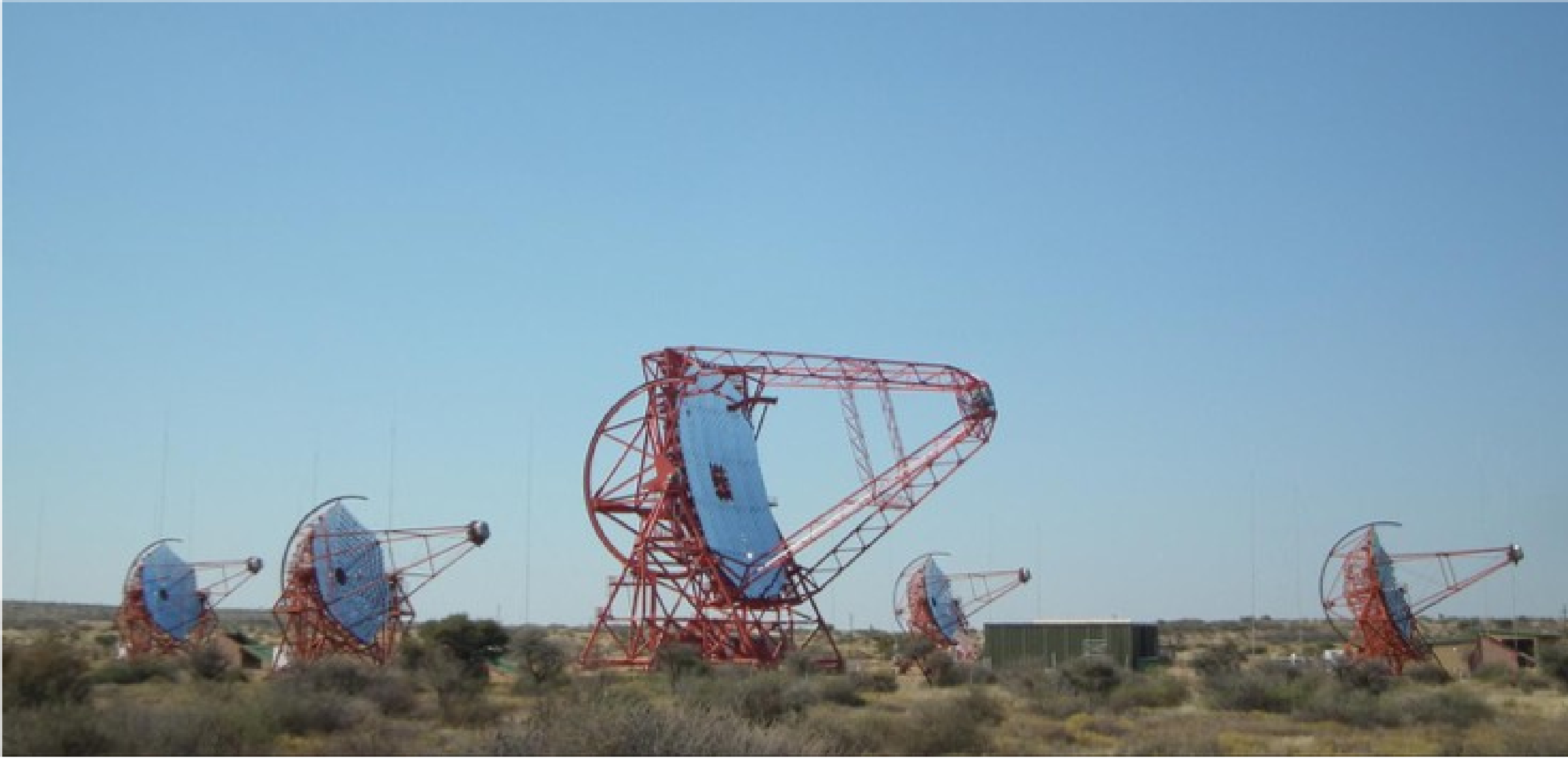


Diffuse Galactic Gamma-Ray Emission with H.E.S.S.

Mathieu de Naurois
LLR – Ecole Polytechnique – IN2P3/CNRS

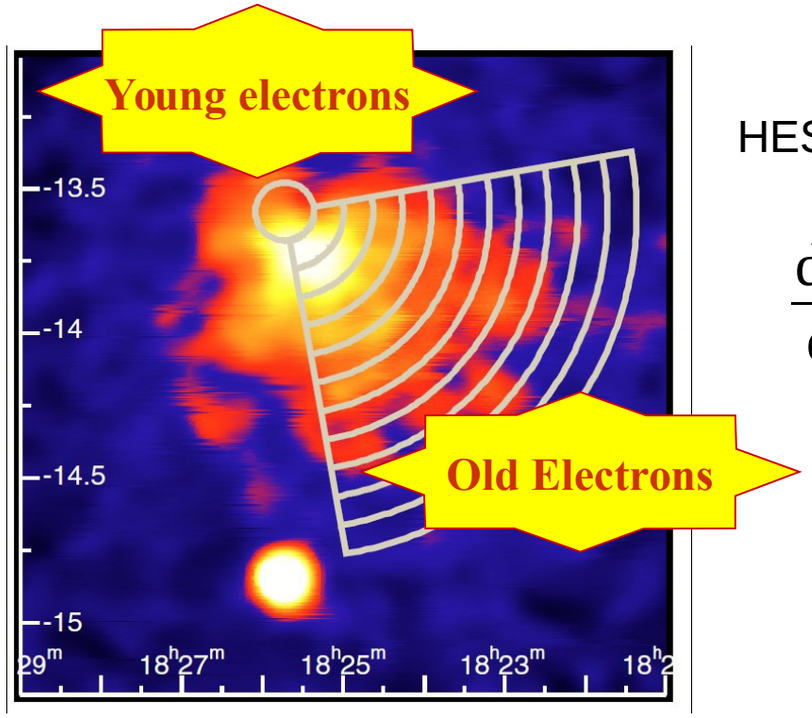
H.E.S.S.

Why study the VHE diffuse emission?

- HE diffuse emission is a prominent galactic features with many ramifications:
  - Cosmic ray propagation, “baryo-tomography” of the Galaxy
  - Search for dark matter,
  - ...
- VHE (> 100 GeV) diffuse emission is expected as well:
  - On small scales: escape of VHE particles from the sources (→ physics of accelerators, radiative cooling, etc)
  - On intermediate scales:
    - interaction of VHE CRs with dense regions (giant molecular clouds, …, e.g. CMZ) tracing release of freshly accelerated particles (talk by A. Viana on the GC pevatron),
    - Projection effect of (unresolved) accelerators (e.g. spiral arms seen tangentially)
    - Dark matter annihilation in GC bulge (talk by C. Farnier)
  - On galactic scale: interaction of the bulk of CRs (hadronic & leptonic) with ISM and radiation fields (Visible, IR and CMB)

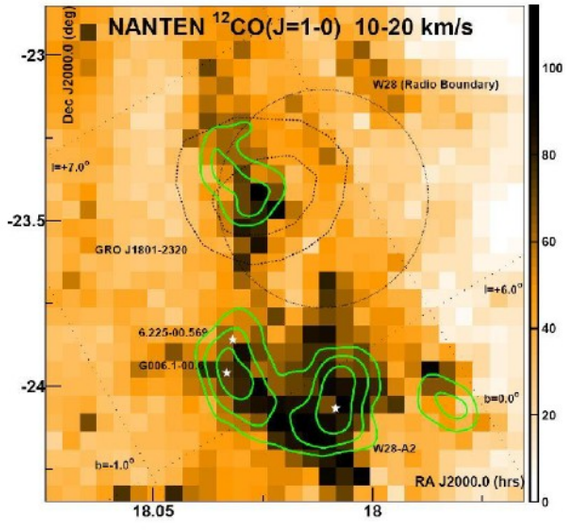
Physics of the sources

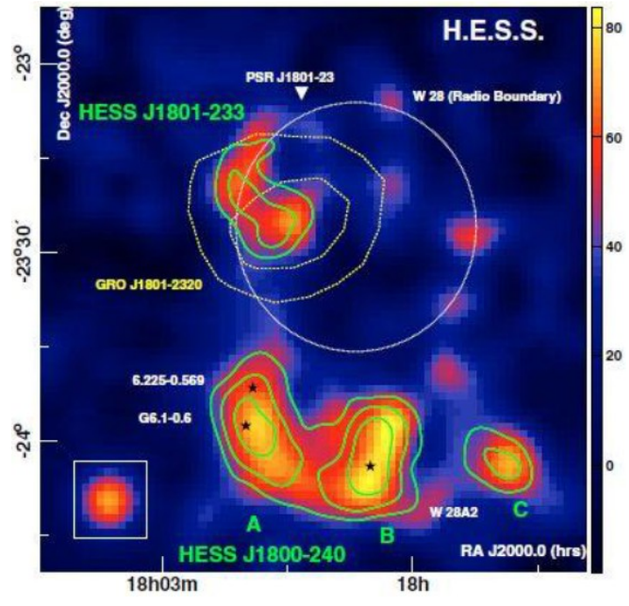
- Radiative properties different from GeV regime:
  - VHE Electrons cool very quickly while escaping the source
    → energy dependant morphology
  - VHE protons less efficiently trapped than GeV ones,
    → need dense target to shine (dense MC in neighbourhood of SNRs, or GC ridge)
- Render subtraction of sources complicated and model dependant



