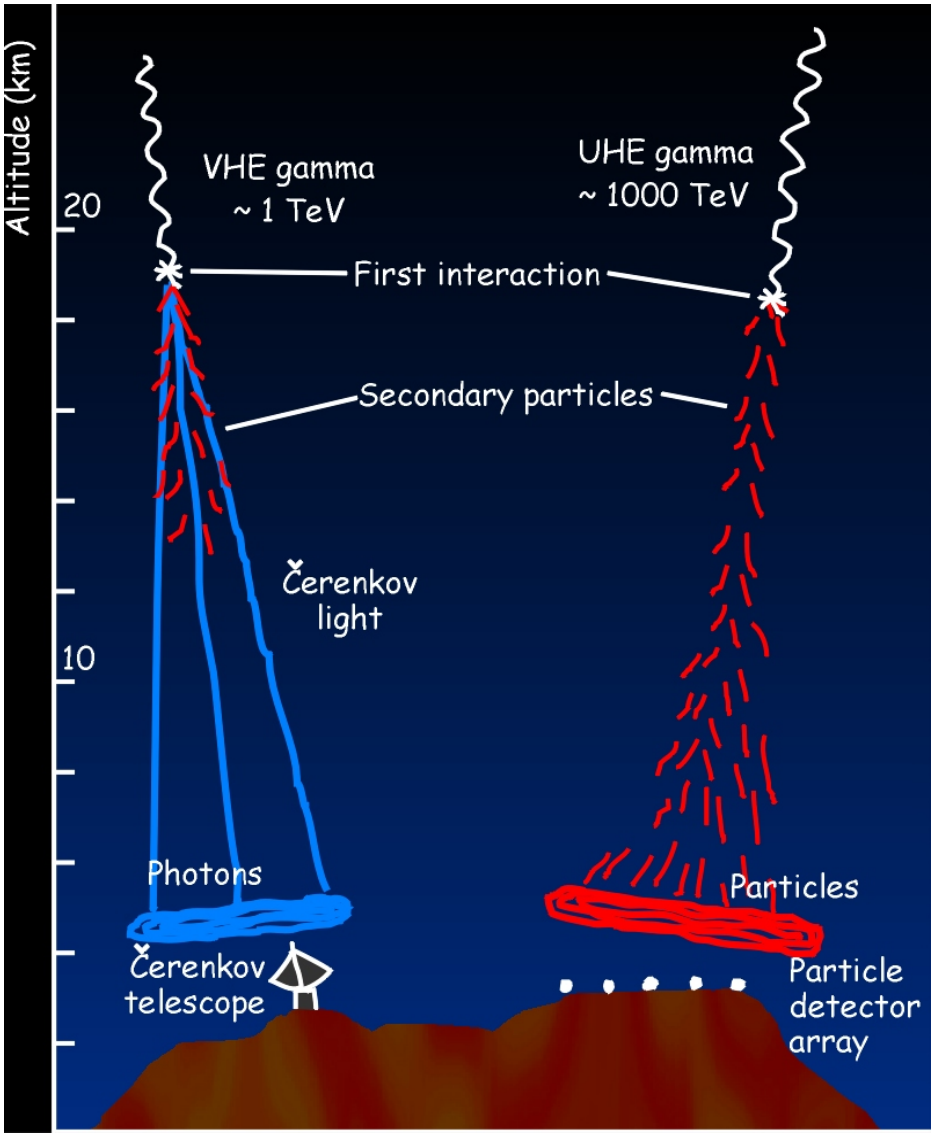
Astrofisica Nucleare e Subnucleare

TeV Astrophysics – II

Exercise #6

- Find the information about the 3 major currently operating IACT telescopes
- Visit the web site of CTA
- Find relevant info for HAWC and LHAASO

