The High Energy Stereoscopic System
Selected Highlights

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H.E.S.S.

CENBG

Rencontres de Blois
31/05/2017

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

An array of telescopes for very-high energy gamma ray astronomy
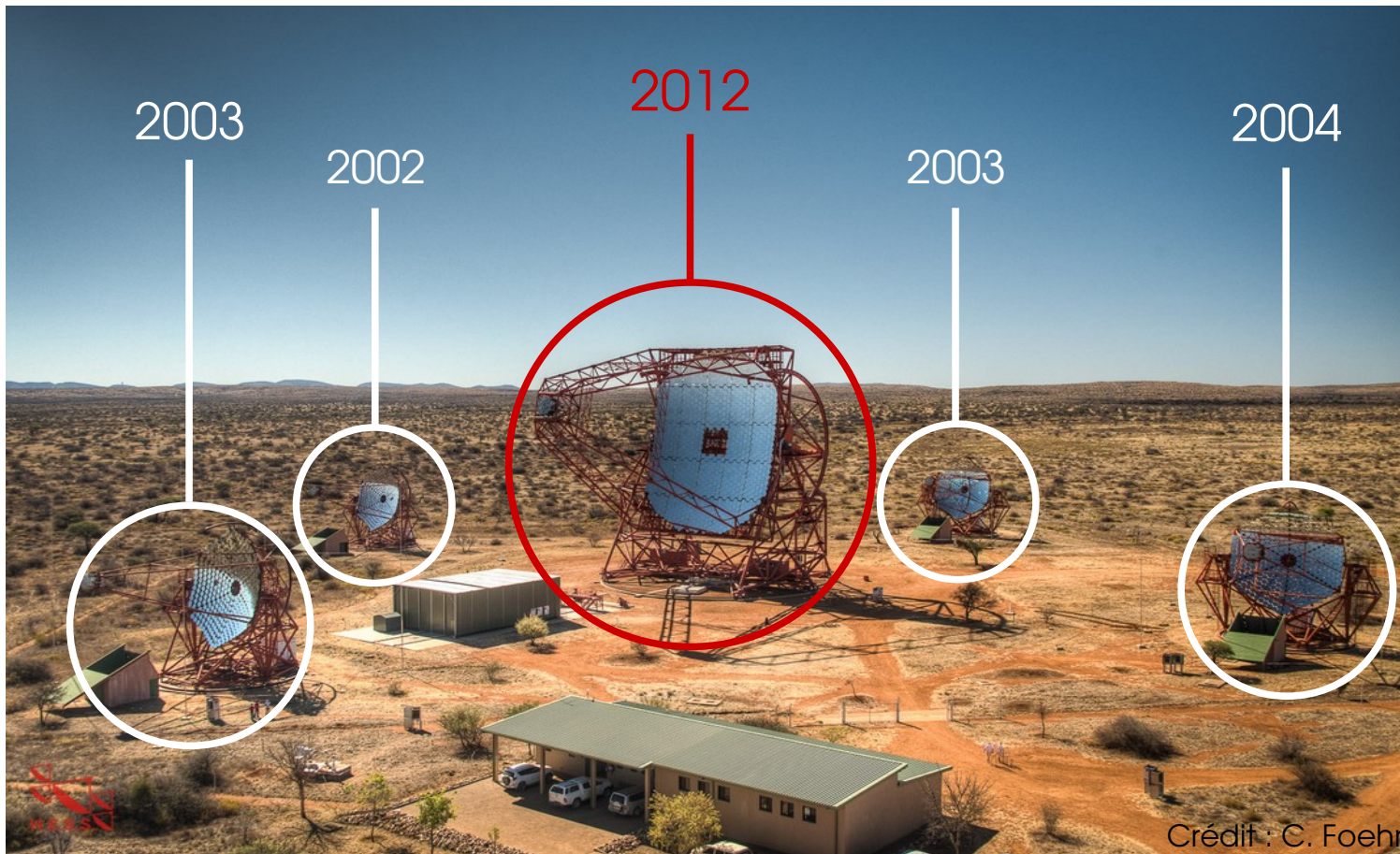

Crédit : C. Foehr

The H.E.S.S. Collaboration

> 40 institutes from 13 countries

~ 250 members

- Mont Khomas, Namibia

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

An array of telescopes for very-high energy gamma ray astronomy

2003 2002 2012 2003 2004

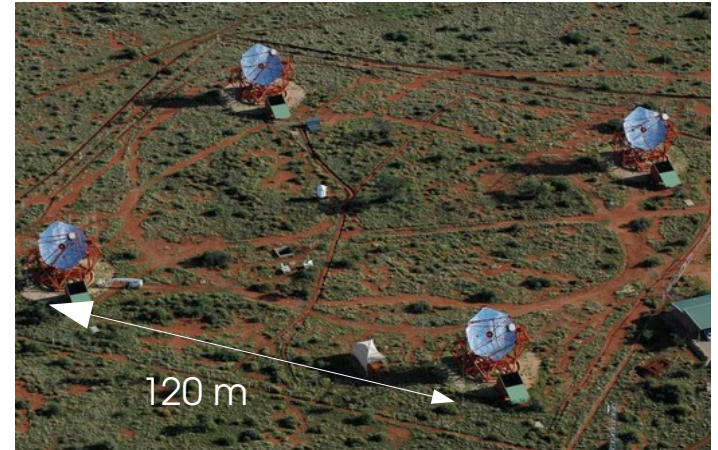Crédit : C. Foehr

The H.E.S.S. Collaboration

> 40 institutes from 13 countries

~ 250 members

- Mont Khomas, Namibia

- H.E.S.S. I : 4 telescopes – 2004

- H.E.S.S. II : 5 telescopes - 2012

The H.E.S.S. array

- High Energy Stereoscopic System

    - 4 telescopes of 107 m²

    - Cameras with 960 PMTs

    - Field of view : 5°

    - 100 GeV – 50 TeV (resolution ~ 10%)
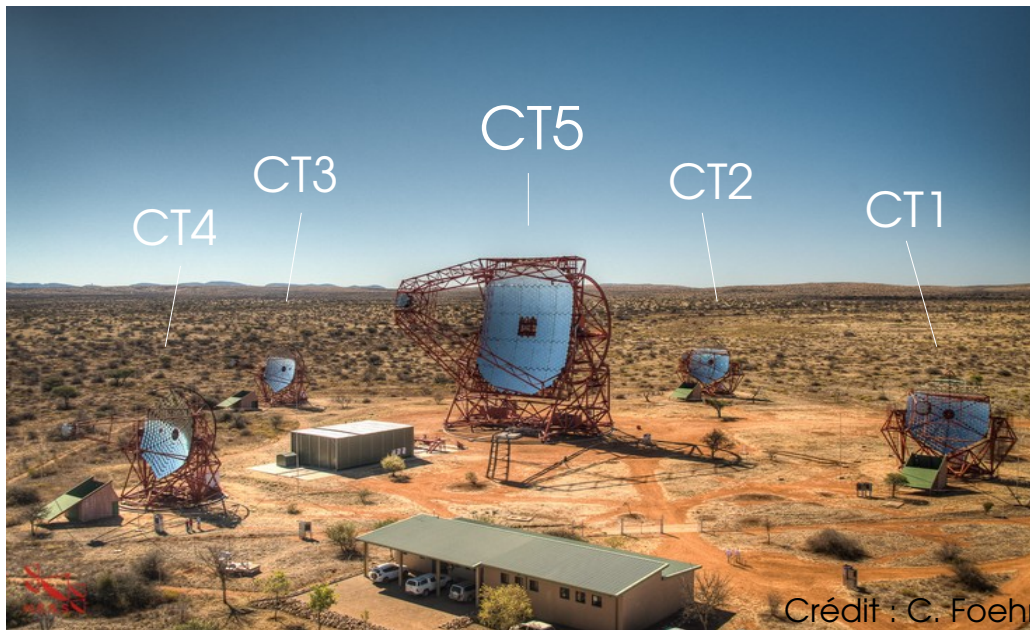
    - Angular resolution < 0.1°

120 m

« Real » astronomy at TeV energies

- A sensitive instrument (1 % « Crab ») …

    … on more than 2 orders of magnitude in energy

- Morphology studies

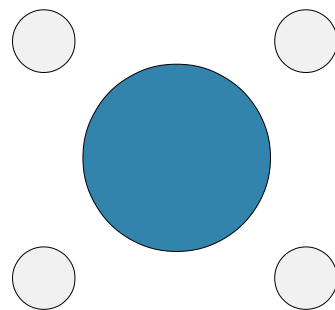- Survey capabilities

- Detailed light-curves

H.E.S.S. II

Crédit : C. Foehr

The H.E.S.S. array – Phase 2

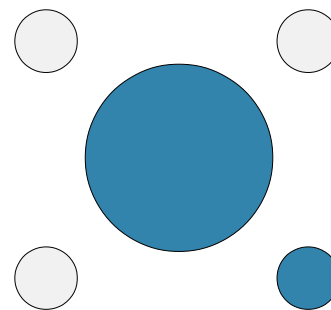CT4   CT3   CT5   CT2   CT1

Crédit : C. Foehr

H.E.S.S. II : additional 5th telescope at the center

- 28 m in diameter, 600 m², 36 m focal length

- Energy threshold lowered to ~ 30 GeV

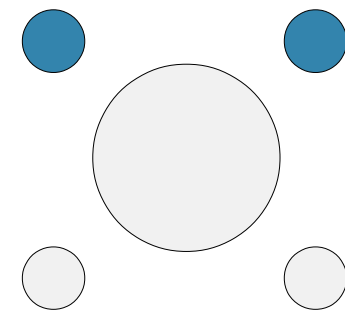- Improved sensitivity and angular resolution

Array Trigger modes :

CT5 "mono":
lowest threshold
no stereo views
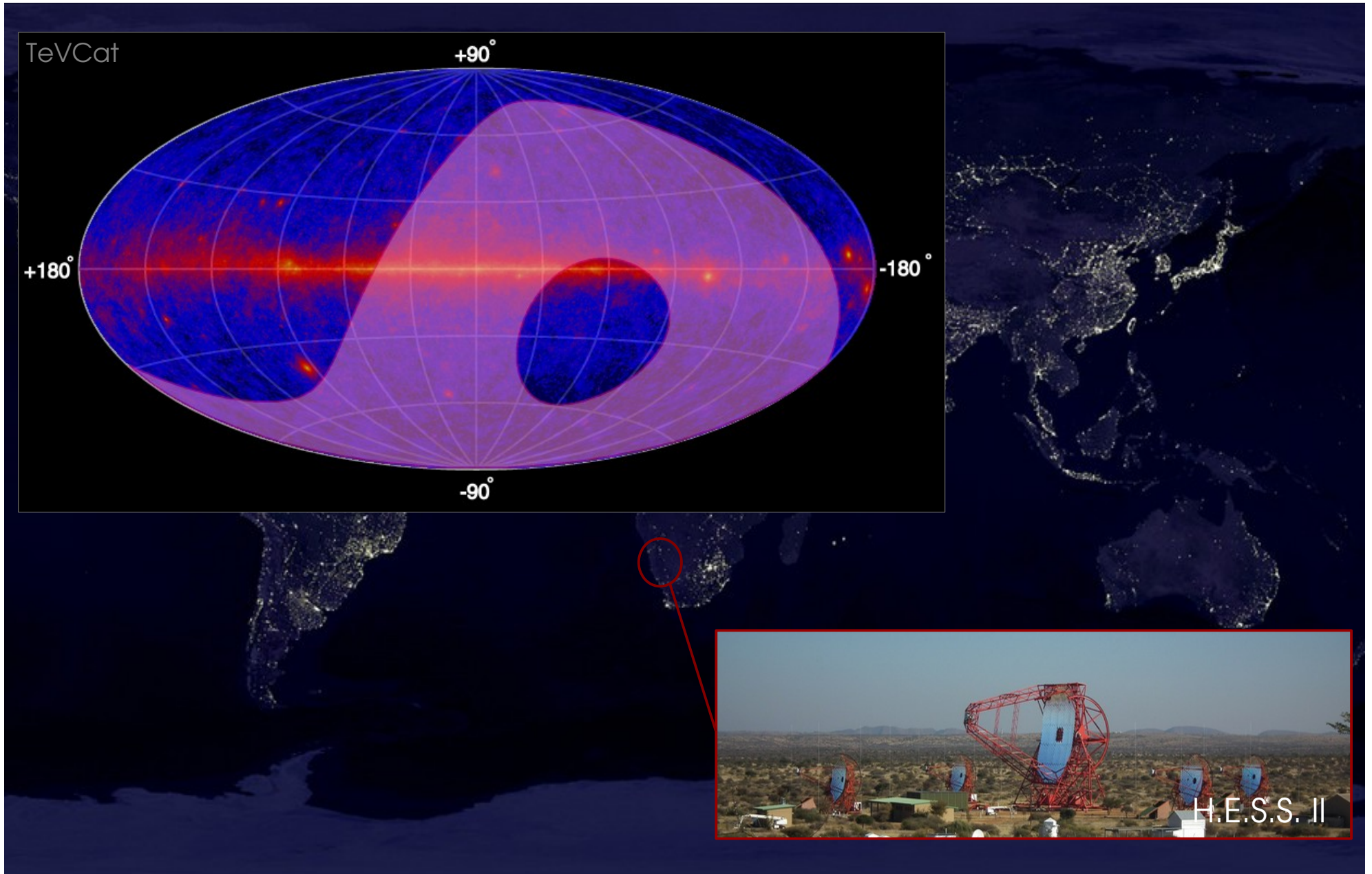~65% of events

CT5 + ≥ 1 of CT1-4
"hybrid"
~30% of events

≥ 2 of CT1-4
~5% of events

Instruments currently in operation

MAGIC

VERITAS

H.E.S.S. II

A southern hemisphere observatory

TeVCat

H.E.S.S. II

The HESS Galactic Plane Survey

- **Goal** : Map the inner regions of the Galaxy to discover new TeV sources

  - Search for the **sources of Galactic Cosmic Rays**

  - Study of charged particles acceleration in astrophysical sources

  - Study high-energy particles propagation in the Galaxy

  - Connection to fundamental physics (Lorentz Invariance, Dark Matter, Axions,...)

