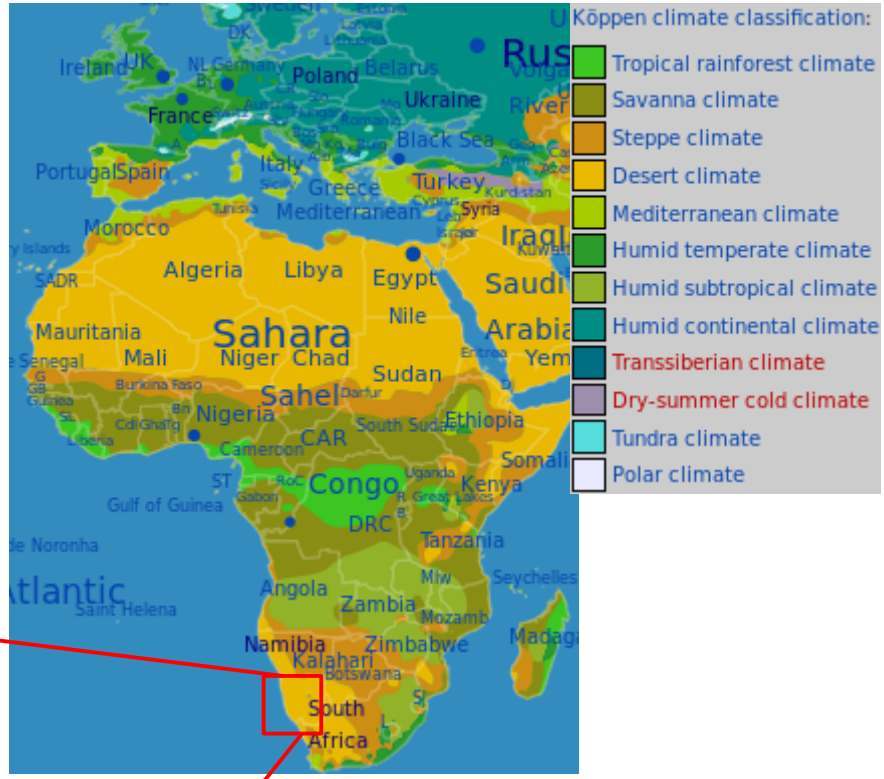
Current status and recent results from H.E.S.S.

Dmitry Zaborov (LLR - Ecole polytechnique)
for the H.E.S.S. collaboration

SciNeGHE 2016, Pisa, Italy, October 18, 2016

H.E.S.S. experiment

International collaboration of ~ 200 scientists from 13 countries: Germany, France, Armenia, Austria, Australia, Ireland, Japan, Namibia, Netherlands, Poland, South Africa, Sweden, UK



Khomas Highlands, Namibia

23° 16‘ S, 16° 30‘ E

100 km from Windhoek

H.E.S.S.: The High Energy Stereoscopic System

Array of Imaging Atmospheric Cherenkov Telescope (IACT)

Phase I (2002-2012): four 12 m telescopes (CT1-4)

Phase II (2012+): One additonal 28 m telescope (CT5)

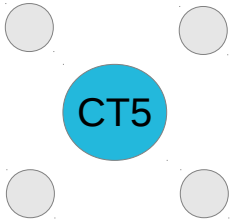
The H.E.S.S. telescopes

	CT 1-4	CT 5
Mirror area	107 m^2	596 m^2
Focal length	15 m	36 m
Nr. of pixels	960	2048
Field-of-view diameter	5.0°	3.5°

Mono & Stereo

The 5-telescope system records stereoscopic images from CT1-5 (any 2 out of 5 telescopes required), as well as low energy monoscopic events from CT5 only

CT5 Mono

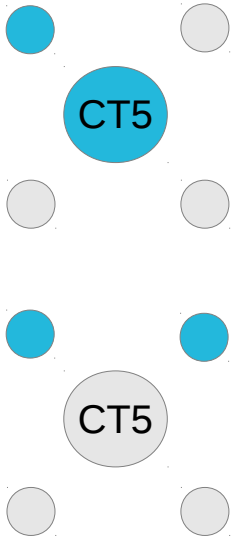


- ☺ Low energy threshold
- ☹ Limited angular resolution and hadron rejection capabilities
- ☹ Poor sensitivity compared to Stereo analysis

Best for:

- ✔ Pulsars (phasogram analysis)
- ✔ High redshift AGN, GRBs
- ✔ EBL at z > 1 (gamma-ray horizon)
- ✔ Spectral measurements at E < 100 GeV

CT1-5 Stereo



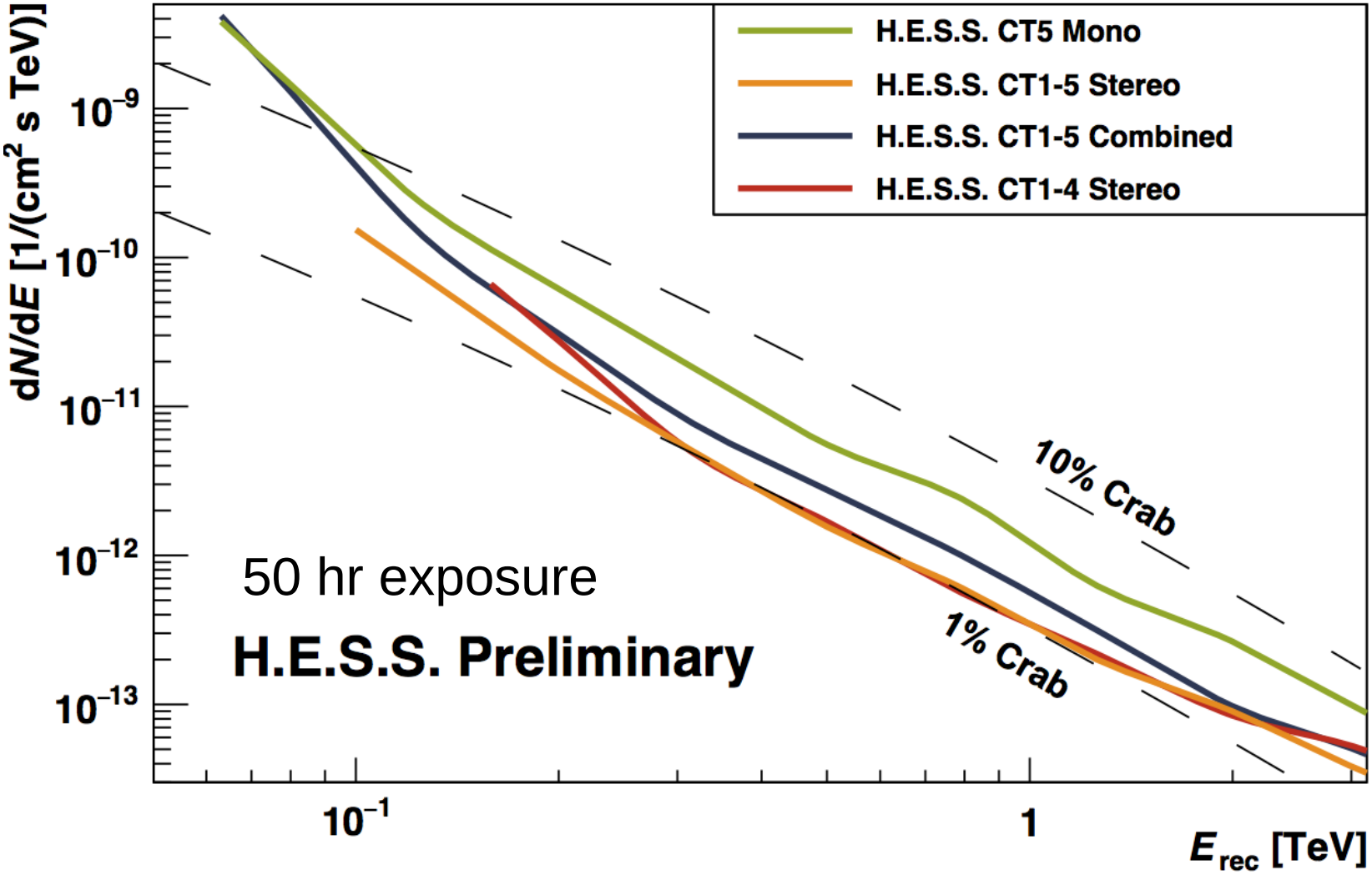
- ☹ Higher threshold than Mono
- ☺ Excellent angular resolution and hadron rejection
- ☺ Excellent sensitivity

Best for:

- ✔ Detection of weak sources
- ✔ Morphology studies
- ✔ Spectral measurements at E > 100 GeV

H.E.S.S. sensitivity

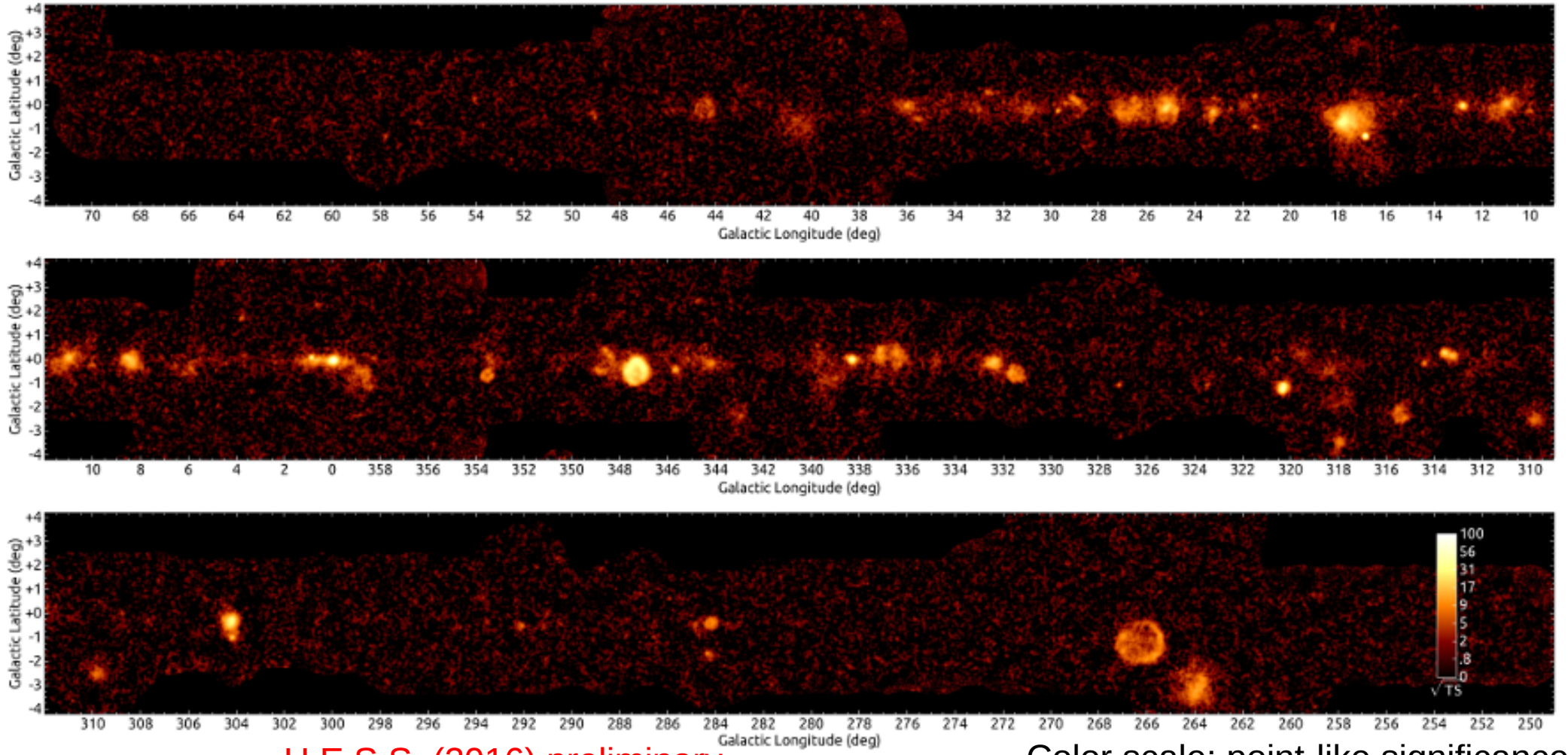
M. Holler et al., ICRC 2016



~ 1000 hr of observations / year

HGPS: The HESS Galactic Plane Survey

- Observations : 2004 to 2013 (HESS I)
- Total Exposure : ~3000 h
- Energy Range : 0.2 - 100 TeV
- Resolution: 0.07 deg



