



# Science highlights from H.E.S.S.

Bronisław Rudak  
CAMK

for the H.E.S.S. Collaboration



60 years ago - the Nobel Prize in Physics 1958  
*"for the discovery and the interpretation of the Cherenkov effect"*

Hall of Fame at Lebedev Physical Institute, Moscow



P.A. Cherenkov

I.Y. Tamm

I.M. Frank



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



- H.E.S.S. phase 1 (09-2002):

- 4 telescopes:  $\varnothing$  12 m, 107 m<sup>2</sup>
- 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,  $\varnothing$  28 m, 600 m<sup>2</sup> (largest IACT in the world)
- 2048 PMTs, Field of view : 3.5°

→ Energy threshold (zenith) ~ 30 GeV



# Galactic science with 15 years of H.E.S.S. data





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

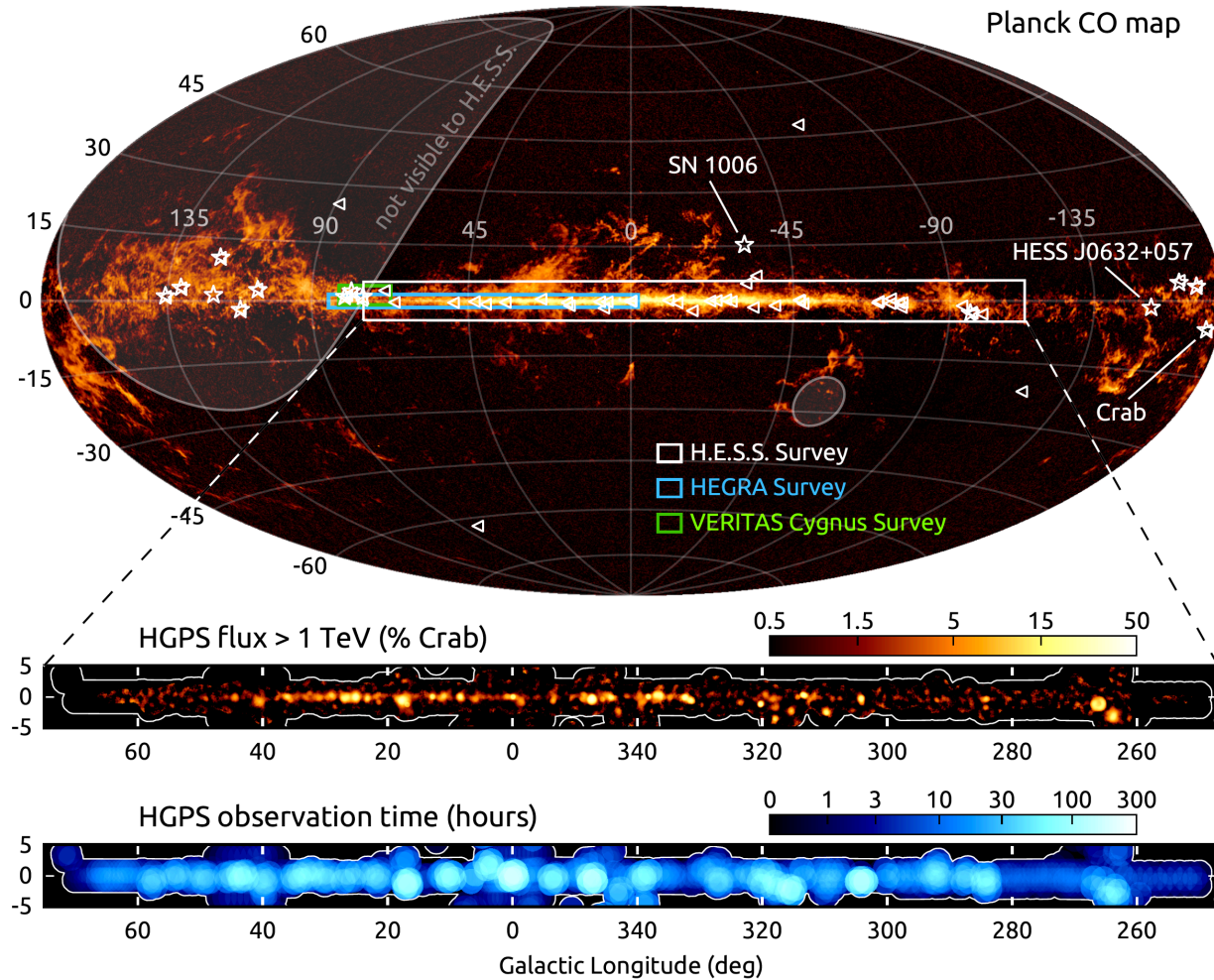
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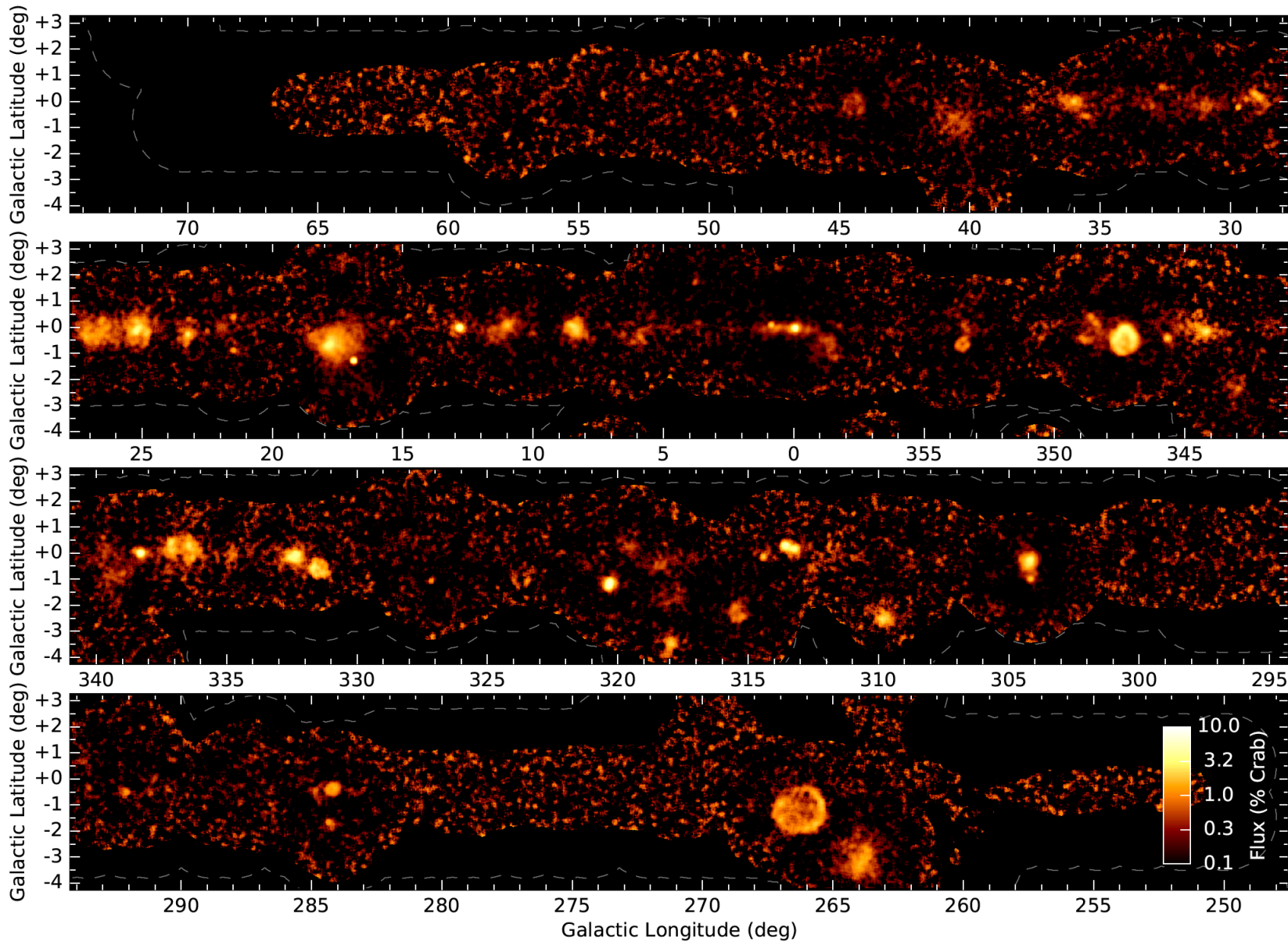
# The H.E.S.S. Galactic Plane Survey (HGPS)



The source catalog available at the CDS via anonymous ftp to [cdsarc.u-strasbg.fr](ftp://cdsarc.u-strasbg.fr) in FITS format