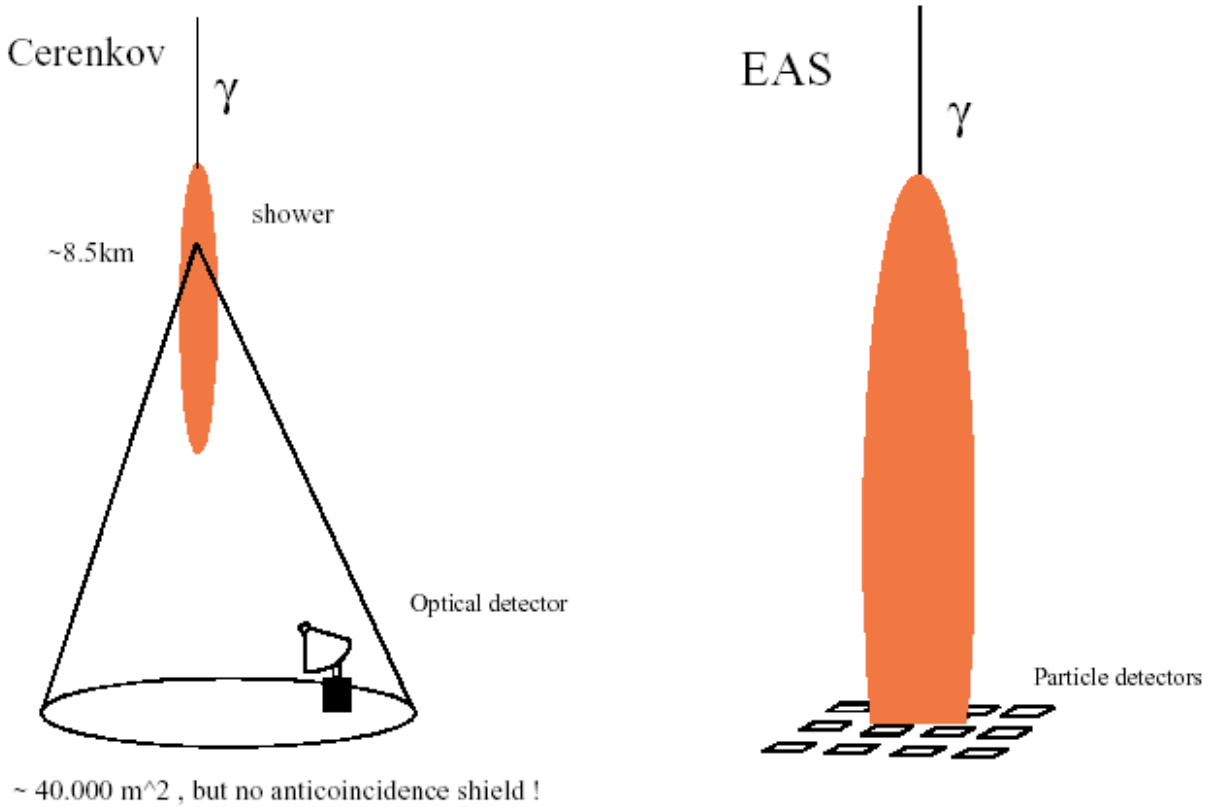
IACT & EAS experiments



- Cherenkov experiments consist of almost-optical telescopes devoted to detect Cherenkov light.
- EAS (Extensive Air Shower) experiments are huge arrays or carpets of particle detectors.
- Cherenkov experiments have lower energy thresholds, but also a lower duty-cycle as well as a smaller field of view.