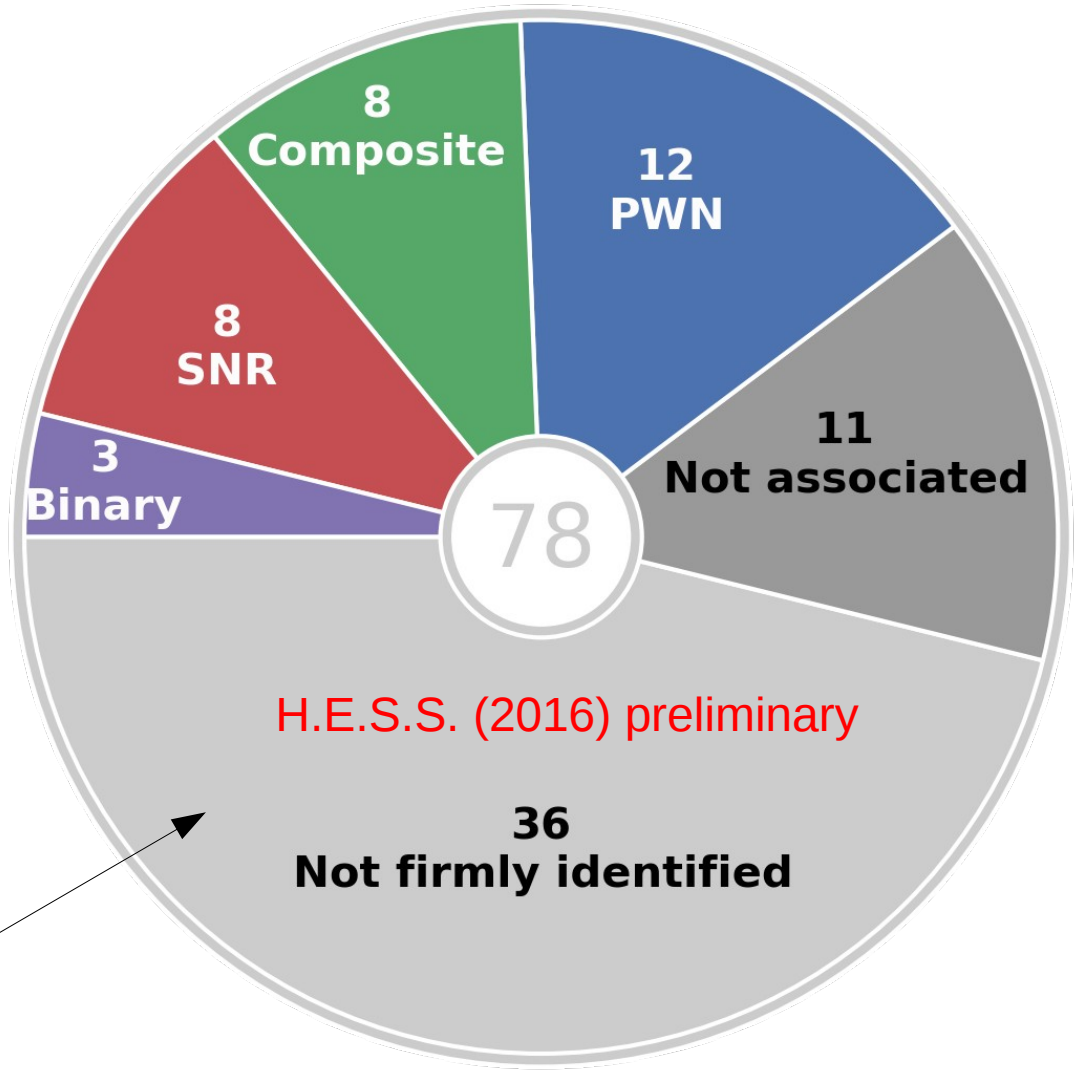
H.E.S.S. (2016) preliminary

Color scale: point-like significance

HGPS: firm identifications and associations by spatial coincidence

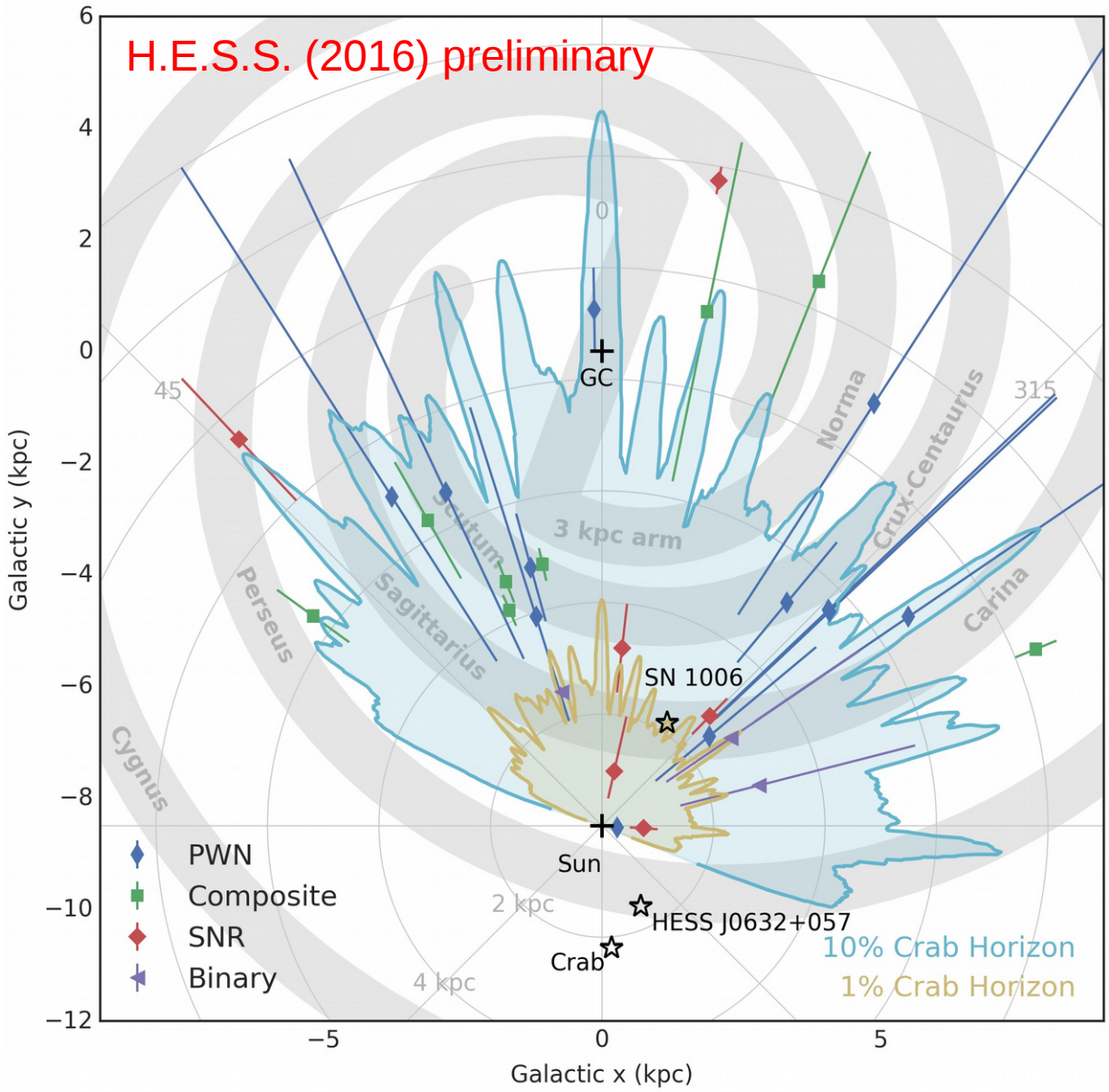
MWL counterparts:

- Pulsars (ATNF)
- PWN (SNRcat)
- SNRs (SNRcat)
- GeV sources (2FHL, 3FGL)

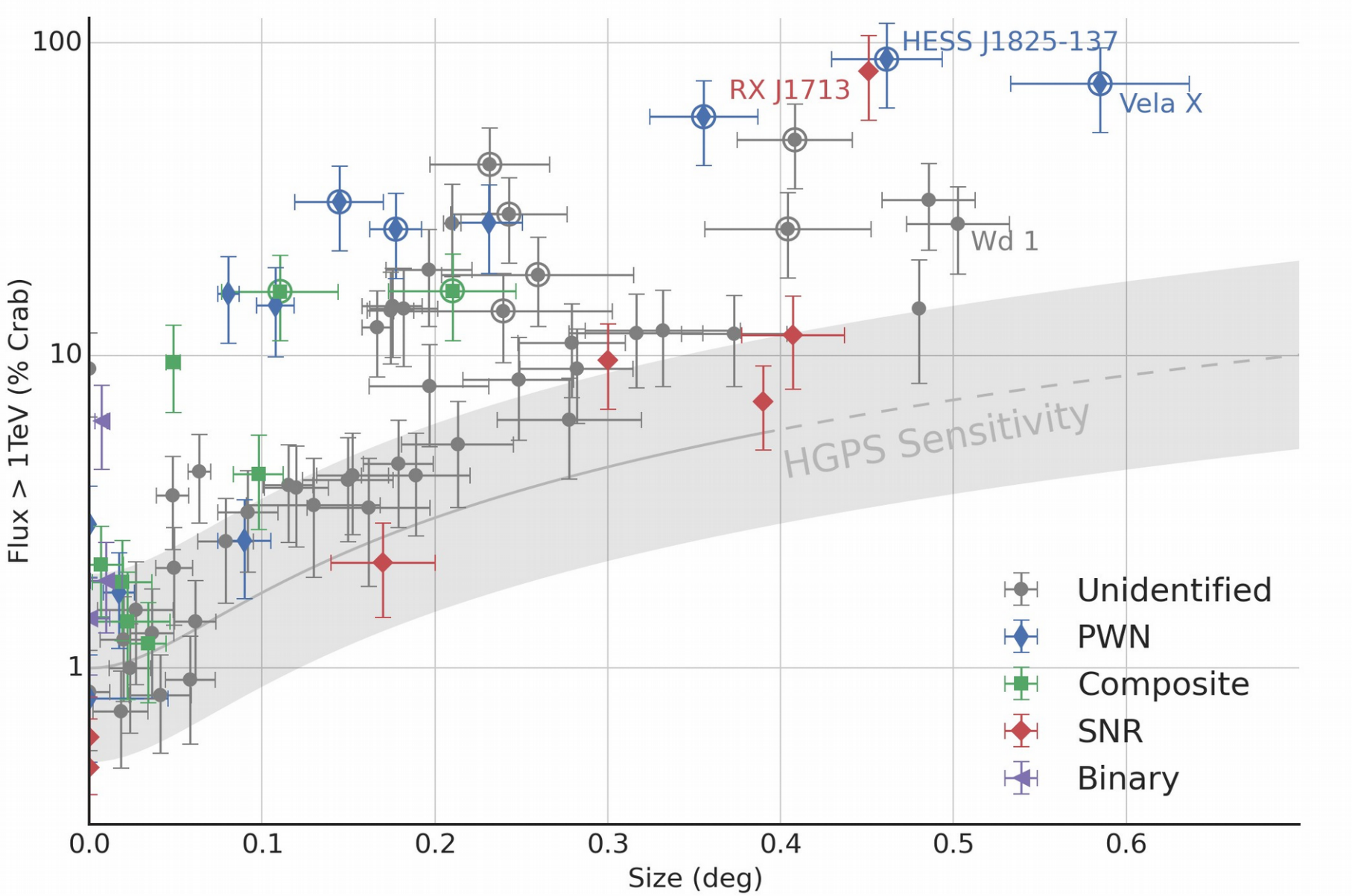


Mostly sources with multiple associations

HGPS: distribution in the galaxy & HGPS horizon



HGPS: source size



HGPS: publications in preparation

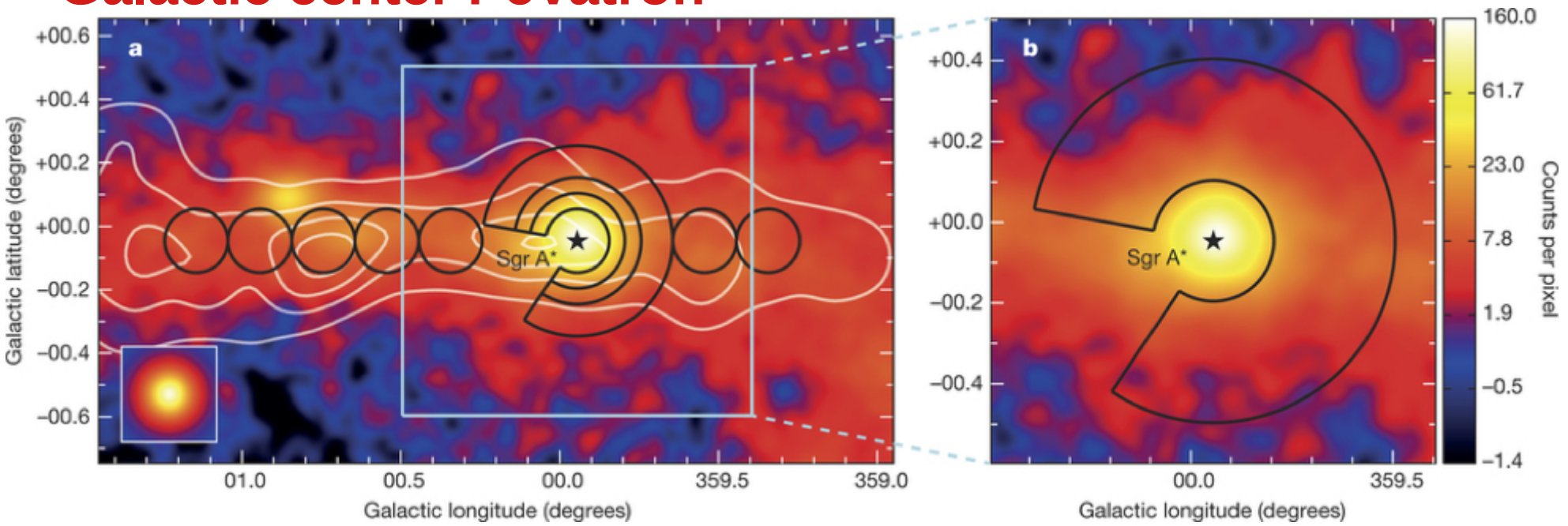
- Paper close to completion
- Maps will be released in FITS format
- Special A&A issue

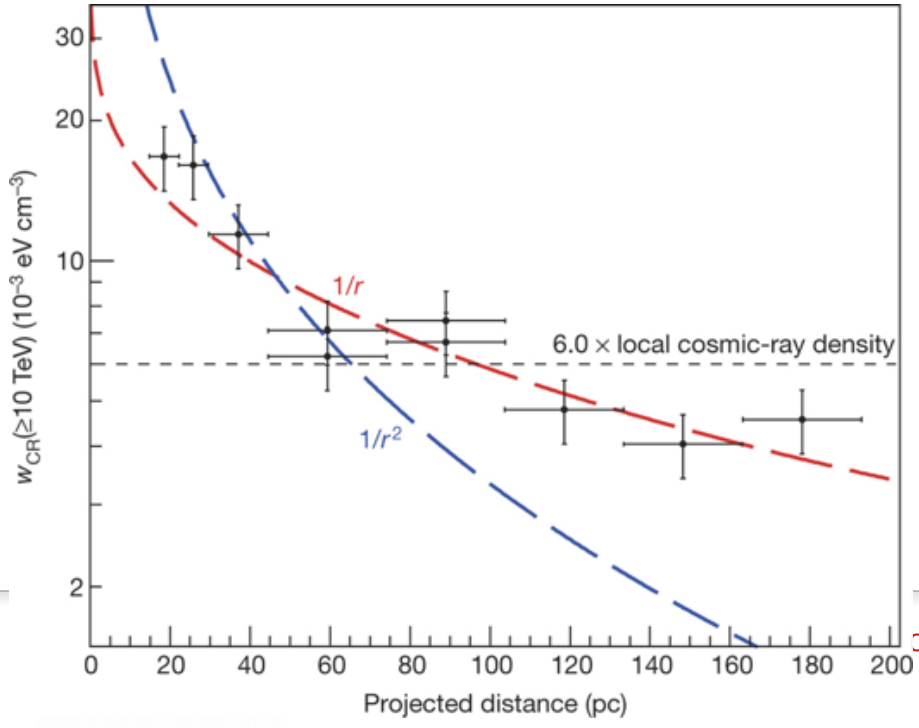
Accompanying papers:

- PWN population study
- SNR population study
- Systematic search for SNR shells
- Systematic search for TeV bow shocks of runaway stars
- ...

