# H.E.S.S.

**Christian Stegmann for the H.E.S.S. collaboration**

**The Future of Research on Cosmic Gamma Rays**
**August 2015, La Palma**

# The H.E.S.S. Collaboration

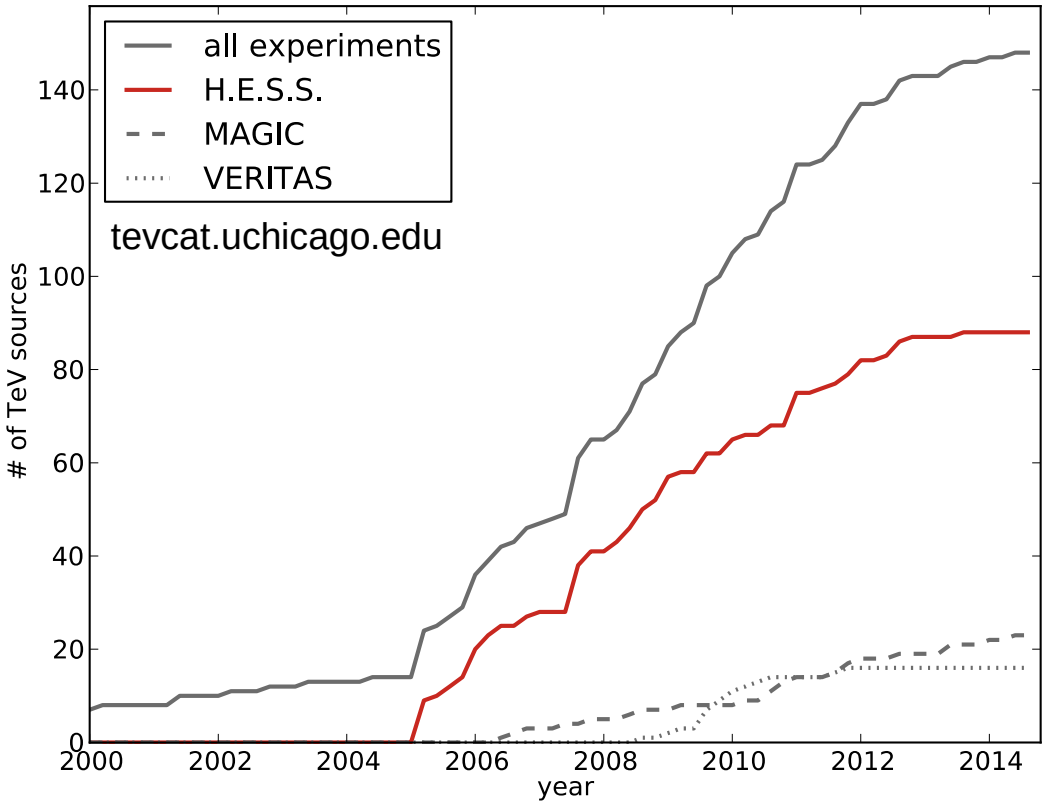
- MPI Kernphysik, Heidelberg, Humboldt Univ. zu Berlin, Ruhr-Univ. Bochum, Univ. Erlangen-Nuremberg, Univ. Hamburg, LSW Heidelberg, Univ. Potsdam, Univ. Tübingen, DESY
- Ecole Polytechnique, Palaiseau, APC Paris, Univ. Paris VI-VII, Univ. Bordeaux, Observatory Paris, Meudon, LAPP Annecy, LUPM Montpellier, CEA Saclay, IPAG Grenoble
- Stockholm University, Royal Institute, Linnaeus University, Durham Univ., Univ, Leicester, Dublin Inst. for Adv. Studies, GRAPPA U. Amsterdam
- Polish Academy of Sciences; Jagiellonian University, Cracow; Nicolaus Copernicus University, Torun; University of Warsaw, Warsaw
- Univ. Adelaide, North-West Univ., Potchefstroom, Wits Univ., Johannesburg, Univ. of Namibie, Windhoek

# The H.E.S.S. Experiment

- H.E.S.S. phase I
  - four 12m telescopes
  - FoV 5 deg
  - energy threshold 100 GeV
  - angular resolution < 0.1 deg
- H.E.S.S. phase II
  - four 12m telescopes
  - one 28m telescope (FoV 3.5 deg)
  - energy threshold O(30 GeV)
  - angular resolution from 0.4 deg to less than 0.1 deg

H.E.S.S. phase I H.E.S.S. phase II

# The H.E.S.S. Experiment



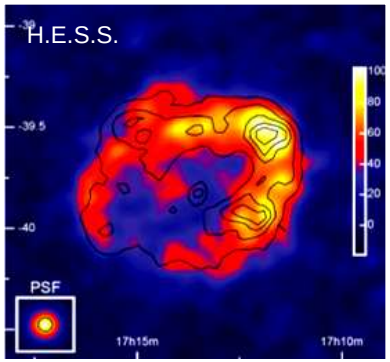

- H.E.S.S. phase I
  - more than 10000 hours of data
  - discovered over 80 new VHE gamma ray sources
  - published over 100 scientific papers, plus numerous conference contributions
- H.E.S.S. phase II
  - towards lower threshold and transients

H.E.S.S. phase I H.E.S.S. phase II

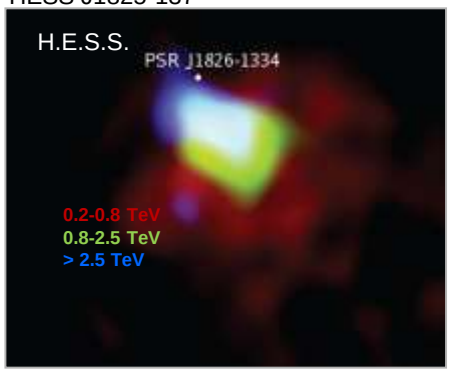
# H.E.S.S. Data Quality

- Morphologies
  - spacial
  - energy-dependent
- Periodicities/Variability
  - from ms to years
- Energy-coverage
  - over several decades
- Source position
  - on the arc-second level

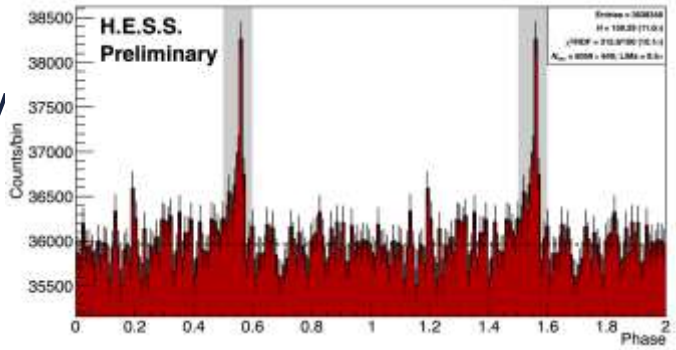
RX J1713-3946



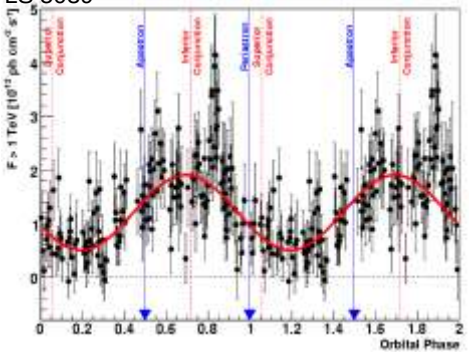

HESS J1825-137



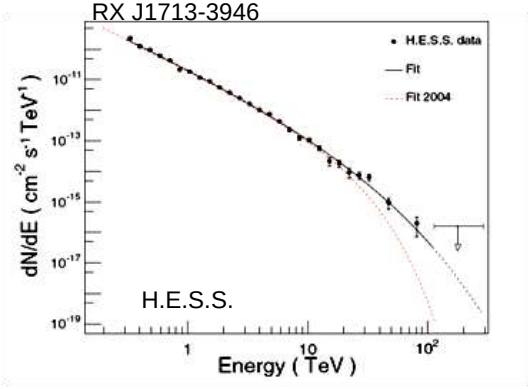

Vela pulsar



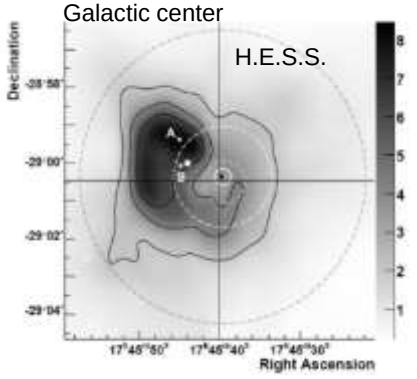

LS 5039




RX J1713-3946



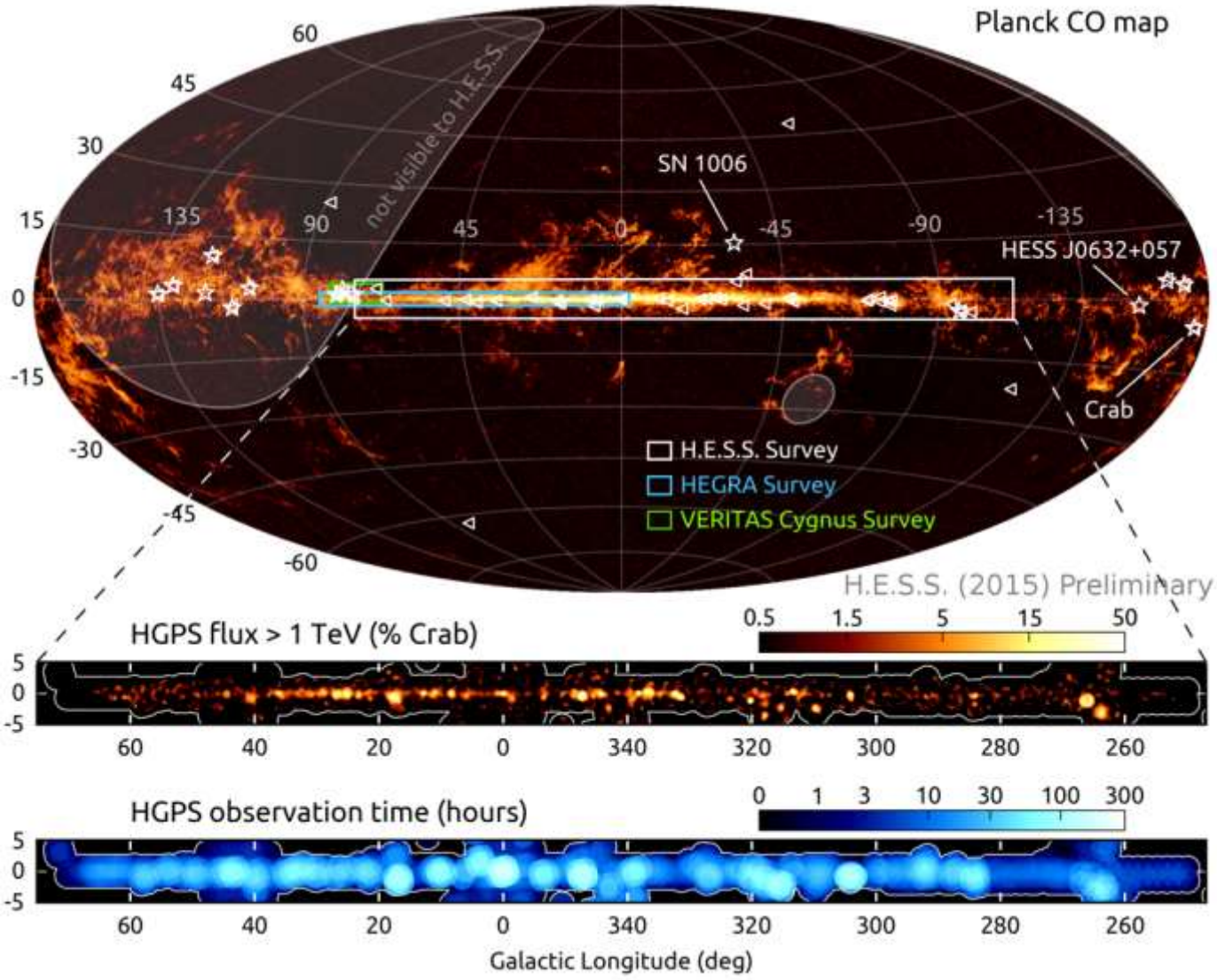

Galactic center



# This Talk

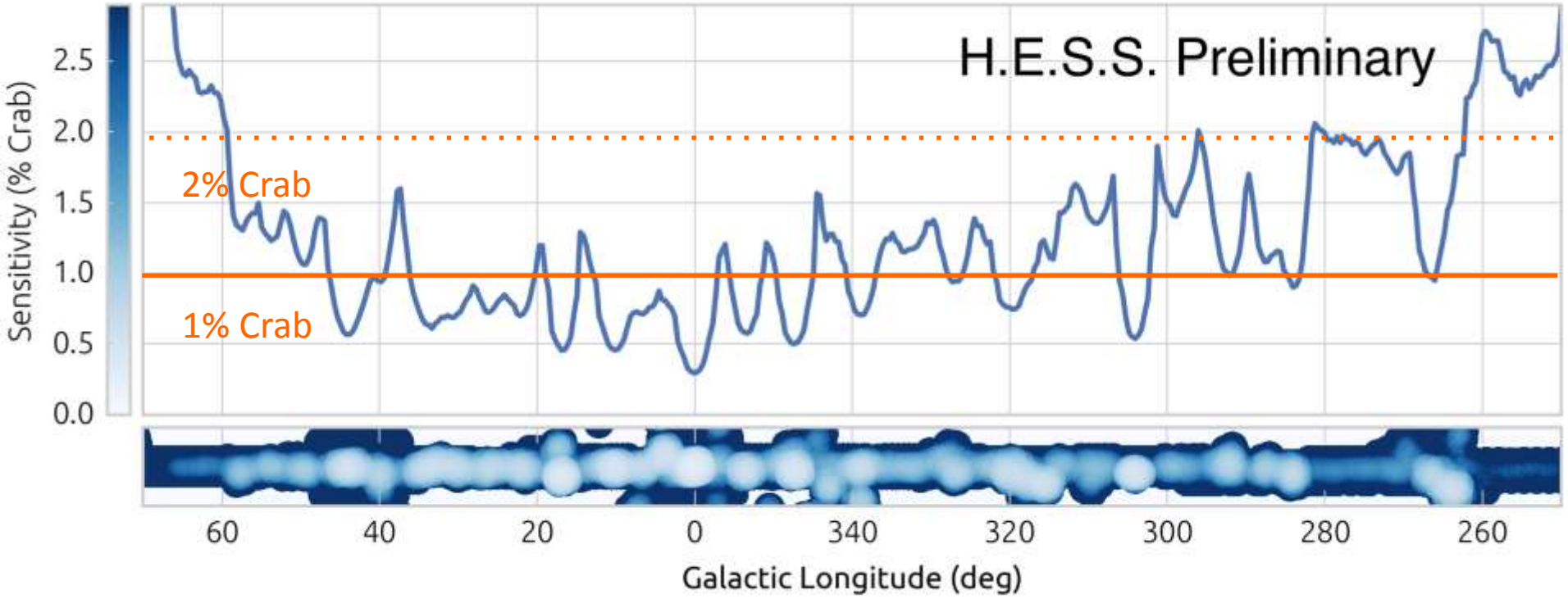
- Towards population studies of gamma-ray sources
- High precision physics of gamma-ray sources
- Pushing experimental borders