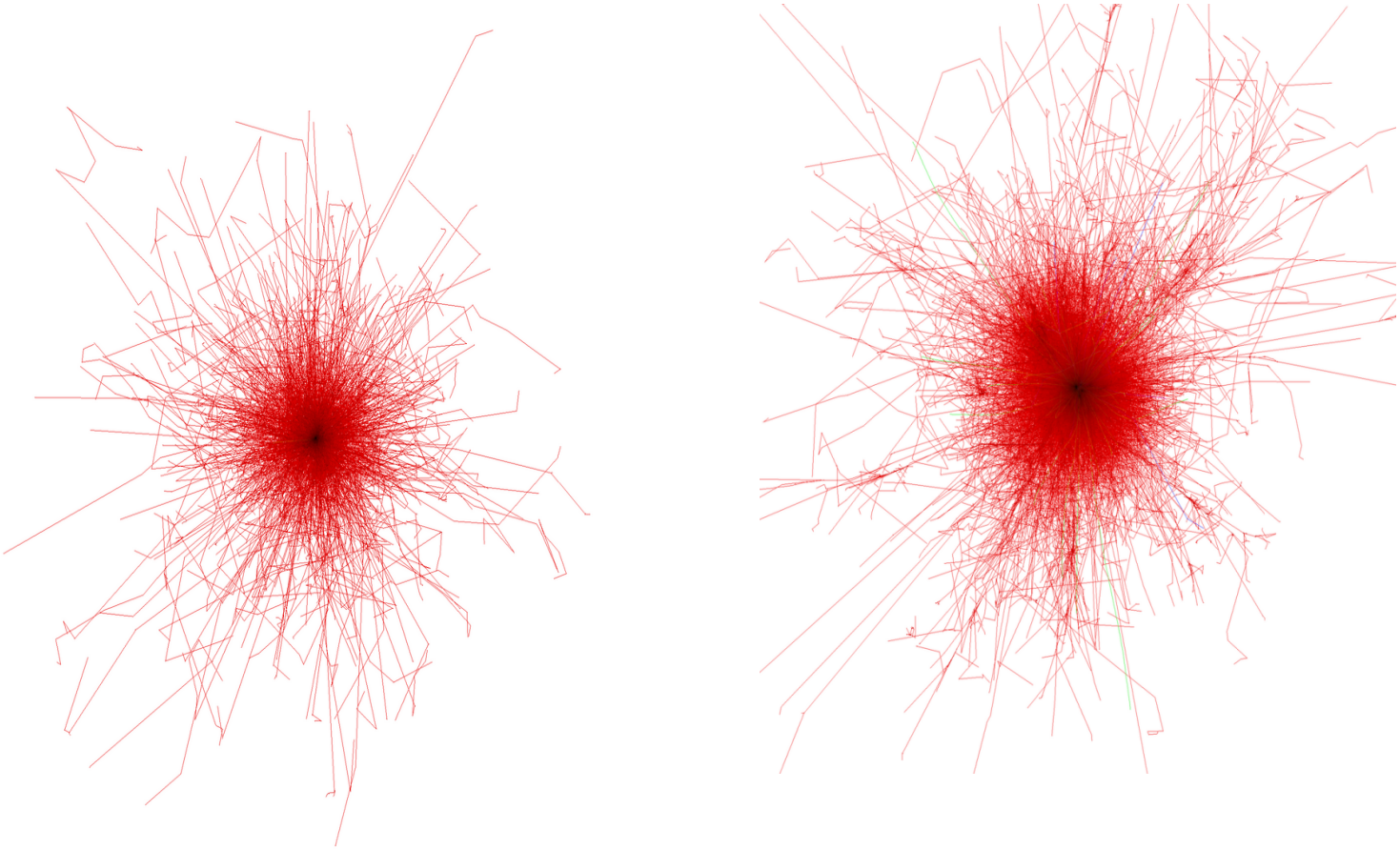
TeV detectors

Cerenkov and Extensive air shower (EAS) gamma ray