Galactic center PeVatron

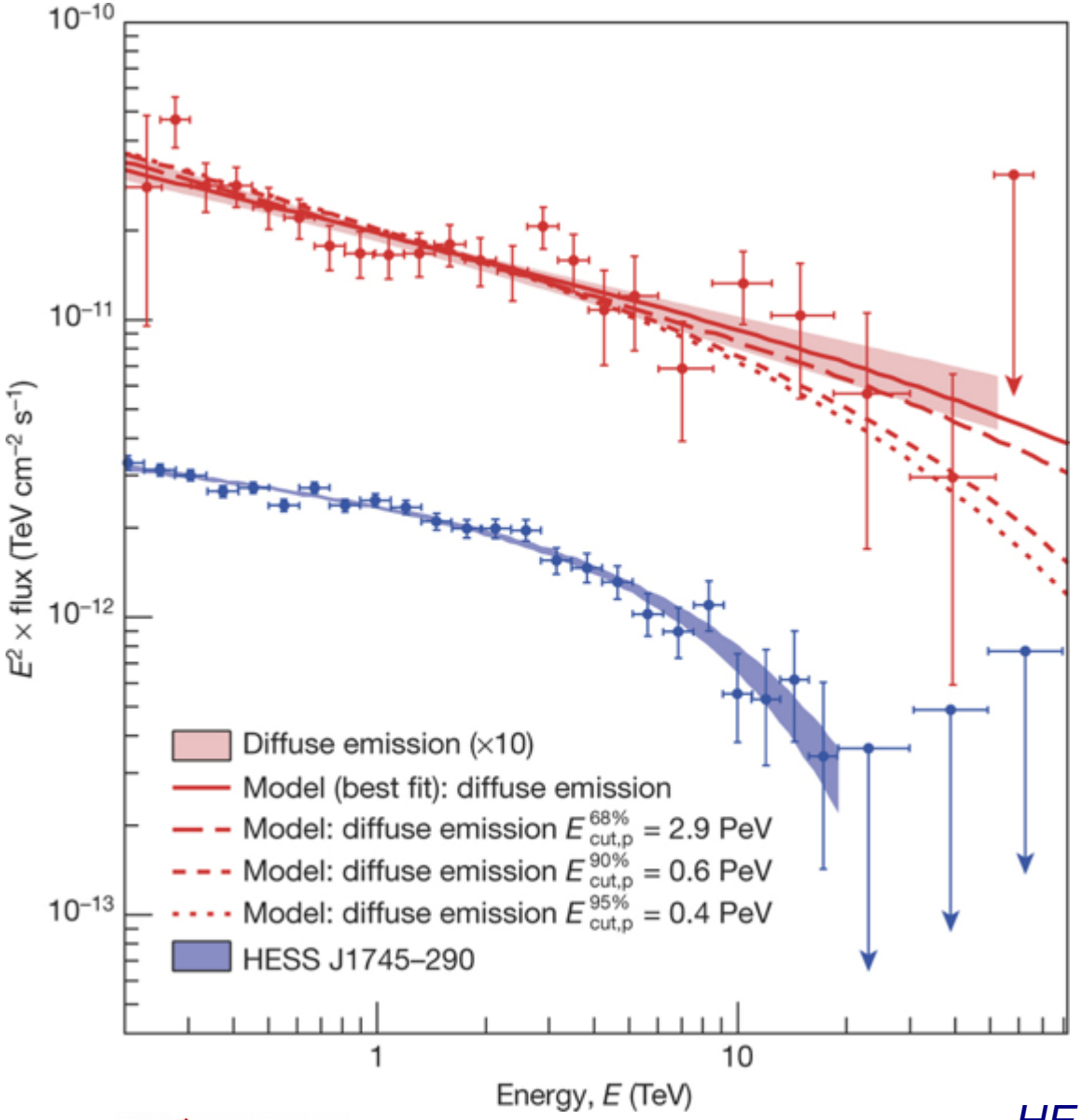
HESS Collaboration, 2016, Nature 531, 476





- Studied the radial energy distribution of CRs in the central region
- 1/r dependence is indicative of cosmic ray acceleration centred on a continuous injector (lasting > 1000 yr) and diffusive cosmic ray propagation

Galactic center PeVatron (continued)

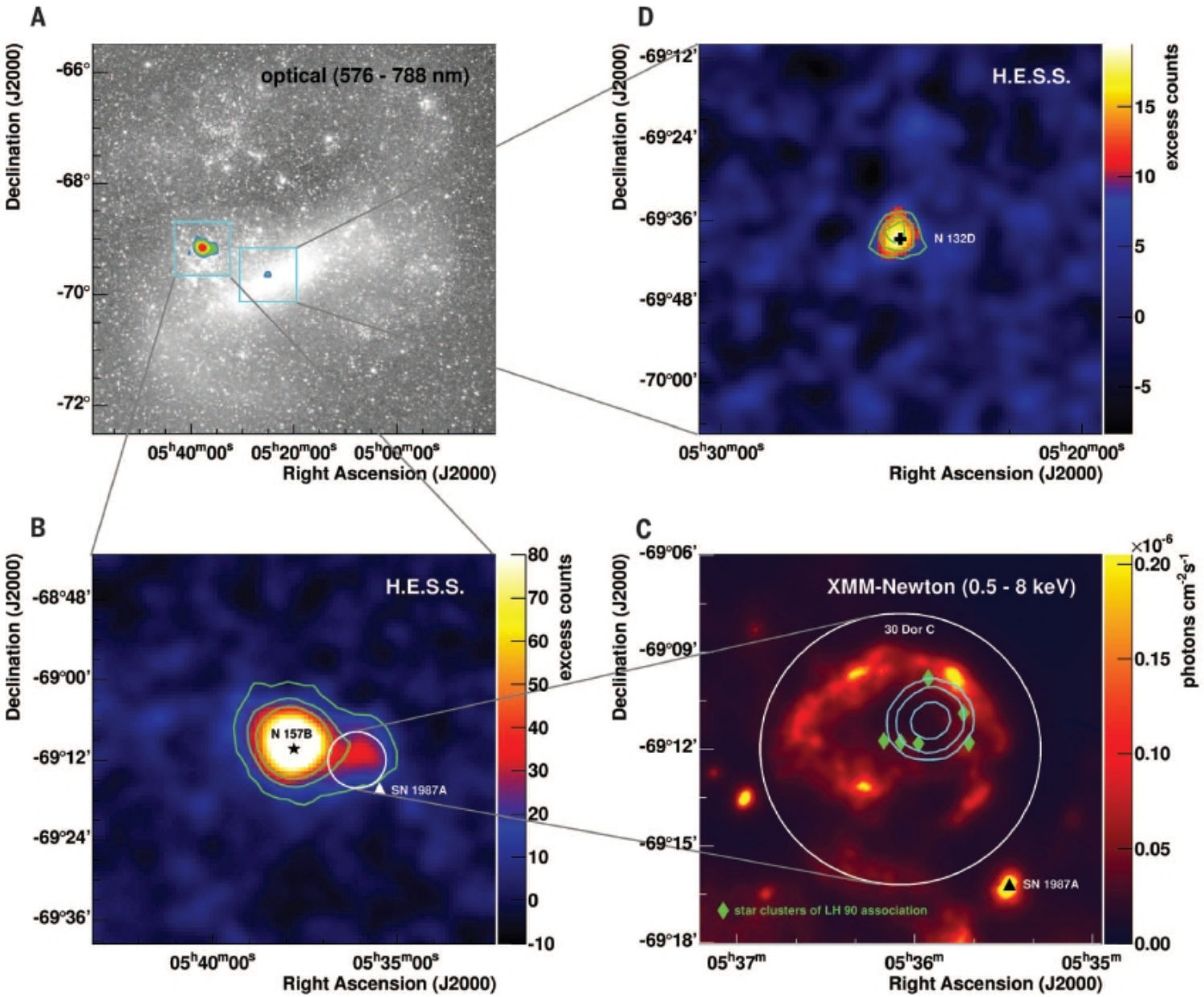


- Central source: cutoff at ~10 TeV
- Diffuse emission: power-law spectrum of index 2.3 extends up to 50 TeV with no evidence of a spectral cut-off
- Solving the proton transport equations gives evidence of a proton injection spectrum extending up to PeV energies

HESS Collaboration, 2016, Nature 531, 476

Large Magellanic Cloud

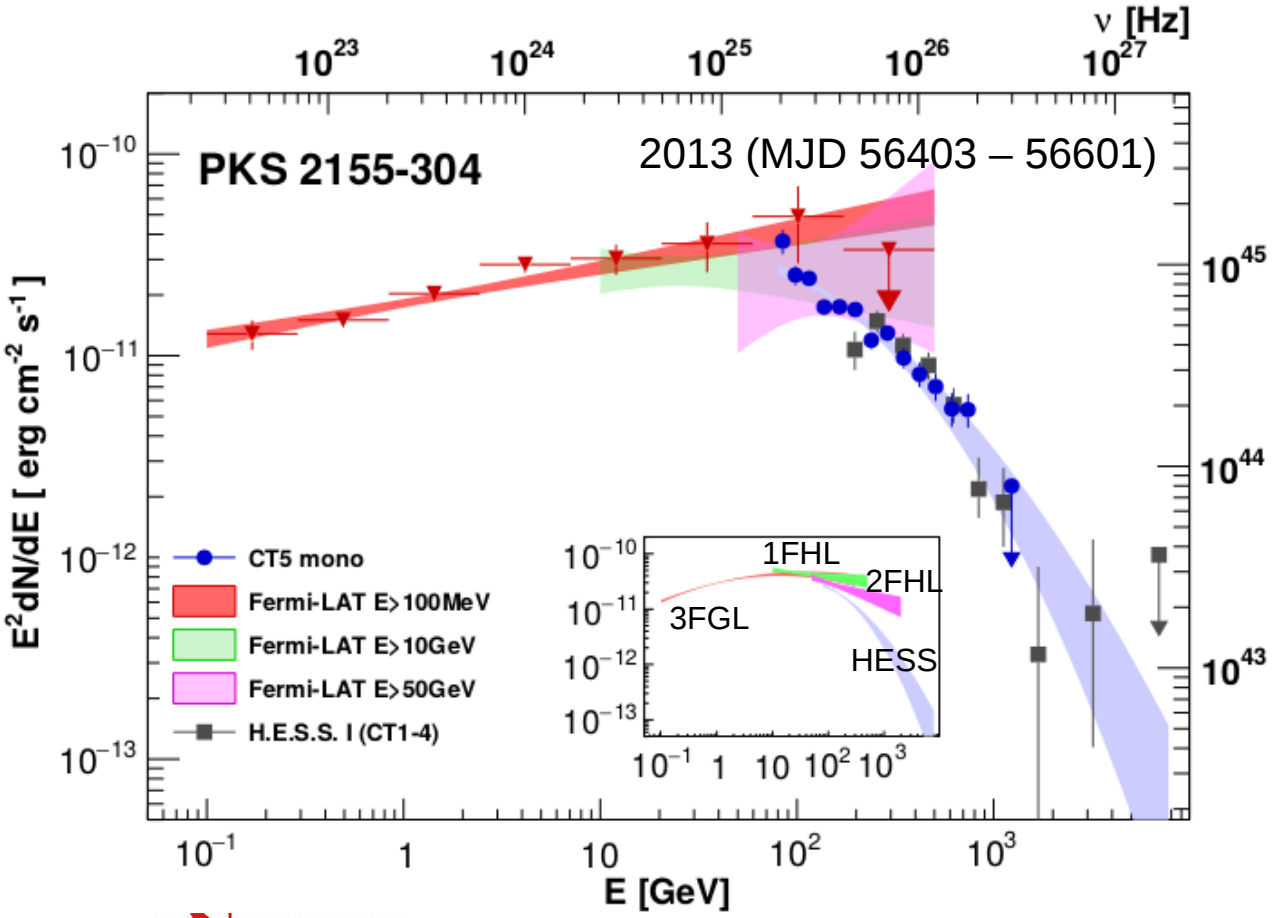
HESS Collaboration, Science 347 (2015) 406

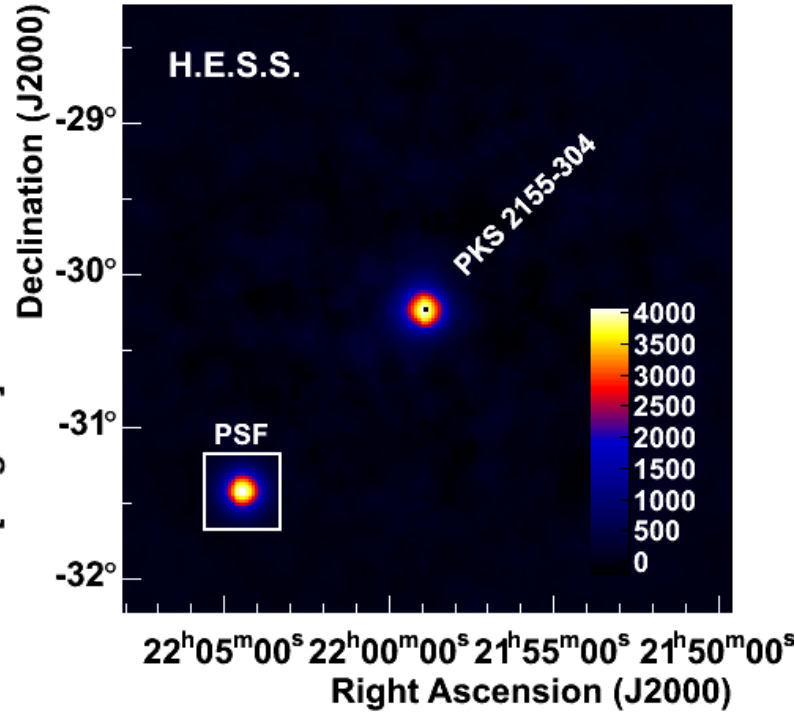


- Extreme environment
  - 10x SFR vs. Milky Way
  - Increased IR fields
  - Large CR densities
- N 157B: The most luminous PWN known
- N 132D: The most luminous SNR known
- 30 Dor C: superbubble (multiple supernovae + strong stellar winds) - new TeV source class

PKS 2155-304 with H.E.S.S. II Mono analysis

- High-frequency-peaked BL Lac object (HBL) at z = 0.116
- Detected at high significance at E > 80 GeV (using „standard cuts“)