# H.E.S.S. Galactic Plane Scan



# H.E.S.S. Galactic Plane Scan

- 2673 hours of high-quality data, taken in the years 2004 to 2013.
  - Longitude l = 250 to 65 degrees, latitude |b| < 3.5 degrees
  - Sensitivity for the detection of point-like sources is at the level of 2% Crab or better



# H.E.S.S. Galactic Scan

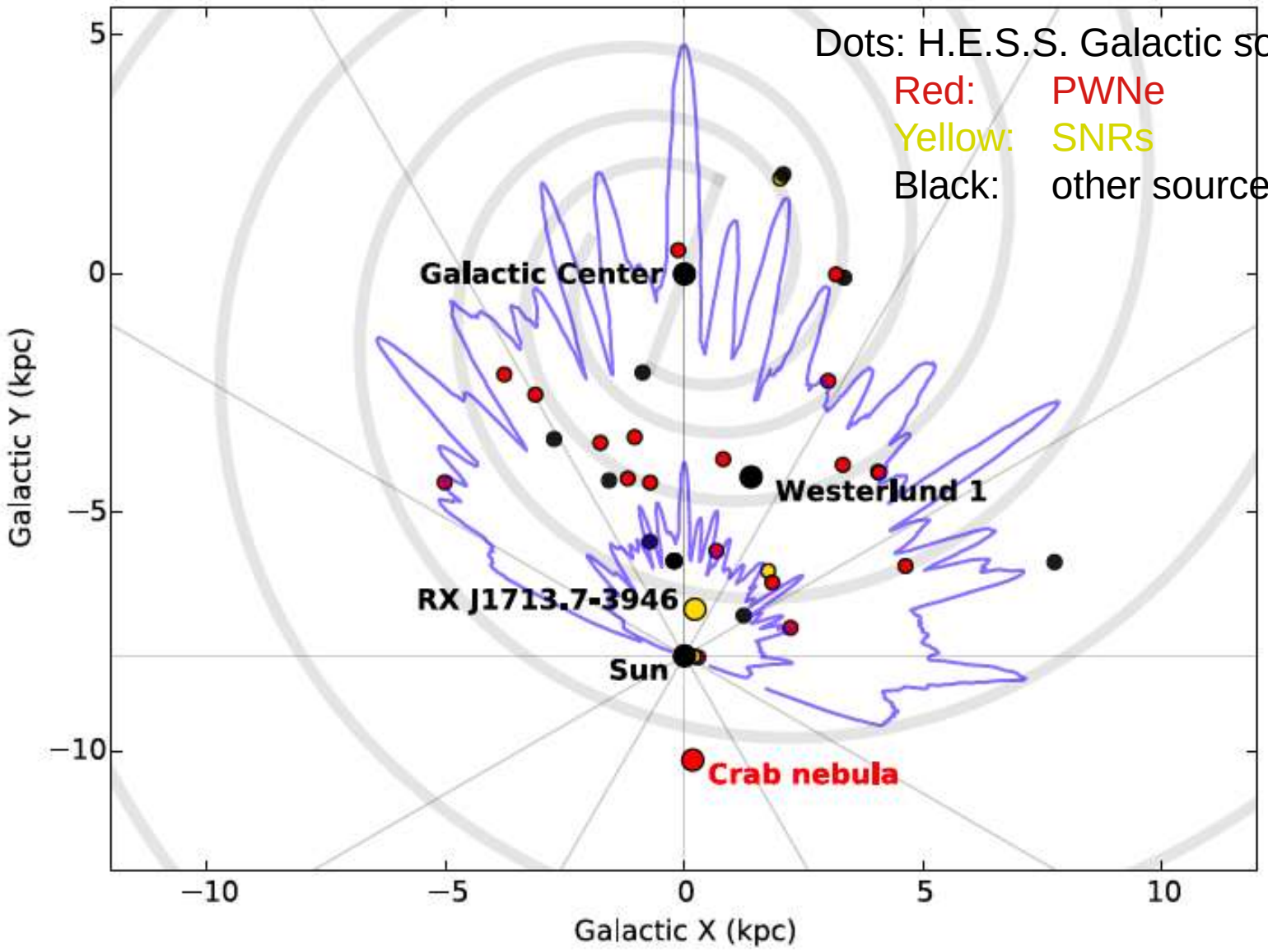
Blue lines: H.E.S.S. horizons for 1% and 10% Crab

Dots: H.E.S.S. Galactic sources

Red: PWNe

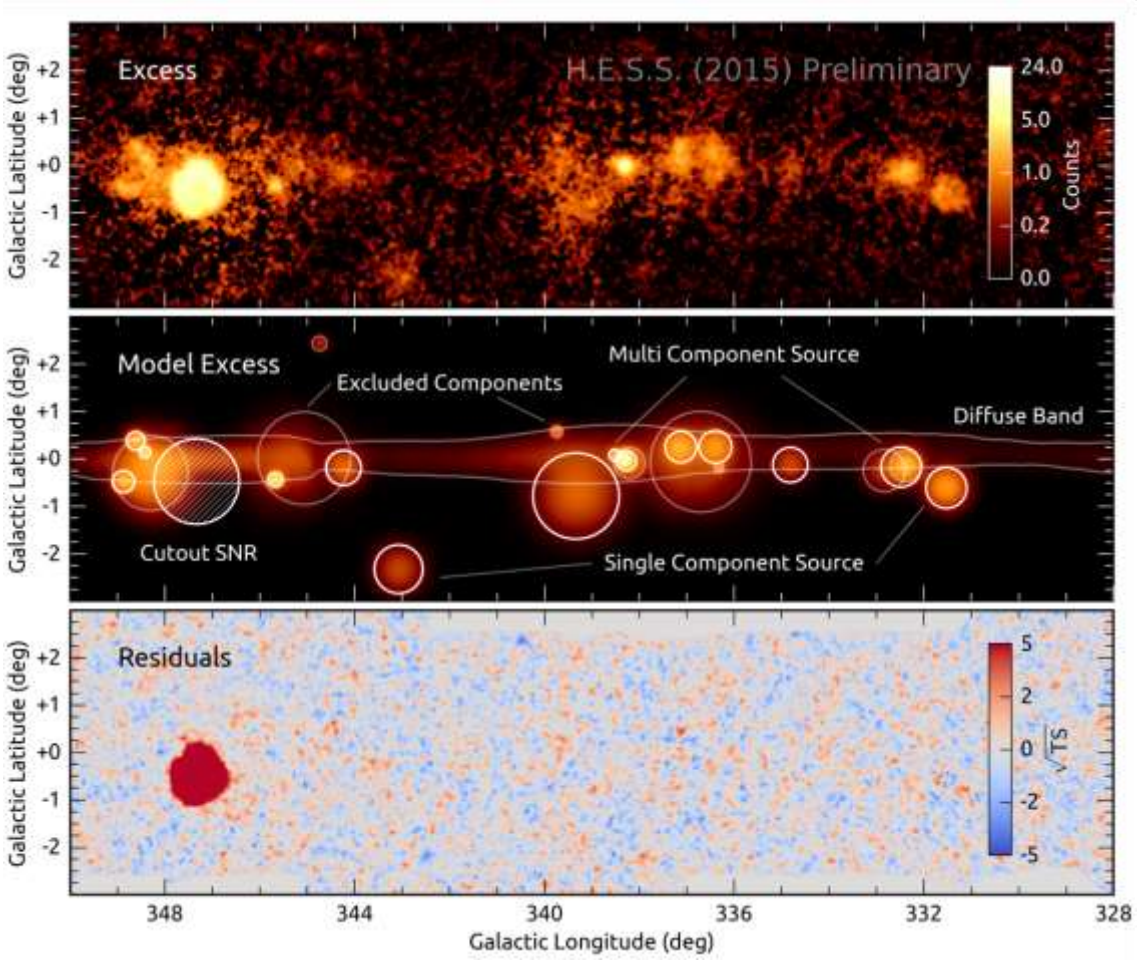
Yellow: SNRs

Black: other sources

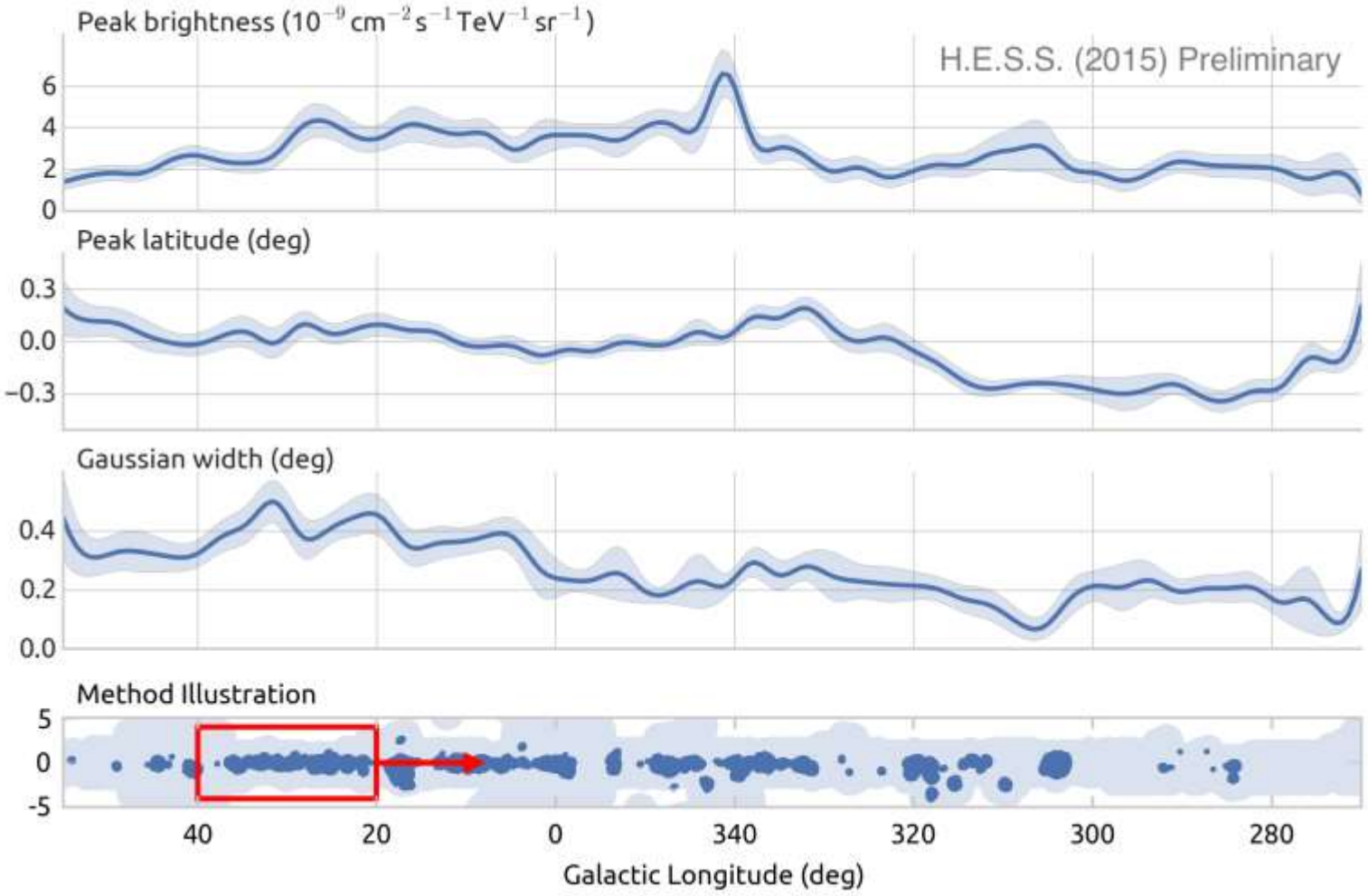


# Morphology Model

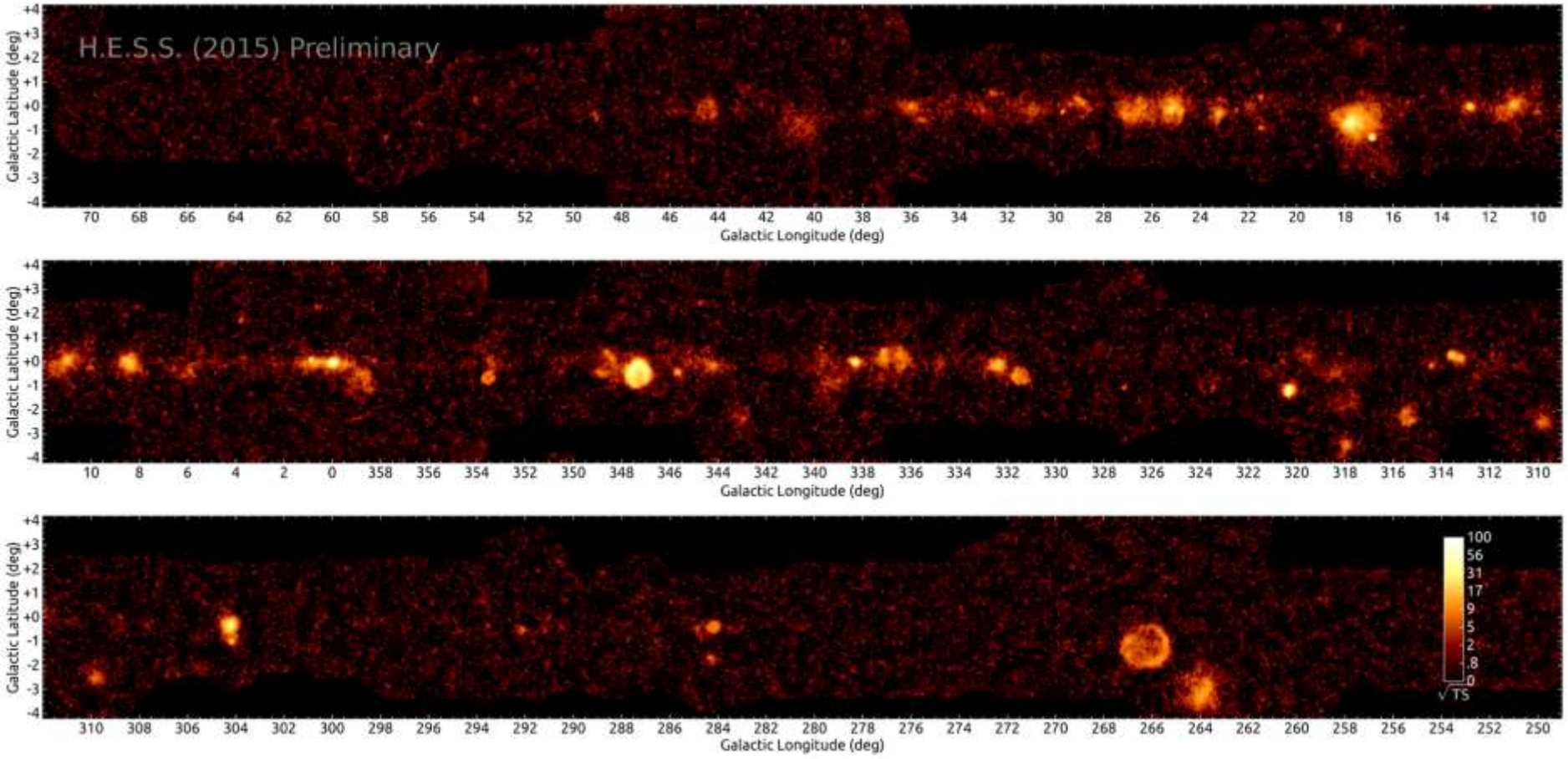
- Source extraction with automatic pipeline
- Likelihood fit of emission by multiple Gaussian components plus diffuse background, Overlapping emission components combined
- HGPS catalog
  77 = 64 + 13 complex sources (e.g. shell SNR) excluded from pipeline



