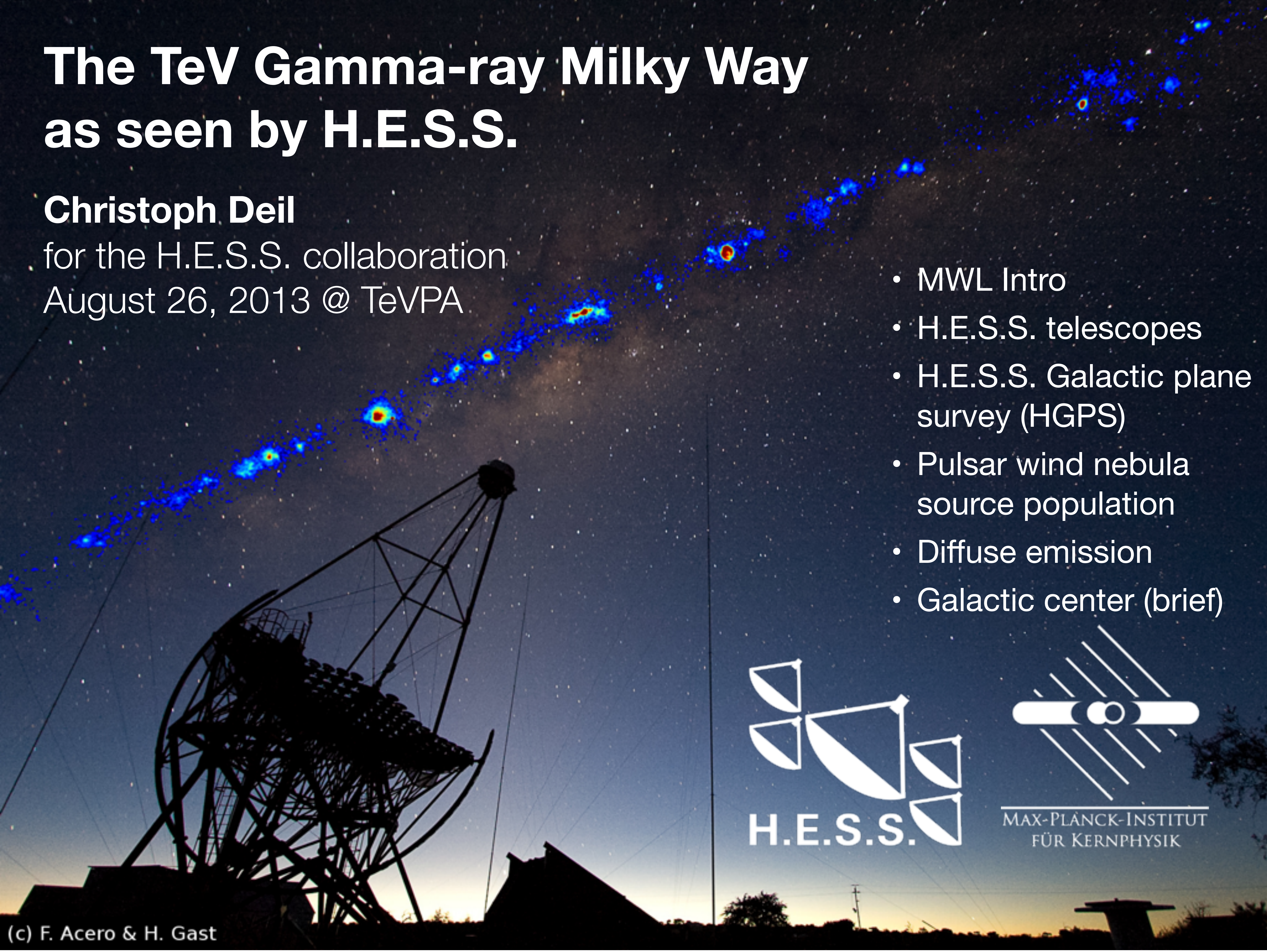
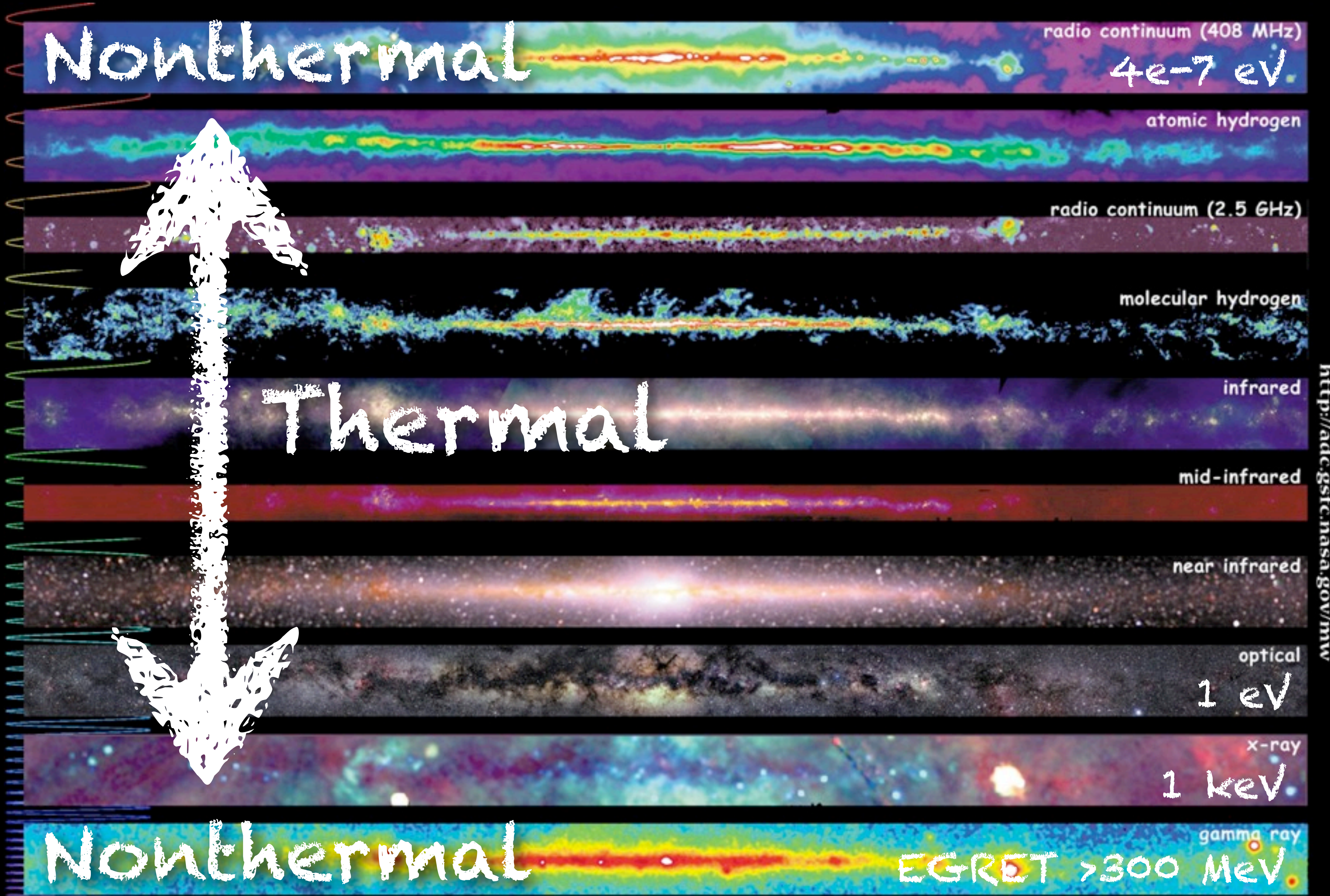
The TeV Gamma-ray Milky Way as seen by H.E.S.S.

Christoph Deil
for the H.E.S.S. collaboration
August 26, 2013 @ TeVPA

- MWL Intro
- H.E.S.S. telescopes
- H.E.S.S. Galactic plane survey (HGPS)
- Pulsar wind nebula source population
- Diffuse emission
- Galactic center (brief)



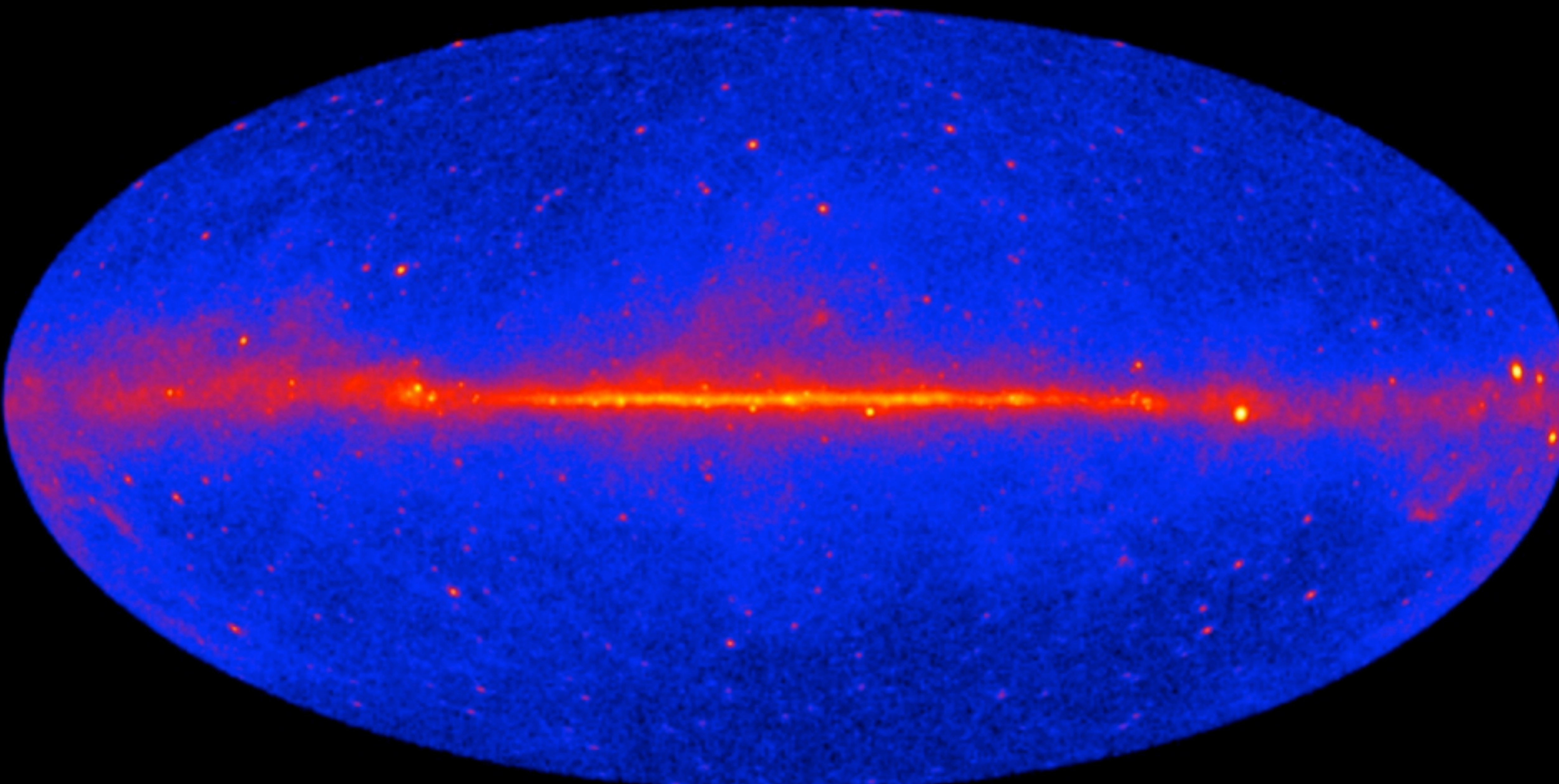


Now we have much better gamma-ray data:

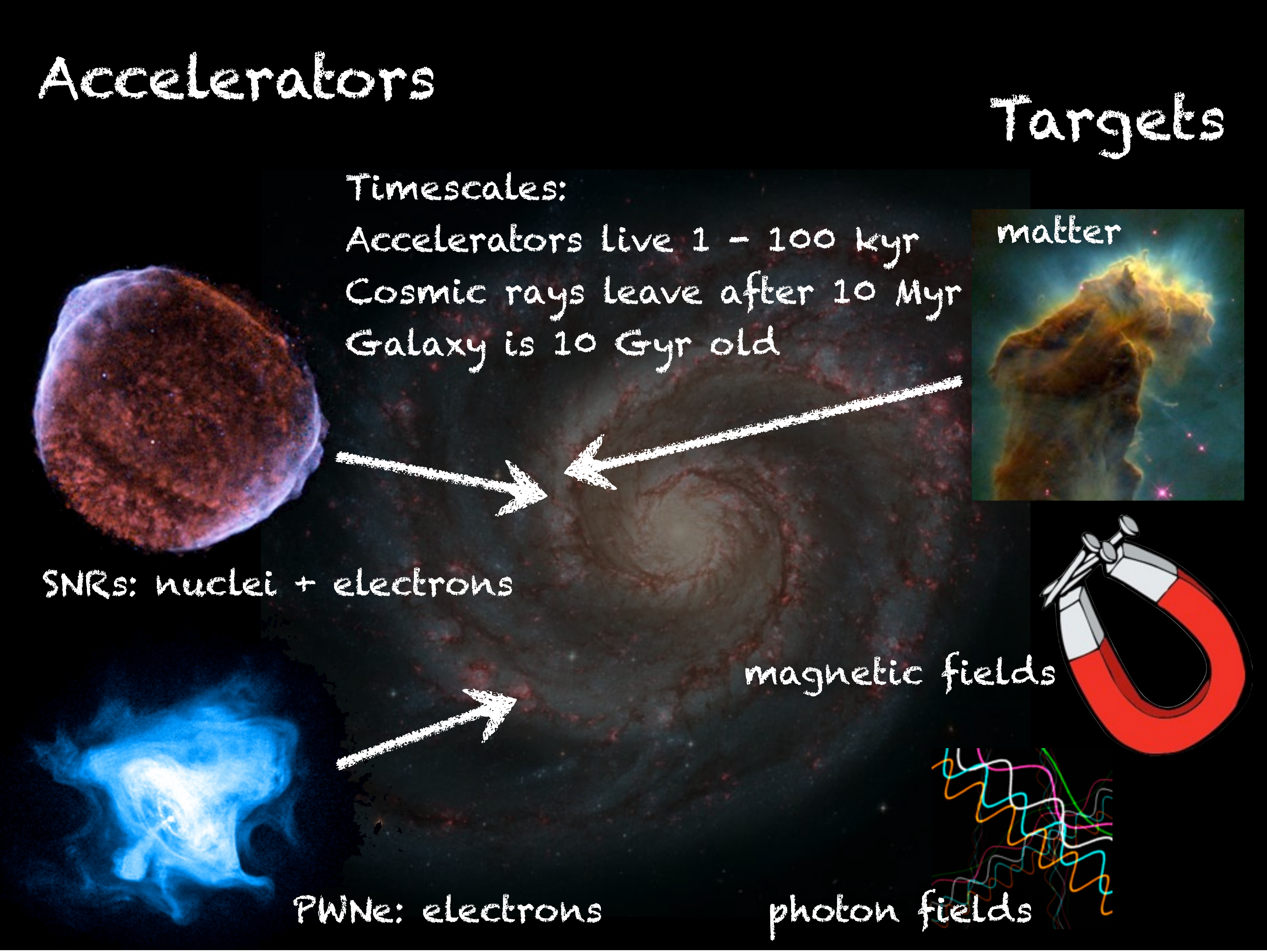
Fermi (100 MeV - 100 GeV) and HESS (100 GeV - 100 TeV)

