



# The VHE Diffuse Galactic Gamma-Ray Emission

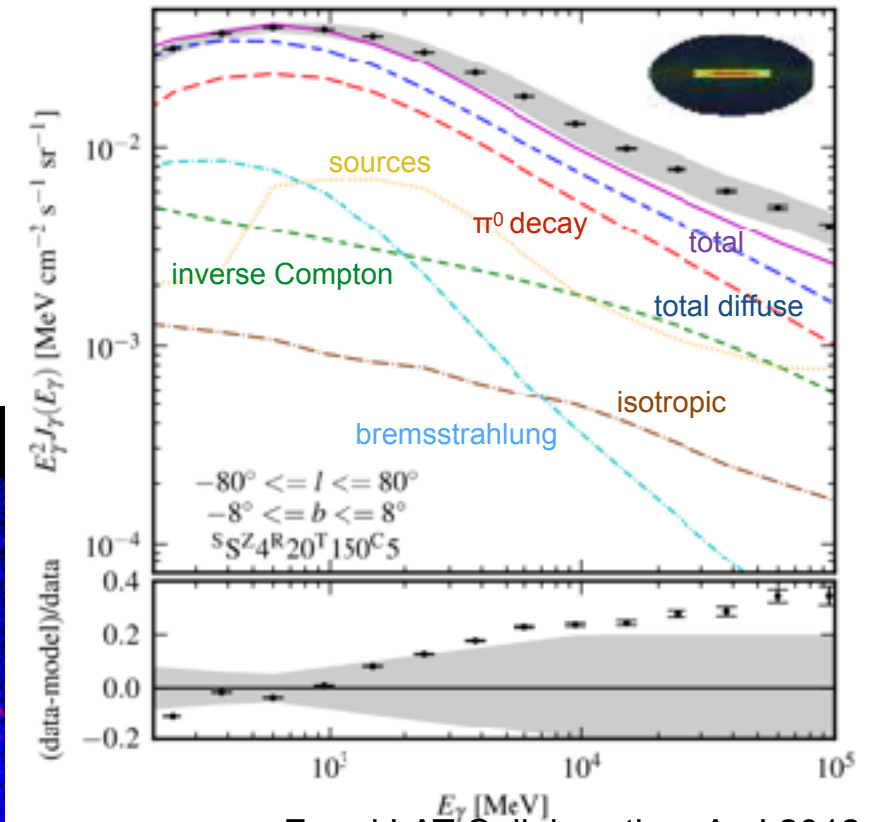
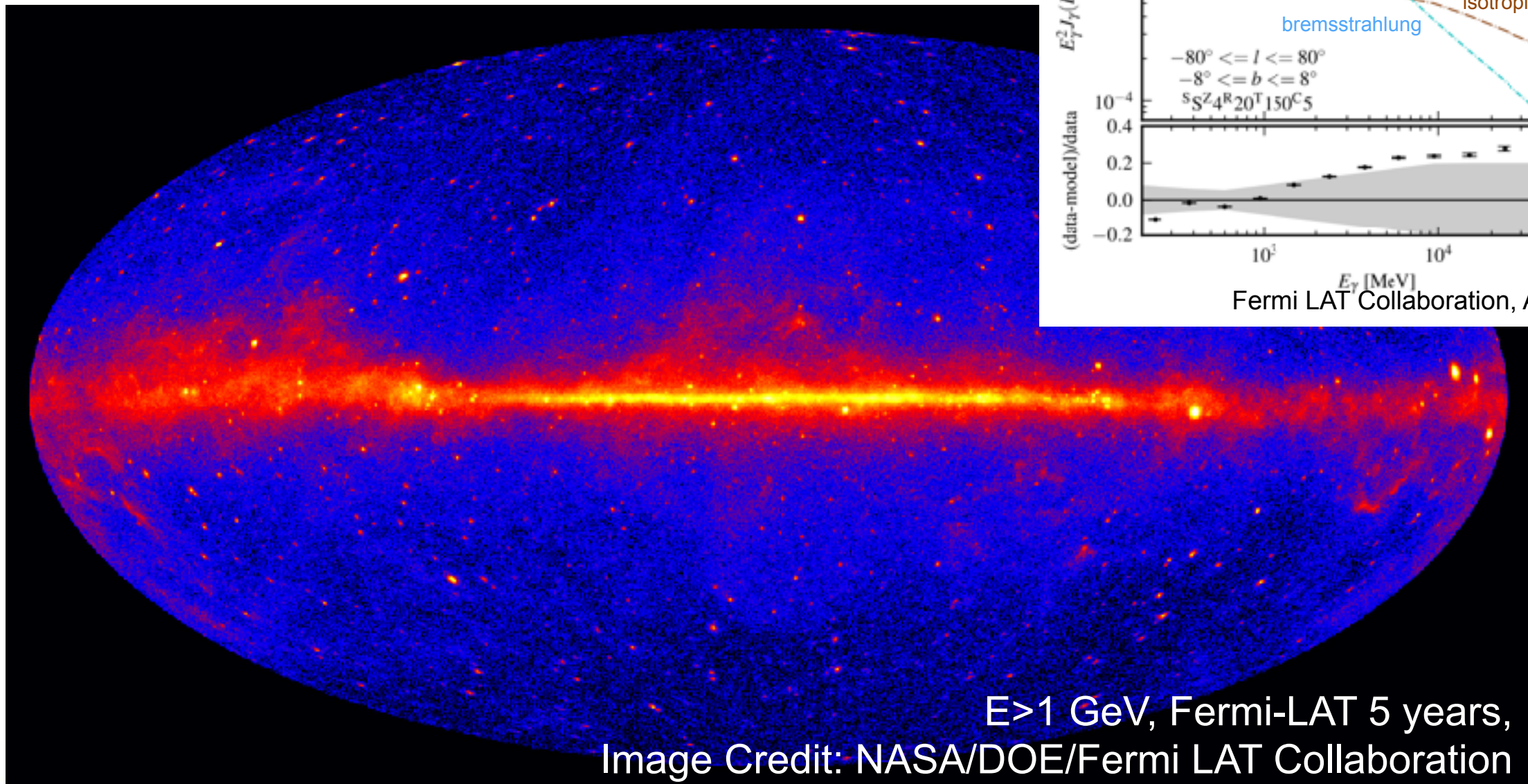


Kathrin Egberts  
Potsdam University



# Diffuse Galactic gamma-ray emission at GeV energies

At GeV energies, we see diffuse emission all along the Galactic plane

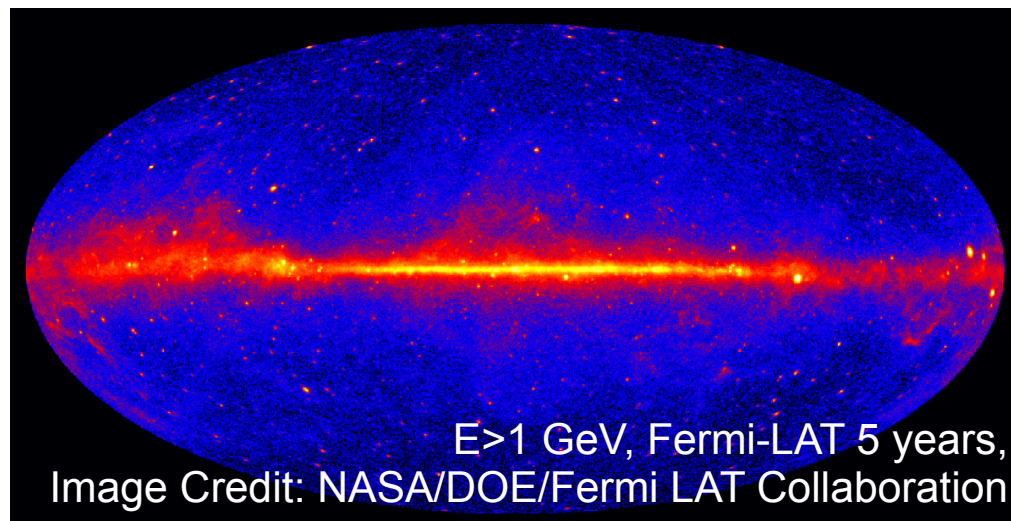


Fermi LAT Collaboration, ApJ 2012

# VHE Diffuse Emission?

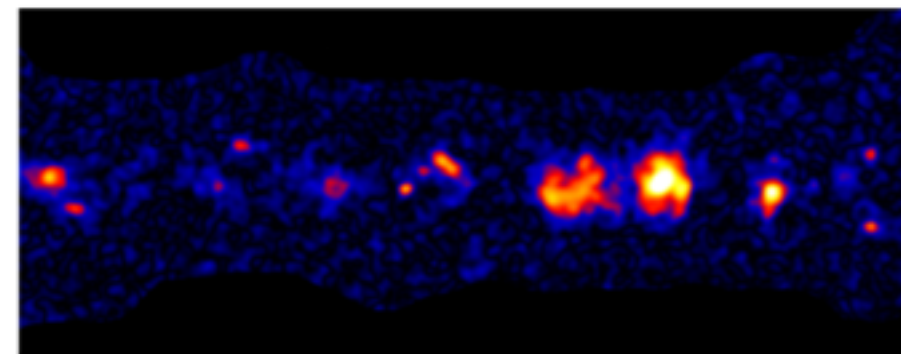
## GeV

- Diffuse emission dominating (mostly hadronic) component
- Renders search for sources difficult



## TeV

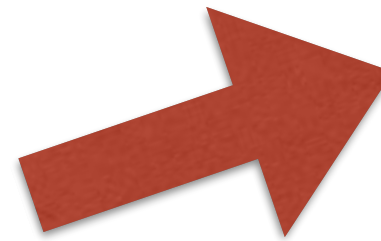
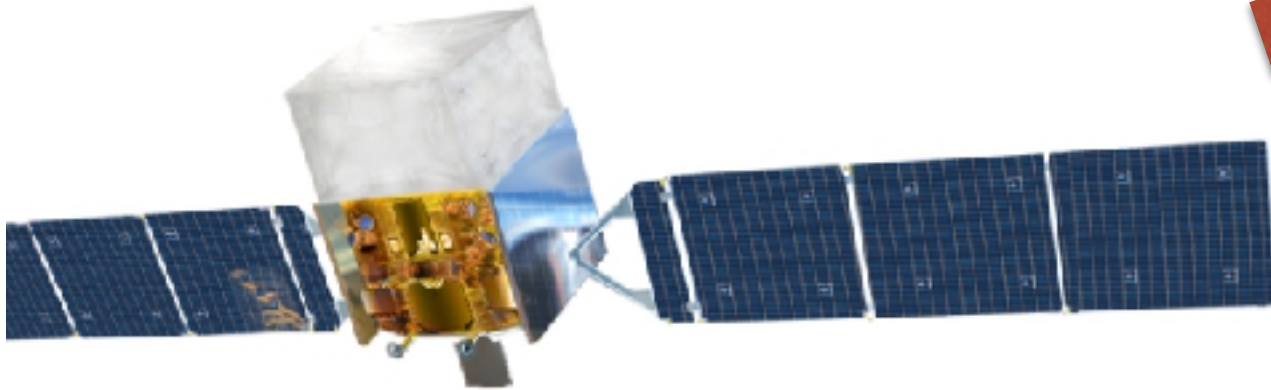
- Emission from hard Galactic sources dominant
- Renders search for diffuse emission difficult