# Gaussian Band Large-Scale Emission Model



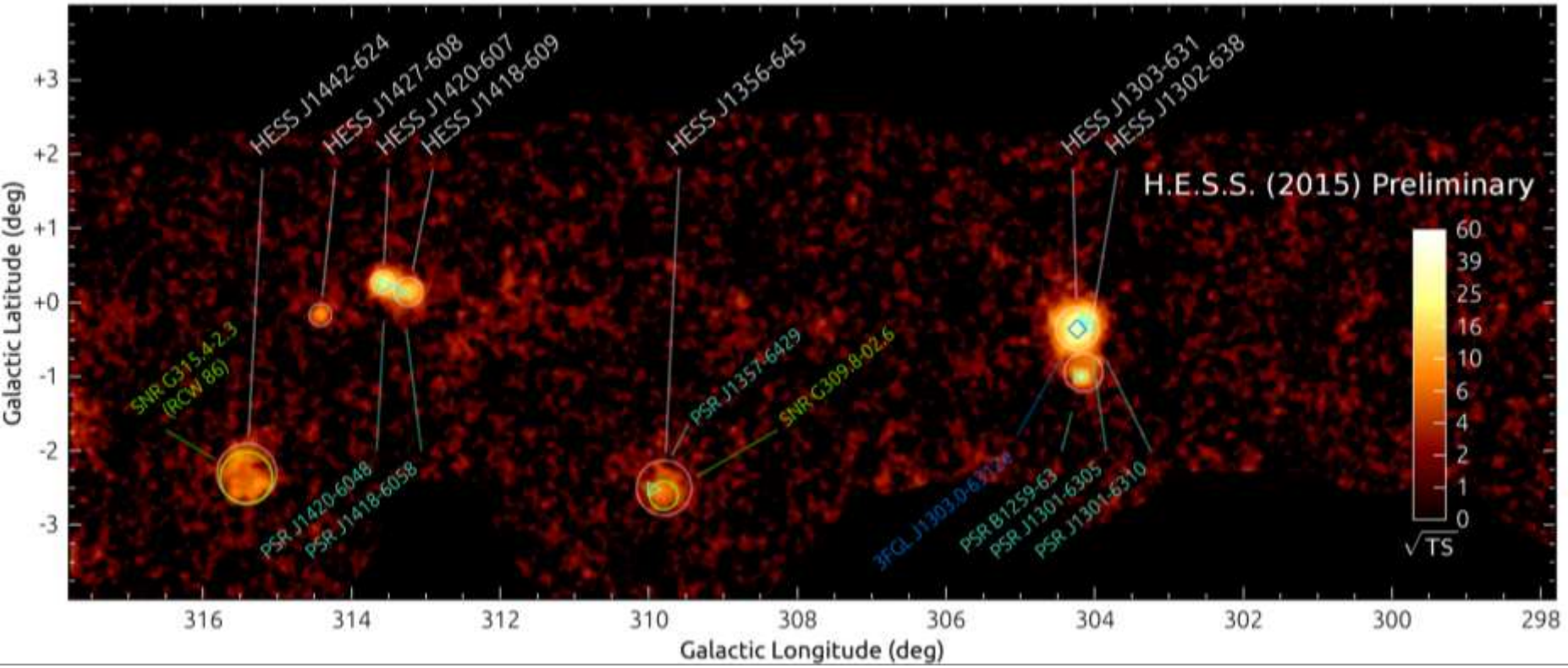
# The Galactic Plane in Gamma-rays



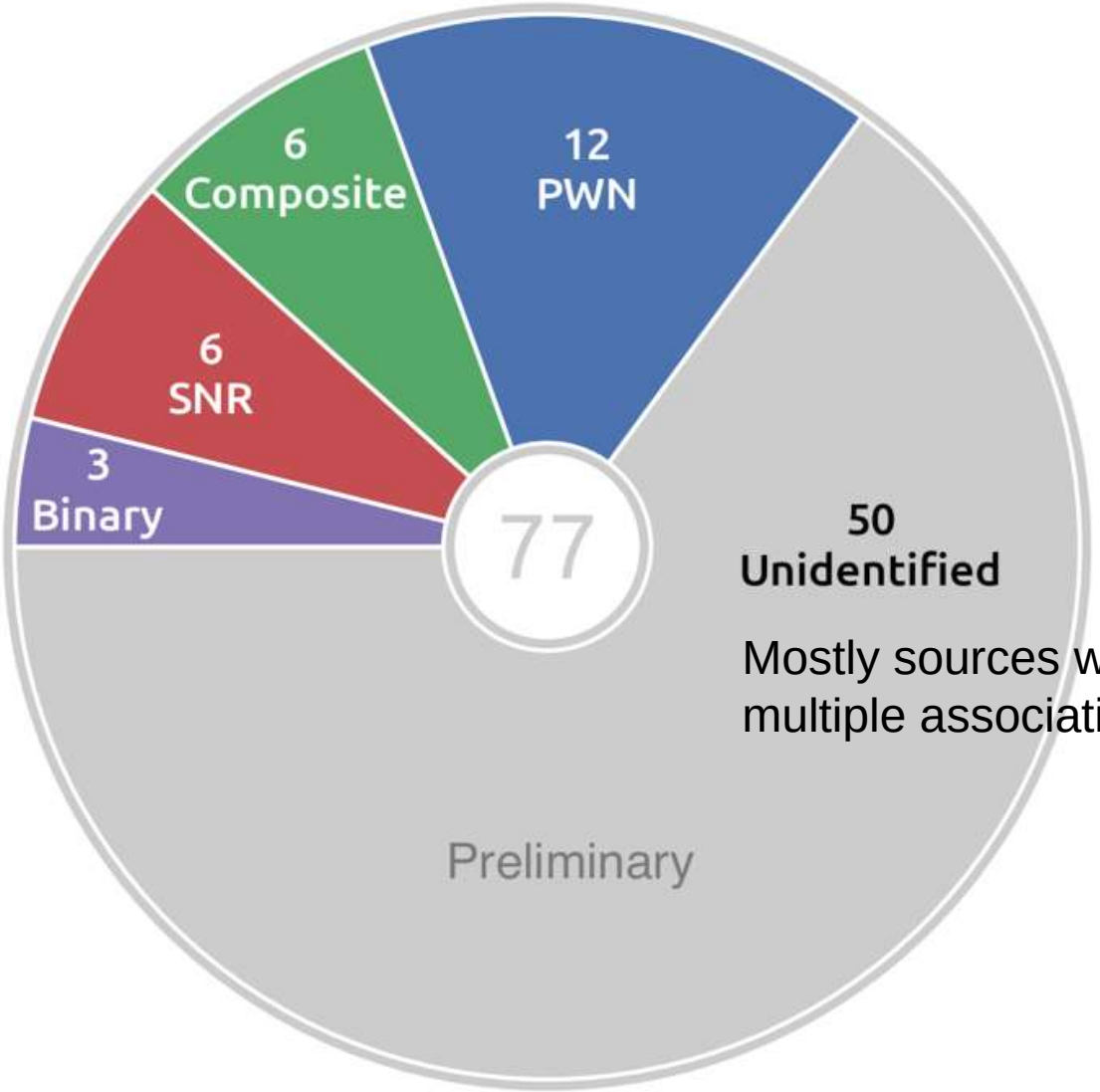

H.E.S.S.

# Associations

- Systematic association of HGPS sources with nearby PSR, SNR, PWN, GeV sources (3FGL and 1FHL)