HESS J1825-137

$$\frac{\mathrm{d}E}{\mathrm{d}t} \propto E^2$$



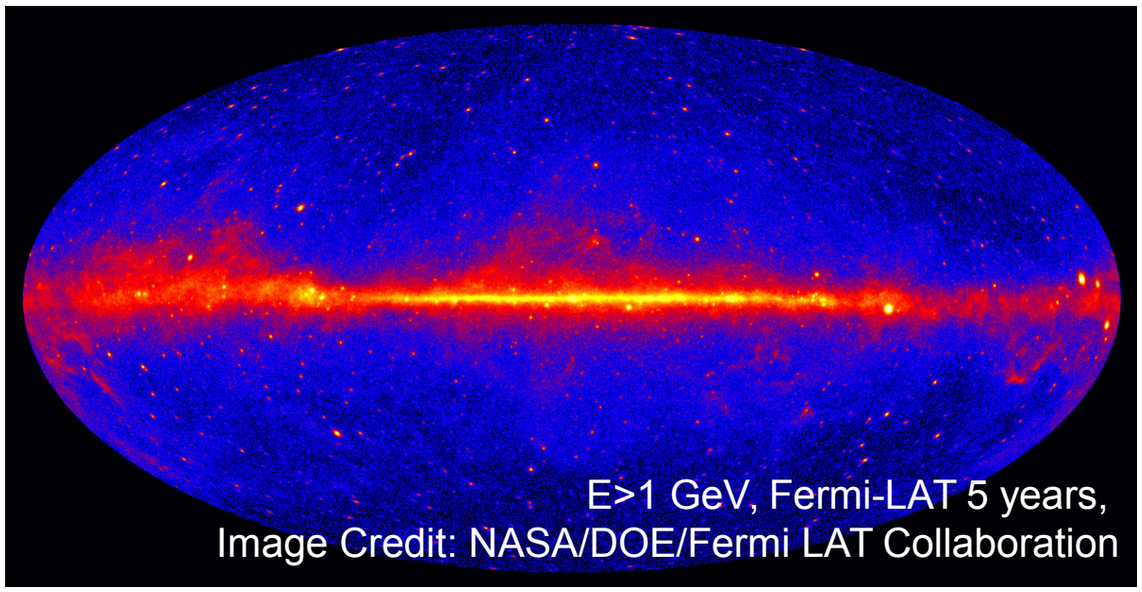


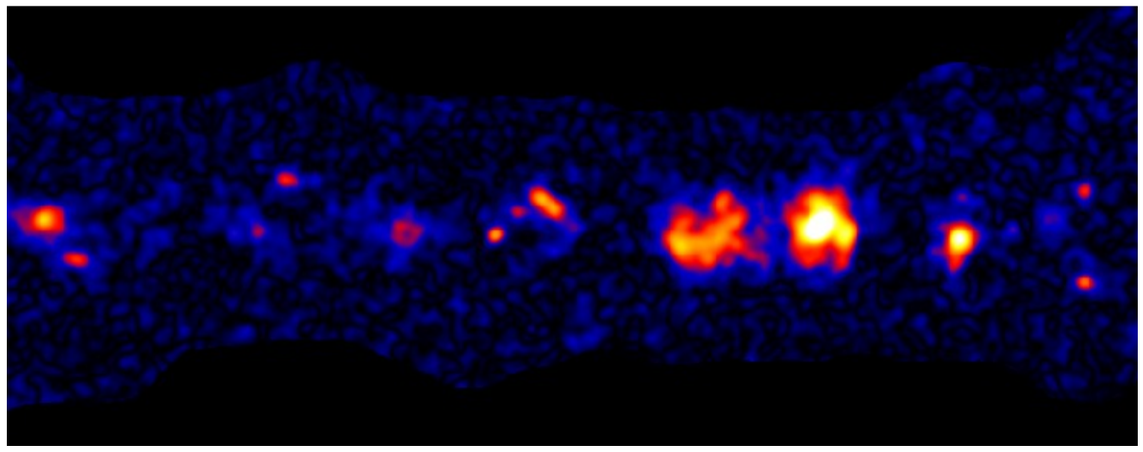
W28, HESS

GeV vs TeV regimes

- GeV diffuse emission (mostly from hadronic contribution) dominant
- Contribution of individual sources well below diffuse emission
- Render search for sources challenging

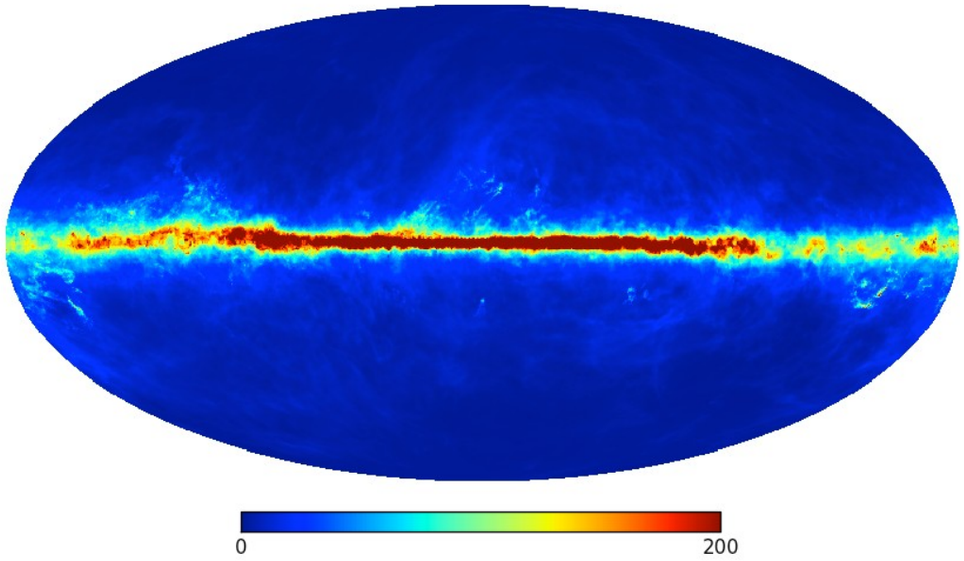
- VHE protons less confined in the Galaxy
- Emission from hard Galactic sources becomes dominant
- Render search for diffuse emission challenging



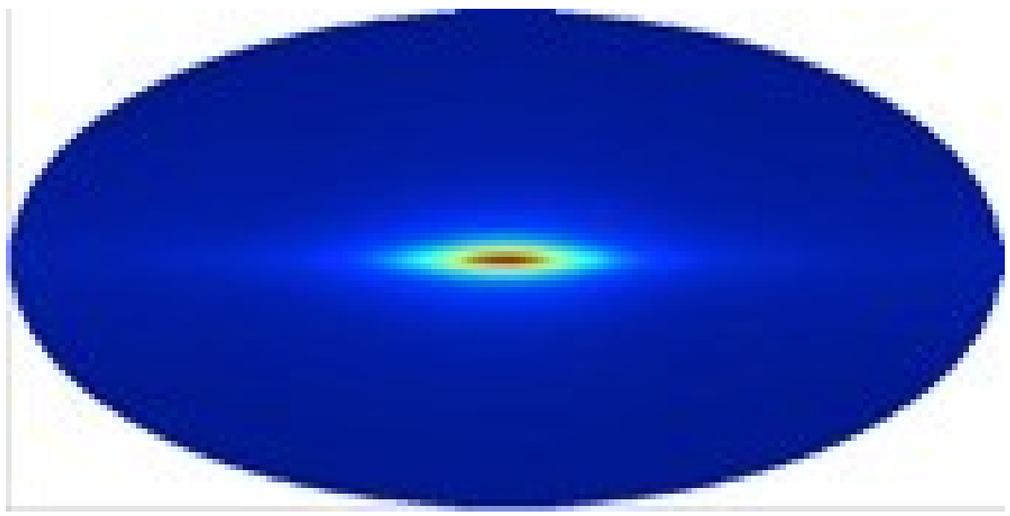


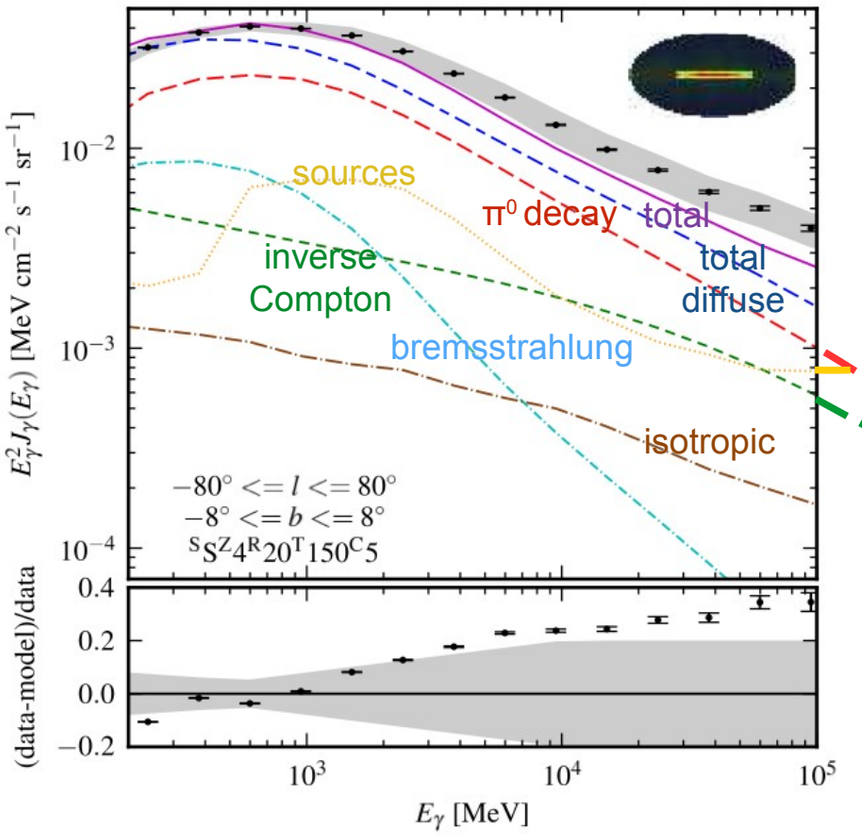
Contributions to HE and VHE diffuse emission

π^0 decay and bremsstrahlung



Inverse Compton





Fermi LAT Collaboration, ApJ 2012

Energy dependant diffusion

rise of p-p cross-section

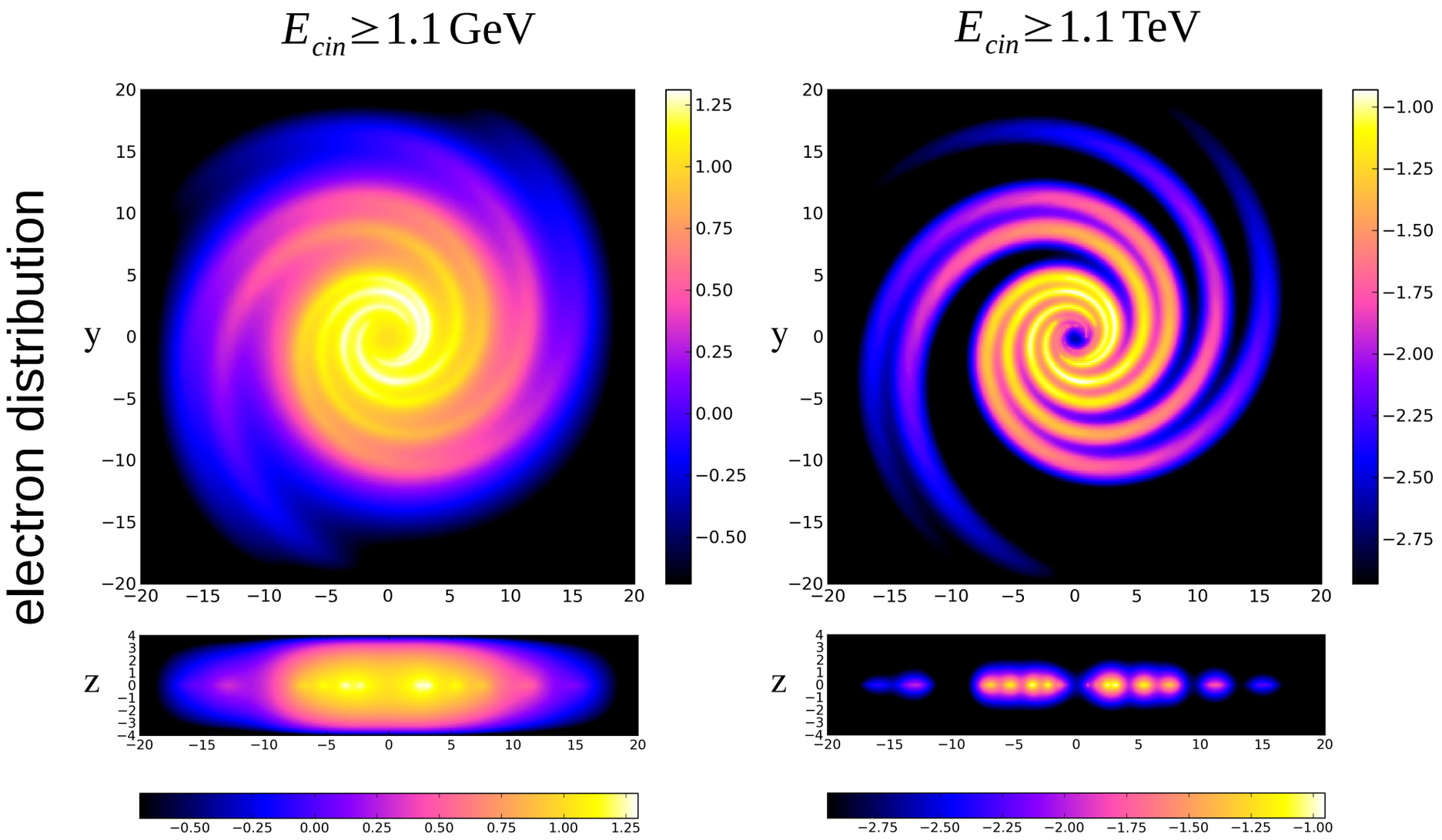
?