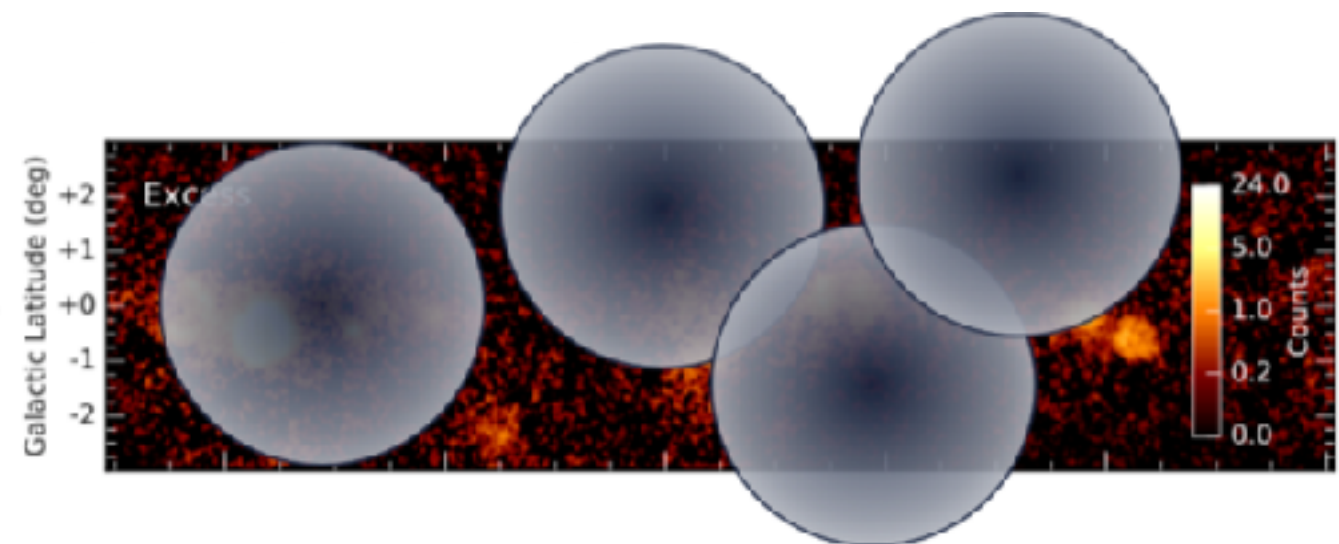
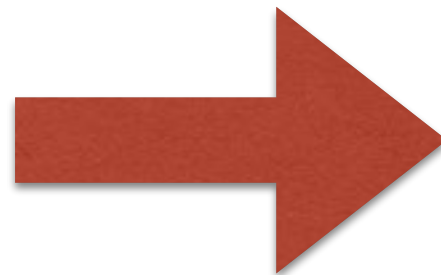
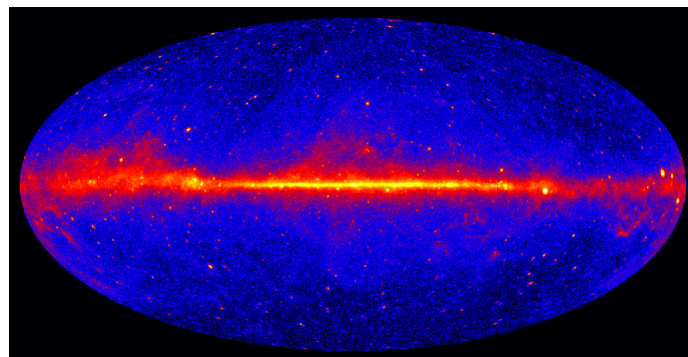
# VHE Diffuse Emission - Technical Aspects

- 1. Less statistics
  - Large detection areas needed
  - Imaging atmospheric Cherenkov technique



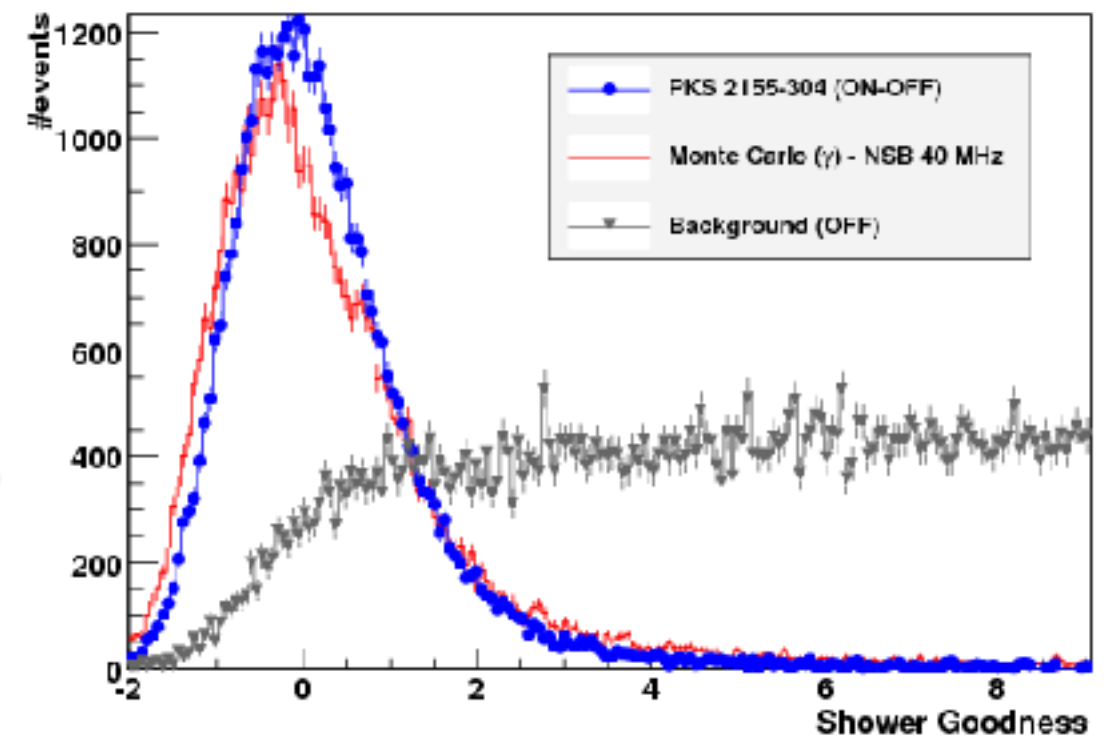
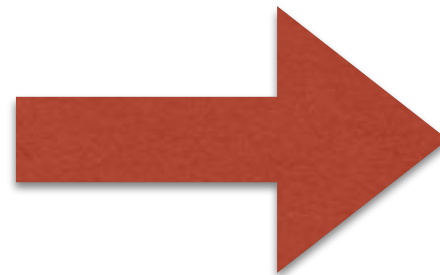
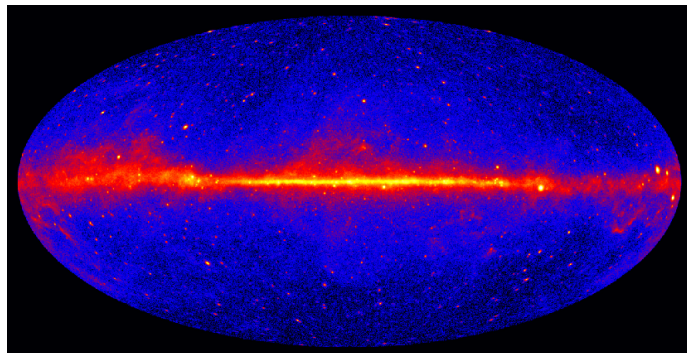
# VHE Diffuse Emission - Technical Aspects

- 1. Less statistics
- 2. Reduction of field of view
  - Need for many pointed observations, large variety of observational conditions



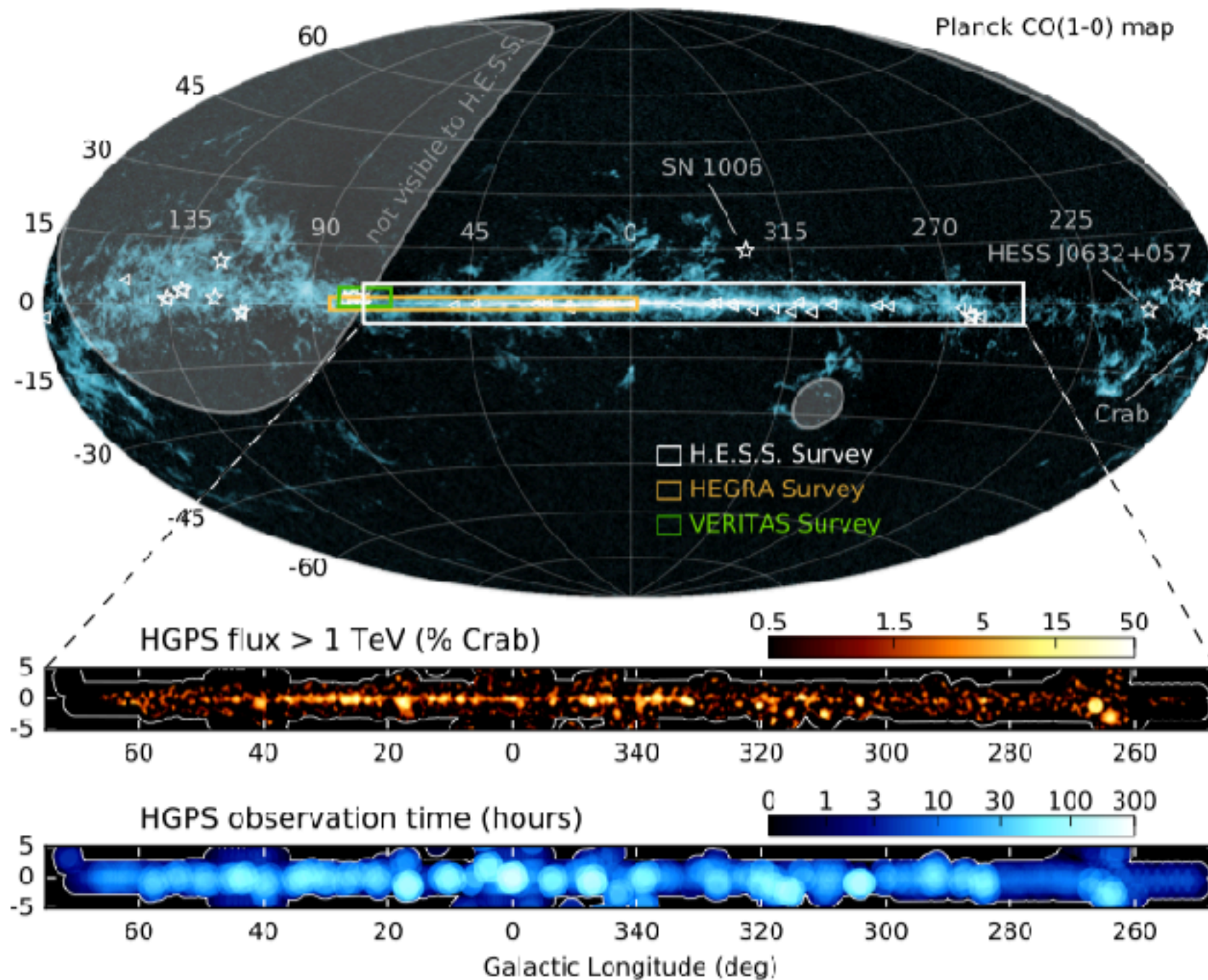
# VHE Diffuse Emission - Technical Aspects