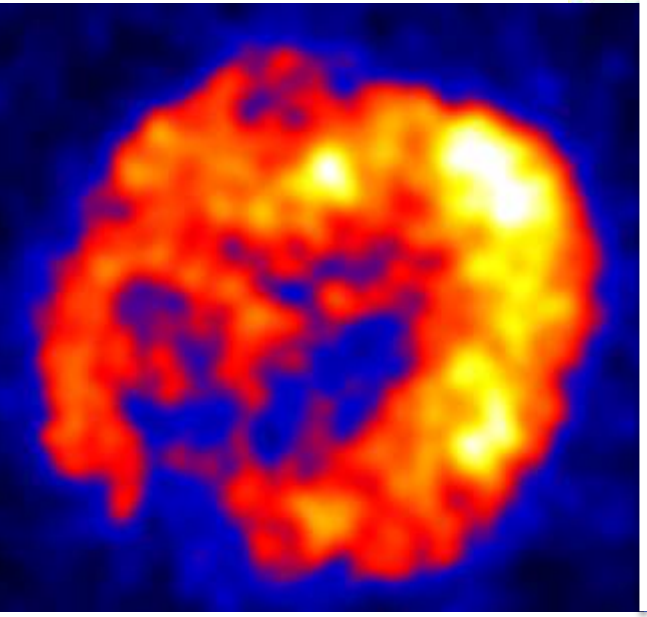


# Identifications

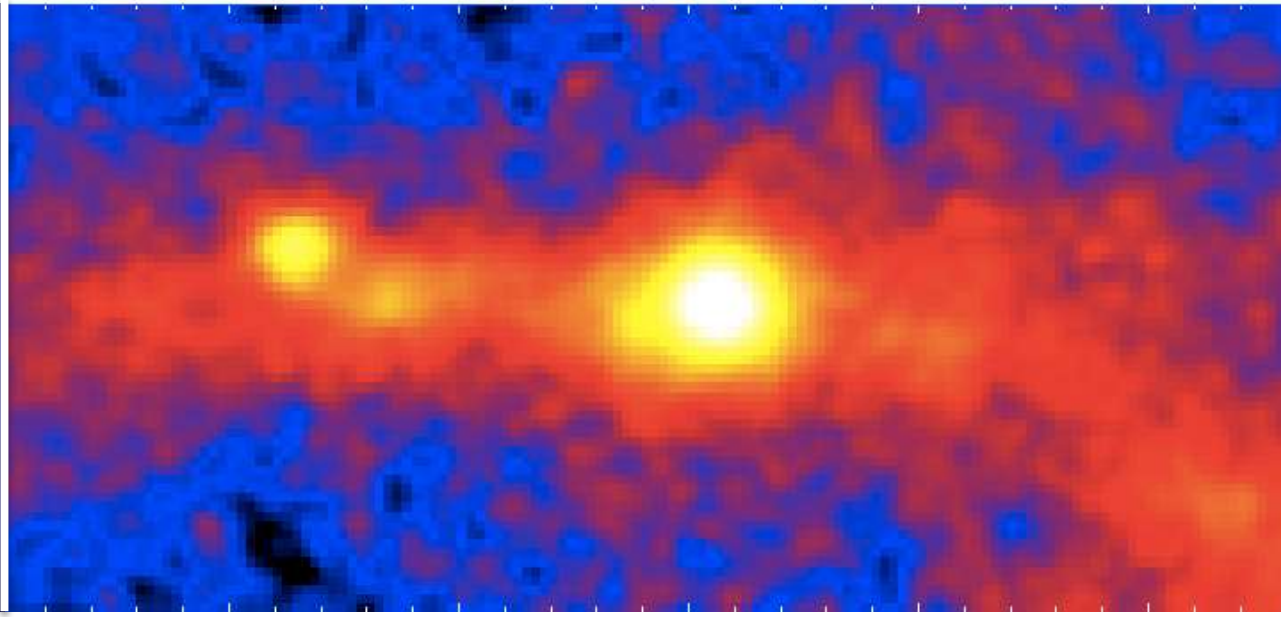



Mostly sources with multiple associations

# Towards Precision Physics

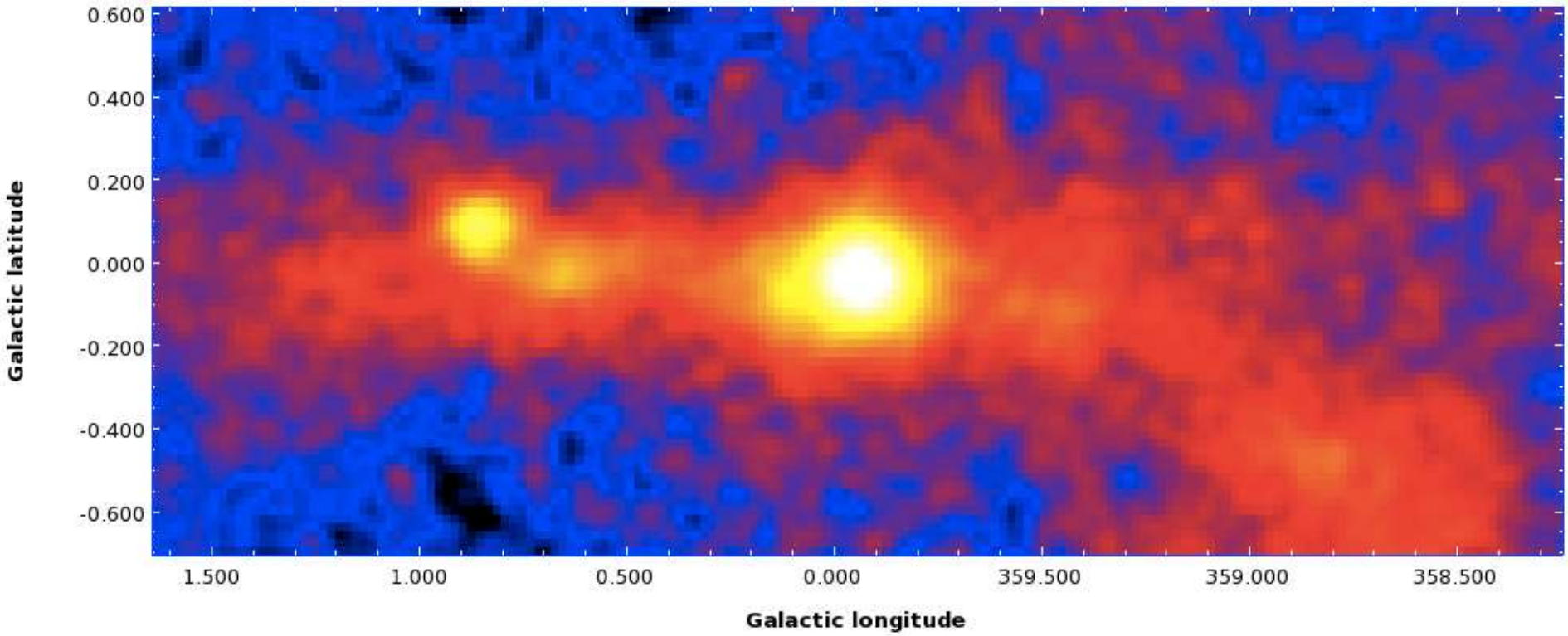


RX J1713-3946



Galactic Center Region

# High Precision Measurement of the Galactic Center

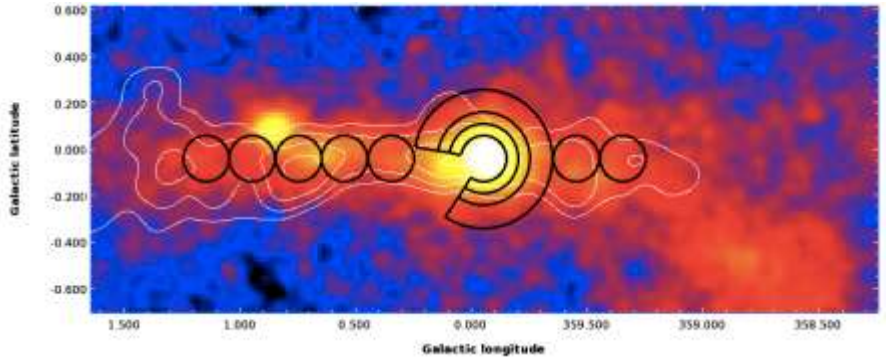


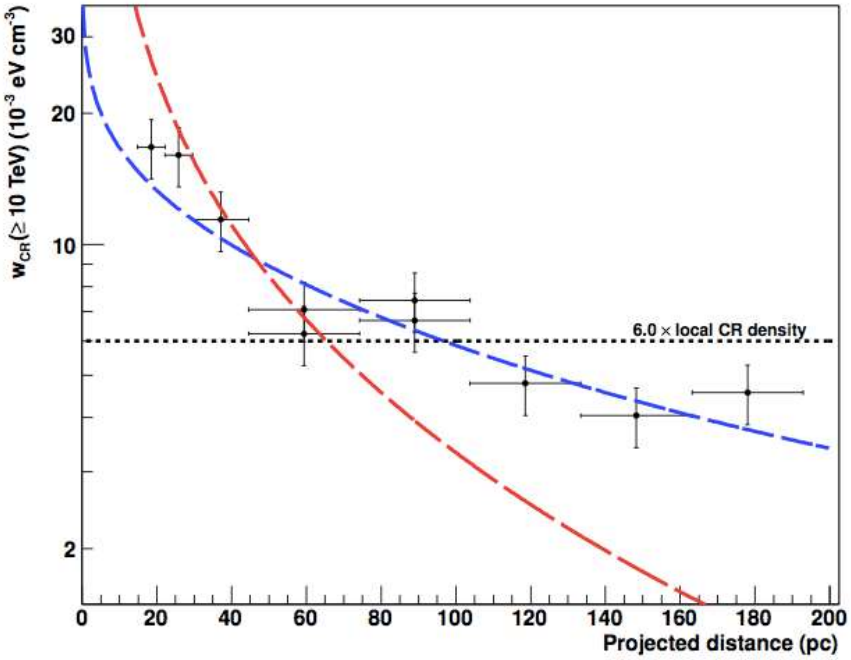

- Full dataset: 2004 – 2012
- 220 hours
- HESS J1745-303, G0.9+0.1 excluded

H.E.S.S.

# Cosmic-ray Density Distribution

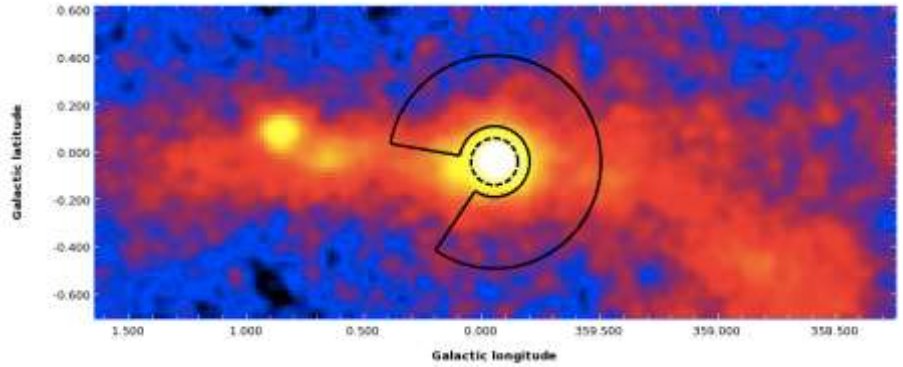
- Correlation with molecular clouds
  → pp interaction target mass (M)
- Gamma-ray luminosity (L) in several regions
  → CR density ~L/M
- Central accelerator located within 10 pc and injecting CRs continuously for > 1kyrs

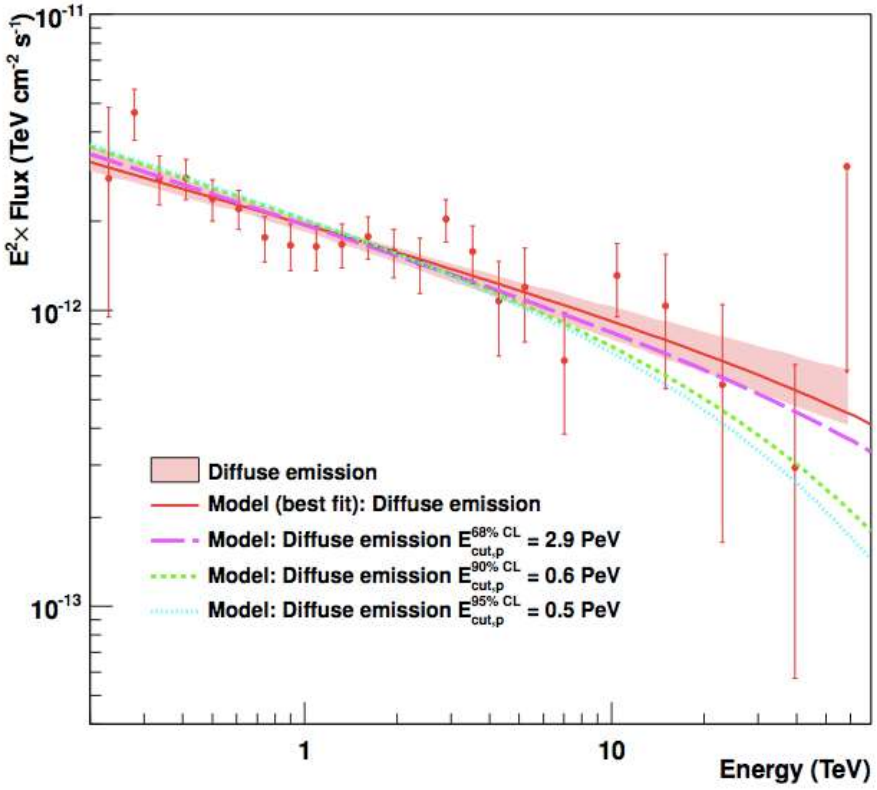


# Diffuse Emission and Injection Spectra

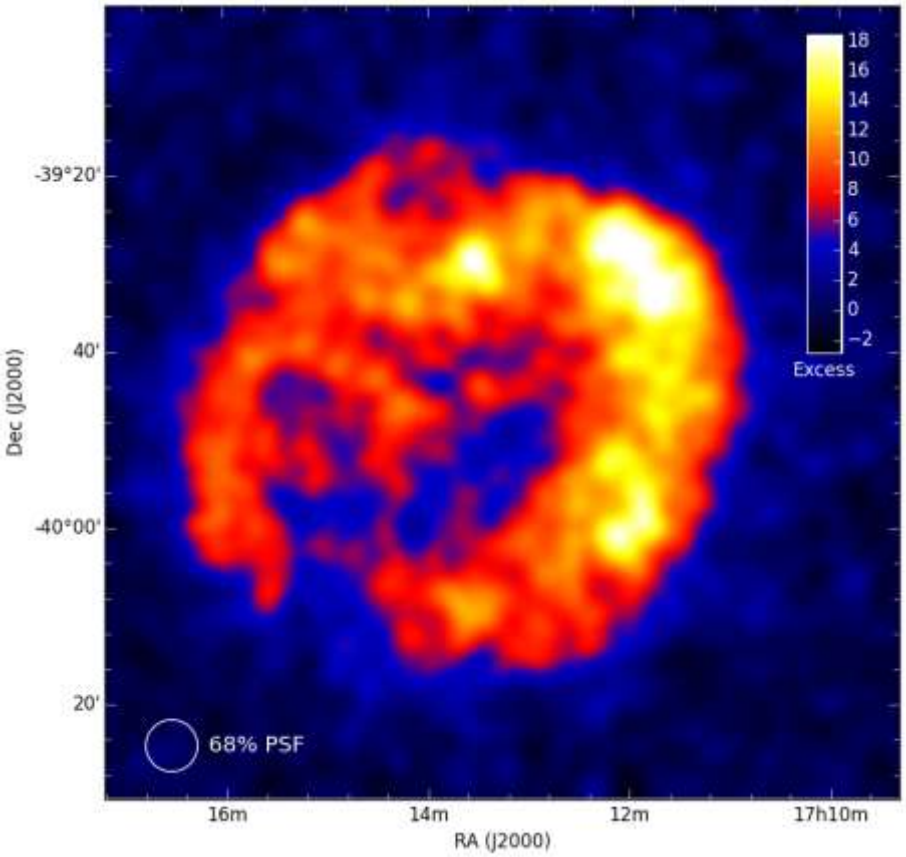
- Diffuse gamma-ray spectrum
  - $E^{-2.3}$ up to 50 TeV w/o cutoff
- Assume central source of protons
  - Solve transport equation of protons
  - fit to HESS data
- Proton injection spectrum:
  - $E^{-2.2}$ power law from GeV to few PeV
  - Cut-off
    0.6 PeV at 90% CL
    2.9 PeV at 68% CL
- **A cosmic PeVatron!**



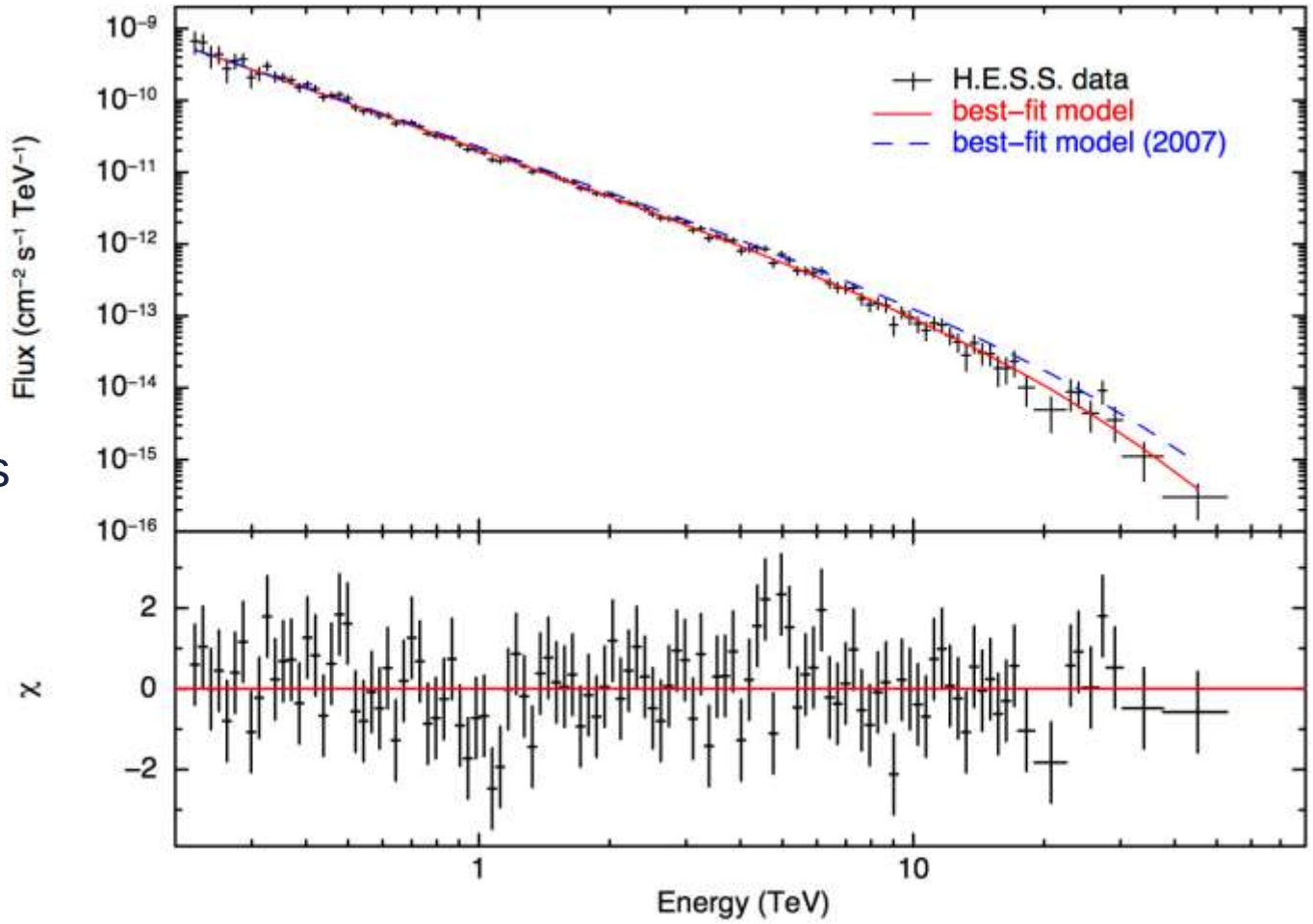
# High Precision Measurements of RX J1713-3946