KN suppression of IC on Visible/IR

- At HE, hadronic component dominant
- At VHE, IC (on CMB) might contribute substantially
- Klein Nishina suppression of IC on Visible/IR → IC traces e± density
- Contribution of unresolved sources?

IC contribution @ VHE

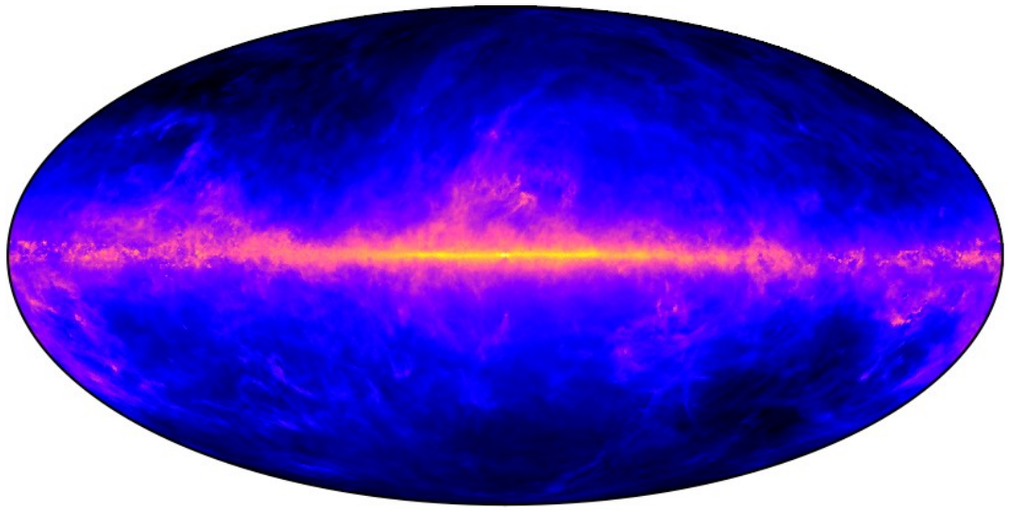
- Example of a PICARD simulation with source assumption (4 arms model) (R. Kissmann)
  - Strong imprint of source distributions on electrons and VHE γ-ray emission (IC on CMB)



Werner et al 2014

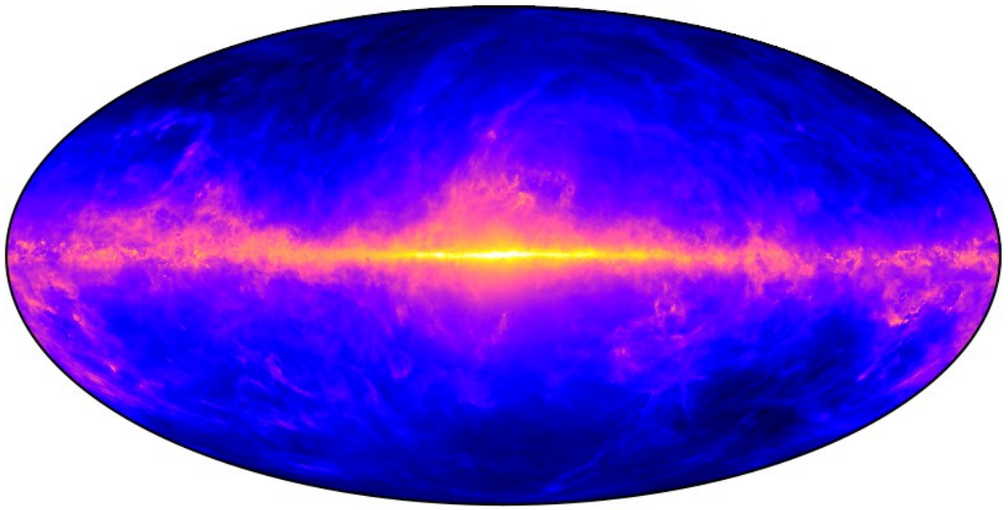
IC contribution @ VHE

- Example of a PICARD simulation with source assumption (R. Kissmann)
  - VHE emission very dependant on source distribution