  → **Each new source of VHE gamma rays is a new laboratory !**
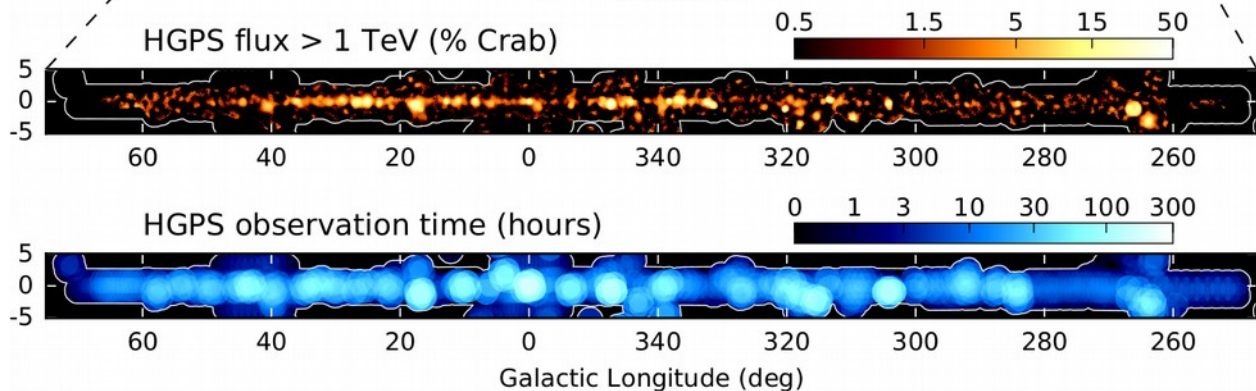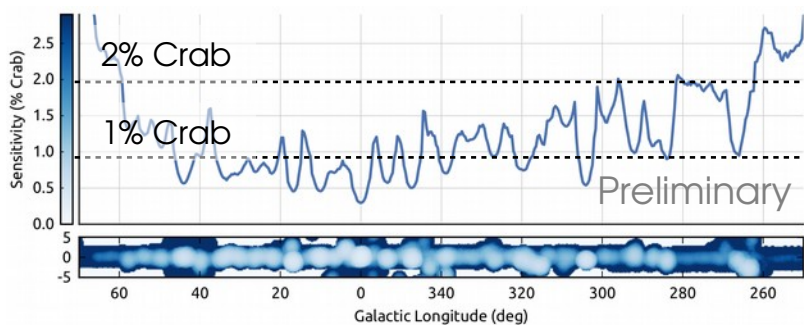
The HGPS : Latest version

10 years HESS survey program achieved !

- Observations 2004 – 2013

- H.E.S.S. I telescopes

- Total exposure ~ 3000 hours

- Energy range > 0.2 TeV

- Resolution : 0.07°

Planck CO(1-0) map
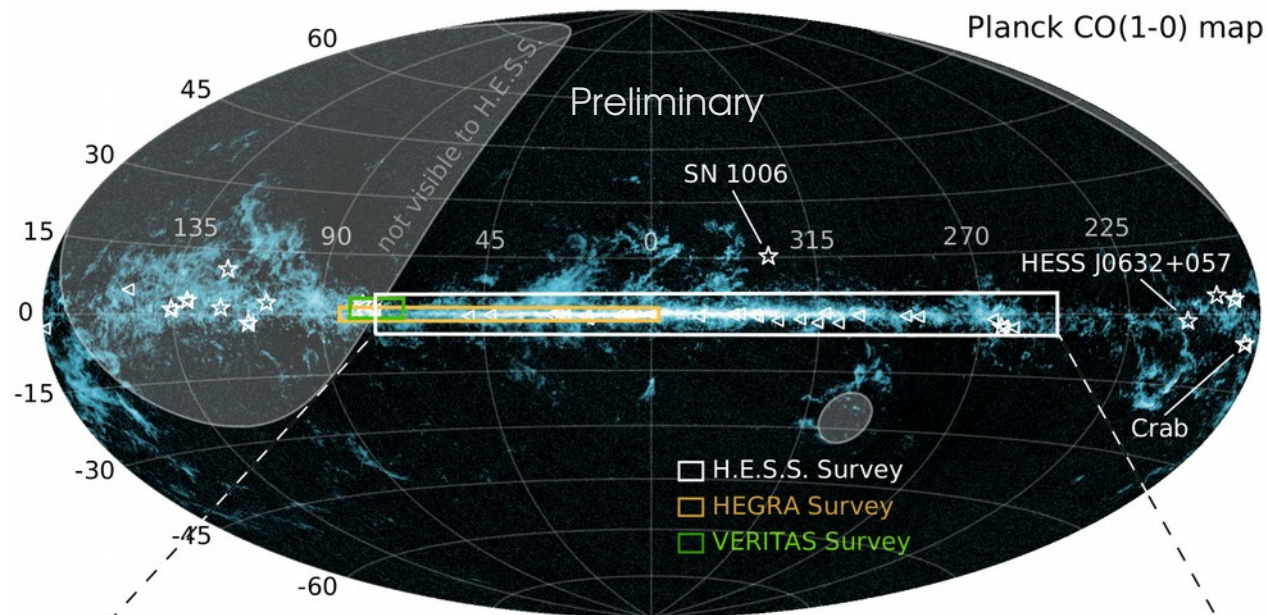
Sensitivity Profile
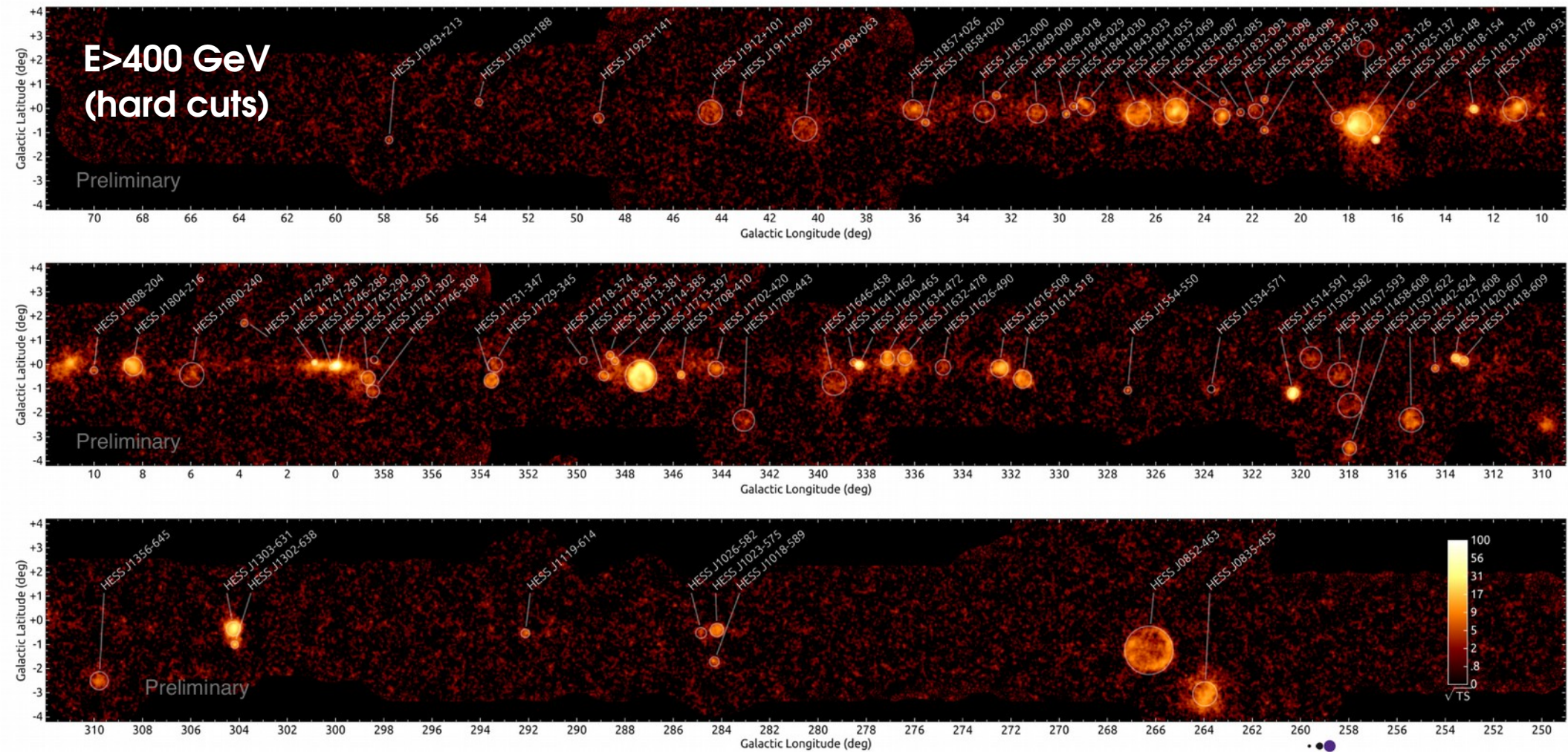Point-like for 5 sigma detection

~ 6000 x 30 mins observation runs
FoV of 2° in radius

The HGPS : Latest version

10 years HESS survey program achieved !

Point-Like Significance map

First comprehensive survey at TeV energies

The HGPS : Latest version

- Public release being finalized :

  - **Maps** in FITS format : Significance, sensitivity, flux (+errors) and upper limits maps

  - **Catalog** : Automatic pipeline for source extraction

    - Survey region split into overlapping Regions of Interest

    - Likelihood fit of emission by multiple Gaussian components + large scale emission component
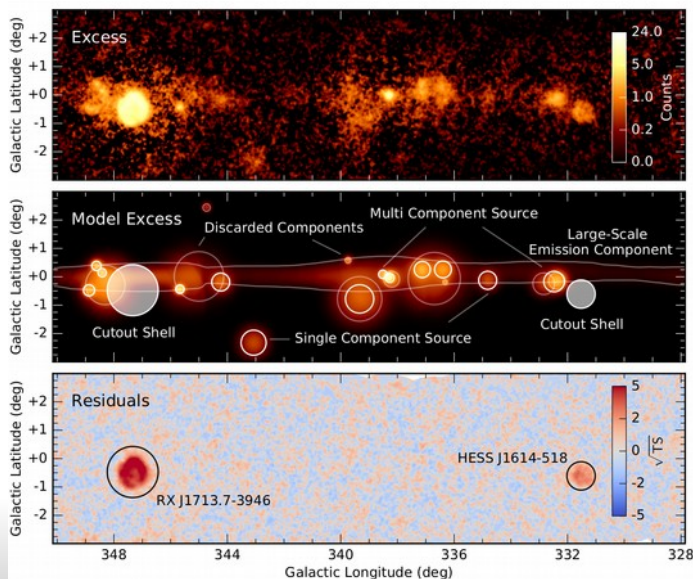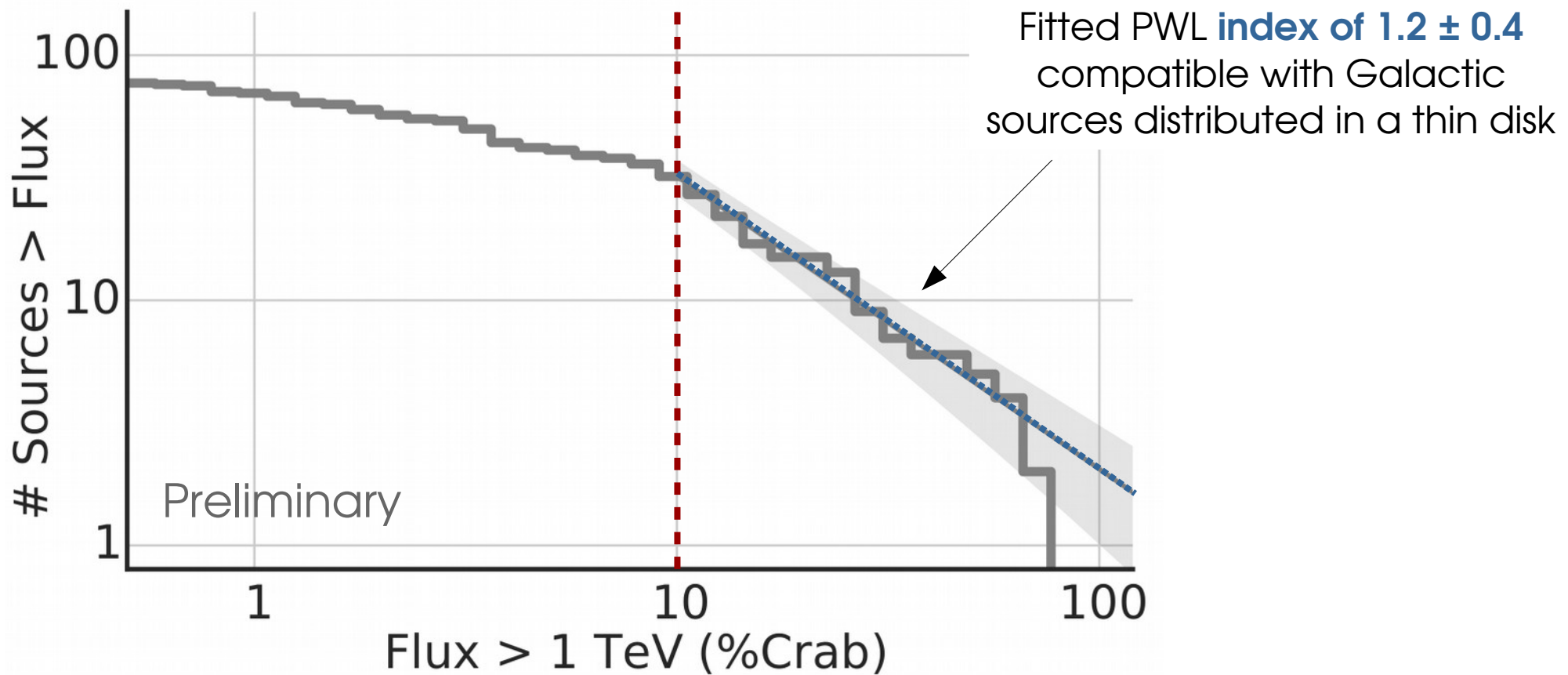

