Highlights From H.E.S.S.

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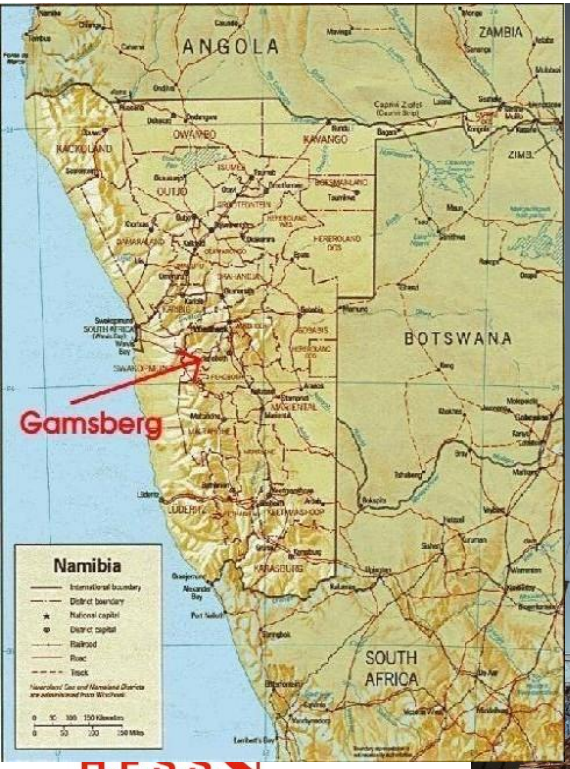
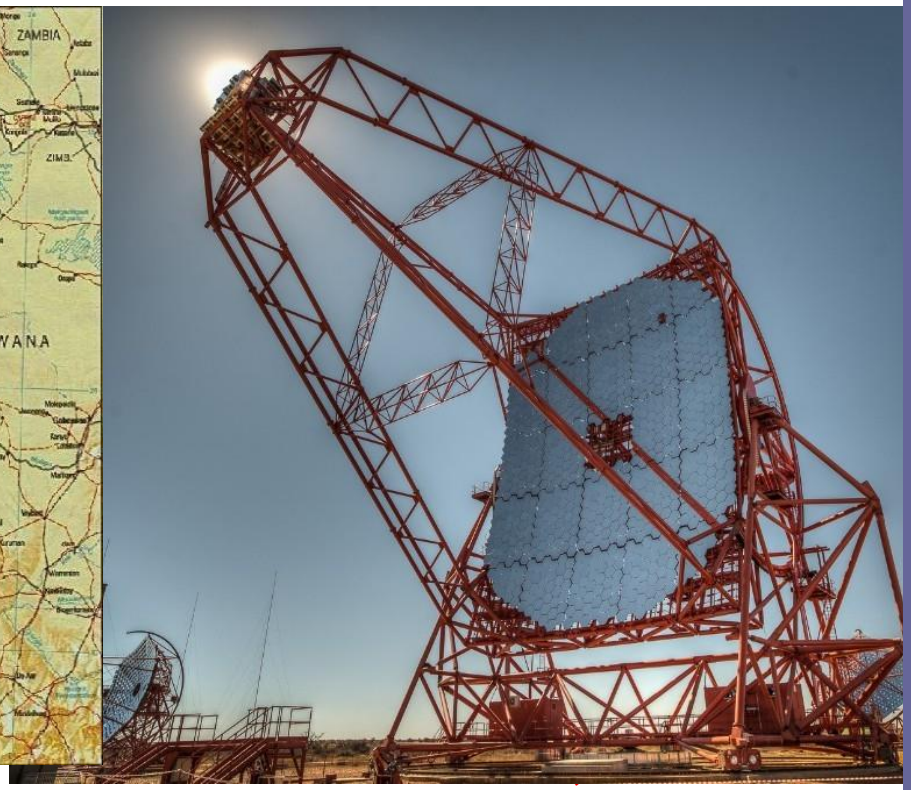
LLR Ecole Polytechnique

H.E.S.S.

High Energy Stereoscopic System

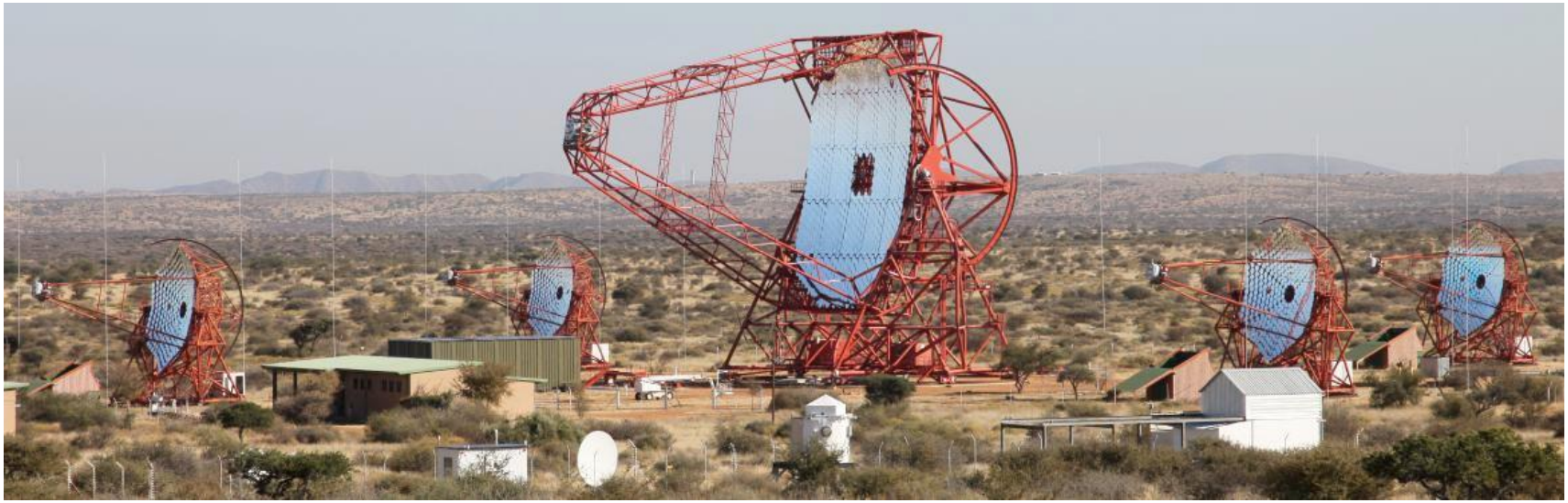
- International consortium 14 countries, ~200 physicists
- Site: 23°16" S, 16°30" E, 1800 m asl, 100 km from Windhoek (Namibia)
  - Good sky transparency, medium altitude & dry weather conditions
  - Southern hemisphere, direct view on the galactic center





MPI Kernphysik, Heidelberg
Humboldt Univ. Berlin
Ruhr-Univ. Bochum
Univ. Hamburg
Landessternwarte Heidelberg
Ecole Polytechnique, Palaiseau
APC Paris
LPNHE Univ. Paris VI-VII
CEA Saclay
CESR Toulouse
LPTA Montpellier
LAOG Grenoble
LAPP Anecy
CENBG Bordeaux
Observatoire de Paris
Dublin Inst. for Adv. Studies
Charles Univ., Prag
Yerewan Physics Inst.
North-West Univ., Potchefstroom
Univ. of Namibia, Windhoek
DESY, Zeuthen
Linne University, Sweden
Leicester University, UK

H.E.S.S.-II



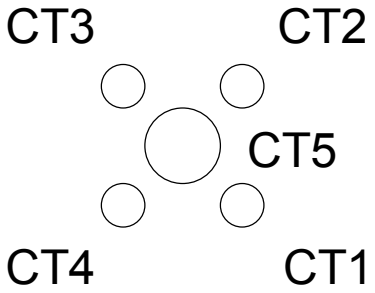
- H.E.S.S. phase 1 (09-2002):
  - 4 telescopes: Ø 12 m,107 m^2
  - Stereoscopic reconstruction
  - 960 PMTs/camera, Field of view : 5°
  - Observations : ~1000h/year
  - Source position : ~ 10”

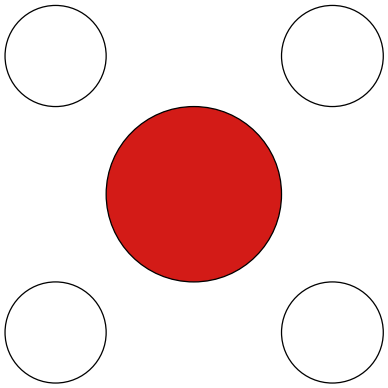
- H.E.S.S. phase 2 (09-2012):
  - a 5th telescope, Ø 28 m, 600 m^2 (largest IACT in the world)
  - 2048 PMTs, Field of view : 3.5°

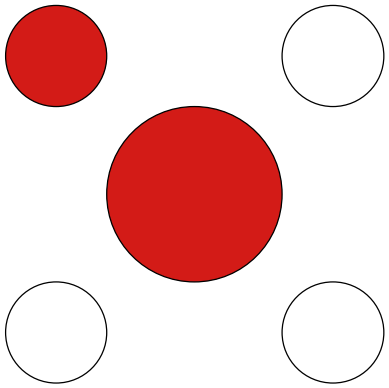
→ Energy threshold (zenith) ~ 30 GeV

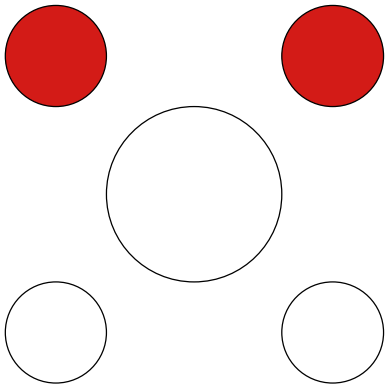
Hybrid Array - Trigger

Only Hybrid Array









CT5 mono
65%

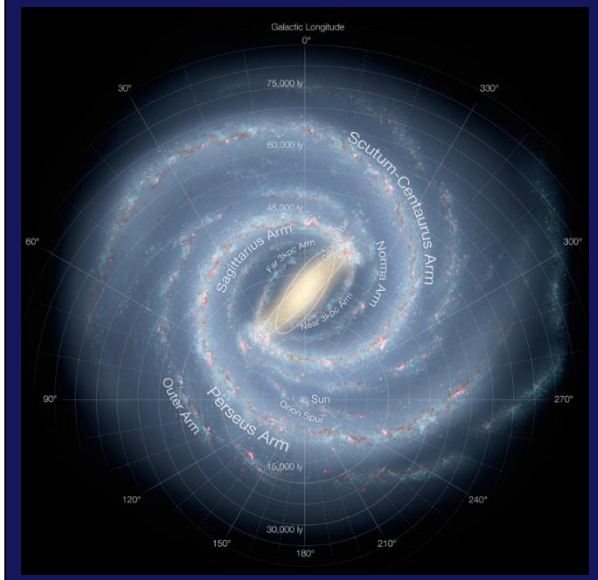
CT5 + ≥ 1 CT1-4
30%

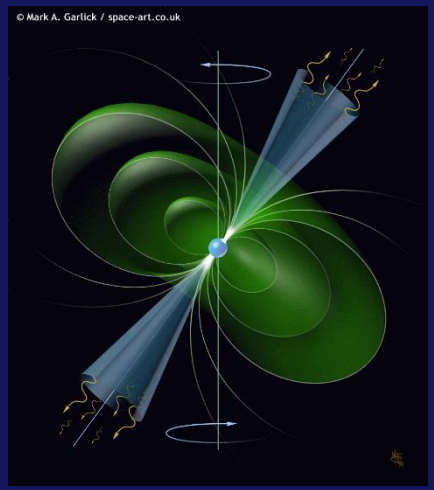
≥ 2 CT1-4
5%

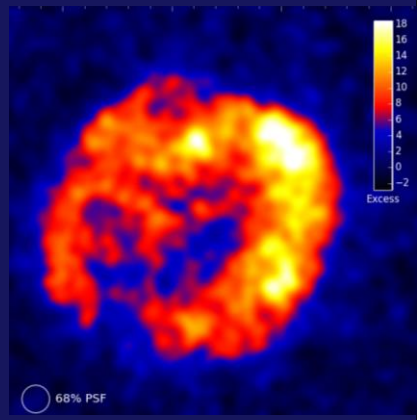
Systematics limited

Statistics limited

Galactic Science



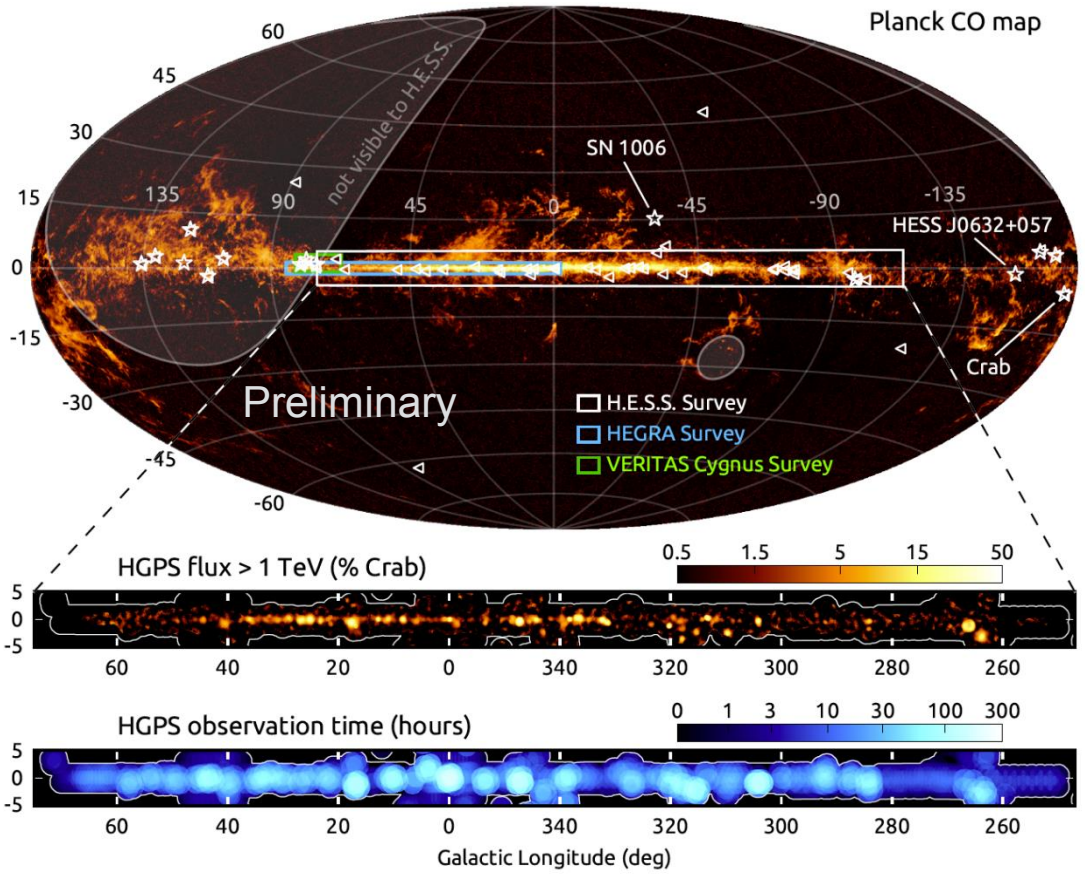




H.E.S.S.-I Legacy Survey

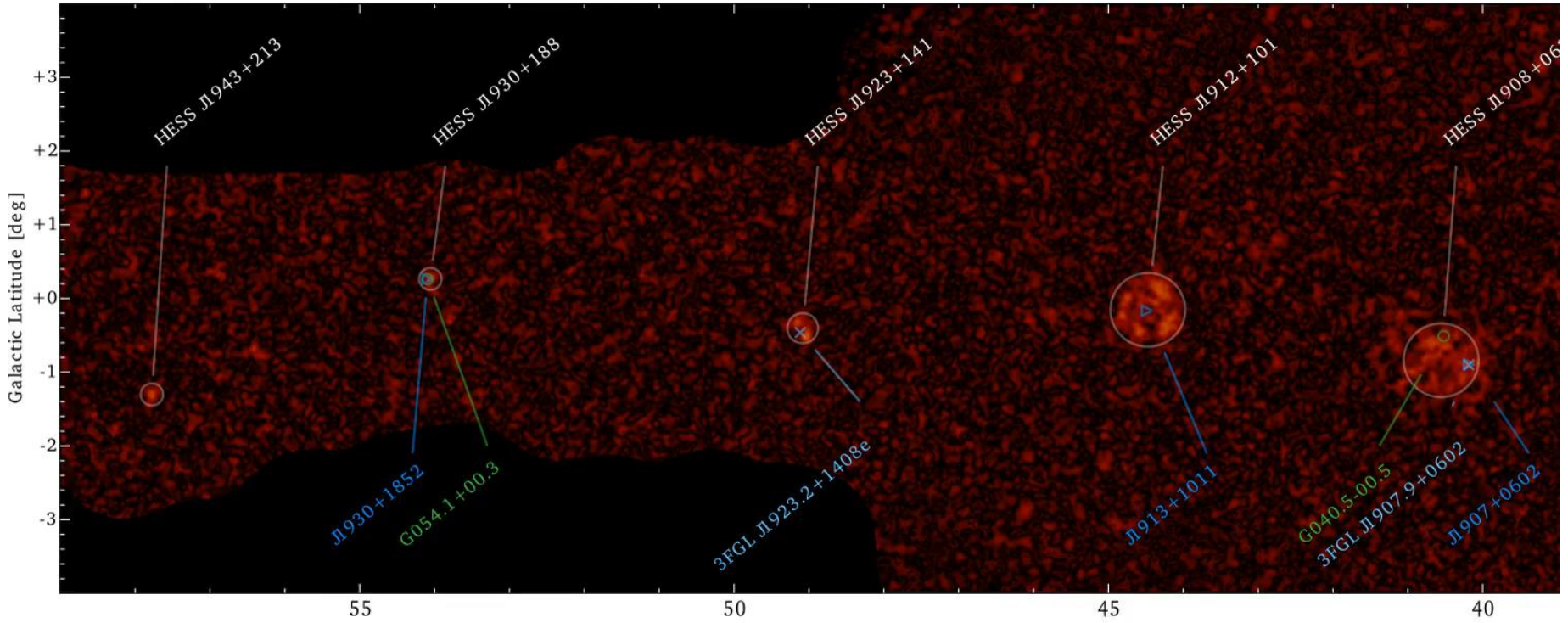
- Major H.E.S.S. project
- Data collected 2004 – 2013
  - 2673 h after quality selection
  - l in [-110°, 70°]
  - b in [-5°, 5°]
  - Inhomogeneous exposure (sources of particular interest)