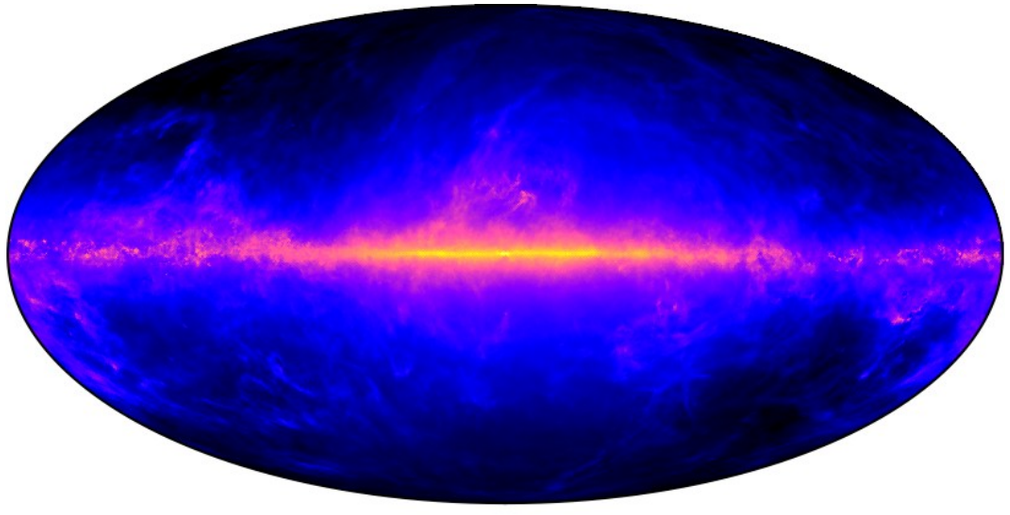


1 GeV

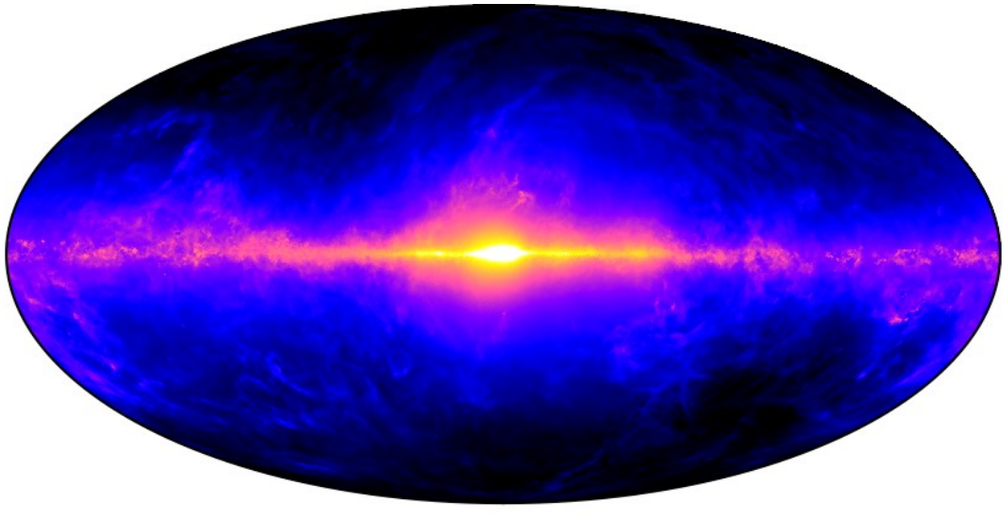
4-arms model



2-arms model



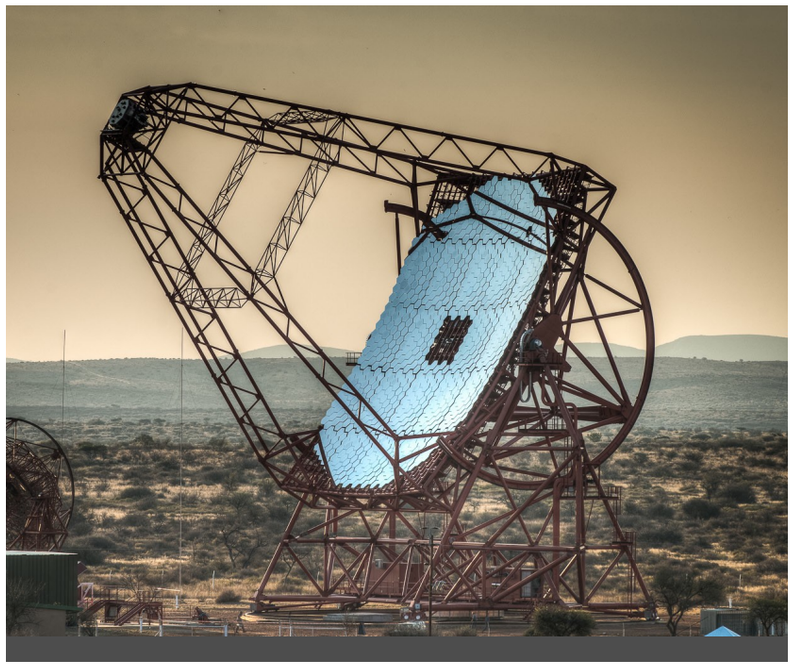
100 GeV

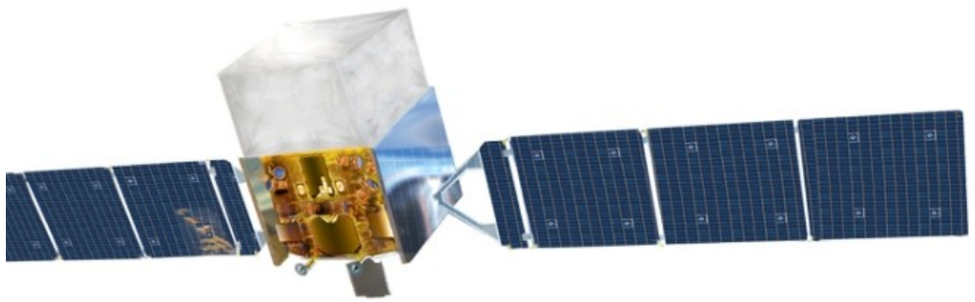


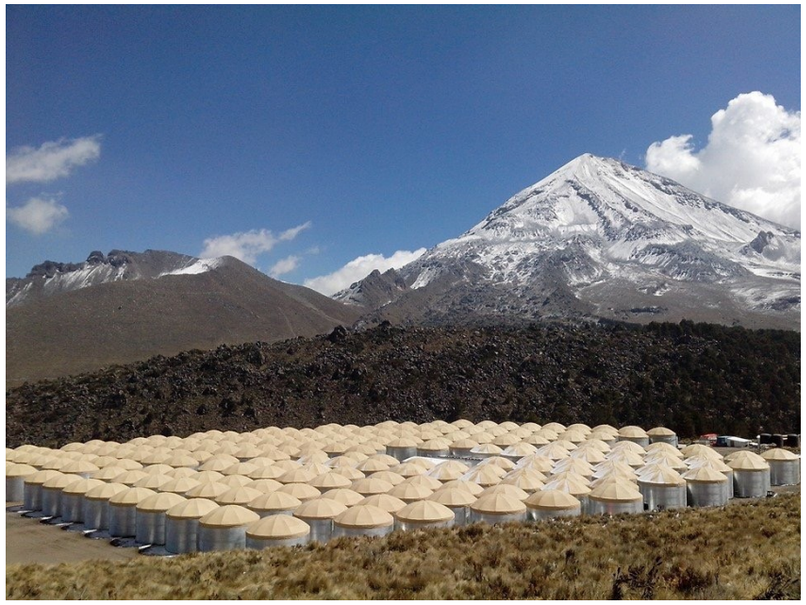
From HE to VHE – I

- Less statistics

- Need for very large detection areas
  - Atmospheric Cherenkov Telescopes
  - Water Cherenkov (HAWC, see talk by S. Hernandez Cadena)



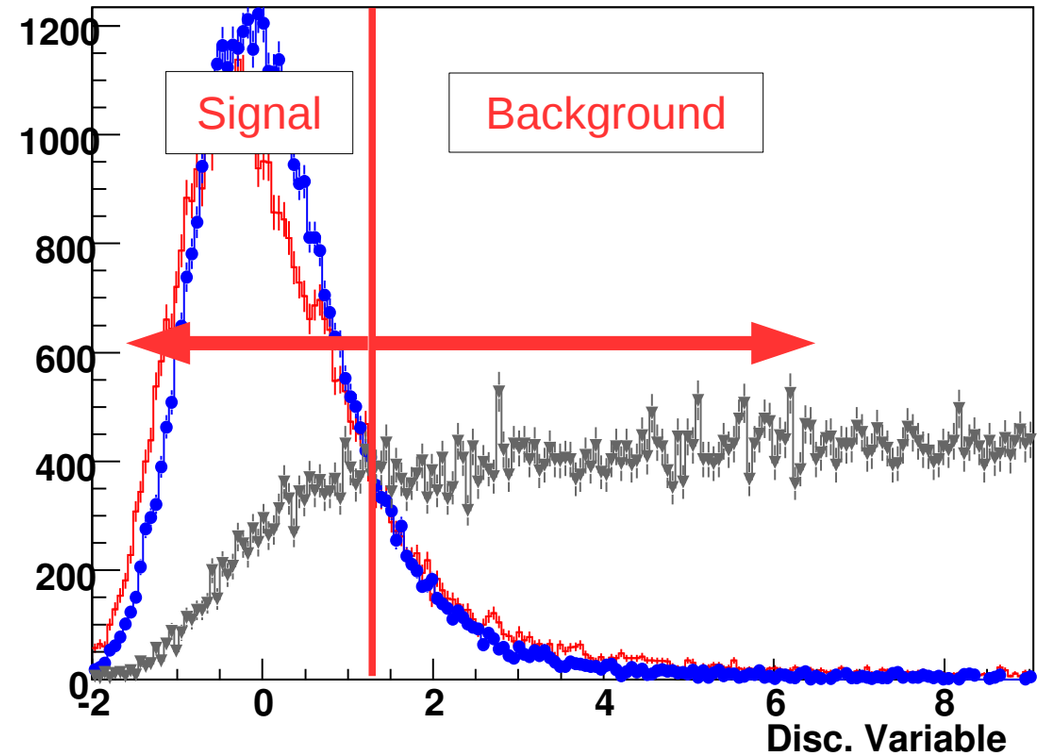




From HE to VHE – II

- "Background-free" instrument

- Background dominated instrument
  - Need for sophisticated and robust discrimination techniques, rejecting ~ 99% of background
  - Very tricky below 100 GeV (small showers with an handful of electrons)
  - Irreducible remaining background

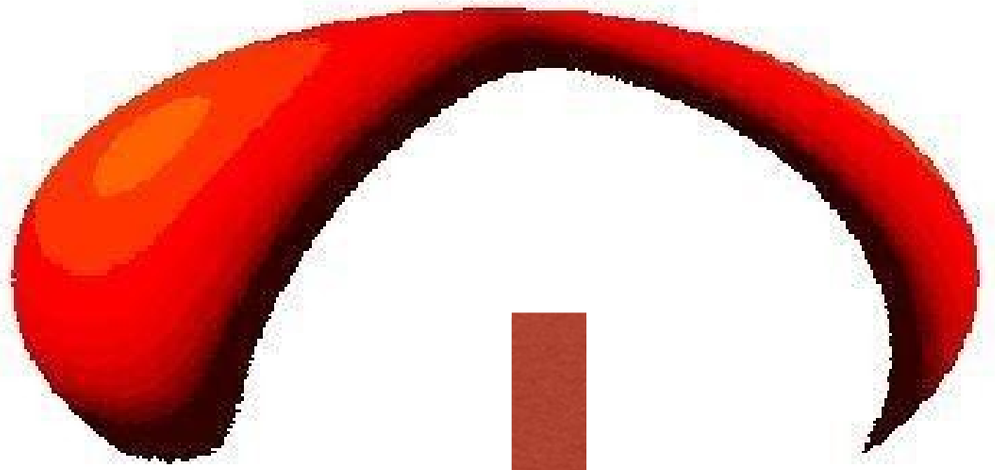


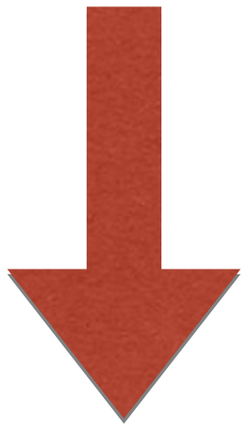
From HE to VHE – III

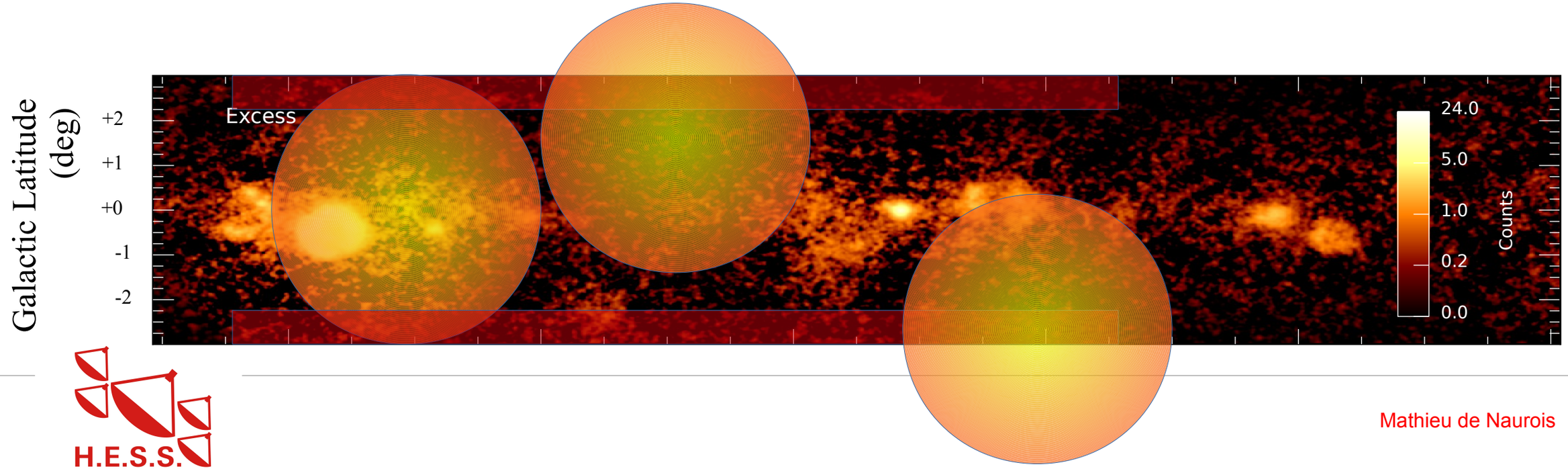
- Drastic reduction of the Field of View

- Need many (O(1000)) pointing observations, spread over many years, with very different observation conditions
- Composite map made of many chunks

