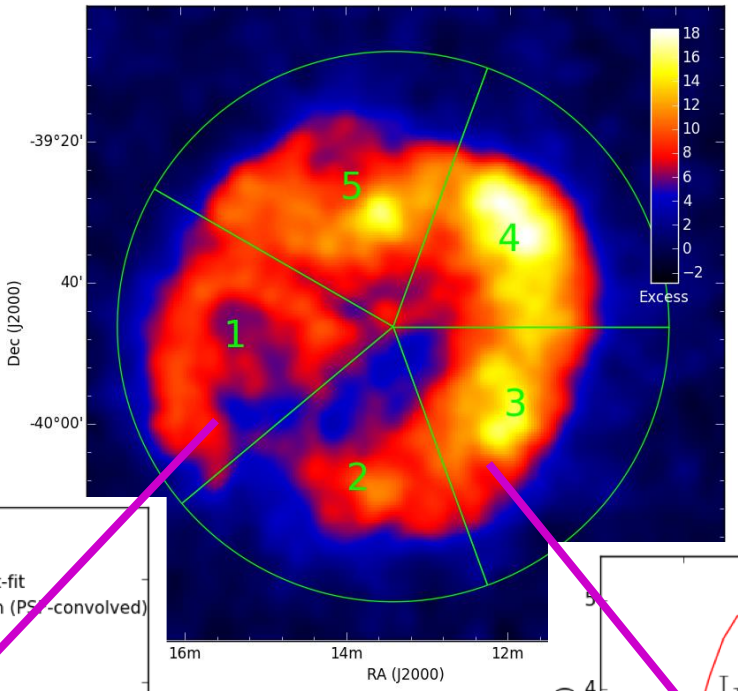






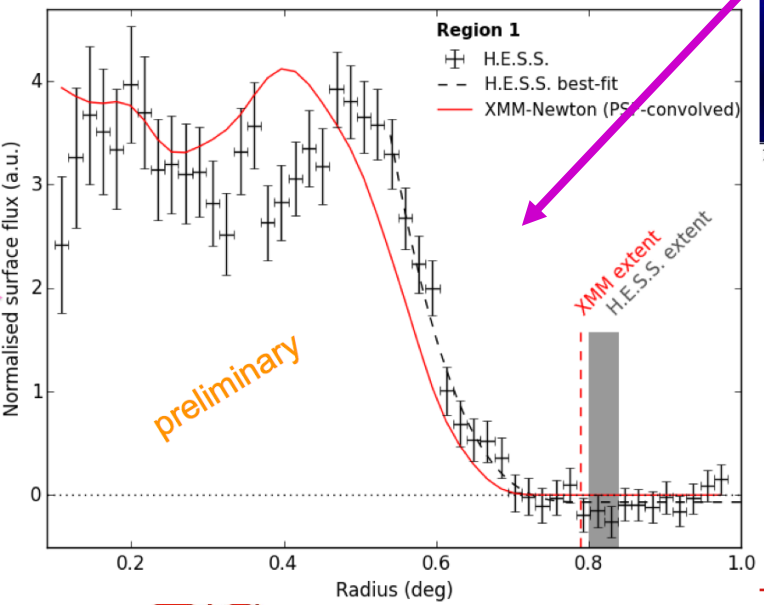
H.E.S.S. Collaboration (**A&A Special Issue**)

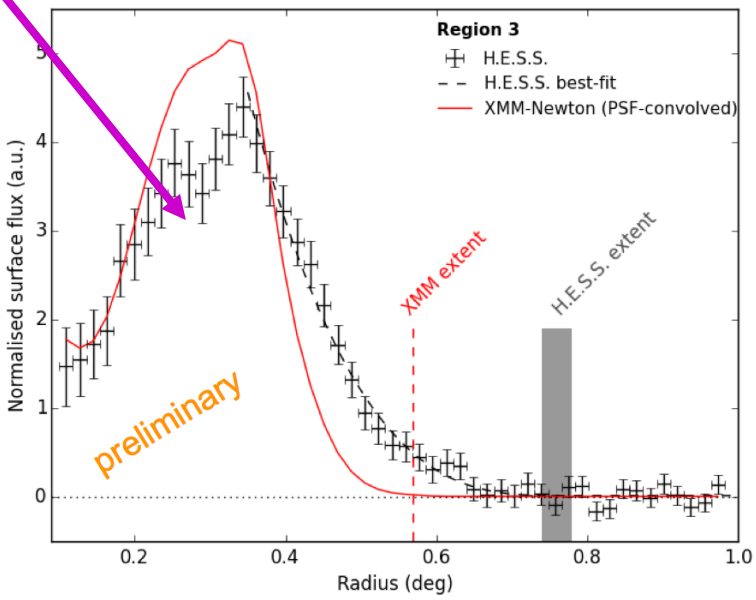
Particle escape



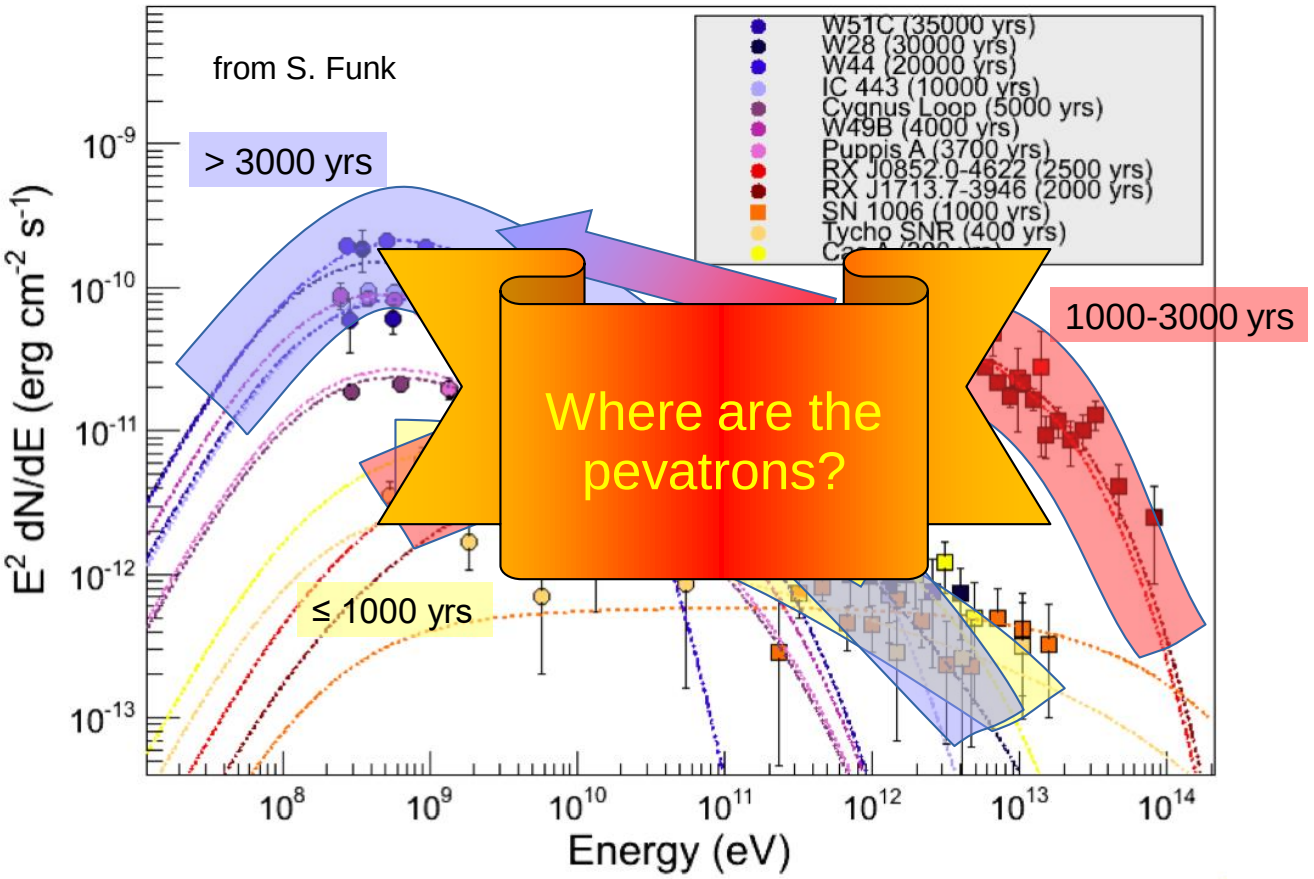
H.E.S.S. Collaboration (**A&A Special Issue**)

Particle escape?