➡ **78 sources**
(14 complex sources - e.g. shell SNR - excluded from pipeline)

Log N(> S) – Log S

HGPS complete to a
flux **~ 10% Crab** for
sources < 1 deg

Fitted PWL **index of 1.2 ± 0.4**
compatible with Galactic
sources distributed in a thin disk

Preliminary
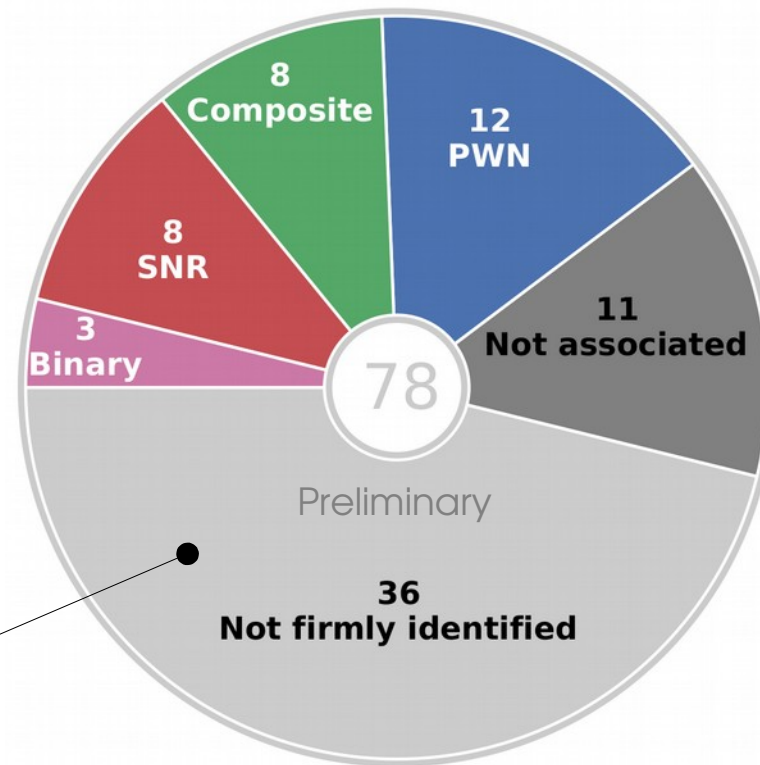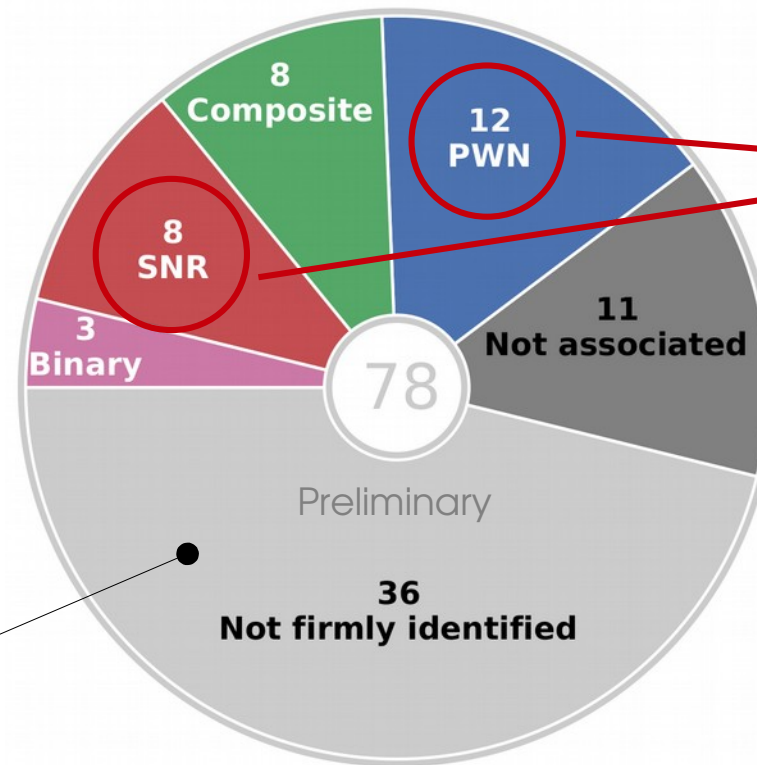
Sources > Flux

Flux > 1 TeV (%Crab)

The content of the Galaxy

Firm identifications & associations by spatial coincidence :

MWL Counterparts :
- Pulsars (ATNF)
- PWN (SNRCat)
- SNRs (SNRCat)

Sources with multiple associations

The content of the Galaxy

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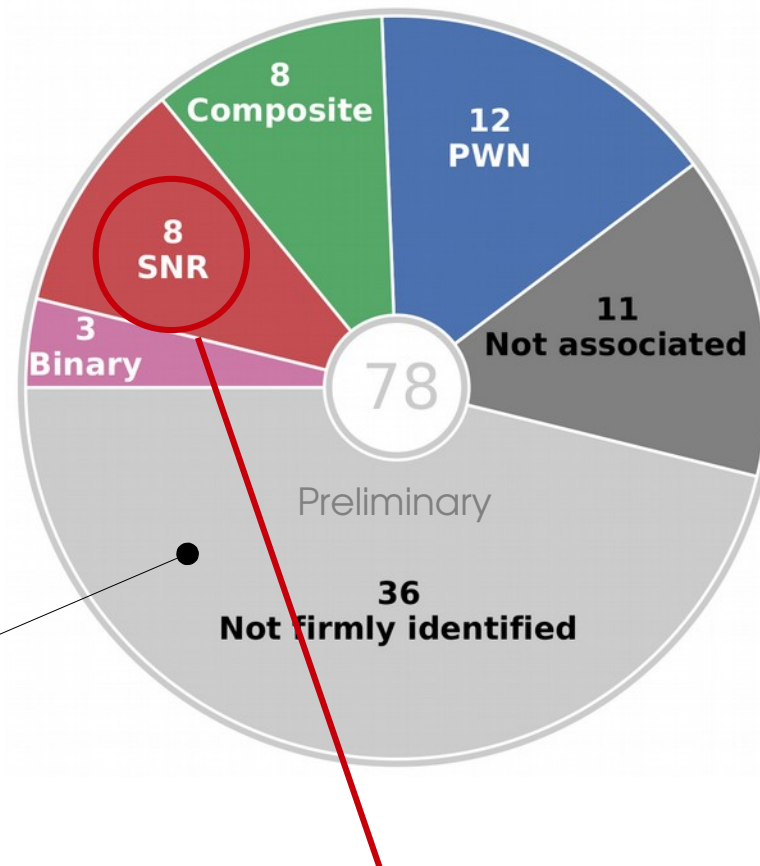
Sources with multiple associations

8 Composite

12 PWN

8 SNR

3 Binary

78

Preliminary

11 Not associated

36 Not firmly identified

Population Studies :
- Pulsar Wind Nebulae (HESS, 2017)
- Supernova Remnants (HESS, in prep)

- Globular Clusters (HESS, 2013)
- Microquasars (HESS, 2016)
- Bow Shocks from runaway stars (HESS, 2017)

The content of the Galaxy

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Sources with multiple associations

8 Composite

12 PWN

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Preliminary

11 Not associated

36 Not firmly identified

SNRs are good candidates for the sources of Galactic Cosmic-Rays

Supernova Remnants : new shells discovered

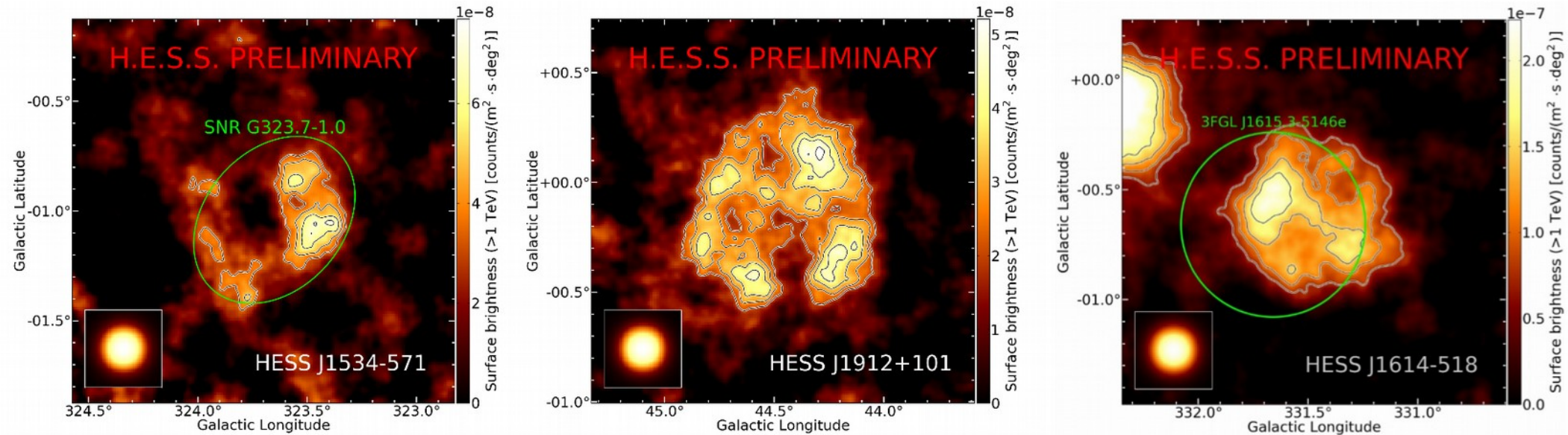Systematic search for shell-like morphologies in the HGPS maps :
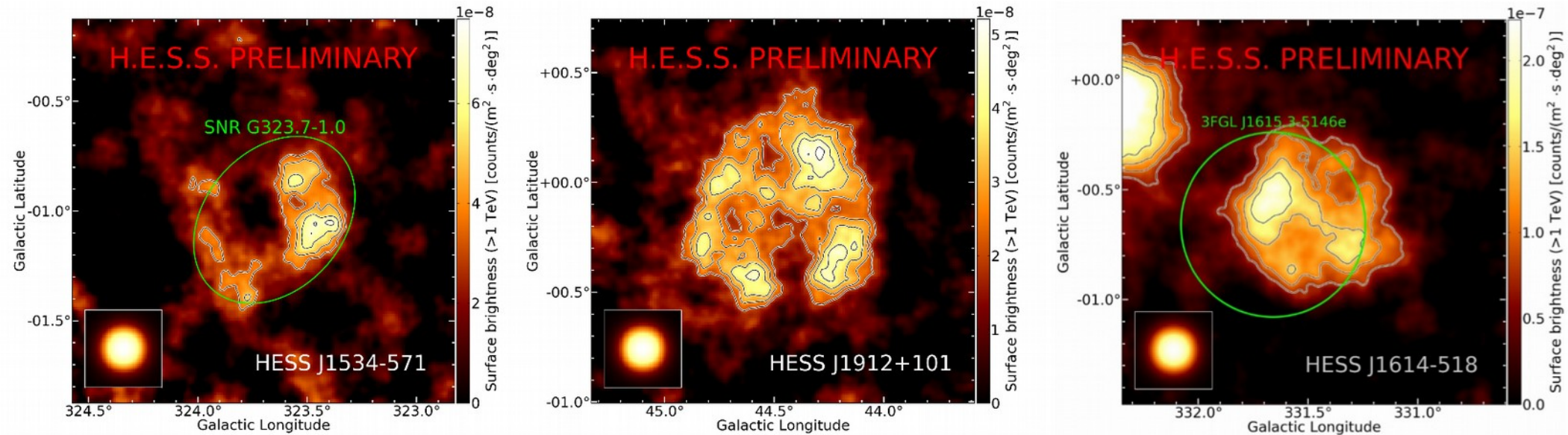
3 new shells discovered :

- **1 SNR confirmed** (coincident with a SNR candidate in radio)