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

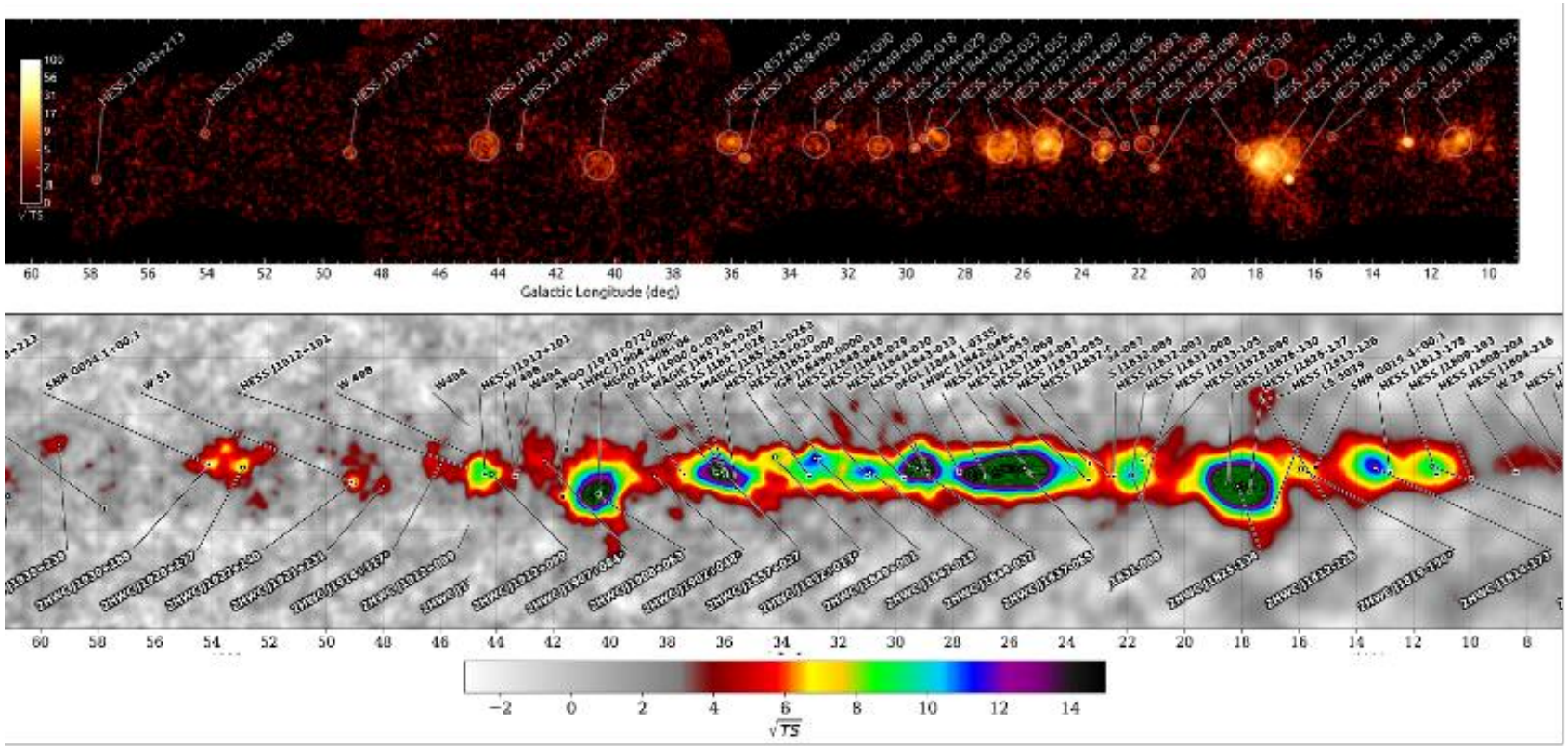


H.E.S.S. Collaboration (**A&A Special Issue**, in prep.)

Sky maps with associations

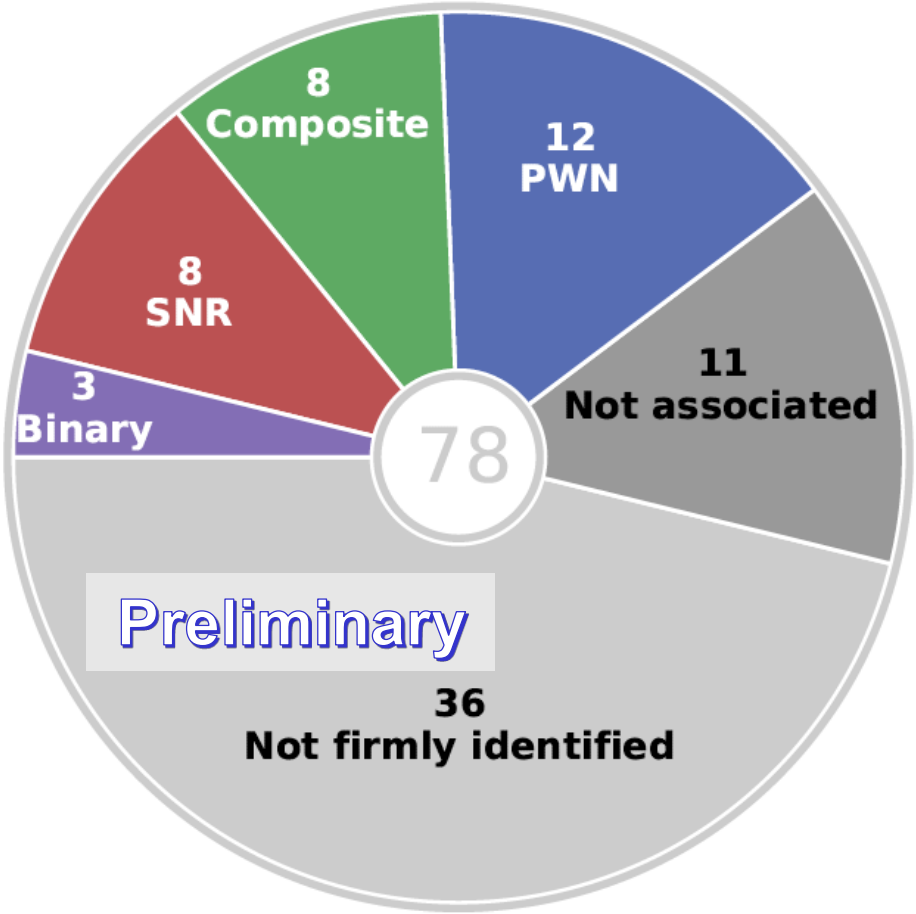


HAWC & H.E.S.S. Galactic Plane Surveys

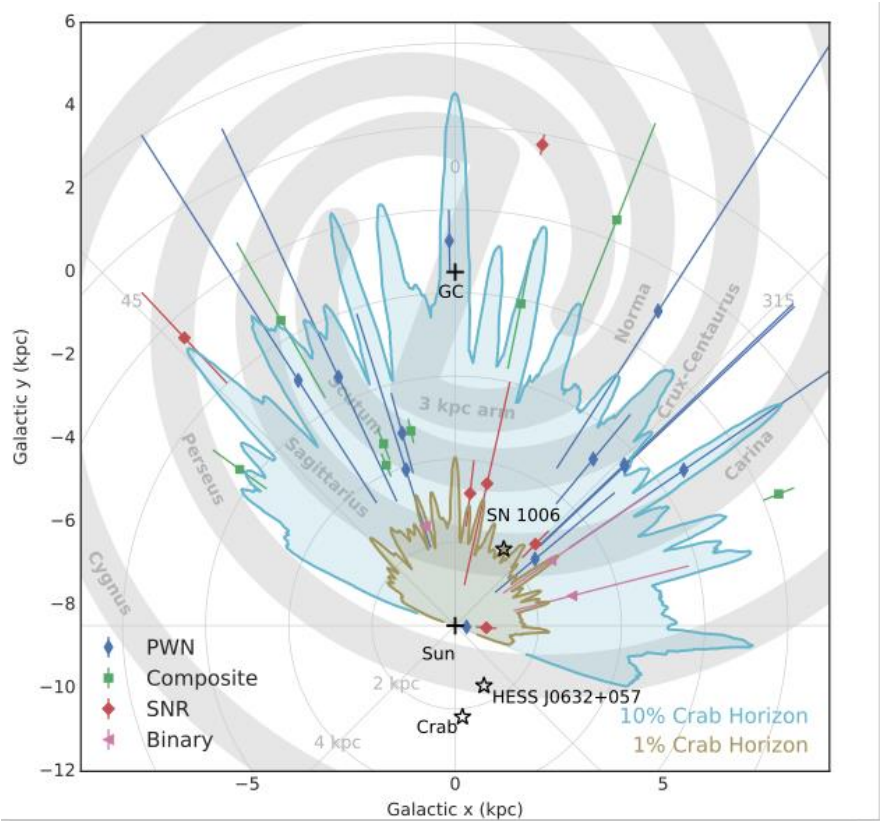


- 15 HAWC sources associated with H.E.S.S. sources
- 7 HAWC sources undetected by IACTs
  - lack of sensitivity to very extended sources?
  - energy-threshold effects?

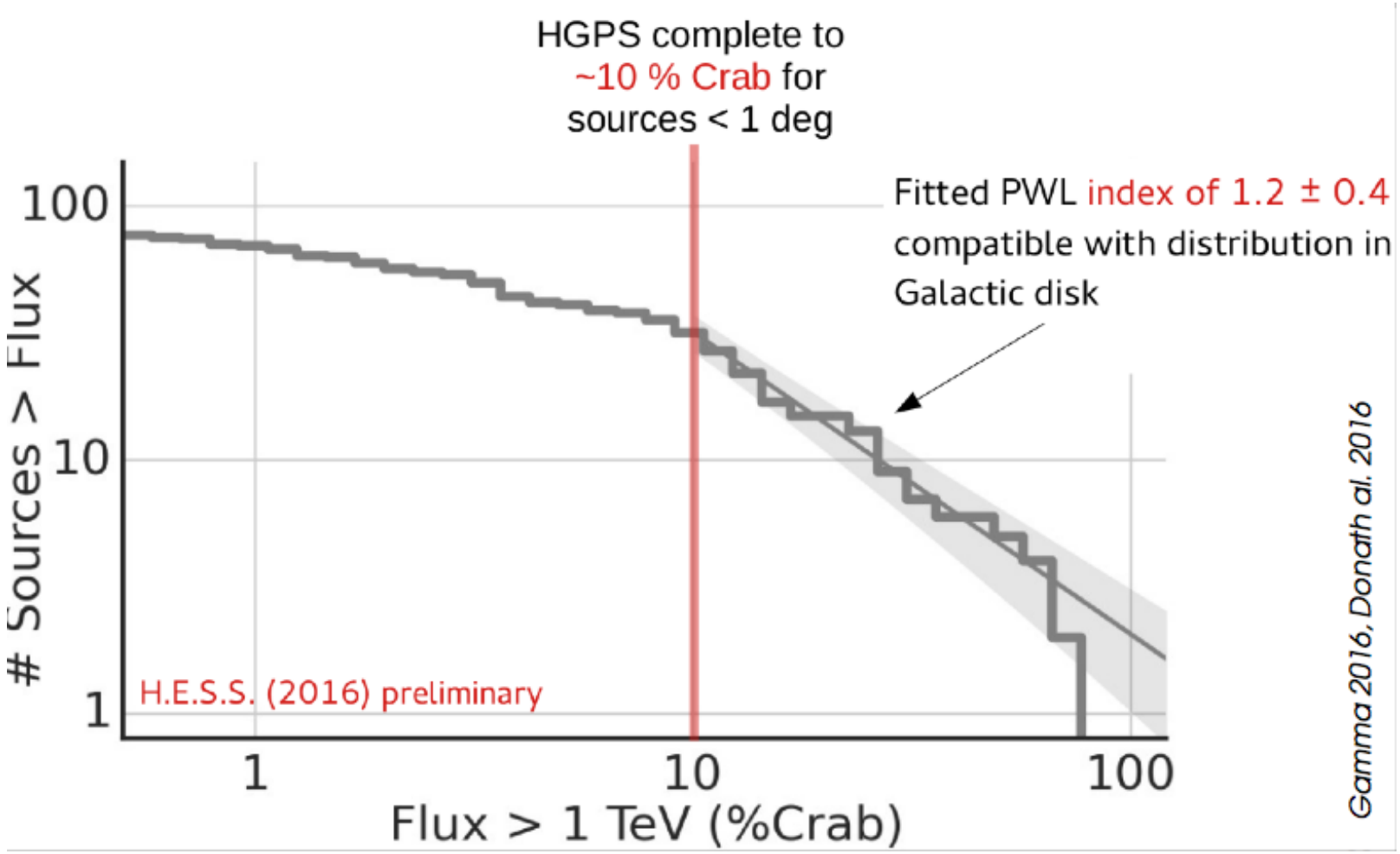
Association and Identification



Horizon



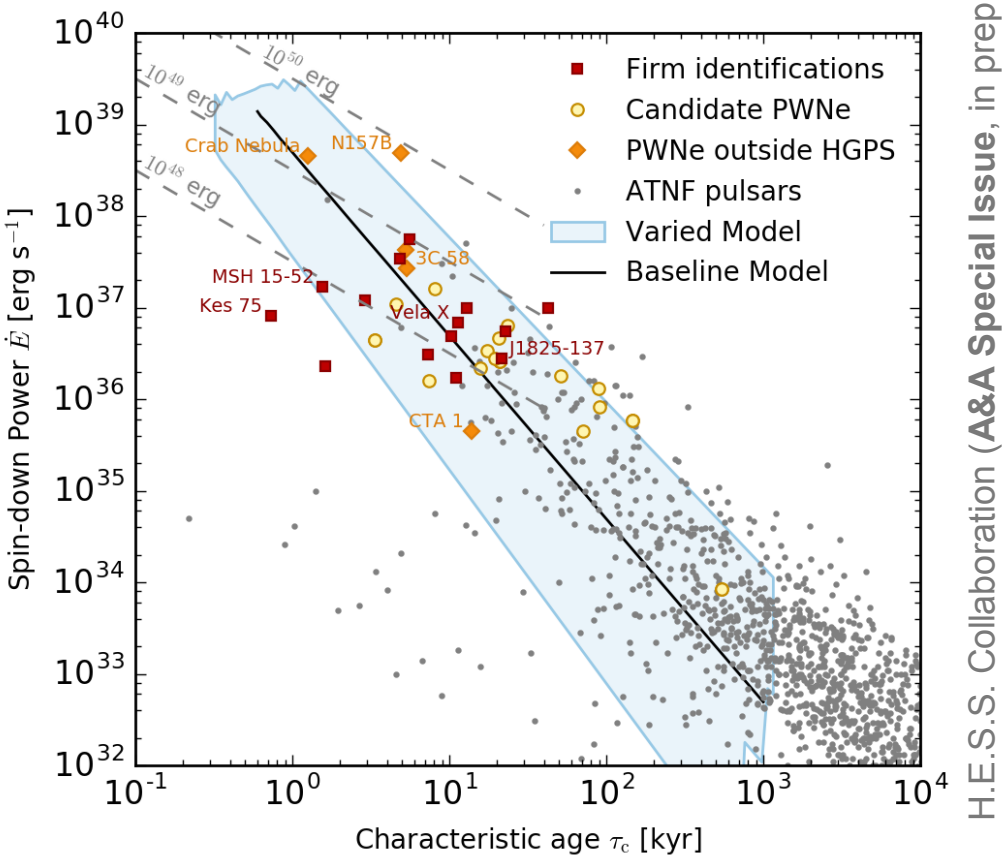
Survey Completeness – "LogN-LogS"