- 1. Less statistics
  - 2. Reduction of field of view
  - 3. New backgrounds arise
- Gamma-ray backgrounds vs. charged-particle backgrounds





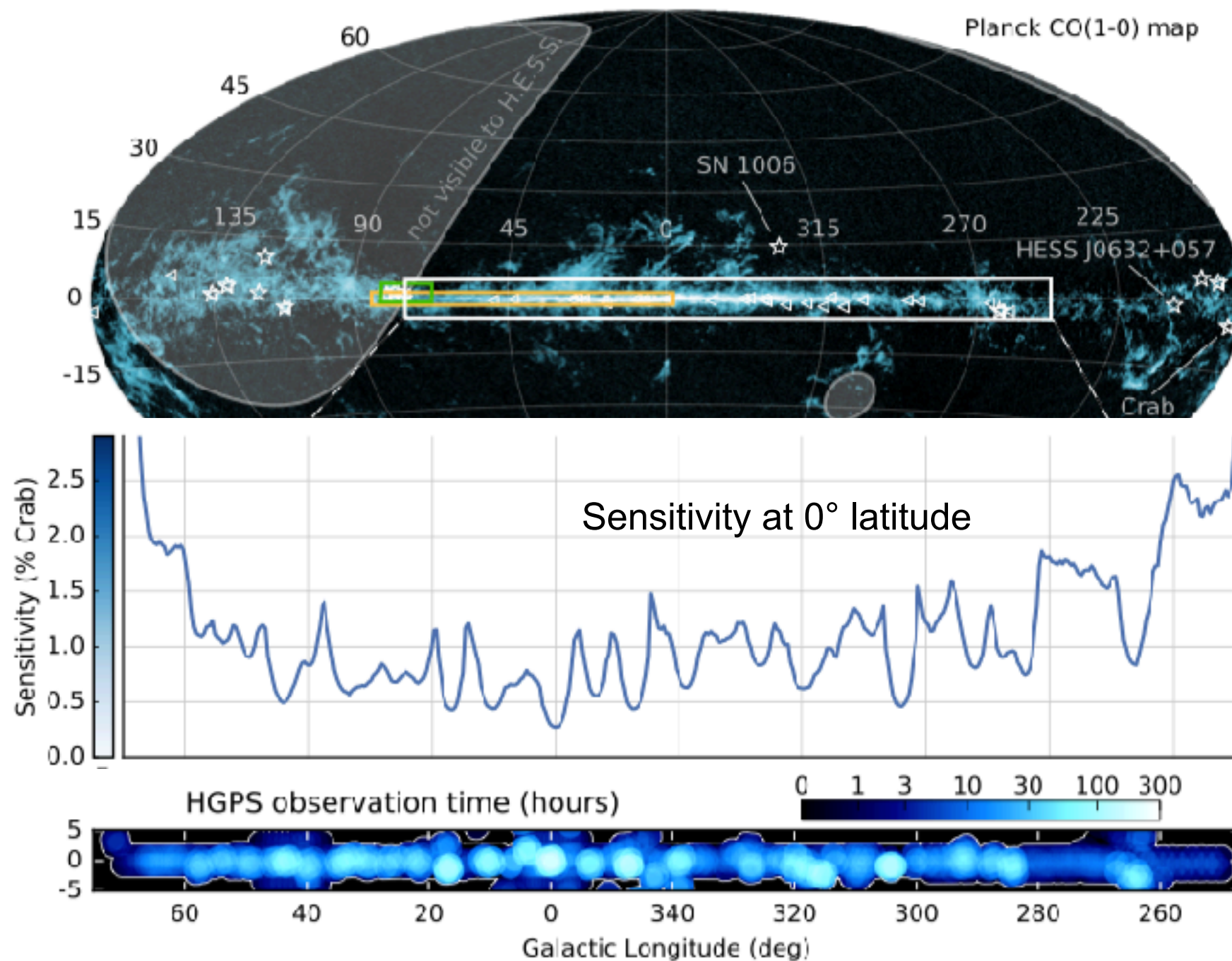
# The H.E.S.S. Galactic Plane Survey



- 2673 hours of high-quality data, taken in the years 2004 to 2013
- Covered area:  
 $l = 250^\circ$  to  $65^\circ$ ,  
 $|b| < 3^\circ$
- Inhomogeneous exposure

H.E.S.S. Collaboration, A&A 2018

# The H.E.S.S. Galactic Plane Survey

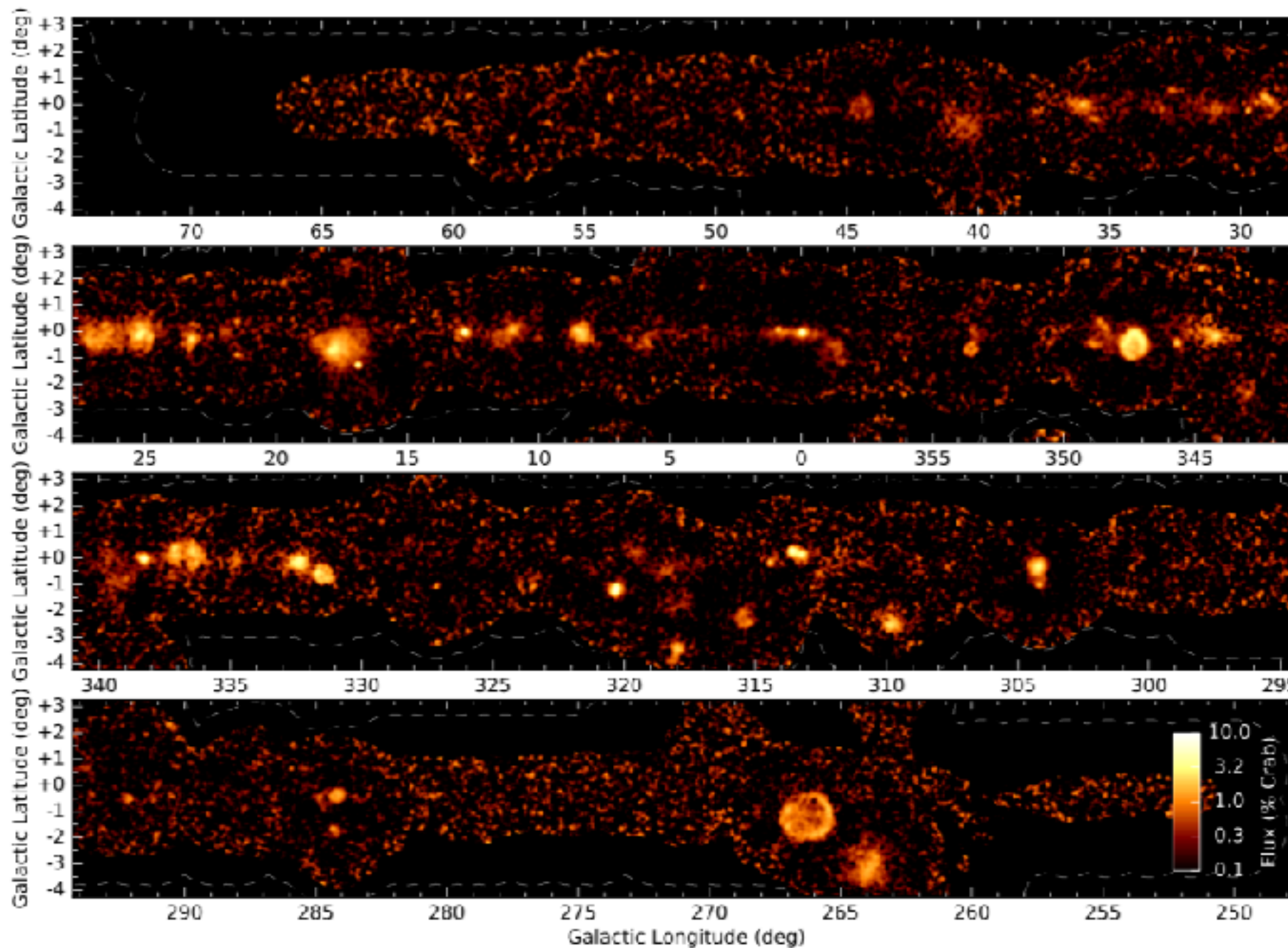


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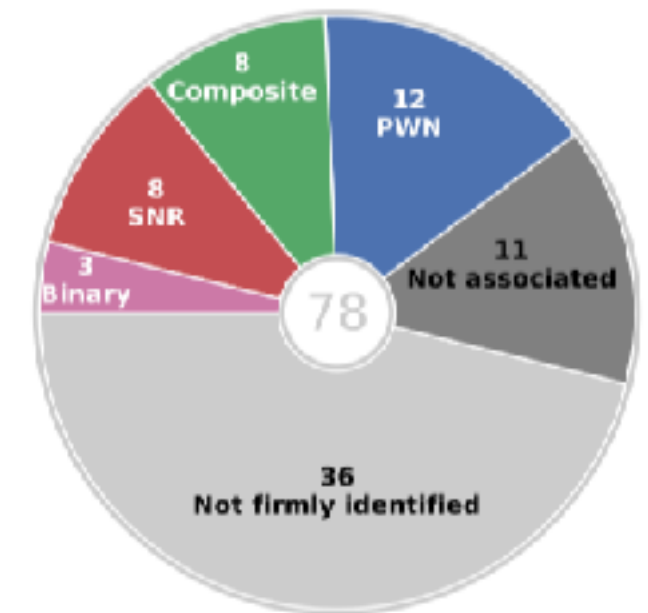
H.E.S.S. Collaboration, A&A 2018