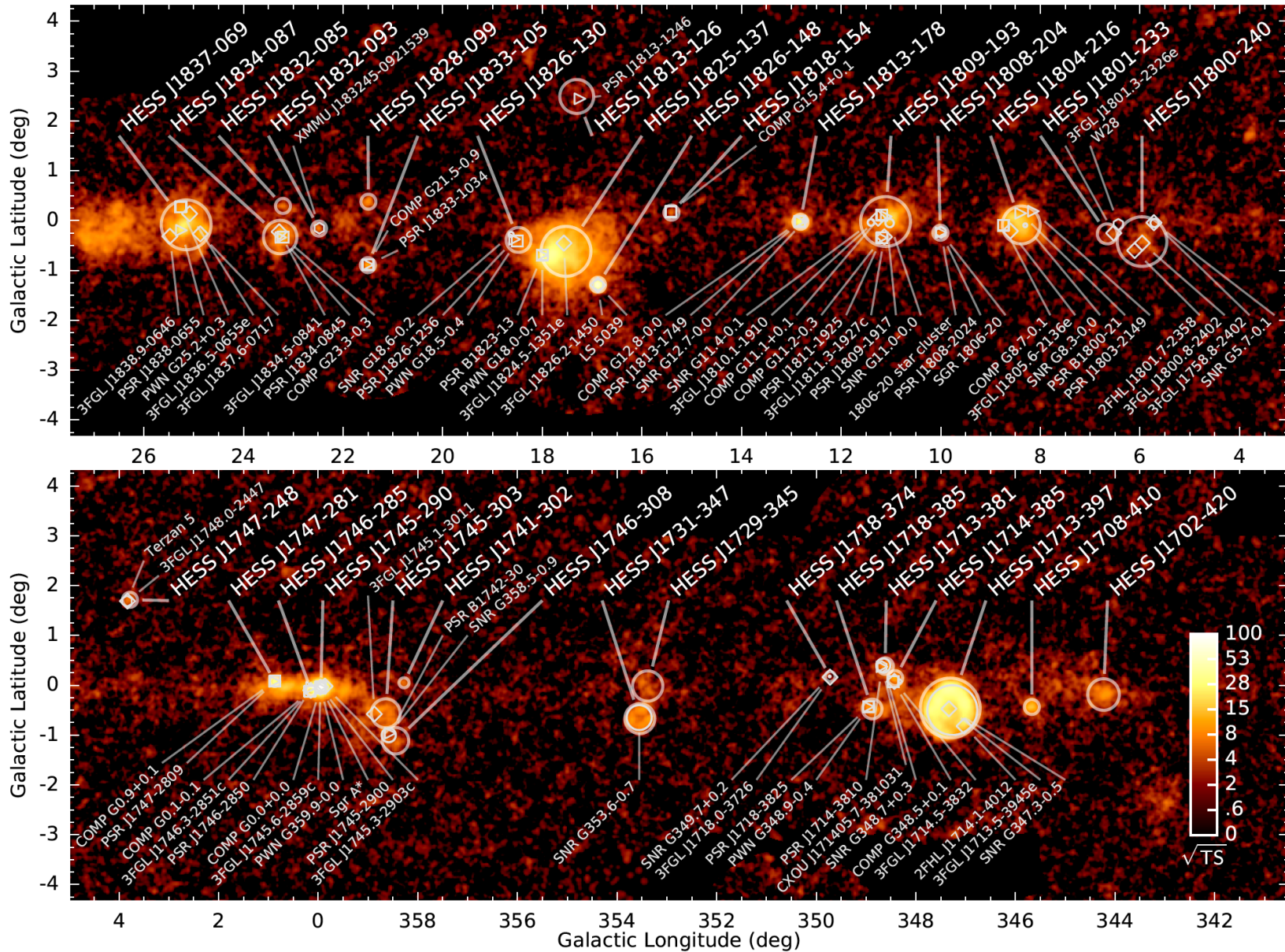
# HGPS sky maps







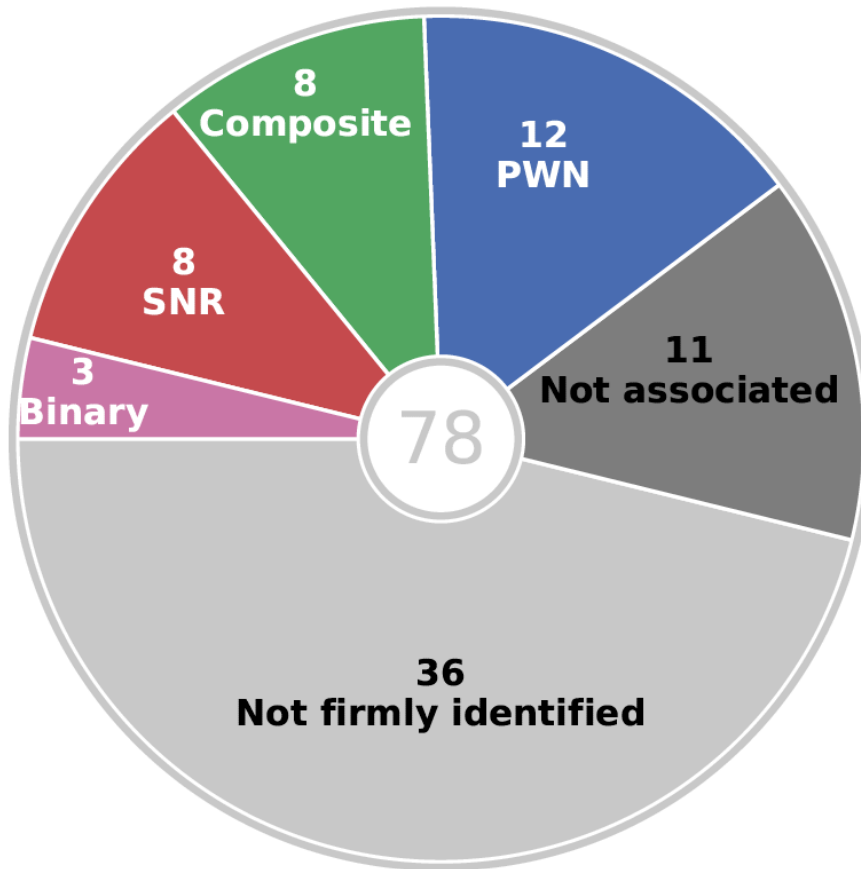
# HGPS sky maps with associations



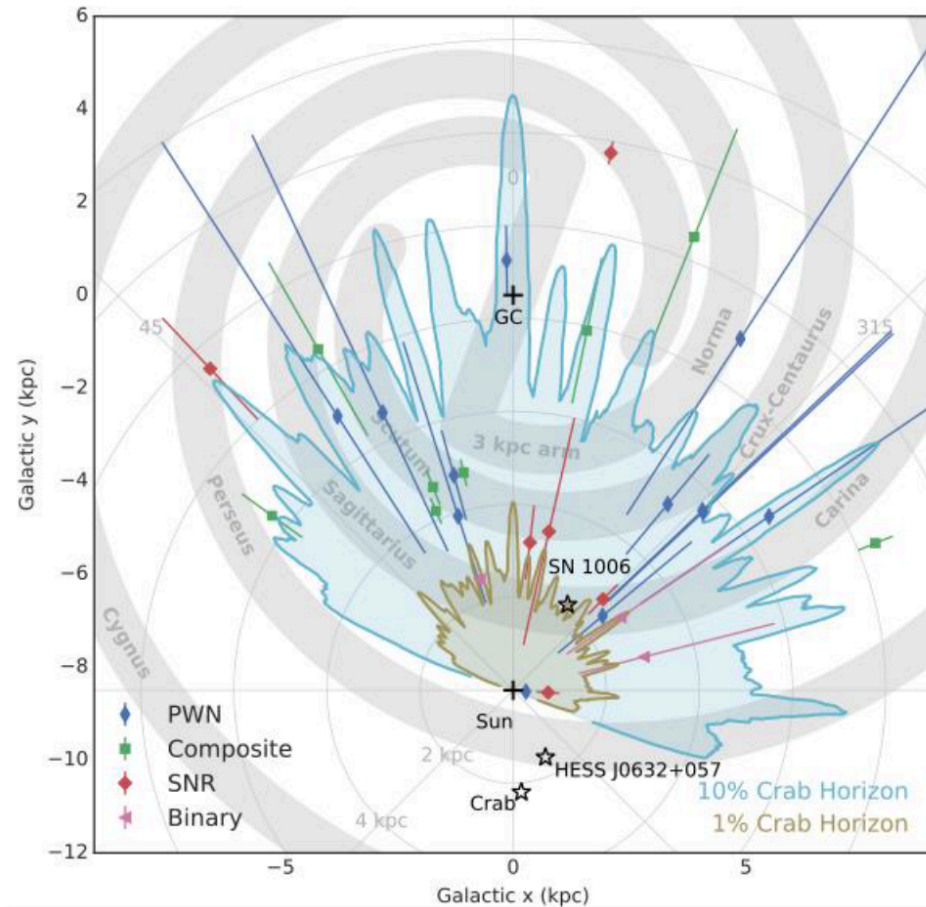


# HGPS – types of sources and its horizon

## Association and Identification

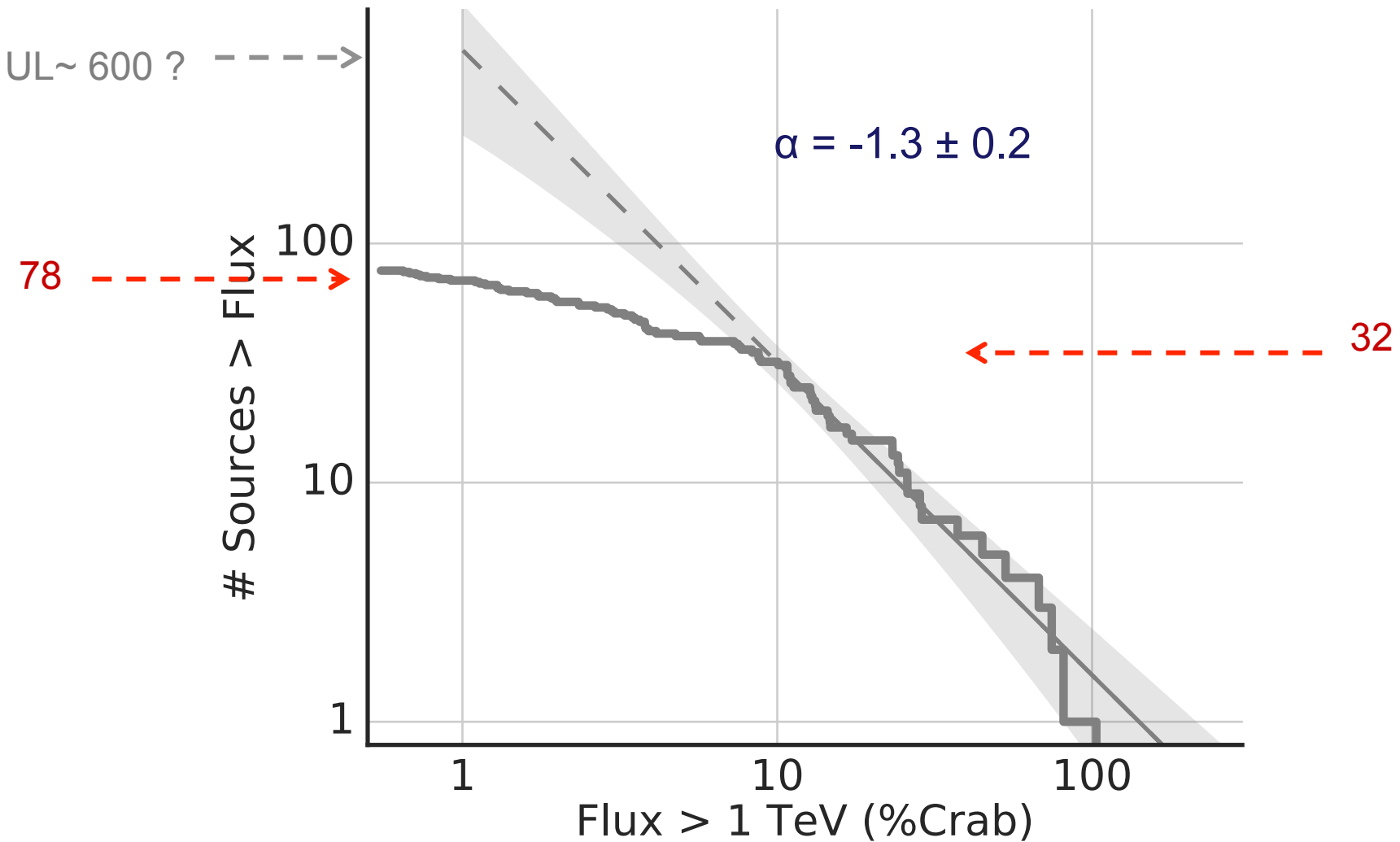


## Horizon



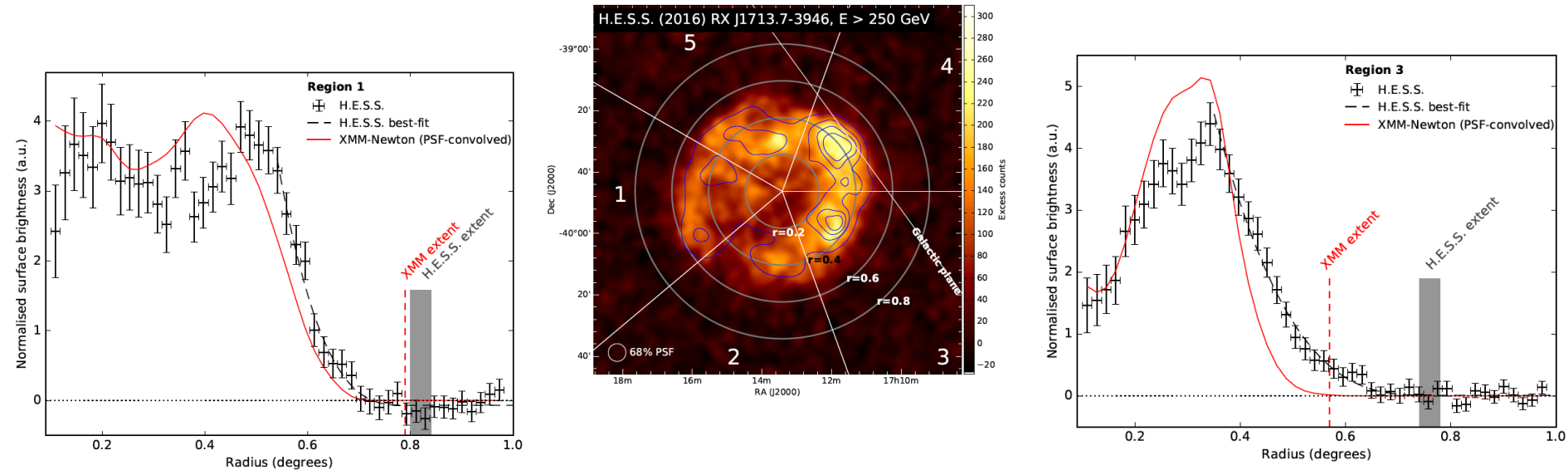


# HGPS: Cumulative $\log N(> S) - \log S$





Discovery of significant differences between the radial extent of emission in X-rays and gamma-rays



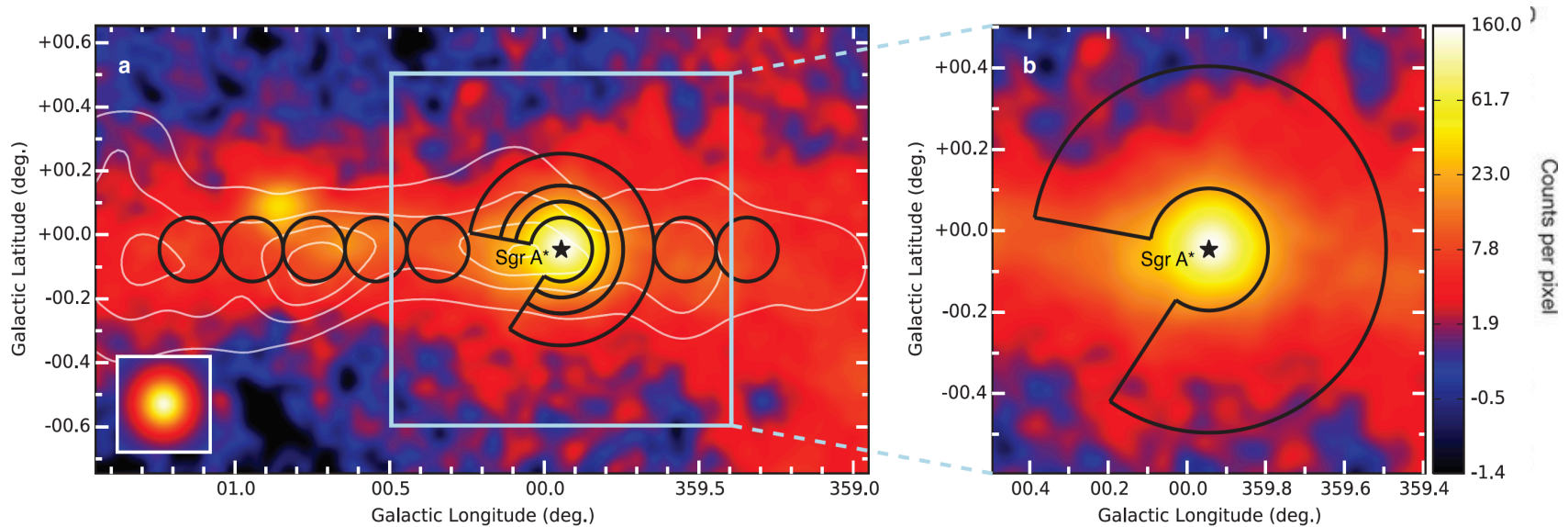
Ultrarelativistic particles present outside the shock region due to:

- escape from the shock region, or
- acceleration in the shock precursor region.