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 $\dot{E} > 10^{36}\ \mathrm{erg.s^{-1}}$

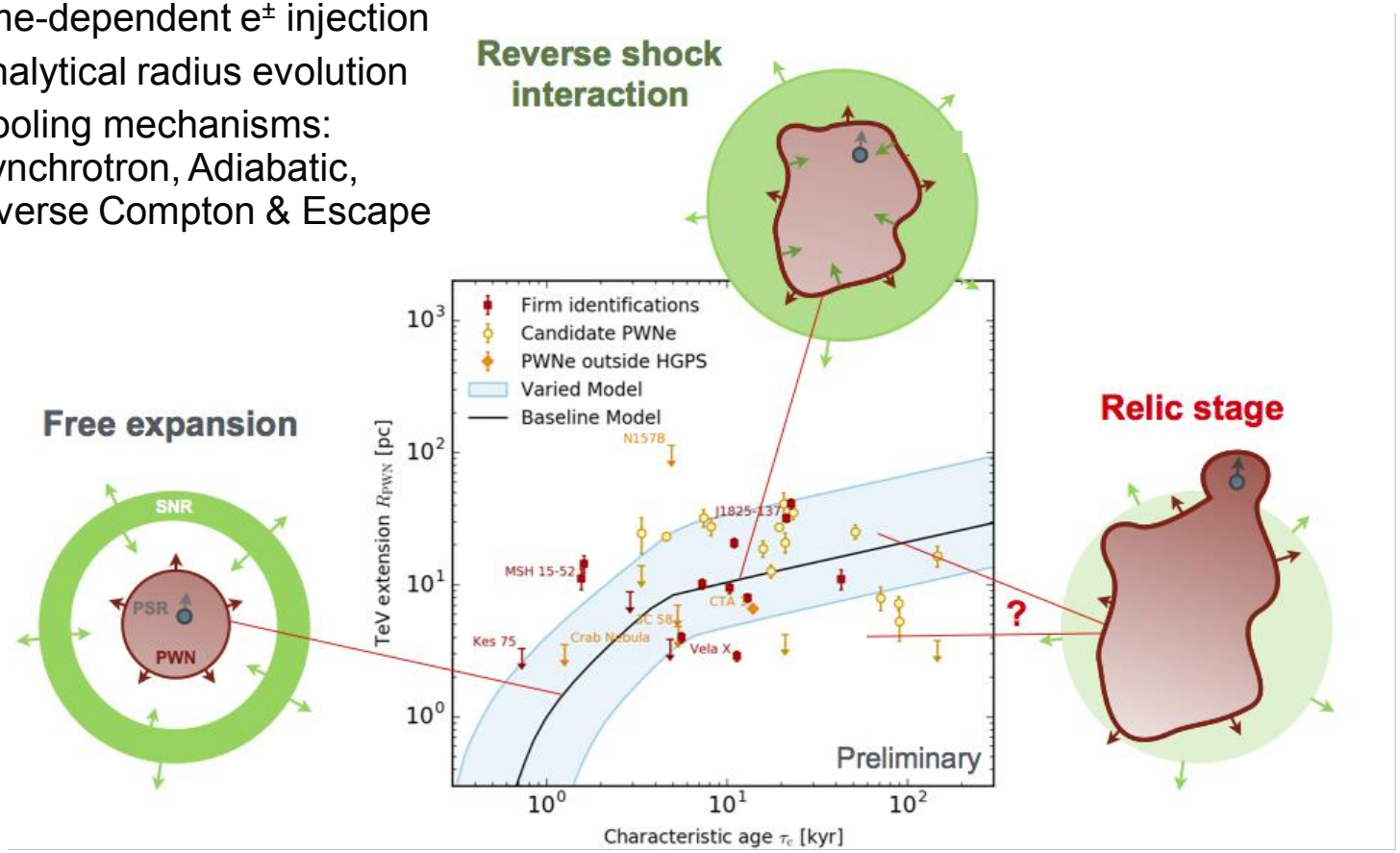
$$\dot{E}(t) = \frac{\dot{E}_0}{\left(1 + \frac{t}{\tau_0}\right)^2}$$



H.E.S.S. Collaboration (**A&A Special Issue**, in prep.) arXiv: 1702.08280

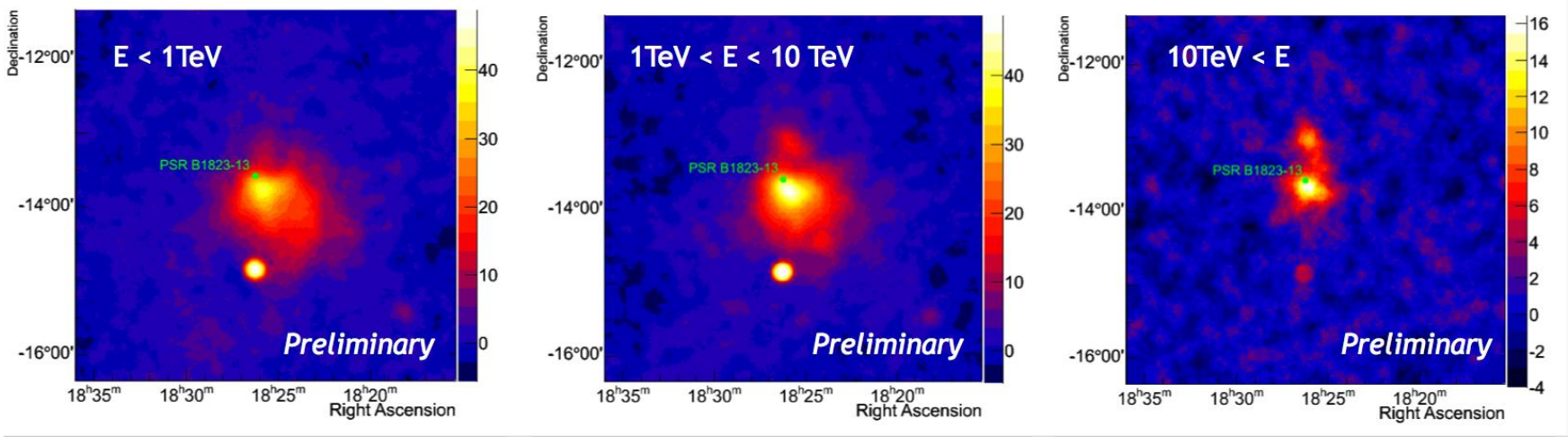
Pulsar Wind Nebulae

- Observable consistent with simple evolution model:
  - time-dependent $e^{\pm}$ injection
  - Analytical radius evolution
  - Cooling mechanisms: Synchrotron, Adiabatic, Inverse Compton & Escape

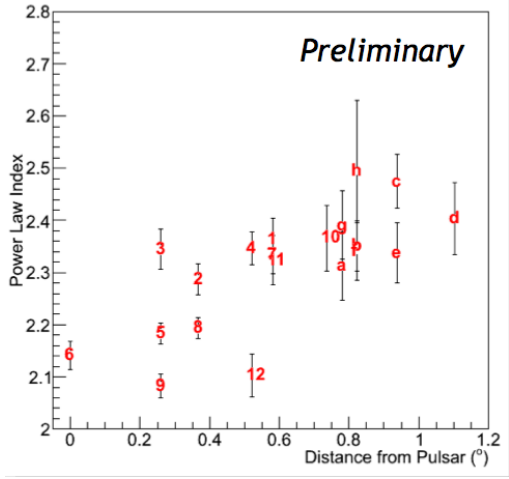


H.E.S.S. Collaboration (**A&A Special Issue**, in prep.)

Electron Cooling in PWN – H.E.S.S. J1825-137

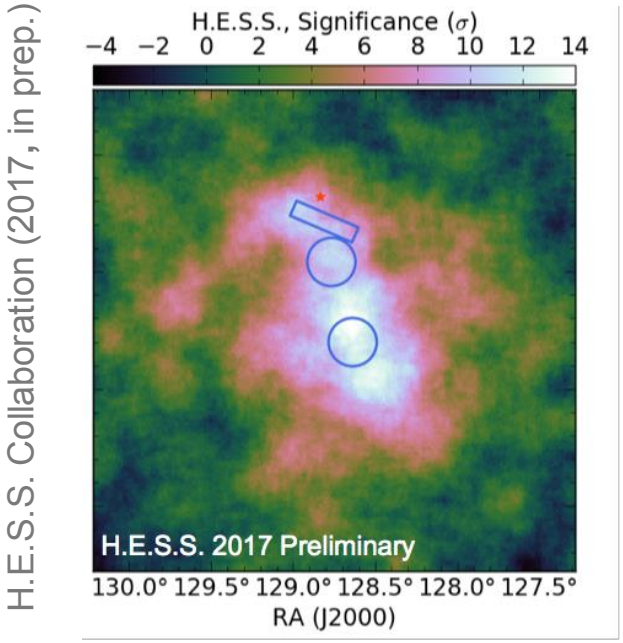


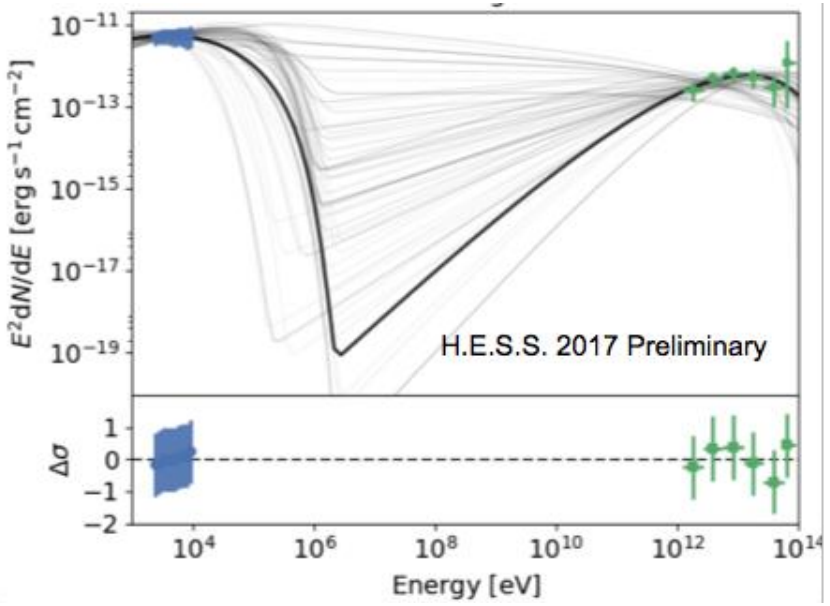
- most extended PWN, ~> 1° from pulsar: (or 70 pc) !
- spatially-resolved analysis showing a steepening of the index with distance: electron loses & diffusion properties
- inner regions spectrum extending to E >~ 50 TeV



ICRC 2017

Constraining parent population in PWN – Vela X





- Joint Suzaku (3-pointings)+H.E.S.S. study centered on Vela X cocoon
- Constrain electron population properties with unprecedented accuracy (bright source, high statistics, peak of IC fully covered by the H.E.S.S. energy-range)
- Allow also for strong constrains on any possible magnetic field turbulence on the studied regions of the cocoon (changes shape of synchrotron spectrum)

ICRC 2017

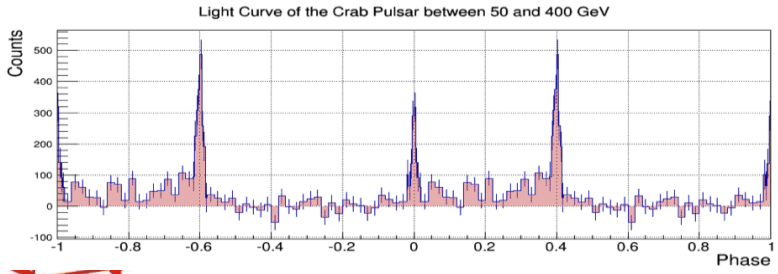
VHE emission from Pulsars...

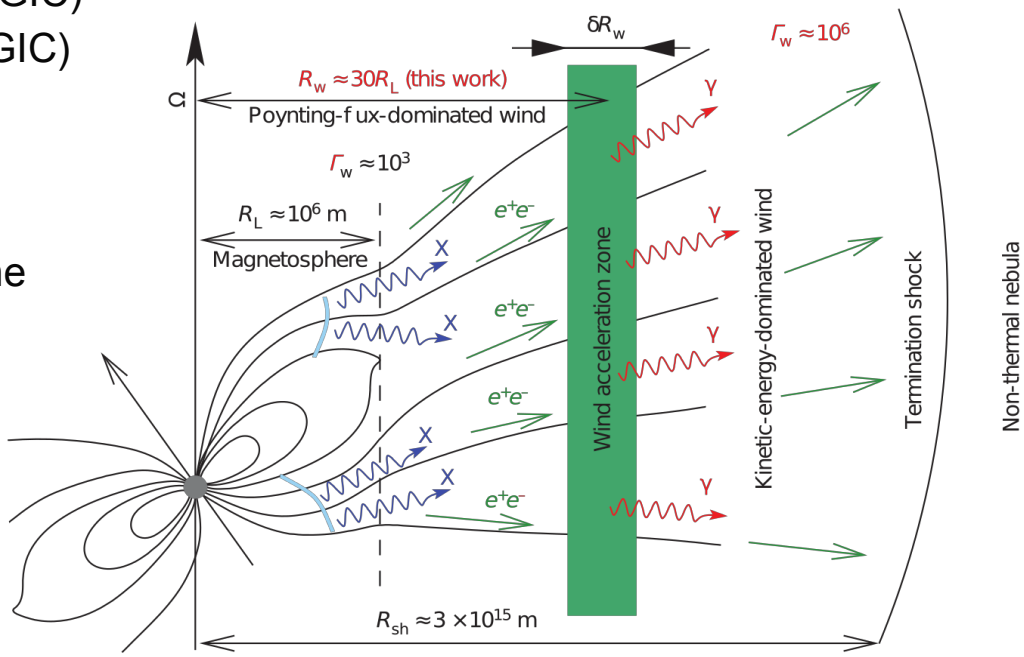
VHE History of Crab Pulsar:

- 2008: First detection of emission above 25 GeV from a pulsar (MAGIC)
- 2011: First detection of emission above 120-250 GeV (VERITAS)
- 2011: First spectrum 25-100 GeV (MAGIC)
- 2012: First spectrum 50-400 GeV (MAGIC)
- 2014: Bridge Emission ≥ 50 GeV (MAGIC)
- 2015: Pulsed Emission from 10 GeV to > 1 TeV (MAGIC)

Challenges for pulsar models

- emission from the neighbourhood of the Light Cylinder (r ~1600km)
- Likely IC emission
- Most compact accelerator so far