$\leftarrow \gamma$

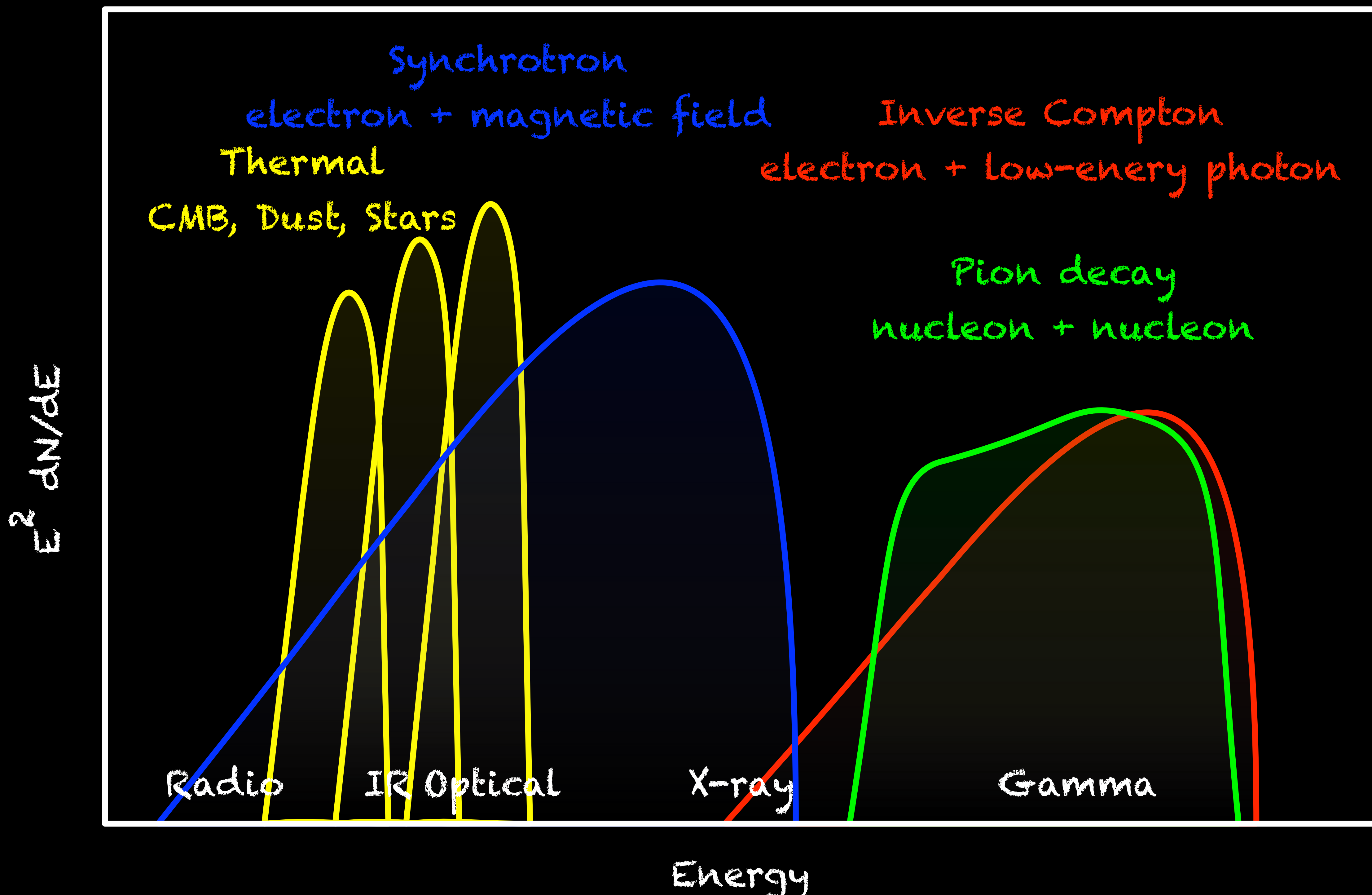
Fermi All-Sky Count Map > 1 GeV



Total = Resolved + Unresolved Sources + Diffuse

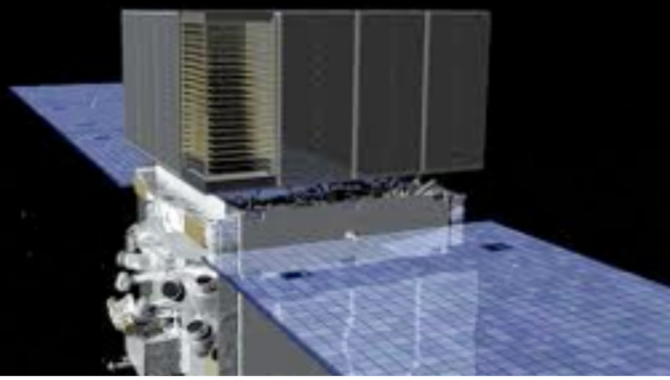

Accelerators
Targets
Timescales:
Accelerators live 1 - 100 kyr
Cosmic rays leave after 10 Myr
Galaxy is 10 Gyr old
matter
SNRs: nuclei + electrons
magnetic fields
PWNe: electrons
photon fields

Nonthermal Emission
(Cosmic ray density) x (target density)

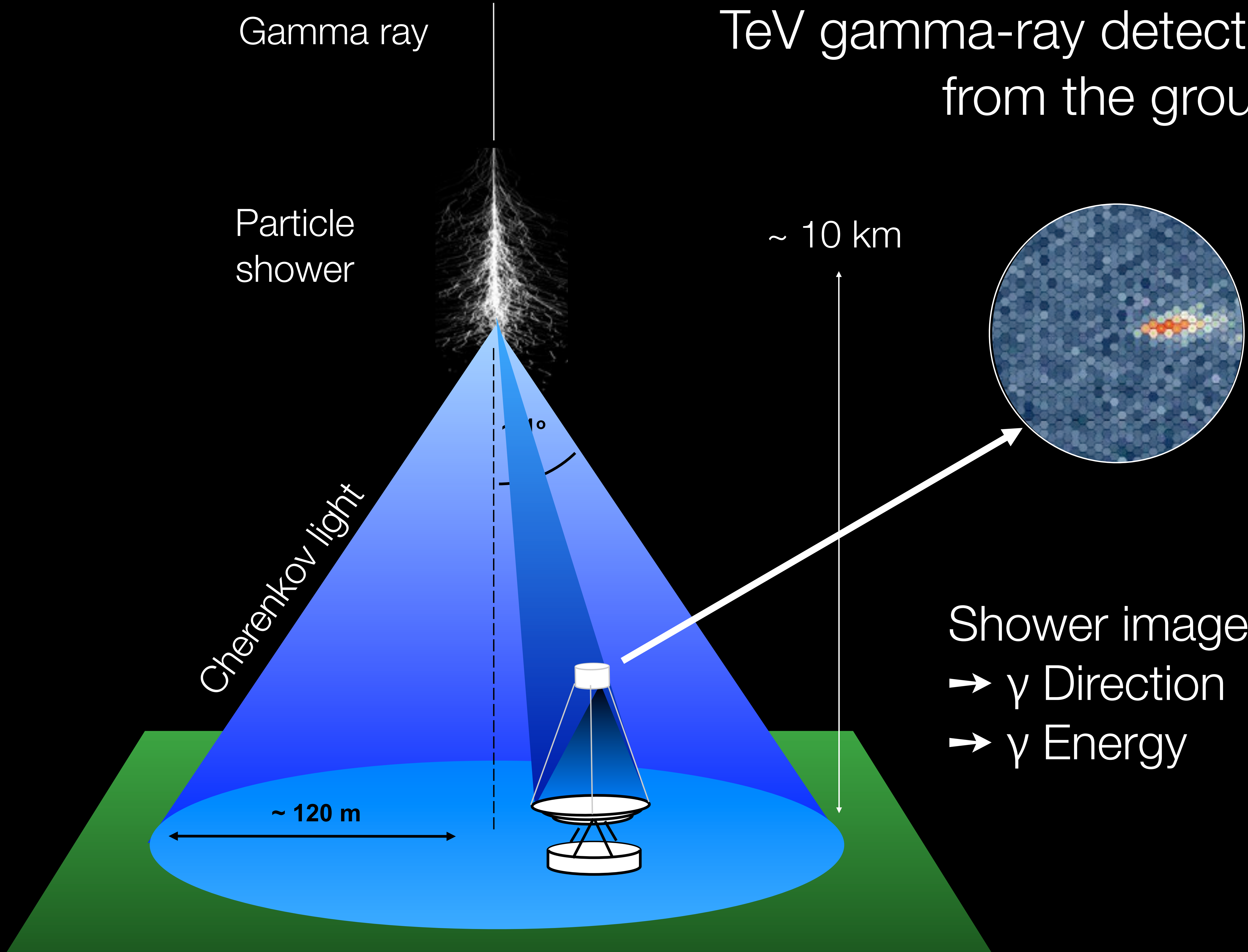


Crab Nebula (radio, optical, X-ray)

The Crab nebula is one
of the brightest TeV sources:
F(>1TeV) = 2.2 x 10^-11 cm^-2 s^-1
= 1 gamma / (10^3 m^2 h)



TeV gamma-ray detection from the ground



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

An imaging atmospheric Cherenkov telescope array

Location:	Namibia	Energy Range: 100 GeV – 100 TeV
Start:	2003	Angular Resolution: 0.1 deg
Pointed Observations		Field of View: 5 deg

Sensitivity: 1% of Crab nebula flux in ~ 25 hours

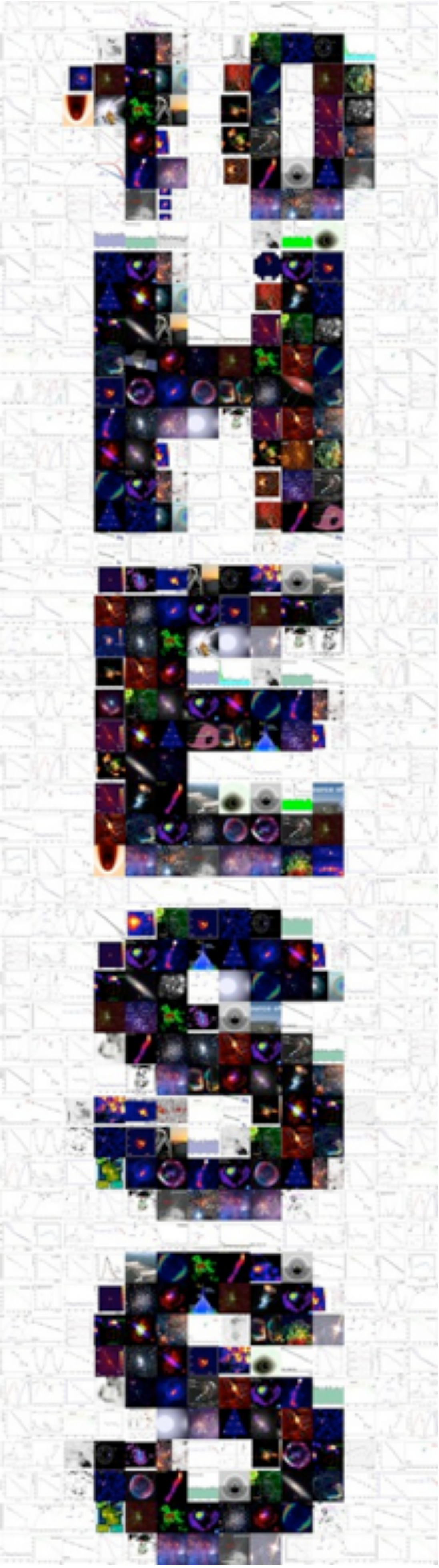
10 years of H.E.S.S. operation

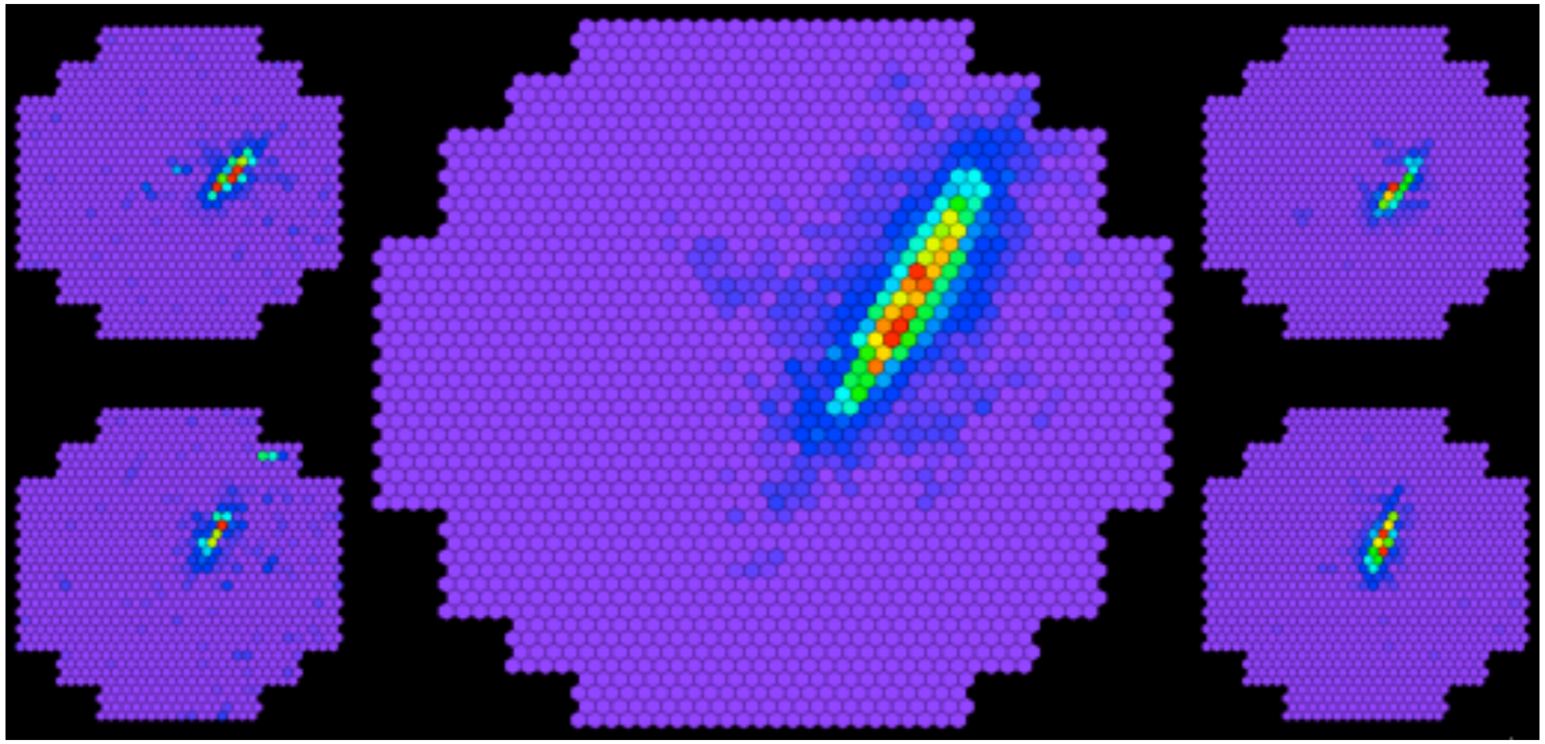
- H.E.S.S. is an international collaboration of ~ 150 physicists / astronomers from many countries (mostly Europe, plus Namibia, South Africa, Australia)