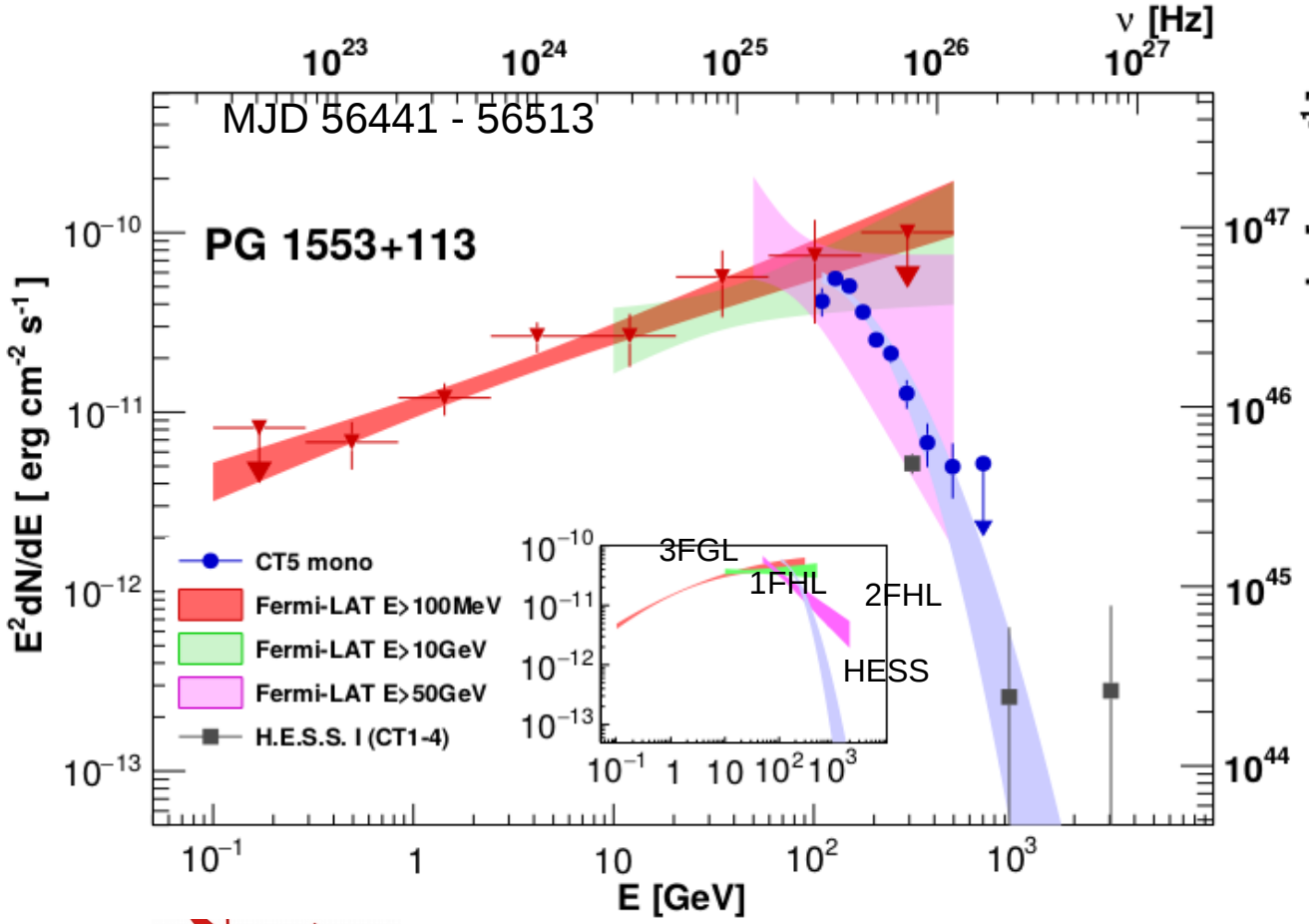


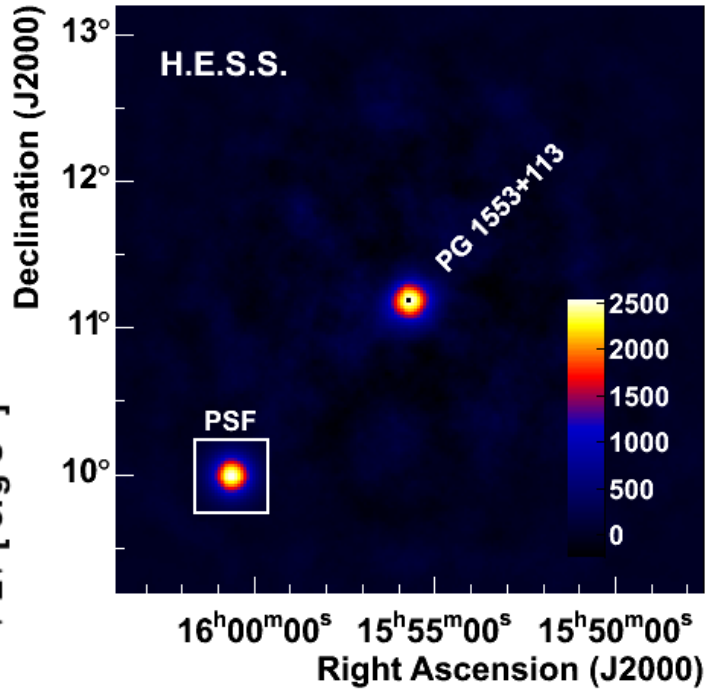


- H.E.S.S. spectrum is well fitted by log-parabola
- Good agreement with contemporaneous Fermi LAT data (Pass 8) and a „H.E.S.S. I“ analysis of the same period

PG 1553+113 with H.E.S.S. II Mono analysis

- HBL at 0.43 < z < 0.58 (Danforth et al. 2010)
- Detected with H.E.S.S. II Mono at E > 110 GeV





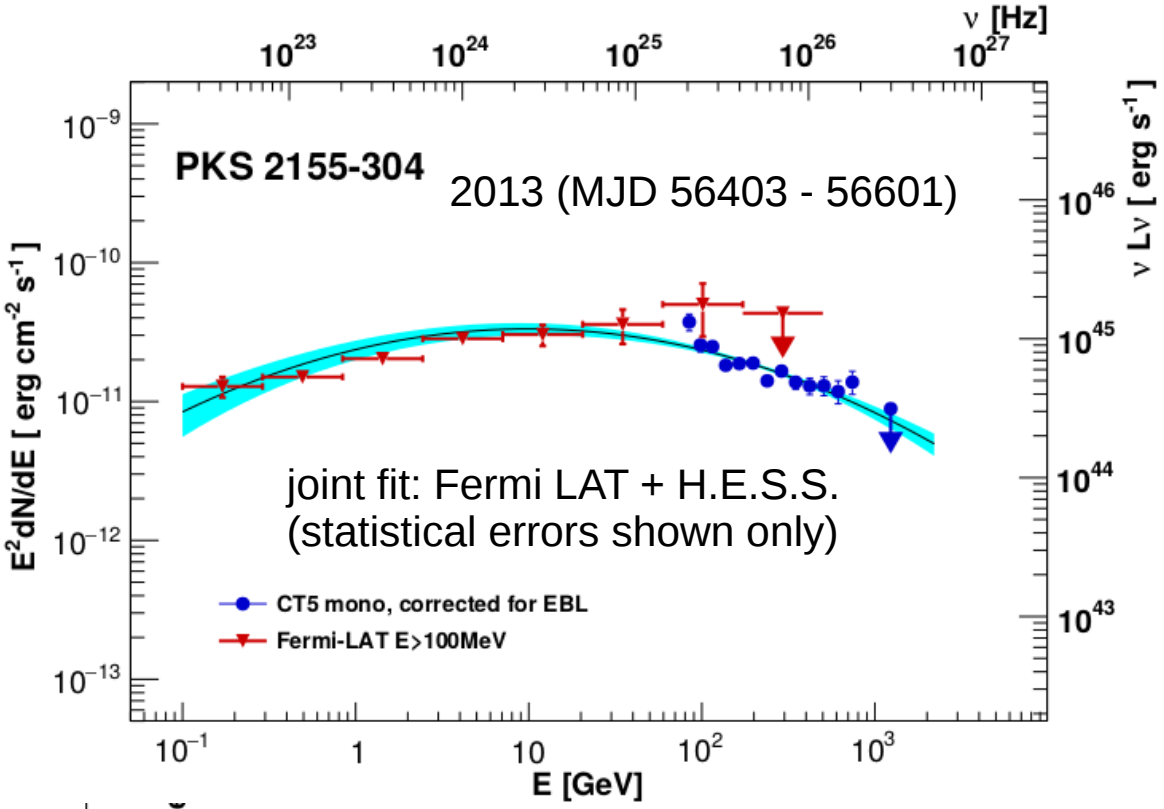
- Good agreement with contemporaneous Fermi LAT data (Pass 8) and a „H.E.S.S. I“ analysis of the same period

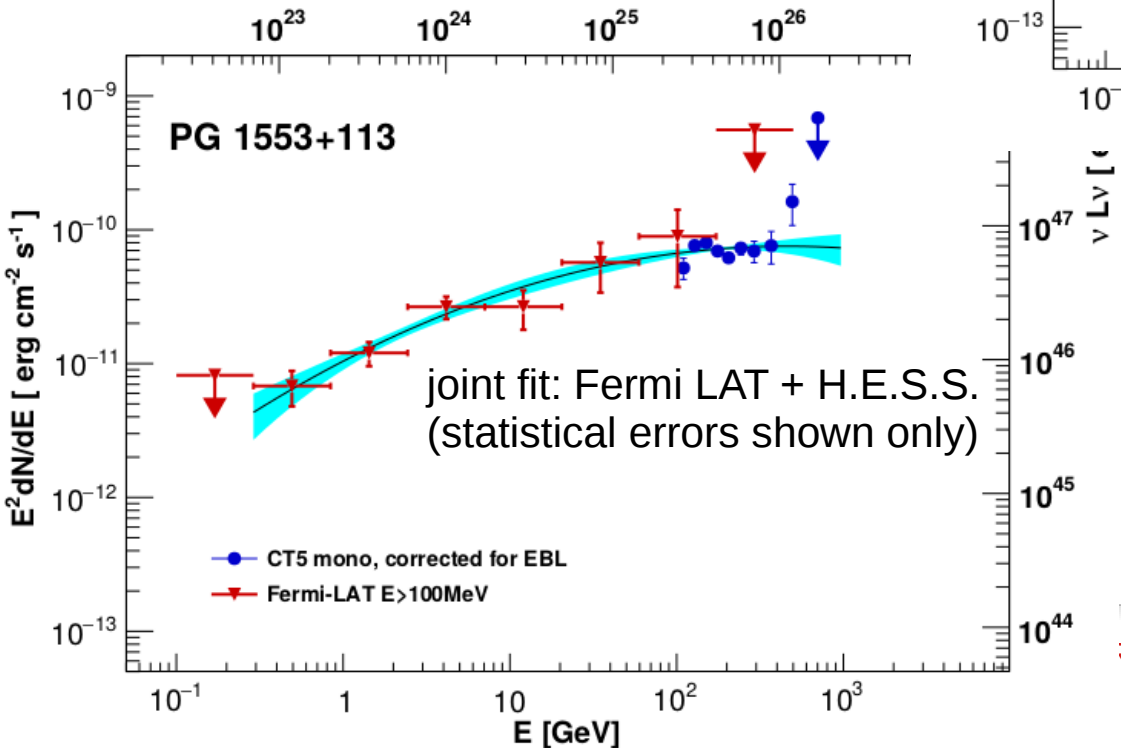
PKS 2155-304 & PG 1553+113: EBL-deabsorbed spectra

PKS 2155-304

- EBL absorption modelled following Franceschini et al. (2008)
- Significant curvature beta = 0.15 ± 0.02 (stat) ± 0.02 (syst)
- log10 (Epeak/GeV) = 0.99 ± 0.19 (stat) ± 0.19 (syst)

D. Zaborov et al, Gamma2016, Heidelberg
Paper submitted to A&A

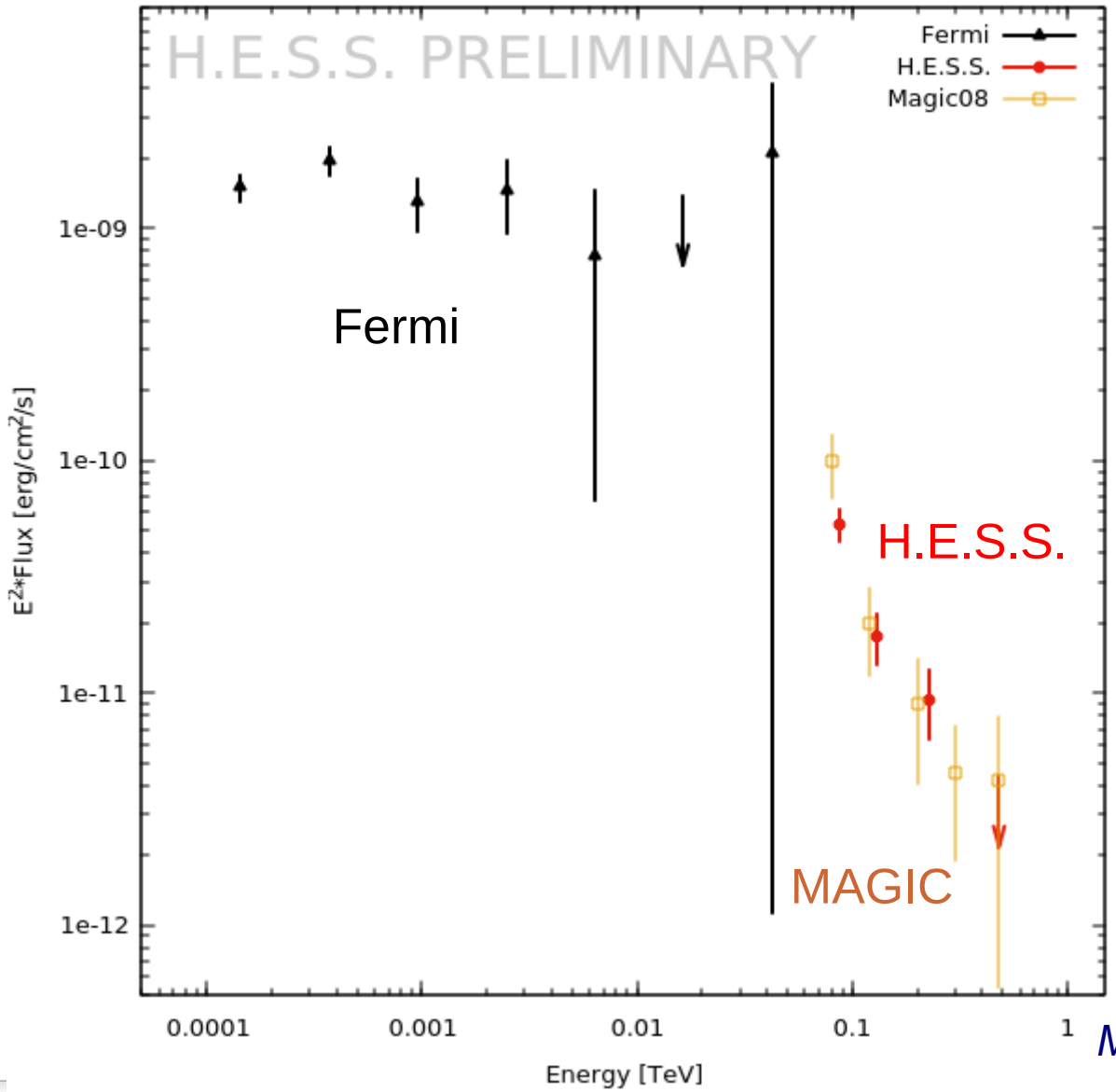




PG 1553+113: assuming z = 0.49

- beta = 0.12 ± 0.05 (stat) ± 0.13 (syst)
- log10 (Epeak/GeV) = 2.76 ± 0.45 (stat) ± 0.93 (syst)
- Systematics due to H.E.S.S. energy scale uncertainty + uncertain redshift