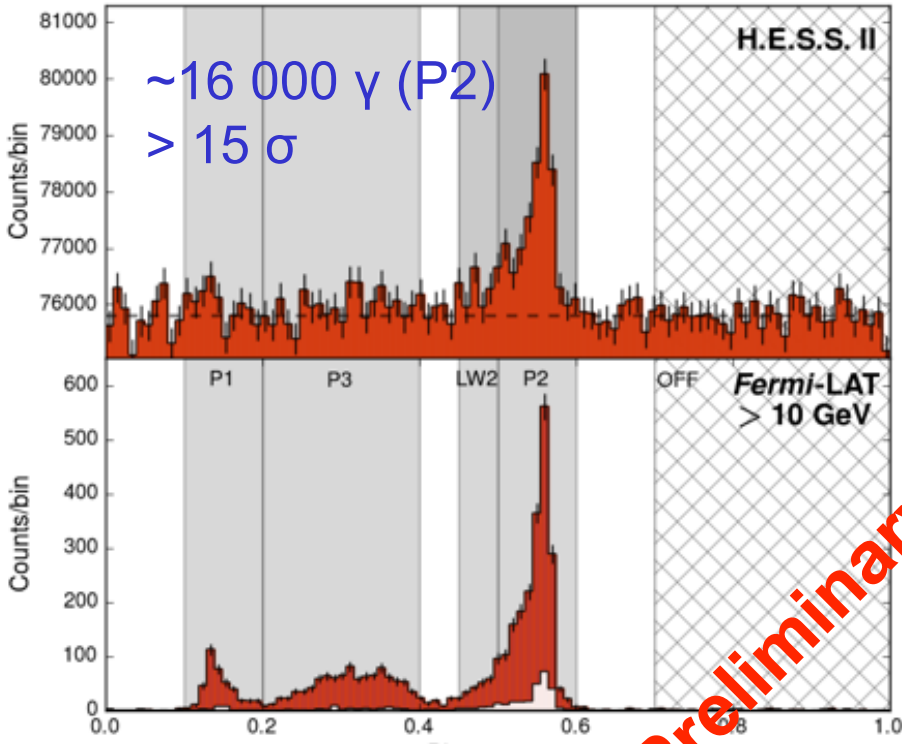




Vela Pulsar

Second VHE pulsar

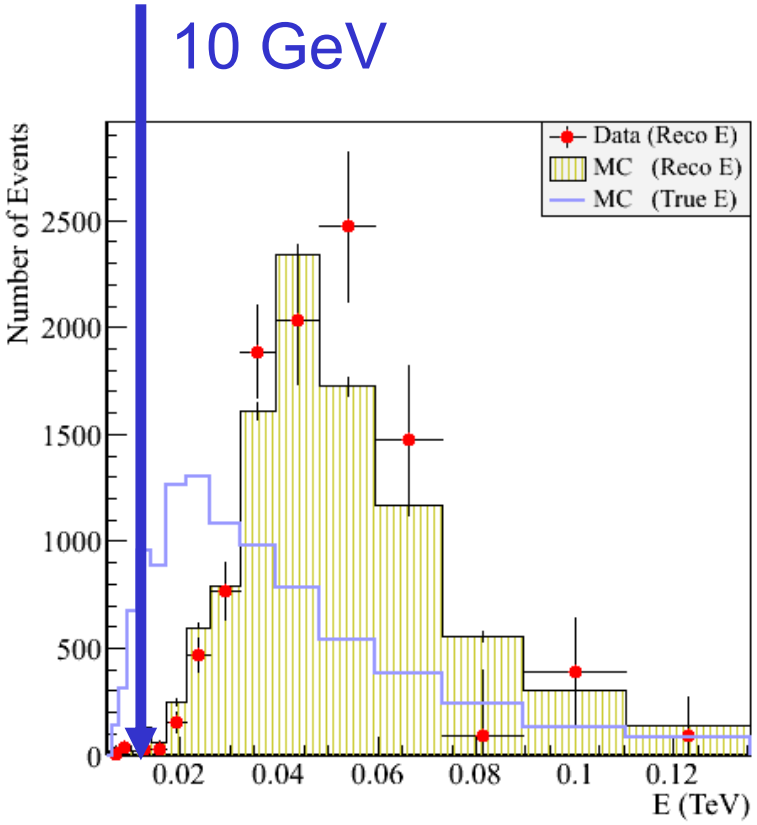
- Second VHE pulsar (H.E.S.S.)
  - Calibration source at the threshold in standard observation mode
  - Deep observation campaign needed to investigate maximum energy and variation of pulse profile with energy
  - Very different regime than Fermi-LAT: huge statistics over a huge background

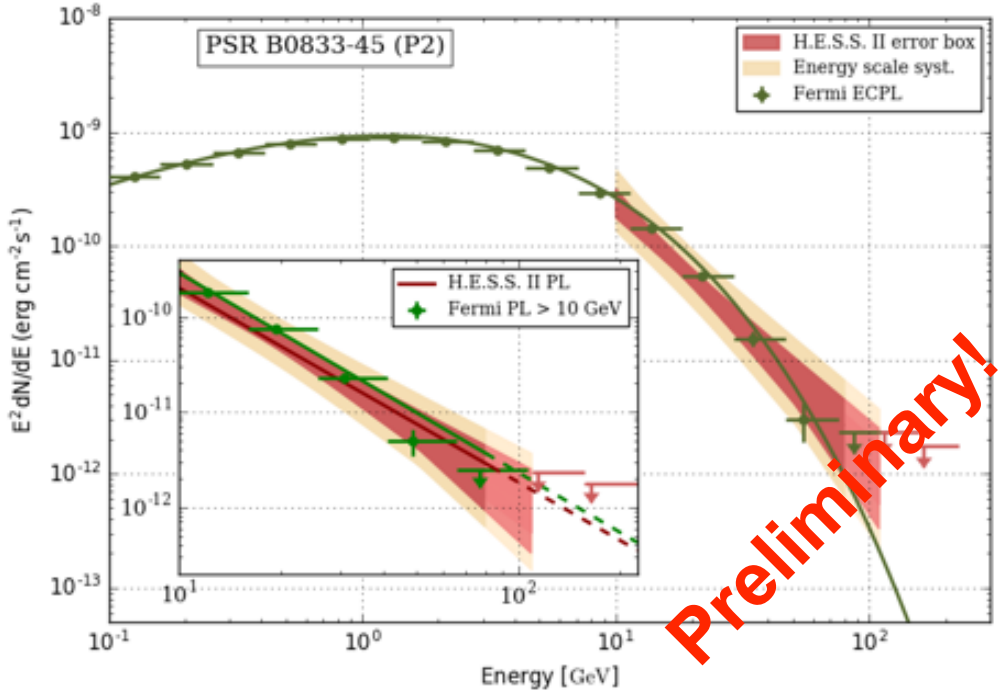


Preliminary!

Vela Pulsar – Benchmark of analysis

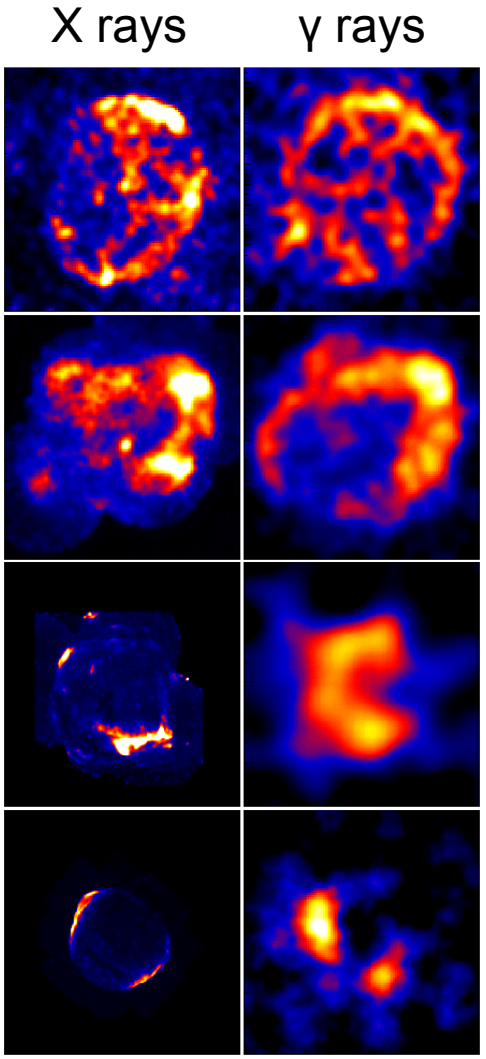
- CT5 able to operate down to 10 GeV
- Excellent agreement with Fermi-LAT: cross-calibration check for CT5
- Is there an hard component? → Deep exposure needed





Population Studies II – Supernova Remnants

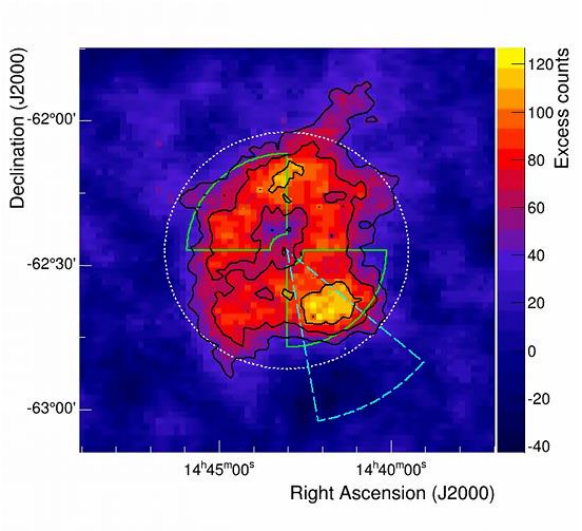
- Second population of VHE sources in Galaxy
- Young, historical supernova, in different evolution stages
  - High quality images, MWL data
- Olders SNRs proven to accelerate protons
  - In interaction with molecular clouds (W28)
  - π^0 bump in Fermi LAT (IC 433, W49A, W51C, W44 …)
- High energy can 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

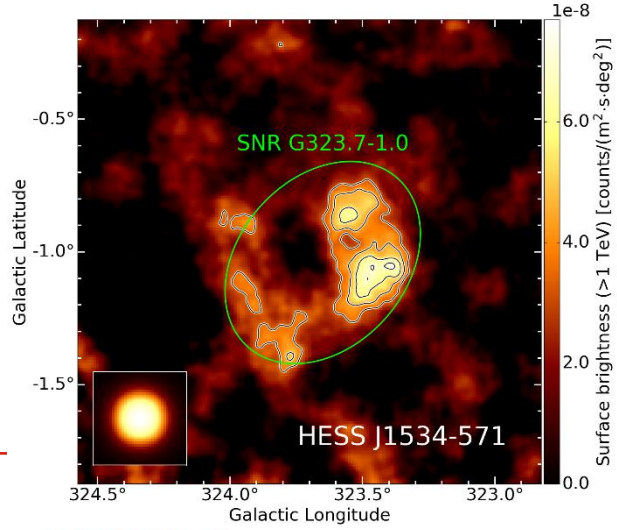


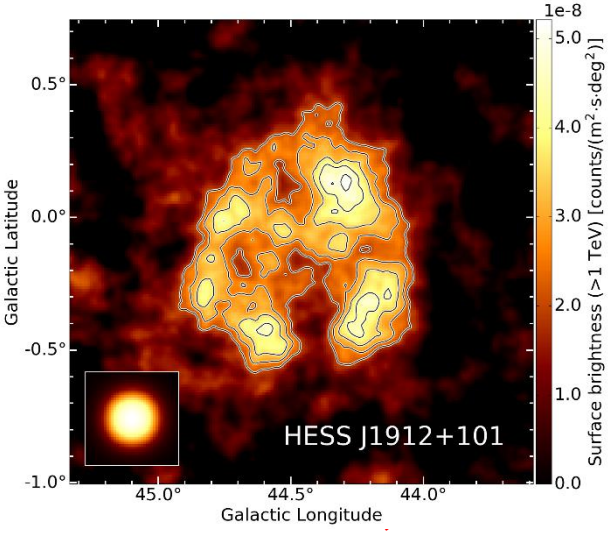
New TeV Shell-type SNRs

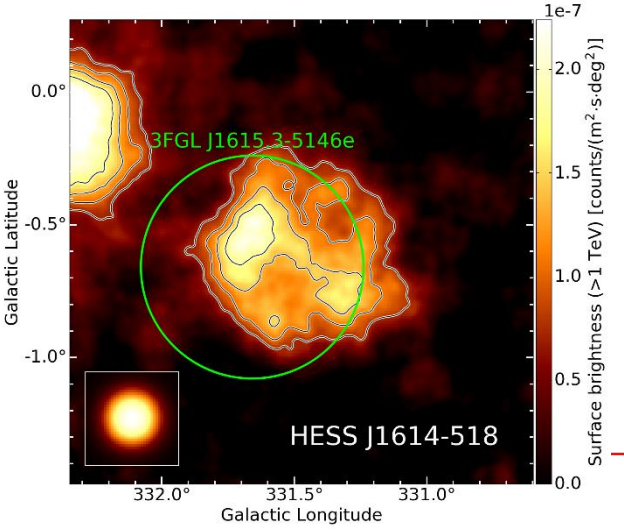
Increasing sample

- 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





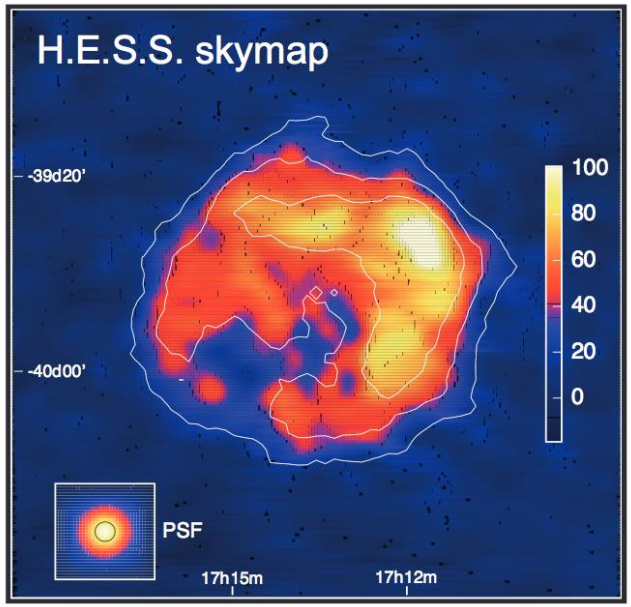


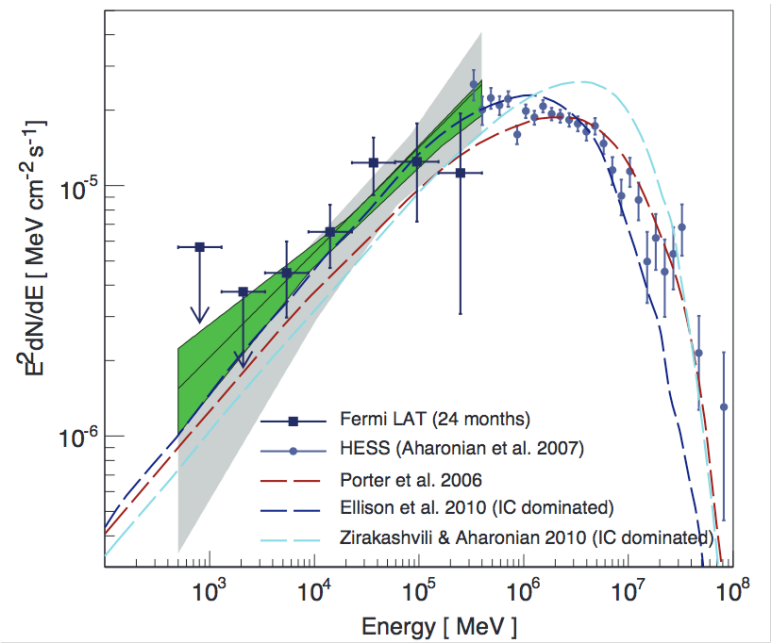


RXJ 1713-3946

- Young (~1.5 kyr) and nearby (1.3 kpc) SNR, First, and brightest resolved TeV shell

H.E.S.S. Collaboration (2006)