# Discovery of a Cosmic PeVatron in the Galactic Centre with HESS I

Zoomed view of the inner ~70 pc and the contour of the region used to extract the spectrum of the diffuse emission.



Full dataset analyzed: 2004-2012 => 220h obs. time (175h acc. corrected)

Point-like source  $> 100\sigma$ , 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)

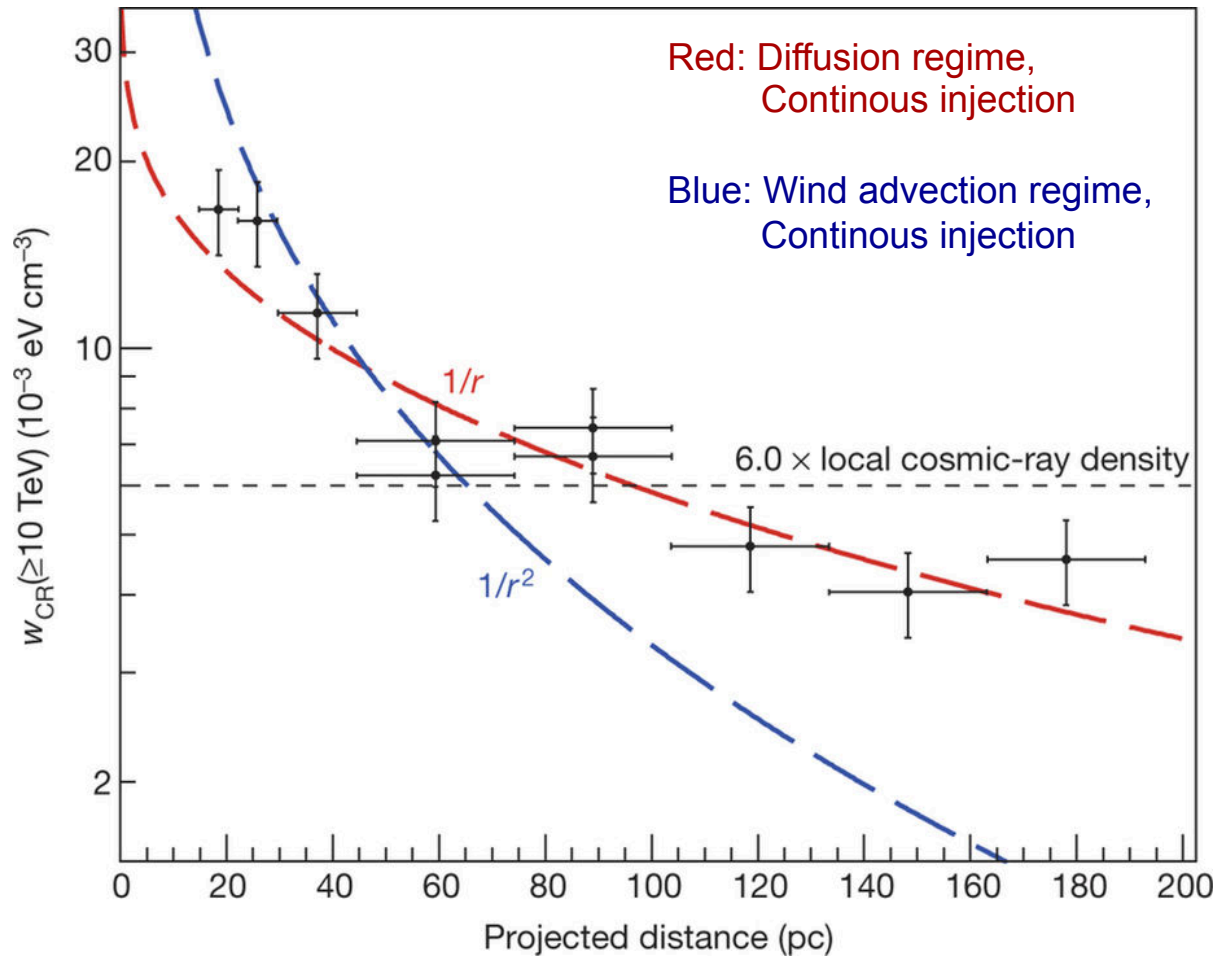
Parent proton population up to 1 PeV (2.9 PeV@ 68% CL)

Central accelerator located within 10 pc and injecting CRs continuously for  $> 1$  kyrs



# Discovery of a Cosmic PeVatron in the Galactic Centre with HESS I

Spatial distribution of the cosmic-ray density versus projected distance from Sgr A\*.

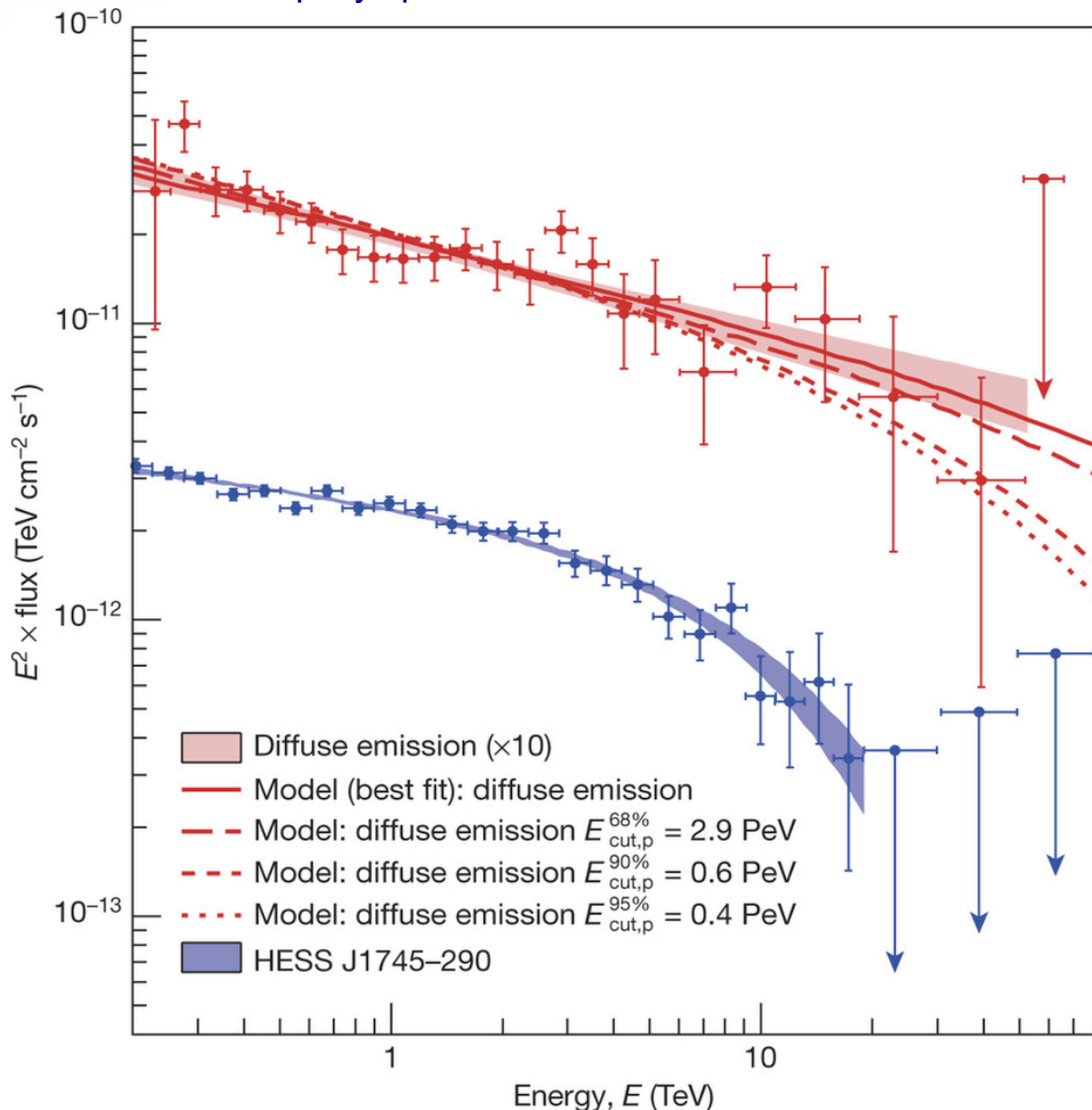




# Discovery of a Cosmic PeVatron in the Galactic Centre with HESS I



VHE  $\gamma$ -ray spectra of the diffuse emission and HESS J1745-290.