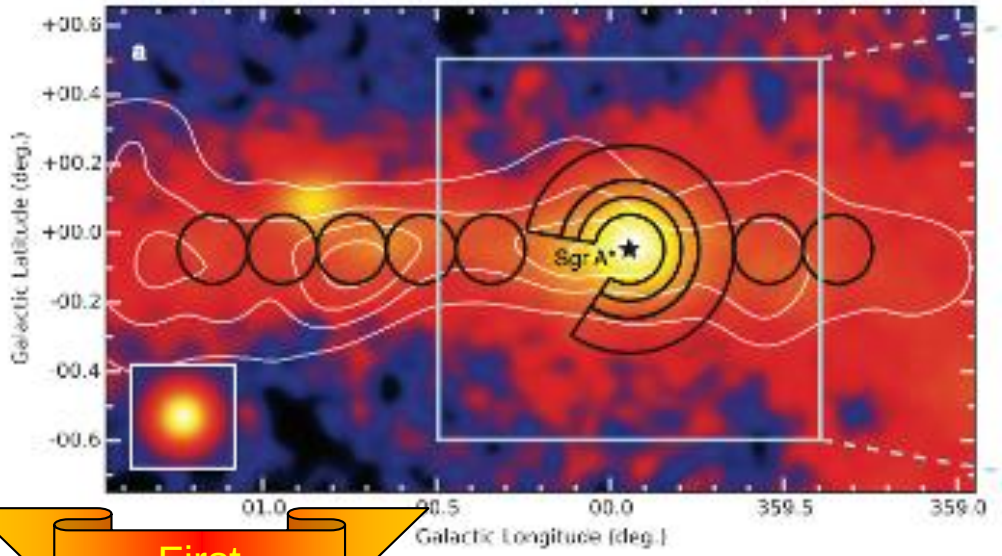
Large sample → evolution of supernova remnants

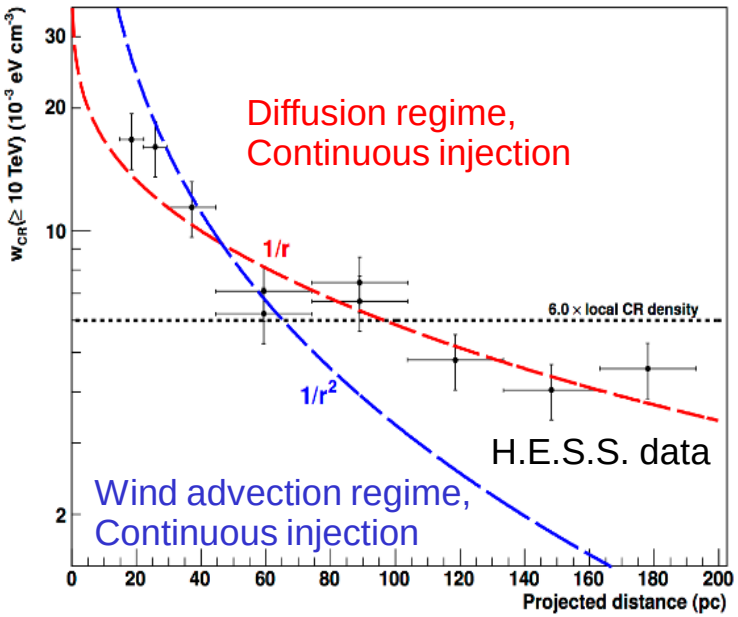


The Galactic Centre region – 10 years after

- Full dataset analyzed: 2004-2012 => 220h obs. time (175h acc. corrected)
- Point like source > 100 σ, central source on top of extended (ridge) emission
- Diffuse emission up to > 50 TeV, attributed to protons accelerated around central black hole and diffusing away (projected radial distribution matches)
- Parent proton population up to 1 PeV (2.9 PeV @ 68% CL)
- Central accelerator located within 10 pc and injecting CRs continuously for > 1 kyrs

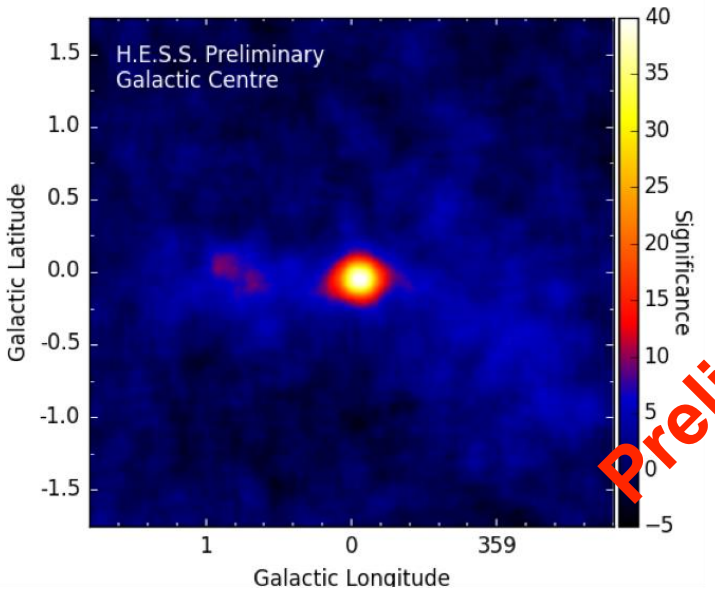
HESS Collaboration, Nature 531 (2016)

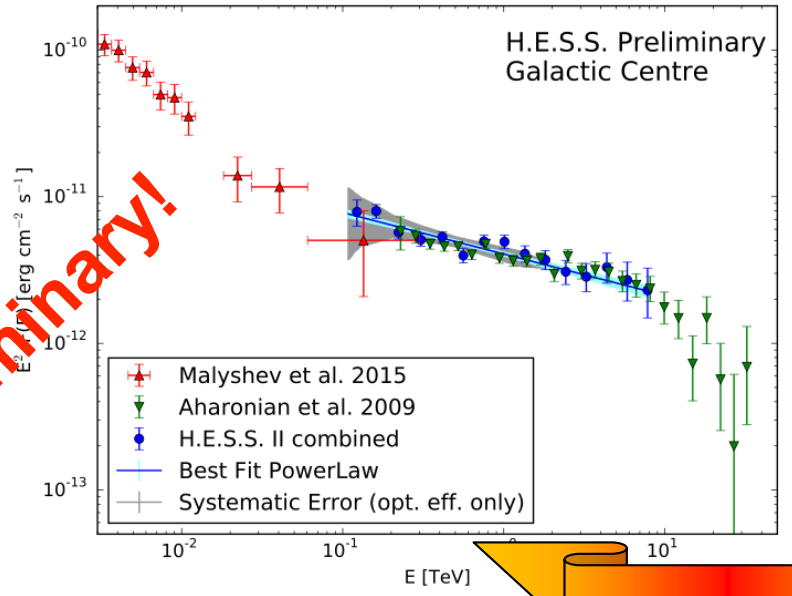




First Pevatron

Galactic Center with H.E.S.S.-II





Preliminary!