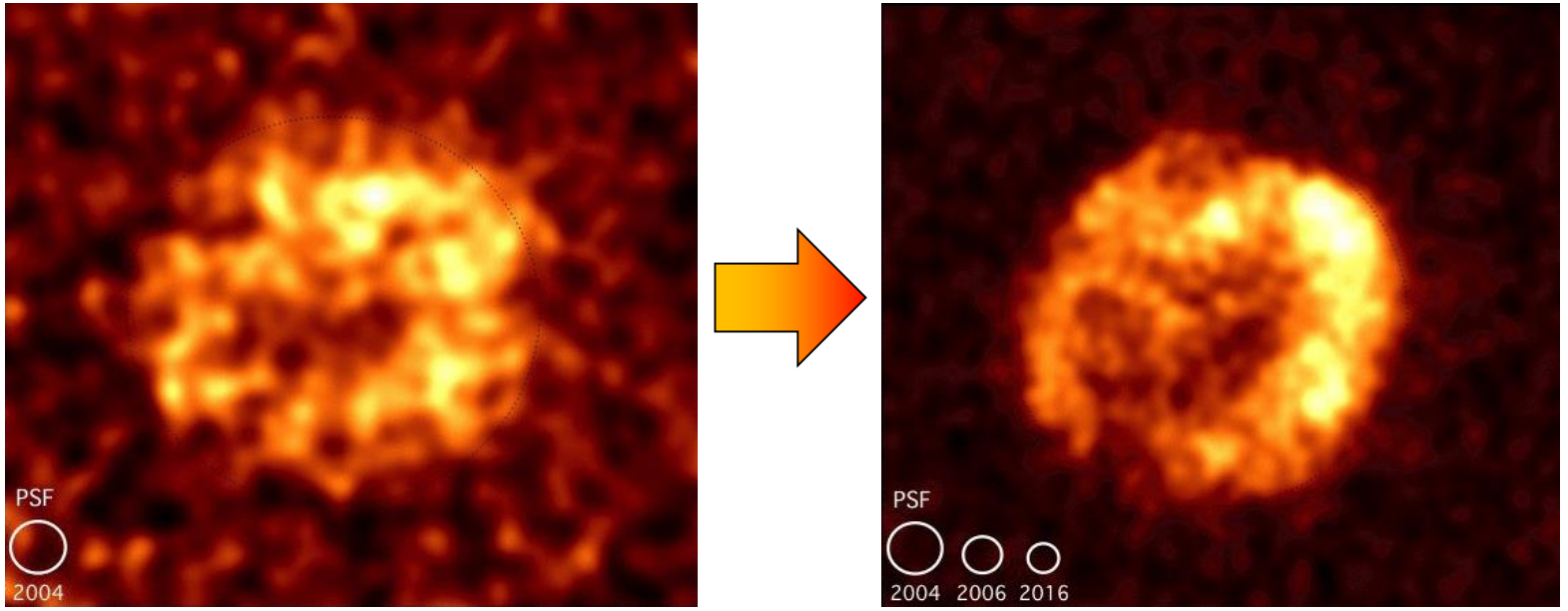


Fermi-LAT Collaboration (2011)

- still, many questions remain…
  - spectral cut-off shape? → electrons vs. protons
  - spatially-resolved spectra w/ unprecedented resolution → resolve physical properties
  - morphology & radial profiles + comparison to X-rays → particle diffusion + escape?

RXJ 1713-3946 – DataSet & Analysis improvements

- 10 years of H.E.S.S. data, improved analysis techniques

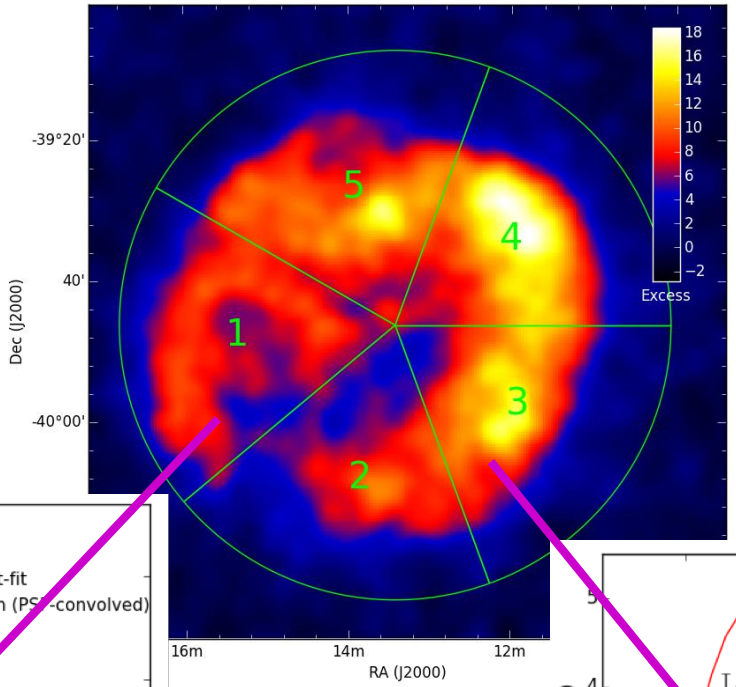


- Factor 2 improvement in statistics (> 27 000 γ)
- Spectrum up to ~50 TeV: cuts off ~ 15 TeV
- Spatially resolved spectra!

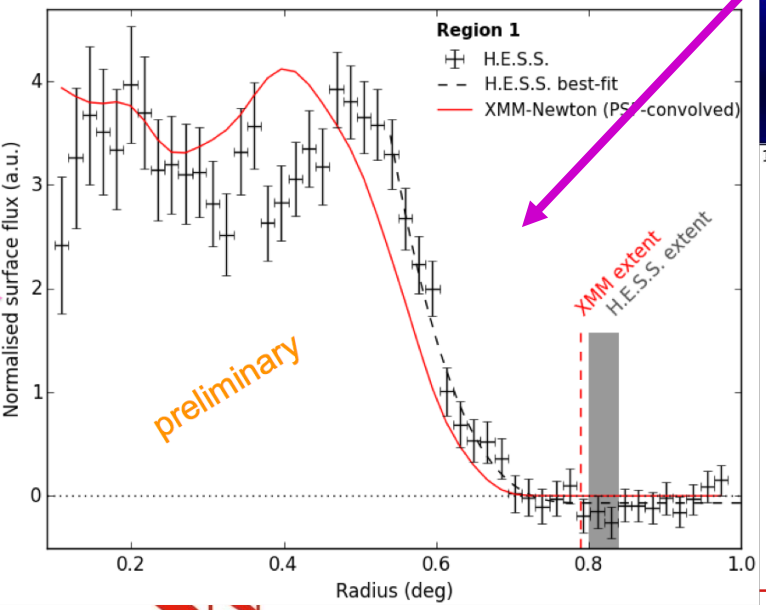
Not a pevatron

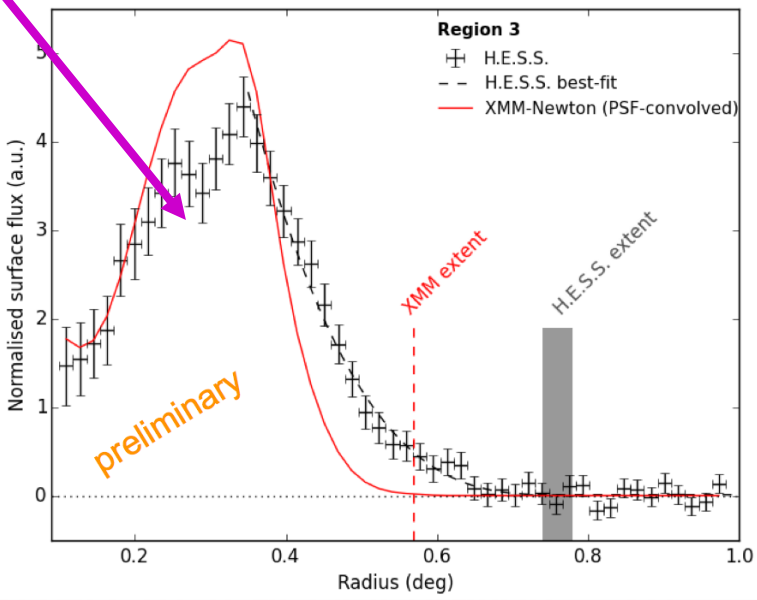
H.E.S.S. Collaboration (**A&A Special Issue**, in prep.)
arXiv: 1609.08671

Particle escape

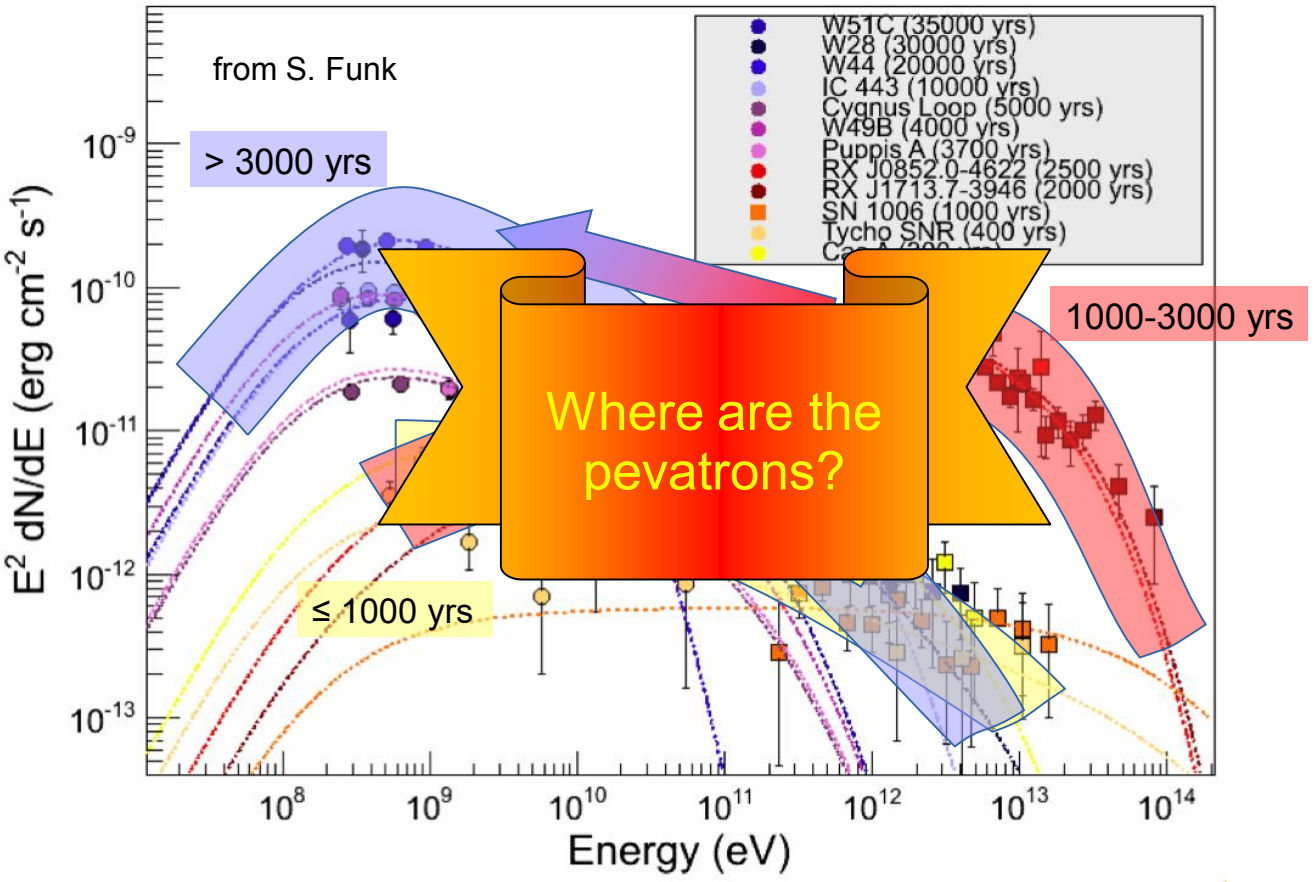


Particle escape?



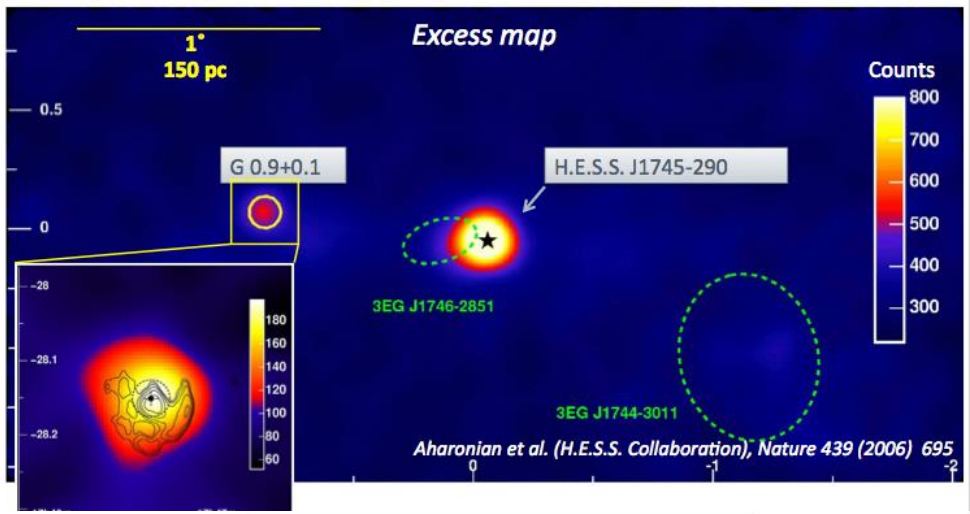


Large sample → evolution of supernova remnants

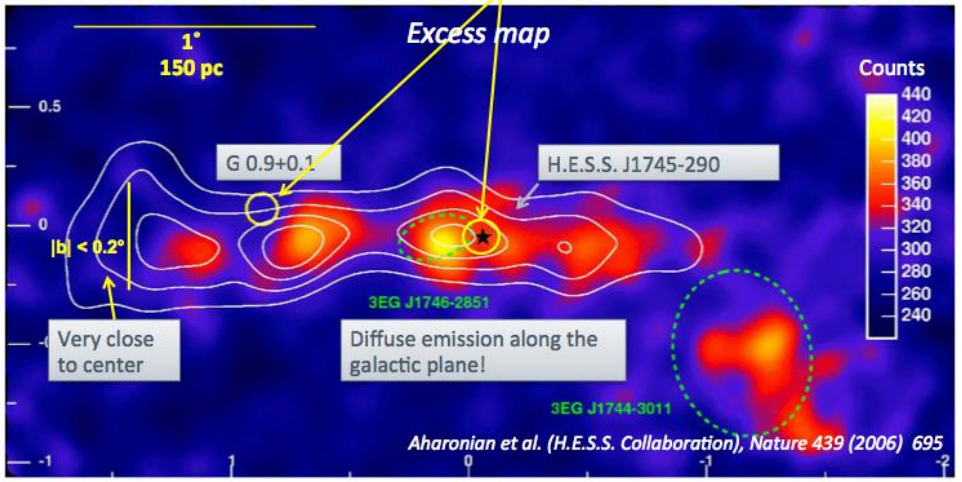


The Galactic Centre region – early results

- 2 point-like sources:
  - HESS J1745-290: unidentified (candidates: SMBH SgrA*, PWN G359.95-0.04)
  - G0.9+0.1: SNR/PWN association
- extended diffuse emission along the galactic plane
  - associated with giant molecular clouds (CS maps as tracers) → hadronic interaction
  - CR energy density higher than the local CR density by an order of magnitude
  - Lack of TeV emission at b>1.0° → CR gradient necessary to explain TeV emission