- Exposure: 170h
- Angular resolution: 0.05º
- Energy threshold: 250 GeV
- Analysis: Model w/ HiRes cuts (de Naurois & Rolland, 2007)

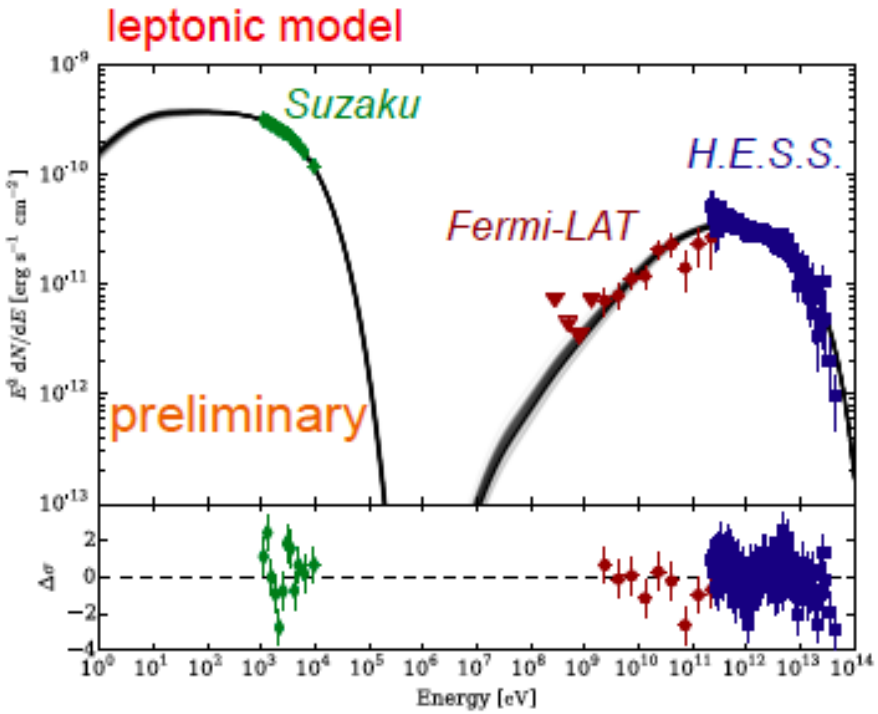


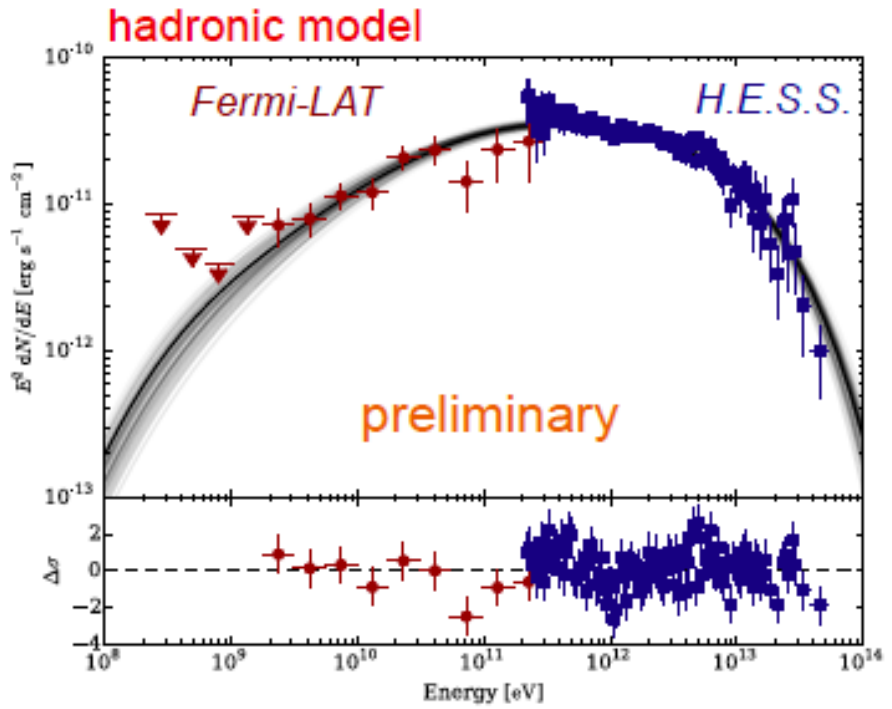
# RX J1713-3946: Full Remnant Photon Flux Spectrum

- Exposure: 150 h
- Threshold: 200 GeV
- Excess: >27000 counts



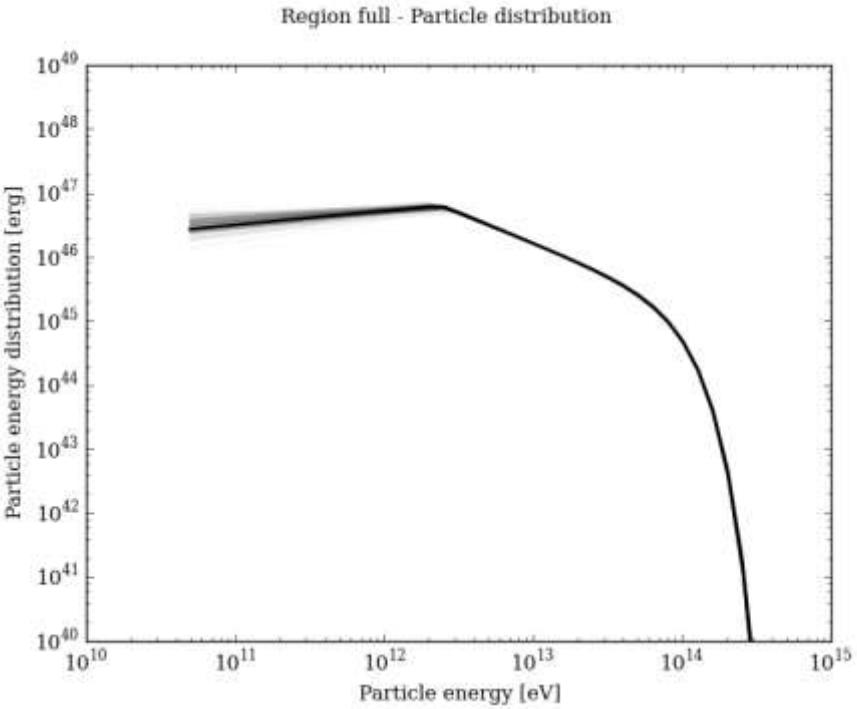
# Modelling the Spectral Energy Distribution

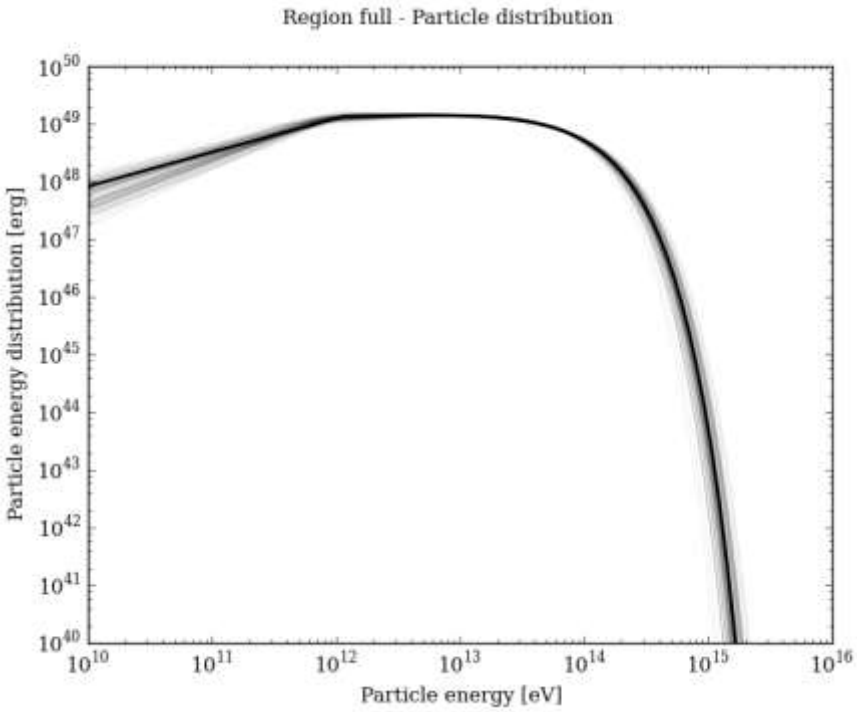



Spectral fits performed with naima (V. Zabalza)

# Particle Distributions

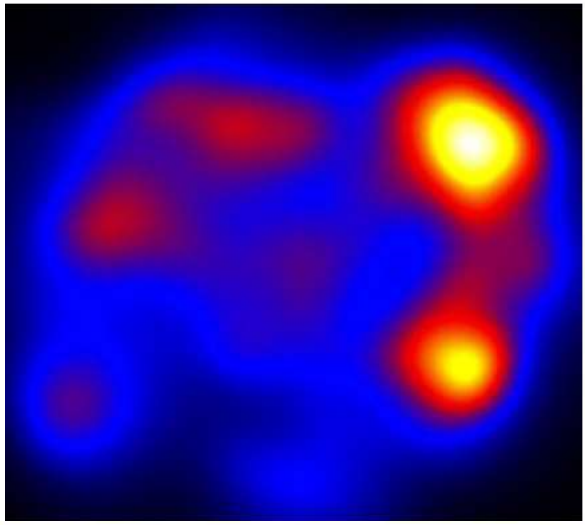


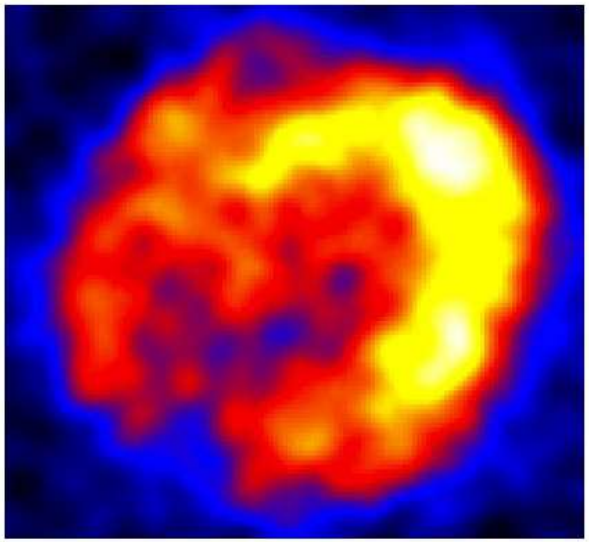

- Break in electron spectrum @ 2.5 TeV
  - Synchrotron cooling?
    Required B-field ~140 μG
    X-ray measurement B = 14.8 ± 0.2 μG
- Break in proton spectrum @ 0.8 TeV
  - energy dependent diffusion into dense clumps?

# Mapping the Magnetic Field

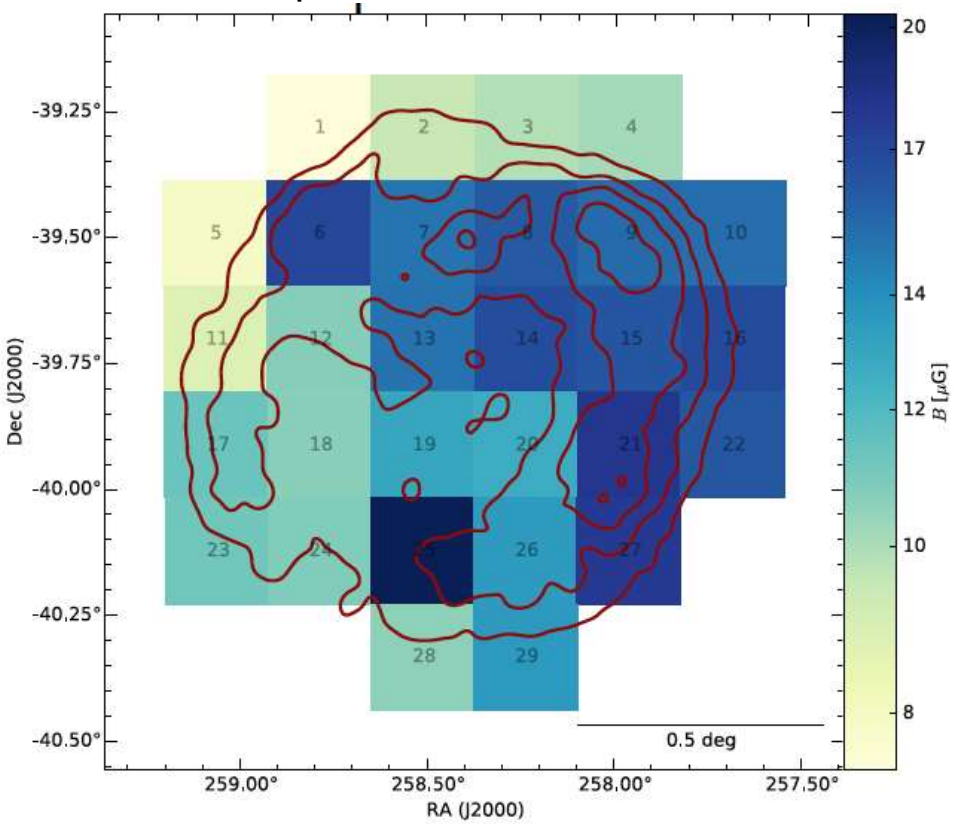
X-rays: XMM-Newton
H.E.S.S. PSF convolved



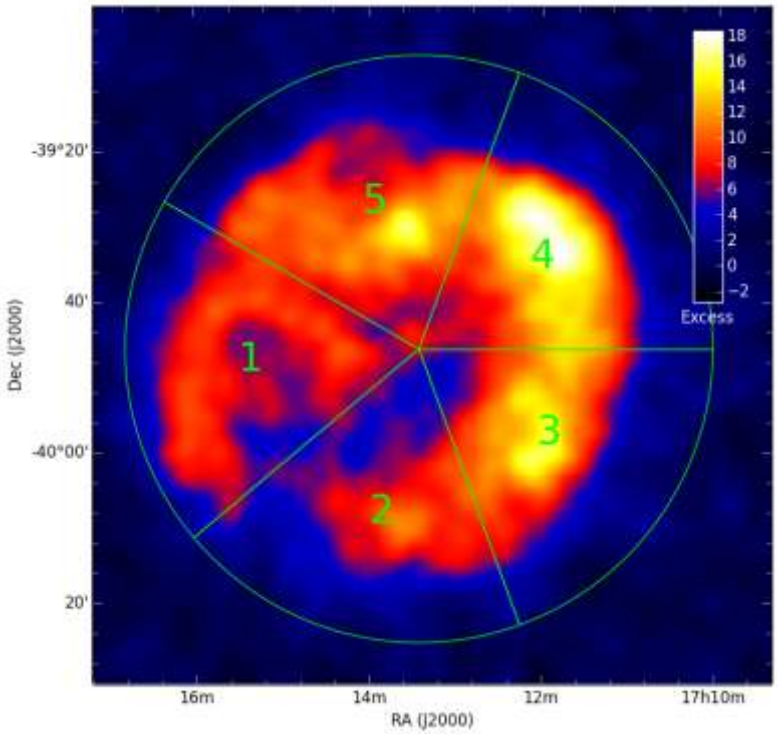
TeV: H.E.S.S.