- 2 SNR candidates

Supernova Remnants : new shells discovered

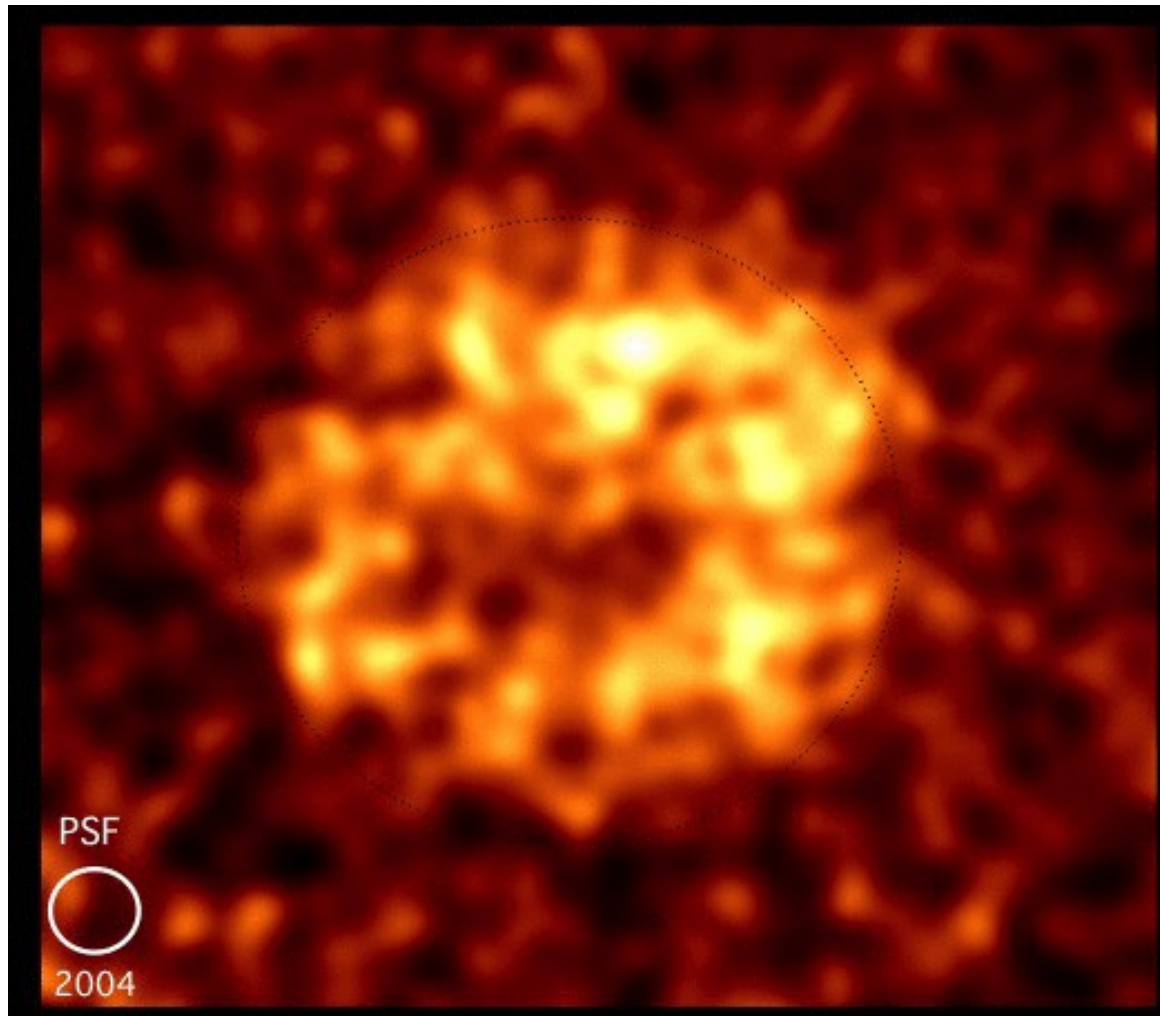Systematic search for shell-like morphologies in the HGPS maps :

3 new shells discovered :

- **1 SNR confirmed** (coincident with a SNR candidate in radio)
- 2 SNR candidates

Resolving SNR shells :

- Gamma ray emission comes from the shock region, where particle acceleration occur
- Hadrons (CR) acceleration ?

Supernova Remnants : RXJ 1713.7-3946

Livetime : 18 h

E_{min} = 1 TeV

Excess = 1430

PSF (R_{68}) : 4.8'

Supernova Remnants : RXJ 1713.7-3946
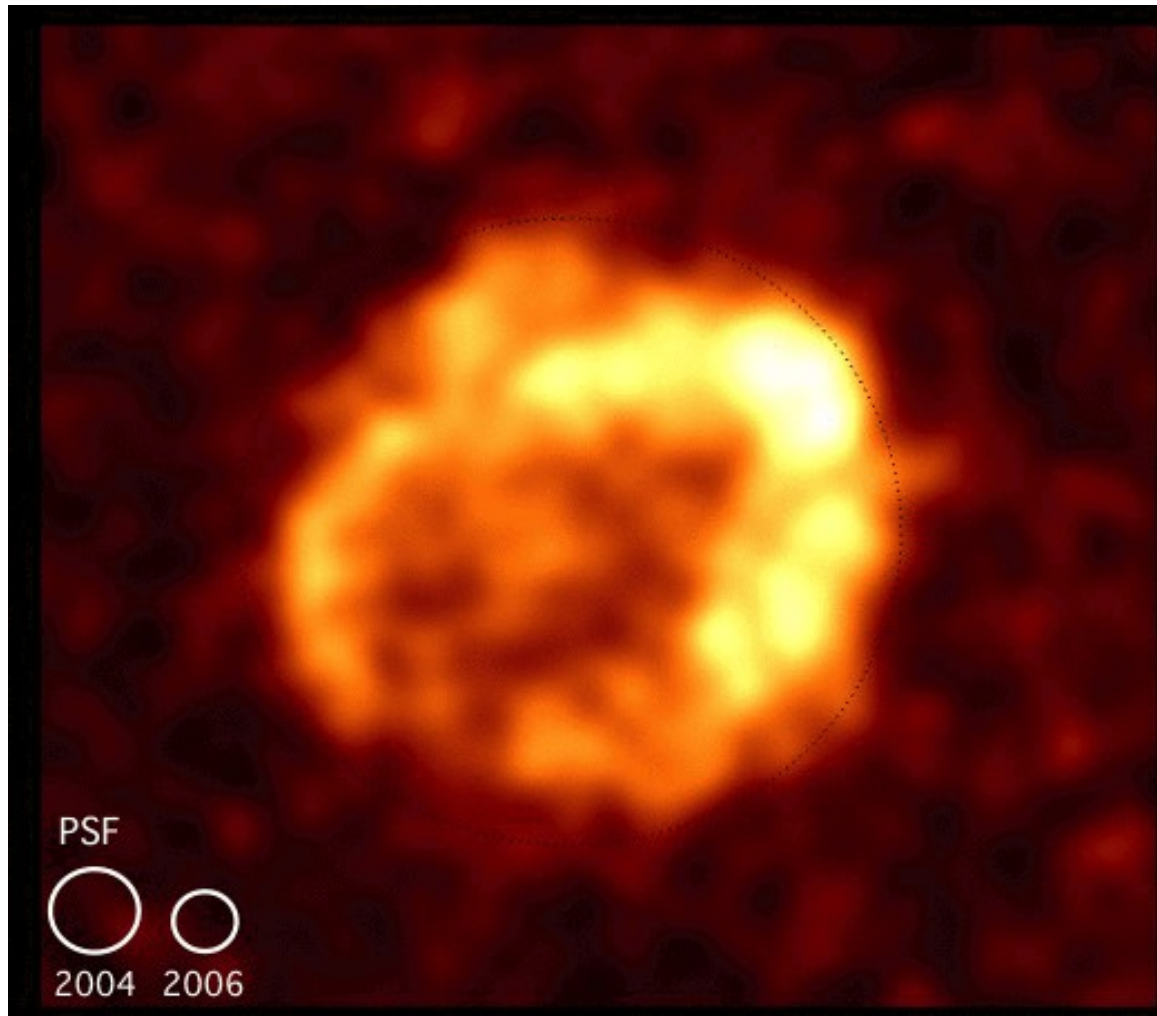
Livetime : 63 h

E_{min} = 0.3 TeV

Excess = 6700

PSF (R_{68}) : 3.6'

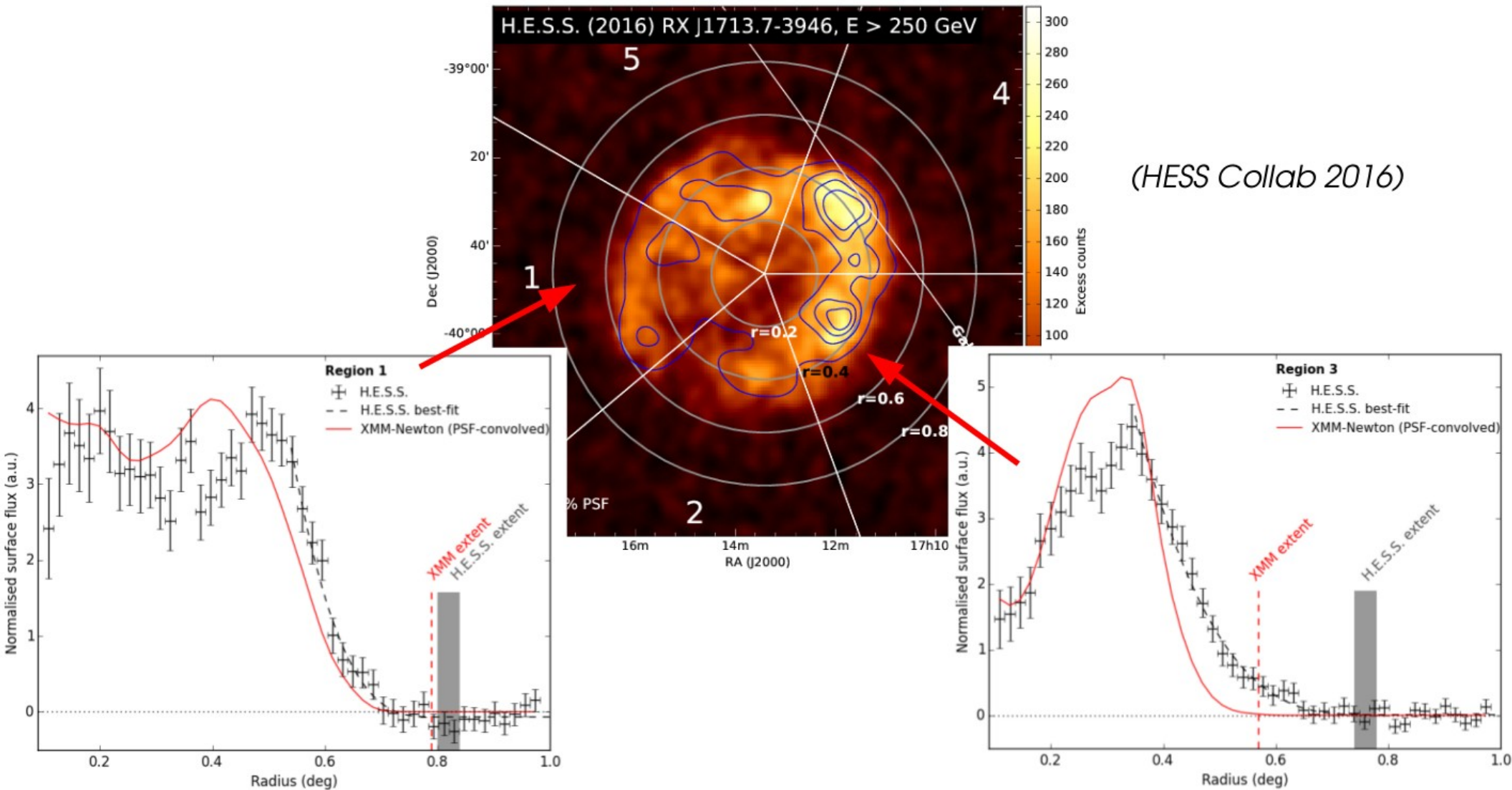# Supernova Remnants : RXJ 1713.7-3946
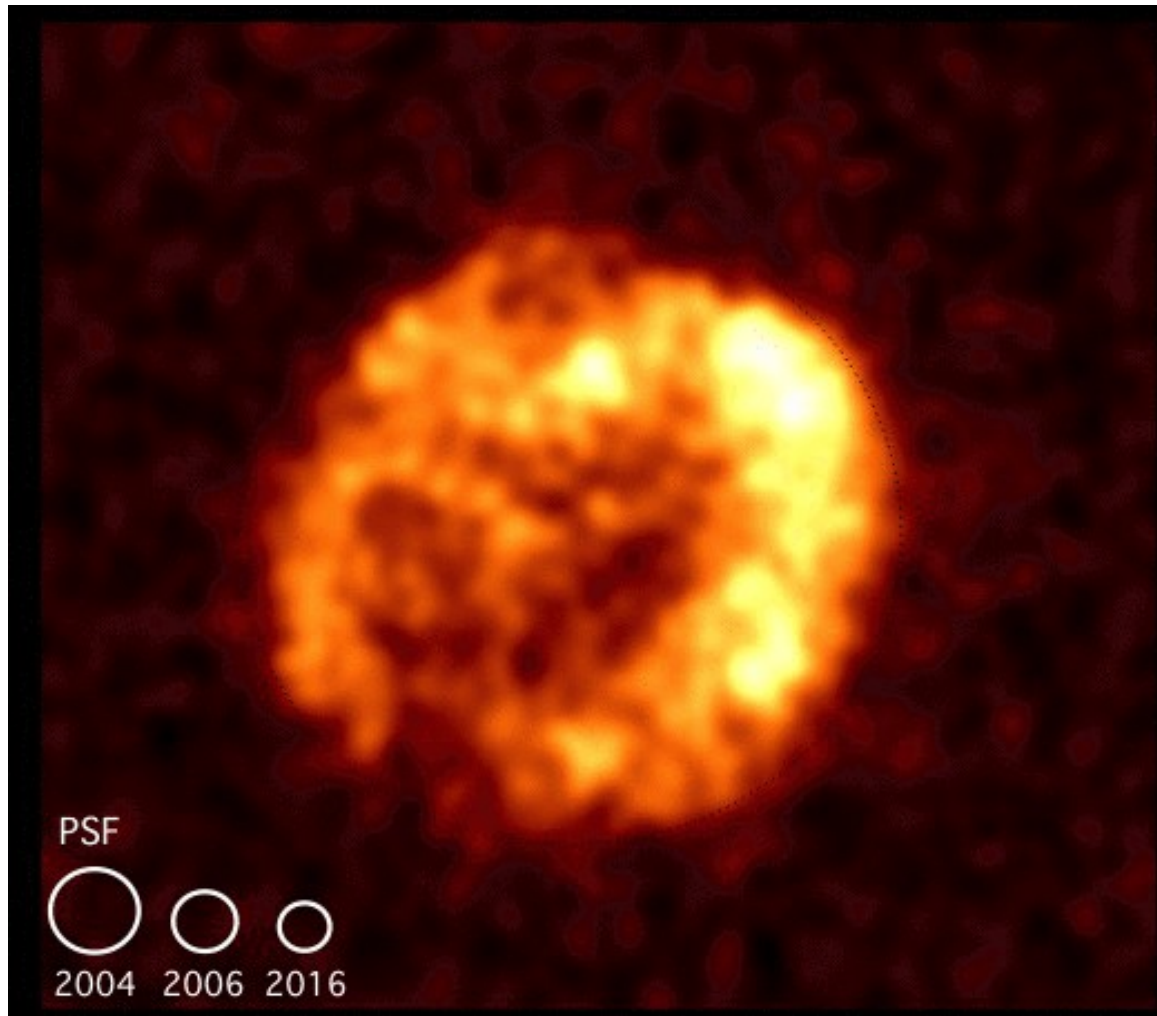
Livetime : 164 h