# The H.E.S.S. Galactic Plane Survey



- Detection of 78 VHE sources along the plane

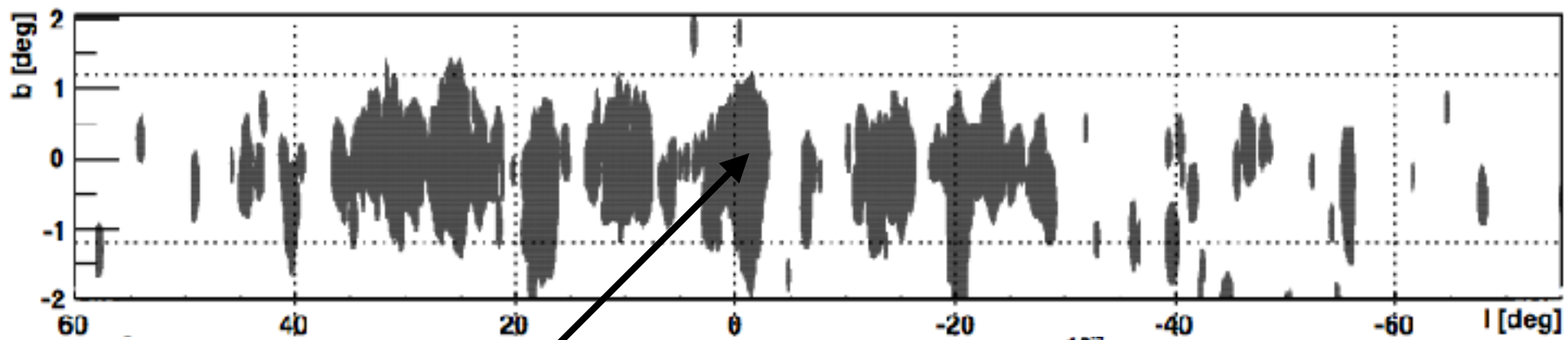


- ... and a component of large-scale diffuse emission

H.E.S.S. Collaboration, A&A 2018

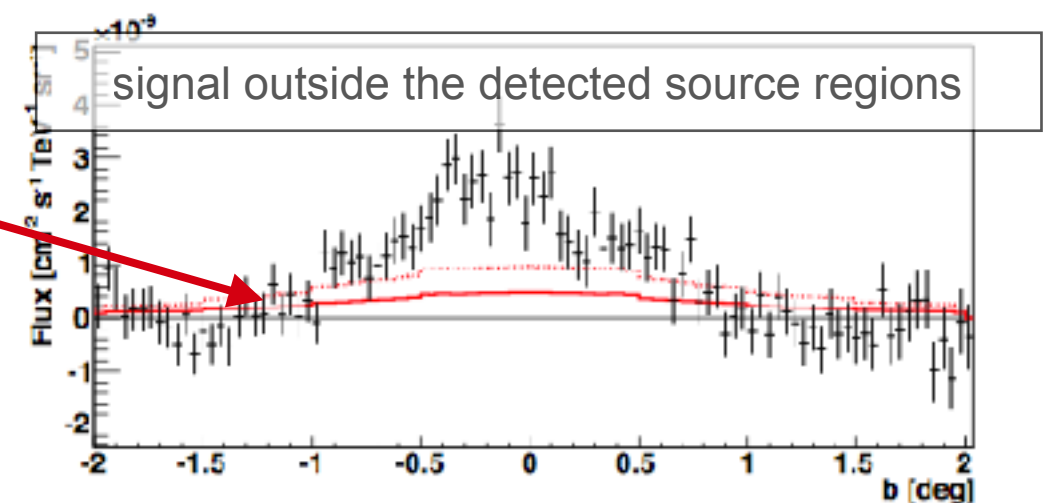
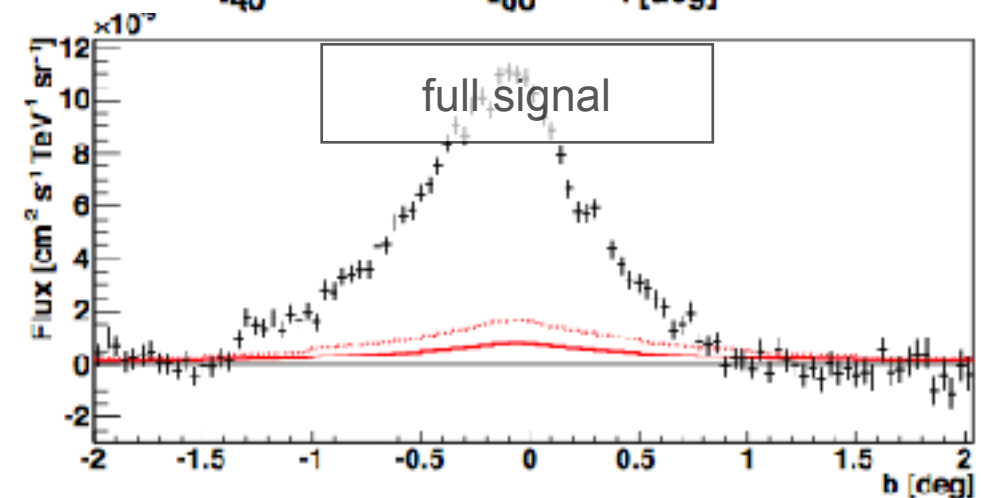


# VHE Diffuse Emission: Proof of Existence



significantly detected  $\gamma$ -ray sources

- Large-scale signal outside source regions
- Accumulates all along the plane
- Estimated minimum contribution of hadronic emission
- Further expected contributions:
  - inverse Compton component
  - unresolved gamma-ray sources

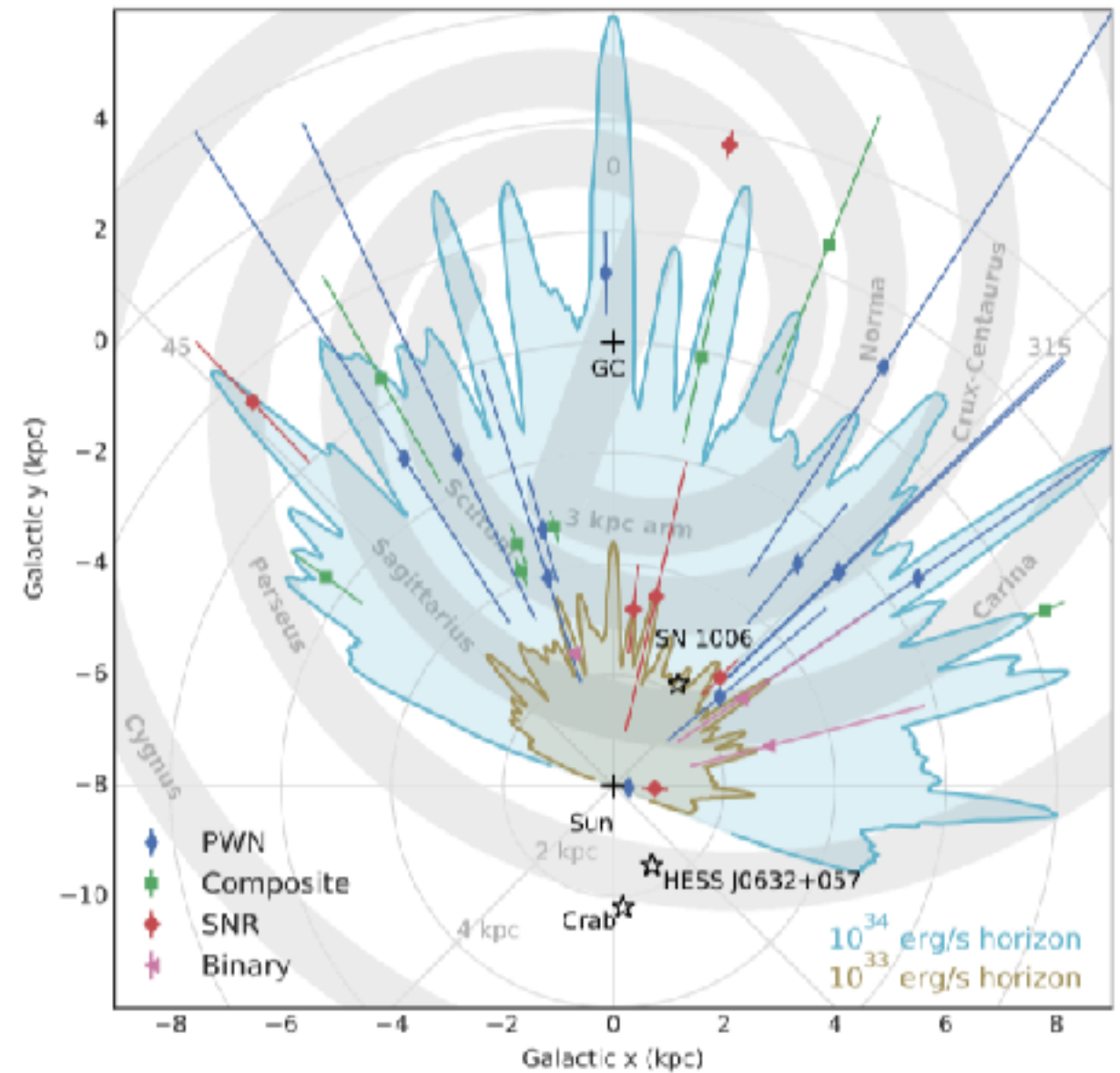
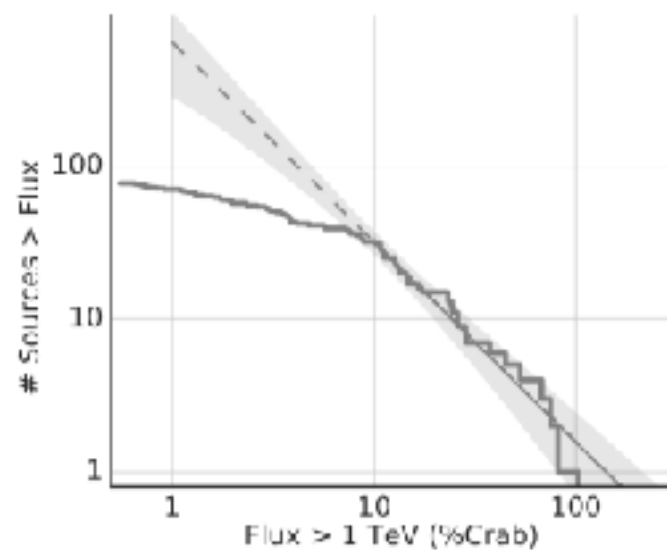