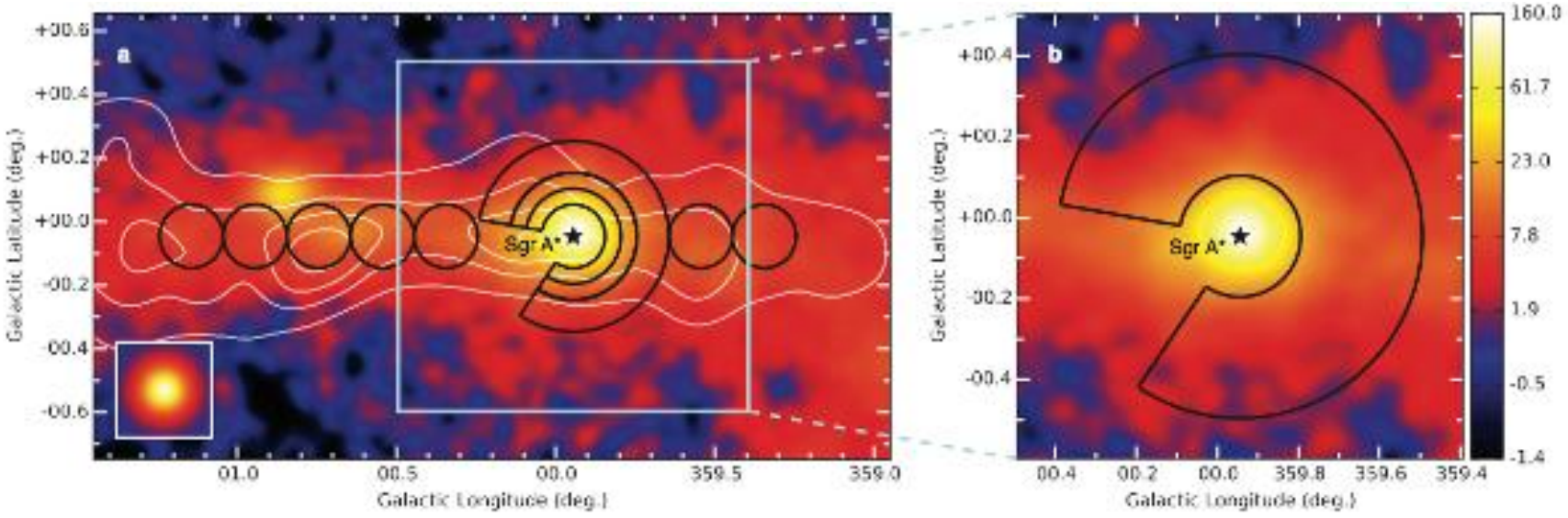


- Search for much fainter emission
- Subtraction of the two bright sources
- Correlation of emission with molecular clouds



The Galactic Centre region – 10 years after

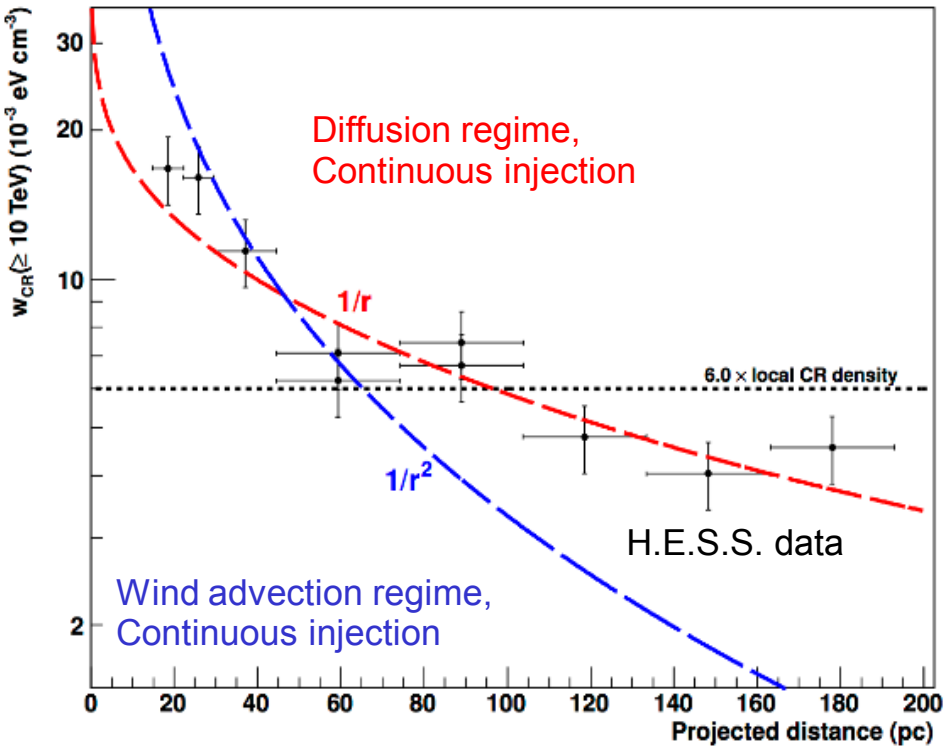
- Full dataset analyzed: 2004-2012 => 220h obs. time (175h acc. corrected)
- Point like source > 100 σ, central source on top of extended (ridge) emission
- Origin of diffuse emission:
  - Interaction of CR (from central BH) with interstellar medium
  - CR acceleration in CMZ (and in particular star forming regions)
  - …



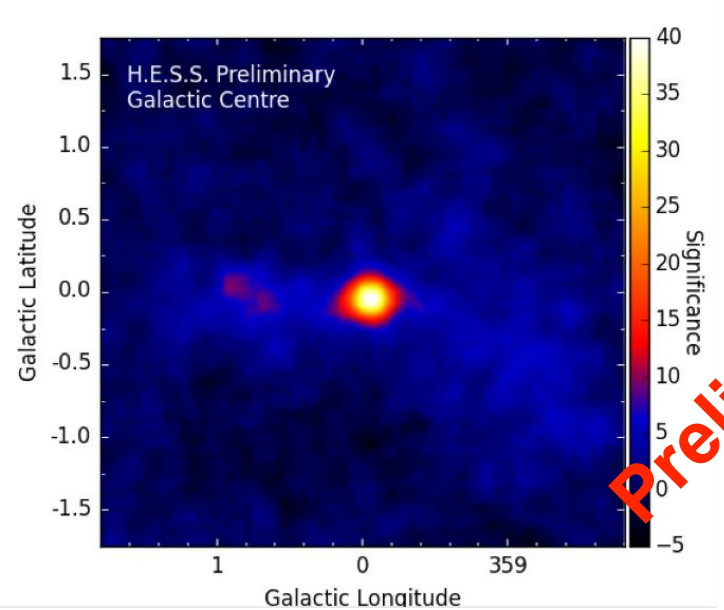
Galactic Centre as Pevatron

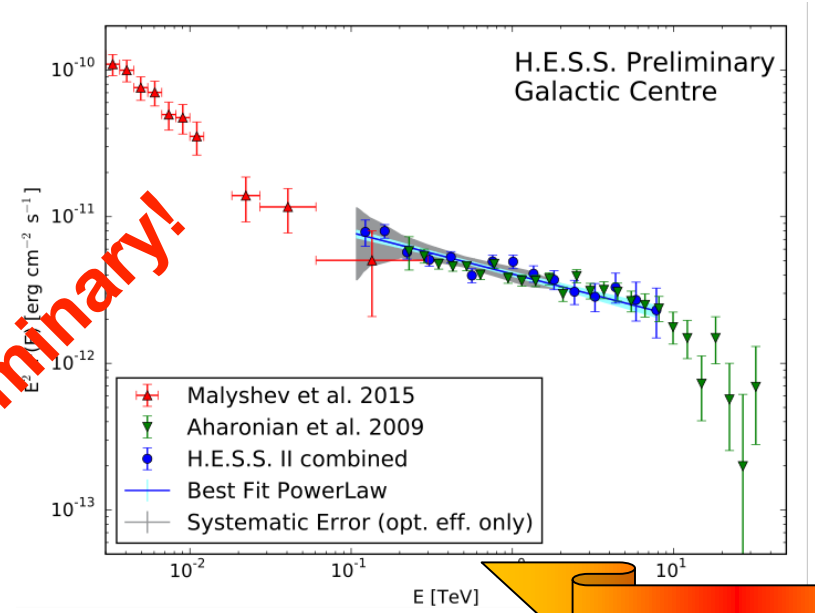
First Pevatron

- Central source: cut-off @ 10 TeV
- Diffuse emission shows no cut-off well > 10 TeV
- Emission profile consistent with propagation of 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



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





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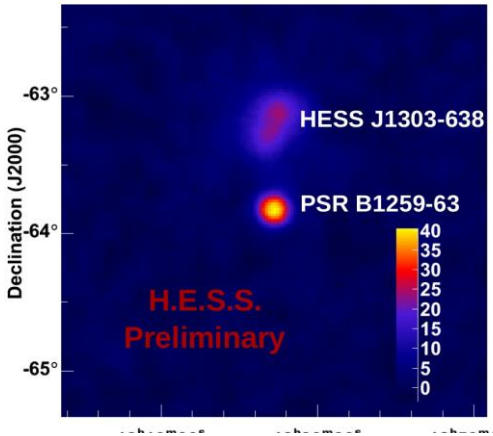
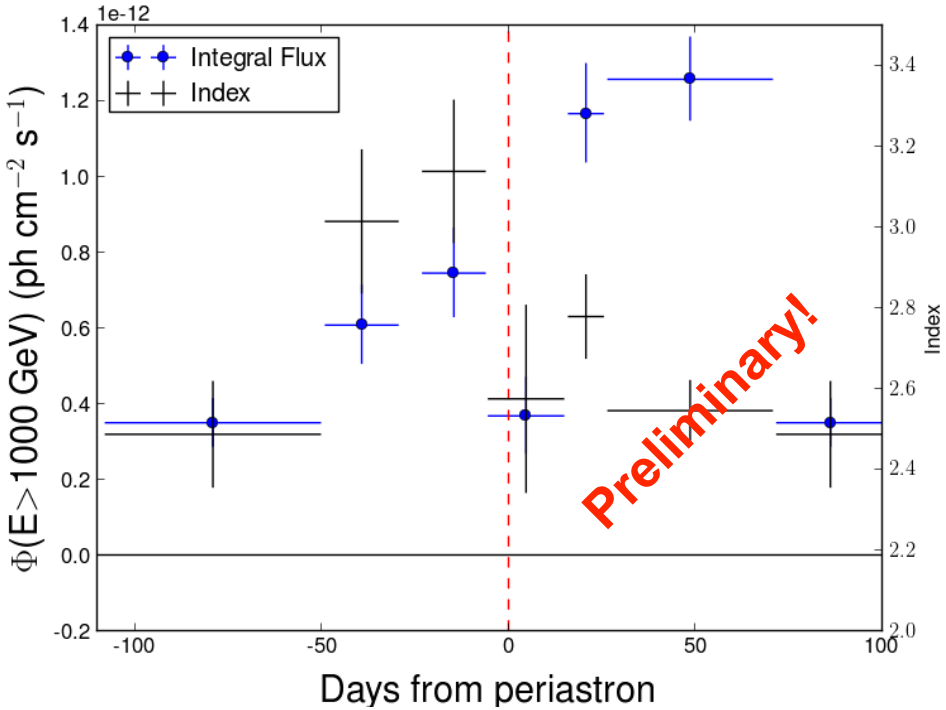
- GC with the H.E.S.S. II array down to ~100 GeV
- Detection of central source (40σ), PWN G0.9+0.1, HESS J1745-303 + diffuse emission
- smooth continuation from spectrum seen in H.E.S.S. I
- E-threshold not low-enough to fully describe Fermi-LAT-H.E.S.S. spectral break
- +50h obs. time coming soon (blinded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

Gamma-ray binaries: third galactic populations
PSR B1259-63 – 2014 periastron passage

- Long-term H.E.S.S. monitoring campaign to cover 2014 periastron
- Simultaneous observation with MWL observatories
- Analysis of new and old data with consistent software
- Confirmed double-peak pattern observed in the long-term LC
- Local minimum at the periastron passage
- Source still active at VHEs at 40-50 days after periastron (GeV flare?)
- Unexpected high emission levels also before 1st disk crossing





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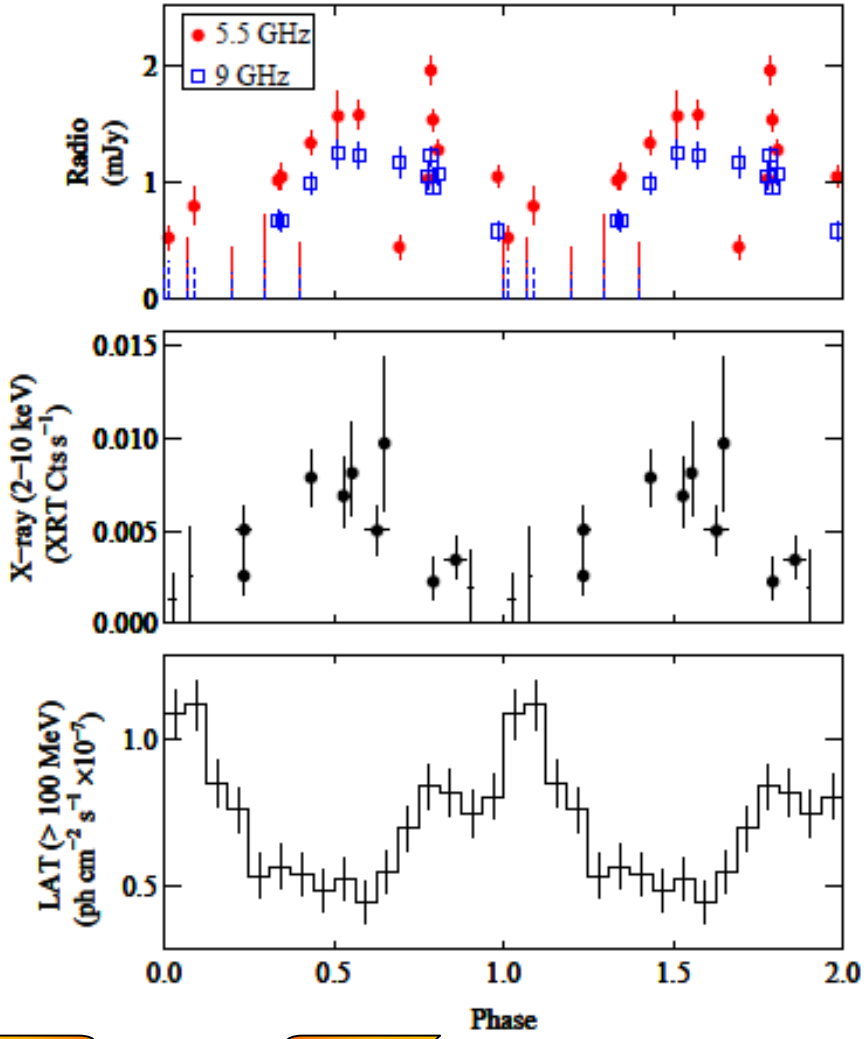
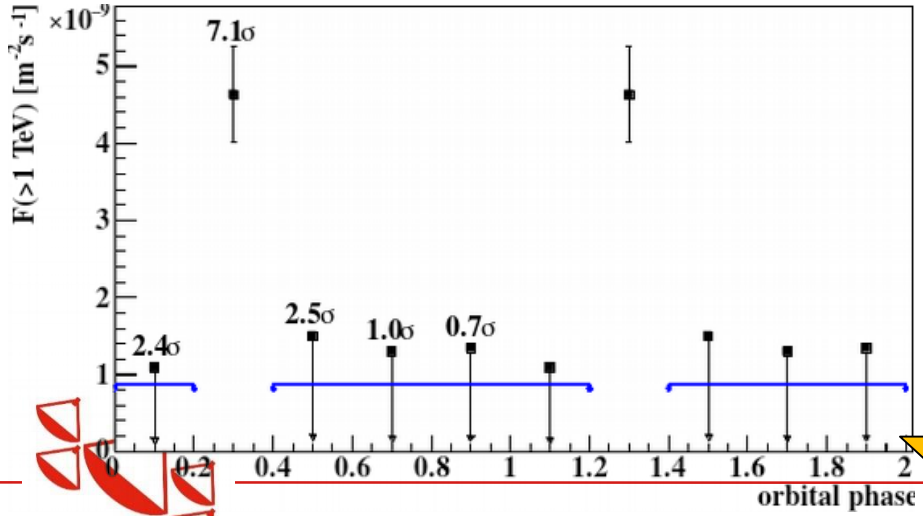
H.E.S.S. Collaboration (2017, in prep.)