telescope concepts

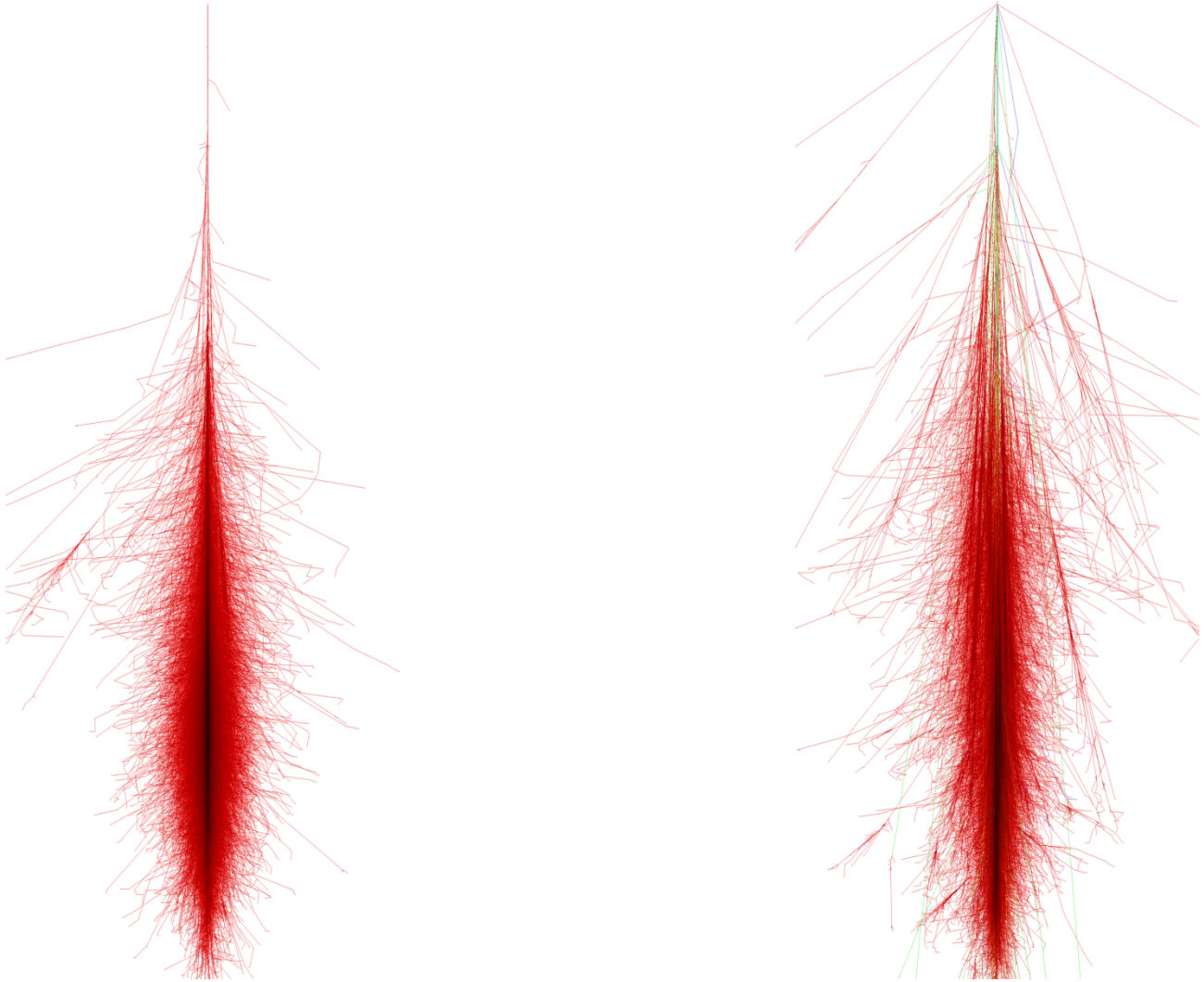


~ 40.000 m^2 , but no anticoincidence shield !