H.E.S.S. Collaboration, PRD 2014



# Unresolved Sources in the VHE Diffuse Emission

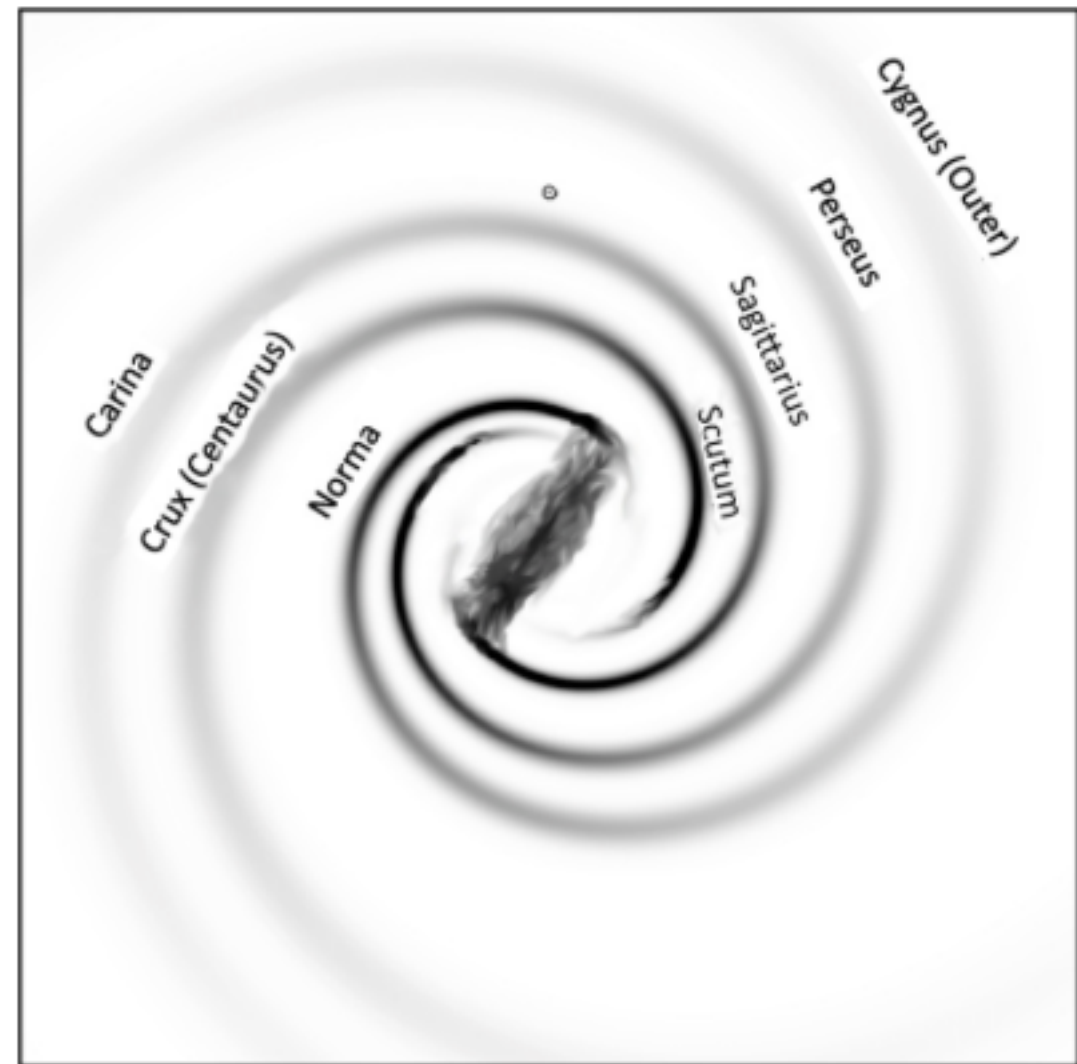
- Because of limited sensitivity: only fraction of Galactic gamma-ray sources is resolved
- Inferring knowledge from detected sources to the whole population
- Easiest approach: use only 1D information: flux



H.E.S.S. Collaboration, A&A 2018

# Simulating a Galactic VHE Source Population

- First approach: characterise gamma-ray sources by position and luminosity at 1 TeV
- Assume the sources to follow the matter density in Milky Way → spiral arm structure (4-arm model) with a bar



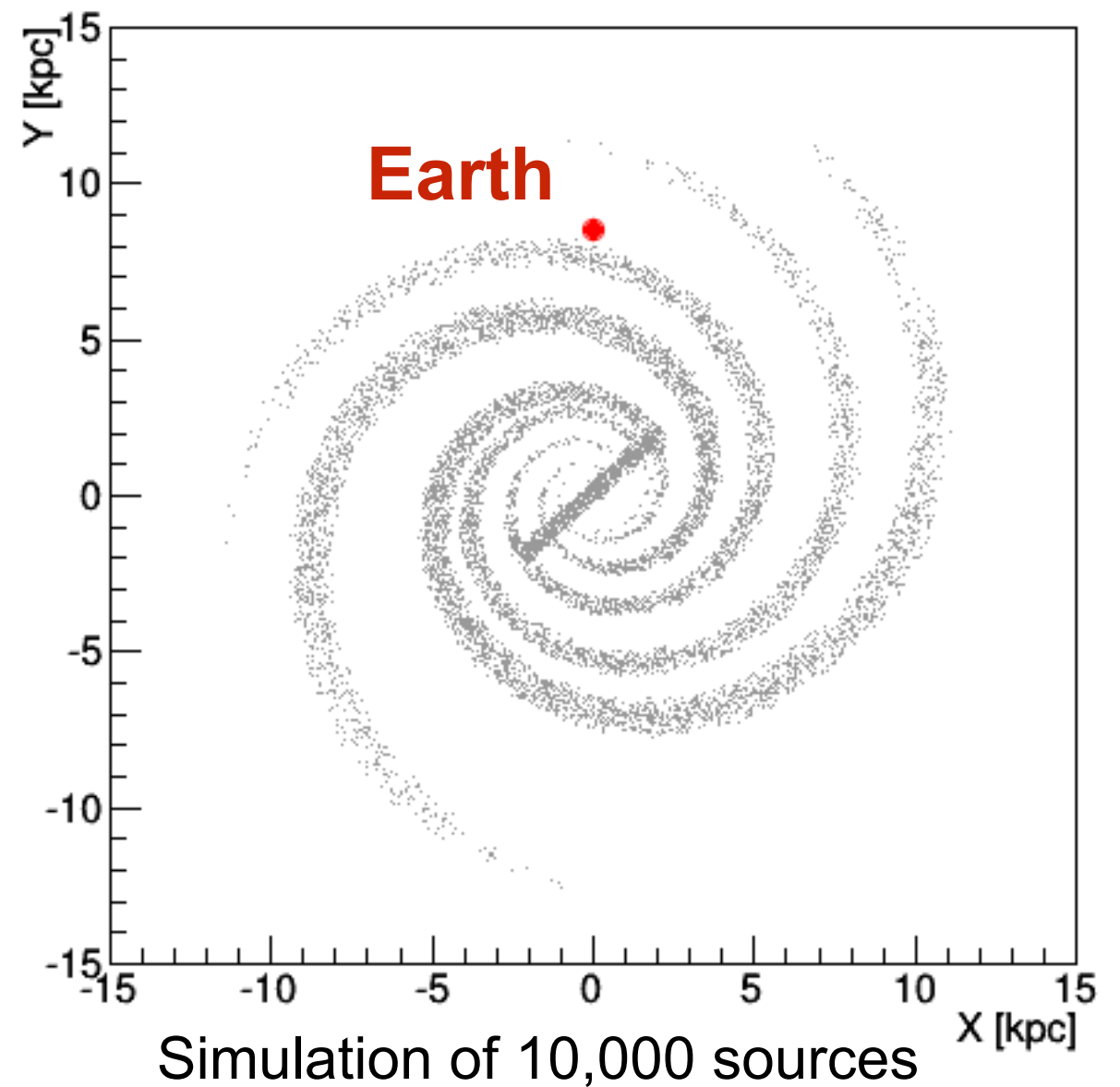
**Figure 9.** Traditional names of the arm segments of the Milky Way superposed on the four-arm model of this work. While the central bar depicted is representative of the maximum bar size consistent with the *COBE* data, its shape and orientation are not constrained by these data.