E_{min} = 0.25 TeV

Excess = 31000

PSF (R_{68}) : 2.9'

→ Deep observations
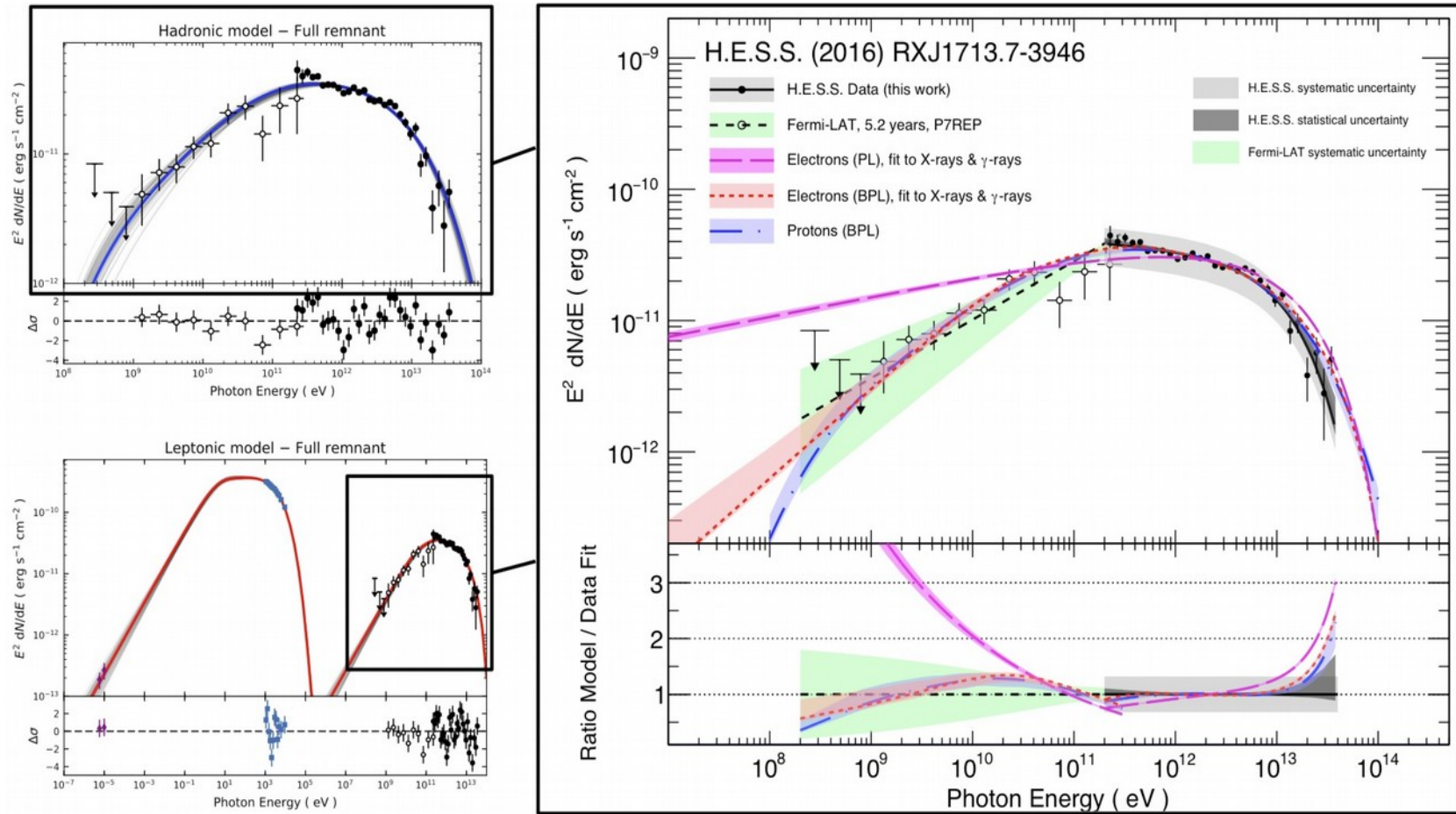and systematics control
leading to precision
measurements

Supernova Remnants : RXJ 1713.7-3946

(HESS Collab 2016)

→ Regions where TeV Gamma-rays extend beyond X-rays :
- Escaping particles ?
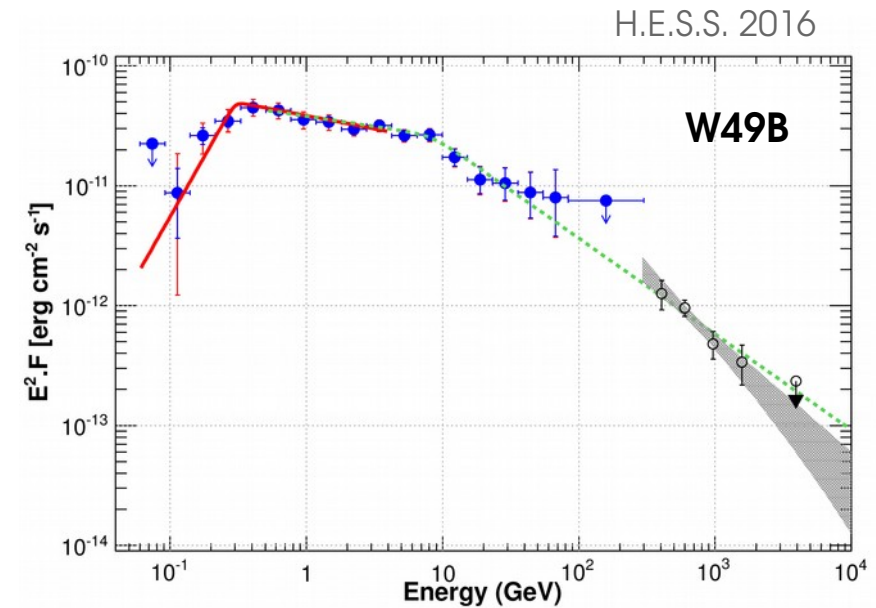- Shock precursor ?

Supernova Remnants : RXJ 1713.7-3946

→ Nature (hadrons or leptons) of the accelerated particles still not clear...

SNR W49B : a proton accelerator ?

- Low energy spectral break as in IC 443, W44 and W51C for which it is interpreted as the « pion bump » feature

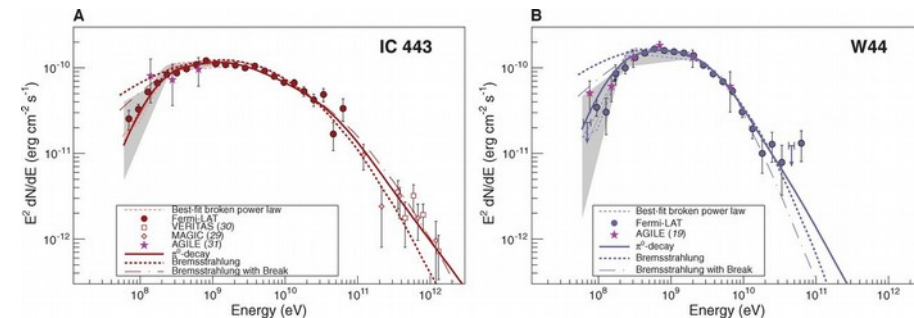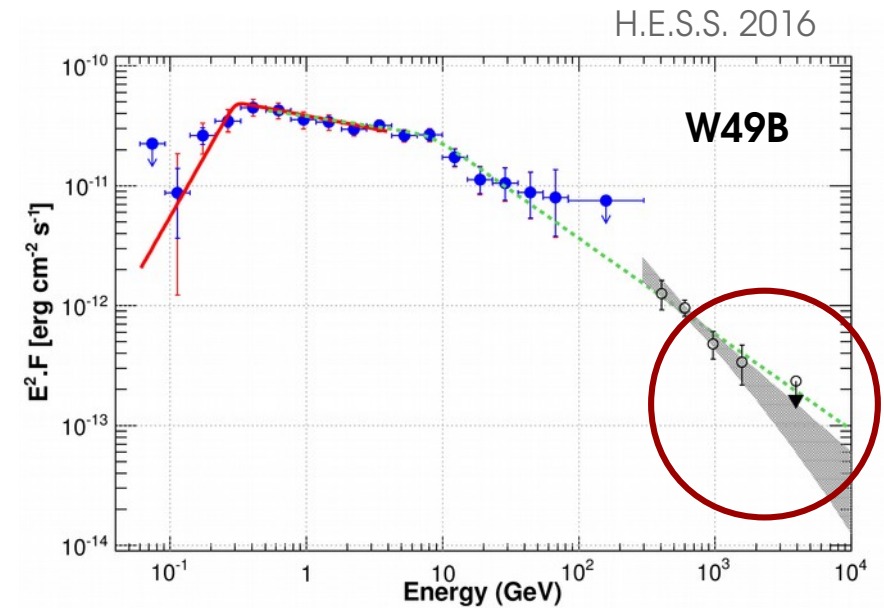→ W49B is most likely accelerating cosmic-ray protons and nuclei
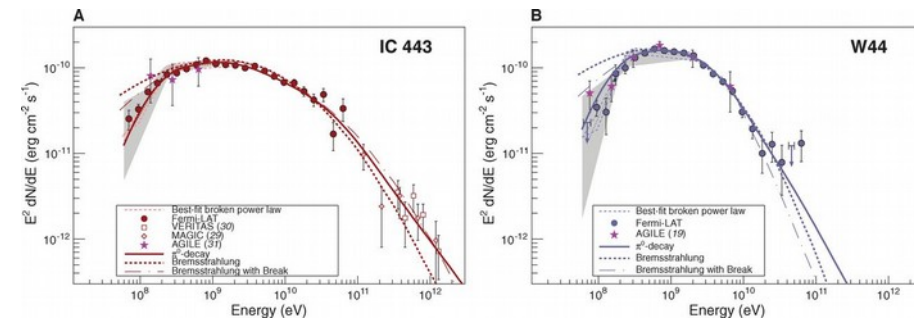
SNR W49B : a proton accelerator ?

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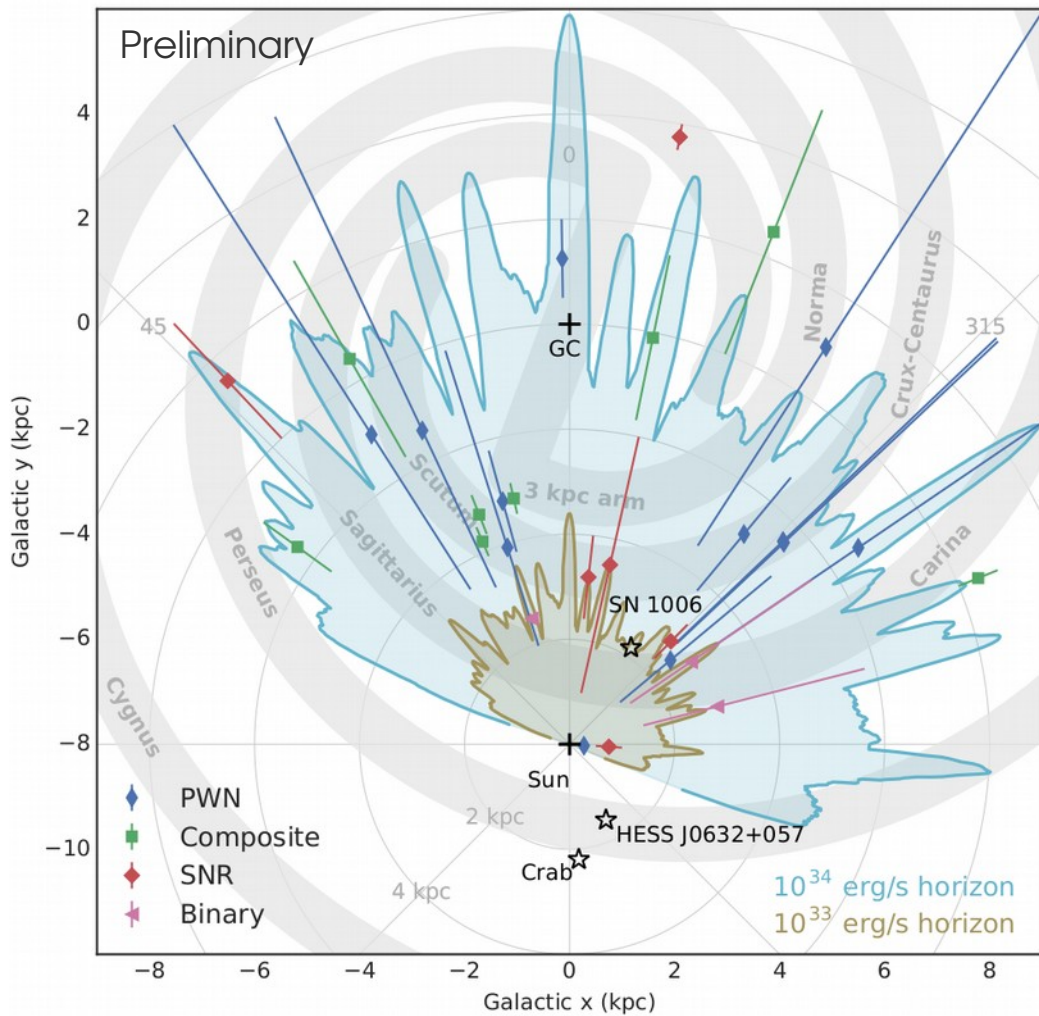→ W49B is most likely accelerating cosmic-ray protons and nuclei

… but the flux is decreasing rapidly at highest energies...