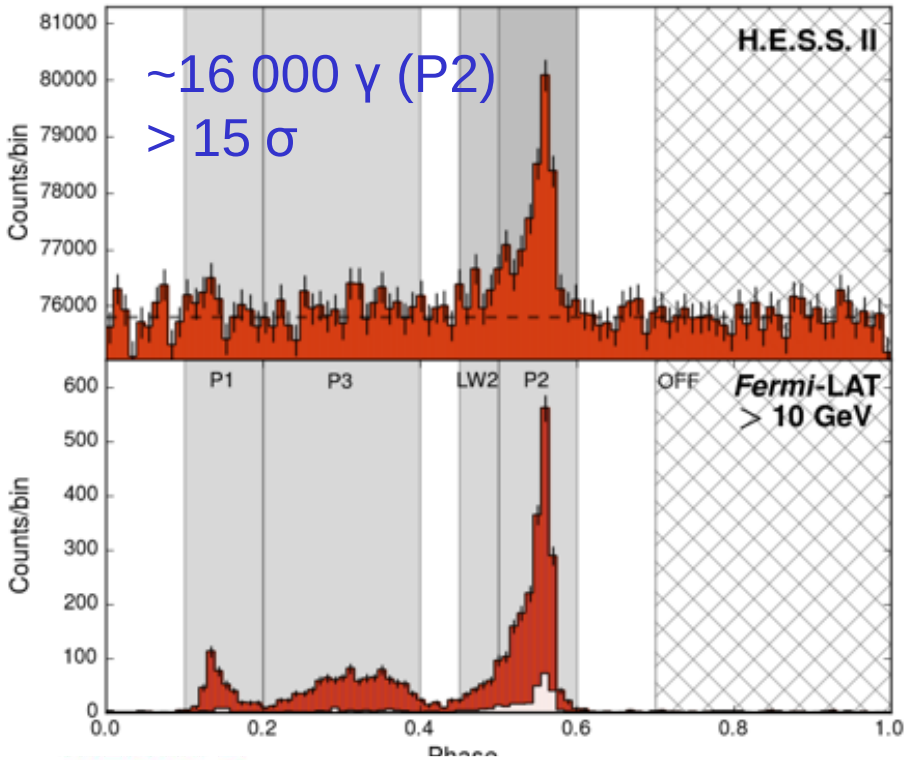
ICRC 2017

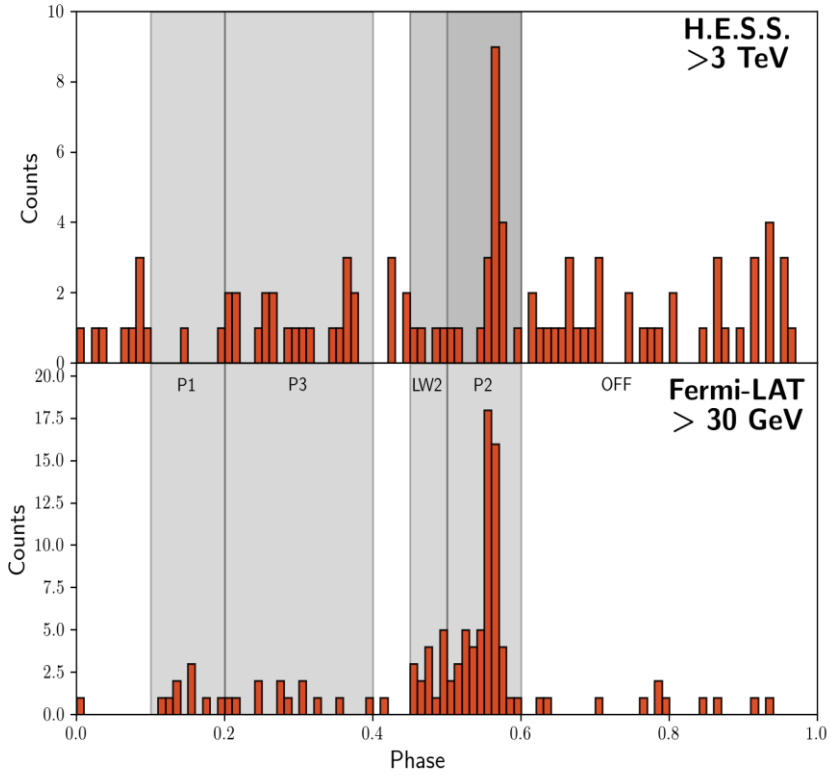
- GC with the H.E.S.S. II array down to ~100 GeV
- Detection of central source (40σ), PWN G0.9+0.1, HESS J1745-303 + diffuse emission
- smooth continuation from spectrum seen in H.E.S.S. I
- E-threshold not low-enough to fully describe Fermi-LAT-H.E.S.S. spectral break
- +50h obs. time coming soon (blinded for dark matter searches…) vs 58h so far…

Vela Pulsar

Second VHE pulsar

- Second VHE pulsar (H.E.S.S.)
  - Calibration source at the threshold in standard observation mode
  - Deep observation campaign needed to investigate maximum energy and variation of pulse profile with energy
  - Very different regime than Fermi-LAT: huge statistics over a huge background
  - First indication of VHE emission > 3 TeV → new component?

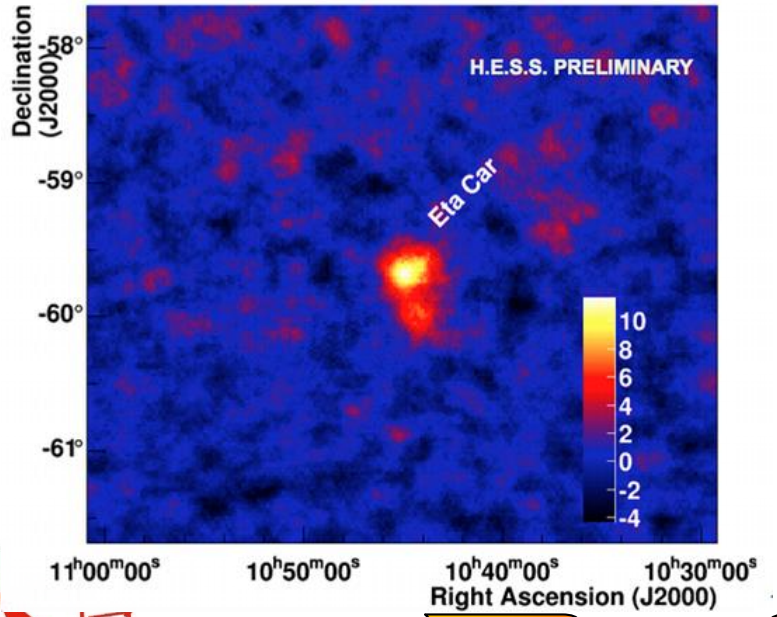




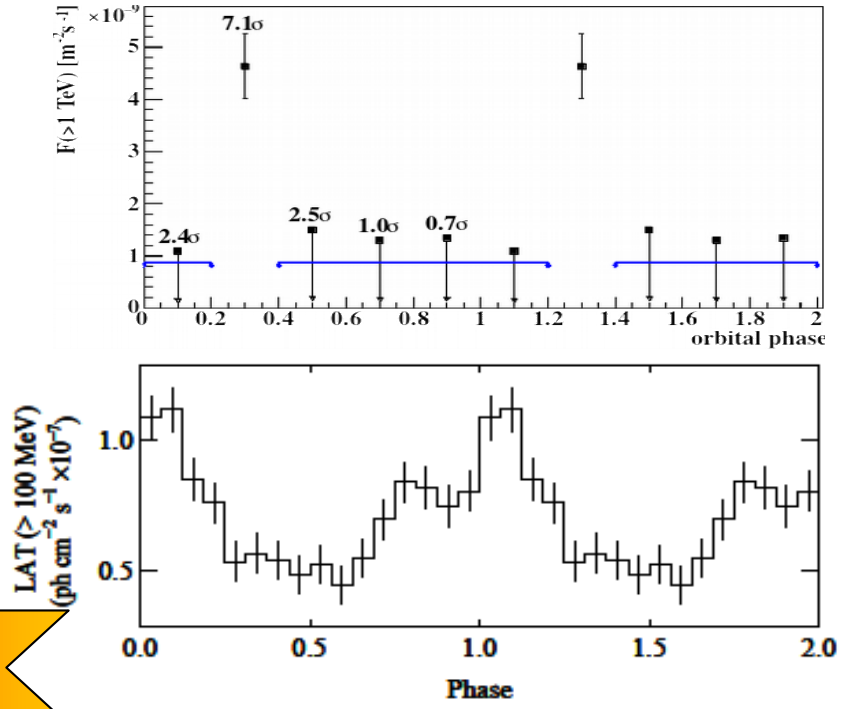
H.E.S.S. Collaboration (arXiv:1807.01302)