Diffuse emission shows a power-law spectrum up to 50 TeV with no sign of a cut-off

Injection model fit to spectrum, solving transport equation of protons injected at the Galactic Centre

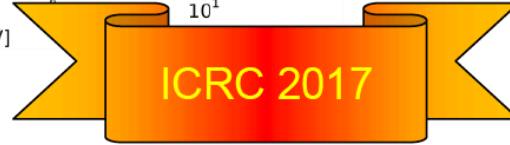
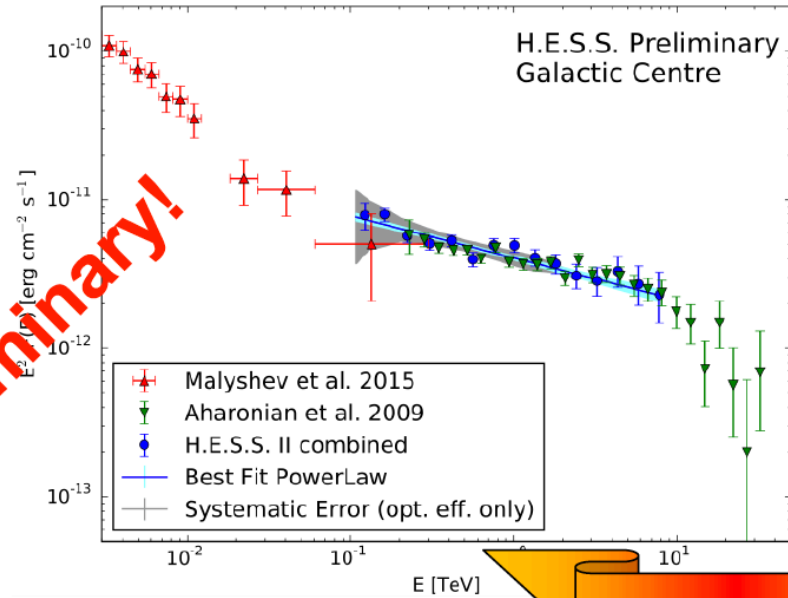
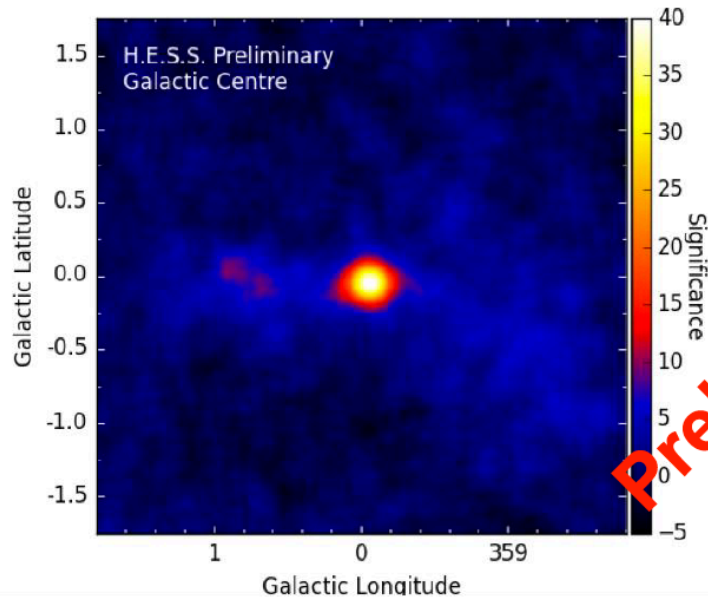
Quasi continuous injection lasting  $\sim 10^4$  years

Total CR power injected at GC  $\sim 10^{38}$  erg/s

Parent proton spectrum extends to PeV energies

**First detection of a galactic PeVatron!**

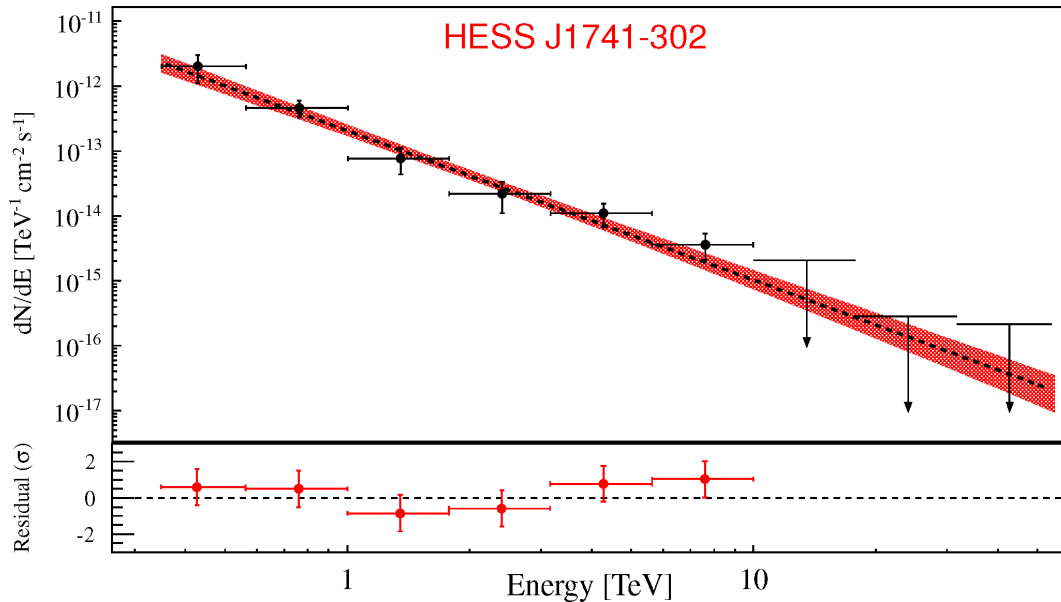
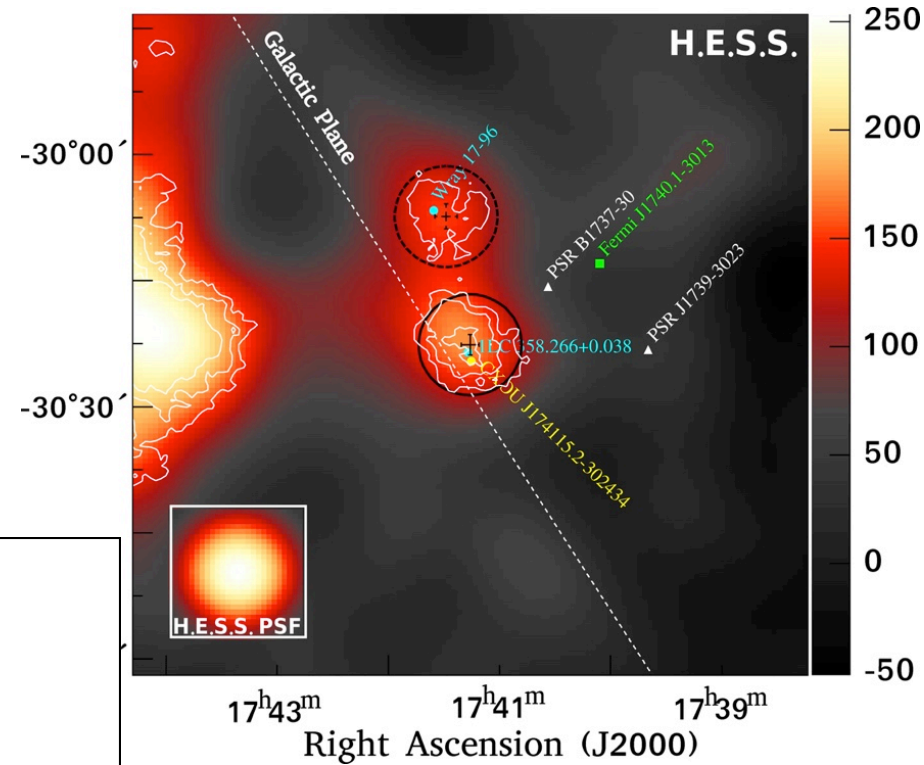
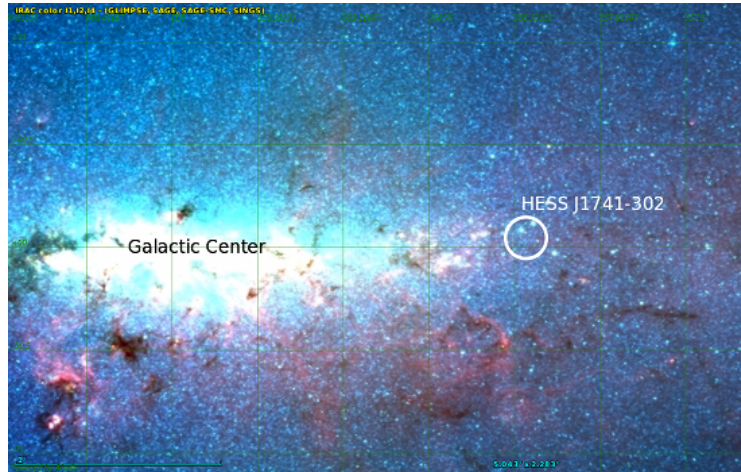
# Galactic Center with H.E.S.S.-II



- GC with the H.E.S.S. II array down to ~100 GeV
- Detection of central source ( $40\sigma$ ), 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...