H.E.S.S. 2016

Ackermann et al. 2013

After the HGPS, SNRs are still good candidates for the sources of Galactic CRs but still no definitive observational proof !

HESS Galactic Horizon
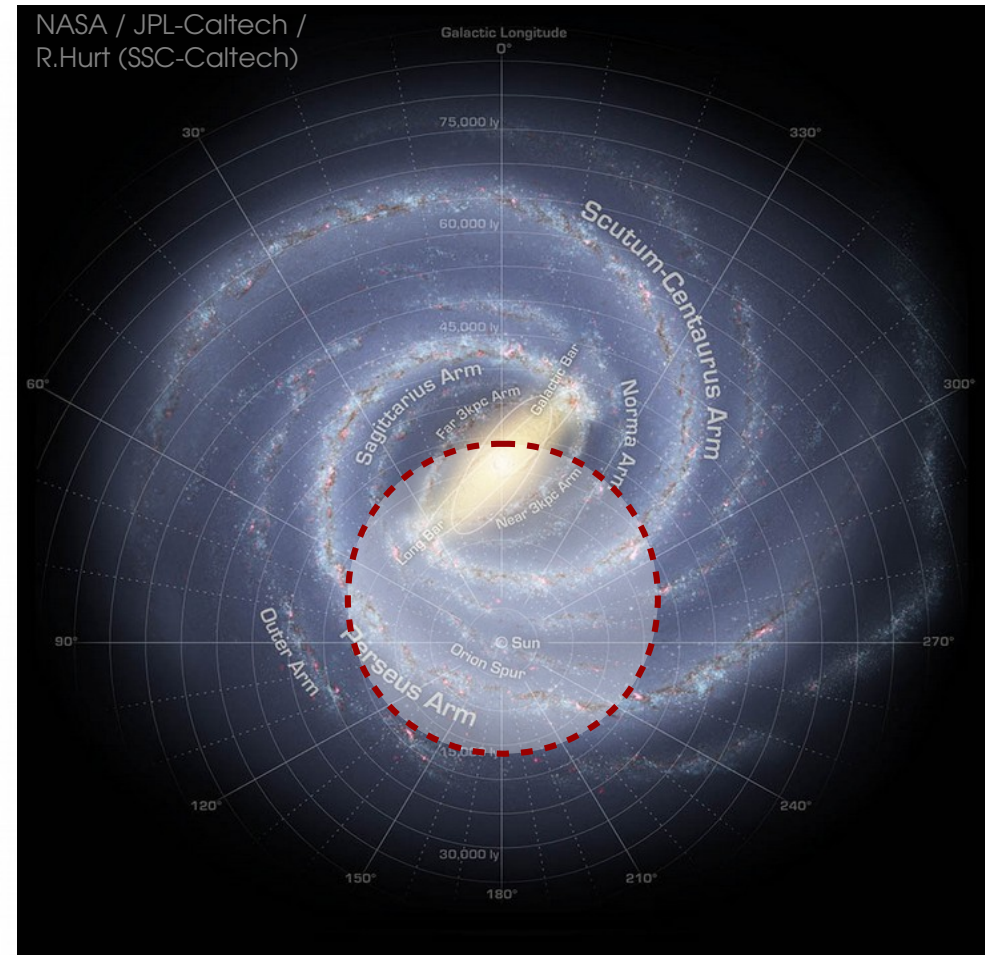
→ HESS only probed a small fraction of the Galaxy (median distance of 7.3 kpc at 10^{34} erg.s^{-1})
→ Large scale emission component = unresolved sources ?

Other than the HGPS and Galactic sources...

- **Active Galactic Nuclei with H.E.S.S. II**

  - CT5 Mono analysis (ideal for high z, soft spectra)

  - E < 100 GeV : bridging the gap with Fermi-LAT

  - Blazar PG 1553+113 : Spectrum consistent with EBL absorption at z ~ 0.49

- **Transients with H.E.S.S. II**

  - Very fast response

    - 95 % of targets in < 60 s

  - Fully automatic system to follow Target of Opportunity alerts

    - Extensive GRB follow-up program

  - Also Fast Radio Bursts, GW, Neutrinos, ...
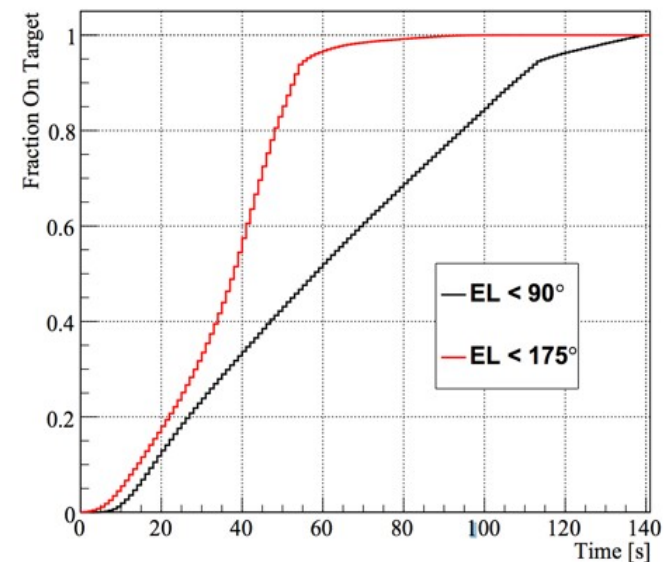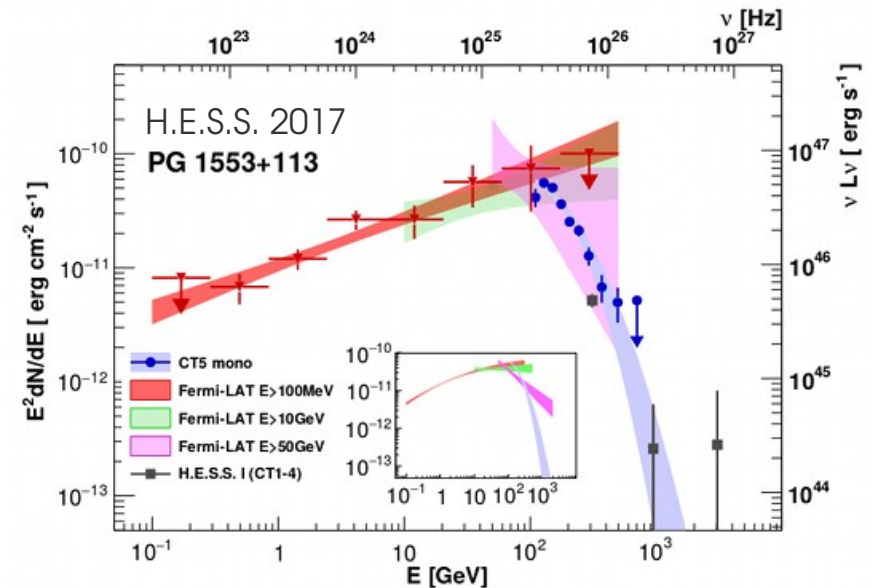
- H.E.S.S. I legacy survey of the inner Galaxy

  - Decade-long HGPS is completed !

  - Release of paper, FITS maps and catalog coming soon

  - Release a number of H.E.S.S. I legacy papers on Galactic Science

  - Population studies & New TeV shells

- Many more results !

  - Vela Pulsar, LMC, Galactic Center, TeV Binaries, Astroparticle physics...

    → Check out the H.E.S.S. Source of the Month webpage !

- H.E.S.S. I cameras electronics upgrade finished

  - Reduce deadtime + increase robustness

- Many more H.E.S.S. results to come soon (ICRC 2017)

Exciting times ahead !
Stay tuned & Thanks for your attention !

The imaging atmospheric Cherenkov technique

- γ interacts in the atmosphere

- Development of a particle shower

- Emission of a brief (~ few ns) and weak flash of Cherenkov light

- Image of the shower with cameras at the focal plane of telescopes

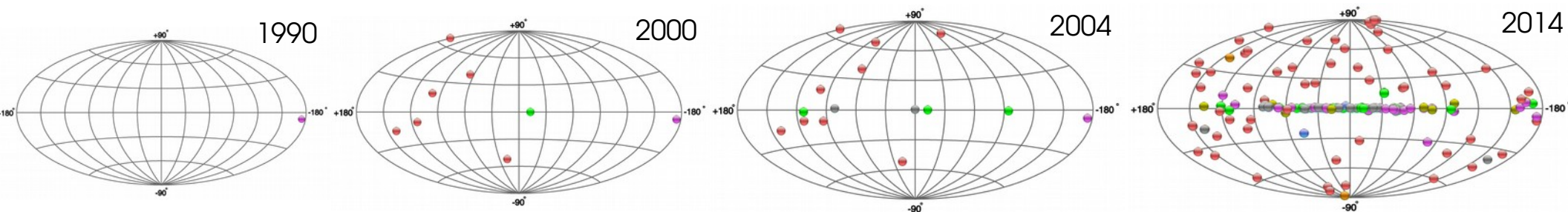| Orientation ➡ | Direction |
| Intensity ➡ | Energy |
| Shape ➡ | Discrimination |

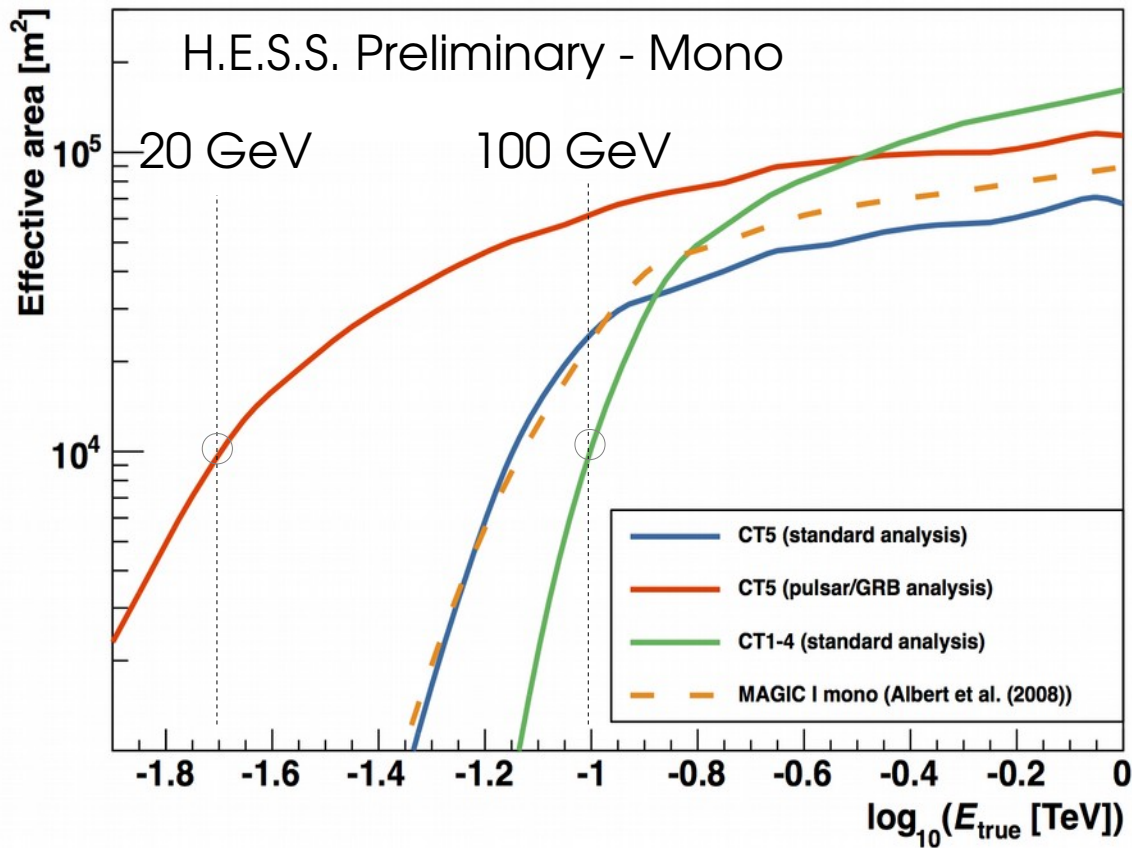Völk & Bernlöhr, 2009
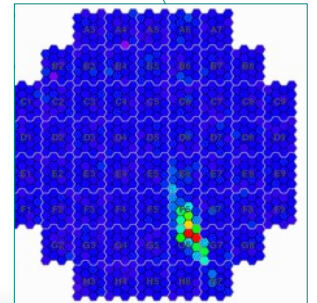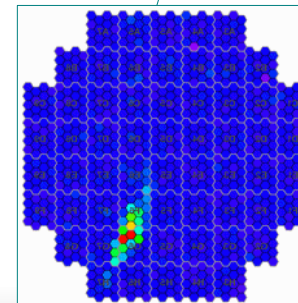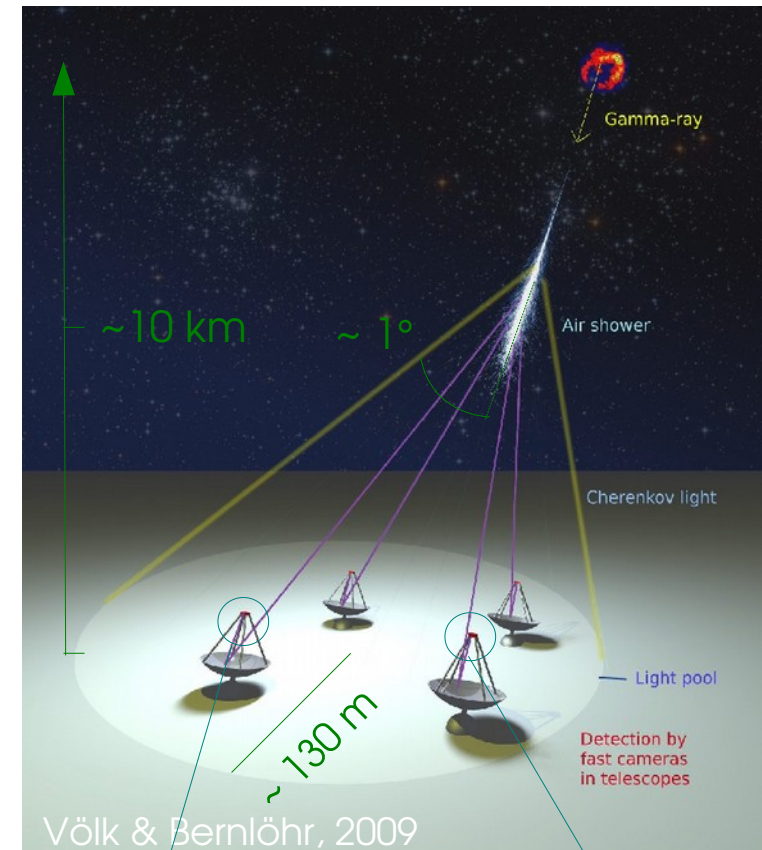
H.E.S.S. I : 10+ years of operation

~ 10 000 hours of observations

- ~50% Galactic / 50% extragalactic

- > 6×10^9 events

~ 90 new sources

- ~ 60 Galactic / ~ 30 extragalactic

tevcat.uchicago.edu

All: Whipple, Crimea, Telescope Array, Durham, MAGIC, VERITAS, H.E.S.S.