New Binary Systems

- Eta Car
- A colliding wind binary system seen now also in very high energy gamma-rays
- Detected with H.E.S.S. II pre-periastron and around periastron (in total > 13 σ)

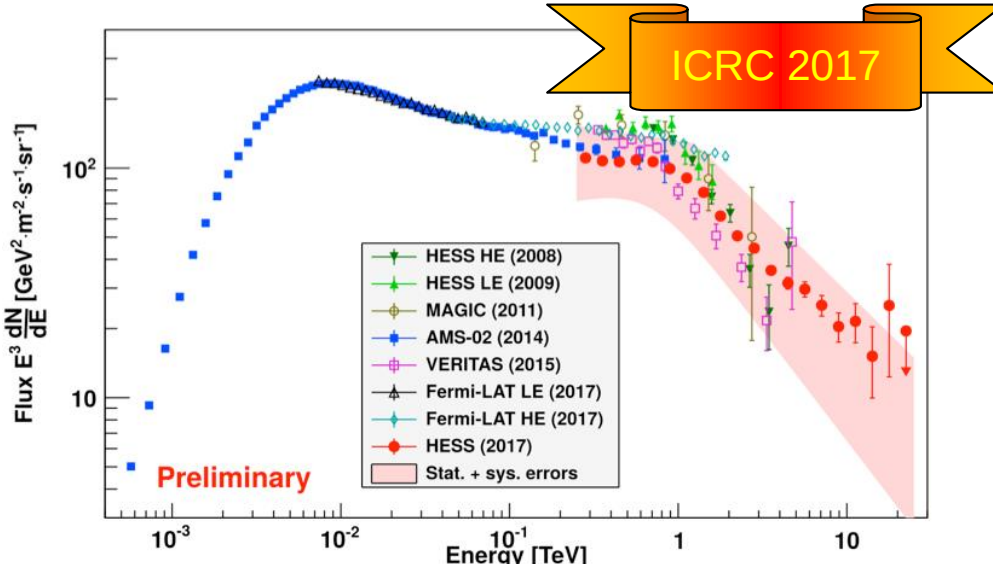


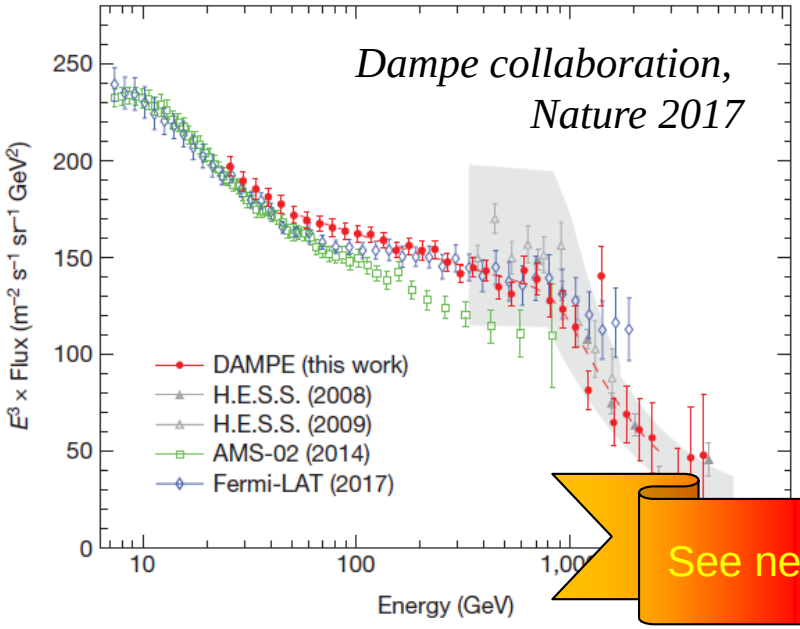
- LMC P3 – A new gamma-ray binary in the LMC
- Discovered in Fermi-LAT data (Corbet et al. 2016)
- Bright companion star O5 III, similar to LS5039 or 1FGL J1018?
- Detected by HESS at phase ~0.3
- Most luminous γ-ray binary

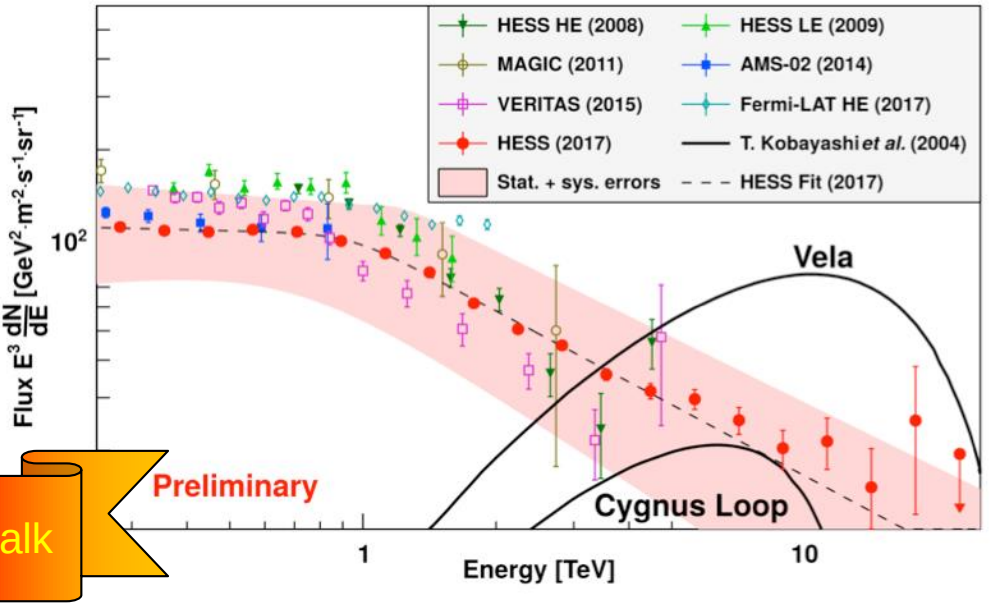


The local CR electron spectrum

- Electron spectrum between 0.25 TeV and 20 TeV:
  - Break at ~1 TeV (change of diffusion regime?)
  - Probing local PWNe and SNRs
- Break recently confirmed by DAMPE