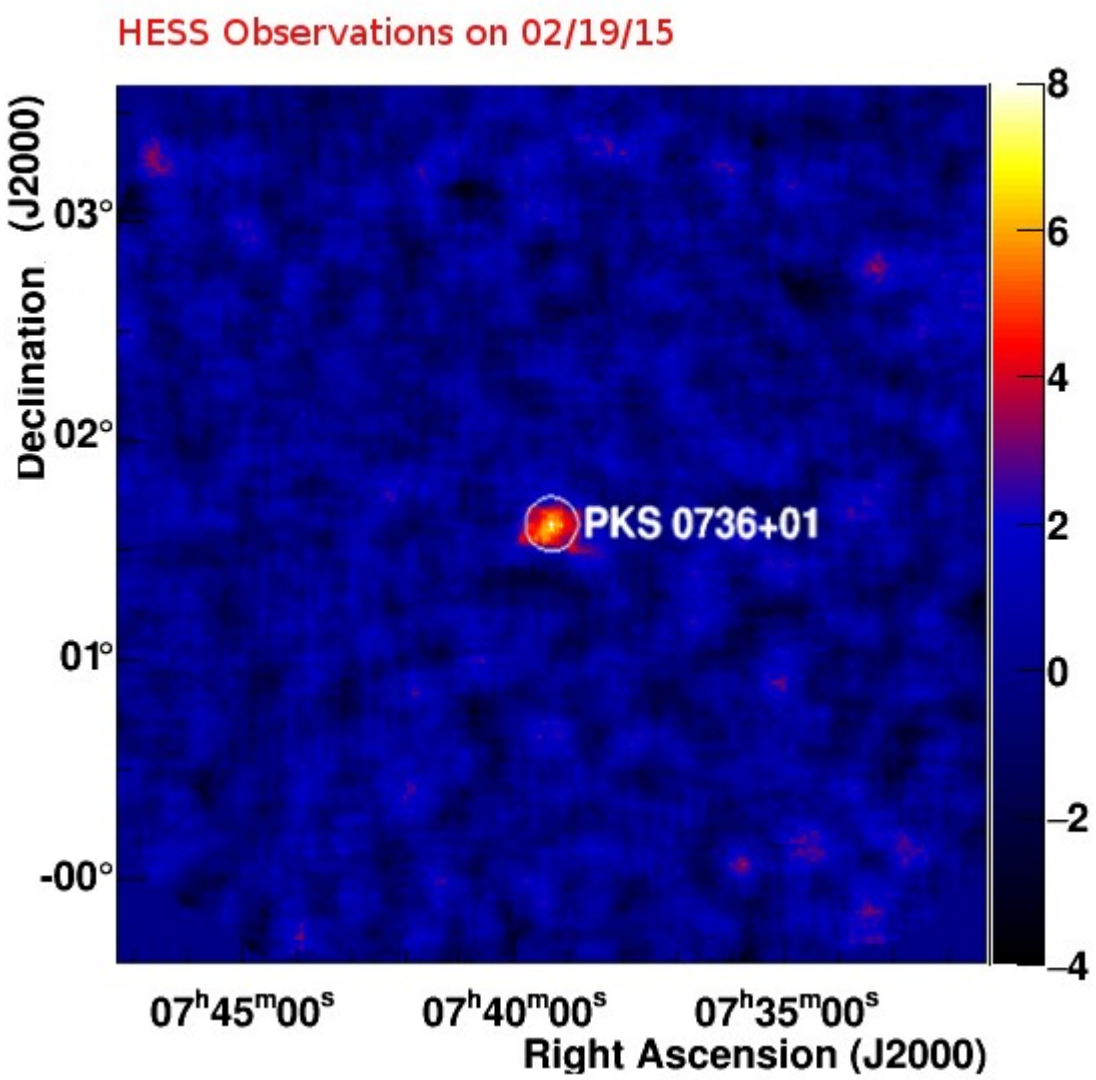
Blazar flare observations: 3C 279



- FSRQ at z = 0.536
- Detected at VHE by MAGIC during flares in 2006 and 2007
- Now confirmed by HESS (8 sigma detection in 3 hr)
- The HESS spectrum matches the 2006 flare MAGIC result

M. Cerruti et al, Gamma 2016, Heidelberg

PKS 0736+017: a new quasar in the VHE sky



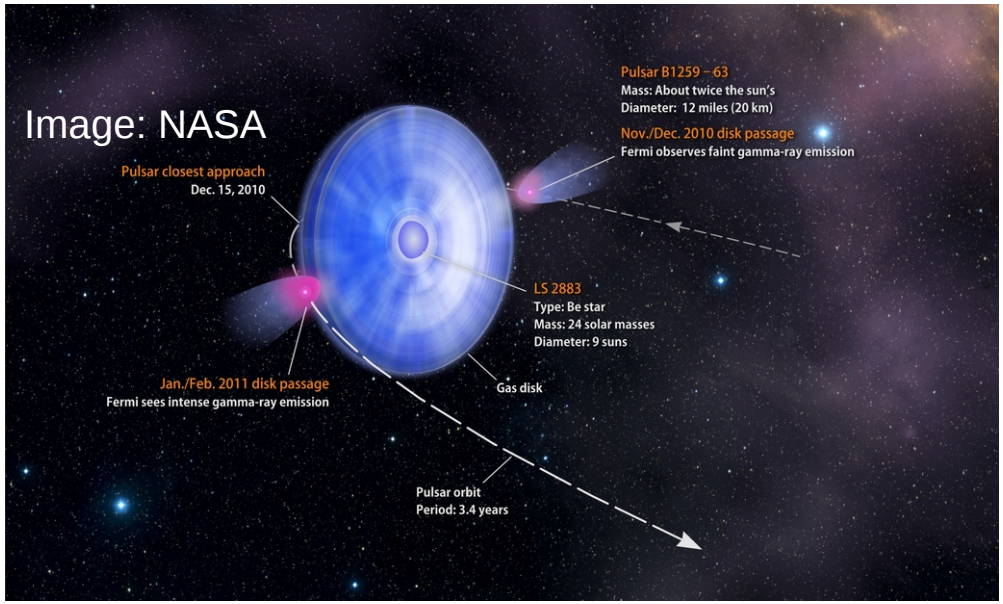
- FSRQ at z = 0.189
- GeV flare reported by Fermi
- Detected by H.E.S.S. on February 19, 2015 (> 7 sigma)
- VHE flux was ~ 10% Crab

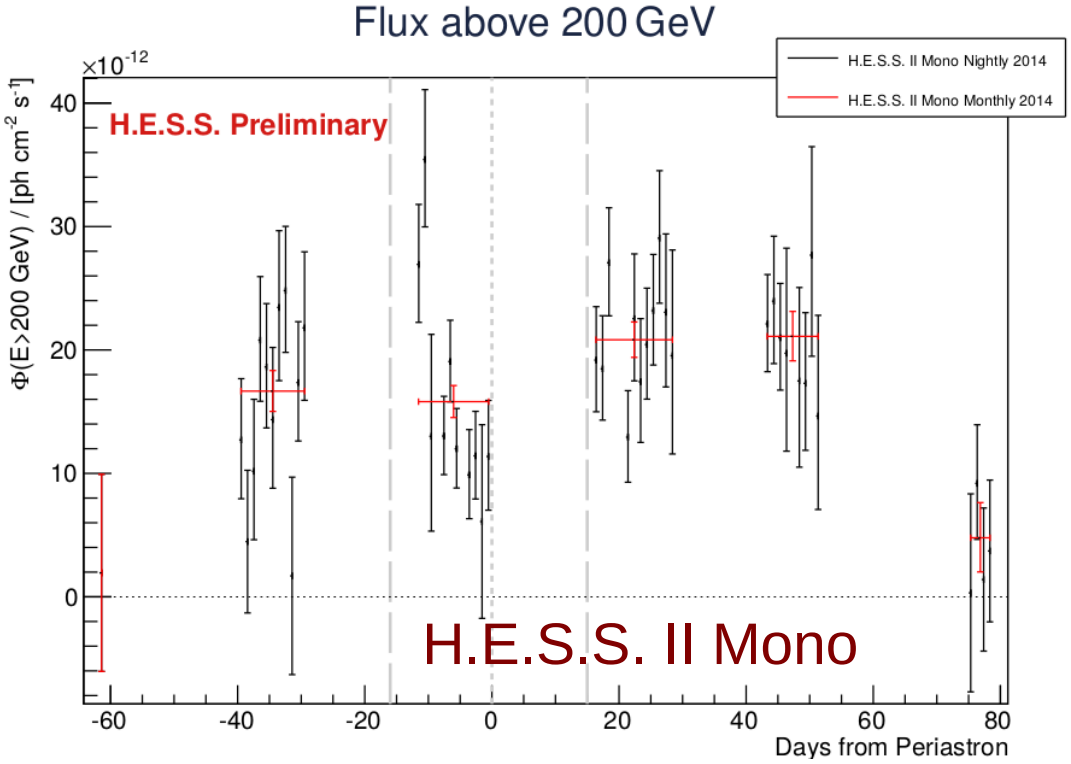
M. Cerruti et al, Gamma 2016, Heidelberg

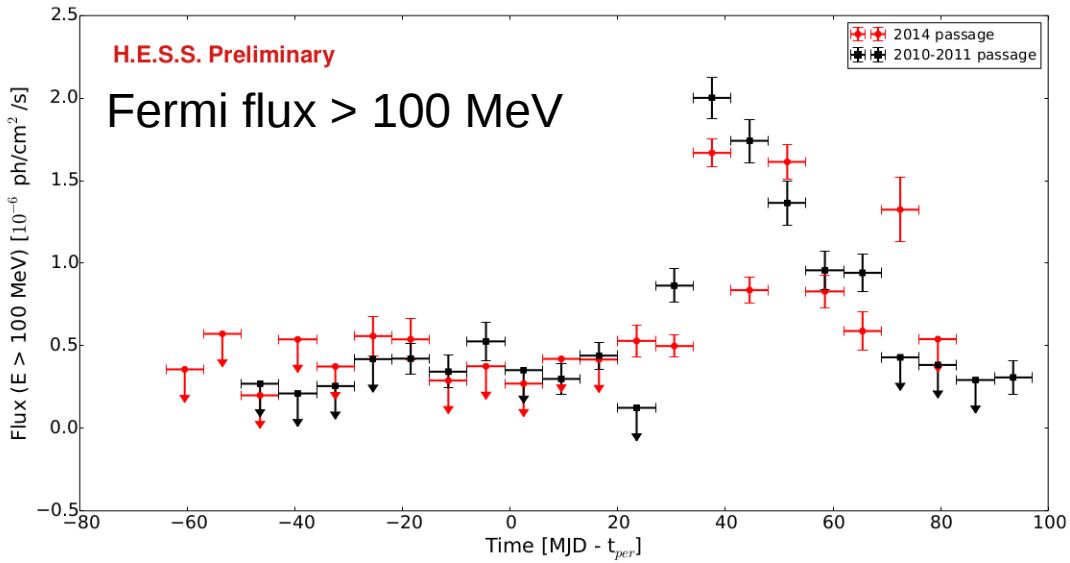
P. Bordas et al, Gamma 2016, Heidelberg

PSR B1259-63 / LS 2883

- Binary system: ms pulsar and massive star
- 3 yr orbital period
- HESS detection near periastron in 2004, 2007, 2007, 2014
- Photon index ~ 2.7
- Emission up to ~ 20 TeV



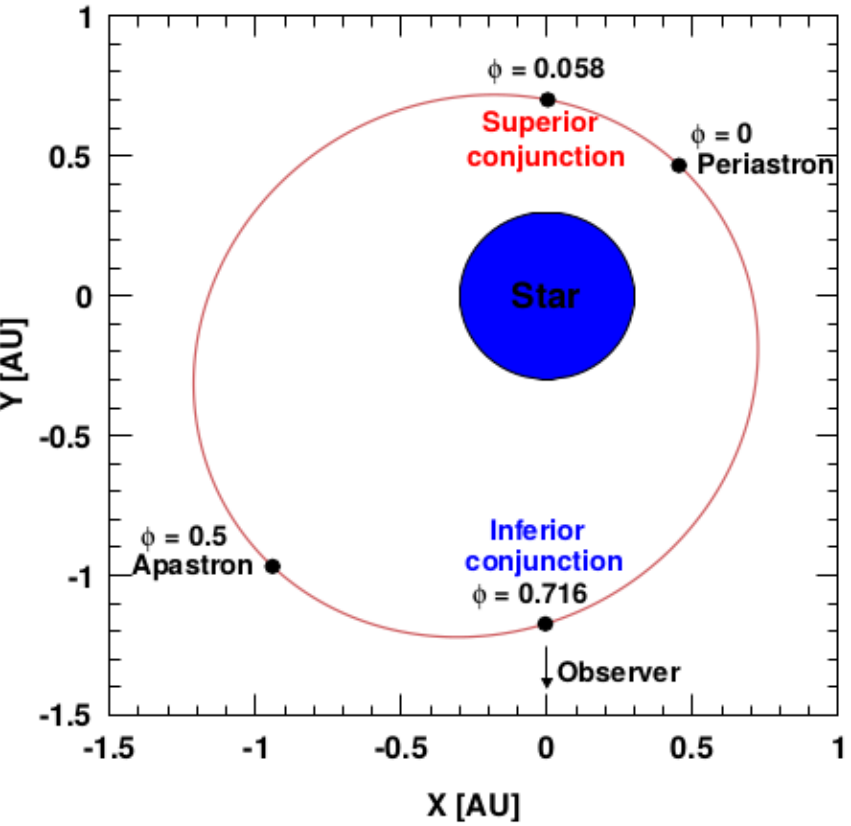


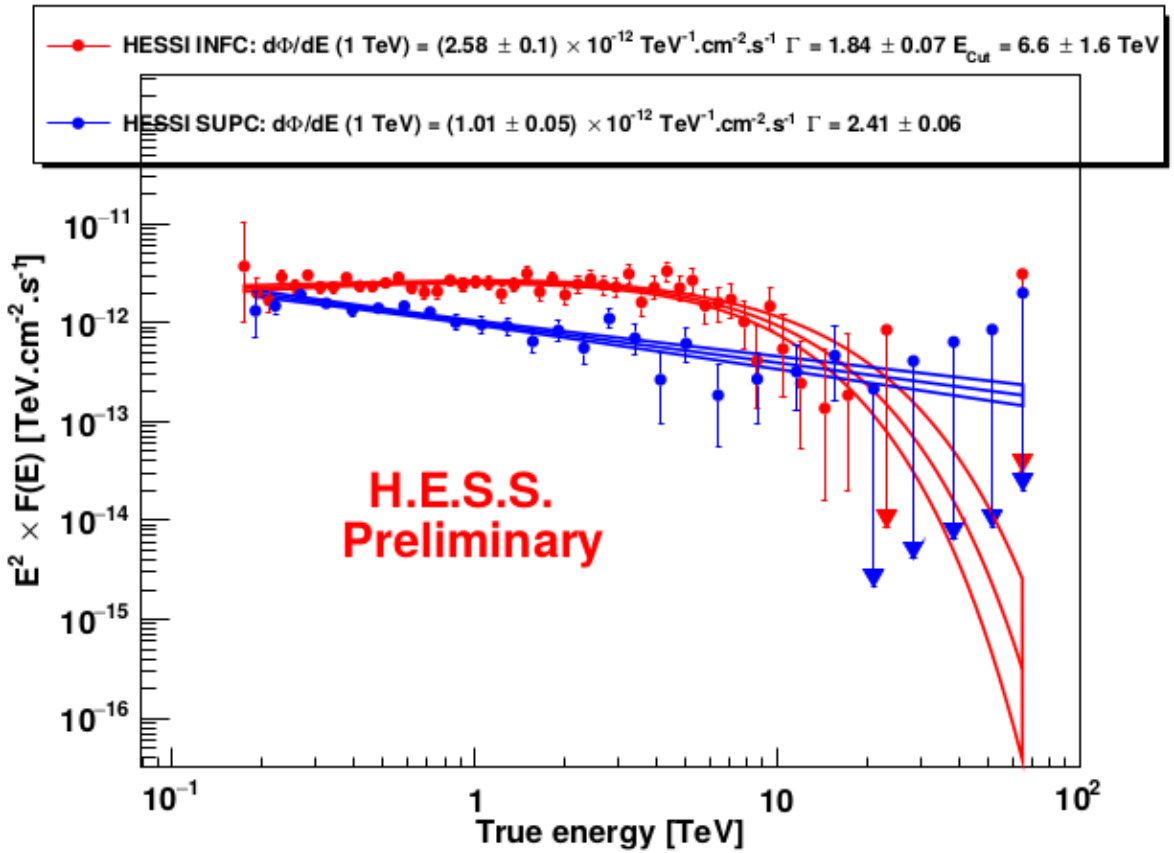


LS 5039

- Binary system of compact object (3.7 M_sun) and massive star (23 M_sun):
- Orbital period 3.9 days