Fermi-LAT instantaneous exposure



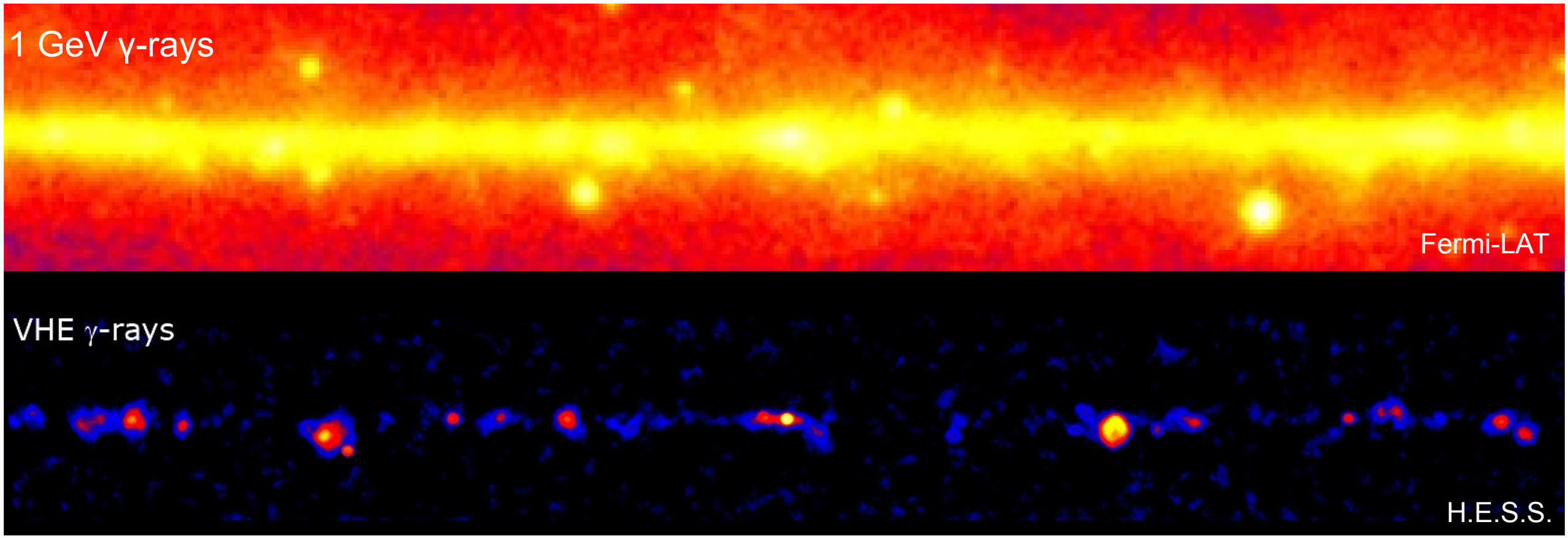




From HE to VHE – IV

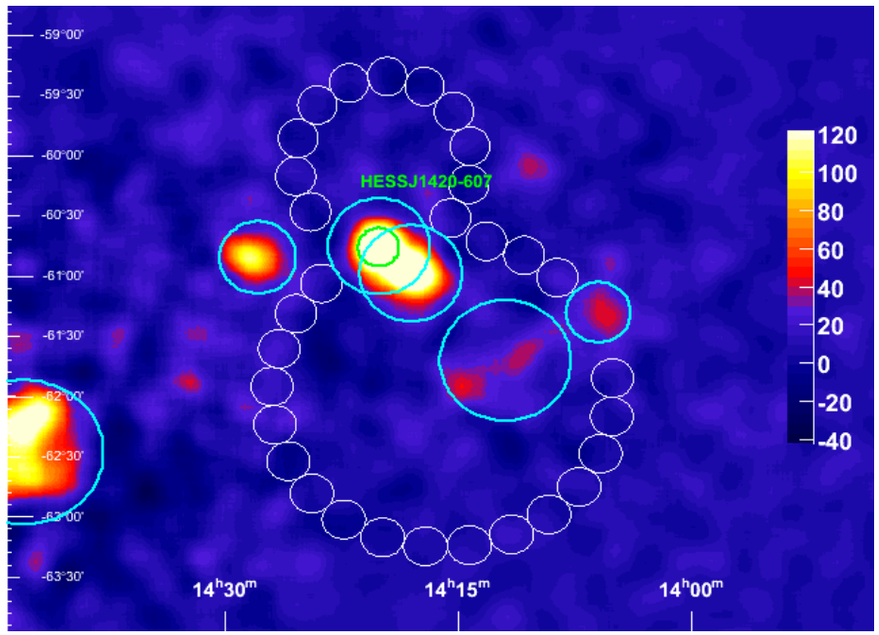
- Very low fluxes compared to HE

- Need for very long integration time ((O(1000 hr))

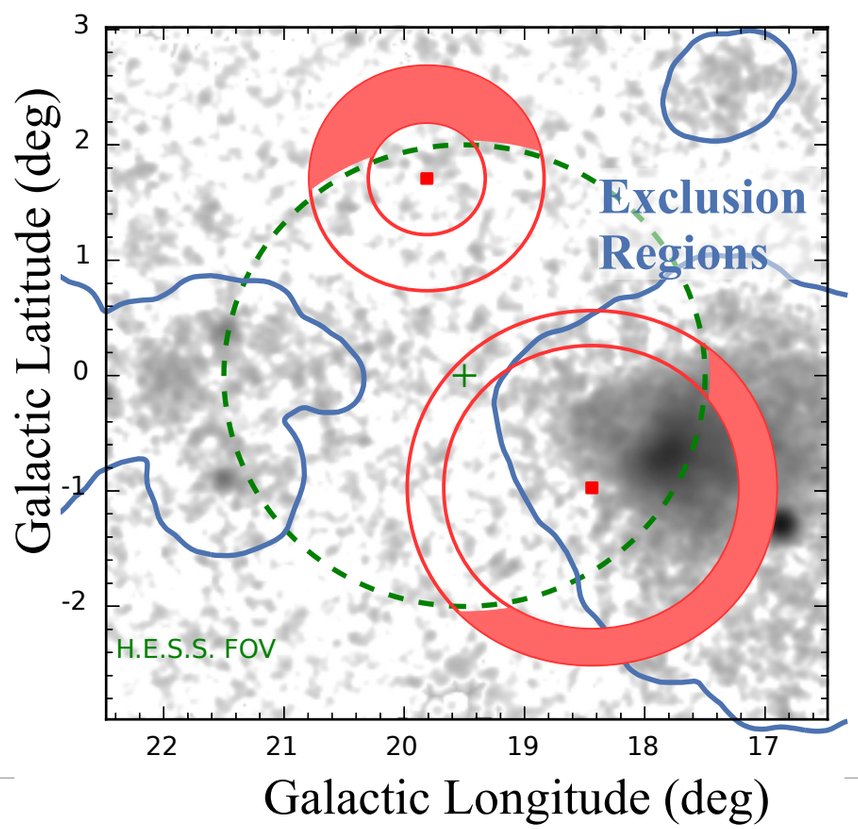


From HE to VHE – V

- Irreducible background (e±, $p \rightarrow \pi^0 \rightarrow \gamma\gamma$)
- More than 10× the expected signal, rising below 100 GeV

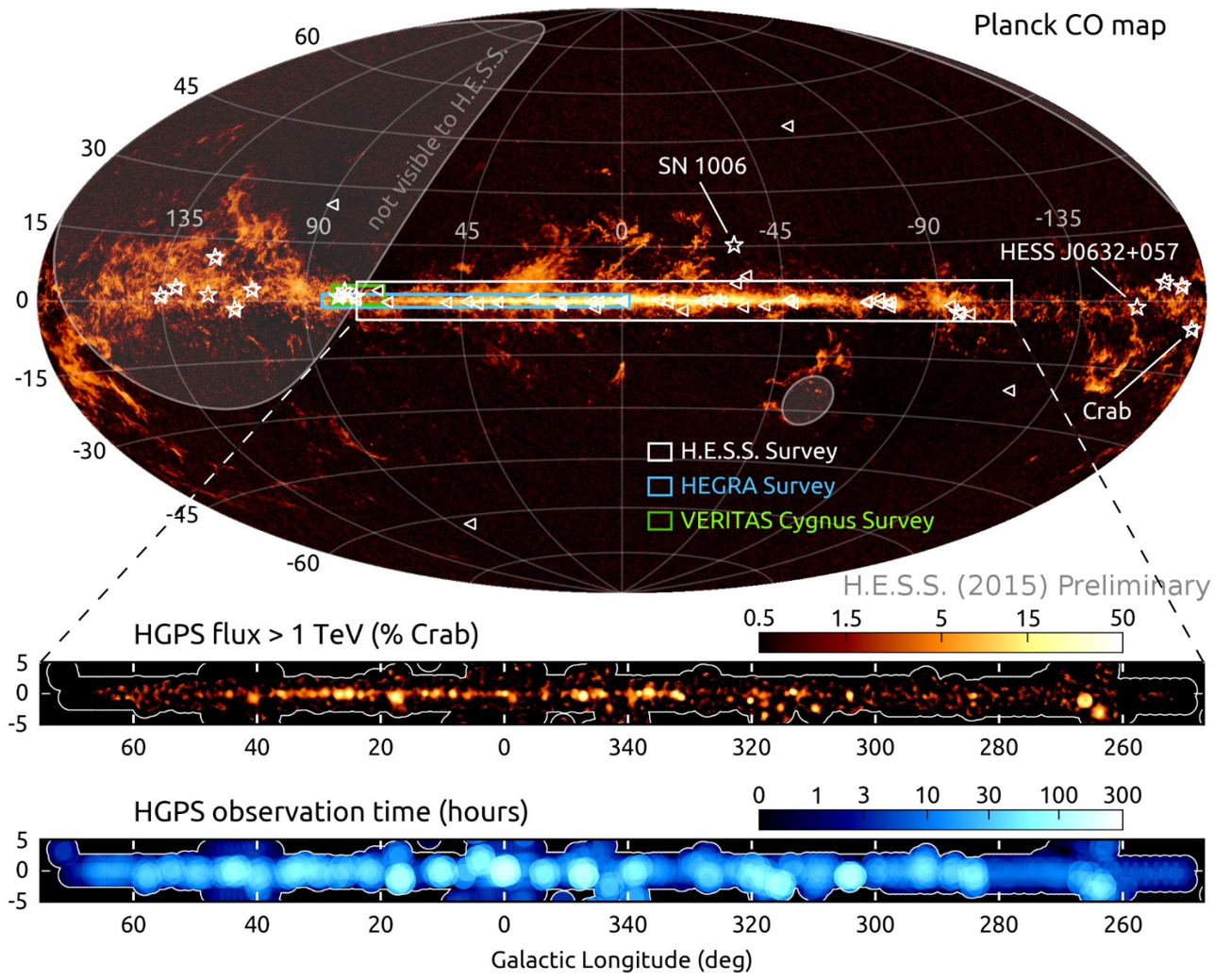


- Need for background subtraction techniques
  - Background usually estimated from "signal free" regions in the FoV + assumption on system response (rotational symmetry, …)
  - Very tricky for large, extended regions and/or very populated regions
  - Becomes a nightmare for large scale diffuse
    - Removes all structures > camera FOV
    - Removes all linear gradients