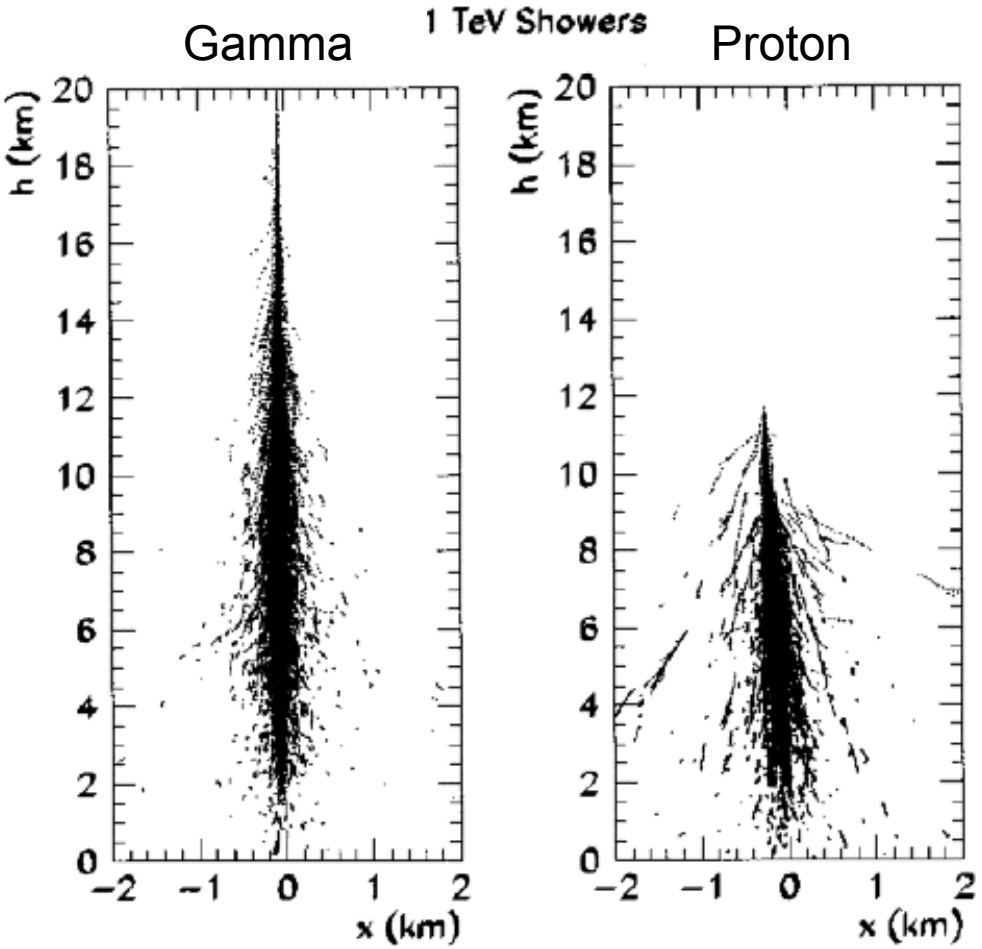
Shower Images



Shower Images

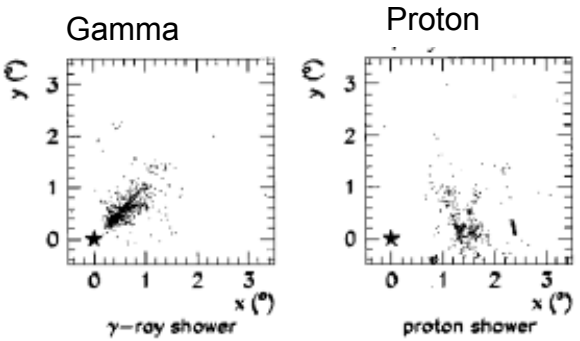


Development of vertical 1-TeV proton and γ-ray shower

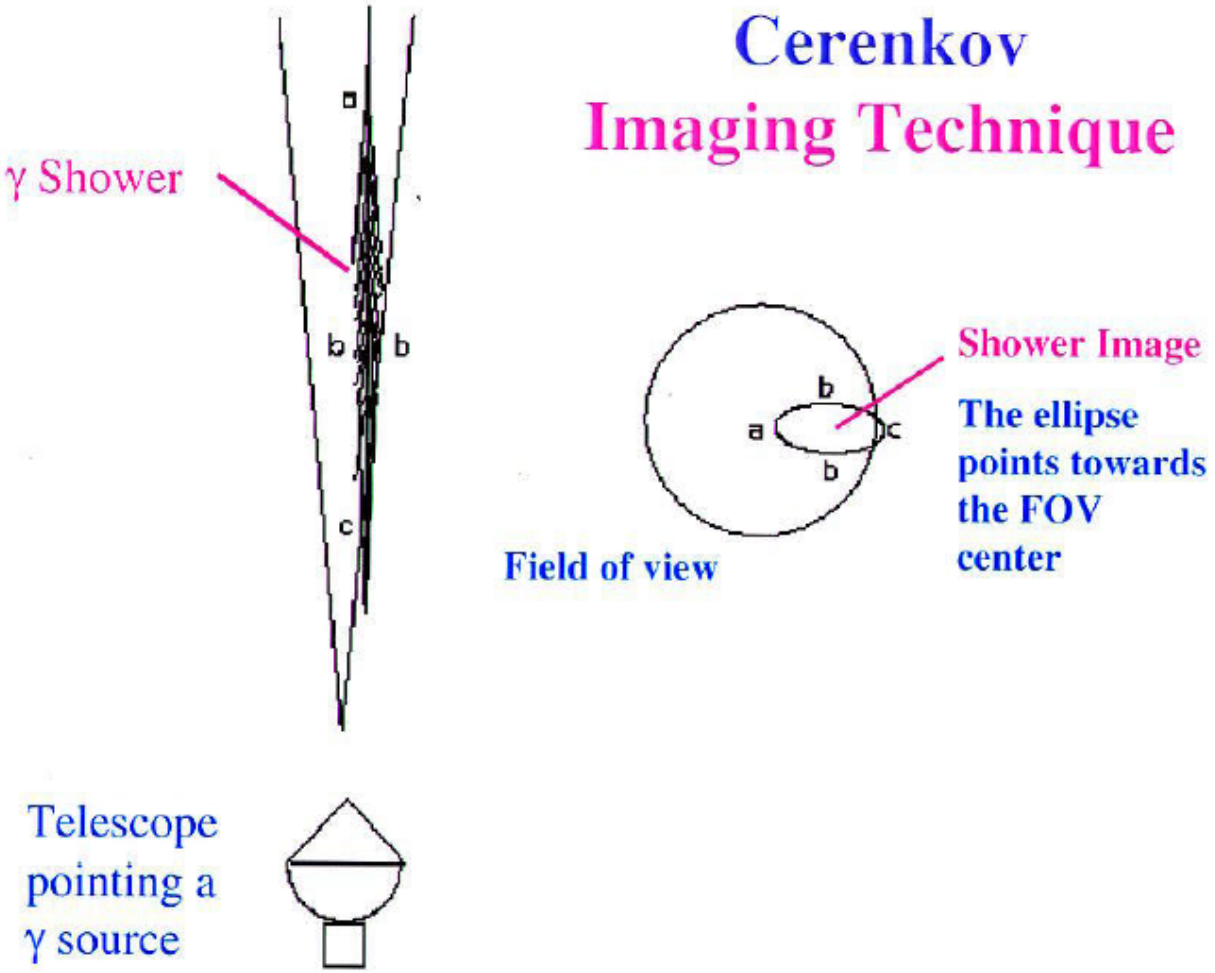