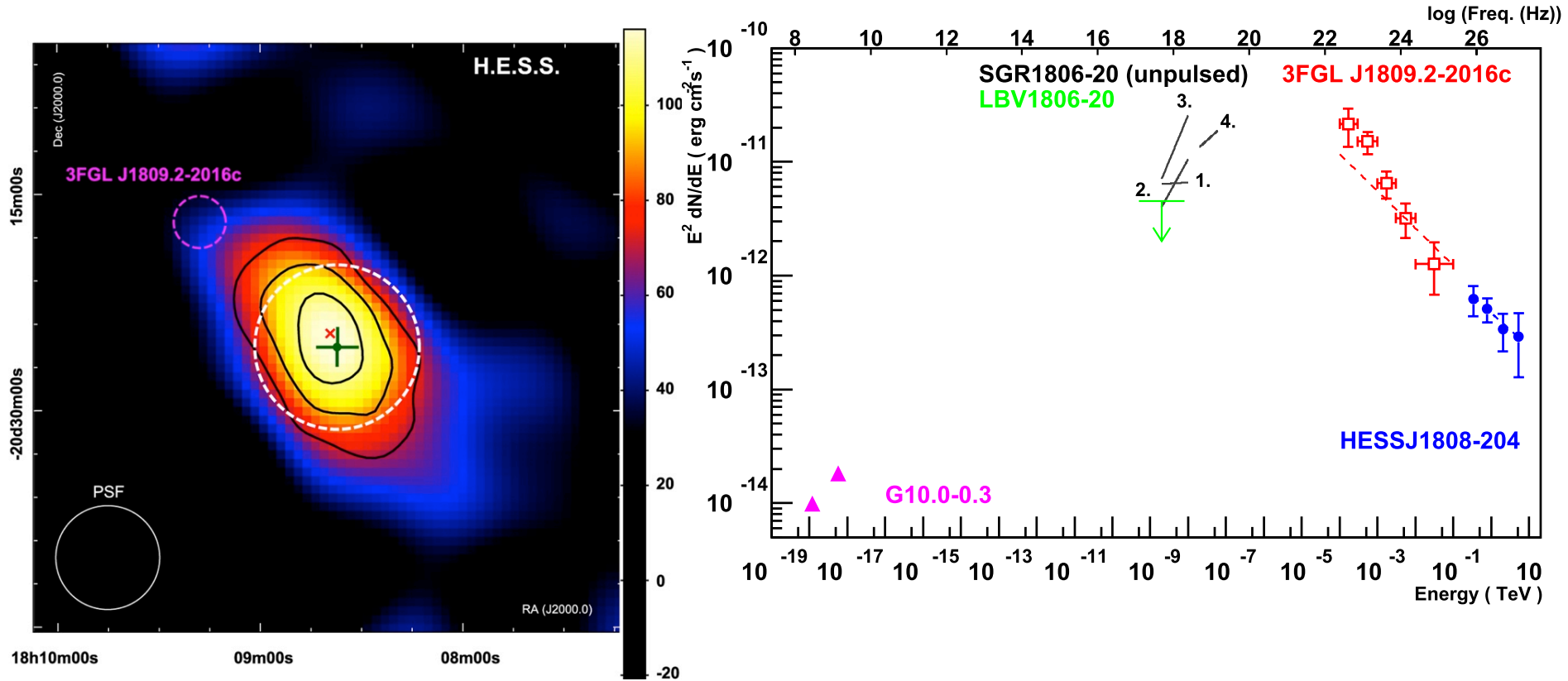


# Dark (hidden) accelerator: extreme particle acceleration in HESS J1741-302 without low-energy footprints



# Discovery of extended VHE gamma-ray emission towards CI\* 1806-20

Is SGR 1806-20 the first VHE magnetar?



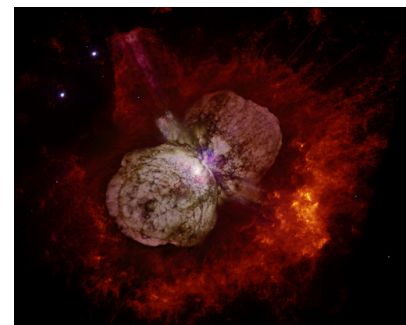
LBV1806-20 is a candidate luminous blue variable (LBV) and likely binary star





# New Binary Systems - Eta Carinae

Binary with high-mass stars, driving supersonic winds  
 $P_{\text{orb}} = 5.54 \text{ yr}$ ,  $e = 0.7$



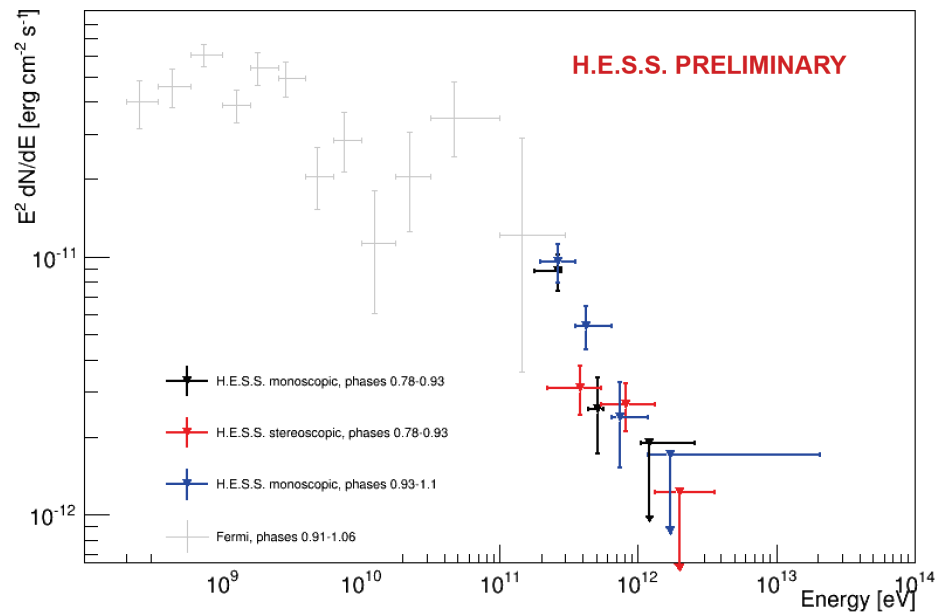
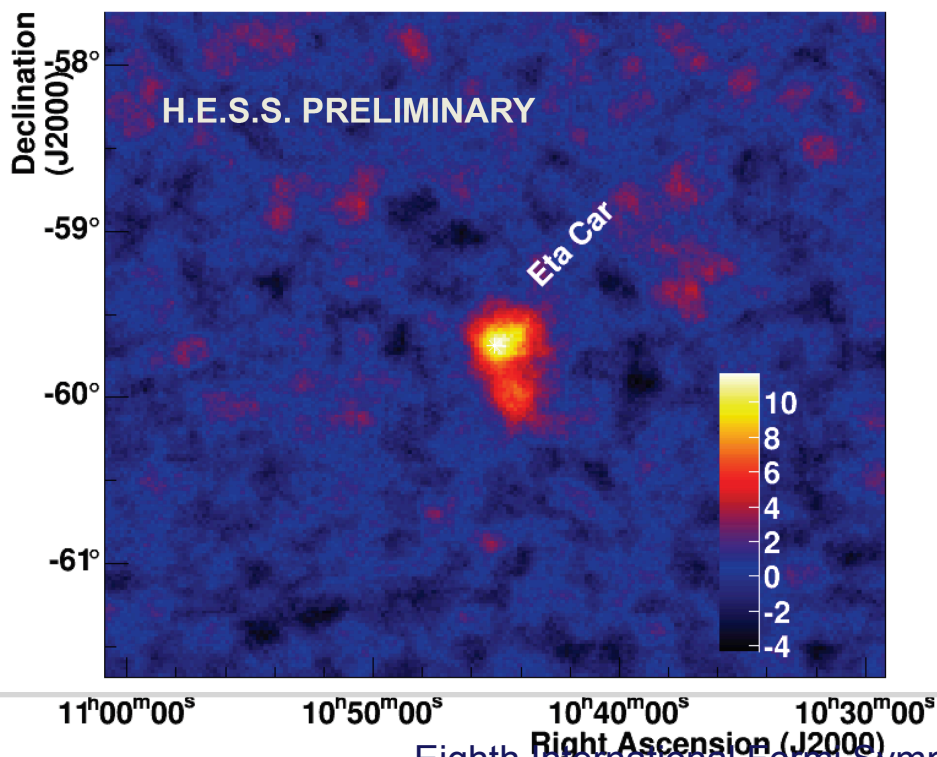
First detection of a colliding-wind binary in VHE  $\gamma$ -rays!

Data taken by HESS II before and after periastron passage

## Spectral energy distribution

PL with Index  $4.04 \pm 0.36 \text{ (stat)} \pm 1.06 \text{ (syst)}$  before periastron  
 $3.52 \pm 0.23 \text{ (stat)} \pm 0.33 \text{ (syst)}$  after periastron

Significance map



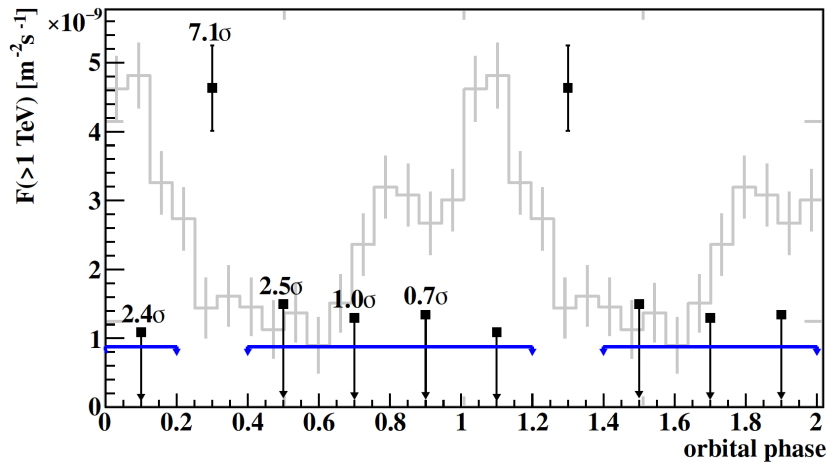
## First VHE detection of an extragalactic binary system

$P_{\text{orb}} = 10.3$  days

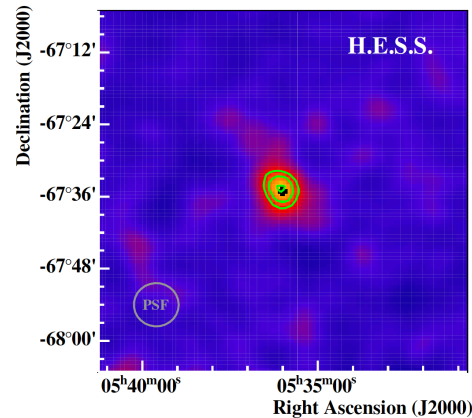
The compact object of unknown nature, the companion star is an O5 III 6th gamma-ray binary system but the only one inside a visible supernova remnant

Most luminous  $\gamma$ -ray binary;  $L(1-10 \text{ TeV}) = 5 \times 10^{35} \text{ erg/s}$