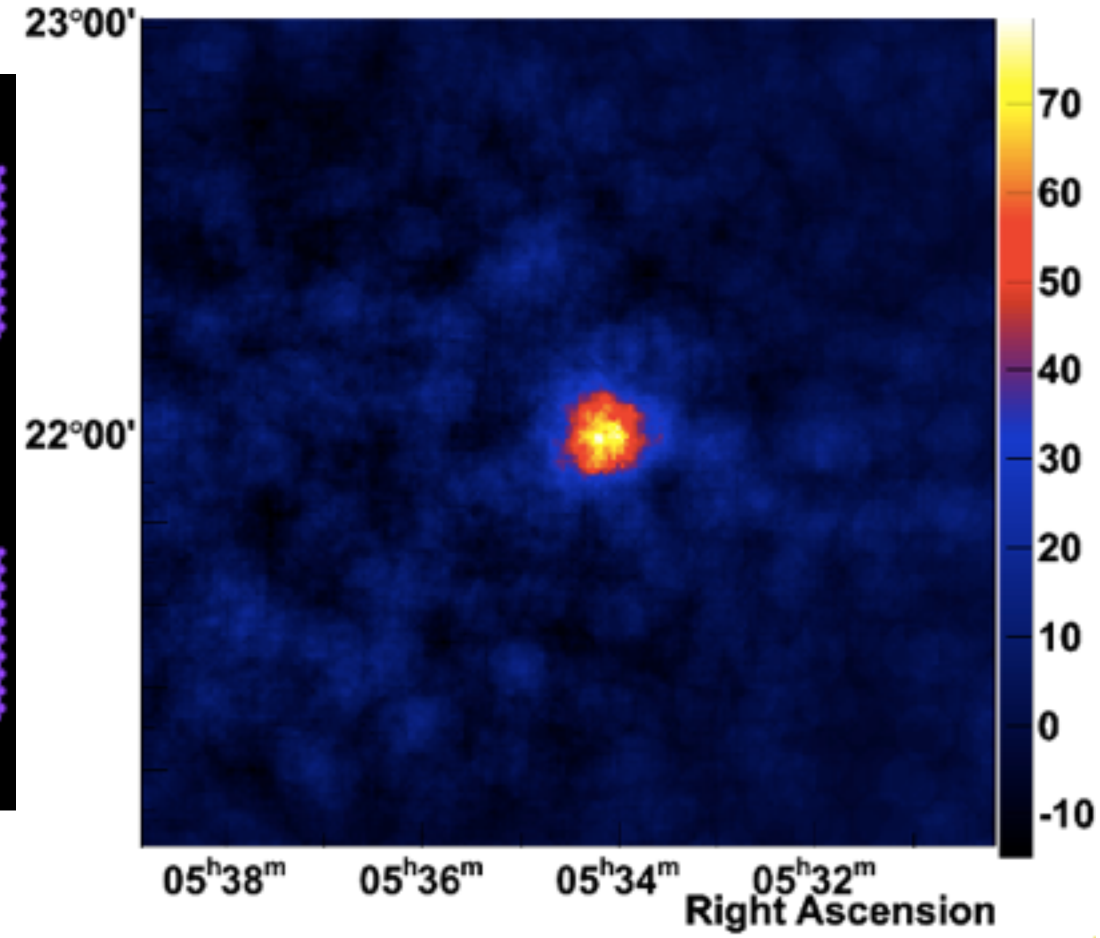
- About 10,000 hours of pointed observations taken:
~ 50% along the Galactic plane, over 60 sources
~ 50% in extragalactic space, ~ 20 sources

- Over 100 scientific papers in reviewed journals

- Listed among the 10 most influential astronomical instruments



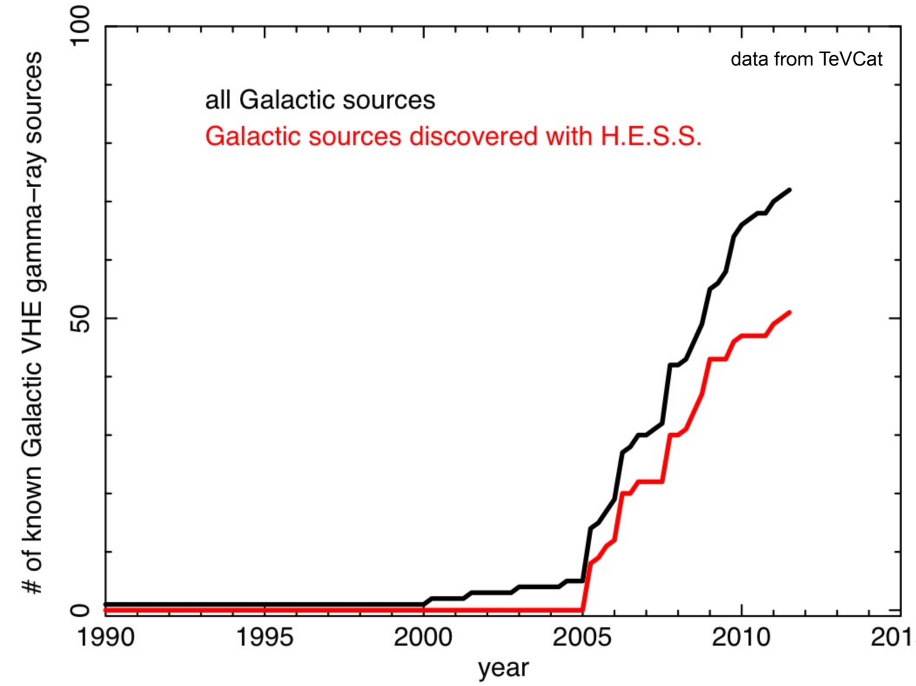


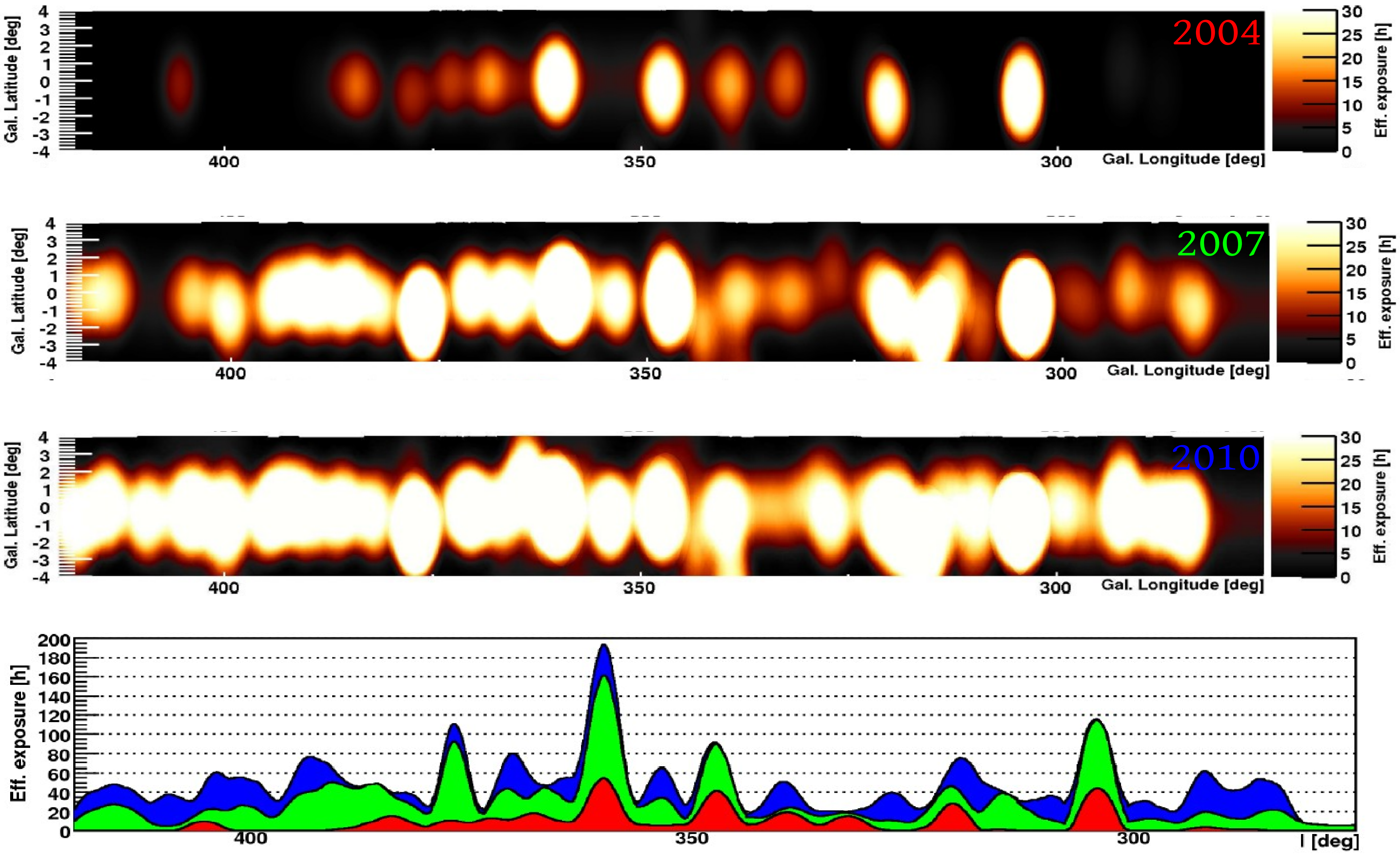


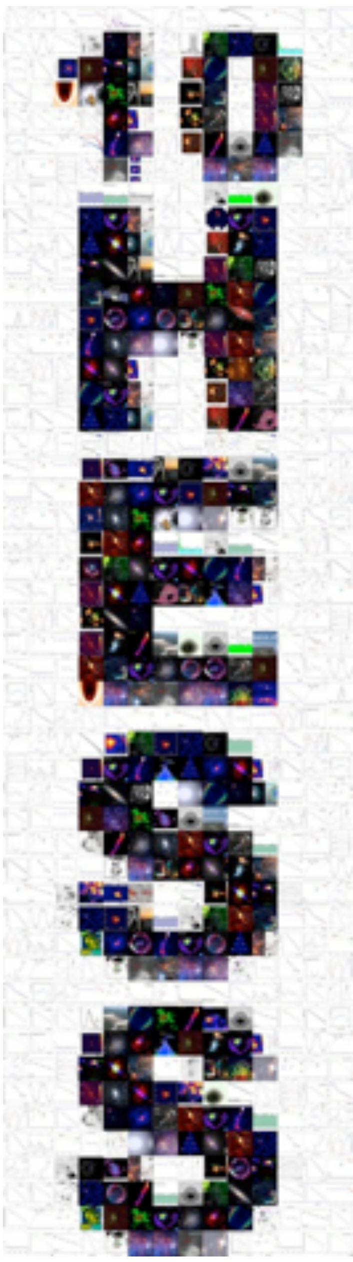
*"The Crab Nebula seen with the **H.E.S.S. II** telescope"*