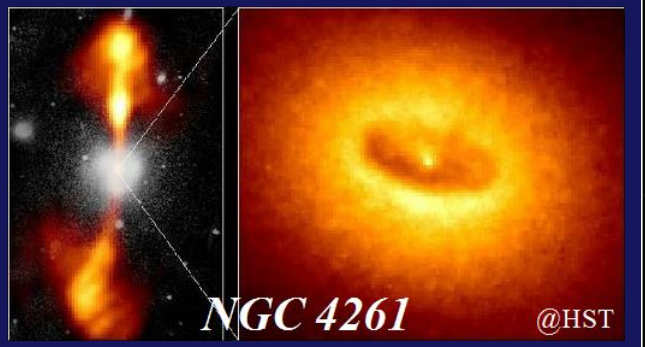


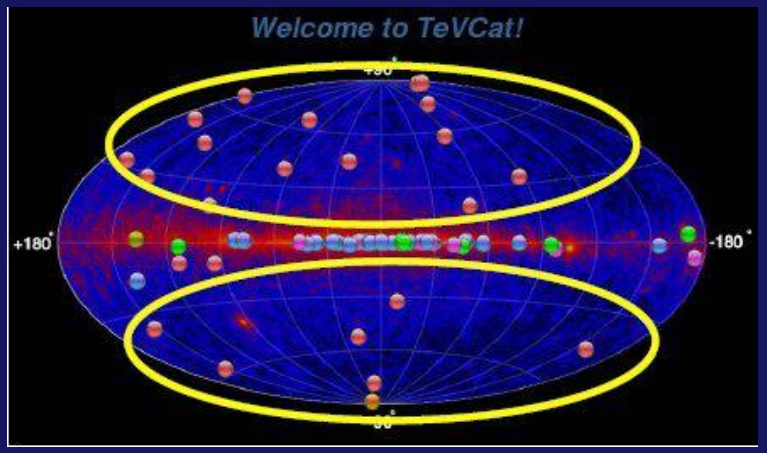




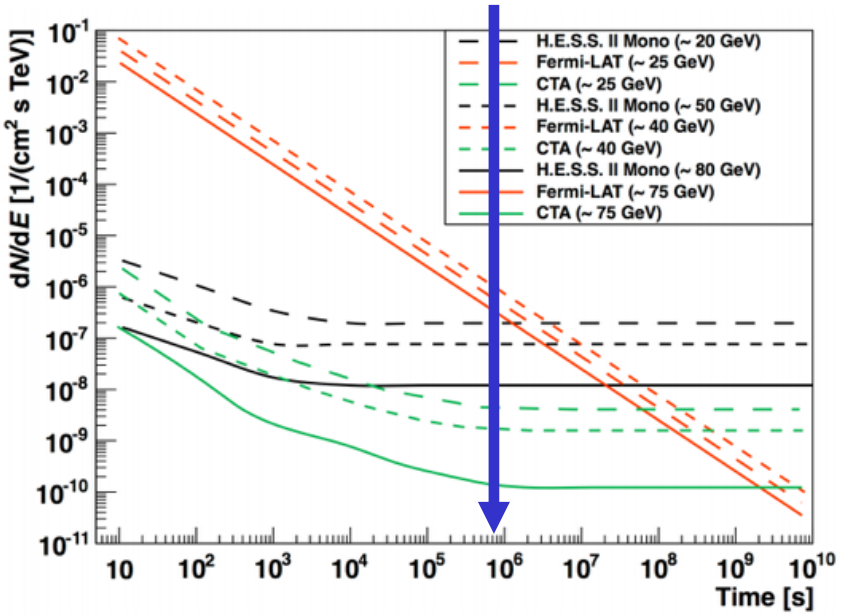
See next talk

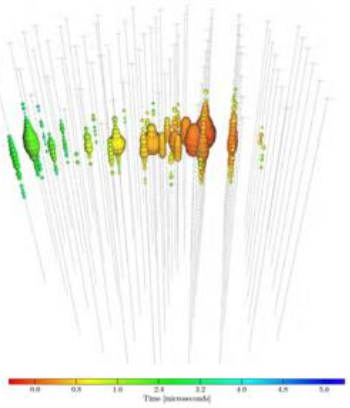
Extragalactic Science





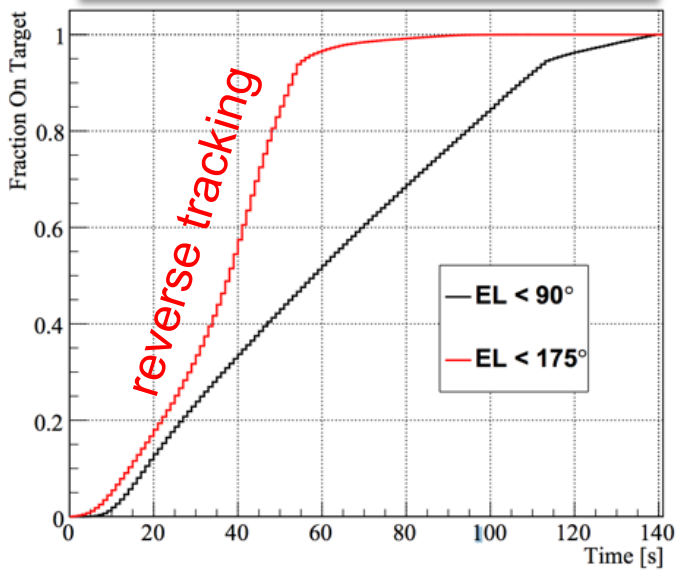
HESS-II as transient machine





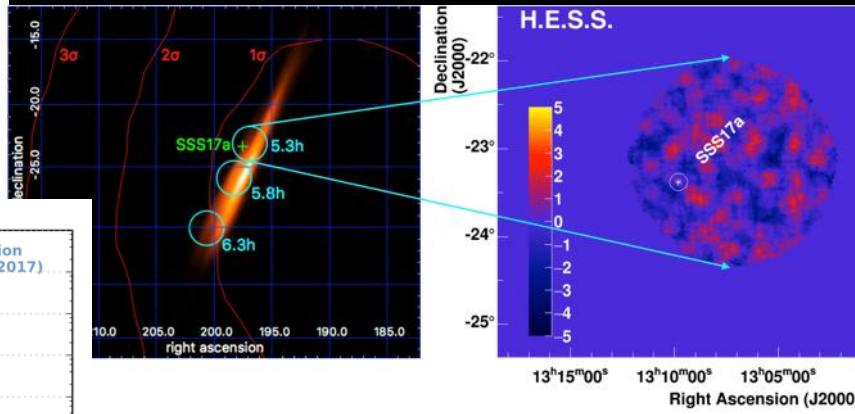
- Fast response time of 28m telescope
- >90% of targets within 60 sec
- Extensive GRB follow-up program
- Fast radio bursts, Neutrino events, Gravitational wave events, …