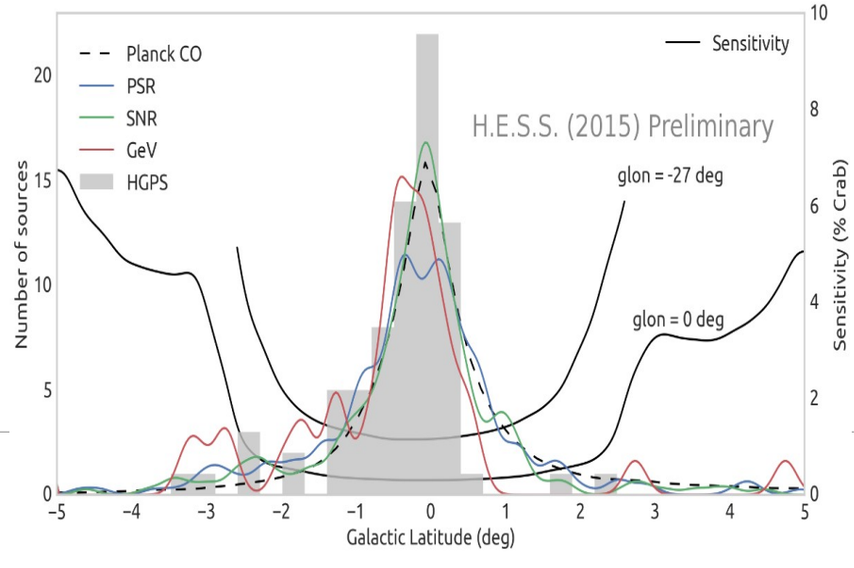


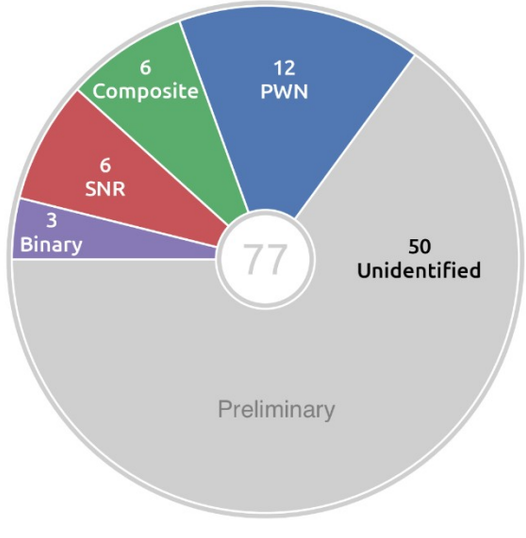
Data Set : HESS Legacy Survey

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



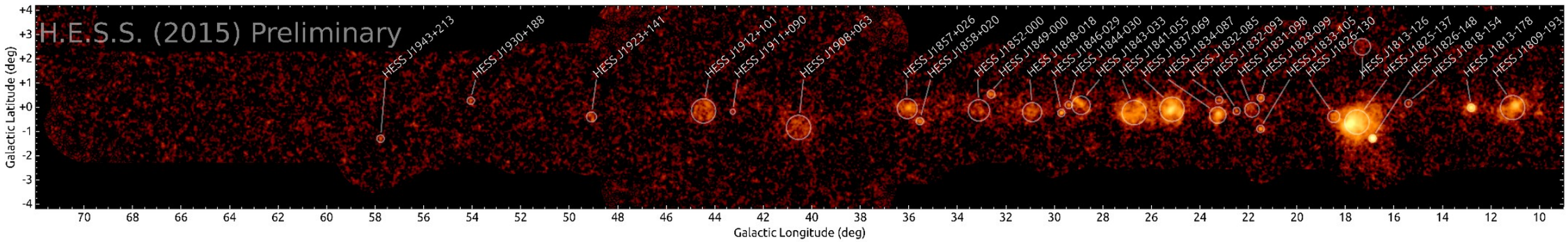
- 77 VHE sources
  - Half of which unidentified
  - Aligned along the Gal. Plane

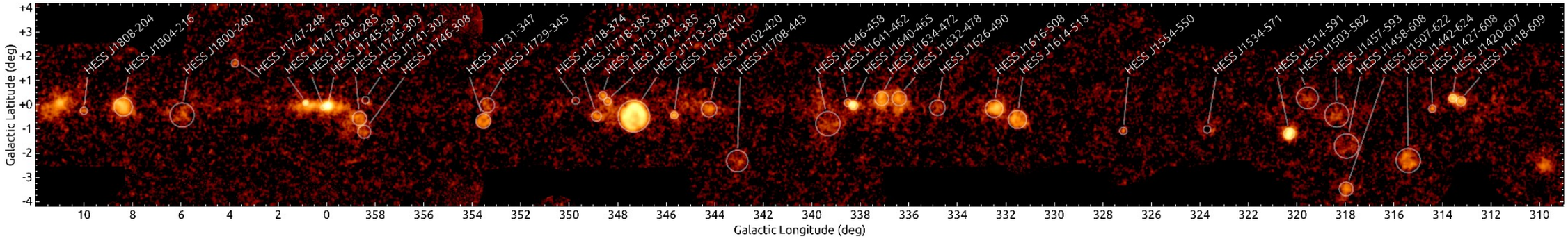


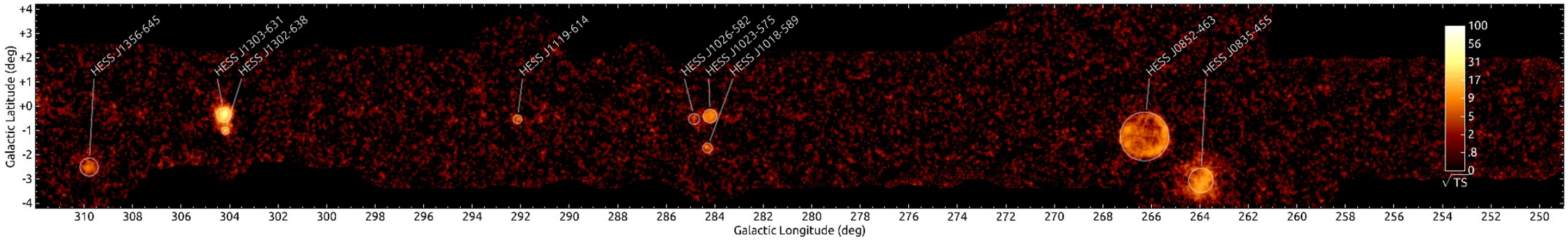


HESS Legacy Survey – TS map

- Wealth of sources aligned along the galactic plane, (very) extended, and often overlapping

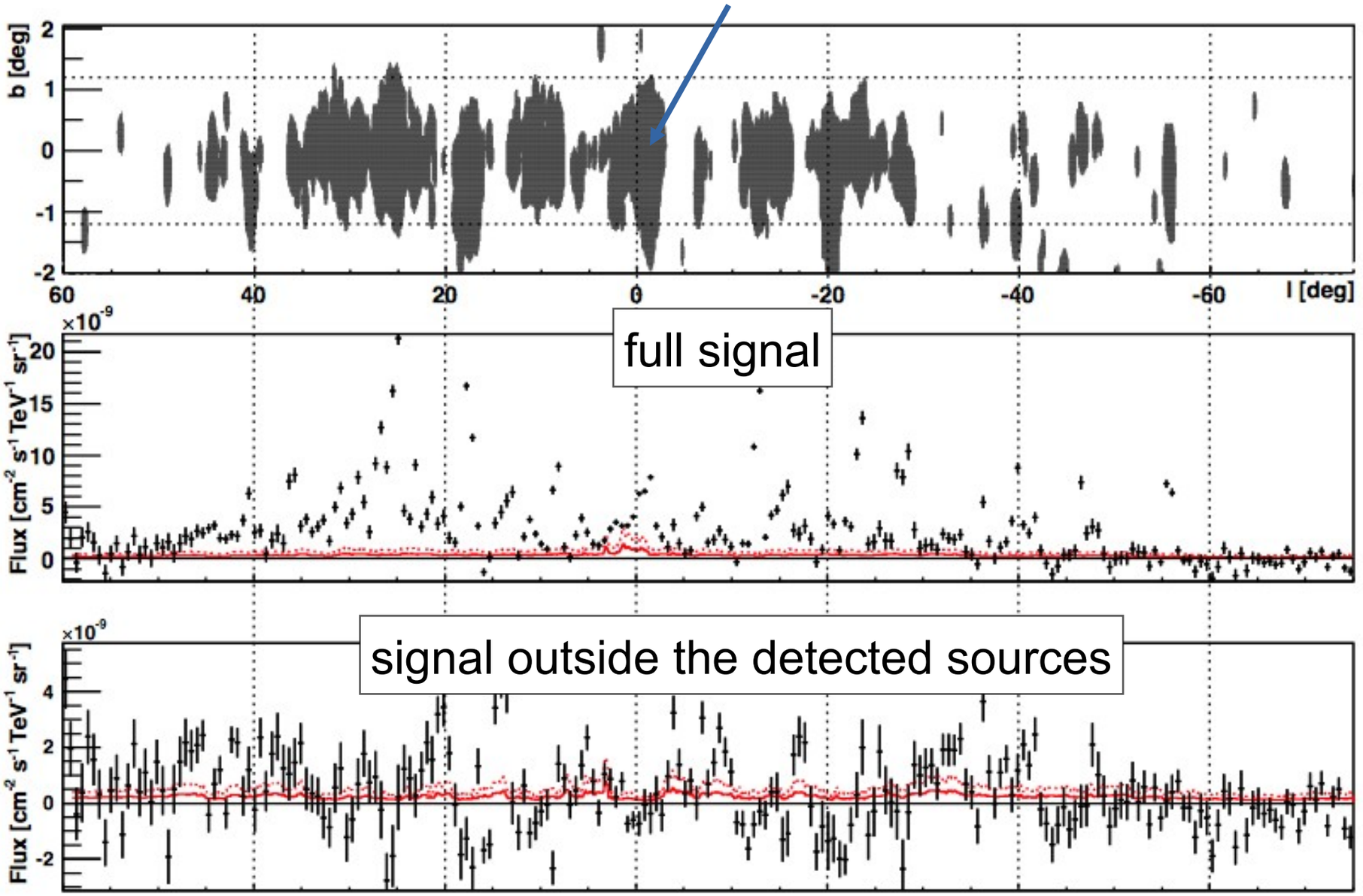






Extraction of a diffuse signal: observations outside detected source regions

significantly detected γ-ray sources

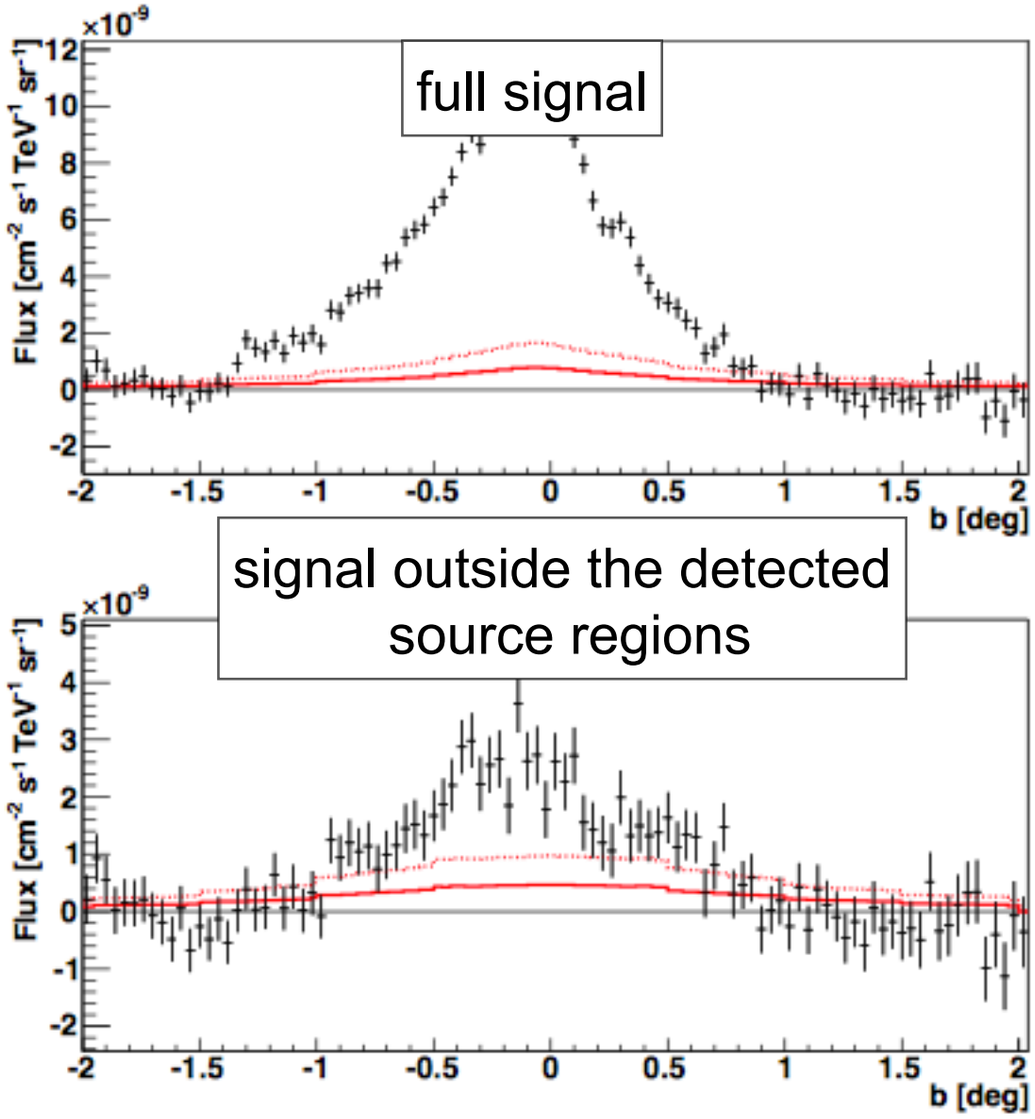


Projection in longitude

H.E.S.S. Collaboration, PRD 2014

Extraction of a diffuse signal: observations outside detected source regions

- Observation of significant excess emission outside the source regions (cumulative by the use of projections)
- Maximum at b ≈ -0.25° at flux of $\sim 3 \cdot 10^{-9}$ TeV^{-1} cm^{-2} s^{-1} sr^{-1} (bias from source distribution)
- Large-scale signal that accumulates all along the plane with larger contributions from central region
- Interpretation?