http://www.mpi-hd.mpg.de/hfm/HESS/pages/home/som/2012/12/

H.E.S.S. Galactic plane survey
Exposure and Source count



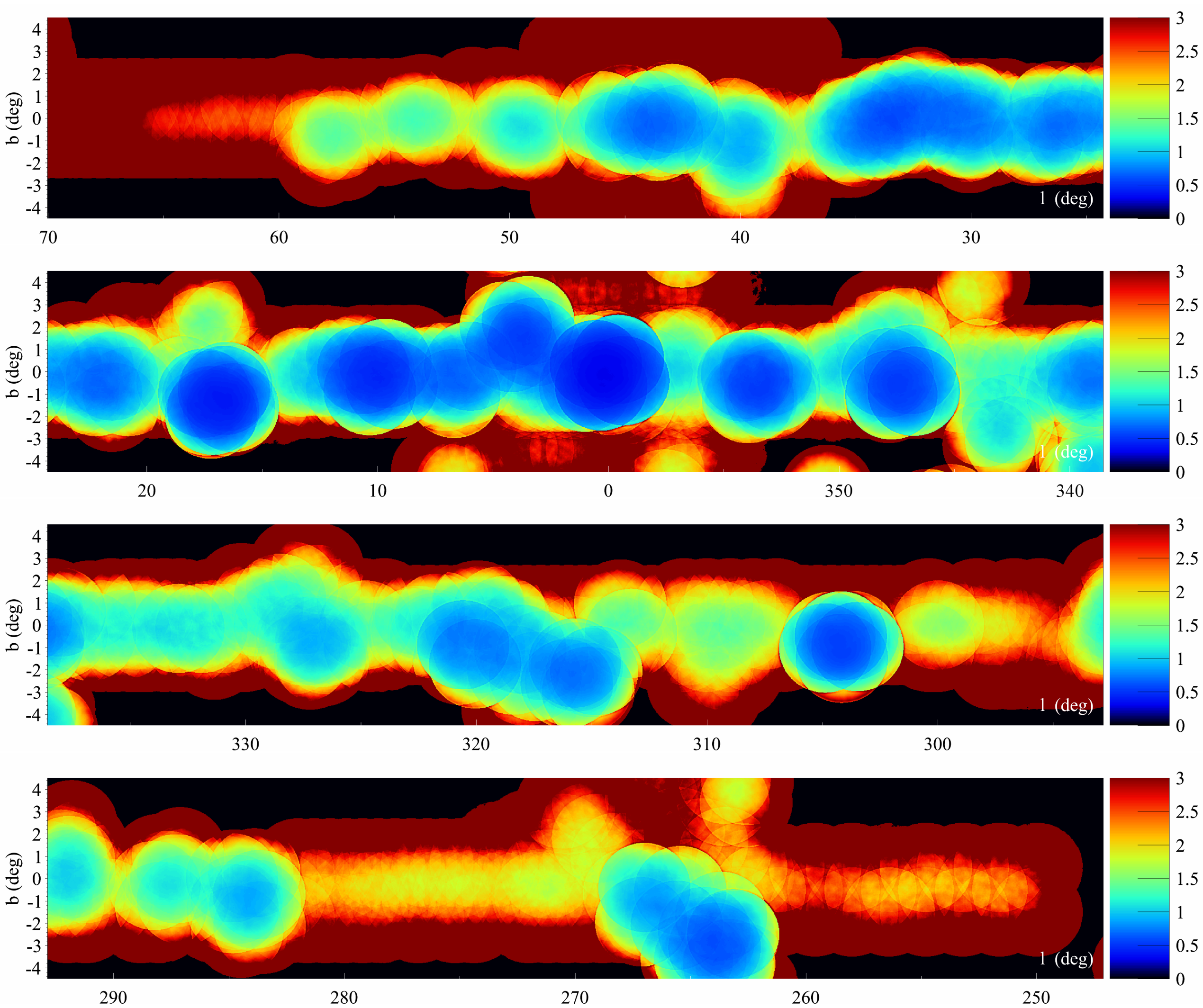


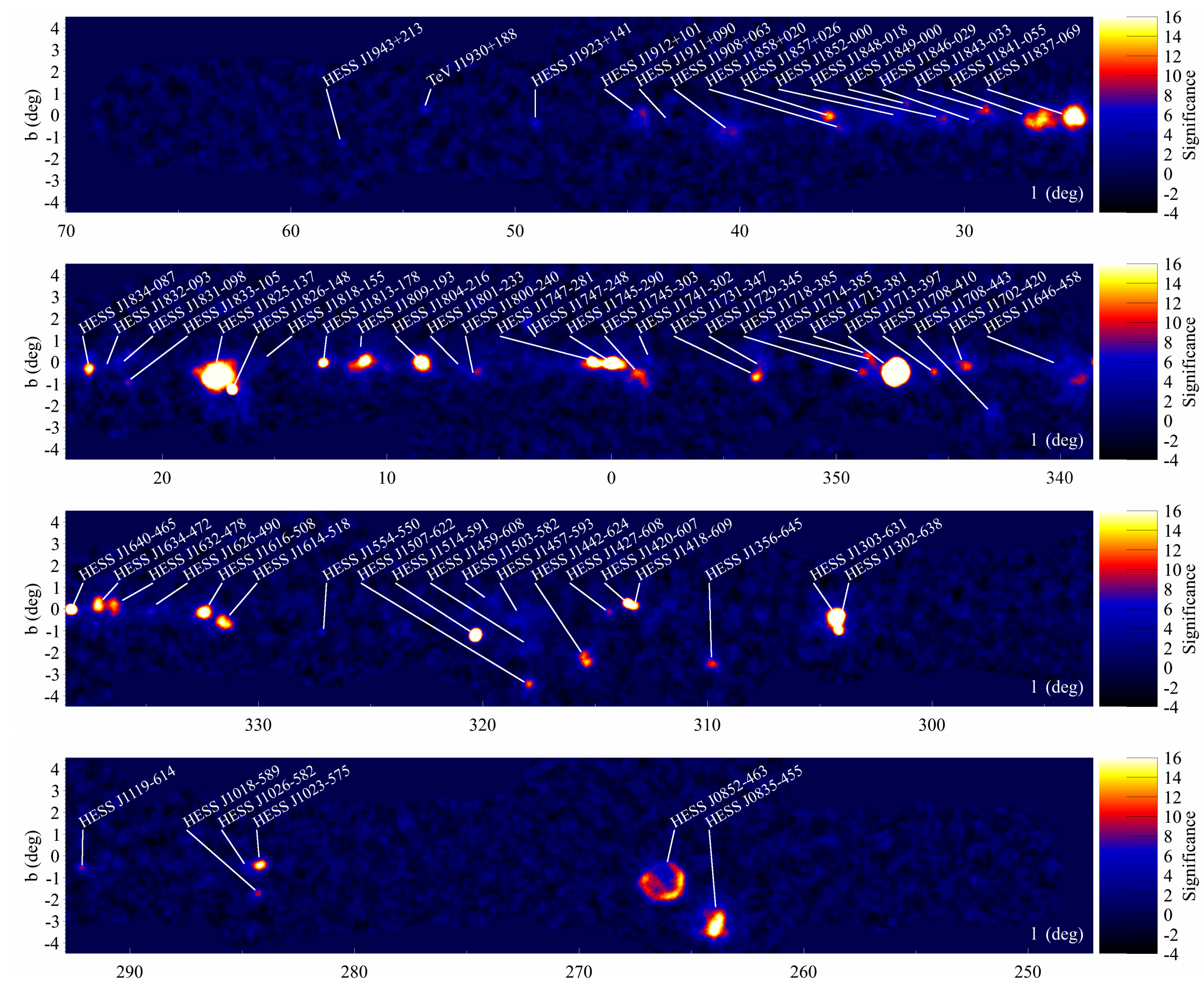


HESS Galactic plane survey 2013
Sensitivity and significance maps

Point source **sensitivity** of **0.5%** to **2%** Crab nebula flux at GLAT = 0 deg, almost **no** exposure beyond |GLAT| > 3 deg

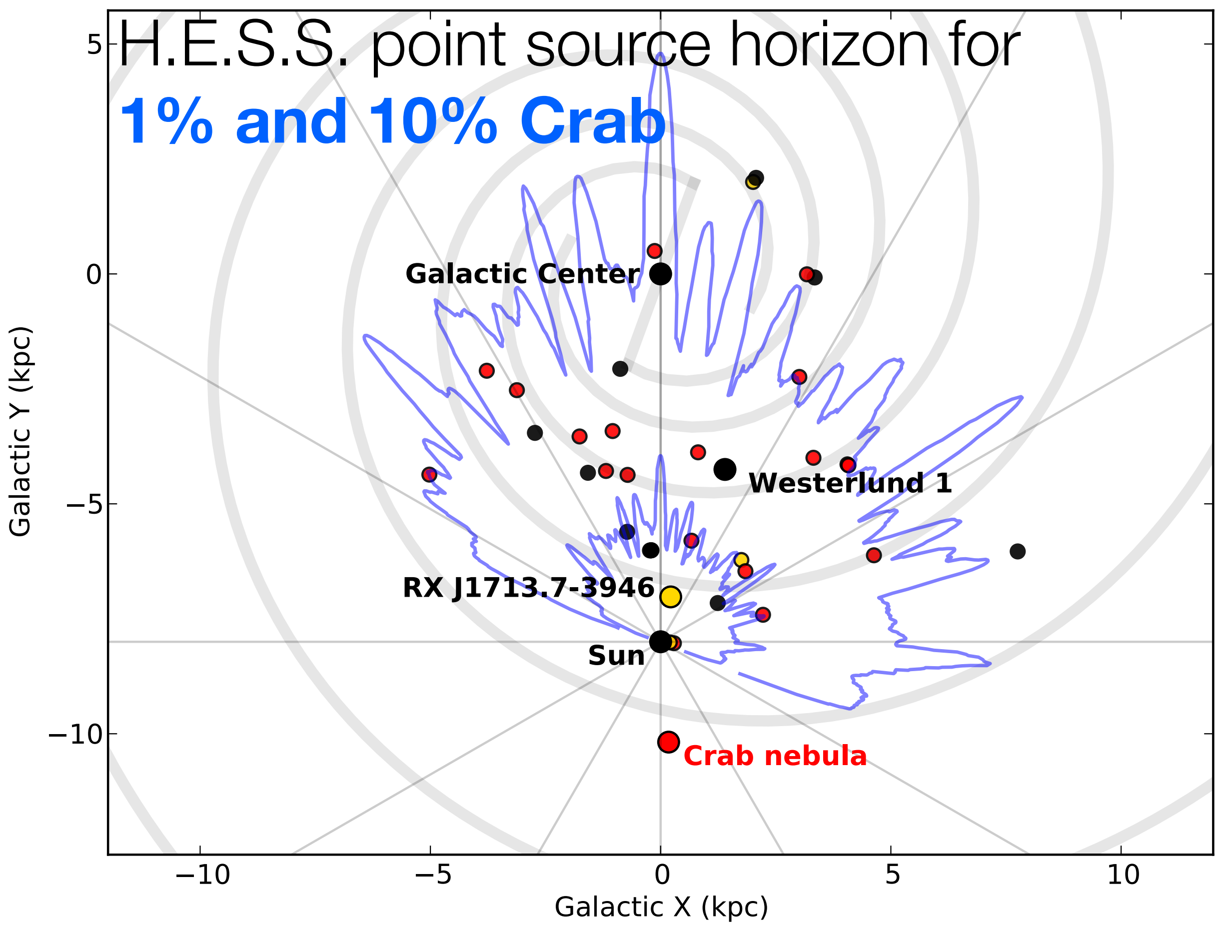
Significance map with blue-red transition at ~ 7 sigma, corresponding to ~ 5 sigma post-trial. Over 60 TeV sources discovered.

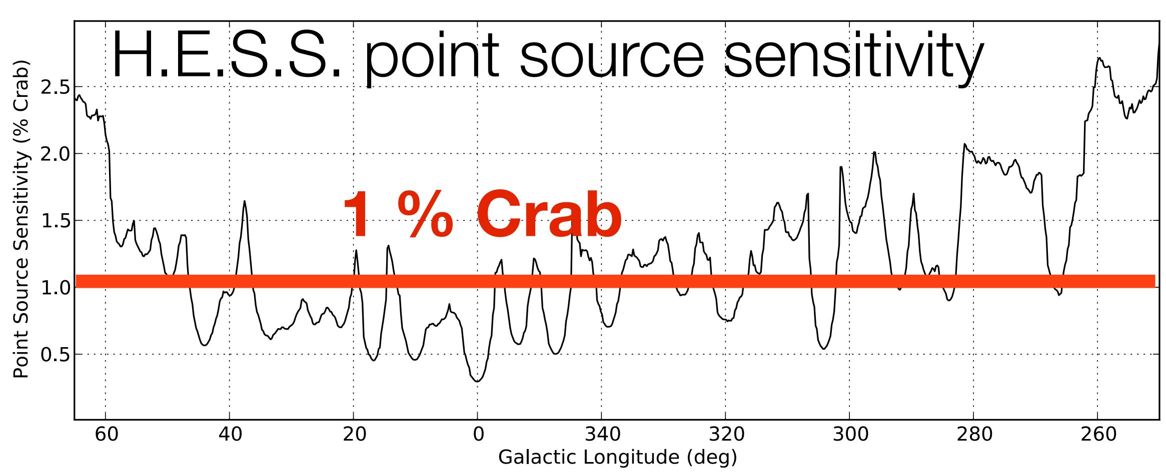




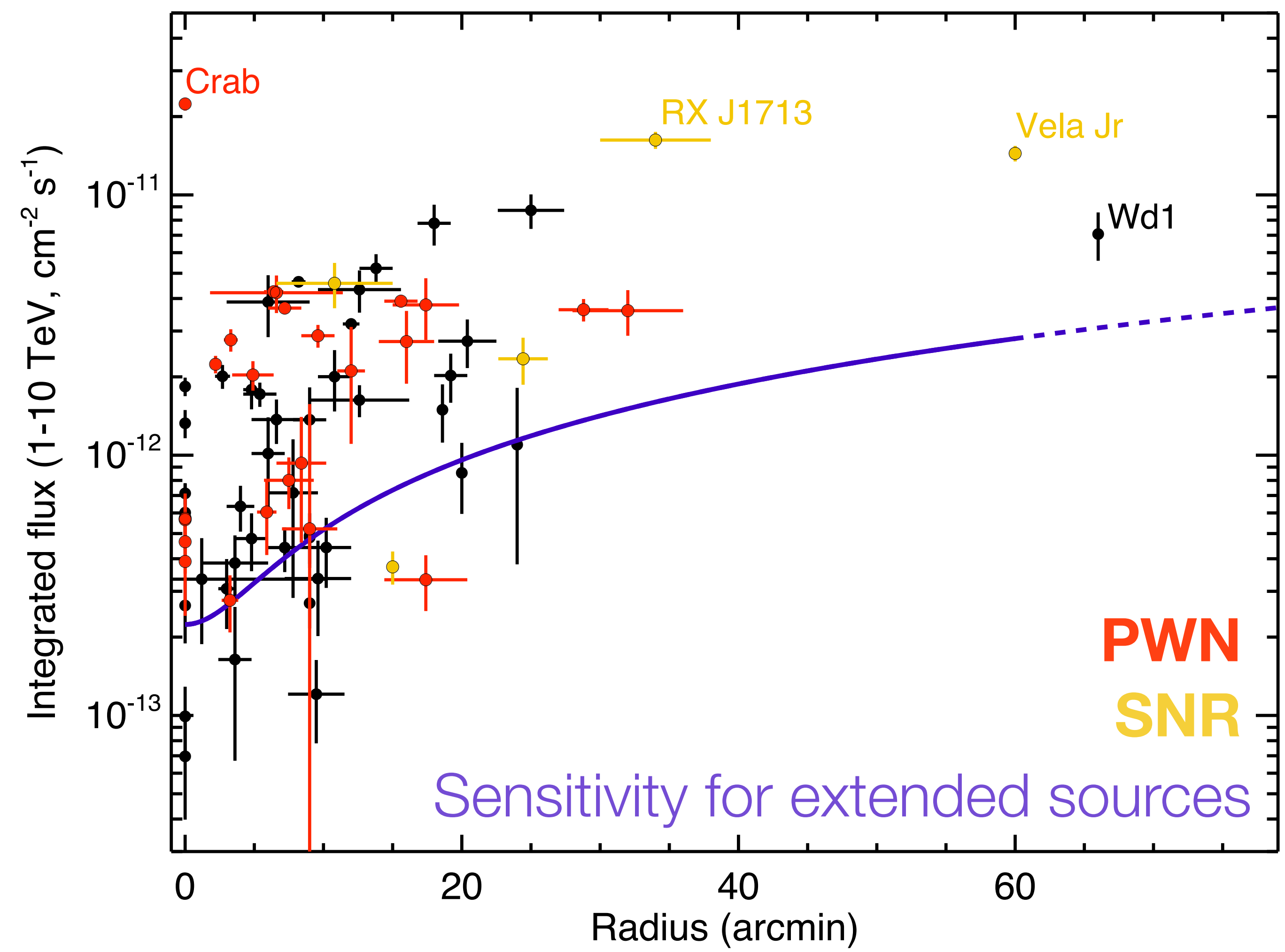
Rencontres de Moriond 2013: “Charting the TeV Milky Way: H.E.S.S. Galactic plane survey maps, catalog and source populations”

Survey sensitivity and horizon





Flux and extension for all H.E.S.S. Galactic sources in TeVCat



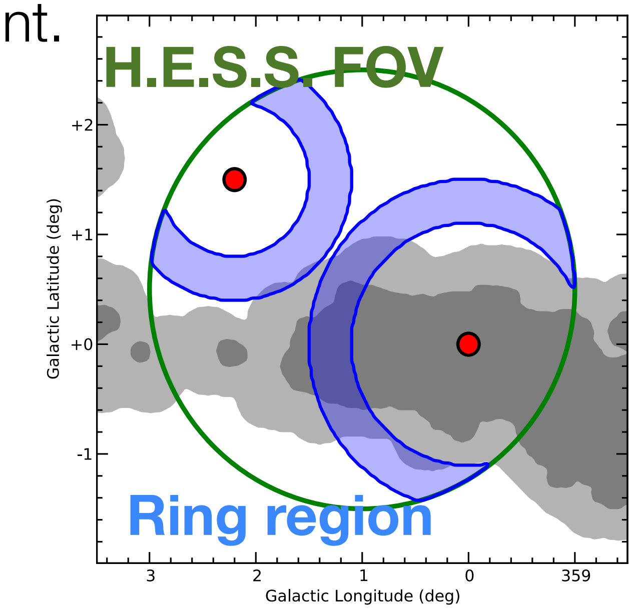
ICRG 2013

"The H.E.S.S. Galactic Plane Survey – maps, source catalog and source population"

H.E.S.S. Galactic plane survey
Source catalog – Method

Step 1: source detection and morphology analysis
Simultaneous likelihood fitting on survey maps assuming Gaussian source shape, taking the exposure, background (ring method) and point spread function into account.
Step 2: "source region" definition and spectral analysis
For technical reasons spectra have to be measured in "source regions" using a different (reflected) background estimation method.