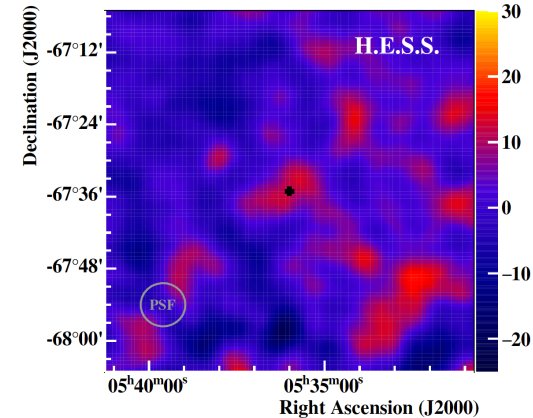
### Folded Light Curve



### Sky Maps



**on peak**  
 0.2 – 0.4  
 41.1 excess events,  $7.1 \sigma$   
 $(5 \pm 1) \times 10^{35} \text{ erg/s}$

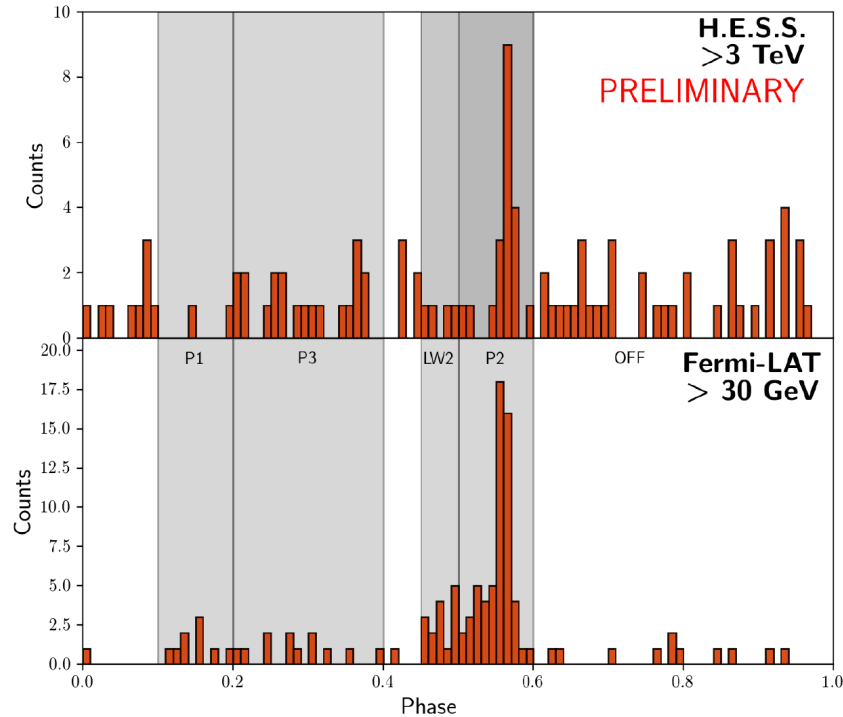


**off peak**  
 0.4 – 0.2  
 35.0 excess events,  $3.3 \sigma$   
 $< 1.2 \times 10^{35} \text{ erg/s}$  (95% CL)



# Second VHE pulsar

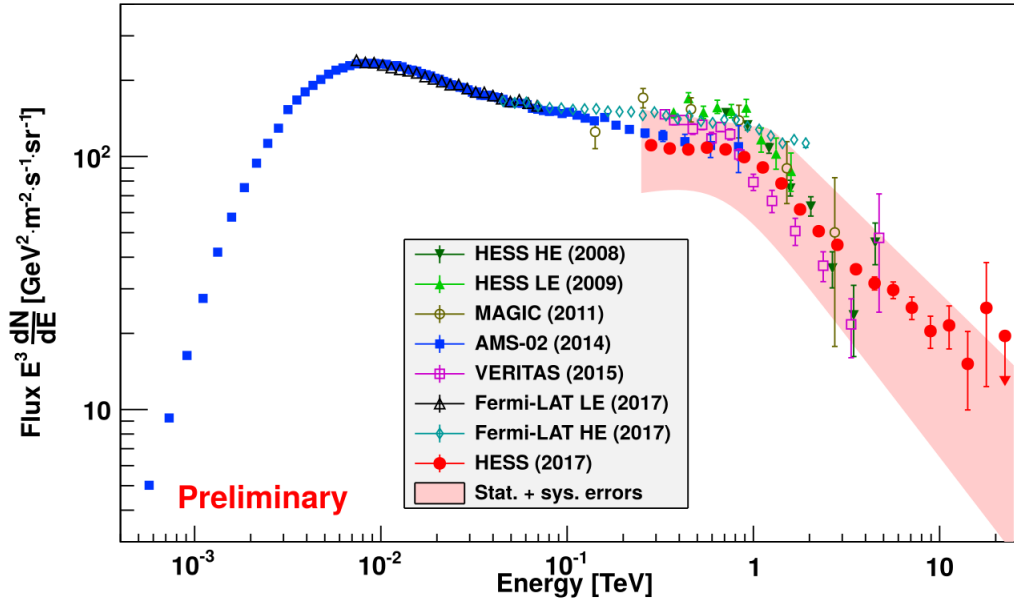
H.E.S.S. detects Vela PSR in the range from 3 TeV to 7 TeV and beyond!  
New spectral component



- Data from 2004-2016 observations
- 60 hours in stereoscopic mode:  
at least 2 telescopes among CT1-CT4
- Significance of the signal,  **$C_m$  test**:  
> 3 TeV:  **$5.3\sigma$**   
> 7 TeV:  **$5.6\sigma$**

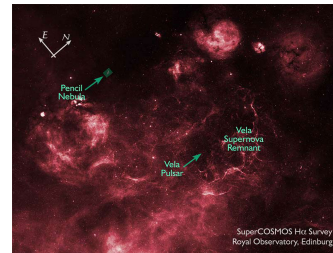
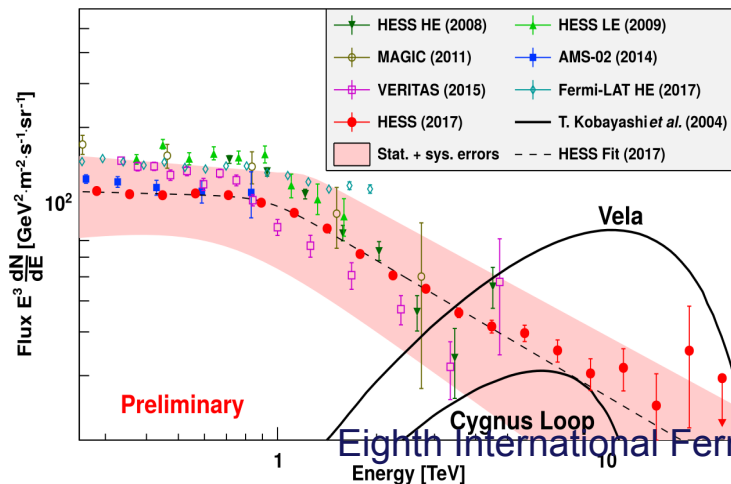
# The local cosmic-ray electron spectrum

Measured with H.E.S.S. from 0.25 TeV up to ~20 TeV



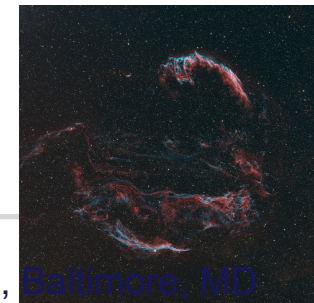
The break at ~ 1 TeV  
(change of diffusion regime?)

The spectrum constrains some local accelerators as proposed sources of such electrons