1990   2000   2004   2014
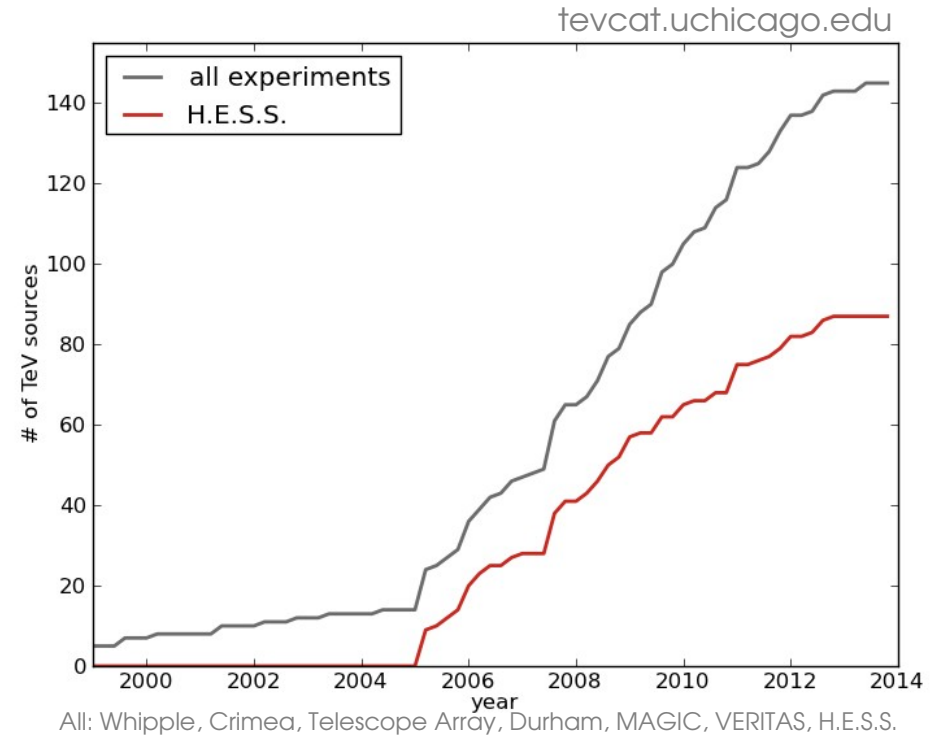
H.E.S.S. II : Performances

H.E.S.S. Preliminary - Mono

- Template (model/MC) based photon reconstruction techniques (de Naurois et al. 2009, Parsons et al. 2013)

- *Standard analysis* (optimised for steady sources) + *PSR/GRB analysis* (for low E detections)
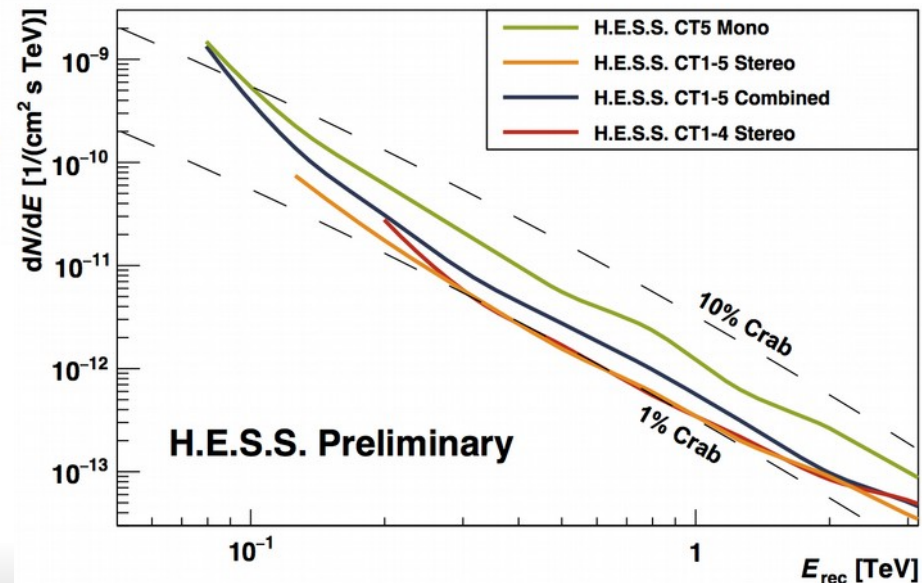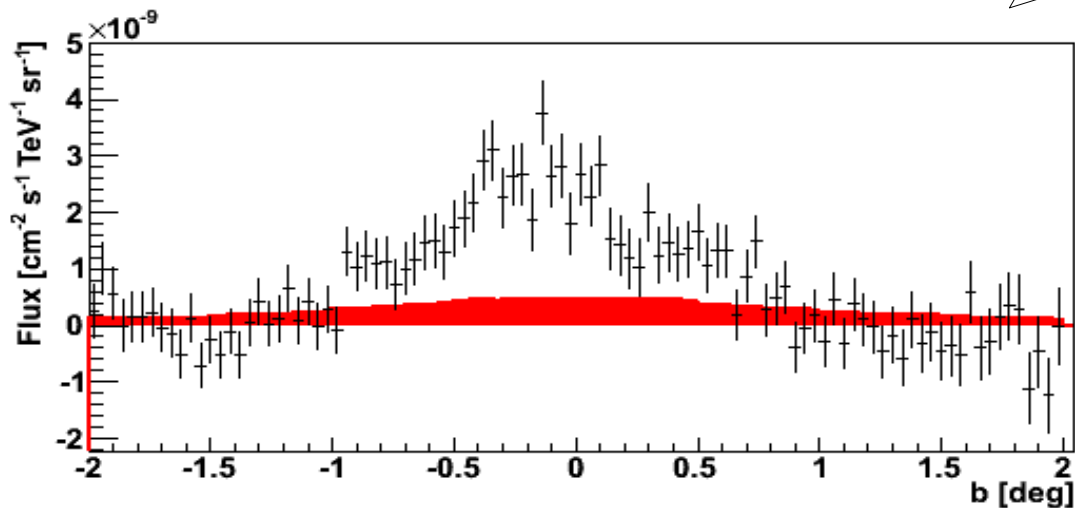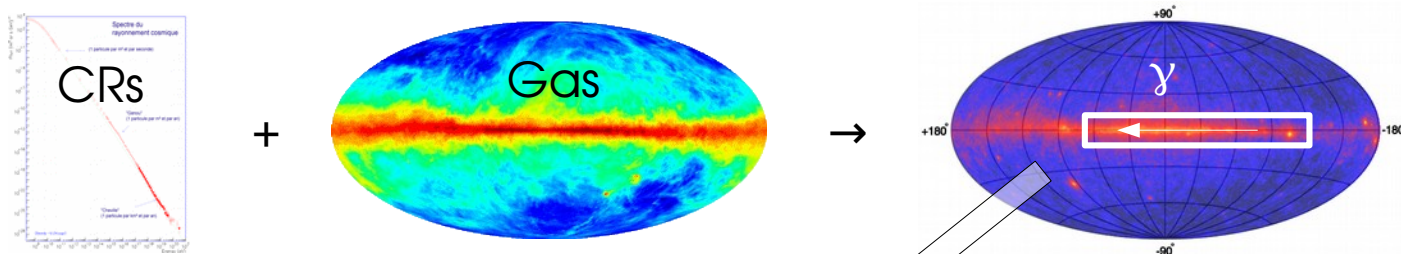
Combined analysis :
- Mono analysis for CT5 only events
- Stereo analysis for Hybrid or « HESS 1 » events

The HGPS : additional studies

- Study of **diffuse emission** in the Galactic plane
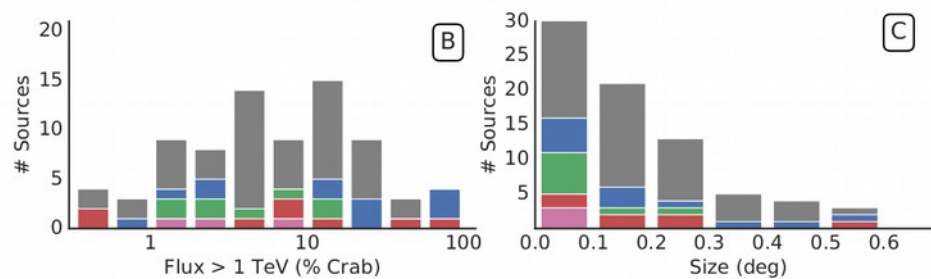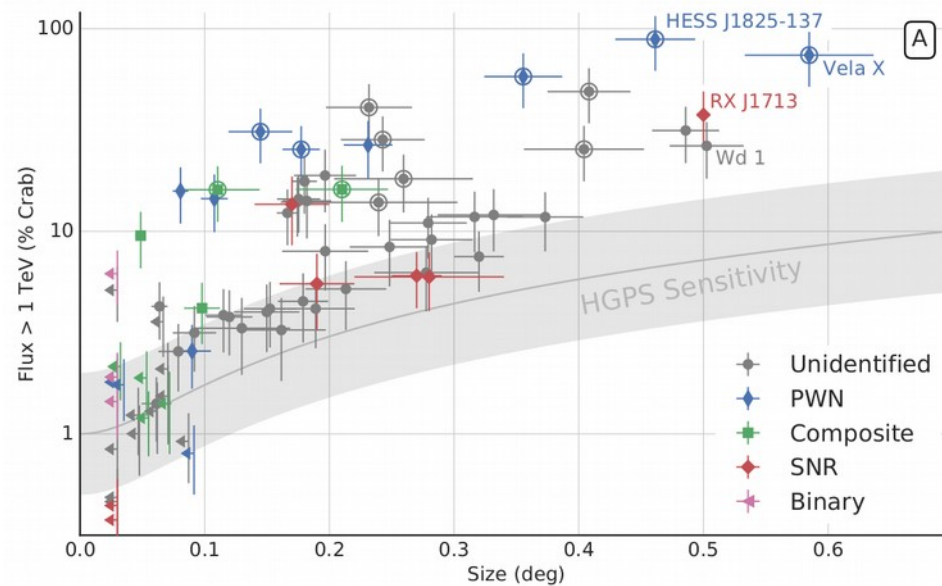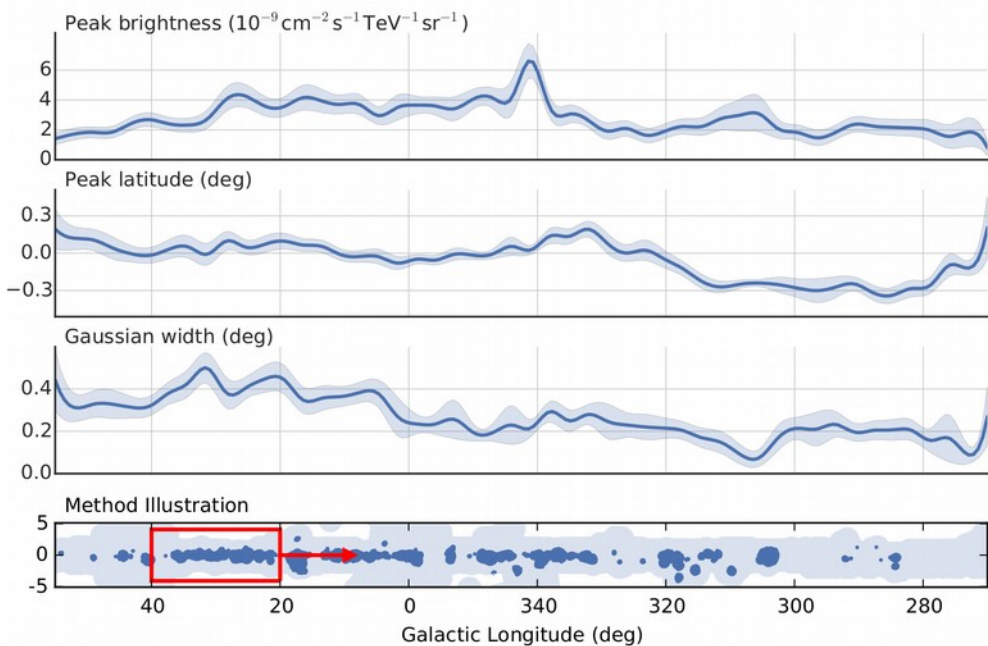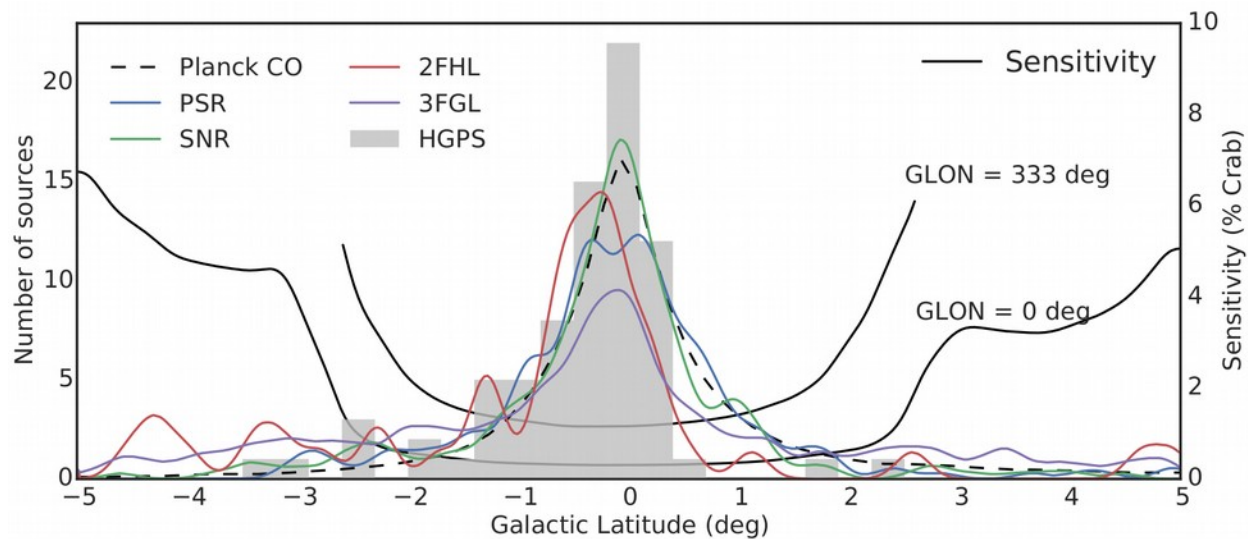
CRs $+$ Gas $\rightarrow$ γ