Positions in the atmosphere of all shower electrons above the Cerenkov threshold

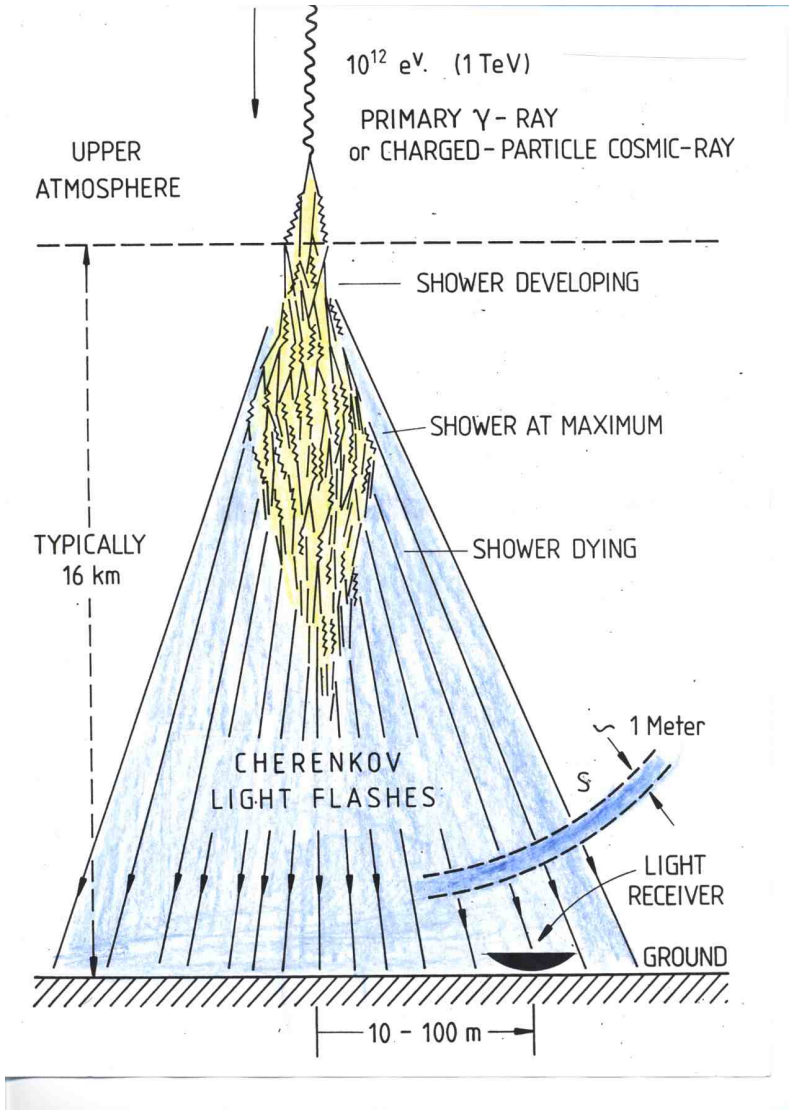
Resulting Cerenkov images in the focal plane of a 10-m reflecting mirror .