*Steiman-Cameron, Astrophys. J. 2010*



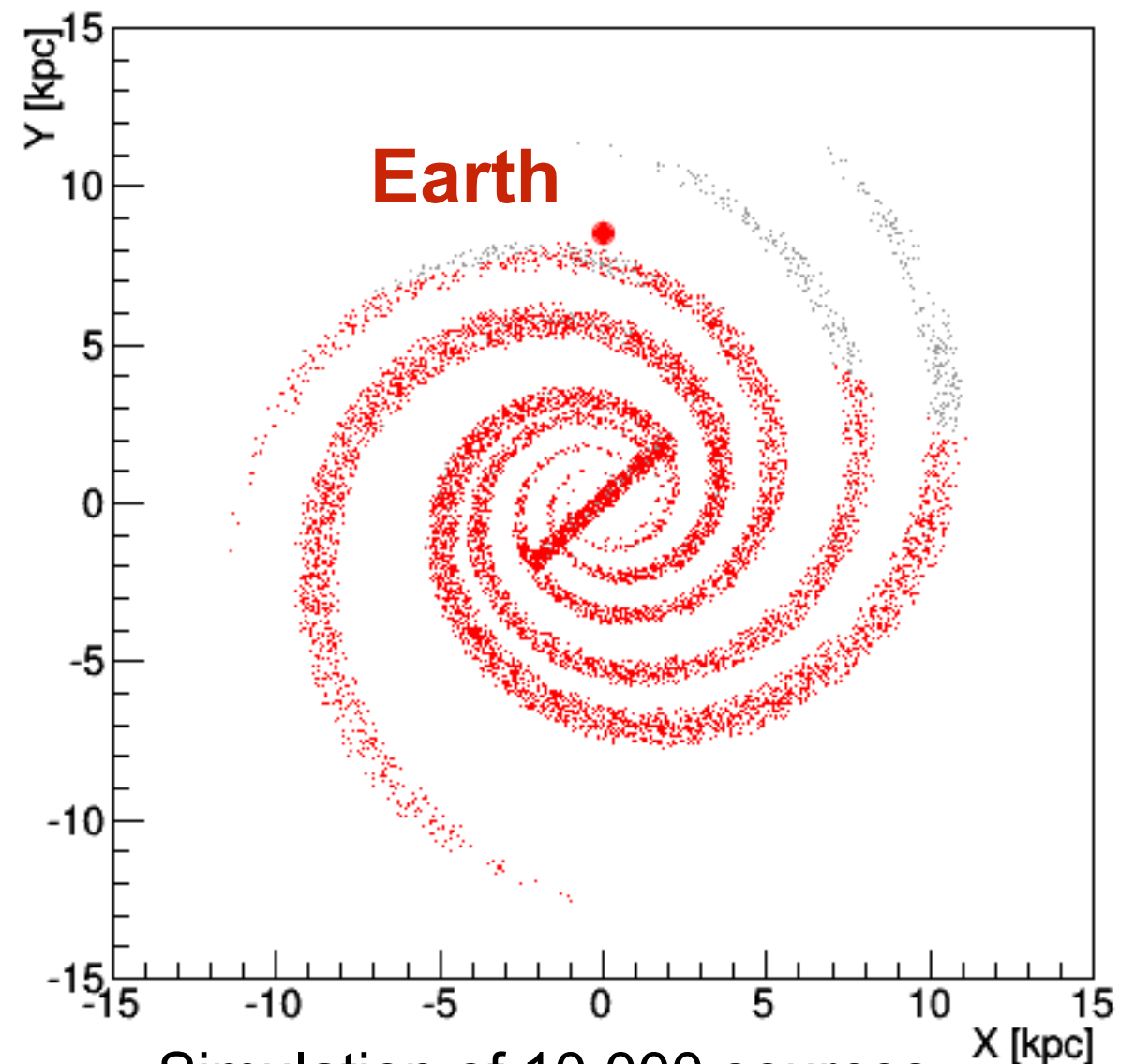
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# Simulating a Galactic VHE Source Population

- Restrict the viewing angle to the region where diffuse emission is observed in the H.E.S.S. Galactic Plane Survey:  
 $-75^\circ < l < 60^\circ$ ,  $-1^\circ < b < 1^\circ$

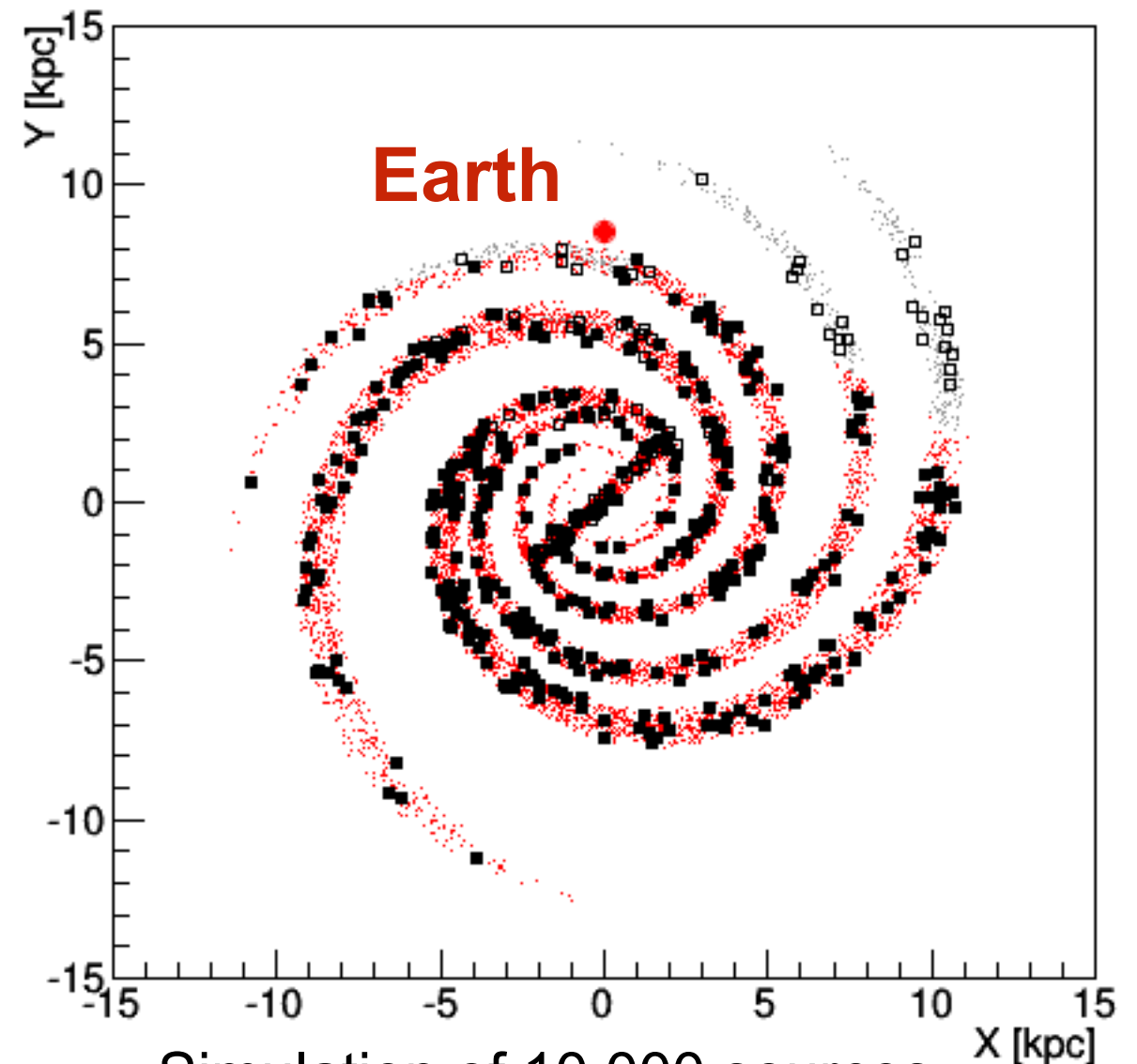


Simulation of 10,000 sources  
**inside** and **outside** the HGPS



# Simulating a Galactic VHE Source Population

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 $-75^\circ < l < 60^\circ$ ,  $-1^\circ < b < 1^\circ$
- Reduce the number of sources to a reasonable number (500) to correctly reproduce statistical scatter
- Determine the spread by simulating many realisations