Total flux outside sources regions versus Galactic latitude :

~ 25% = Galactic cosmic rays

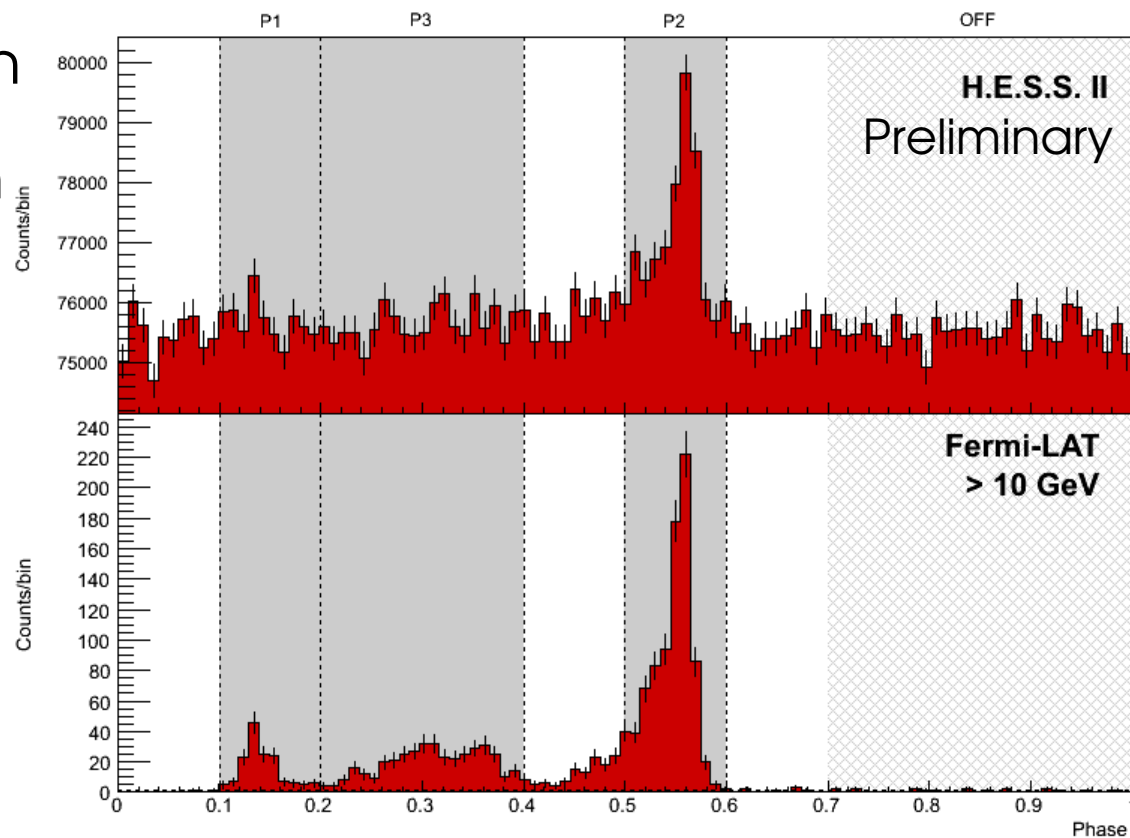~ 75% = Unresolved sources

HESS Collaboration, PRD 2014

HGPS Results

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

- 2nd VHE pulsar detection after the Crab

  - Very low E (threshold ~ 20 GeV)

- 16000 γ-rays, 16σ detection

- Regime very different than Fermi-LAT : background !
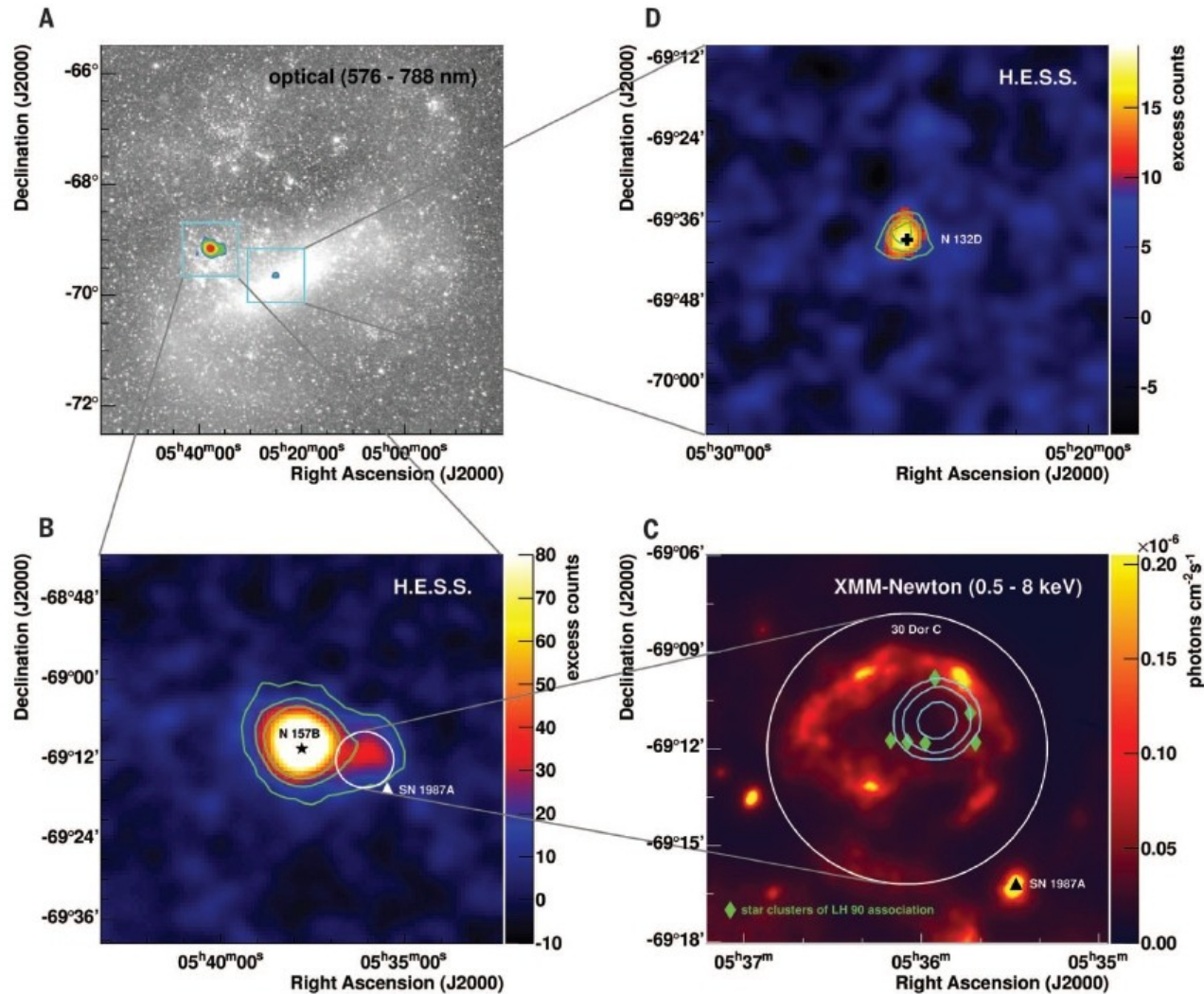
  - P2 compatible in position and width

More observations : probe potential component at high energies

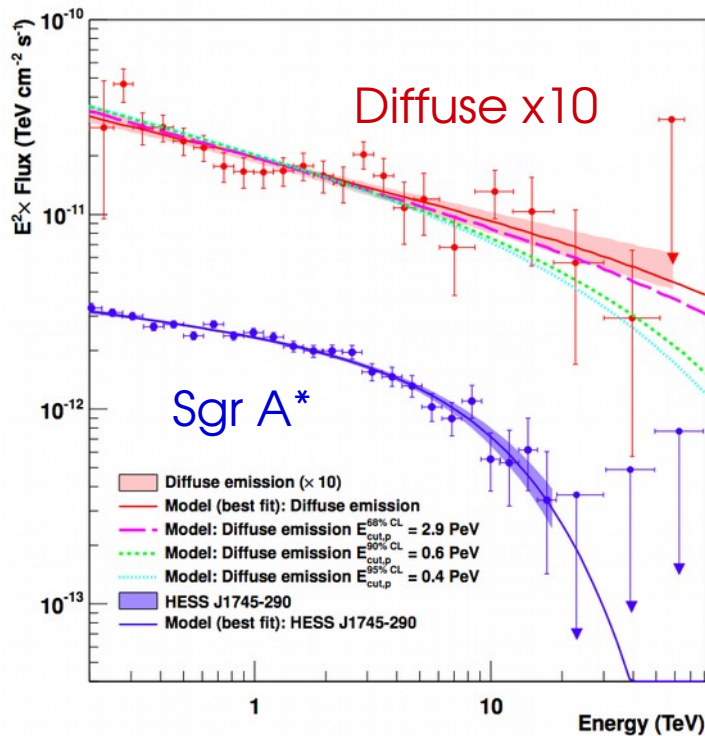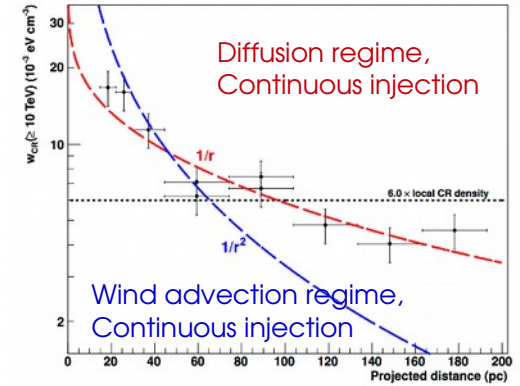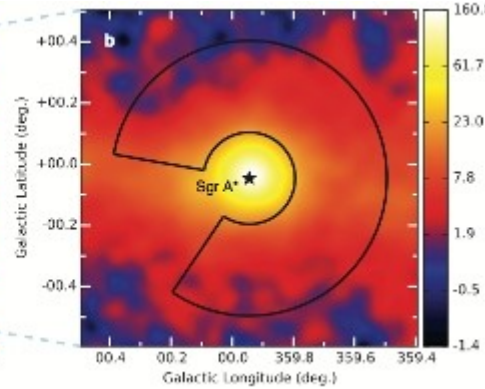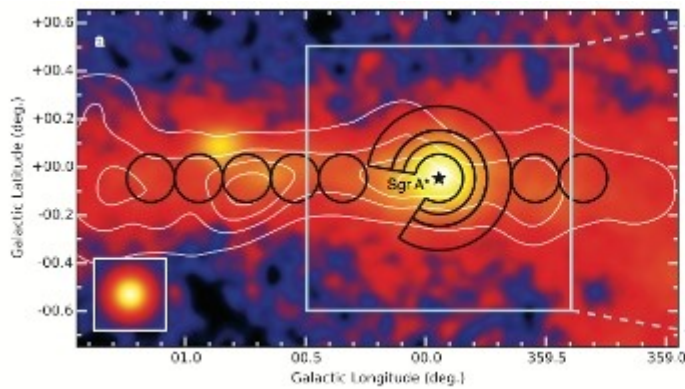Djannati-Ataï et al 2015, 2016, H.E.S.S., in prep.

LMC

- LMC Survey Program

- 1st detection of stellar-type objects outside the Milky Way

- New TeV source class : superbubble 30 Dor C

- Most luminous PWN known

- New binary LMC P3!

H.E.S.S. 2015, Komin et al. 2017

Galactic Center : First PeVatron discovery

H.E.S.S. 2016

- 220 hours of data (2004-2013)

- Point-source + Large scale emission

  - CR from BH diffuse and interact with ISM

- Gamma-ray Spectra :

  - Cut-off for the central source, **not** for the diffuse

    ➔ $E_{p,cut}$ = **2.9 PeV (68 % CL)**

    ➔ $E_{p,cut}$ = 0.6 PeV (90 % CL)

Galactic Center : Halo

- Dark Matter searches

    - Strong astrophysical background

    - 2x dataset

    - better constraints

    - higher energies