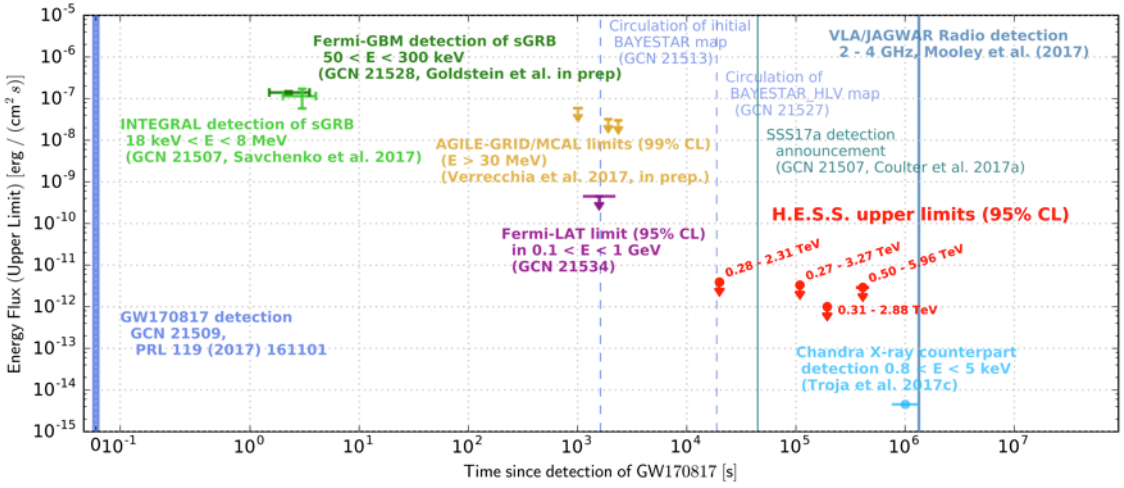
H.E.S.S. 28 m telescope slewing time



The birth of multi-messenger astrophysics: GW170817

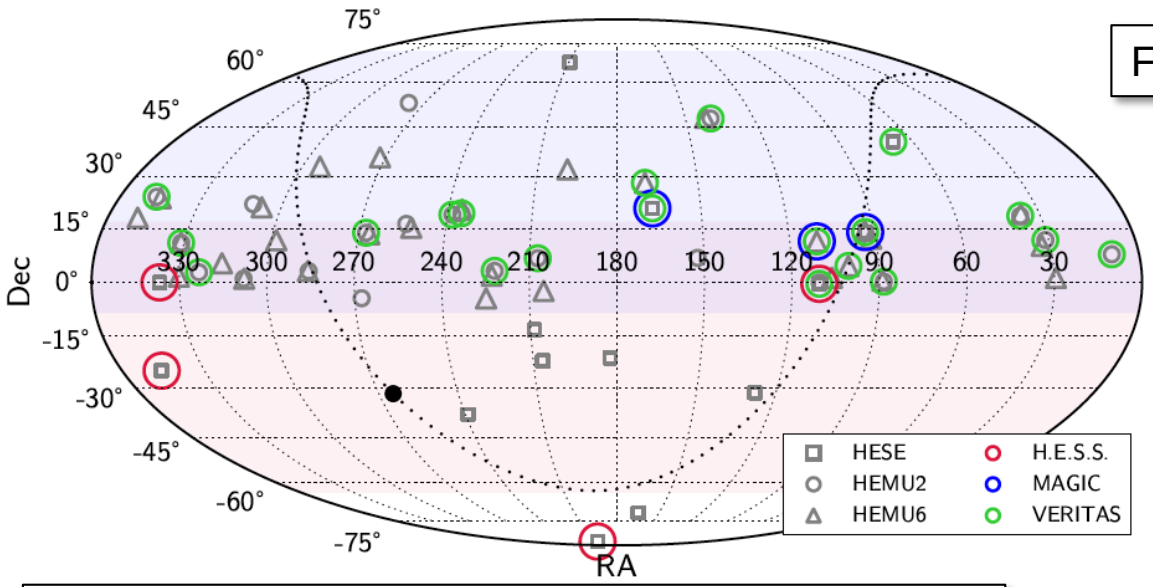
- Binary NS merger detected with Ligo+Virgo
  - Multi-wavelength campaign
  - Short gamma-ray burst
  - Kilonova (NIR, optical, UV)
  - Delayed X-ray and radio emission
- H.E.S.S. observations started T0 + 5.3 hrs
  - First ground-based pointing instrument
  - Monitoring campaign over 5 days
  - Constraints on non-thermal emission
  - F(0.27<E[TeV]<8.55) < 1.5 x 10-12 erg/cm^2/s





H.E.S.S. collaboration,
ApJL 850 (2017) L22

Neutrinos and FRBs



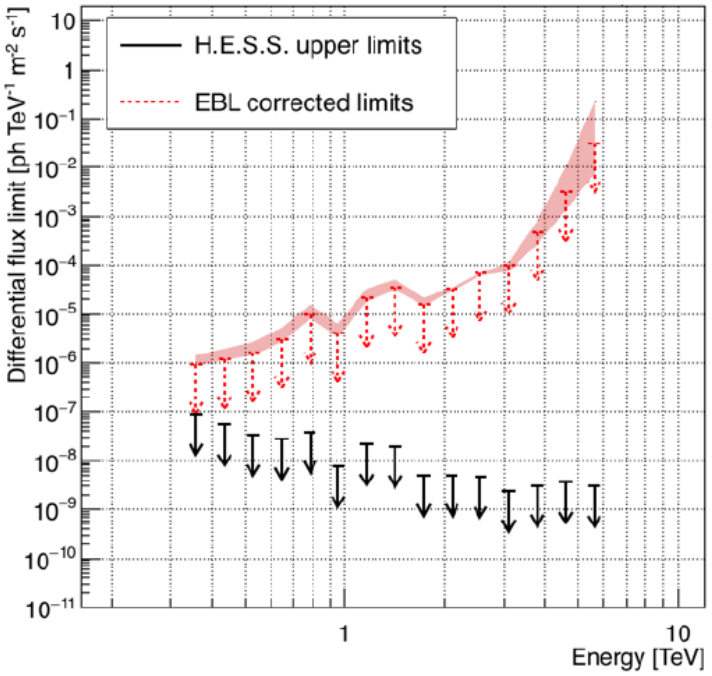
Follow-ups of Ice-Cube events

IceCube-EHE-170922: Massive MWL campaign
2017/09/27: H.E.S.S. ATEL: TeV limit
Observations continued on TXS 0506+056
Only upper limits with H.E.S.S.

IceCube ++,
Science 361 (2018)

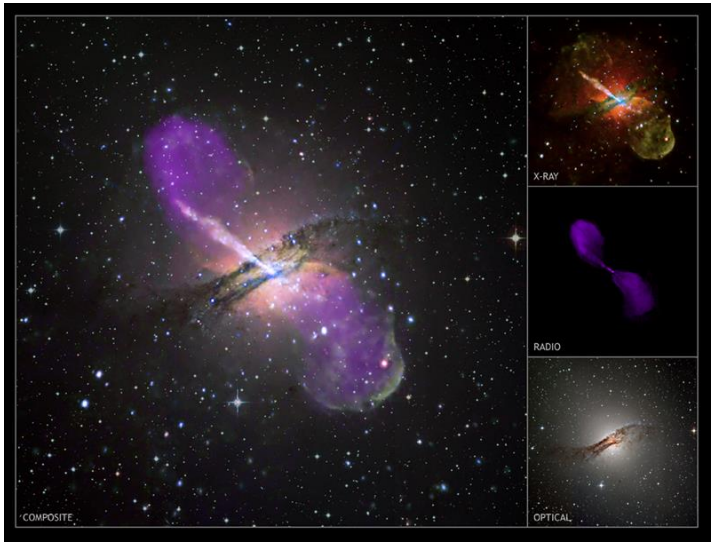
FRB 150418 (z=0.492)
TeV constraints on the
afterglow emission (t > 15 hrs)

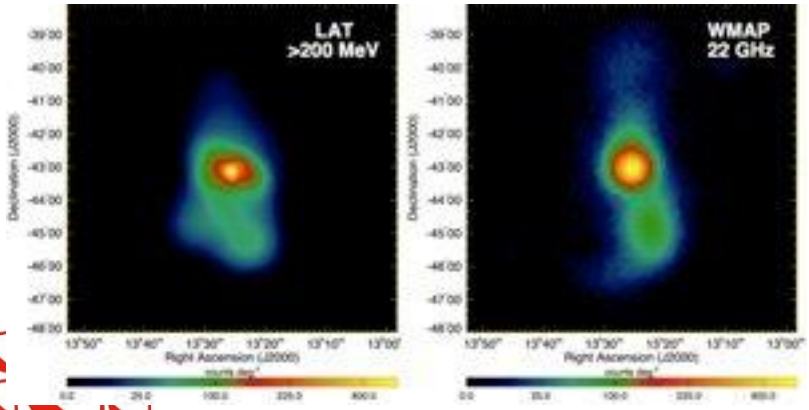
H.E.S.S. collaboration, A&A 597, 2017

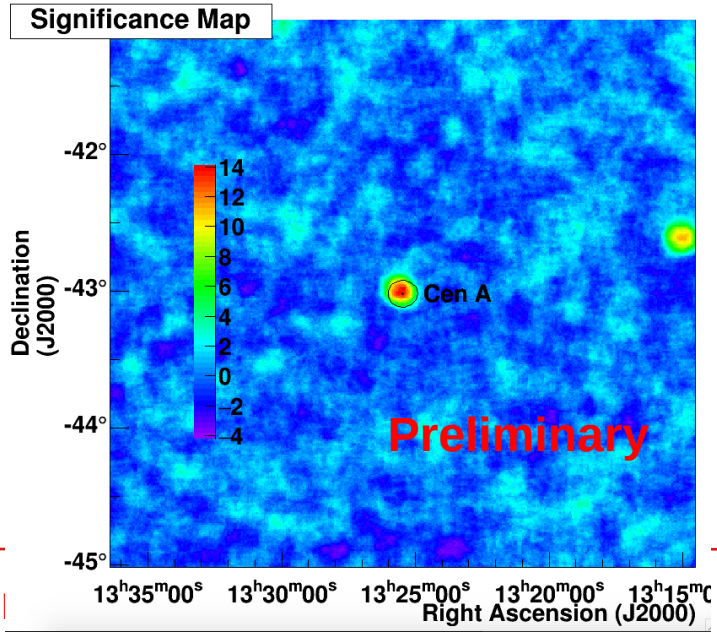


Centaurus A

- Radio Galaxy (NGC 5128) of FRI type
- Nearest active galaxy at a distance of 3.7 Mpc
- Possiblility of detailed morphological analysis ($1^\circ \simeq 65$ kpc).
- Fermi-LAT : extended lobes
- Deep H.E.S.S. Observations from 2004 to 2013
  - 202 hours of live time
  - Change in hardware state, observation conditions
  - Detection significance: 13.1σ, S/B ratio: 0.5