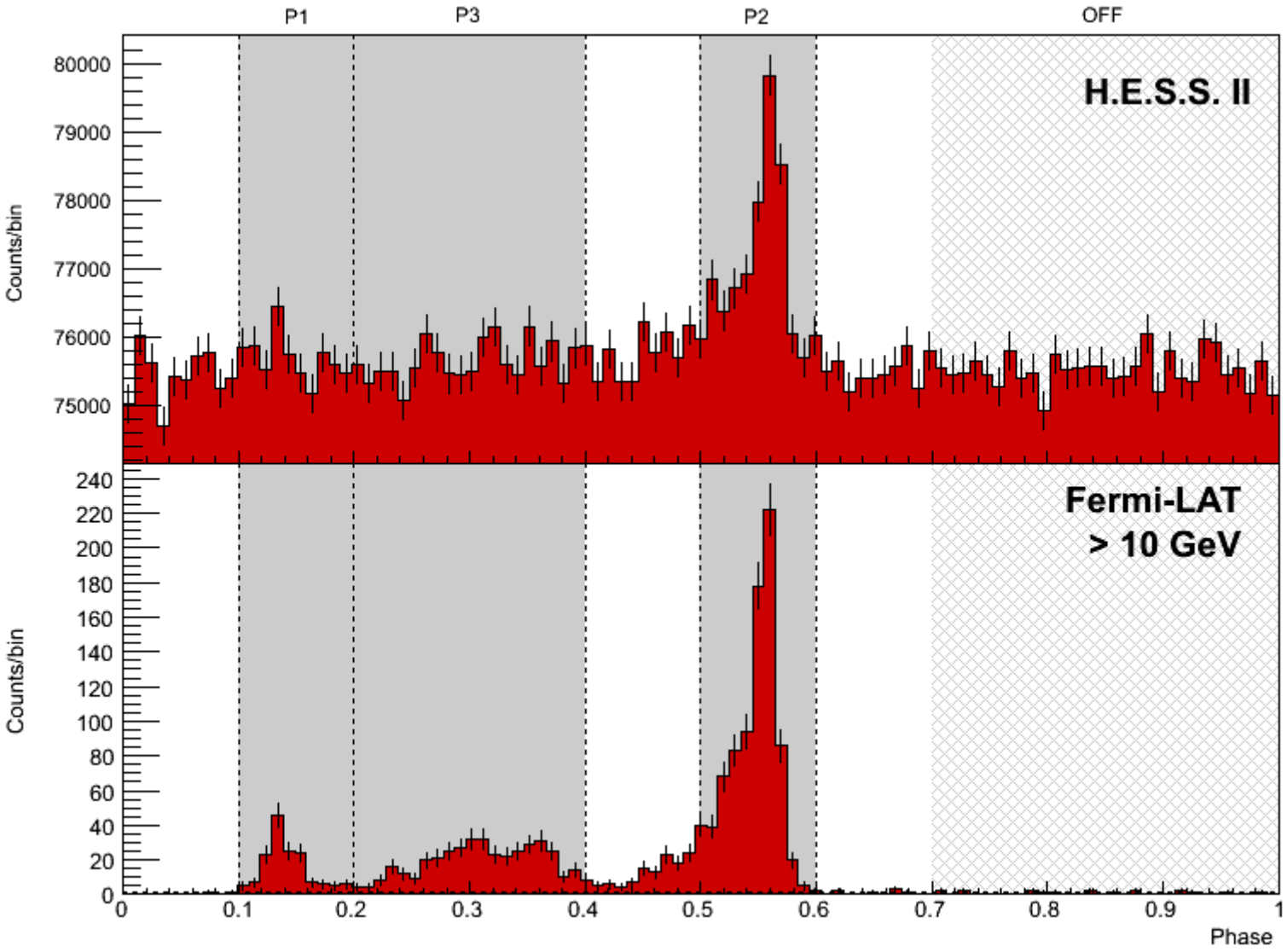
- H.E.S.S. probes the spectral evolution as a function of the orbital phase





C. Mariaud, Gamma2016, Heidelberg

Vela Pulsar detection with H.E.S.S. II Mono



P2 is detected with ~16000 excess events at a significance of > 15 σ

P1 & P3 show some excess, but they are not significant

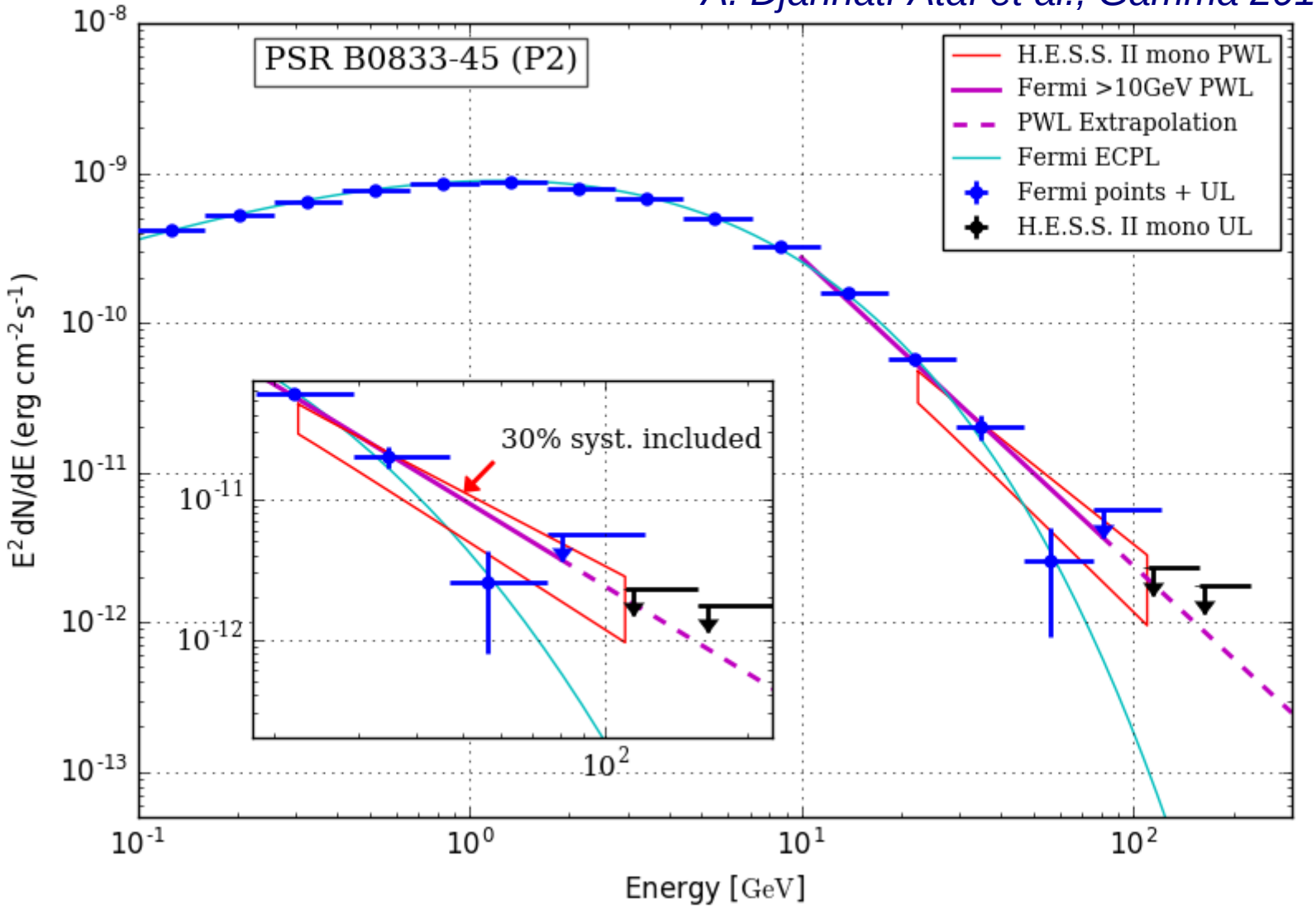
Second VHE pulsar! (after Crab)

A. Djannati-Ataï et al., Gamma 2016, Heidelberg

Vela Pulsar SED

Exponentially cut-off model is preferred over straight power-law extrapolation of Fermi spectrum

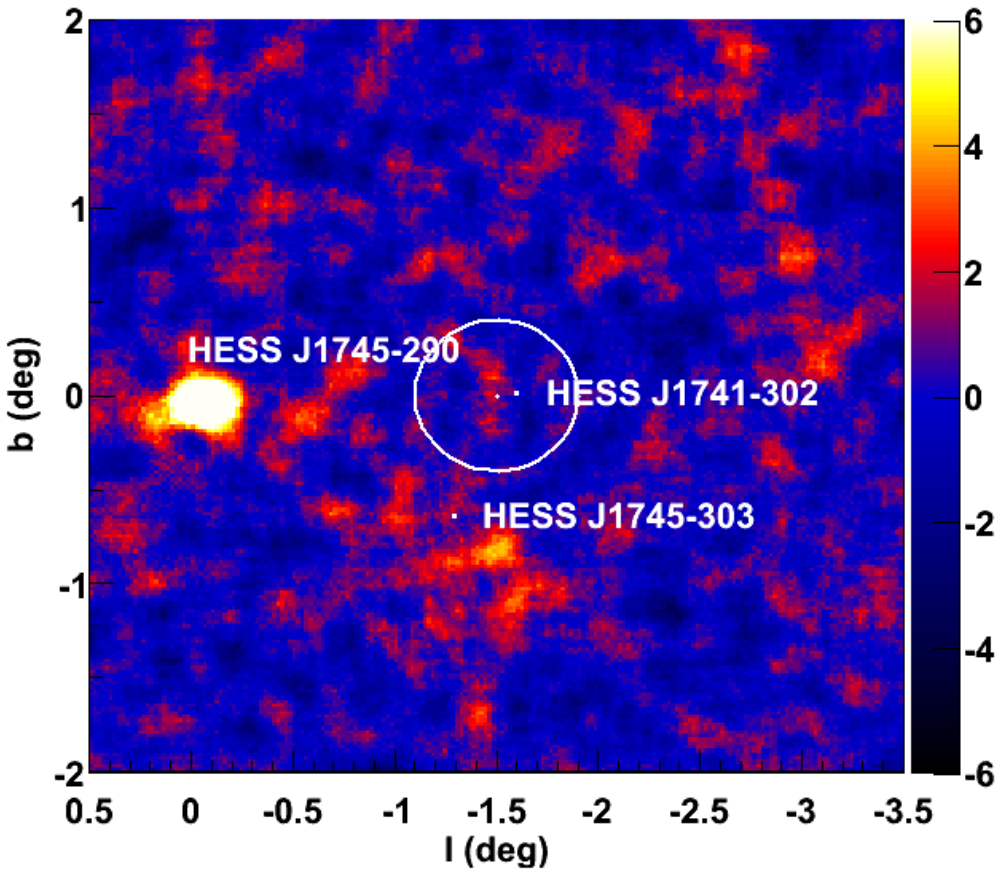
A. Djannati-Ataï et al., Gamma 2016, Heidelberg

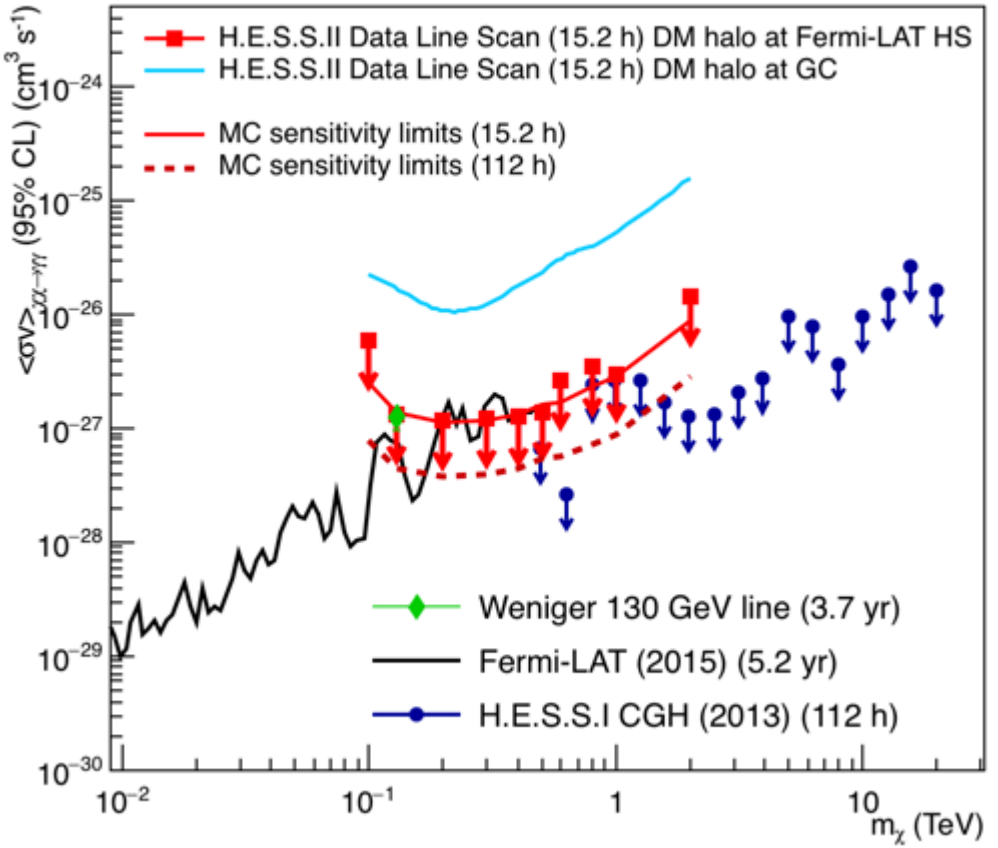


Upper Limits on the 130 GeV Fermi Line

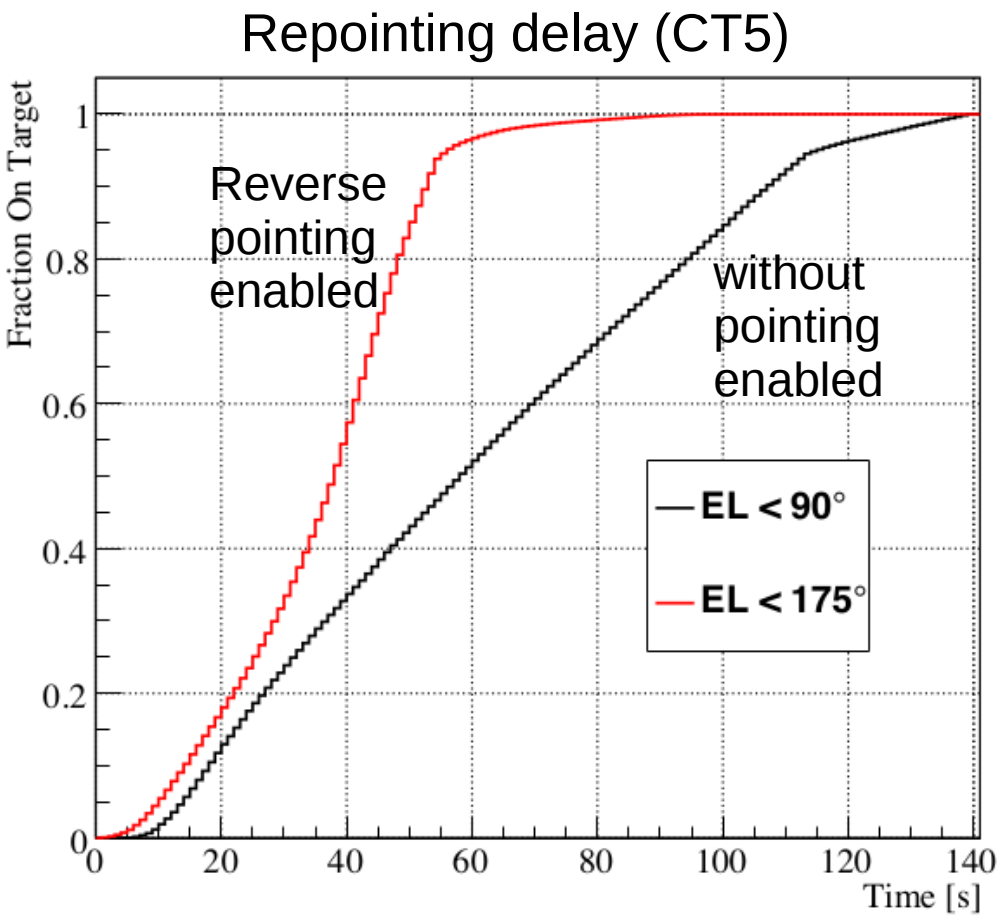
Phys. Rev. Lett. 117, 151302

- HESS II stereo analysis shows no evidence of 130 GeV excess at the Fermi hotspot position
- Upper limits derived from H.E.S.S. II stereo analysis
- Exclude the 130 GeV line at 95% C.L.