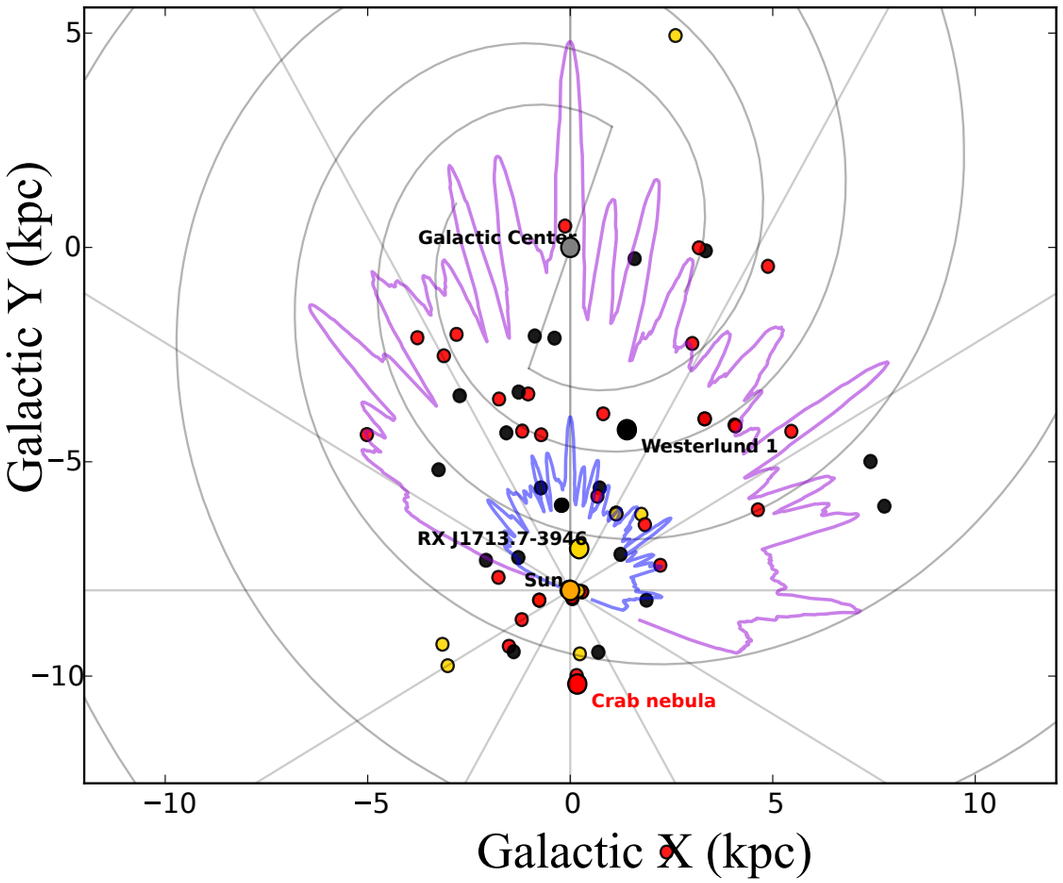


H.E.S.S. Collaboration, PRD 2014

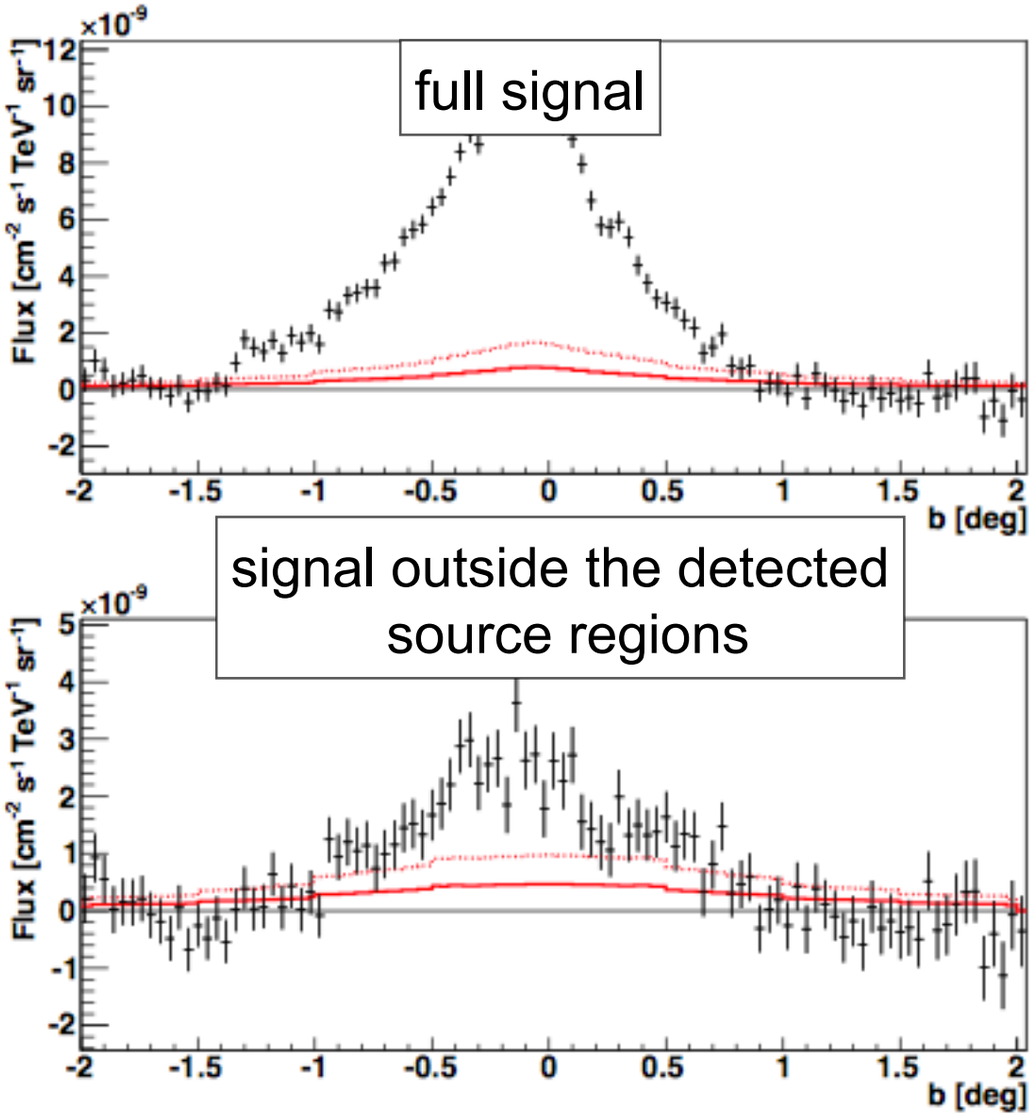
Projection in latitude

Unresolved sources

- Unresolved sources contributions: HESS survey not complete
- First luminosity functions to be released soon
- Work in progress...



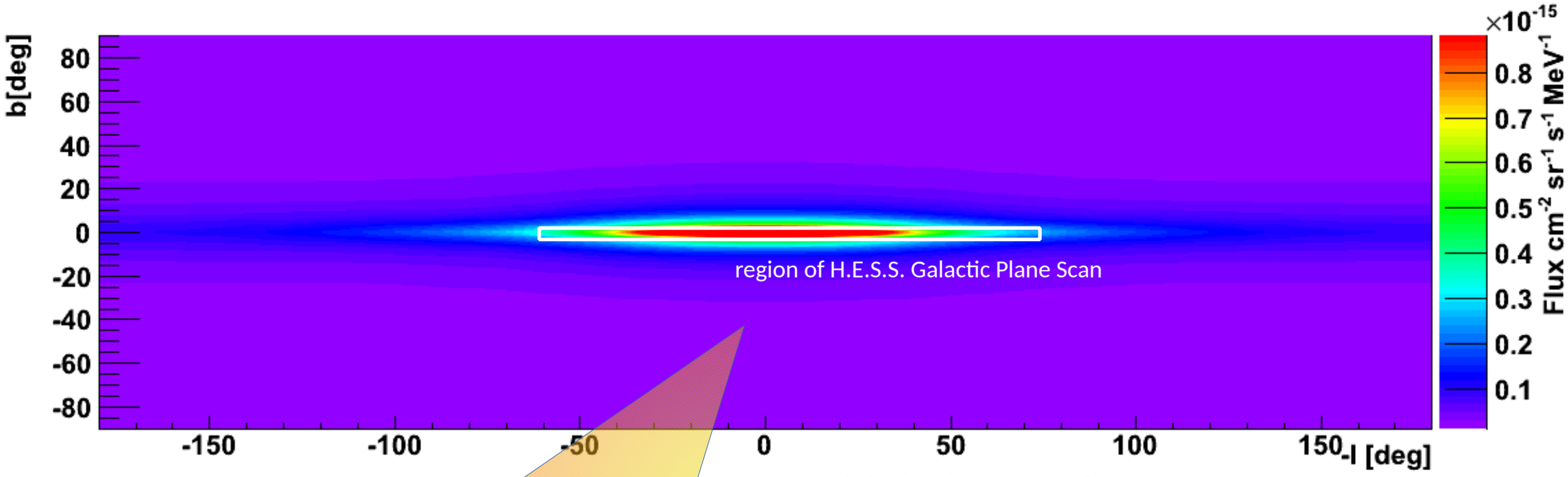
Blue and magenta lines: H.E.S.S. horizons for 1% and 10% Crab
Dots: H.E.S.S. Galactic sources
- Pulsar Wind Nebula
- Yellow: SNRs
- Other sources