Vela SNR

Cygnus Loop SNR





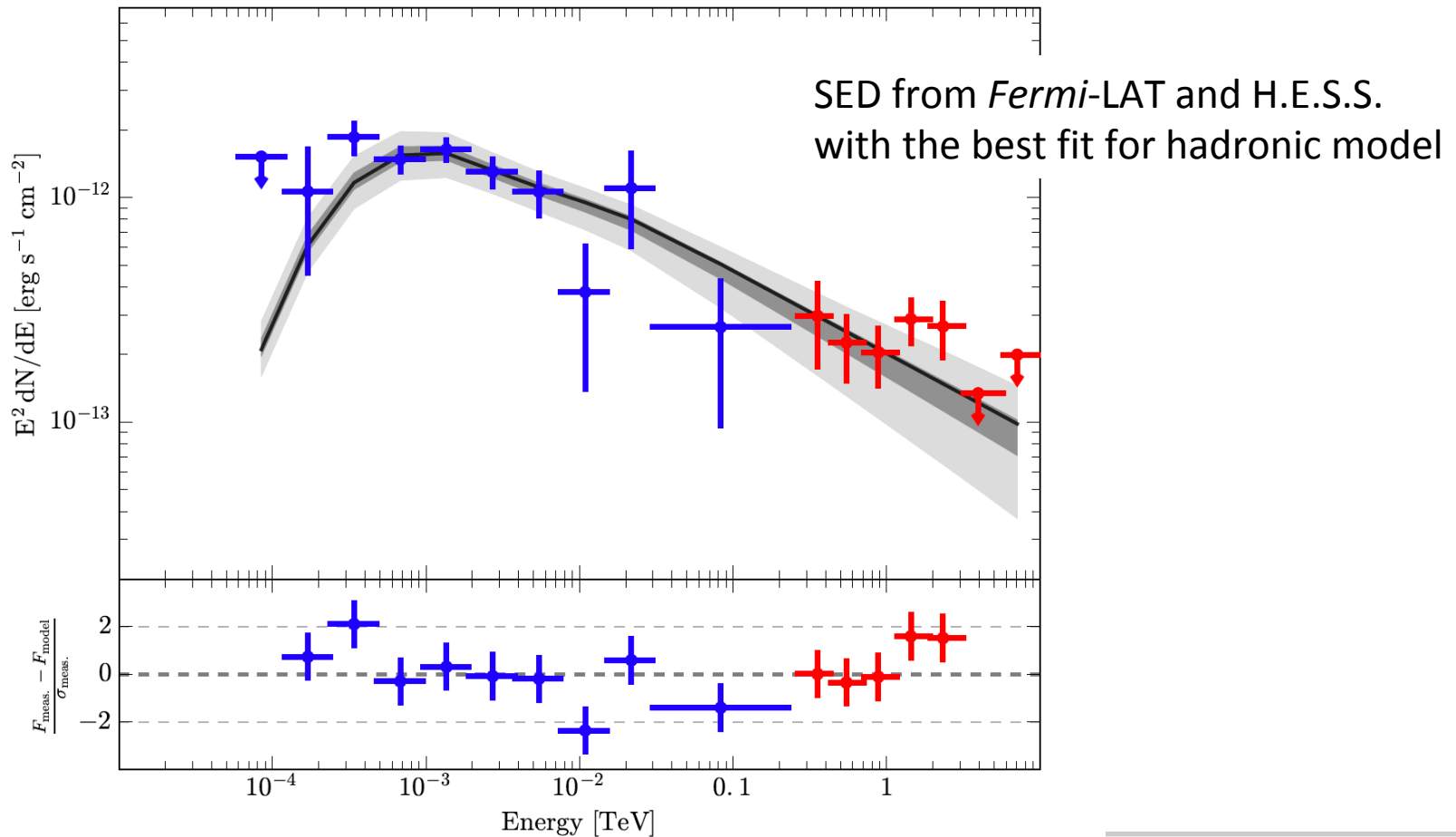


# Extragalactic science



# Starburst galaxy NGC 253 revisited by H.E.S.S. and *Fermi*-LAT

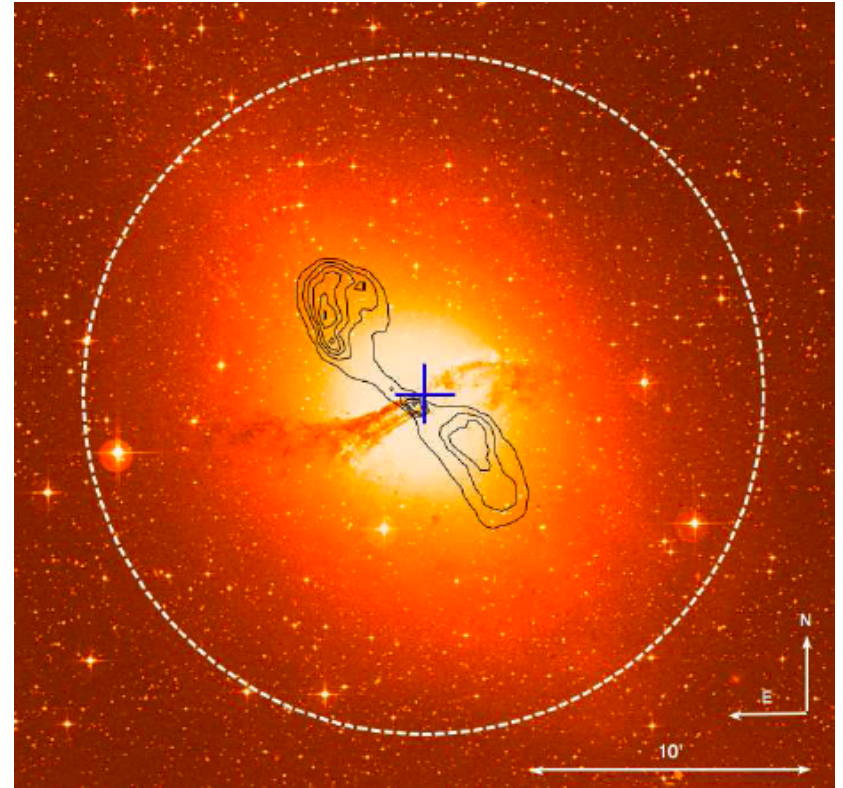
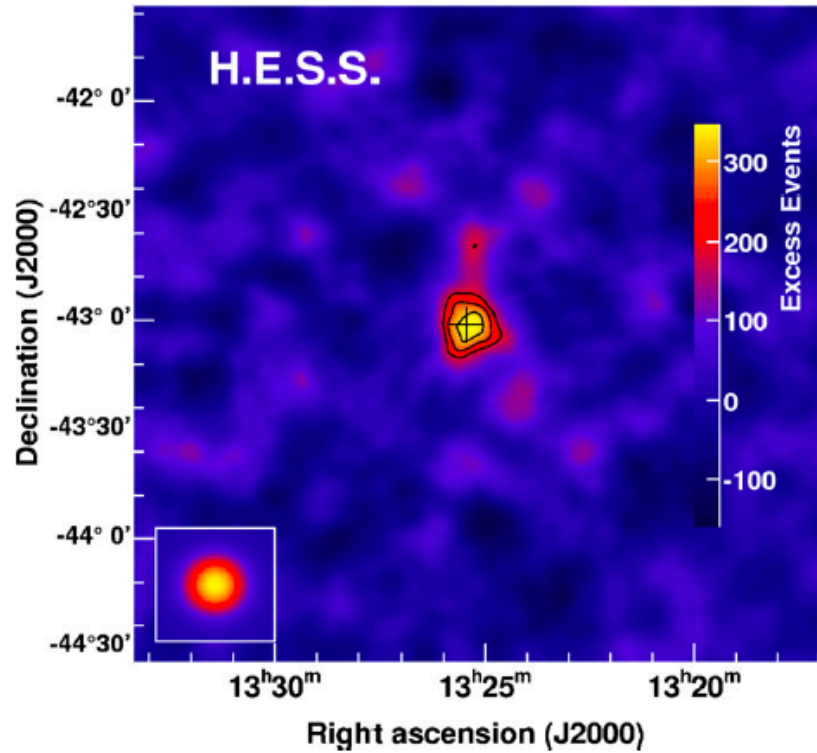
General aim: to test the paradigm that SNRs are the main source of Cosmic Rays in the Galaxy





# Centaurus A

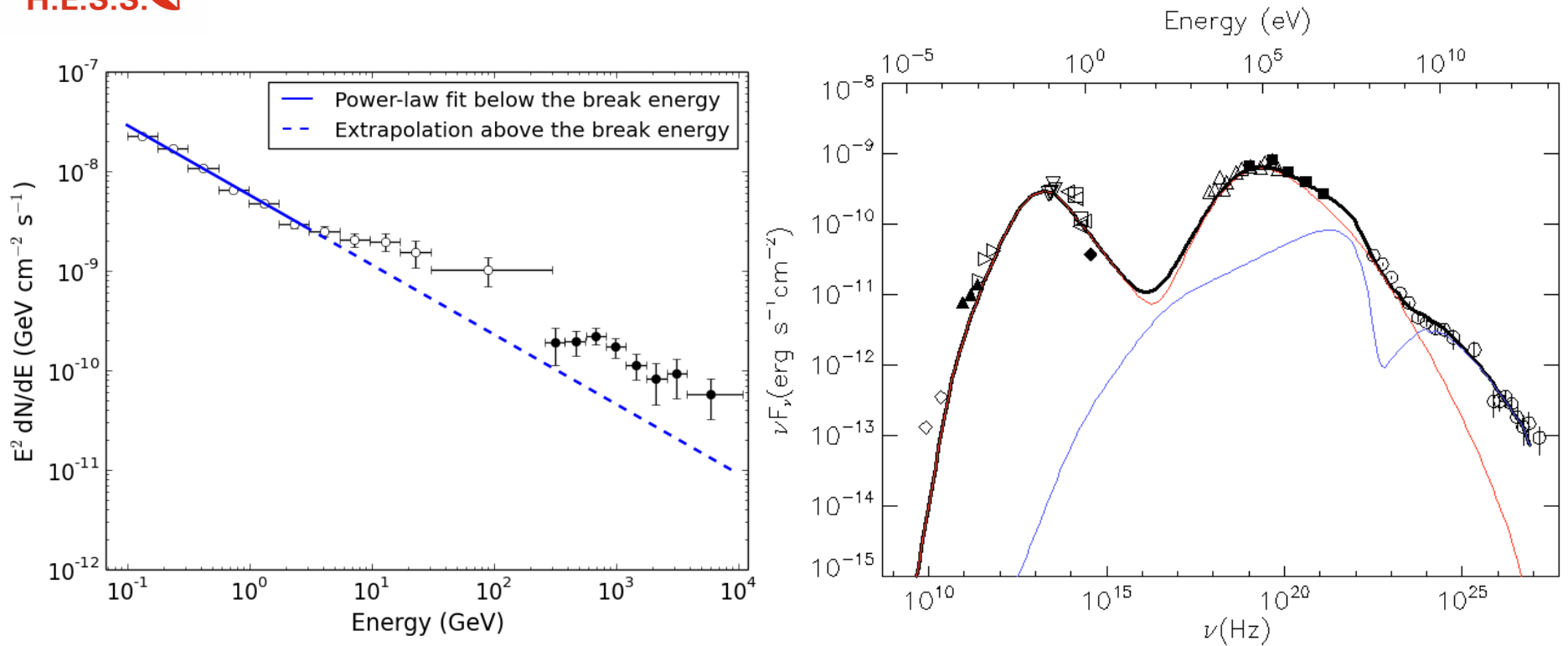
FRI type galaxy, the nearest active galaxy at 3.8 Mpc



from the discovery paper by H.E.S.S., 2009



# The core of Cen A by H.E.S.S. and *Fermi*-LAT



Is the hardening of SED jet-related?

Spectral model: two SSC components required to fit the data.





# Entering Multimessenger Observations with HESS-II

Fast response time of 28m telescope,

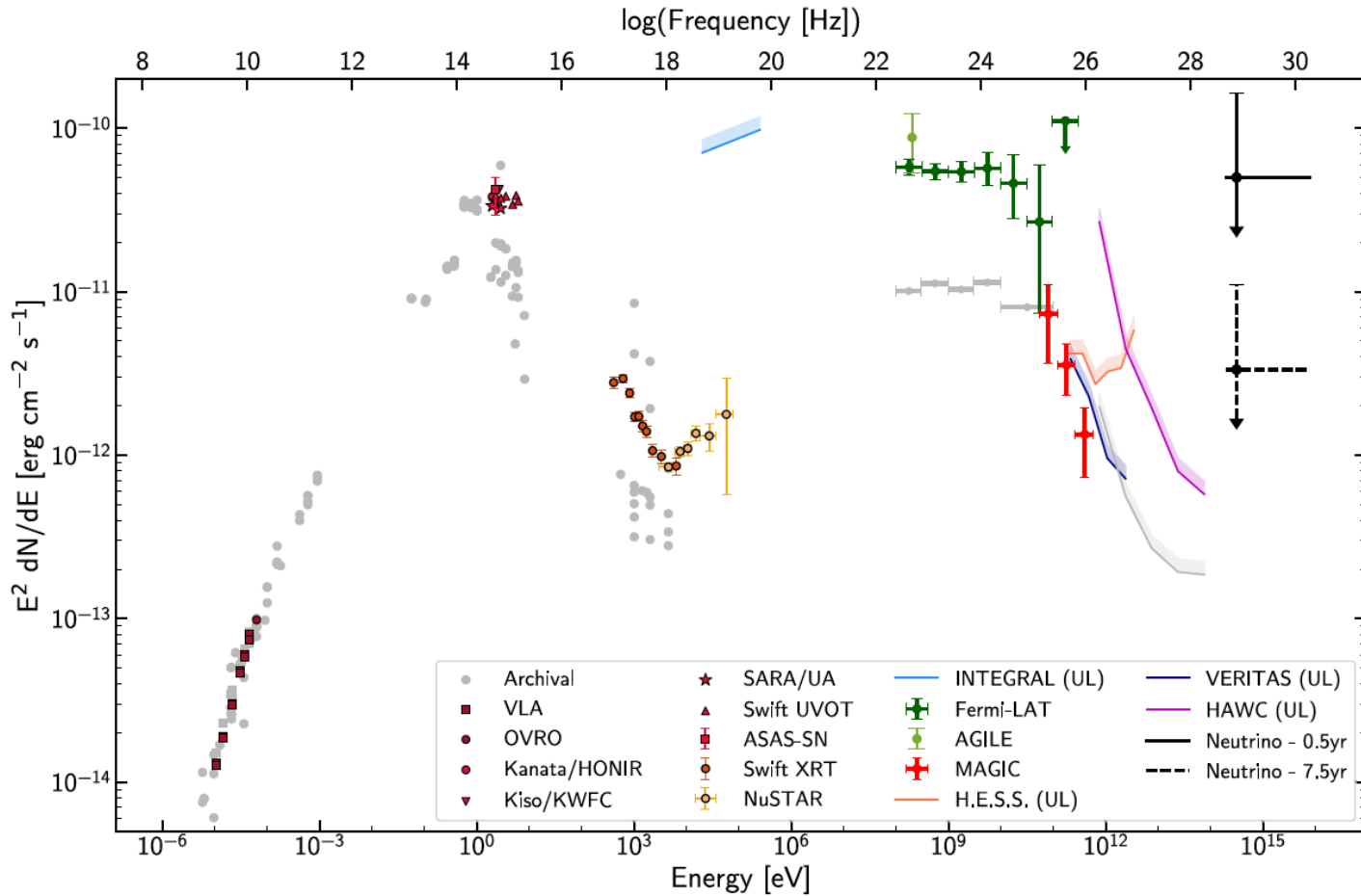
>90% of targets within 60 sec

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- GRB follow-up program
- Fast radio bursts
- Neutrino events
- Gravitational wave events