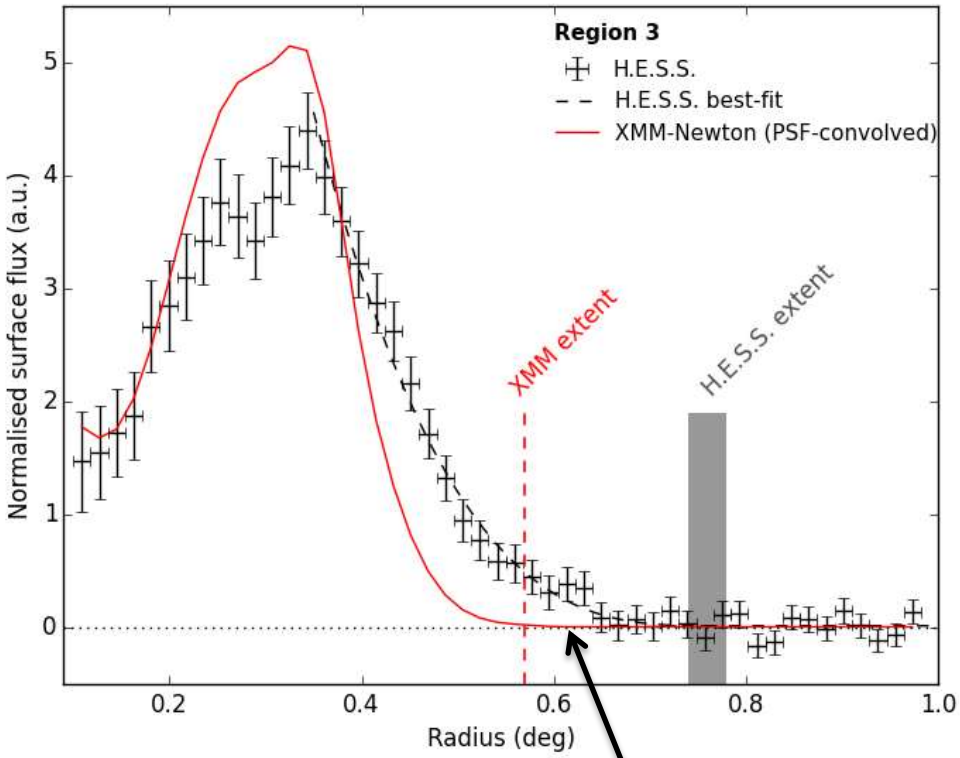


B-field map



# Radial Profiles: X-ray vs TeV

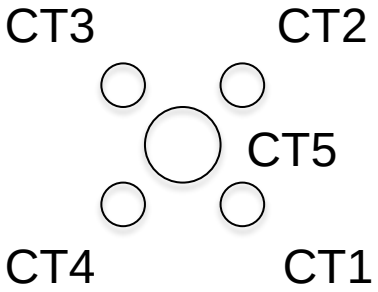



particle escape?

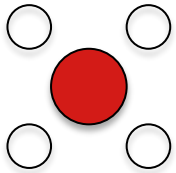
# H.E.S.S. II Performance

# H.E.S.S. II

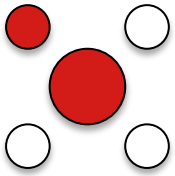



- Operation of the first mixed system of Cherenkov telescopes

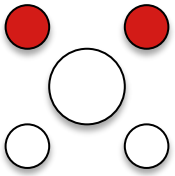
- **Trigger**, all configurations simultaneously



CT5 mono
65%



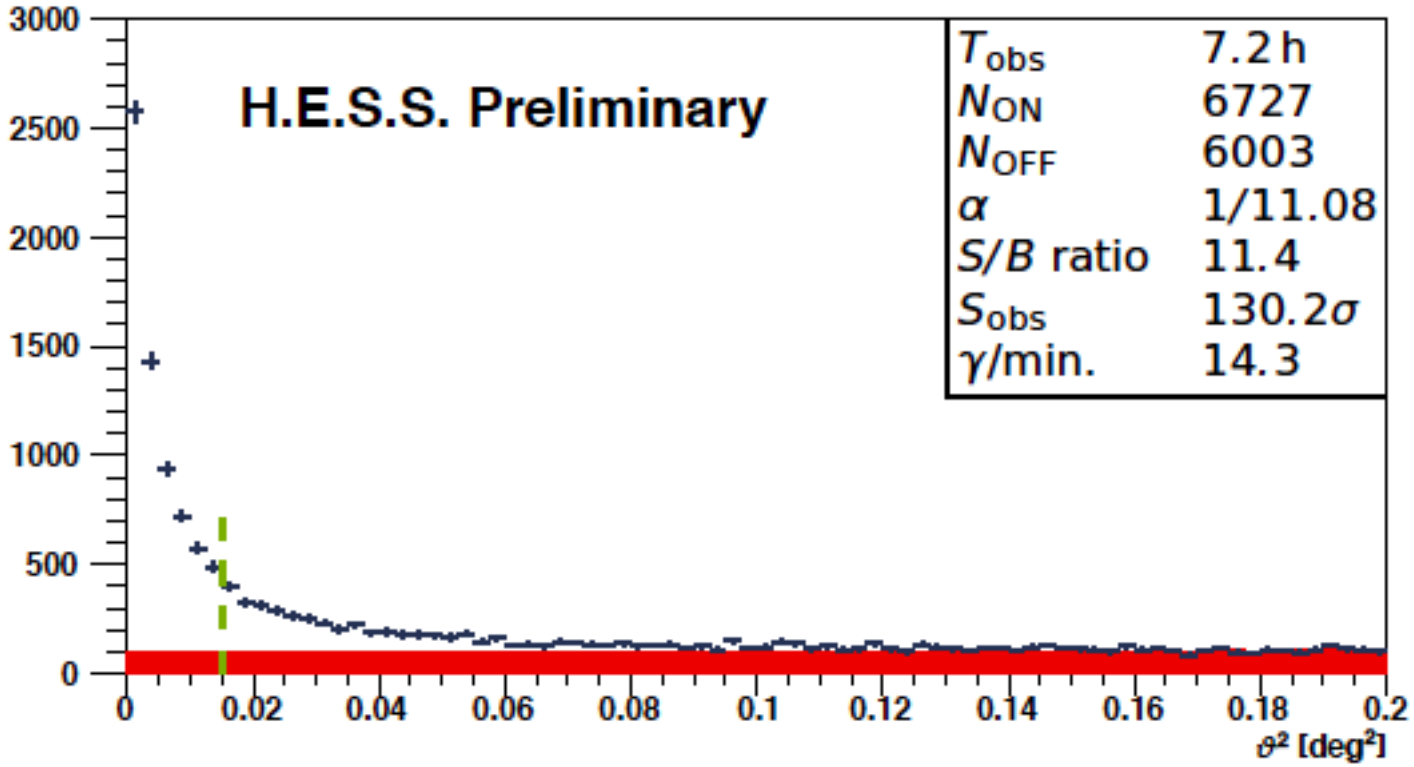
CT5 + ≥ 1 CT1-4
30%



≥ 2 CT1-4
5%

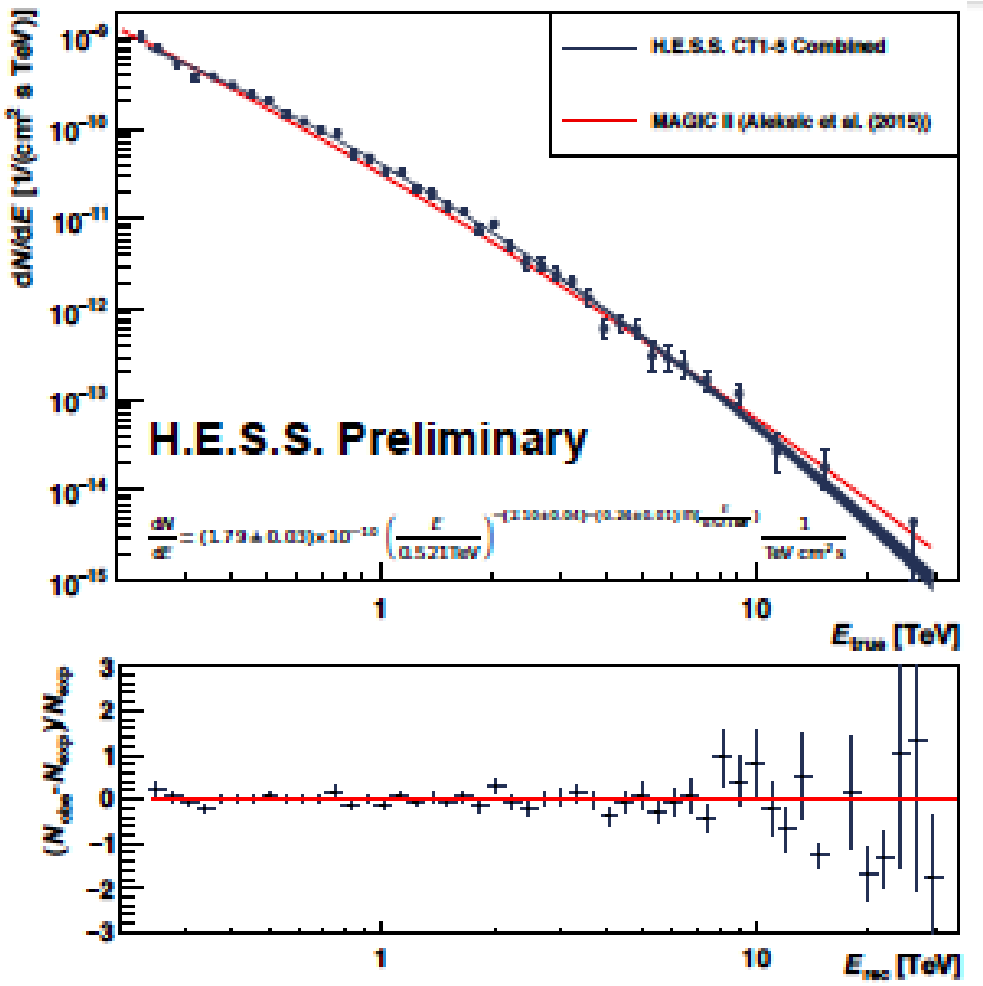
- **Analysis**
  - Mono = CT5 only
  - Stereo = ≥ 2 telescopes
  - Combined = Mono + Stereo (select better fit in overlap region)

# Crab with H.E.S.S. II



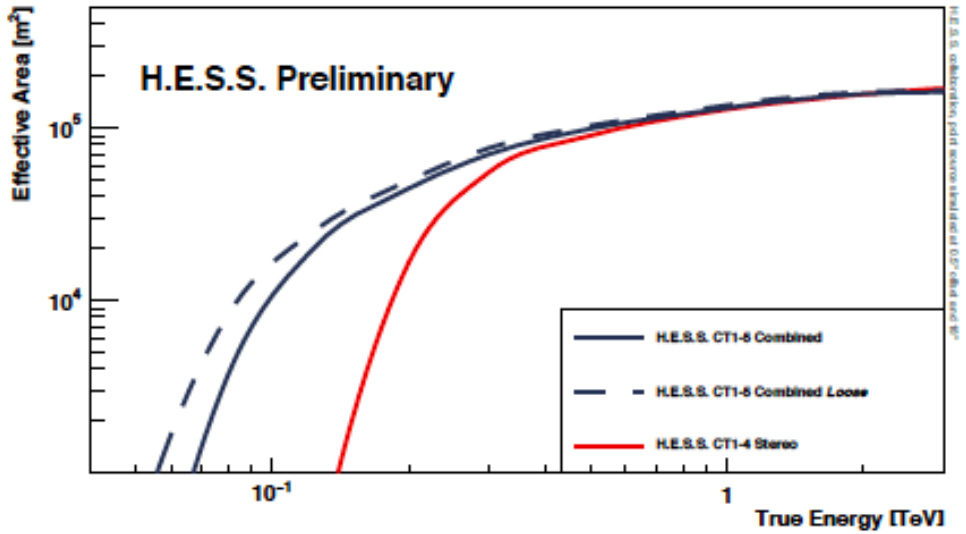
# Crab Energy Spectrum

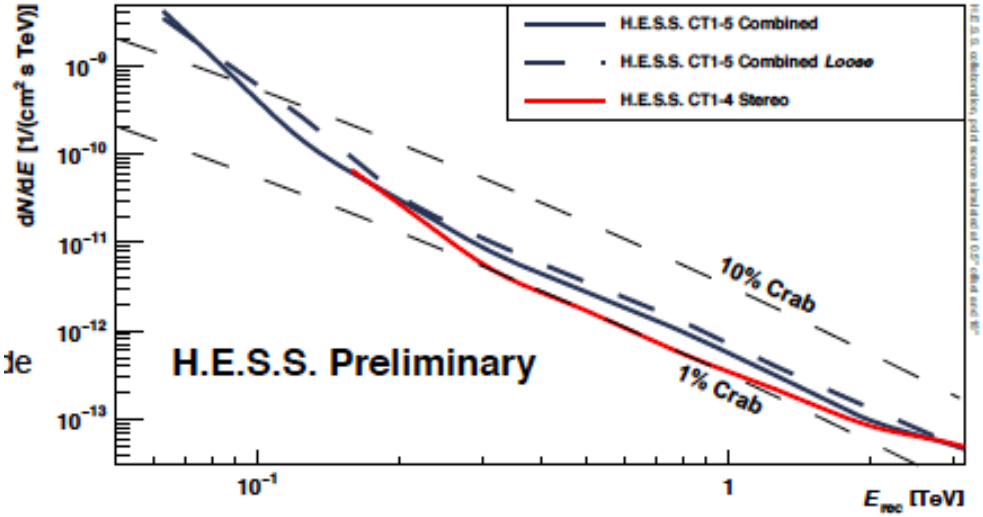
- Energy threshold ≈ 230 GeV
  - H.E.S.S. I: ≈ 440 GeV
  - possible to go lower (systematics to be understood)