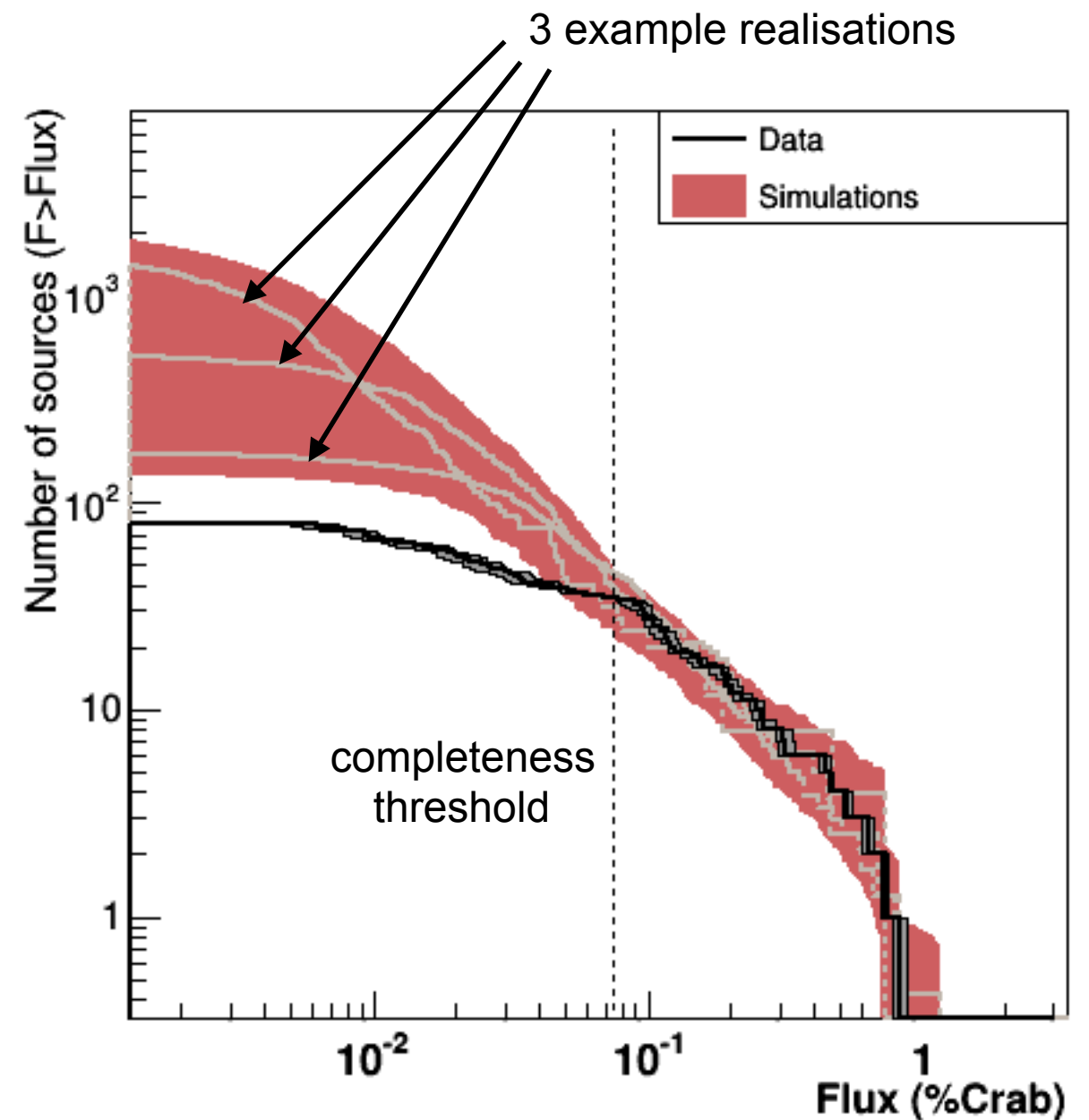


Simulation of 10,000 sources  
inside and outside the HGPS

■/□: Simulation of 500 sources  
inside/outside of the HGPS

# Simulating a Galactic VHE Source Population

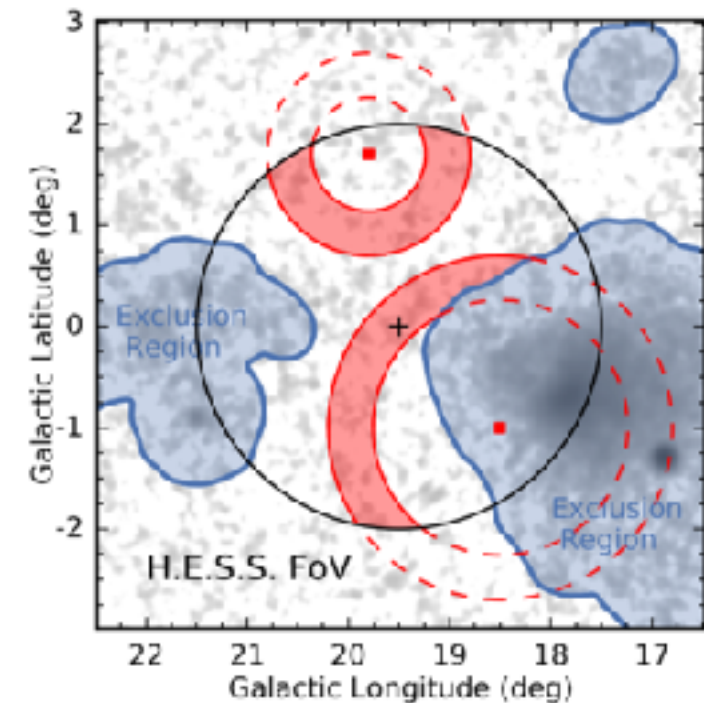
- Fit of the individual realisations to the measured log N - log S in the range of completeness:
  - Fit in x and y: scaling of source luminosity and total number of sources
  - Disregard distributions that fail to describe the data
  - Use 68% containment in each flux bin to determine scatter of simulations
- Deficit below completeness threshold corresponds to the amount of unresolved sources
- → minimum of 50% of diffuse signal is unresolved sources





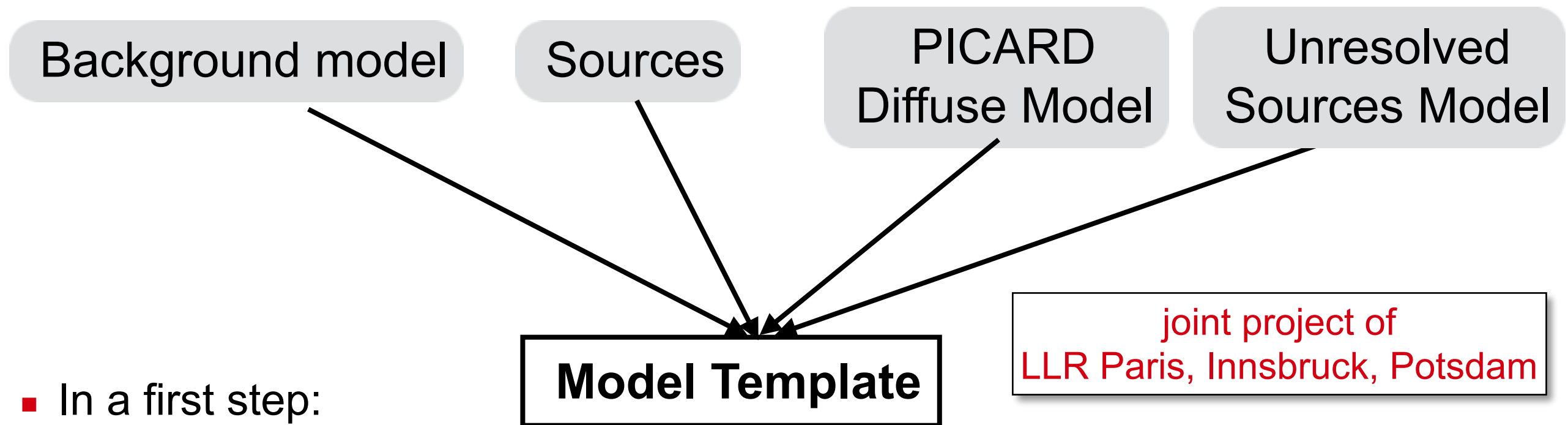
# Dealing with the Charged-Particle Background

- Subtraction of hadronic background is necessary because of imperfect gamma/hadron separation
  - Performed in background measurements in the FoV (+ assumption on system response)
  - Results in subtraction of any large-scale gamma-ray emission together with the background
- method generally not suited for large-scale emission regions
- need for new methods → template fitting approach



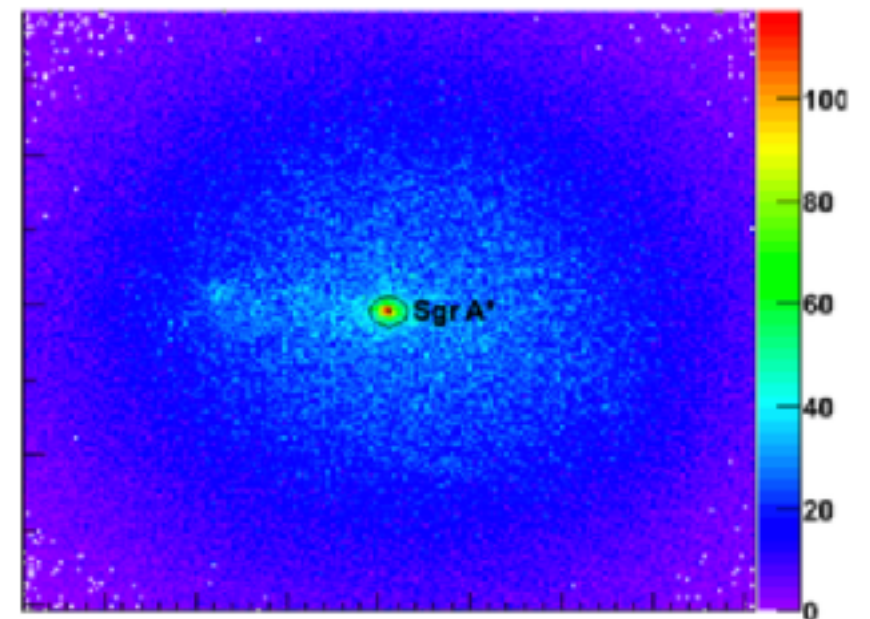
# Template Fitting Approach

- Instead of a background subtraction, perform a several-component 2D (+ energy) fit



- In a first step: exclusion of sources
- Requires:
  - Diffuse model
  - Unresolved model
  - Background model

**Likelihood Fit**





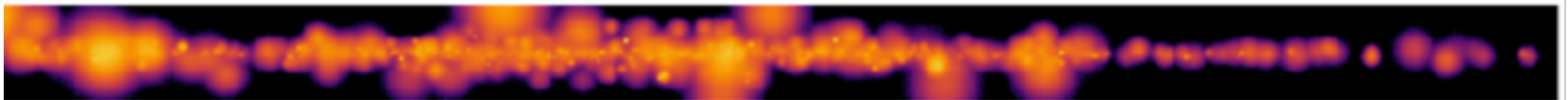
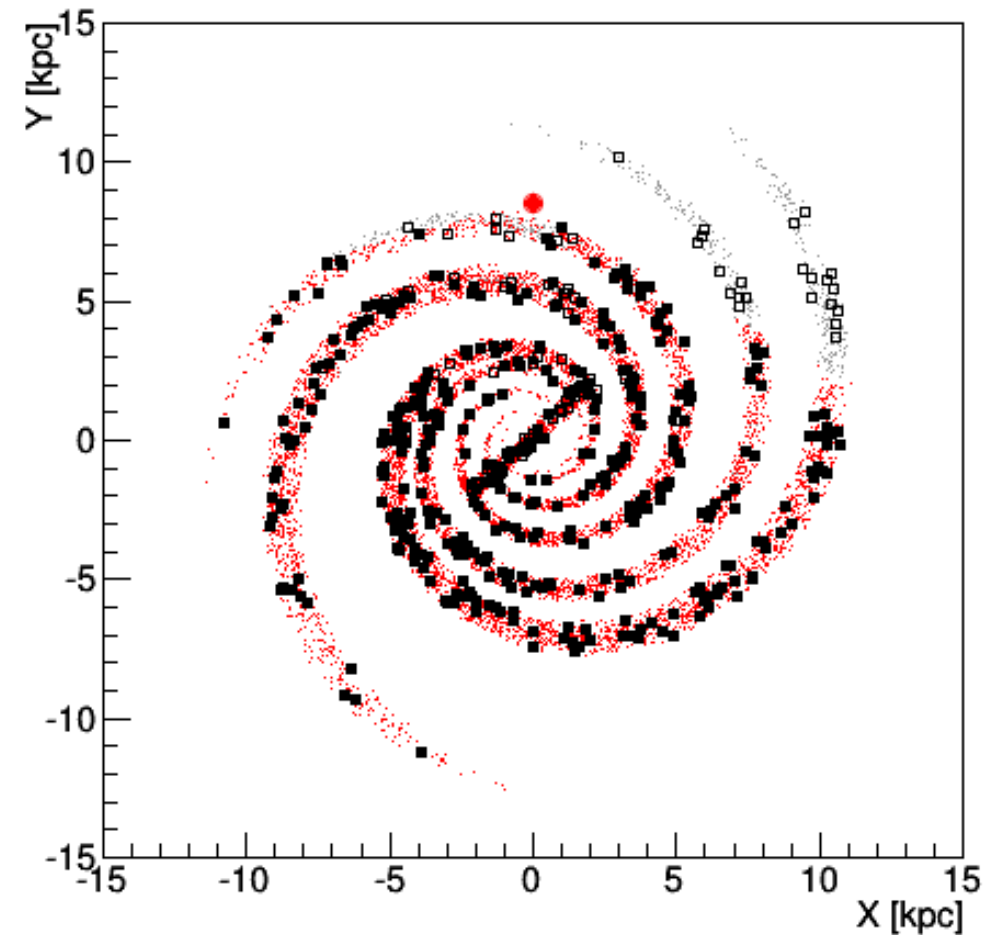
# Towards Background Templates

- Approach taken so far: generation from extragalactic observations
- Large uncertainties due to varying observation conditions like
  - zenith and azimuth angle (can be handled by binning extragalactic observations in bands)
  - night sky background
  - array configuration and detector conditions
  - Earth magnetic field
- A new concept promises significantly reduced uncertainties:  
**Simulation of the full observation conditions for every observation run**
  - not feasible for the full background of hadronic cosmic rays and  $e^\pm$  (computationally intensive and issues with the quality of hadronic models)
  - instead: simulations of diffuse gamma-rays