Illustration of the ring background estimation method



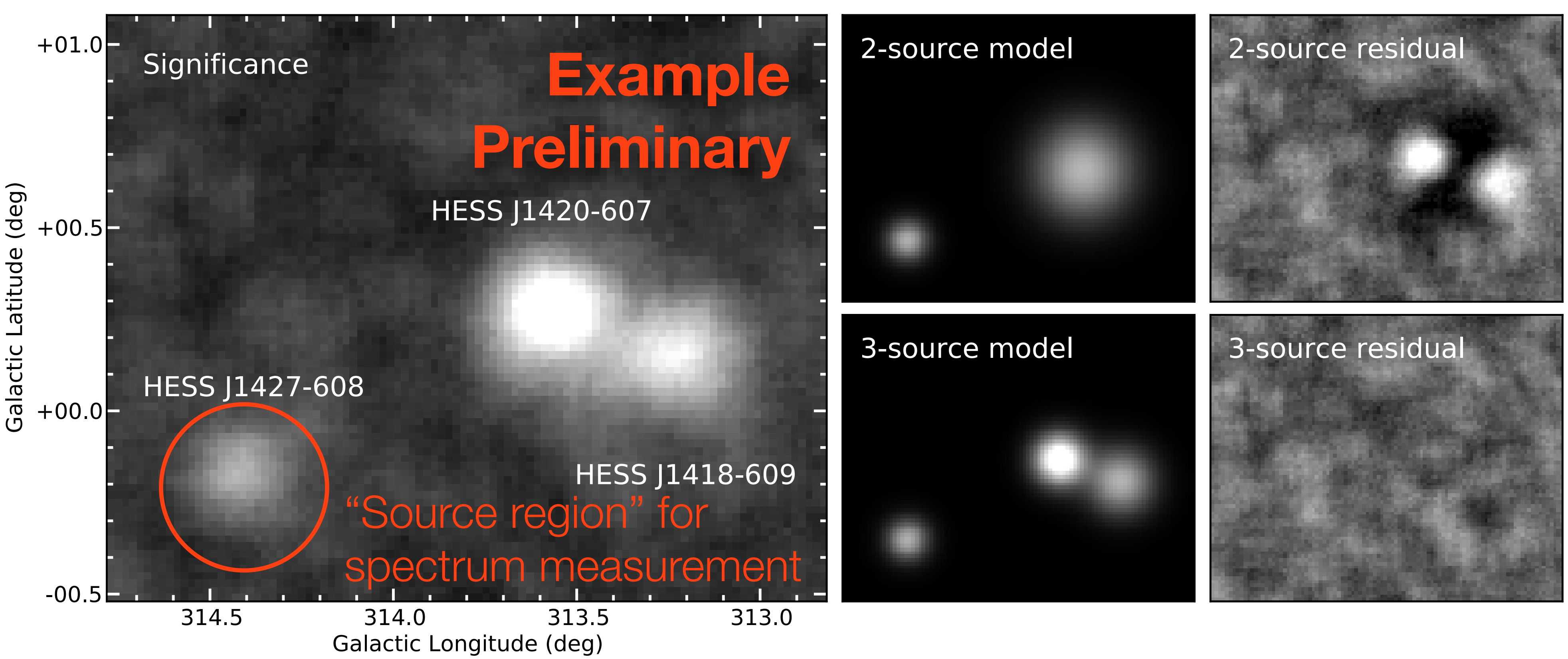
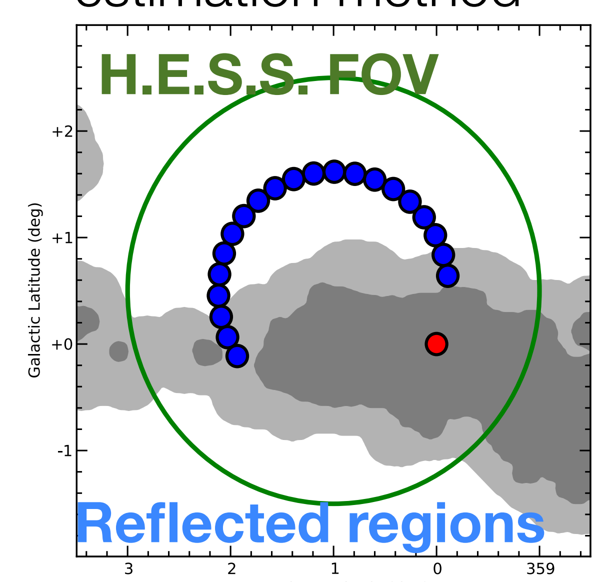


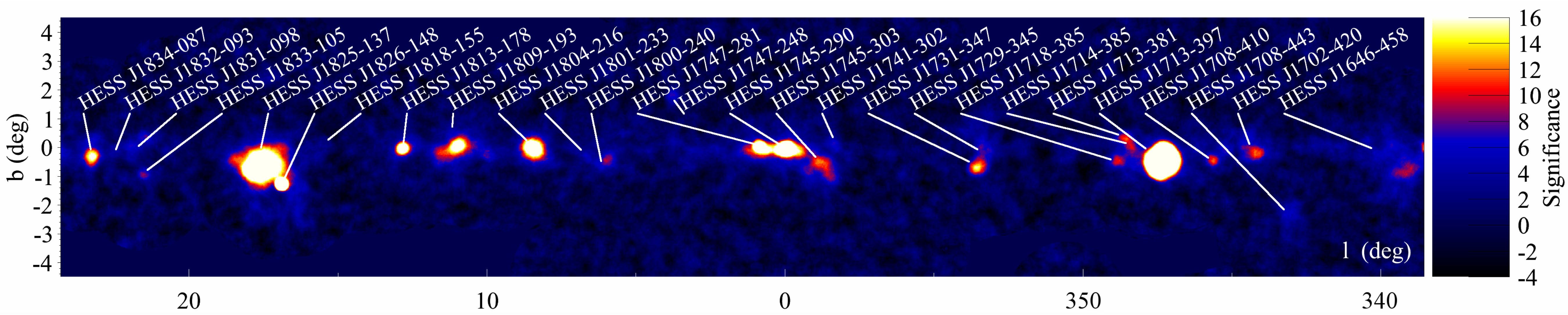
Illustration of the reflected background estimation method



Rencontres de Moriond 2013: "Charting the TeV Milky Way: H.E.S.S. Galactic plane survey maps, catalog and source populations"

H.E.S.S. Galactic plane survey
Source catalog – Challenges

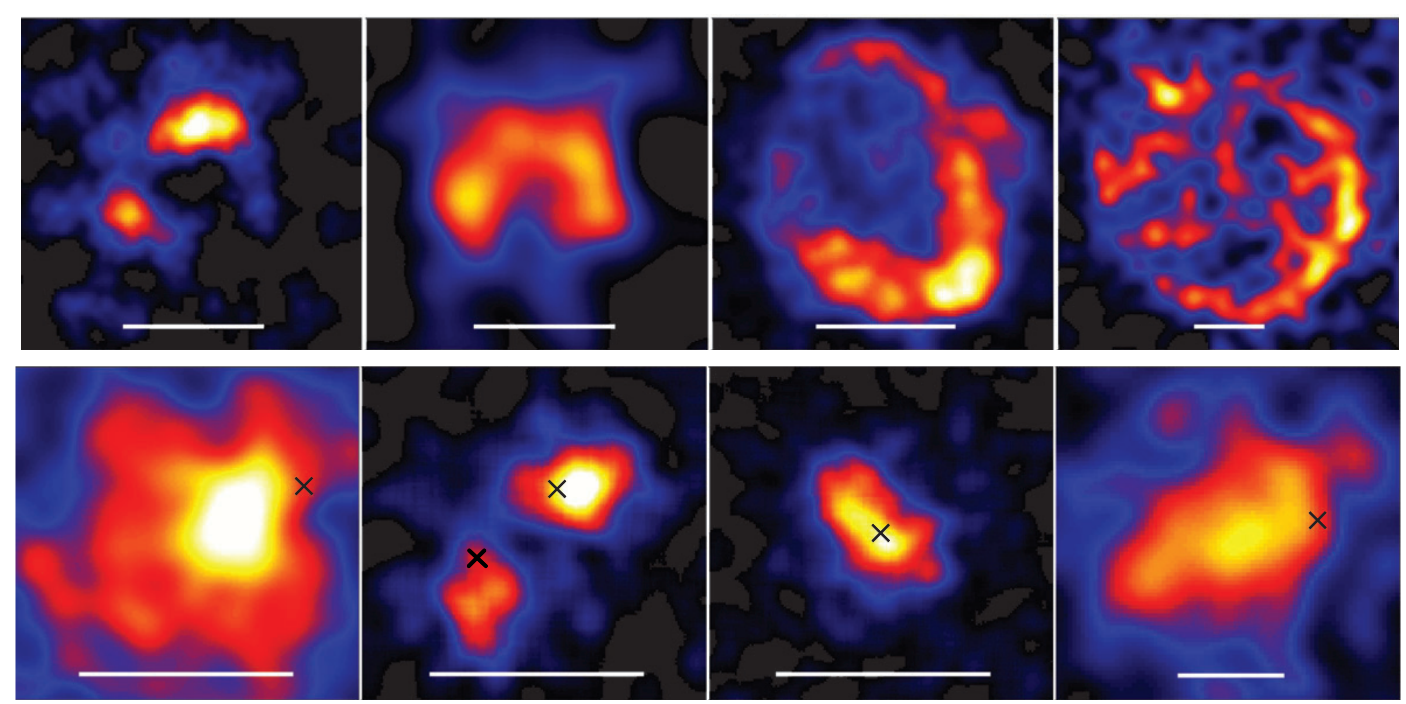
1. High source density in the inner Galaxy