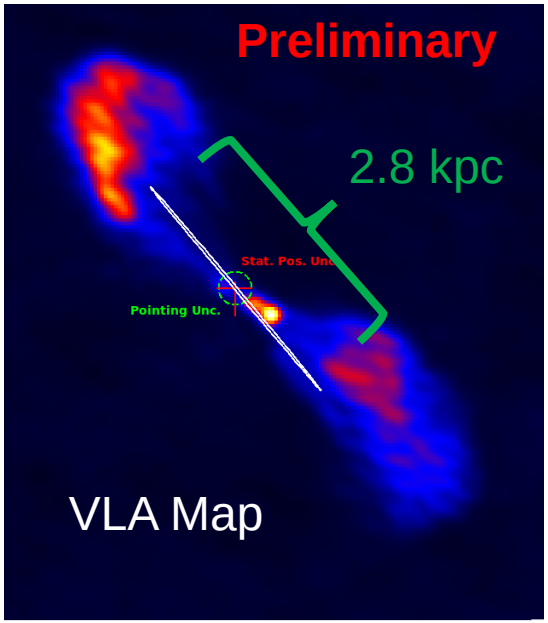






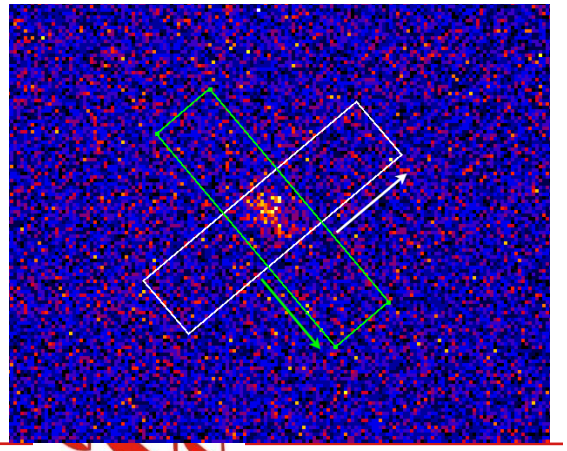
Resolving the emission

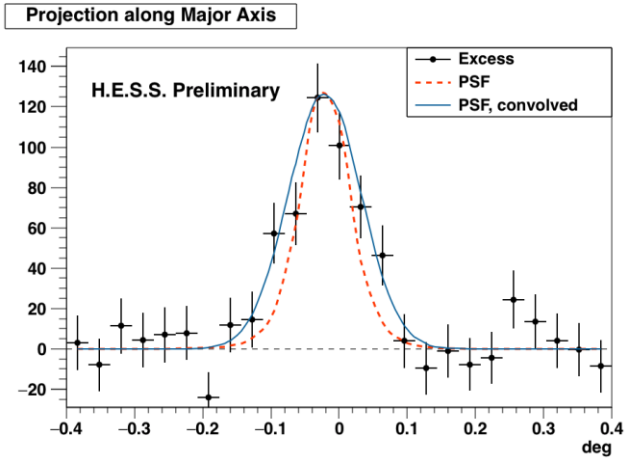
- Resolved emission:
  - Gaussian width of semi-major axis: (0.0435 + 0.0122 - 0.0116)°
  - Point-like in the transvers direction
  - Aligned with radio jets

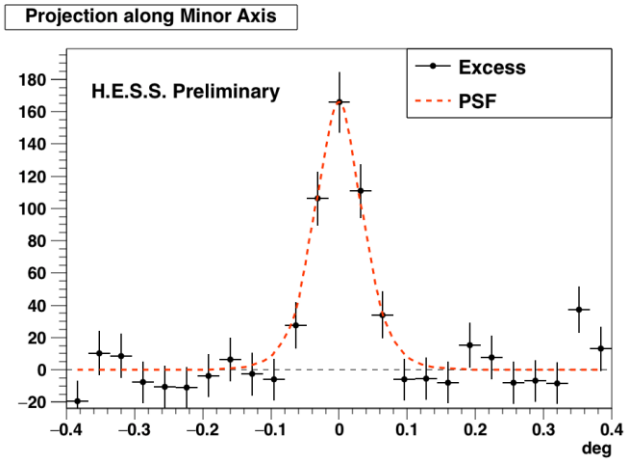


Symm. Gauss vs. Point-Like	Asymm. Gauss vs. Point-Like	Asymm. vs. Symm. Gauss
3.54σ	5.15σ *(5.47σ)*	4.18σ *(5.56σ)*