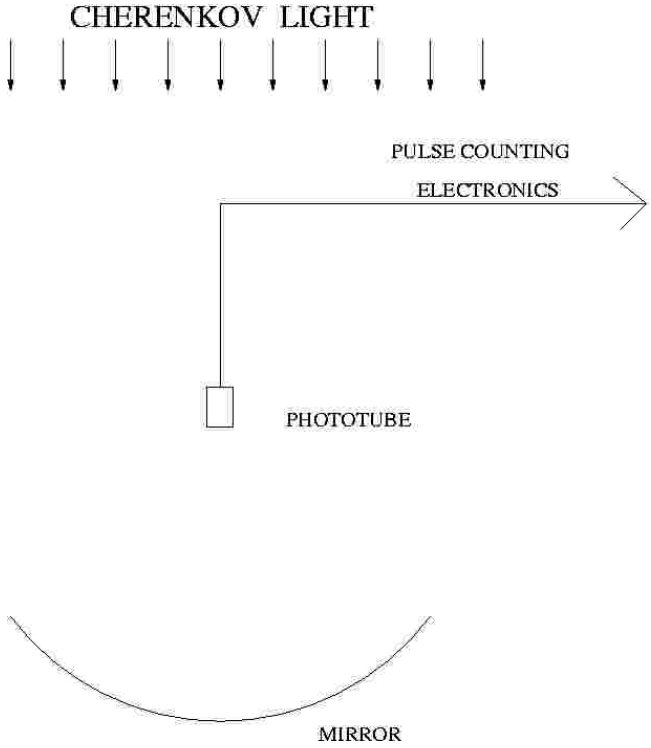


TeV detectors



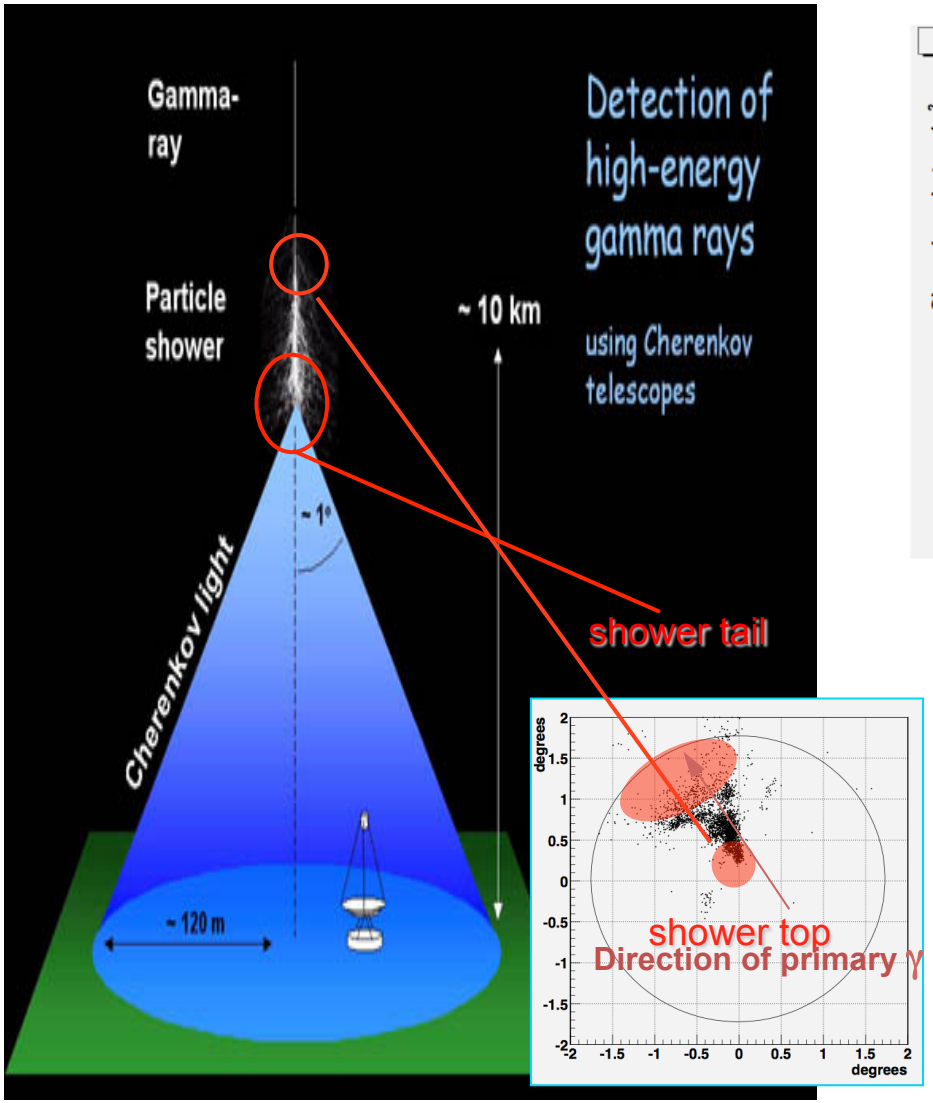
TeV detectors

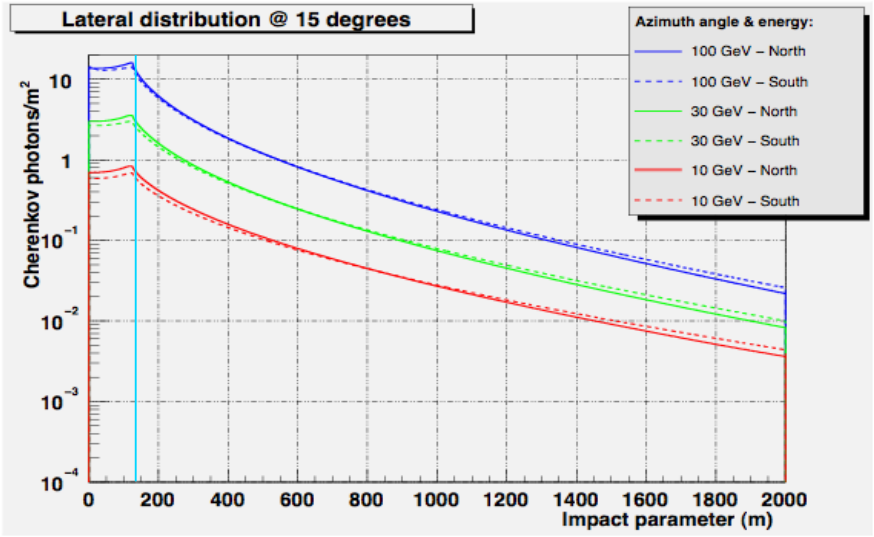