2. Unknown source morphologies.

Shell-type supernova remnants

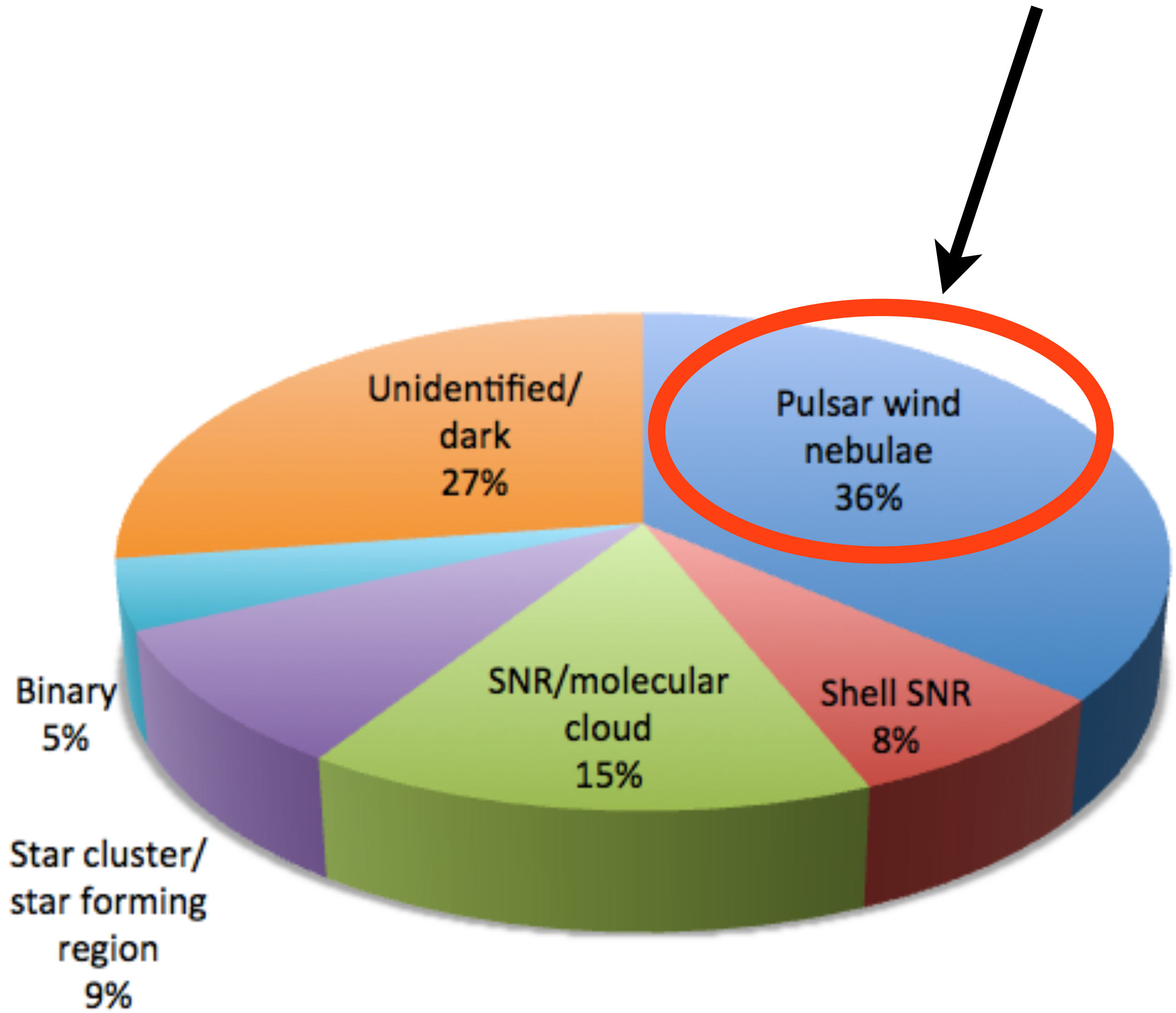
Pulsar wind nebulae



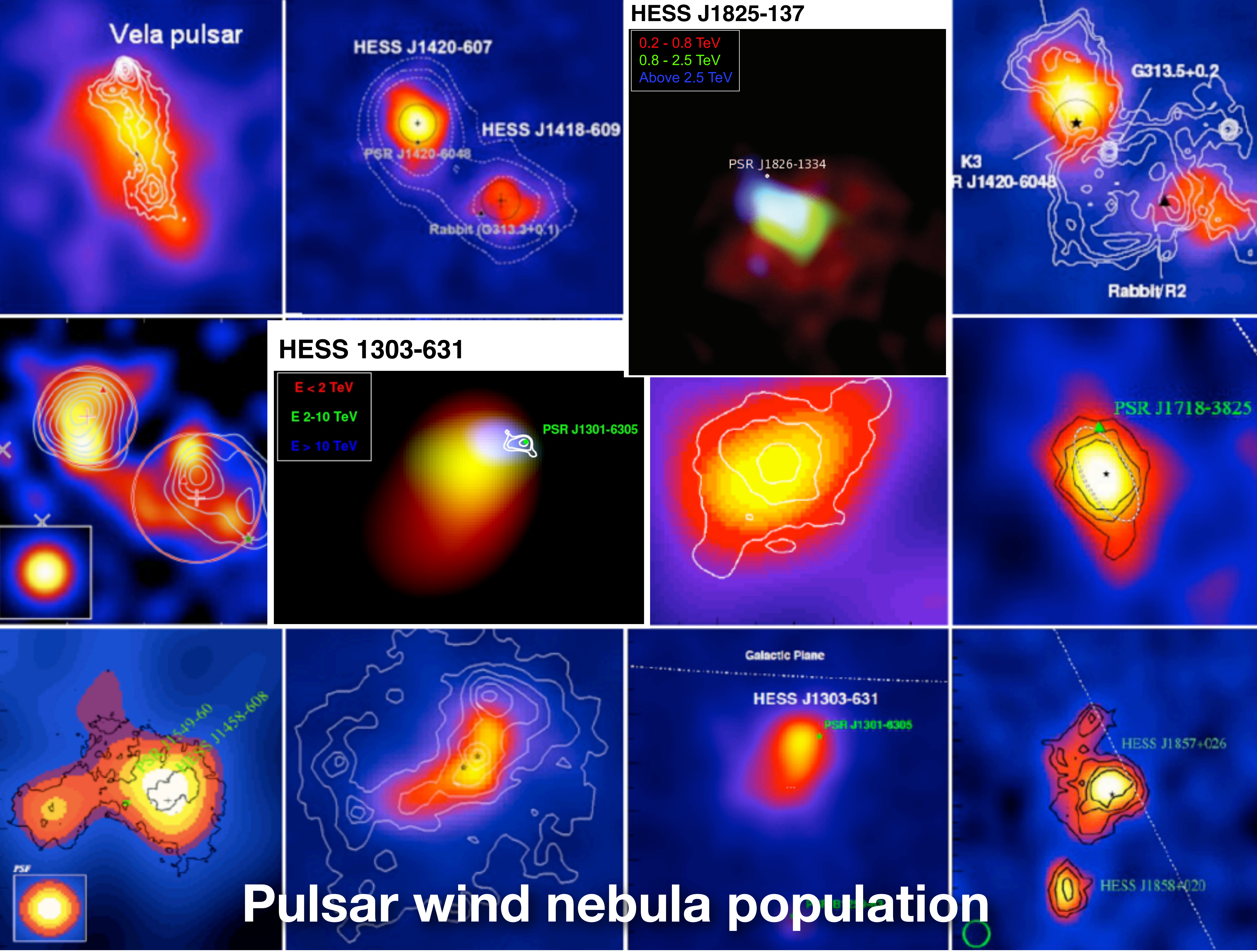
Source populations

In this talk only time to look at PWNe.
For more info see e.g. this talk:

Wed 9:00 am
Emma de Ona-Wilhelmi
"Galactic TeV overview"

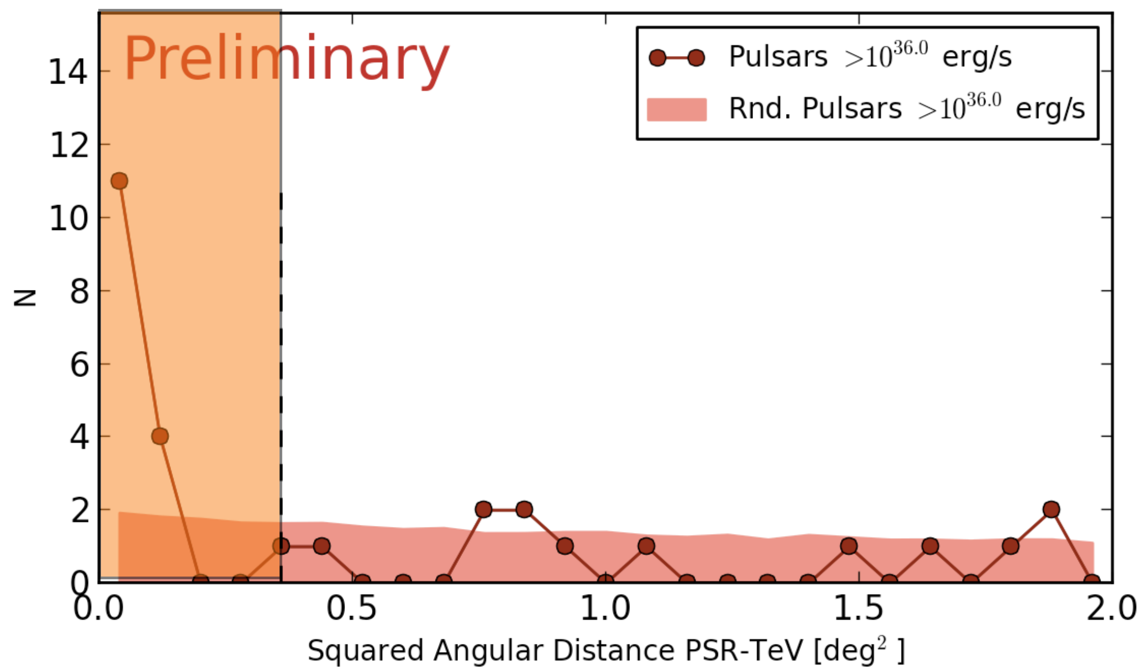


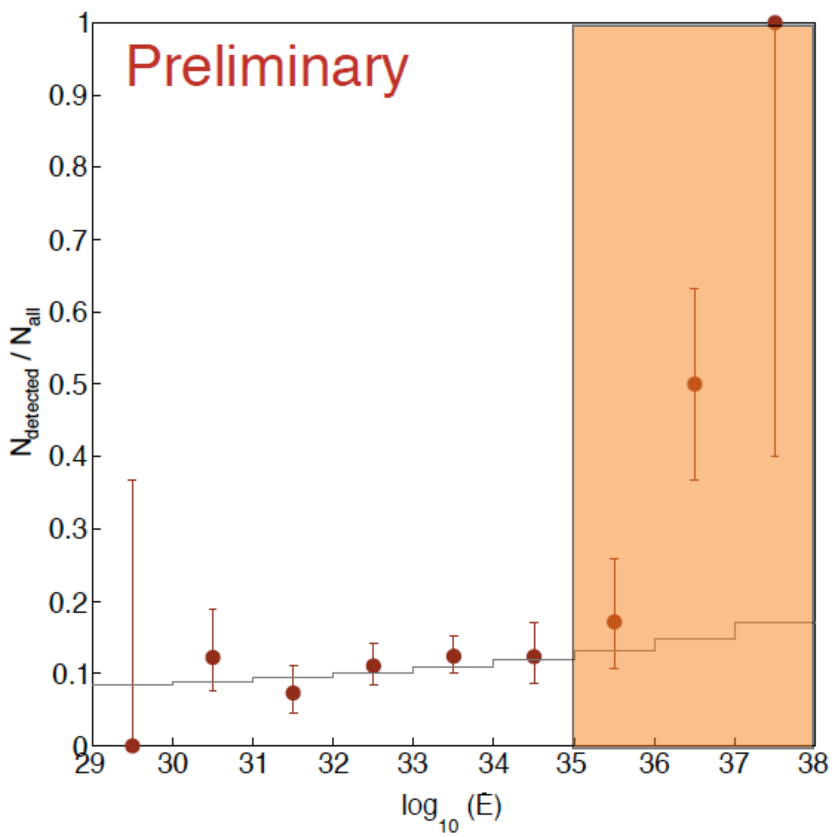
http://www.mpi-hd.mpg.de/hfm/HESS/pages/home/som/2012/09/



Pulsar wind nebula population

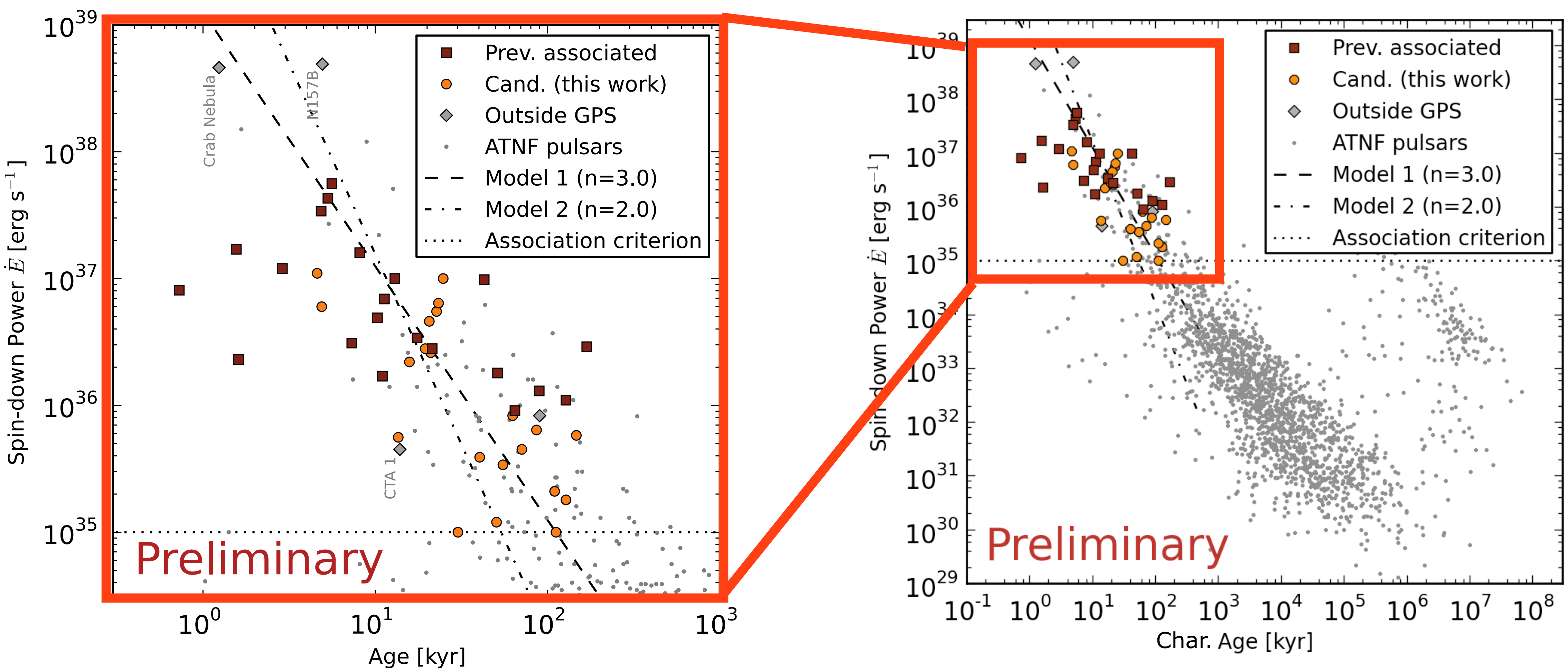
Correlation of HGPS TeV sources and pulsars





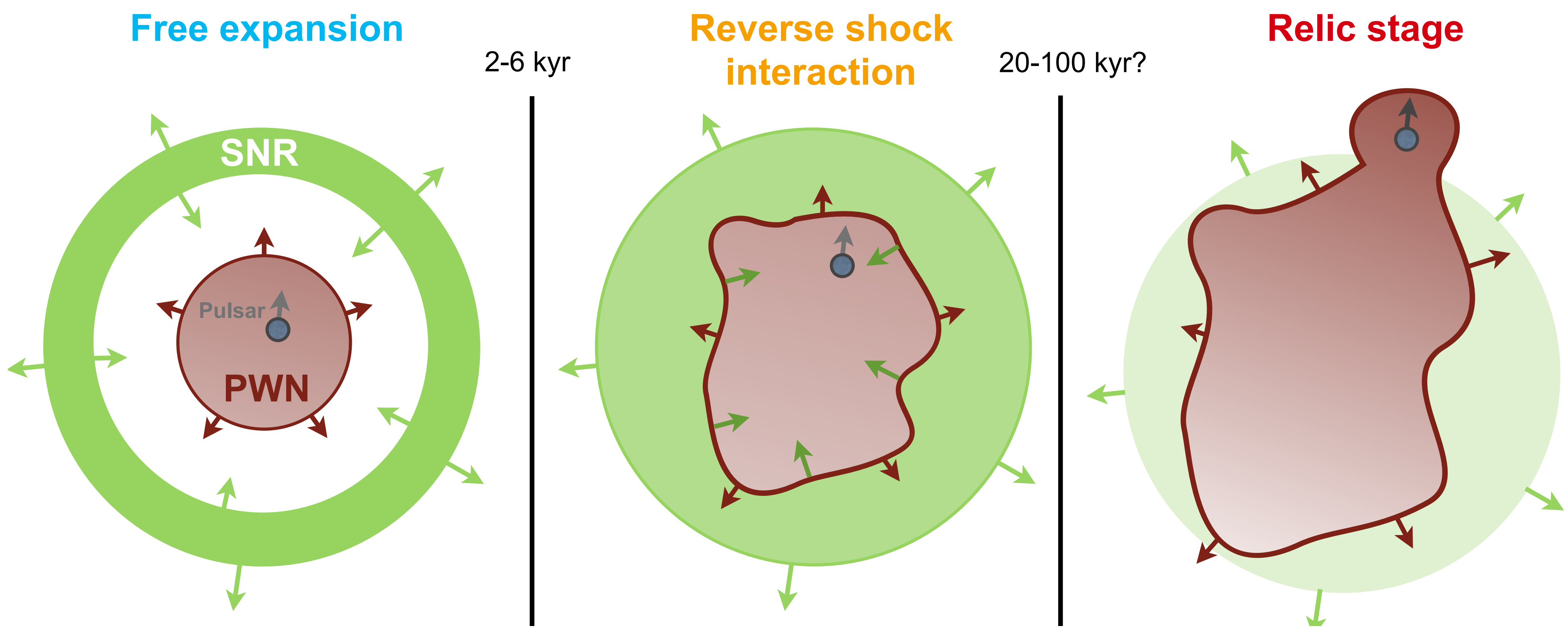
- High-Edot pulsars tend to have TeV signals within ≲ 0.5°
- No correlation beyond chance coincidences below 10^{35} erg/s
- Very simple (low-bias) preselection of **candiates**

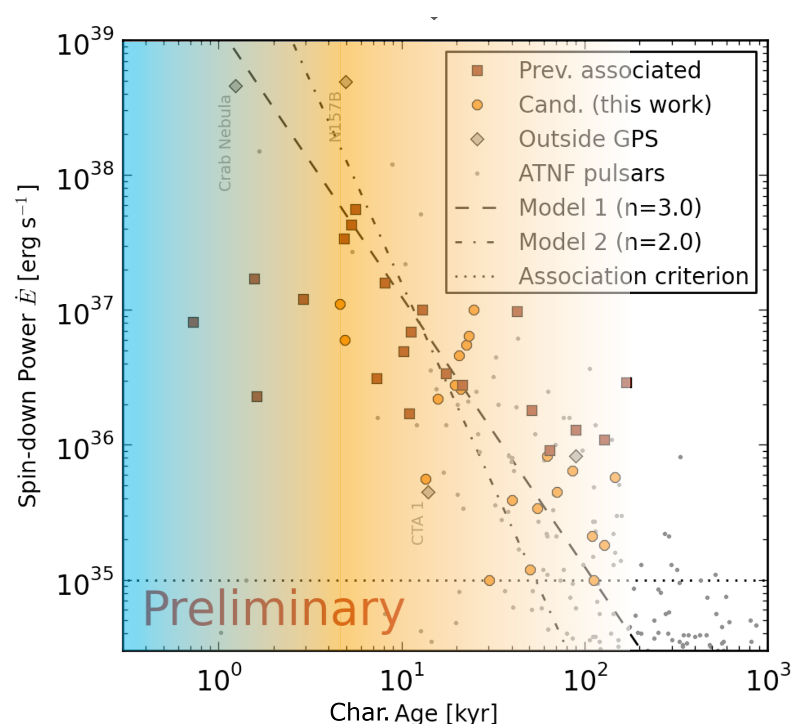
Preselection result



ICRG 2013 *"A Population of Teraelectronvolt Pulsar Wind Nebulae in the H.E.S.S. Galactic Plane Survey"*

PWN evolution theory in a nutshell





- Most TeV PWNe are probably in the reverse shock interaction phase.
- This makes a population study difficult, because PWN nebula evolution will depend on environment (gas, magnetic field, supernova remnant evolution, ...)