# H.E.S.S. II Performance

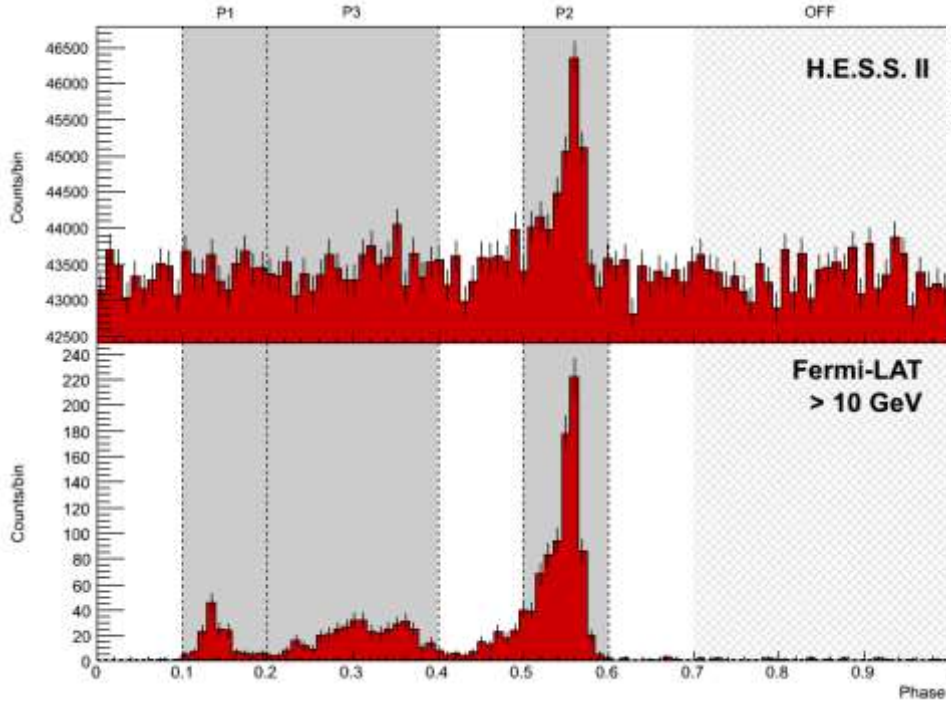
- Analysis
  - Standard
  - Loose
- Thresholds
  - Normal @ 20º: 80 GeV
  - Normal @ 45º: 250 GeV
- Sensitivity
  - 50h
  - S/B ≥ 0.05 for each bin

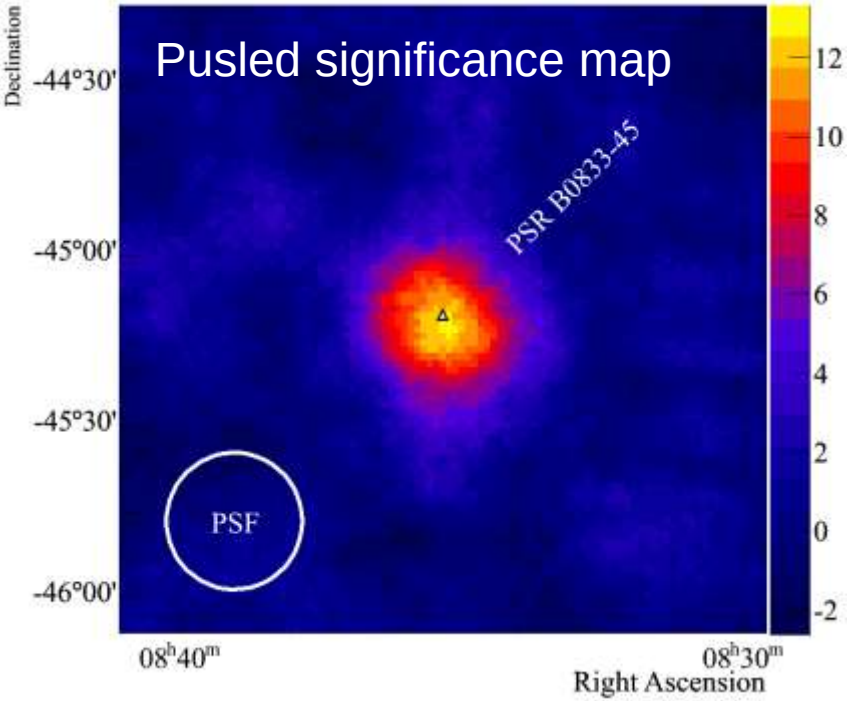


# Vela Pulsar

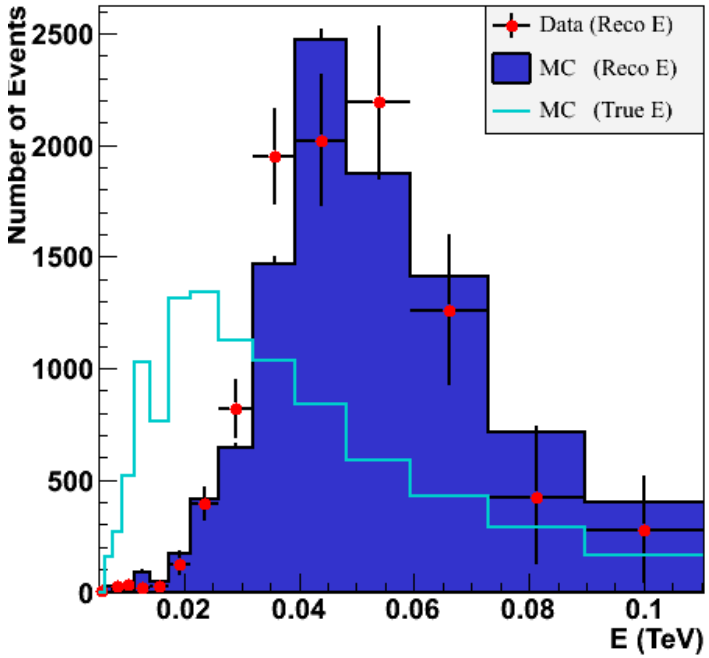
- 24h high quality data collected in 2013 and 2014
- Zenith angle range [20° - 35°]
- Analysis cuts optimised for gamma-ray events below 100 GeV
- Effective area at 20 GeV and 20° zenith angle: **1.9 x $10^3$ $m^2$**

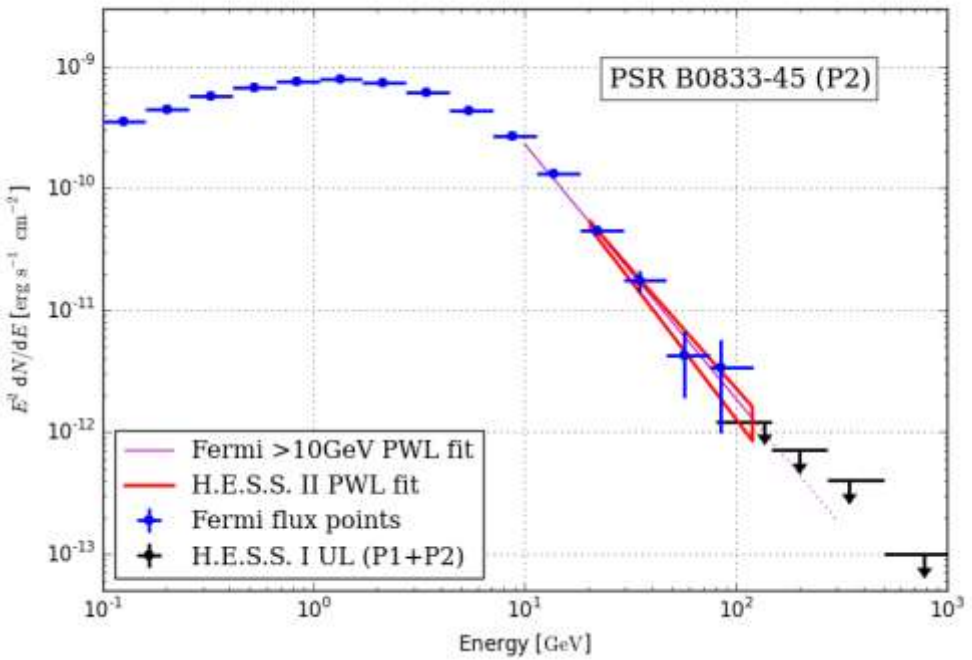


# Vela Pulsar: Spectral Energy Distribution

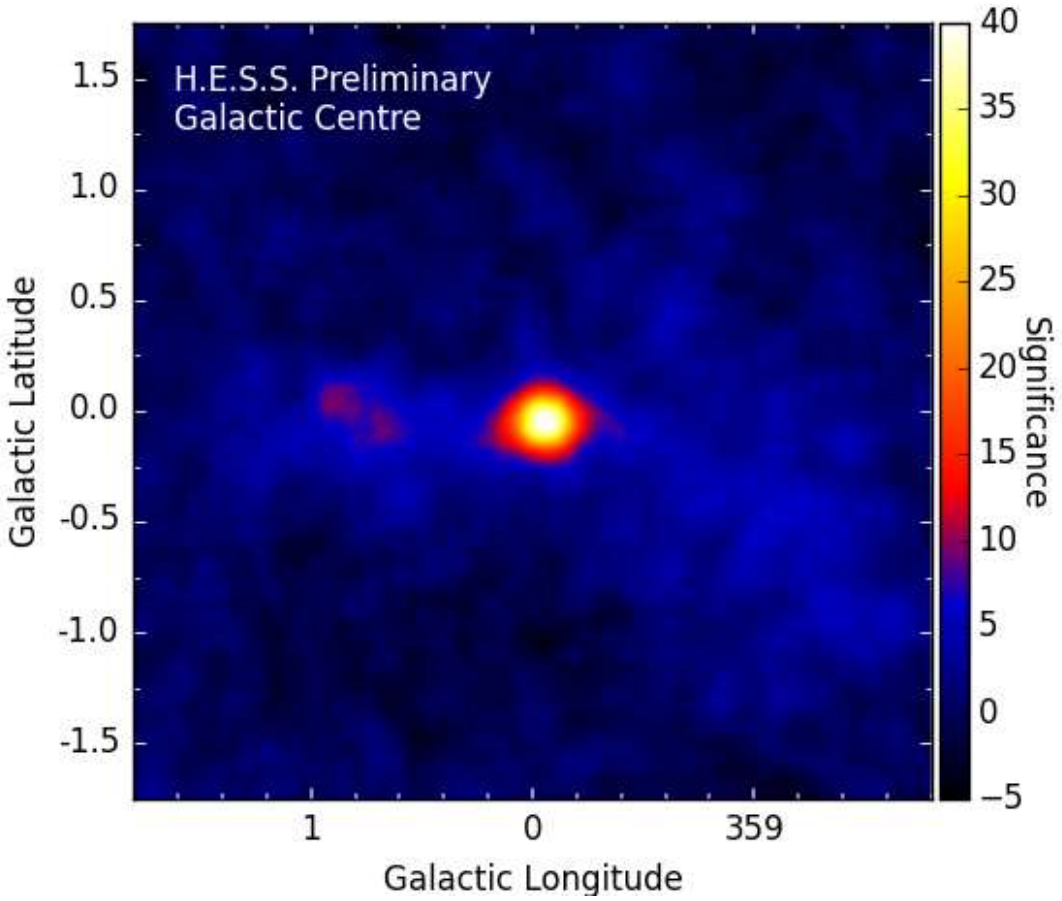
- H.E.S.S. II energy range: 20 GeV -> 120 GeV
- Statistics limit definite conclusion between
  - power law
  - sub-exponential cut-off power law



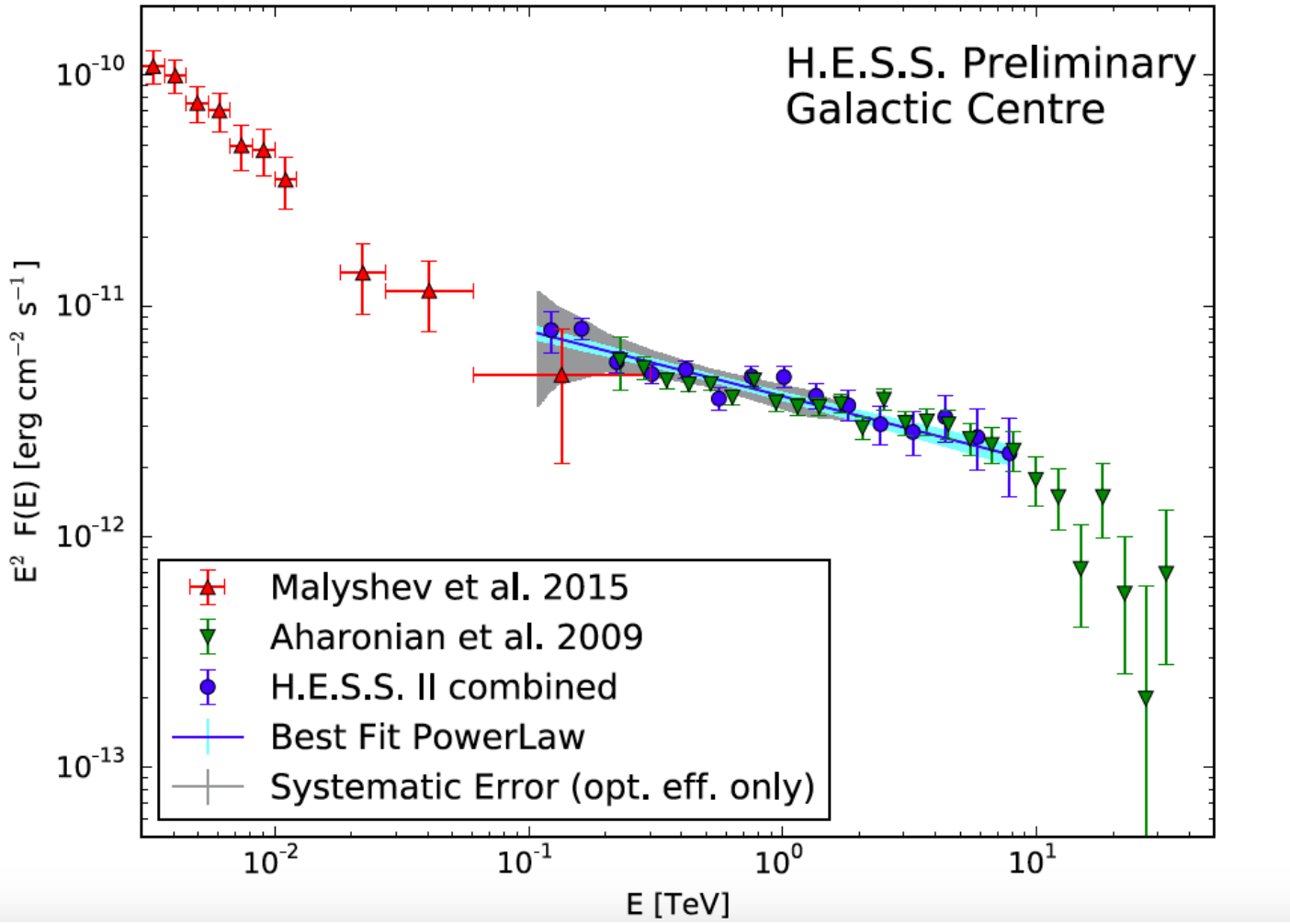



# Galactic Center with H.E.S.S. II

- 58.6 h taken in 2013 and early 2014
- Zenith angles from 5º-45º deg (mean 22º),
- offset for Sgr A* position 0º-1.4º (mean 0.5º)
- More data on disk