HESS GRB observation scheme



- **Automatic follow-up on prompt GRB alerts**
- 180 degree azimuthal rotation in 110 s
- Possible to drive the telescopes through zenith rather than rotate by 180 deg (reverse mode)
- System now supports alerts via GCN and VO
- Can also follow neutrino, FRB and **gravitational wave alerts**
- „**Afterglow“ observations** can be **scheduled manually** (e.g. when the source rises above horizon)

R. D. Parsons et al, Gamma 2016, Heidelberg

H.E.S.S. and gravitational waves

Potential role of H.E.S.S.

- Search for VHE gamma-ray counterparts
  - Yes = discovery
  - No = upper limits
- In case of VHE detection, refine localisation (~ 0.1° PSF)
  - Better localisation than GW itself, Fermi GBM, ...
  - Good enough for X-ray follow-up (e.g. Swift)

Challenges

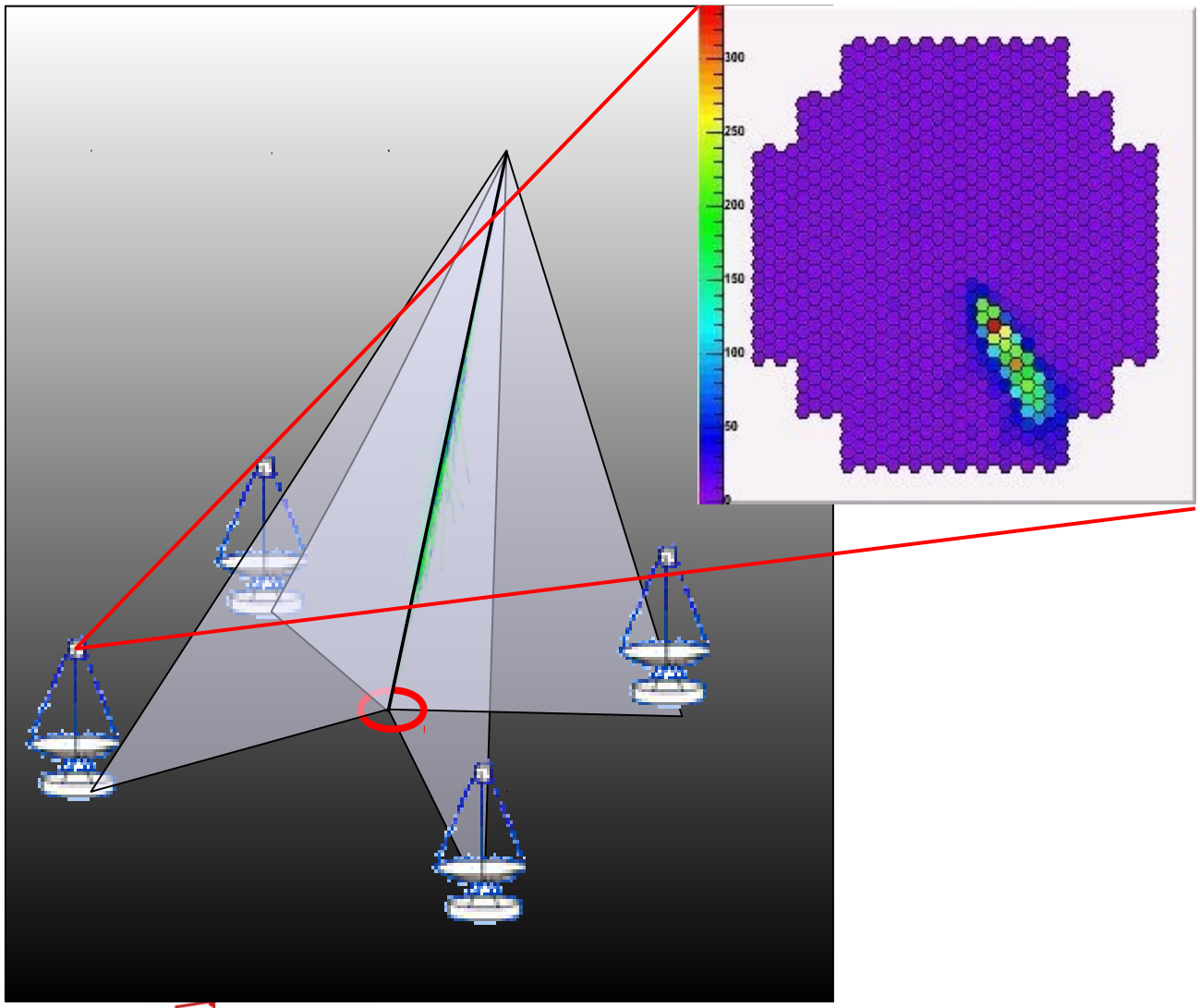
- GW localisation region typically much larger than HESS field-of-view (5 deg diameter)
  - Need better localisation (either from GW detectors or MWL counterparts)
- Limited duty cycle of H.E.S.S. (Sun, Moon, weather, ...)
  - Prompt follow-up not always possible

Conclusion

- HESS Galactic Plane Survey is complete and final results are about to be released
- Many other results from H.E.S.S. I data analyses (not possible to cover all here)
- First H.E.S.S. II journal publications, many new results on the way (spectral measurements of AGNs, Fermi line limits, new FSRQ detections, binaries, Sgr A*, ...)
- H.E.S.S. I camera electronics is now being upgraded to optimize the array performance
- Operations assured through 2017; extensions under ducussion

Backup

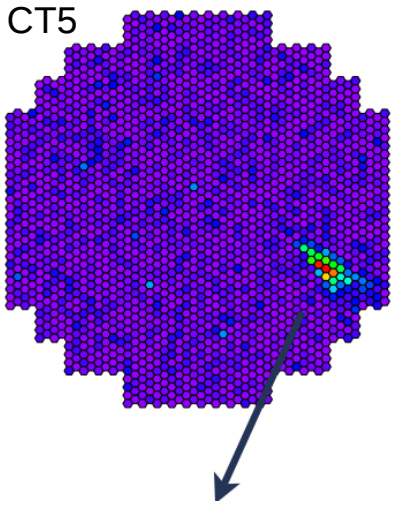
Imaging Atmospheric Cherenkov Telescope technique



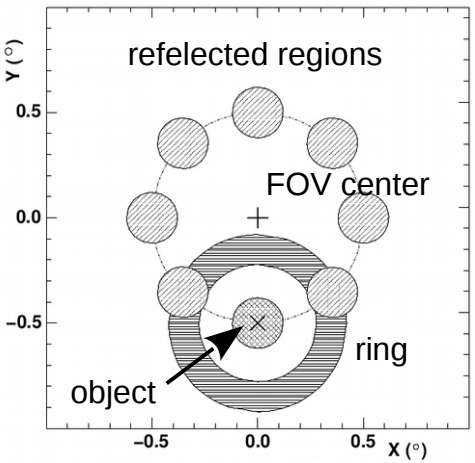
- Shower develops in the atmosphere
- Ultra relativistic e± emit Cherenkov light ~10 km above ground
- Cherenkov light is focues by large segmented mirrors
- Fast camera (1 ns) installed at the telescope's focal plane records the image of the shower
- Stereoscopy greatly improves reconstruction and identification of particles

H.E.S.S. II Mono Analysis

- Relies on **fine-pixelated CT5 camera images**
- The **Model Reconstruction** (*M. de Naurois & L. Rolland, Astropart. Phys. 32 (2009) 231*) **adapted for Mono analysis** (*M. Holler et al., ICRC 2015 I/509 (poster)*)
- Event selection **cuts optimized for soft spectrum** (photon index 3 or softer), giving consideration to systematic errors

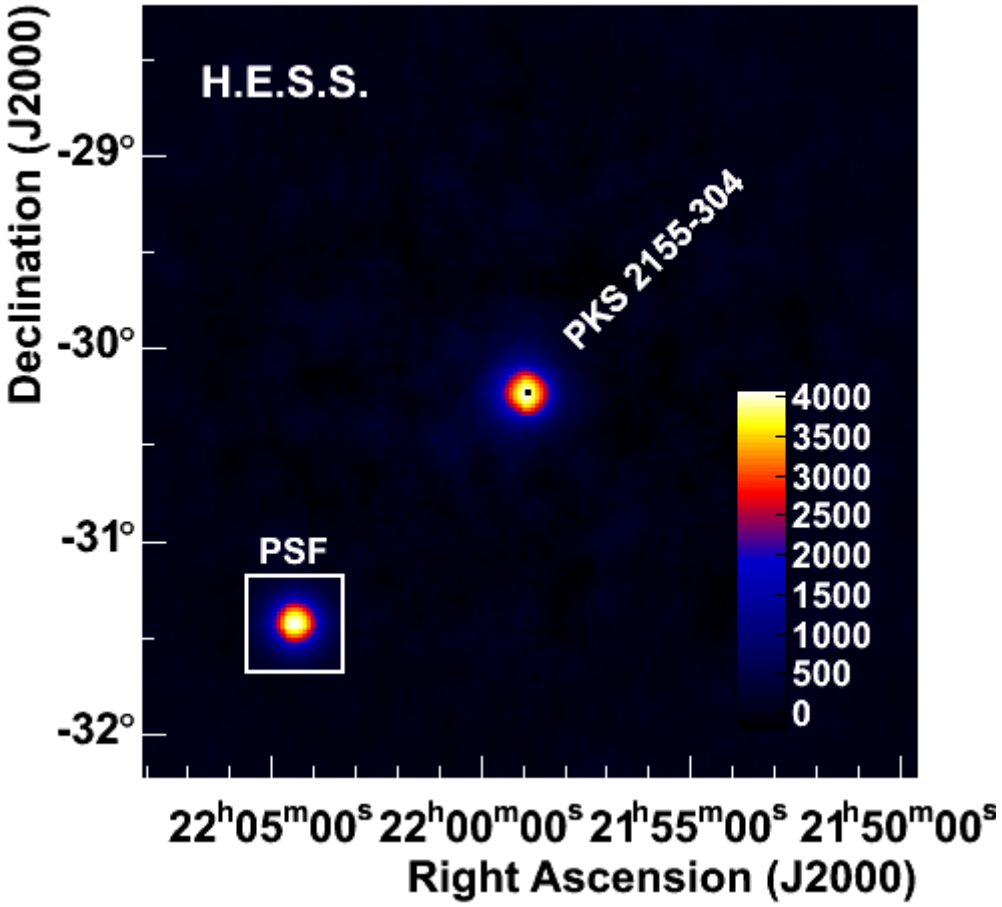


Fit image with model template
==> direction, energy, ...

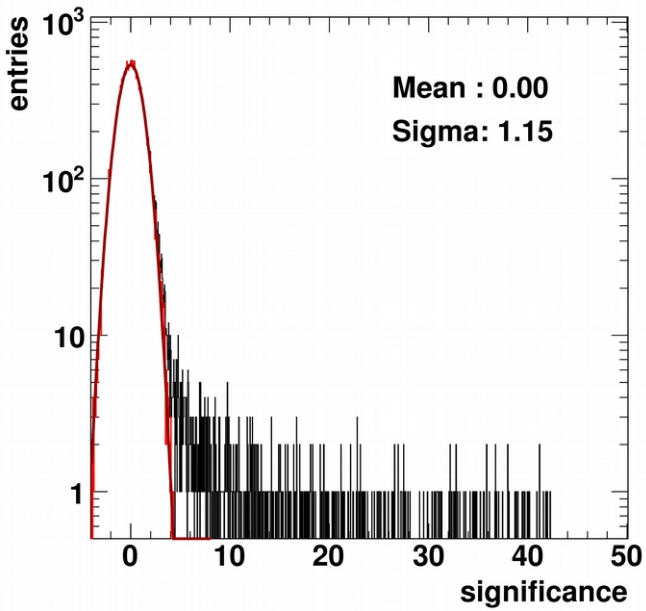


- **Run Quality** selection includes meteo information, trigger rates, camera sanity and telescope tracking status
- Maps are generated using the **Ring Background** method; θ^2 distributions and spectra are obtained using the **Reflected Region** method (*F. Aharonian et al., A&A 457 (2006) 899, D. Berge et al., A&A 466 (2007) 1219*)