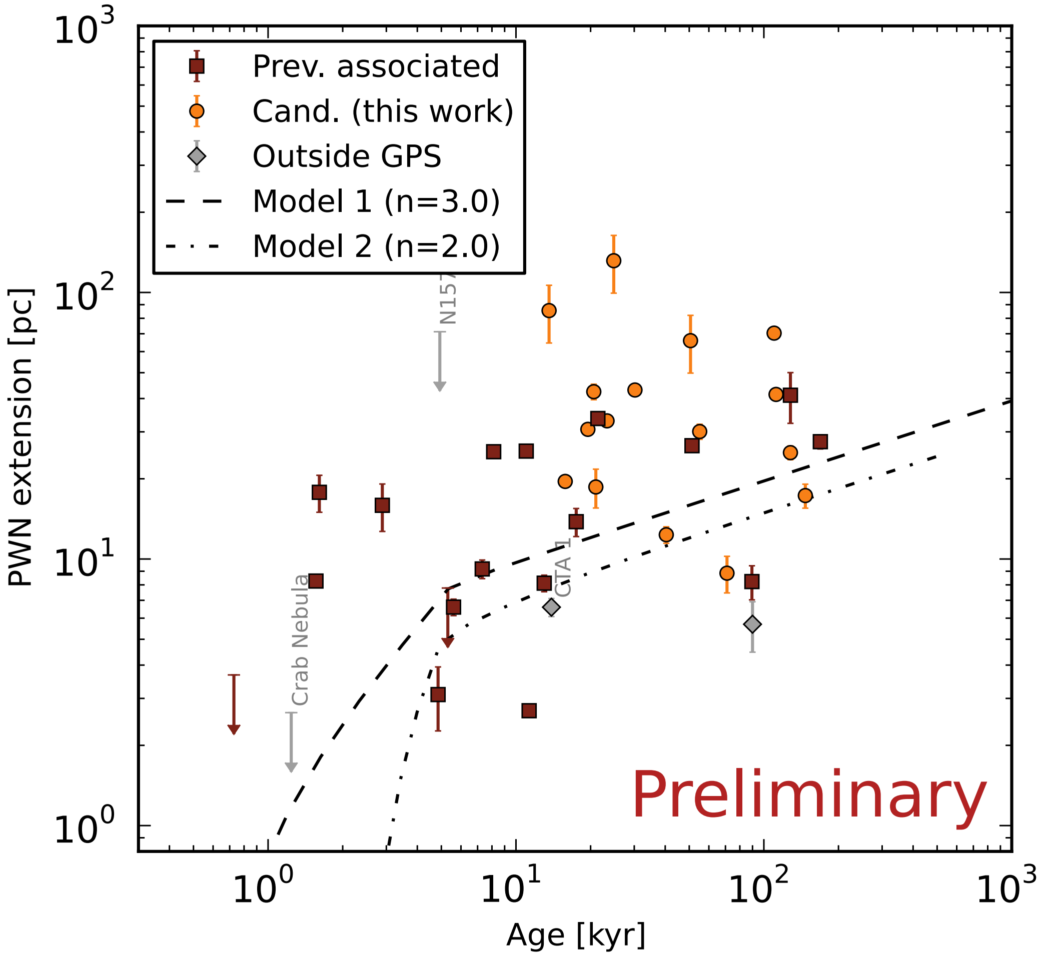
HGPS PWN source population evolution

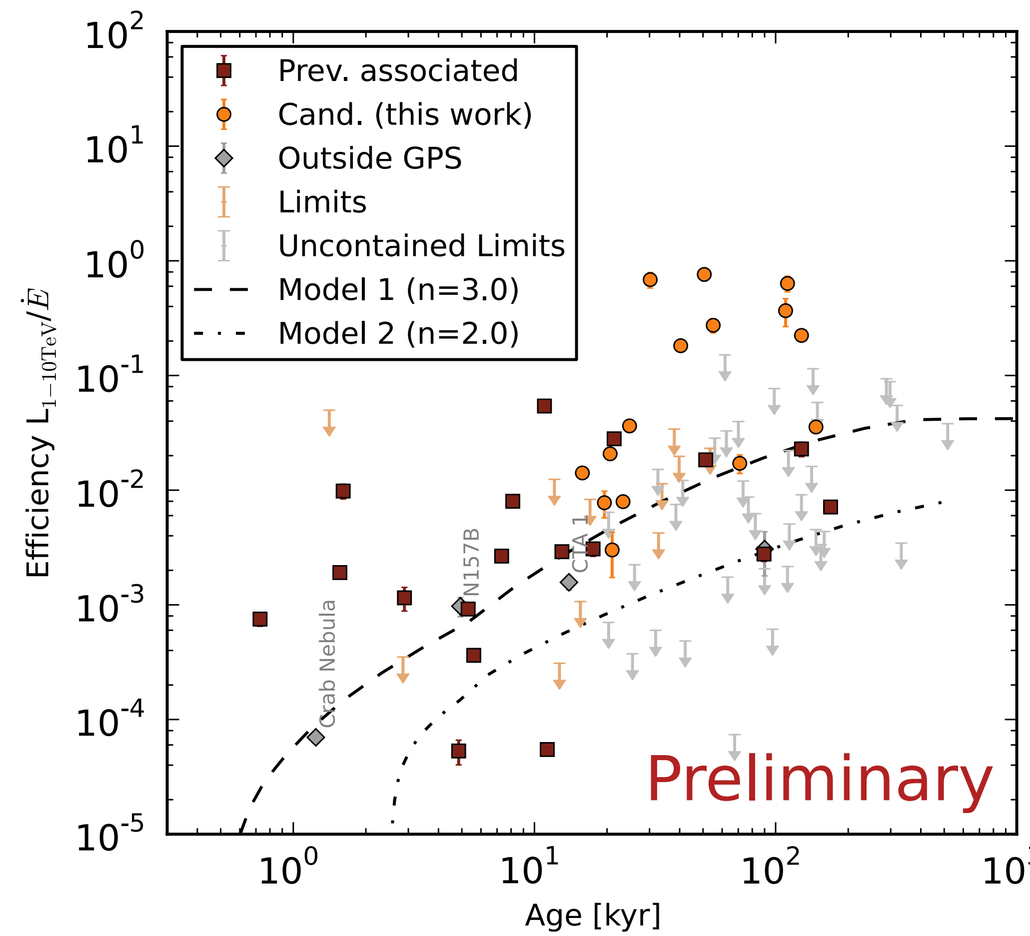
TeV nebula extension evolution

- Strong variations, probably from surrounding medium or SNR interaction
- Roughly follows trend of $R_{PWN} \sim t^{0.3}$
- Some candidates are clearly larger than the general trend

TeV nebula efficiency evolution

- This efficiency compares *current* TeV emission from *accumulated* electron population to *current* Edot
- Modeling based on Mayer et al. 2012 (arXiv: 1202.1455), now including the free expansion phase.



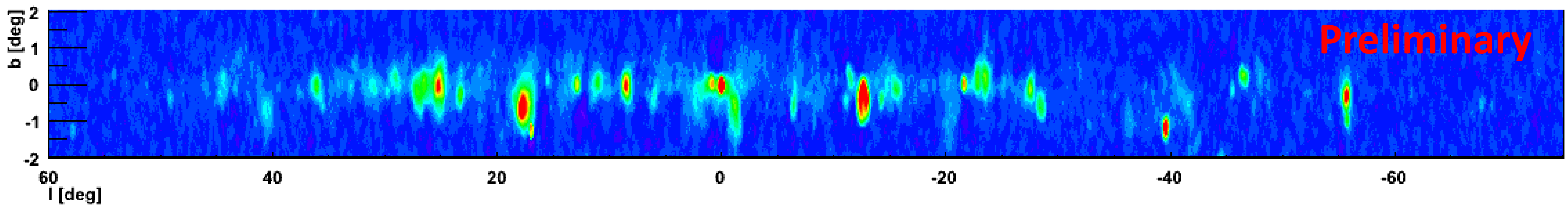


ICRC 2013

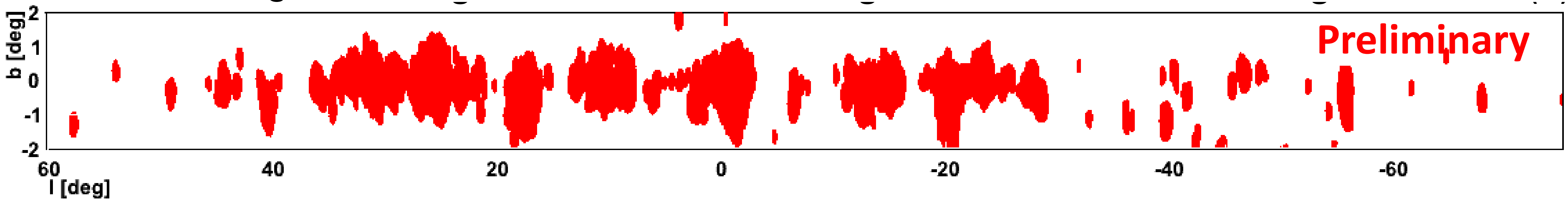
"A Population of Teraelectronvolt Pulsar Wind Nebulae in the H.E.S.S. Galactic Plane Survey"

Diffuse emission – analysis region

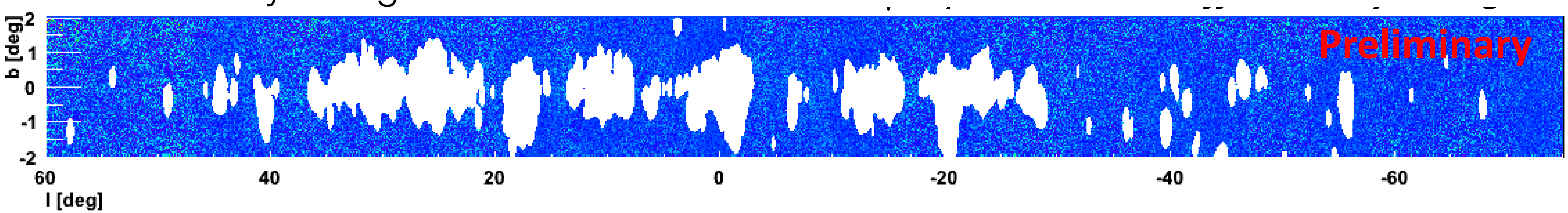
Significance map



Excluded regions mask in red.



Diffuse analysis region in blue.

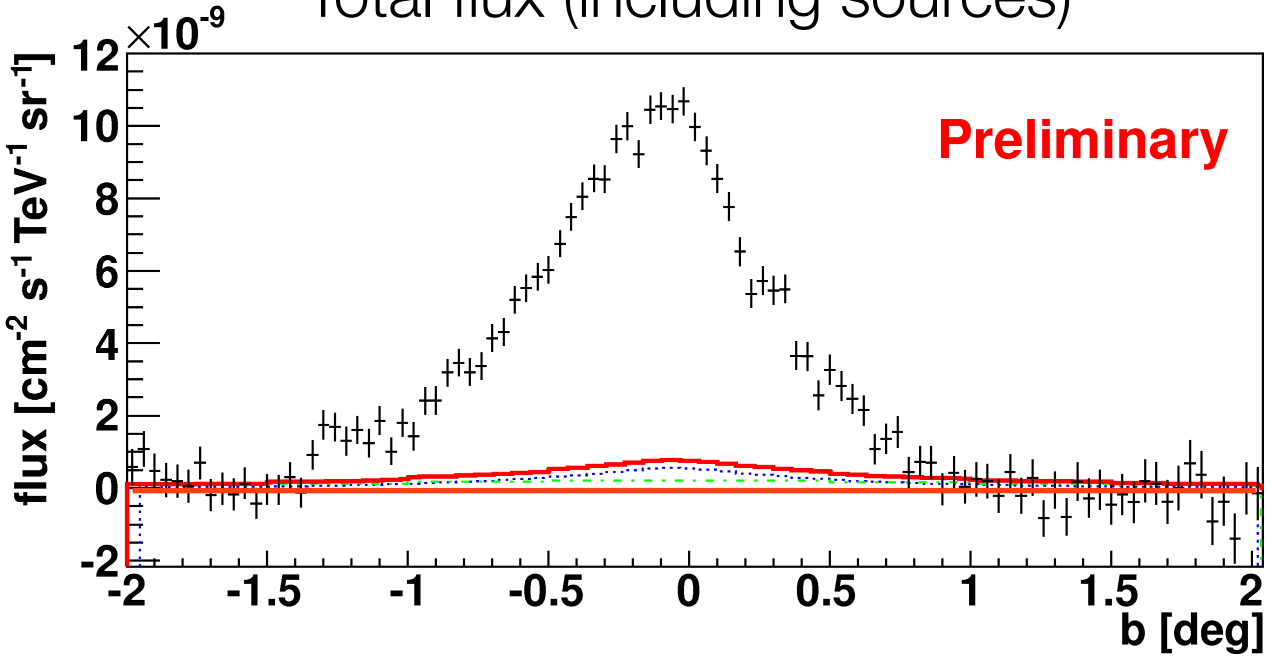


Method used to define exclusion mask:
threshold significance map and dilate excluded regions.