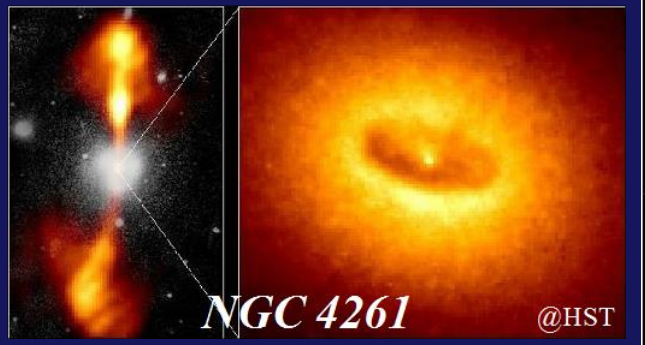
LMC P3 – A new gamma-ray binary in the LMC

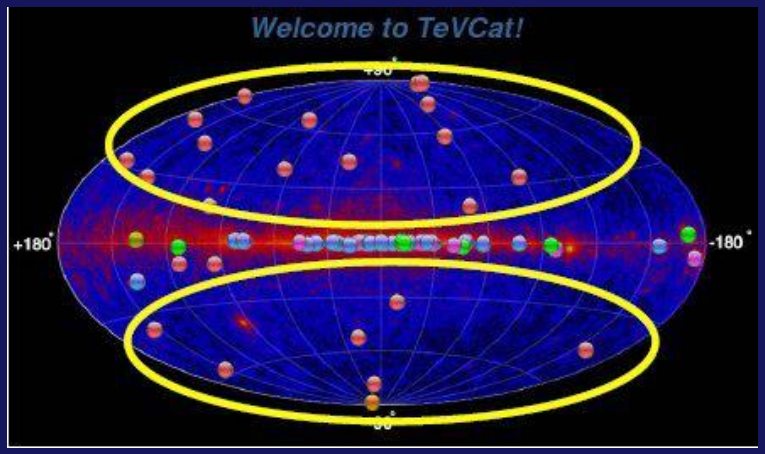
- Luminous High-Mass Gamma-Ray Binary discovered in Fermi-LAT data (Corbet et al. 2016)
- HE gamma rays in anti-phase with X-rays (Swift) and radio (ATCA)
- Bright companion star O5 III, similar to LS5039 or 1FGL J1018?
- Detected by HESS at phase ~0.3
- Most luminous γ-ray binary





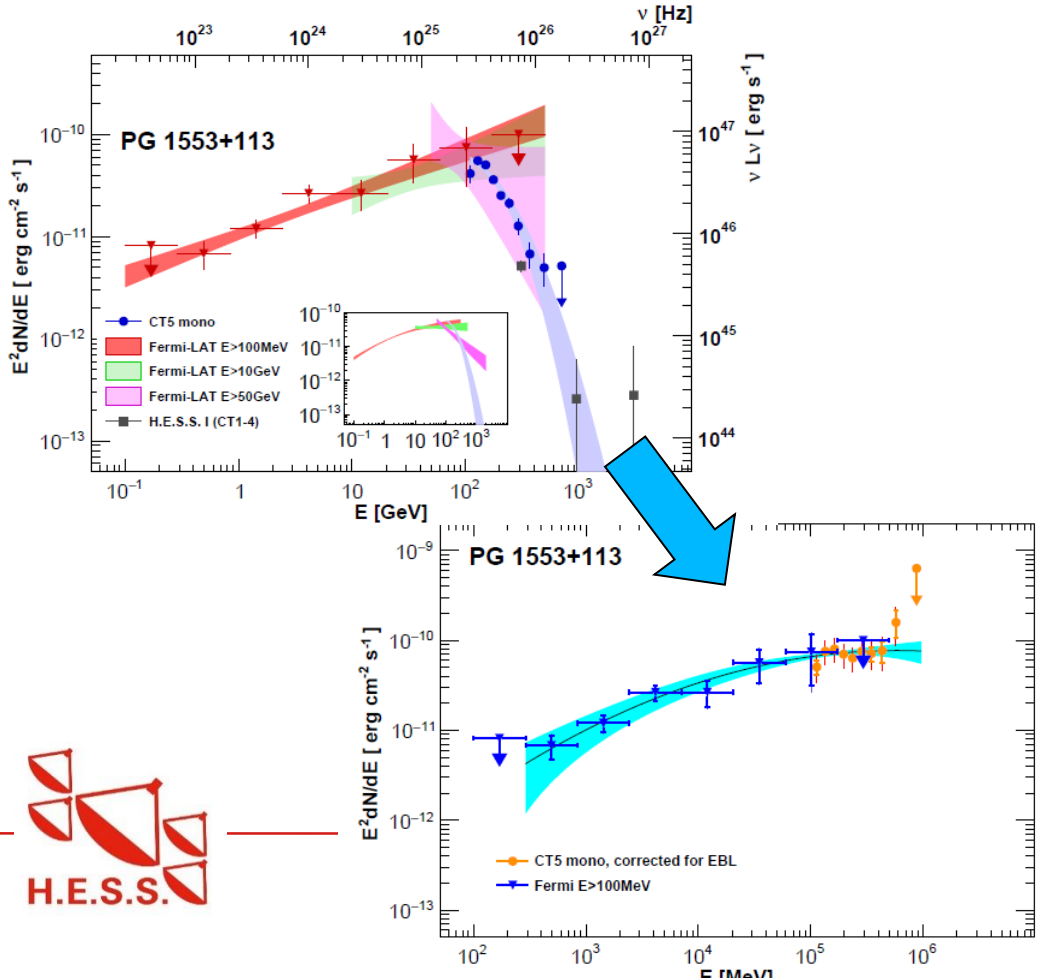
Extragalactic Science

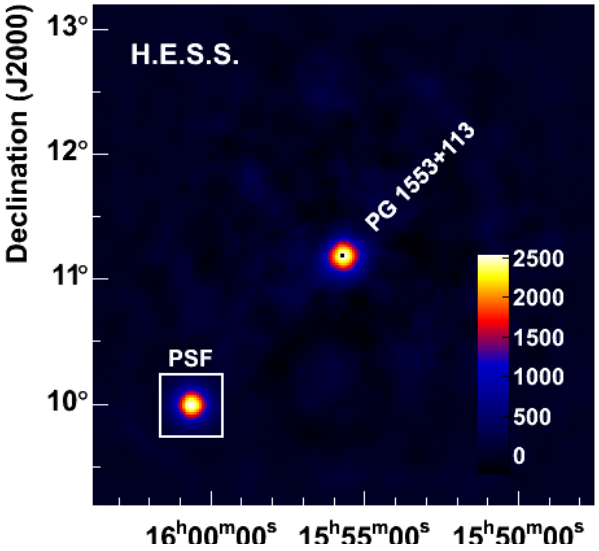


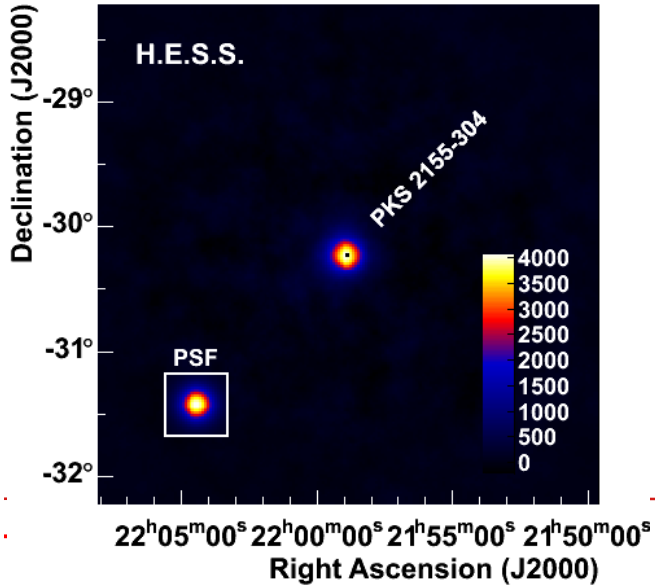


HESS-II observations of AGNs (< 100 GeV)

- Bridging the gap with Fermi-LAT with high statistics
- Spectra consistent with EBL absorption

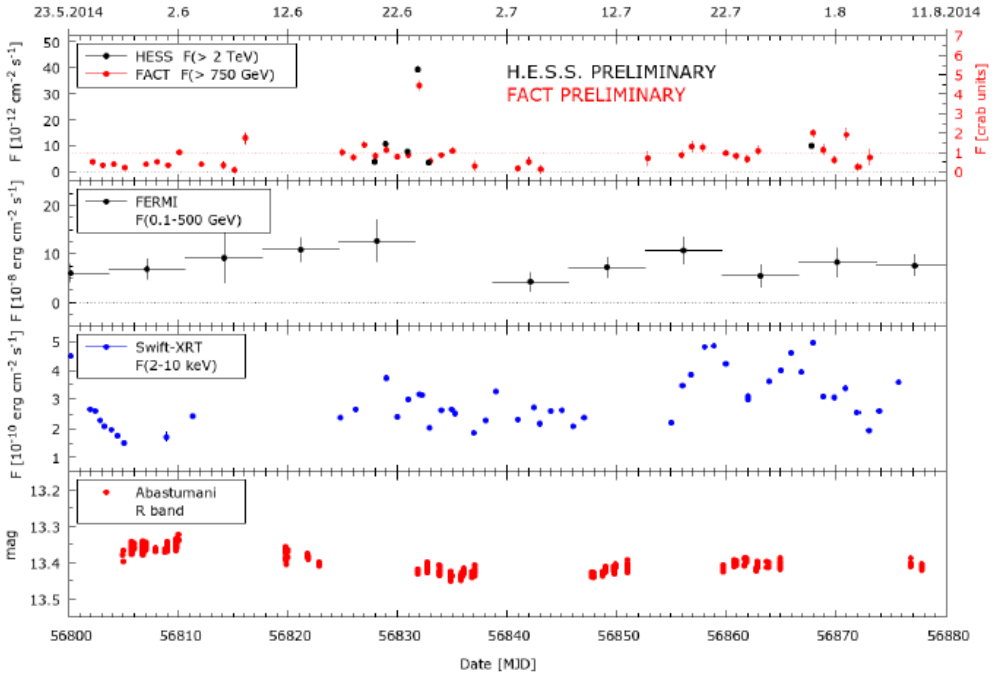






Mrk 501 – June 2014 Flare

- Exceptional flare from Mrk 501, observations triggered by a FACT alert
- Caught with H.E.S.S.-II Mono allowing lower threshold (1 TeV @ ~64° elevation)
- Good agreement with FACT
- Hard spectrum in high state → IC peak moving to higher energies
- LIV invariance studies, log-normality, …



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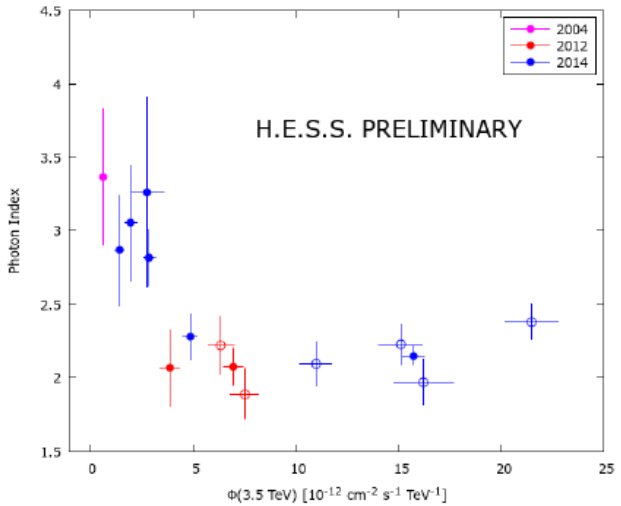
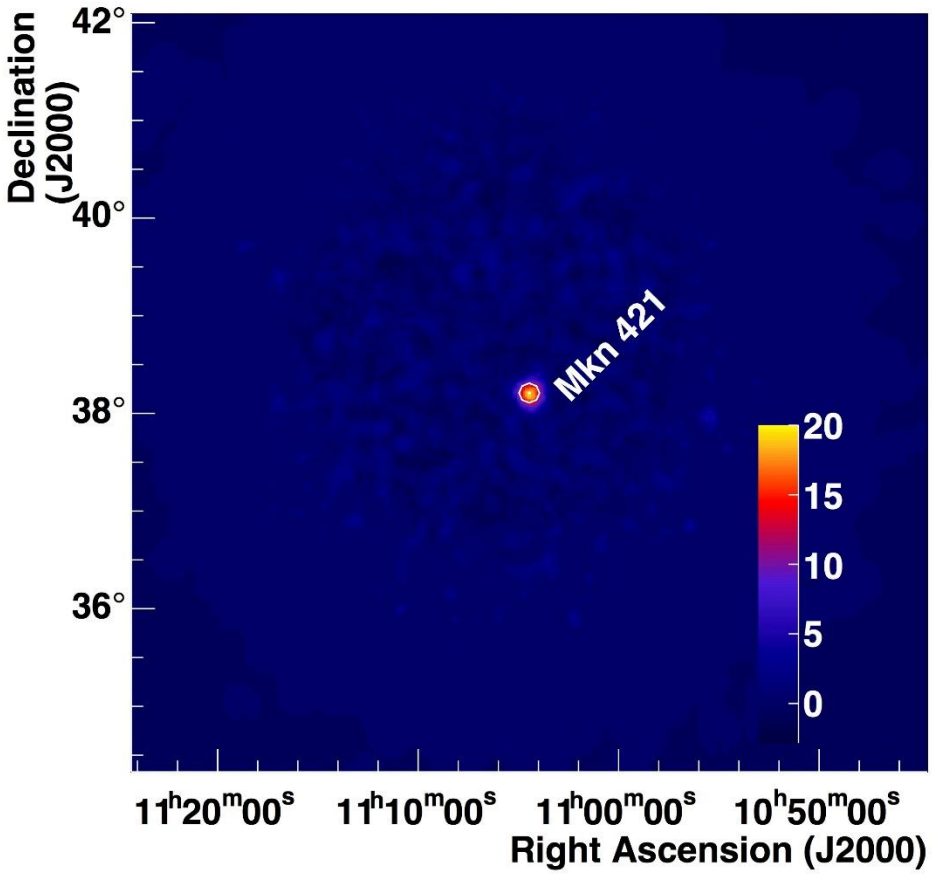


Bright flare from Mrk 421

- Alert received from HAWC during the HESSIU Commissioning (complete camera electronics refurbishment to allow for lower dead time and better synergies with CT5)
- Clear detection (20 σ)
- Validation of the NECTAr readout concept for CTA



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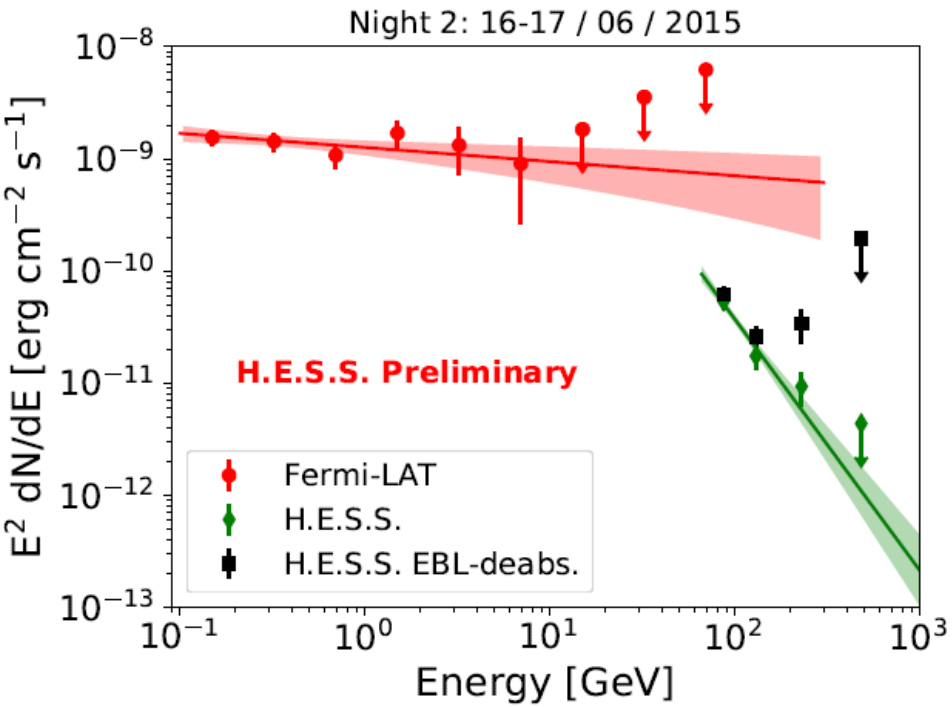
Extremely bright flare from 3C 279

- FSRQ @ z=0.54, highly variable
- Increase of flux by a factor 10 above 100 MeV (historical maximum), variability timescale 2 min (Fermi-LAT)
- HESS-II Mono observation
  - Threshold 66 GeV
  - Detection at 8.7 σ in 2.2h
  - Very steep spectrum (Γ>4) due to EBL absorption
  - Constrains on spectral cutoff → constrains on parent electron population and/or on internal absorption → distance of emitting region (>10^{17} cm)
  - Constrains on EBL
  - Constrains on LIV