H.E.S.S. Collaboration, PRD 2014

IC component

- Inverse Compton scattering on CMB: smooth, very extended structure, >> HESS FOV
- Largely suppressed due to background subtraction technique



Inverse Compton component calculated with GALPROP (E = 814 GeV)

around 95% of the signal is lost in this analysis due to background subtraction

Hadronic component

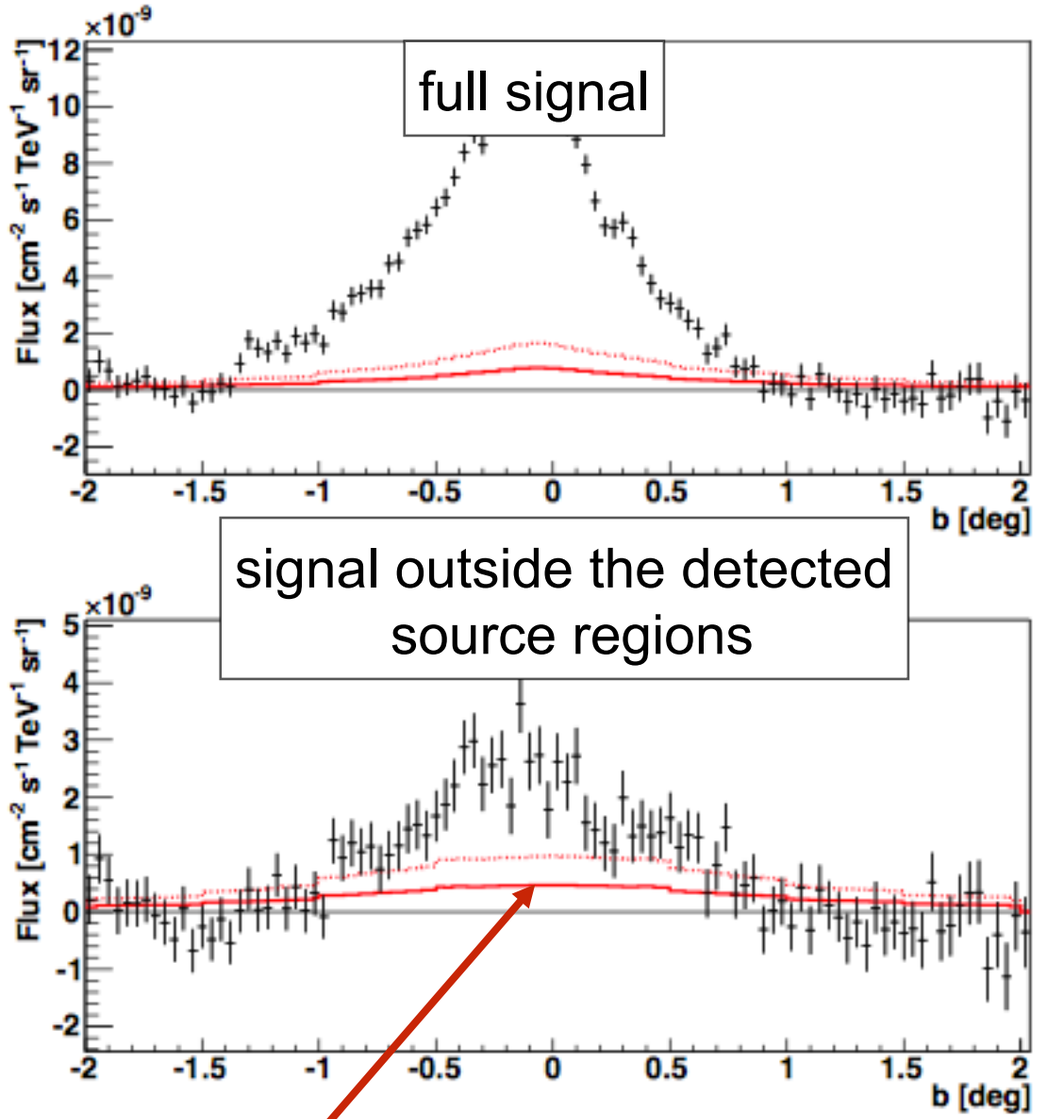
- hadronic gamma-ray emission via pion decay:

$$\Phi_\gamma(E_\gamma) = \int \mathrm{d}l_d \int \frac{\mathrm{d}\sigma_{p\gamma}}{\mathrm{d}E_p} n(l,b,l_d) \times J(E_p)\,\mathrm{d}E_p$$

  - Target material n(l,b,ld):
    - HI (Leiden-Argentine-Bonn survey)
    - H2 traced by CO (NANTEN) with conversion factor $X_{CO} = 2 \cdot 10^{20}$ cm^{-2} K^{-1} km s^{-1}
  - Cosmic-ray spectrum J(Ep): measured at Earth

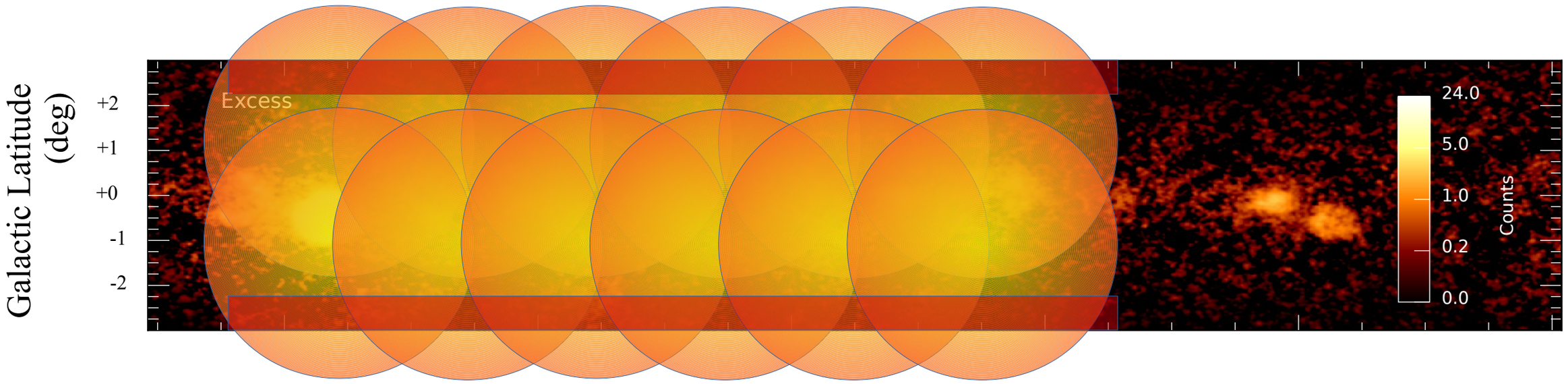
strong assumption!
very likely the cosmic-ray fluxes are much higher

minimum hadronic model with protons only/inclusion of heavier nuclei



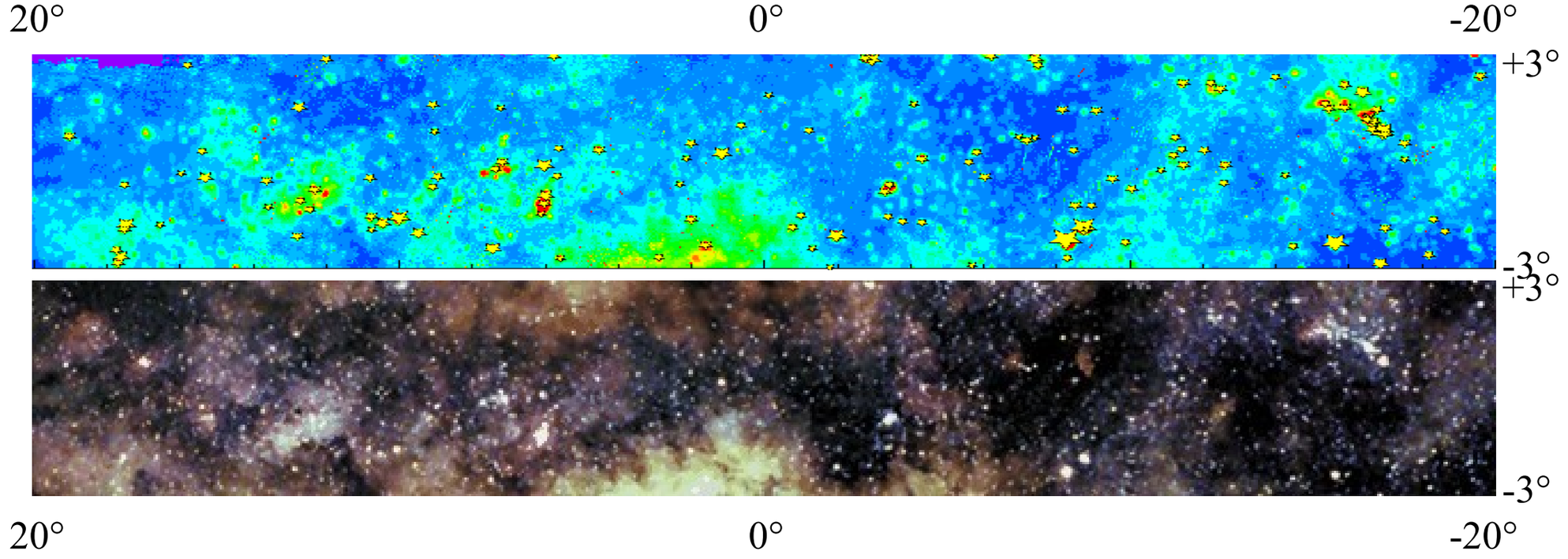
about a third of the signal is lost due to background subtraction
→ contribution of 17% (36% when considering heavier nuclei) to the total signal

Next Step - Template Fitting



- Construct one IRF for each observation run (~28 mn), taking into account various instrumental effects (NSB, …)
- In a first stage, use “side-band” to normalize on the measured number of gamma-like events
- In a second stage, O(6000) free parameter global fit

Next step – Template fitting

- Caveats:
  - Changing observation conditions from run to run (zenith angle, night sky luminosity, angle to magnetic field, non-operational pixels, …)
  - Results in variation in trigger rate and angular response
  - Dedicated run-wise simulations are needed to determine the response function on each run
  - Need response functions for γ-like background as well!
  - …
  - 

NSB measured in HESS pixels (top) and in optical (bottom)

Summary and Outlook

- Diffuse Galactic gamma-ray emission is a powerful tool to investigate cosmic rays in the Milky Way
- Diffuse TeV observations with imaging atmospheric Cherenkov telescopes are challenging due to very low fluxes, the limited field of view, and the handling of the background
- H.E.S.S. has detected for the first time a first large-scale VHE diffuse signal along the Galactic plane - **H.E.S.S. Collaboration, PRD 2014**
- Due to the applied background subtraction, the signal needs to be treated as a kind of lower limit (with different contributions varying in the recoverability of the signal)
- The observed signal is very likely to be a combination of unresolved gamma-ray sources and a "truly diffuse" hadronic component, with only small admixture of inverse Compton
- Measurement demonstrates the potential of imaging atmospheric Cherenkov telescopes in terms of diffuse Galactic gamma-ray emission, but is only a starting point → more sophisticated analysis methods under development