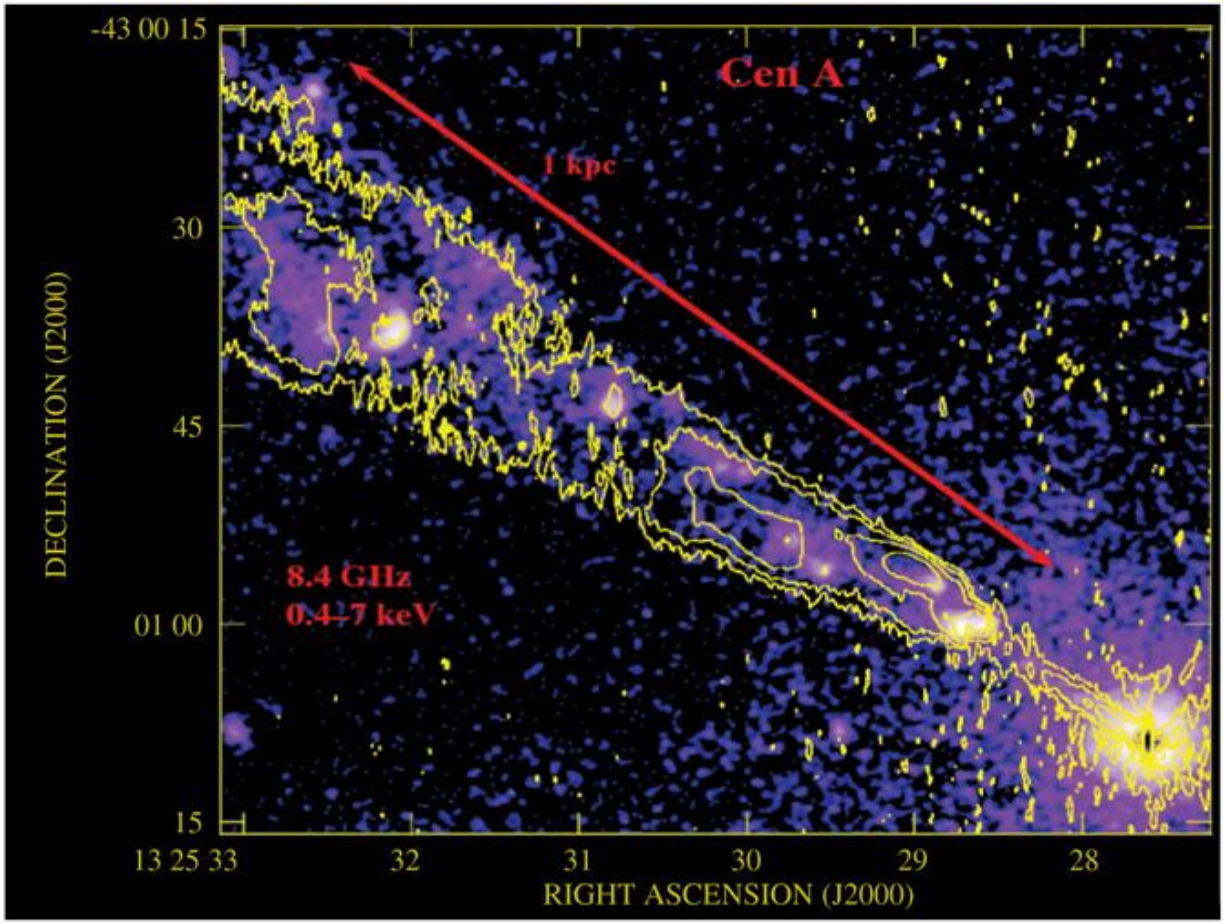
- Confirmed by radial projections







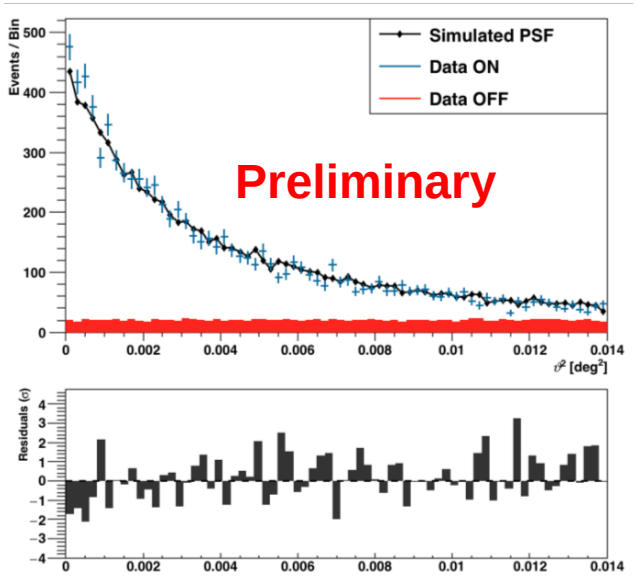
Extended VHE emission along the kpc-scale jet in Cen A?



(Credit: Schwartz 2010, Hardcastle et al. 2003)

- Chandra X-ray image of the first kpc of Cen A's jet.
- VLA radio (8.4 GHz) emission (contours) correlates with X-rays.
- X-rays are continuously emitted throughout jet.
- if X-rays are due to synchrotron, electrons need to be accelerated everywhere (short cooling timescale for $\gamma \sim 10^8$)
- Up scattering of soft photons (dust & starlight)

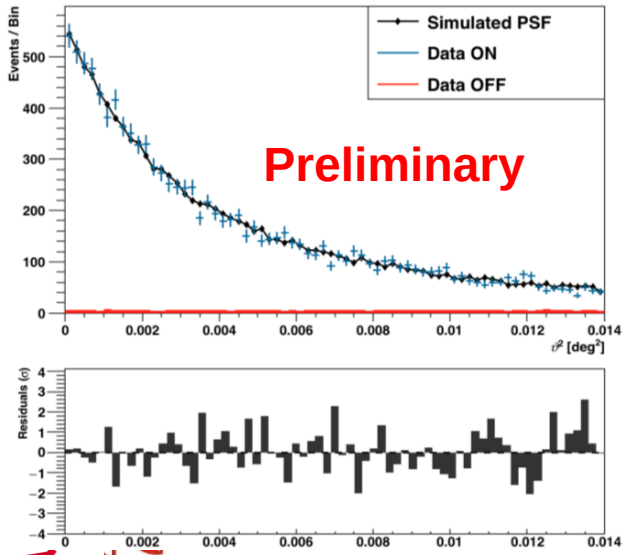
Tests on Point-Like Sources



PKS 2155-304

Detection significance: 125σ
S/B ratio: 6.9
Source appears point-like
Extension upper limits (2D Gaussian width):

- 13.7'' (1σ)
- 23'' (3σ)



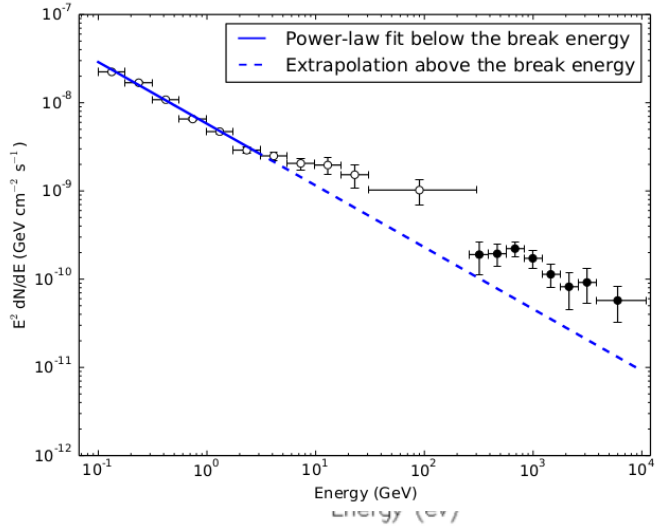
Markarian 421

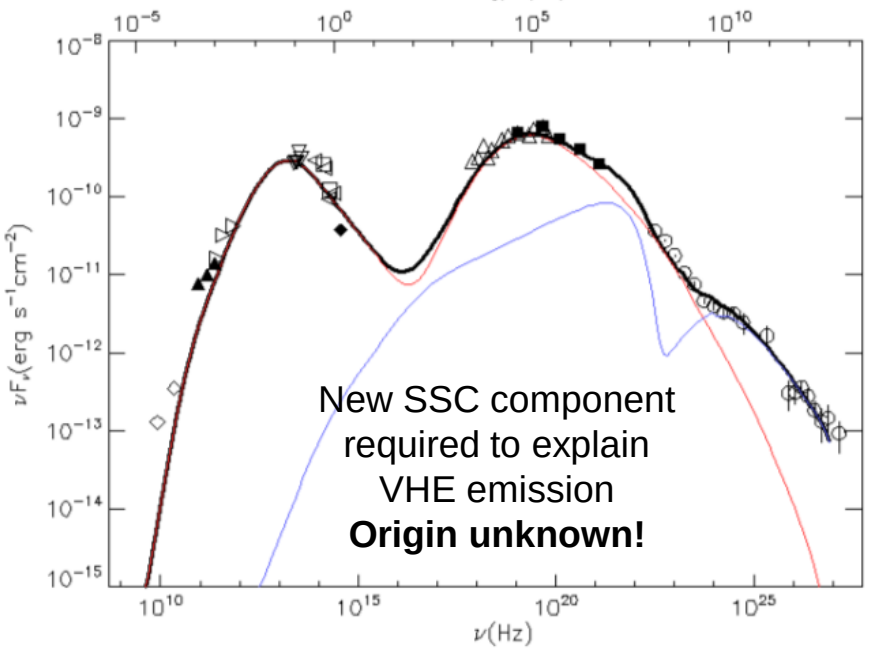
Detection significance: 196σ S/B ratio: 35
No hints of systematics despite extremely large zenith angle
Extension upper limits (2D Gaussian width):

- 23.4'' (1σ)
- 33.5'' (3σ)

Cen A energy spectrum

- Latest study used over **200 hours** of data, combined with Fermi Pass 8 analysis
- Trying to model and understand the full gamma-ray spectrum
- Spectrum begins to harden at a few GeV
- Evidence for a new emission component





Conclusions

- Personal, biased selection of results. Many uncovered topics: AGN flares, FSRQs, Radio Galaxies, Starburst Galaxies, Searches for dark matter, EBL absorption, Lorentz invariance, Spectro-imaging of PWNs, Hadronic signature in SNRs, Superbubles, extreme sources in LMC, ….
- VHE astronomy is experiencing a phase transition: key science projects, requiring deep (>100 h) exposure, population studies
- HESS-II connecting to Fermi-LAT, transient phenomena
- Multi-wavelength, multi-messenger approach becoming of primordial importance.
- Still many new results to come on individual sources
- HESS-I upgrade successful (lower threshold and reduce dead time)
- Extension of HESS operations beyond 2019 currently under discussion (pre-CTA era)