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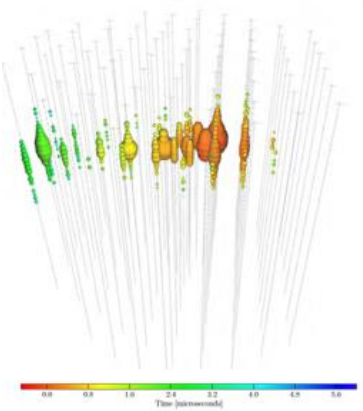
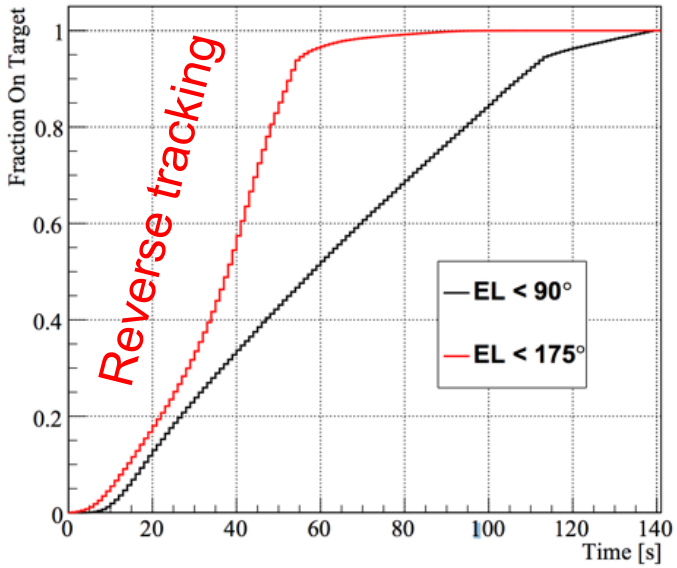
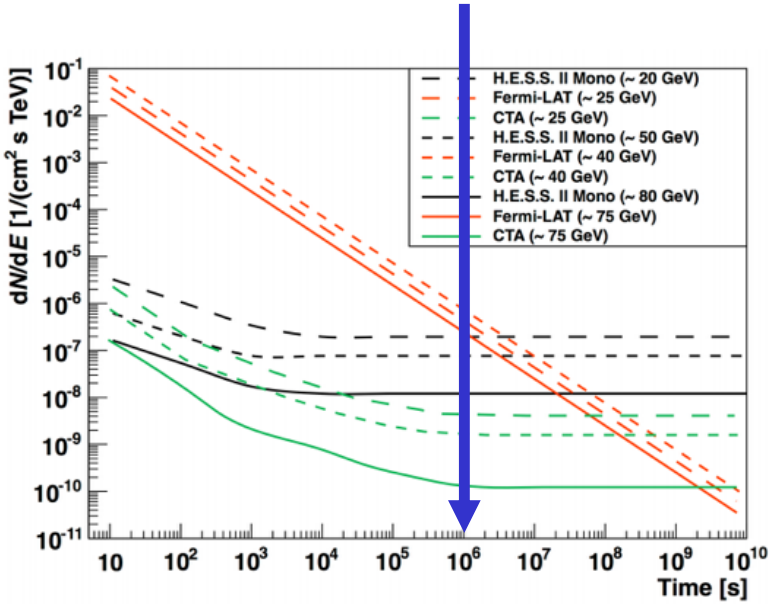
HESS-II as transient machine

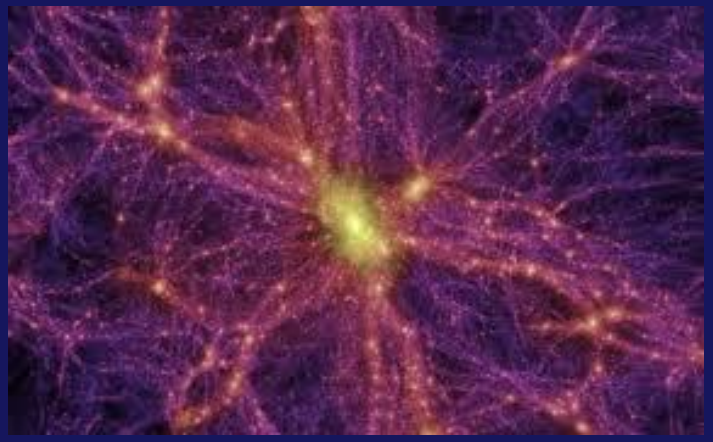
- Very fast response time of HESS-II
- 50% of target within 60s
- Recently on target 37s after a Antares neutrino
- Extensive GRB follow-up program
- Only upper limits so far, waiting.
- Large MWL program: GRB, FRBs, Neutrino counterparts, GW
- Stay Tune.

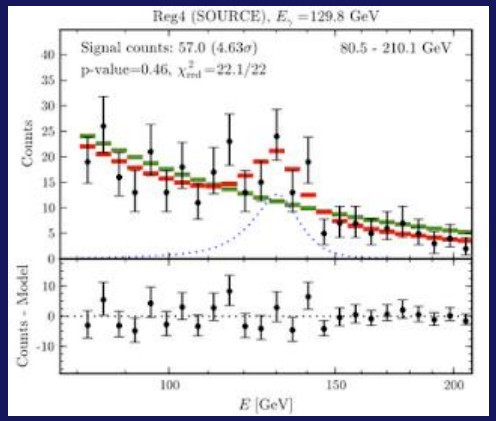






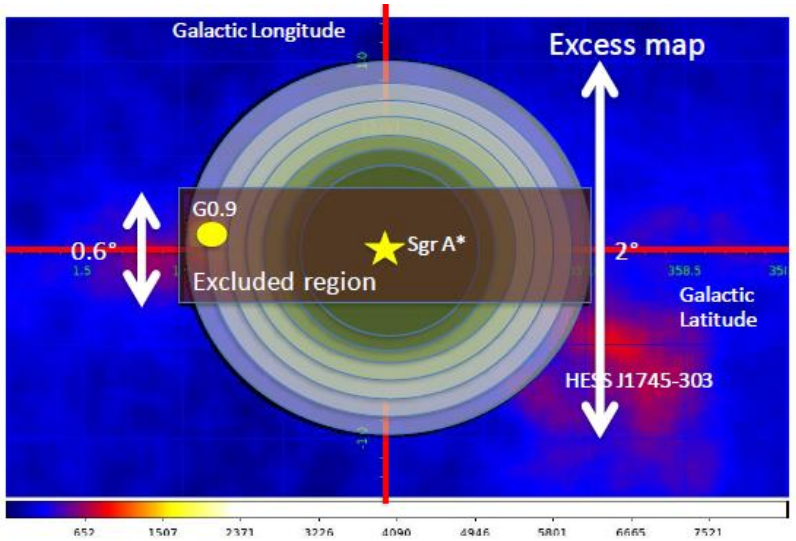
Astroparticles

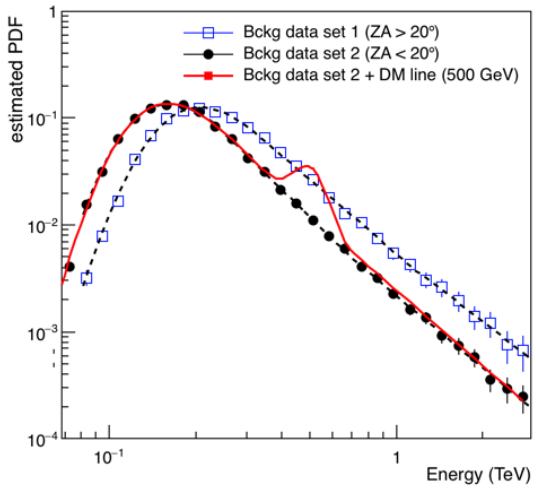


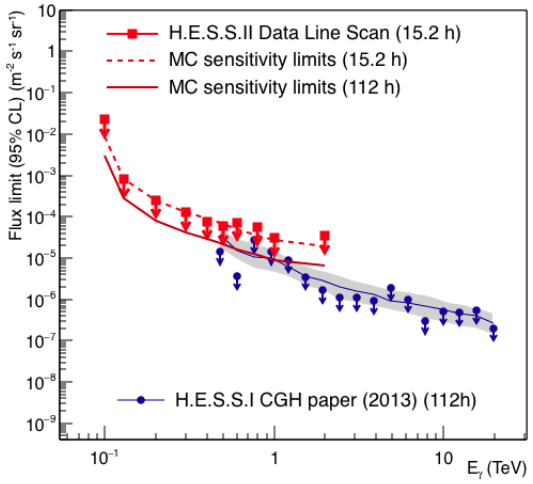


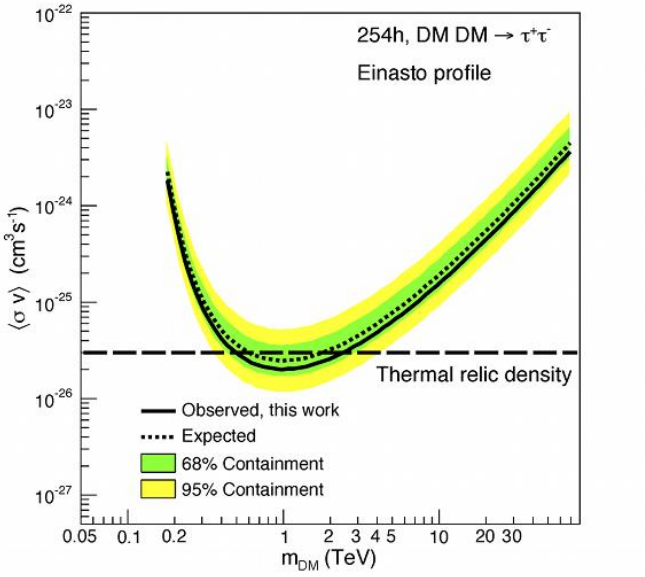
Dark Matter Searches

- Current target:
  - Galactic Centre Halo
  - Dwarf spheroidals
- Strategies
  - Deep observations (≥200 h)
  - Optimal statistical treatments
  - Search for annihilation lines
- New, very constraining upper limits



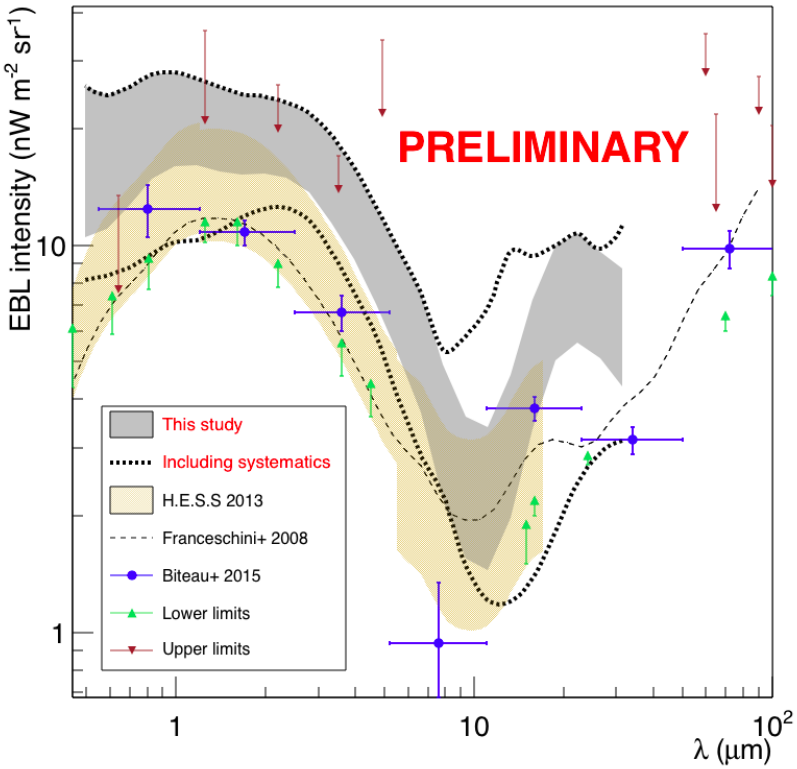






EBL constrains

- Absorption of VHE γ-rays by pair creation on EBL/CMB
- Achievable Constrains:
  - Single sources at large distance provide upper limits
    - PKS 1441-25 (VERITAS & MAGIC)
    - 1ES 1101+496 (MAGIC)
  - Measurement of several sources at different distances allow to measure the EBL (HESS)

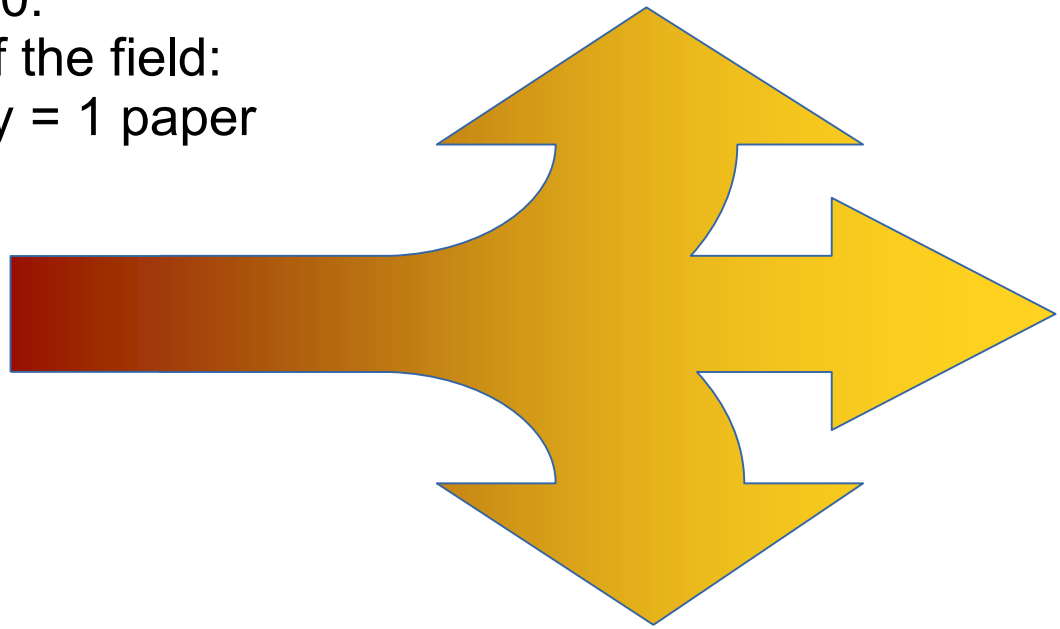


First actual measurement of EBL

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

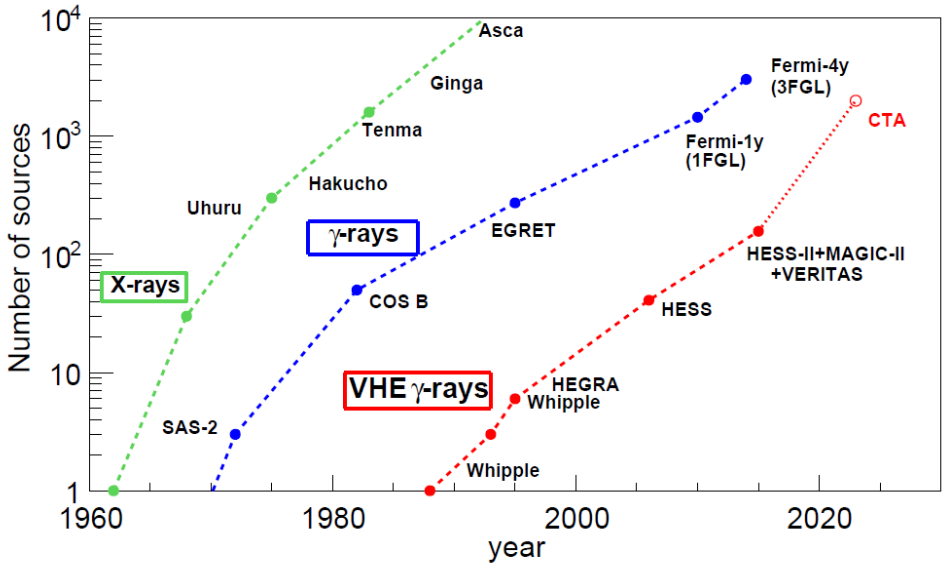
The Unknown, still searching for

- Dark Matter
- Exotic Physics
- Transients

Conclusions

- VHE astronomy is experiencing a phase transition: key science projects, requiring deep (>100 h) exposure
- Many new results to come
- Hope for breakthrough in transient phenomena
- HESS-I ongoing upgrade to further lower threshold and reduce dead time

"Kifune" plot 2015



Fishing-in-the dark time is over, precision measurement era is starting