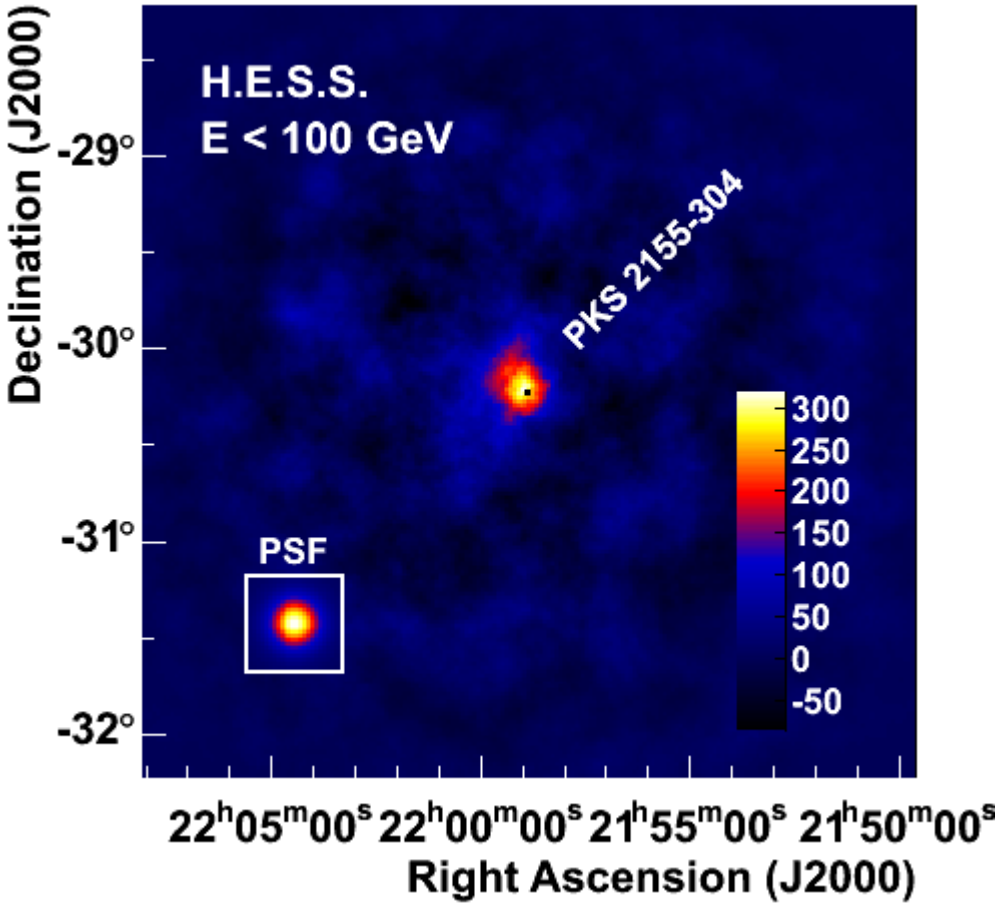
PKS 2155-304



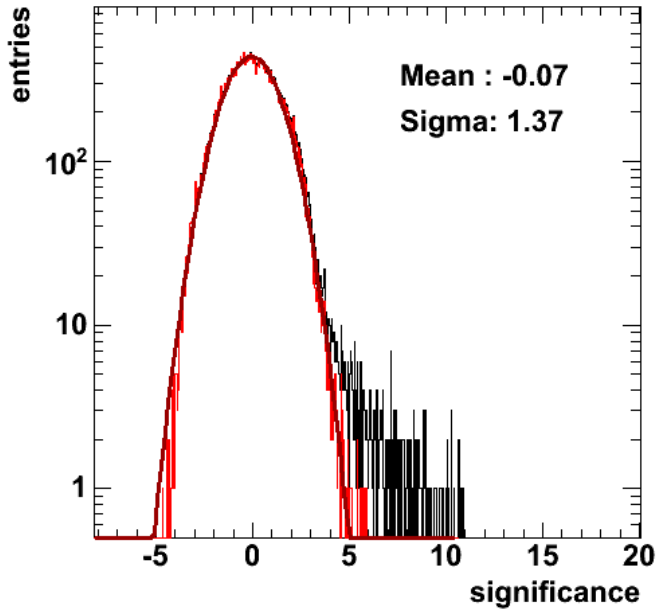
- The source is detected at ≈ 42 s
- (56 hr live time, Mono Standard cuts)
- The energy threshold is ≈ 80 GeV
- (median zenith = 16°)
- Background under control



PKS 2155-304 at E < 100 GeV

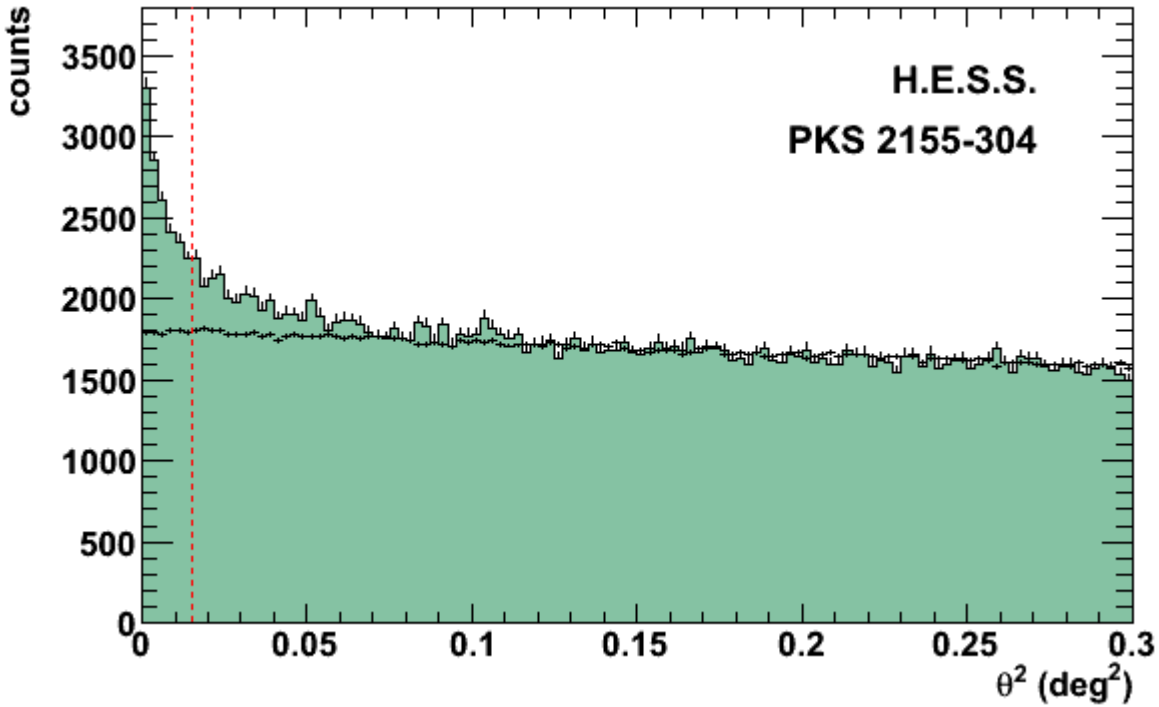


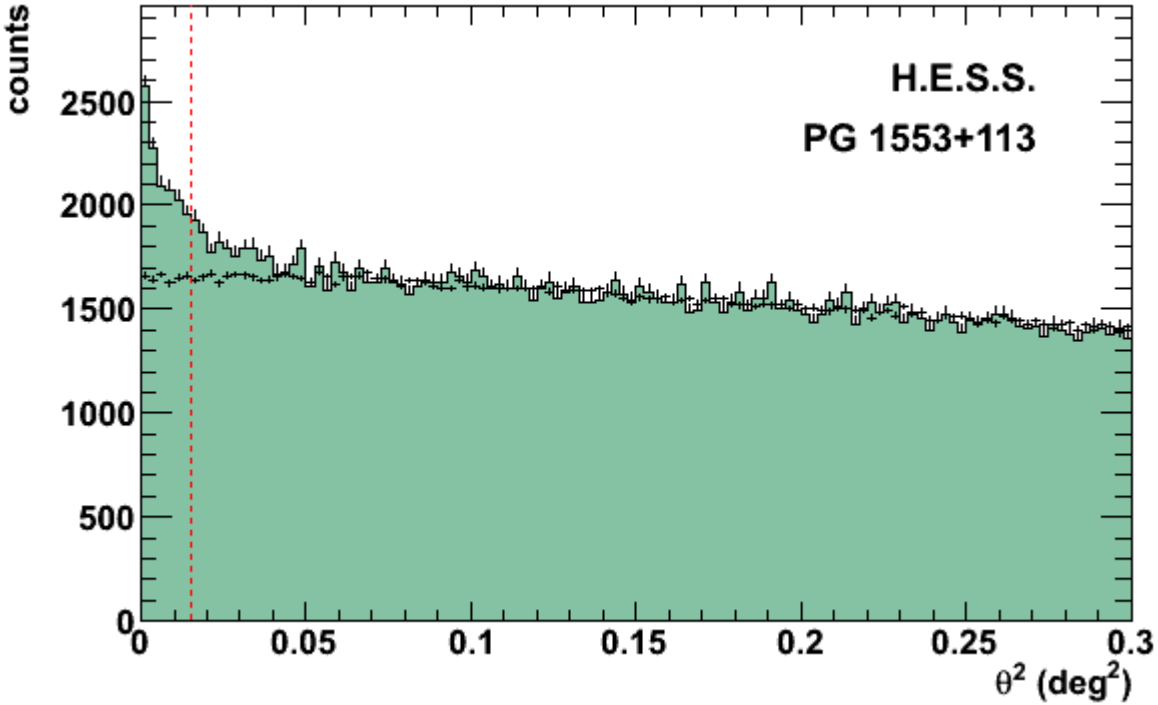
- Using only events with reconstructed energy < 100 GeV, the source is detected at 10 s
- Systematic effects in background subtraction limit our sensitivity at low energies

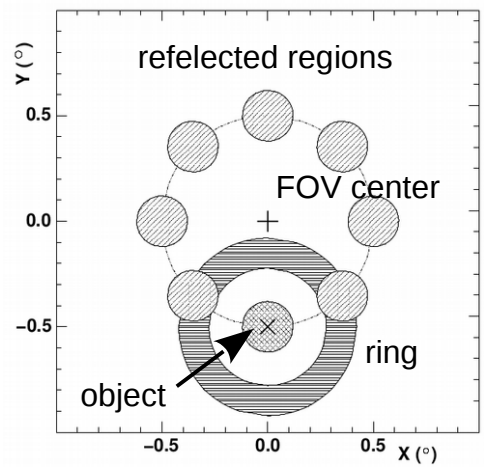


Theta2 plots

- Plot of θ^2 (squared angular distance from target position) using the reflected background method (with multiple OFF regions)
- Cut at θ^2 = 0.015 deg2



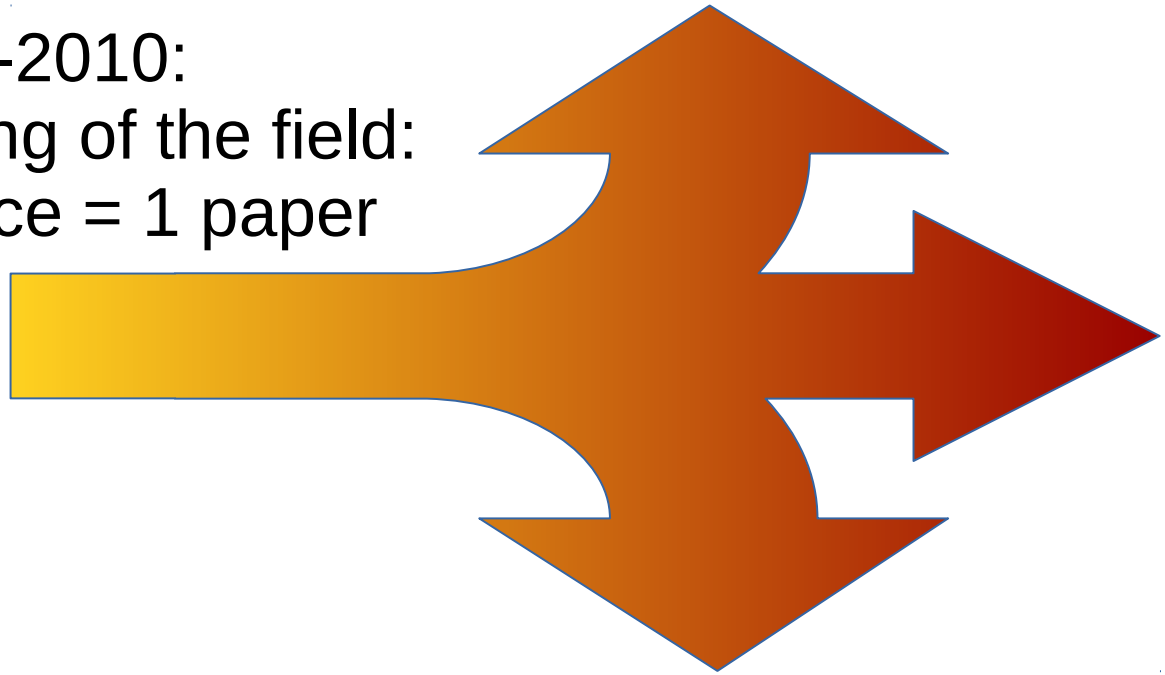




Directions for VHE gamma astronomy

Surveys, populations studies

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



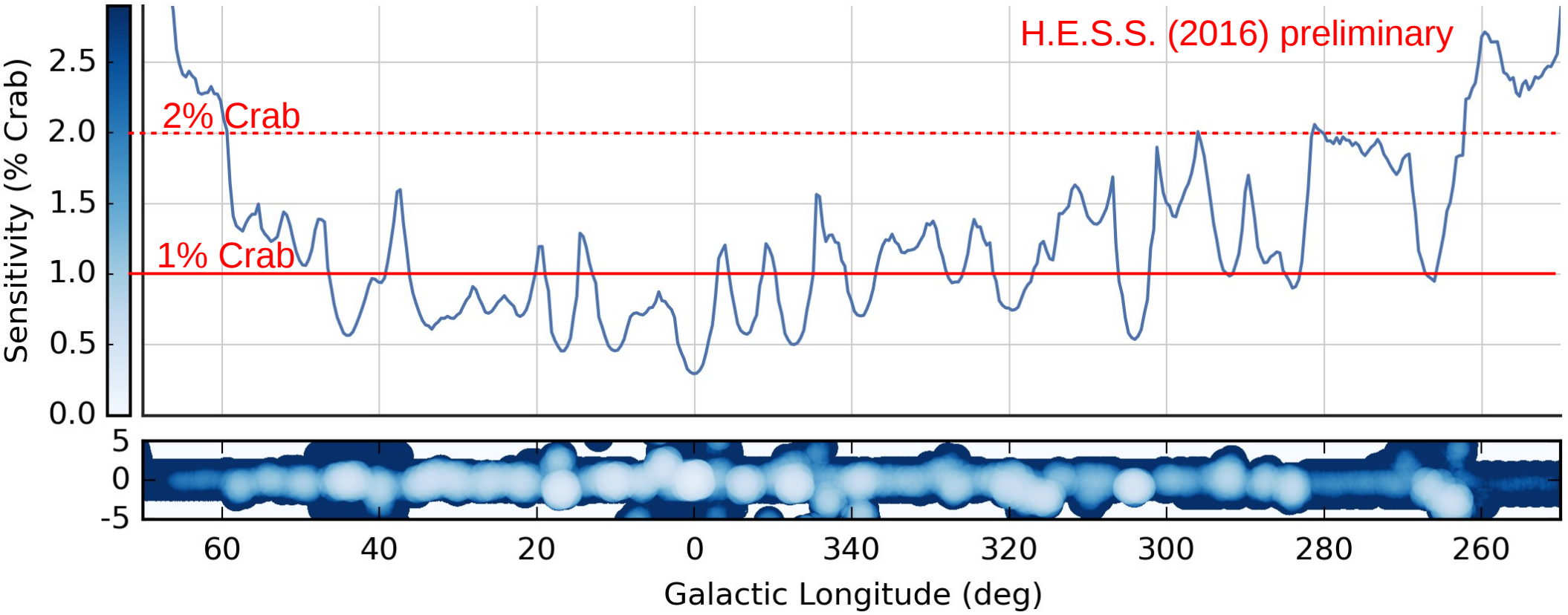
Key Science projects,
Deep investigation
of specific objects

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

Slide from M. De Naurois, ICRC 2015

HGPS sensitivity profile

- Point-like 5 sigma sensitivity



Microquasars

- H.E.S.S. observations of three targets in 2004, contemporaneous with RXTE observations:
  - GRS 1915+105, after flux decrease in radio band (15 GHz), Apr 28–May 3
  - Circinus X-1, covered periastron period, June 18–20
  - V4641 Sgr, after rapid brightening in radio, optical and X-ray regimes, July 7–8
- No detection in HESS; upper limits set
- Paper accepted by A&A: http://dx.doi.org/10.1051/0004-6361/201527773

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

H.E.S.S. Collaboration, H. Abdalla[1], A. Abramowski[2], F. Aharonian[3, 4, 5], F. Ait Benkhali[3], A.G. Akhperjanian[6, 5], E.O. Angüner[7],