# Galactic Center Energy Distribution



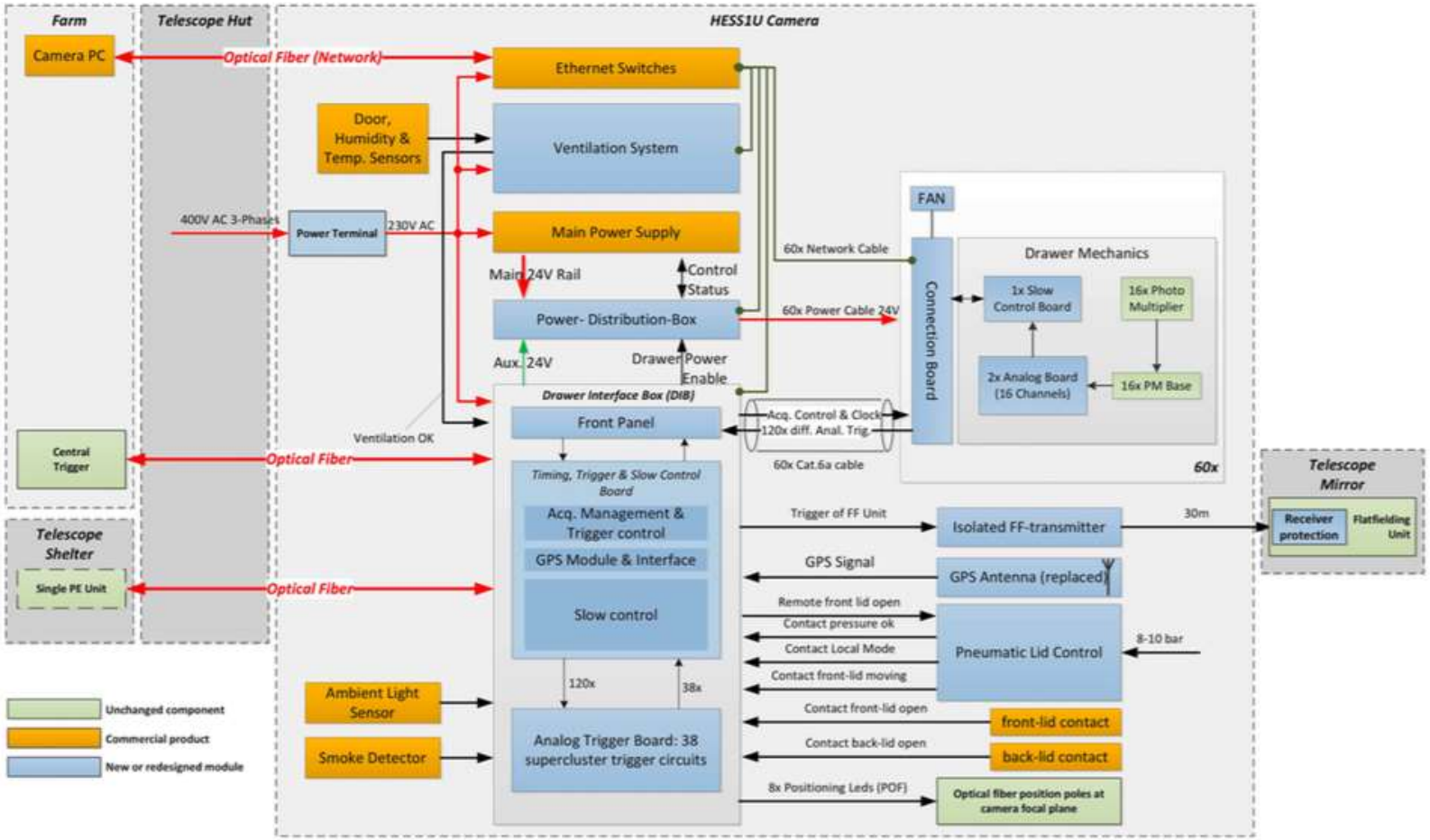
# H.E.S.S. I Camera Upgrade

- Motivation
  - decrease deadtime
  - increase up-time
- prepare for at least 3 more years of operation

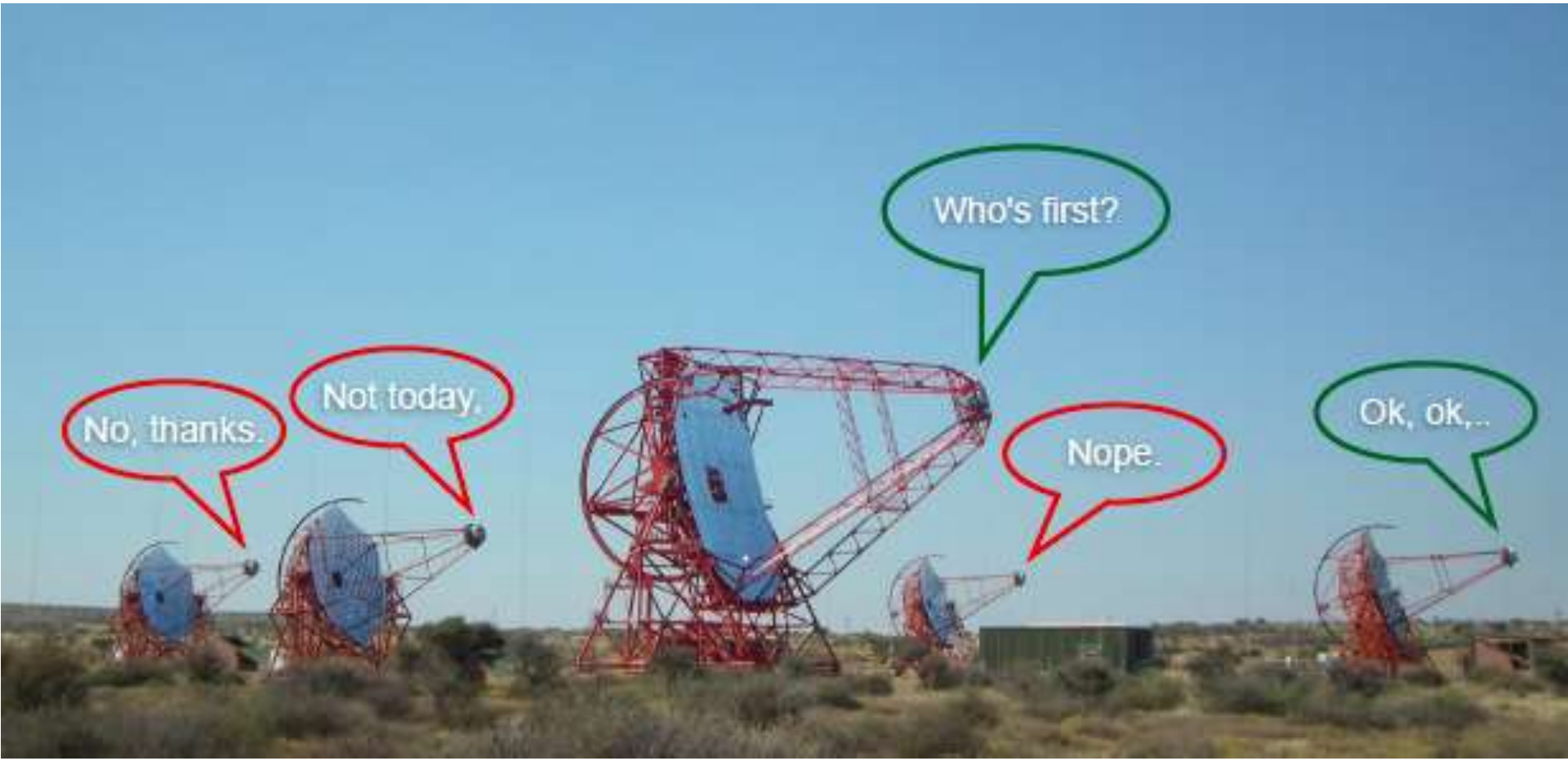
| What | How much/many |
|---|---|
| Pixels | 960 |
| Power (Drawer) | 29 W |
| Power (Camera) | 5-6 kW |
| Dynamic range | 2000 |
| Bandwidth | 300 MHz |
| Sampling rate | 1 GHz |
| Readout window | 16 ns * |
| High Voltage | 1.0 - 1.6 kV |
| Dark rate (PMT) | 100 - 500 MHz * |
| Data rate (Camera) | 1 kHz * |
| Data rate (array) | 1.7 kHz * |
| Event size | 12 kB (uncompressed) |
| Data bandwidth | 1 GBit/s |
| Weight | 910 kg |
| Field of view | 5° |

H.E.S.S.

# A New Camera

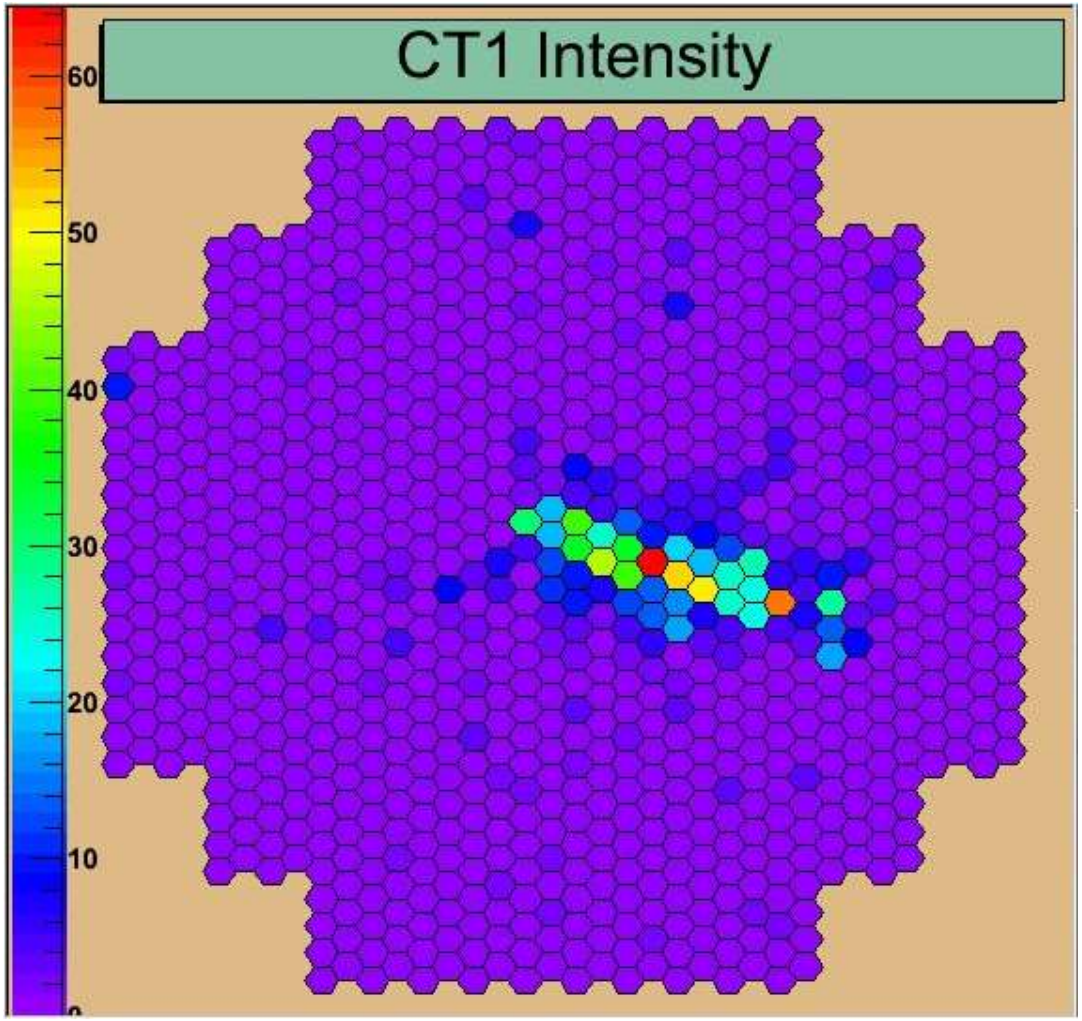

Farm
Telescope Hut
HESS1U Camera
Camera PC
Optical Fiber (Network)
Ethernet Switches
Door, Humidity & Temp. Sensors
Ventilation System
400V AC 3-Phase
Power Terminal
230V AC
Main Power Supply
Main 24V Rail
Control Status
Power- Distribution-Box
60x Network Cable
60x Power Cable 24V
FAN
Connection Board
Drawer Mechanics
1x Slow Control Board
16x Photo Multiplier
2x Analog Board (16 Channels)
16x PM Base
60x
Aux. 24V
Drawer Power Enable
Drawer Interface Box (DIB)
Front Panel
Acq. Control & Clock
120x diff. Anal. Trig
60x Cat.6a cable
Ventilation OK
Central Trigger
Optical Fiber
Timing, Trigger & Slow Control Board
Acq. Management & Trigger control
GPS Module & Interface
Slow control
Telescope Shelter
Single PE Unit
Optical Fiber
Trigger of FF Unit
Isolated FF-transmitter
30m
Telescope Mirror
Receiver protection
Flatfielding Unit
GPS Signal
GPS Antenna (replaced)
Remote front lid open
Contact pressure ok
Contact Local Mode
Contact front-lid moving
Pneumatic Lid Control
8-10 bar
120x
38x
Ambient Light Sensor
Smoke Detector
Contact front-lid open
Contact back-lid open
front-lid contact
back-lid contact
Analog Trigger Board: 38 supercluster trigger circuits
8x Positioning Leds (POF)
Optical fiber position poles at camera focal plane
Unchanged component
Commercial product
New or redesigned module

# The first camera to be upgraded



# Upgrade of CT1 in July/August

# CT1 is working



# Summary

- H.E.S.S. is
  - continuing to contribute to our understanding of the high-energy Universe
  - filling the gap between Fermi-LAT and IACTs
- Exciting times ahead of us

# H.E.S.S. I Highlights: A selection

- Diffuse emission
  - after subtraction of sources
- Galactic center
- Extreme SNR
  - HESS J1640-465: The brightest
  - G349.7+0.2: The farthest
- Population studies
  - Pulsar wind nebulae population
  - AGN limits
- many more