# The IceCube-170922A event and the flaring blazar

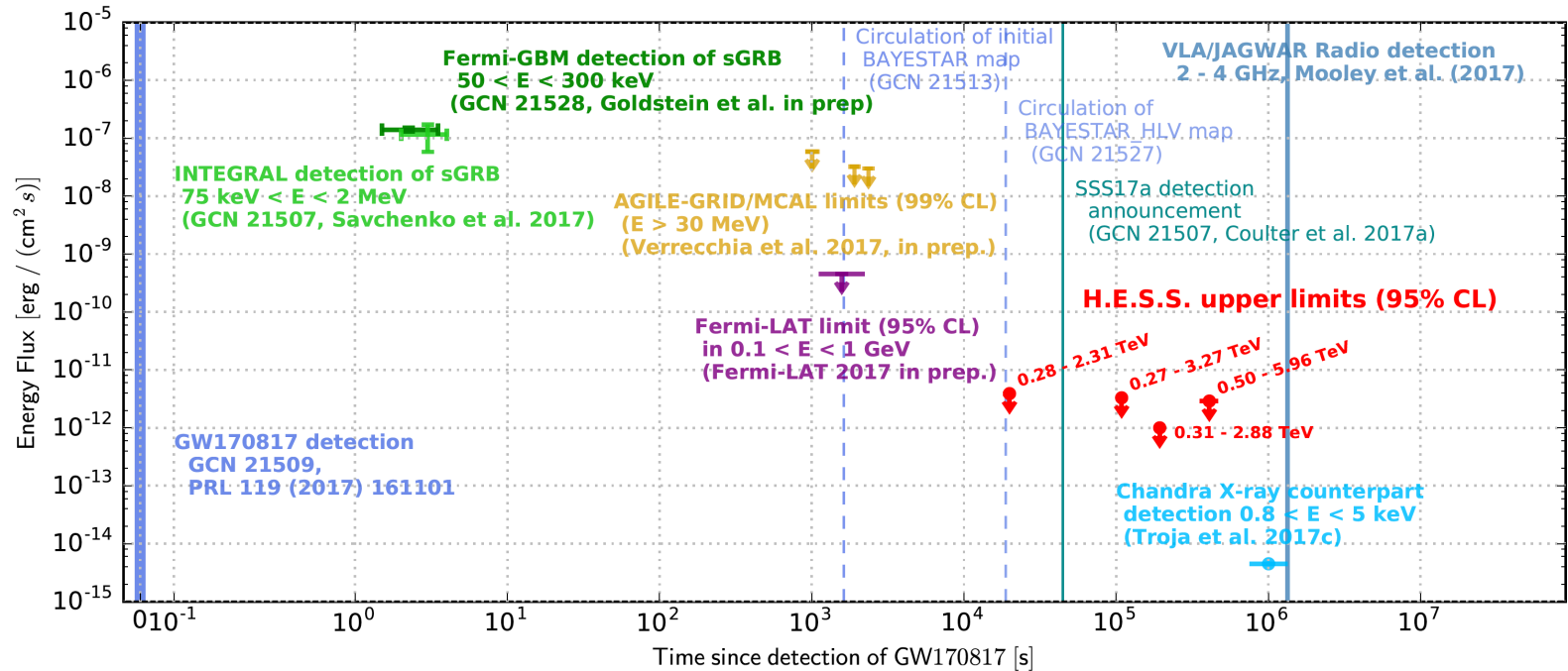
## Spectral Energy Distribution of TXS 0506+056





# Multi-messenger astrophysics: GW170817

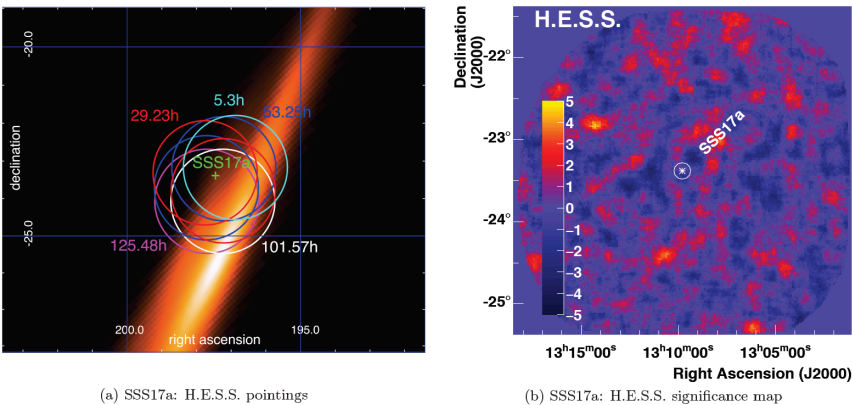
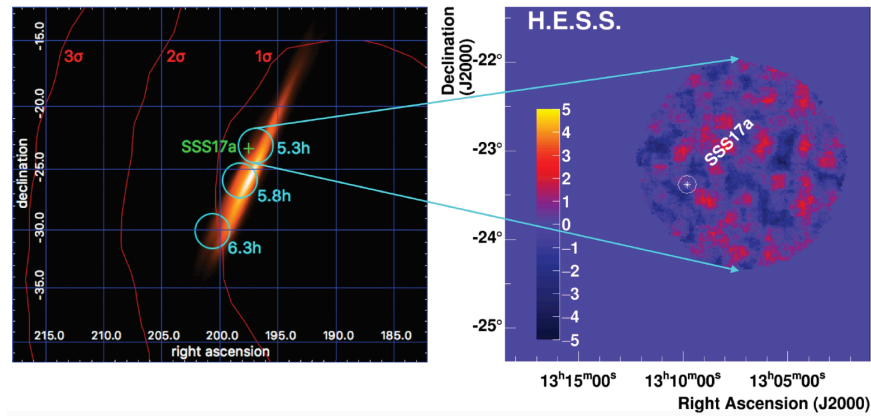
## Binary Neutron Star merger detected by LIGO + Virgo



H.E.S.S observations started T0 + 5.3 hrs

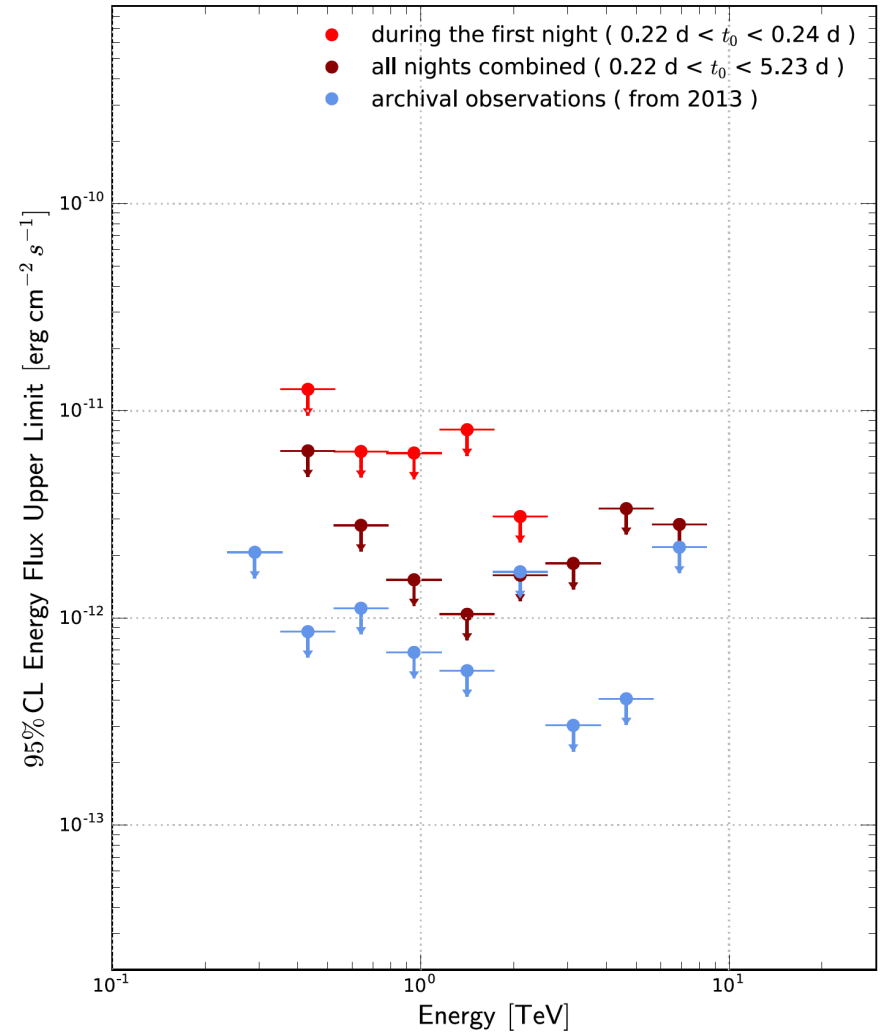
Three observation runs were taken that night.  
energy range: 270 GeV to 8.55 TeV

## Constraints on non-thermal emission



(a) SSS17a: H.E.S.S. pointings

(b) SSS17a: H.E.S.S. significance map



(a) SSS17a: H.E.S.S. limits





# Summary

15 years of HESS operations resulted in important discoveries of VHE sources of various types

HGPS - main recent achievement; allows population studies of PWN and SNR in the pre-CTA era

Discovery of pulsed multi-TeV emission from Vela pulsar is expected to influence significantly pulsar studies with CTA

HESS-II joined Multimessenger Astronomy thanks to its capabilities as a transient machine

HESS deserves an extension of its operations until CTAO-South becomes reality



# Advertisement

## **H.E.S.S. first public test data release**

arXiv:1810.04516 [astro-ph.HE]

Event lists and instrument response functions  
for observations (27.9 hrs in total) of:

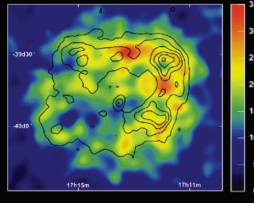
- the Crab nebula,
- PKS 2155-304,
- MSH 15-52,
- RX J1713.7-3946,
- and
- empty fields for background modeling (20.7 hrs).

In compliance with the open format  
specifications for CTA Observatory.

Science tool packages:

Gammapy  
ctools

<http://gammapy.org>  
<http://cta.irap.omp.eu/ctools>



**FITS data**

Data level 3, public test release 1  
September 2018