Run-Wise Simulations, *Markus Holler et al.*, ICRC 2017

# Towards Unresolved Templates

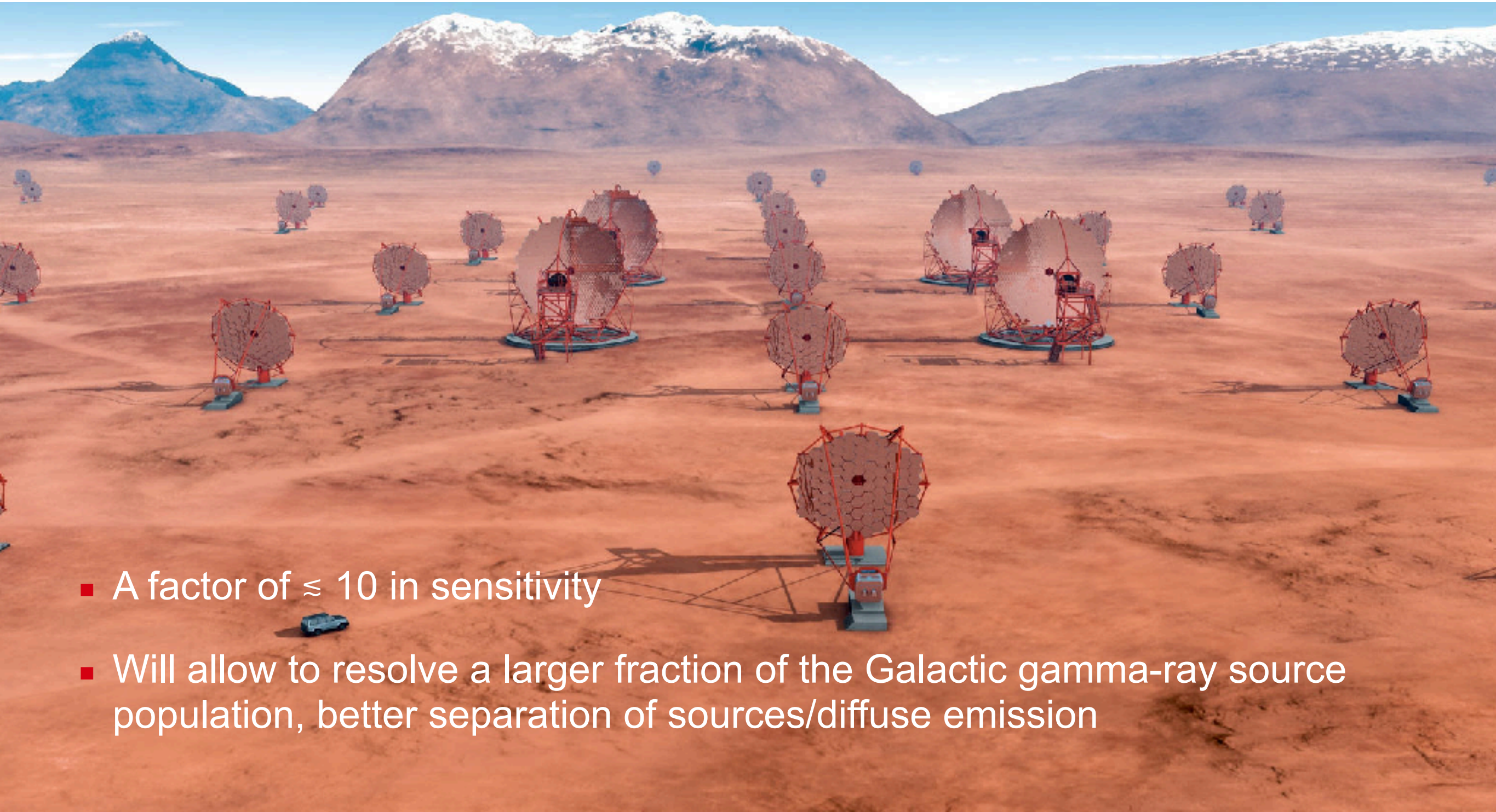
- Inclusion of source extension
- More realistic source models
- Constrained by HGPS sources in the range of completeness



Work in progress by *Constantin Steppa*



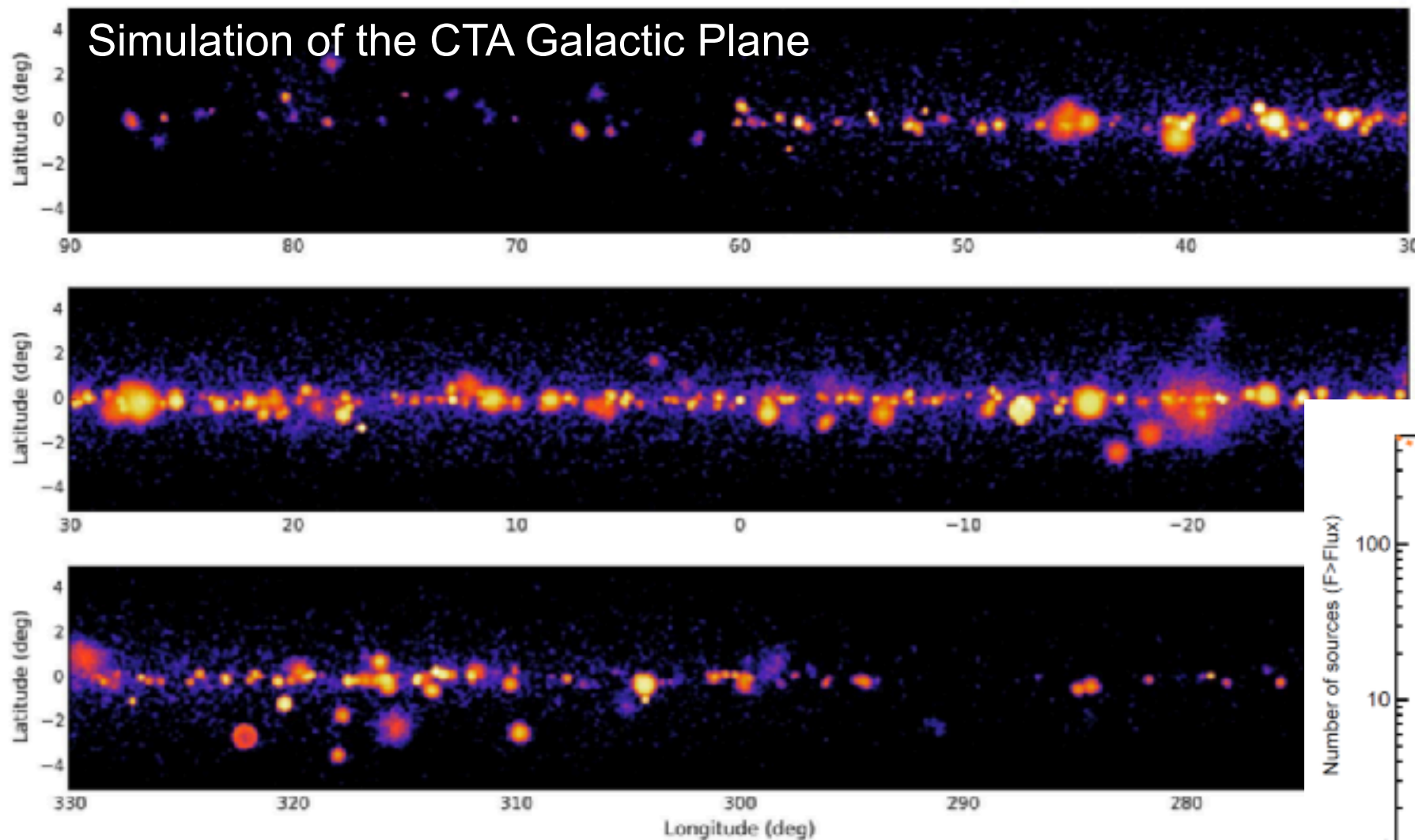
# What can we hope to see with CTA?



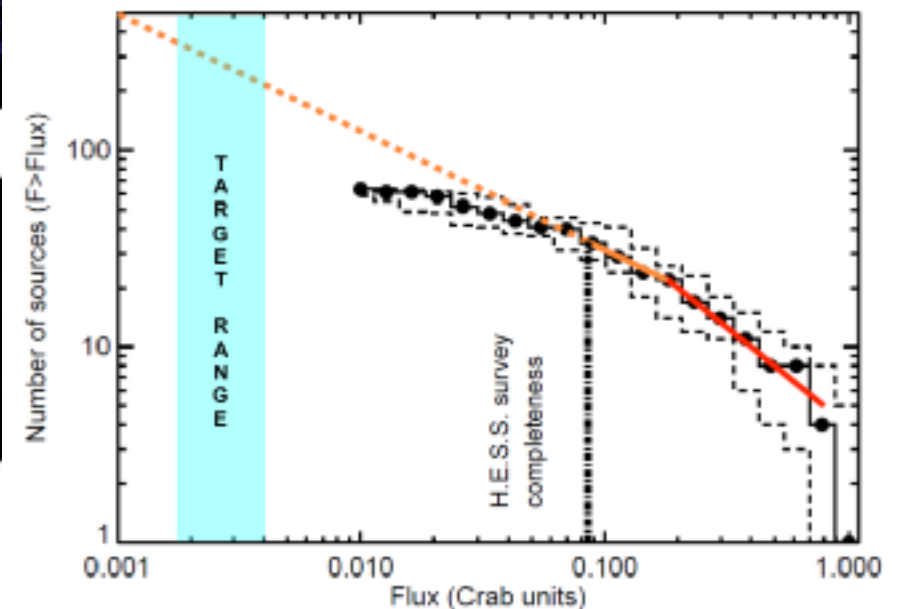
- A factor of  $\approx 10$  in sensitivity
- Will allow to resolve a larger fraction of the Galactic gamma-ray source population, better separation of sources/diffuse emission



# What can we hope to see with CTA?



CTA Collaboration, *Science with CTA*, 2017



- Modelling of the population still crucial because of remaining incompleteness of population and source confusion (but more information allows refinement of source models)
- Furthermore, the understanding of diffuse emission is crucial for measurement of weak and extended Galactic sources with CTA

# Summary & Conclusion

- VHE diffuse emission exists and is measurable (though measurements are challenging)
- Issue with background subtraction: part of the signal irrecoverable
- Signal composition changes compared to HE diffuse emission: especially large contribution of unresolved gamma-ray sources expected
- Need for a good understanding of the gamma-ray source population, close interconnection between sources and diffuse emission
- More sophisticated analysis techniques underway (template fitting)
- Measurements will provide constraints to CR physics and propagation models