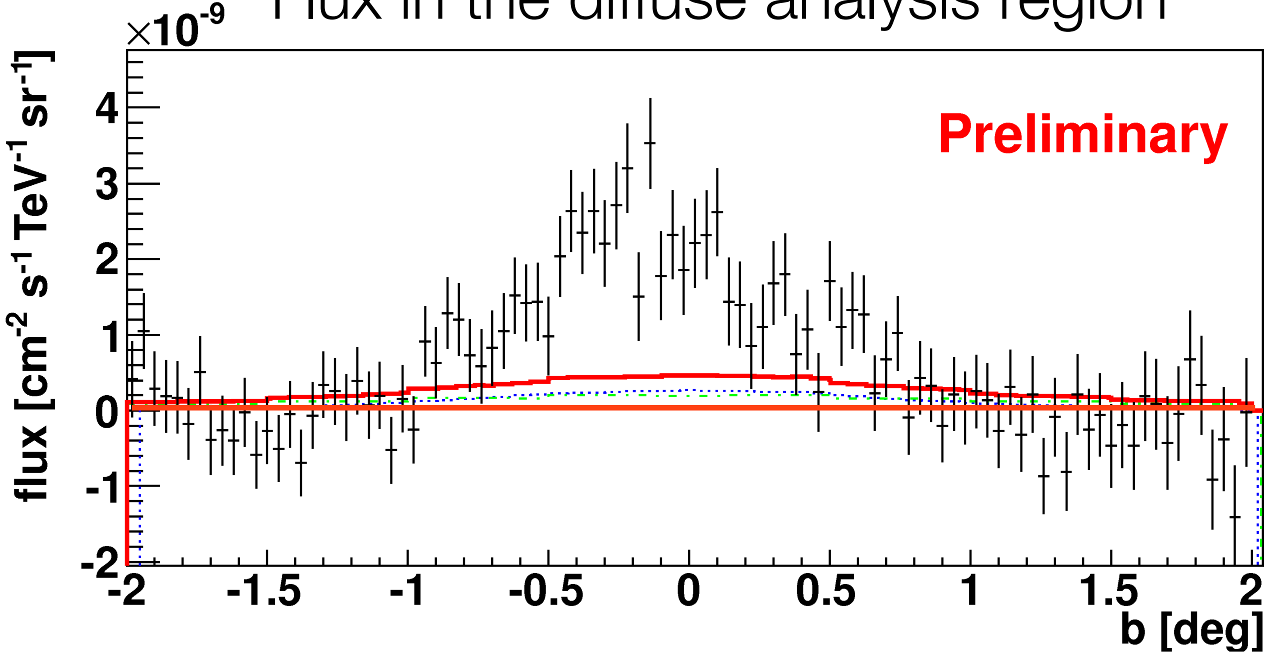
Galactic latitude flux profiles

- Average differential flux @ 1 TeV
  - GLON = -75 deg ... +60 deg
  - GLAT = -2 deg ... +2 deg
- HESS measurement in black. Hadronic emission model in red.
- Statistically significant TeV flux excess in the diffuse analysis region.
- Maximum at GLAT = -0.25 deg at flux of 3 x 10^{-9} TeV^{-1} cm^{-2} s^{-1} sr^{-1}.
- Caveat: background subtraction method would partially subtract large scale-height components

Total flux (including sources)



Flux in the diffuse analysis region

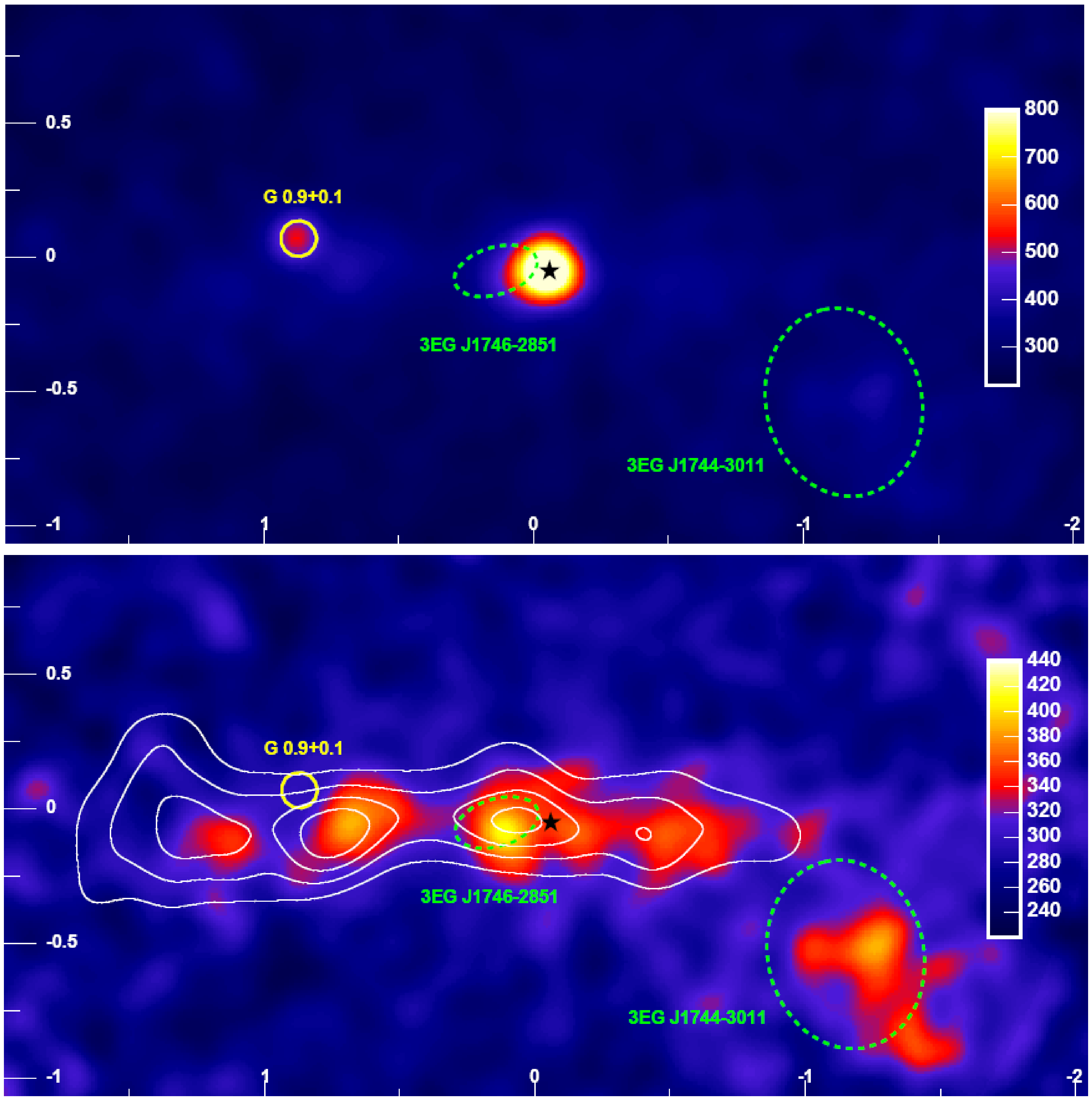


ICRC 2013 *"Diffuse TeV Gamma-Ray Emission in the H.E.S.S. Galactic Plane Survey"*

Origin of the TeV flux excess in the diffuse analysis region?

- "Guaranteed" minimal hadronic contribution (cosmic ray sea hadrons interacting with gas in the Milky way disk) ~ 25% of measured flux in the diffuse analysis region.
- Inverse Compton leptonic emission (cosmic ray sea electrons interacting with interstellar radiation fields)
- Source emission from unresolved sources or "tail emission" from known very extended sources.
- Disentangling different components contributing to the excess in the "diffuse analysis region" (i.e. away from significant sources) is very hard, because sources and diffuse emission (and exposure and thus background) all have a similar spatial shape.

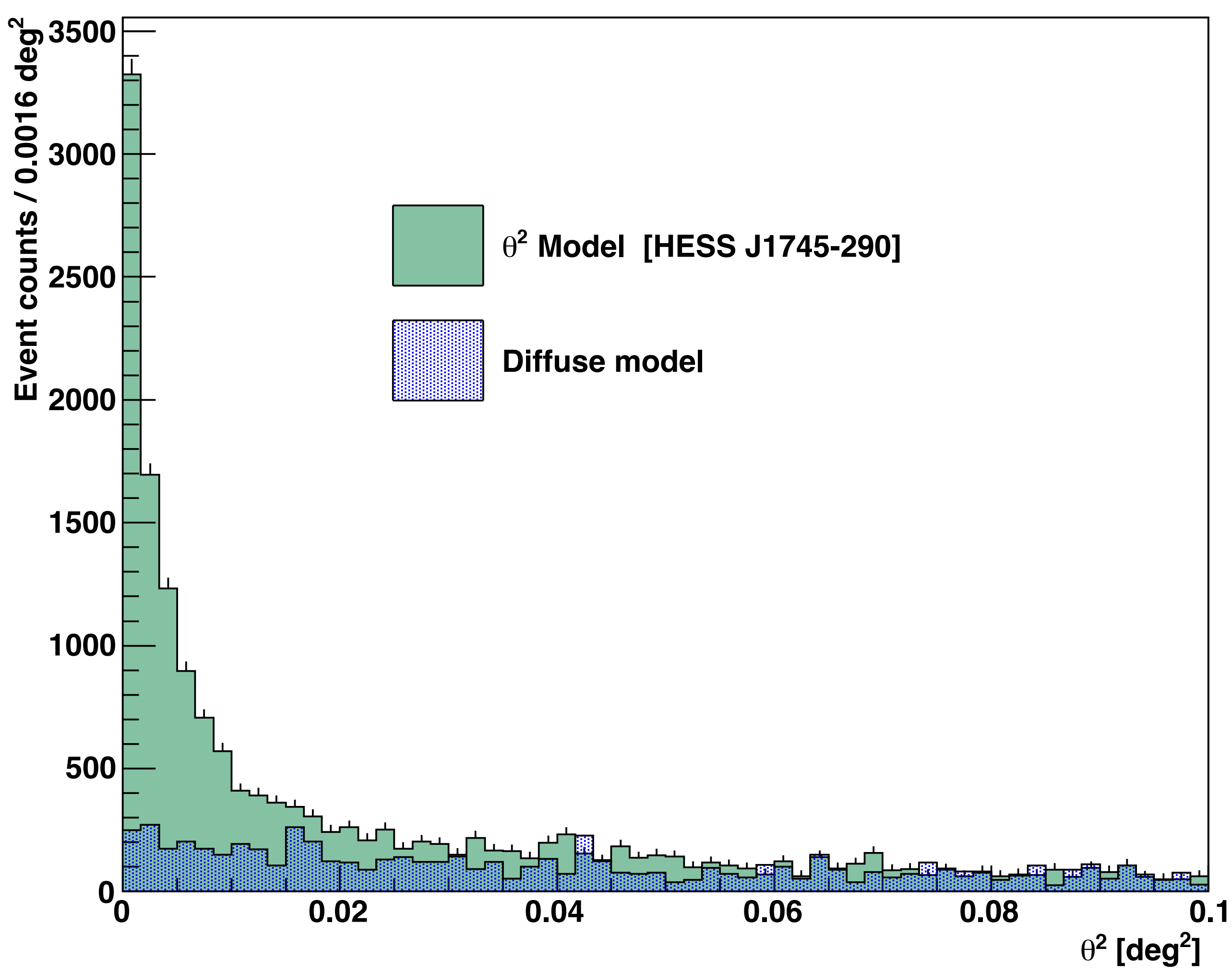
Sources and diffuse emission in the Galactic center region

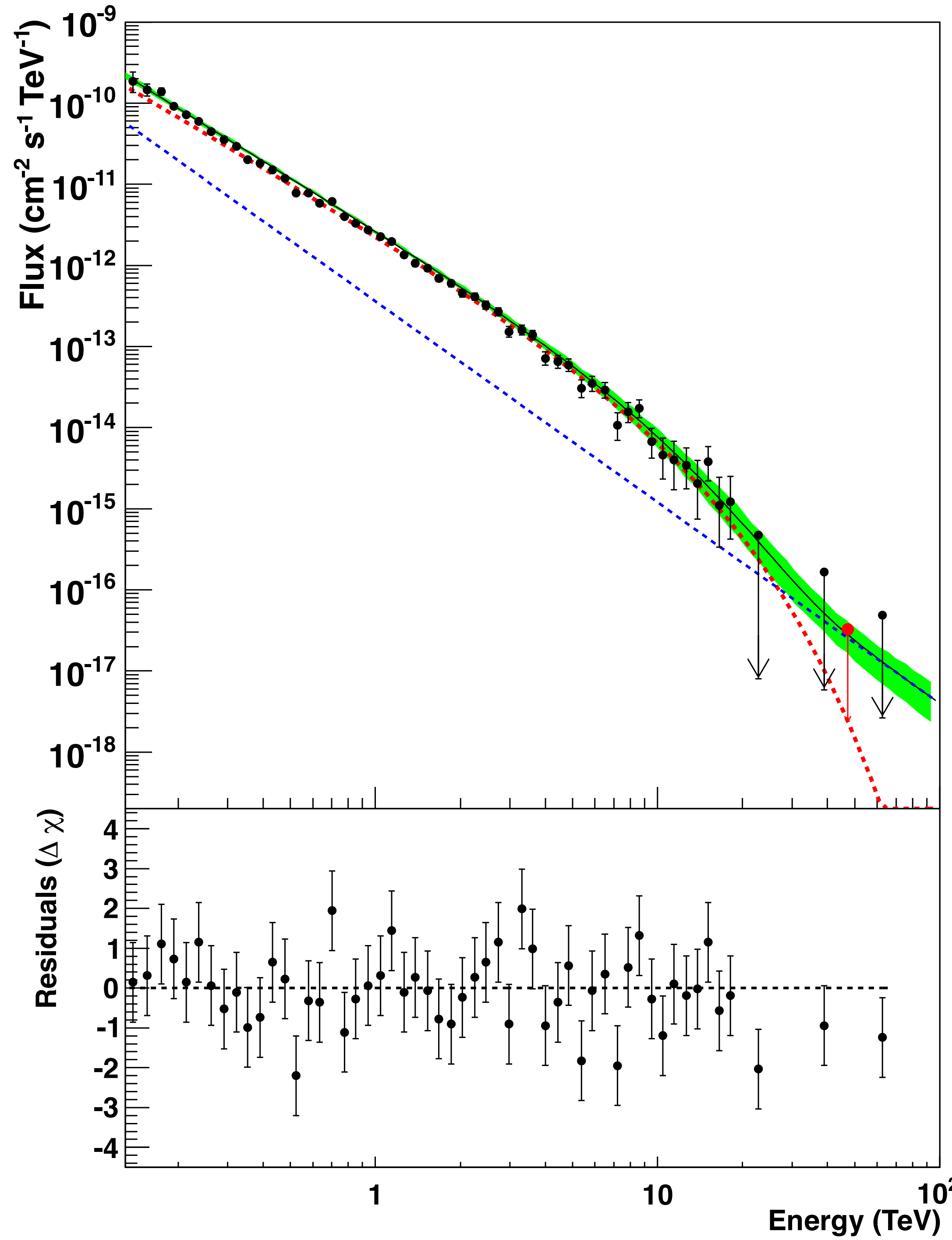


H.E.S.S. (2006)

Galactic center source

(19 +- 5)% diffuse contribution





ICRC 2013 *"Spectral analysis of the Galactic Center emission at very-high-energy gamma- rays with H.E.S.S"*

Summary & Outlook

- H.E.S.S. has over the past decade performed the first sensitive TeV Galactic plane survey.
- A release of sky-maps and a source catalog in FITS format are in preparation.
- H.E.S.S. has detected TeV emission from a large variety of Galactic sources.
- Pulsar wind nebulae seem to be the largest Galactic TeV source class.
- Upcoming H.E.S.S. studies on
  - Galactic diffuse emission
  - Galactic center region
  - TeV PWN and SNR population
  - individual new sources

  ... see ICRC 2013 contributions: arxiv.org/html/1308.1548v2
- Other lower-energy observations (especially gamma-ray, X-ray and radio) are crucial to identify and understand TeV sources.
- Thanks for having me in this session!

Wed 9:00 am
Emma de Ona-Wilhelmi
"Galactic TeV overview"