Direction ~ → arc-min
Energy Resolution ~ →10%
Background ~ → ?

Imaging Atmospheric Cherenkov Telescopes

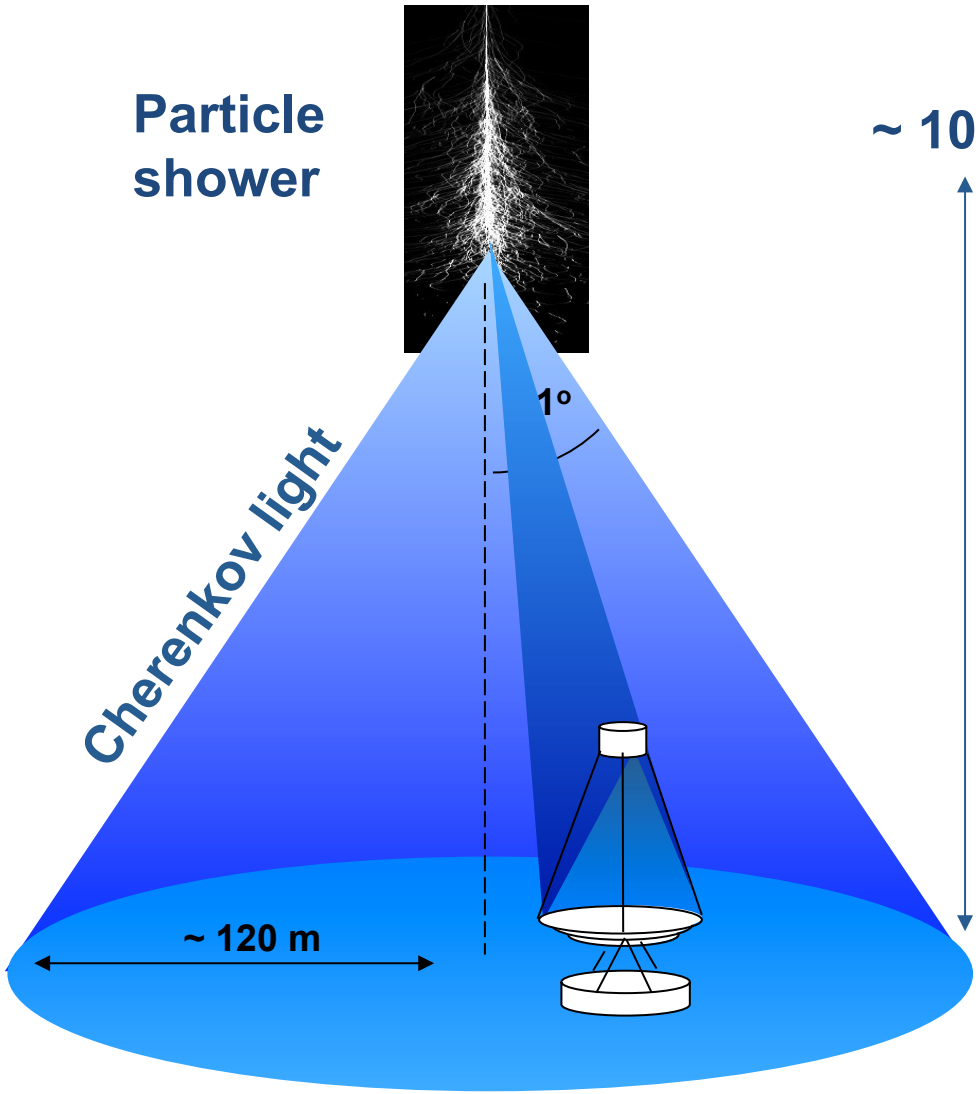




The principle:

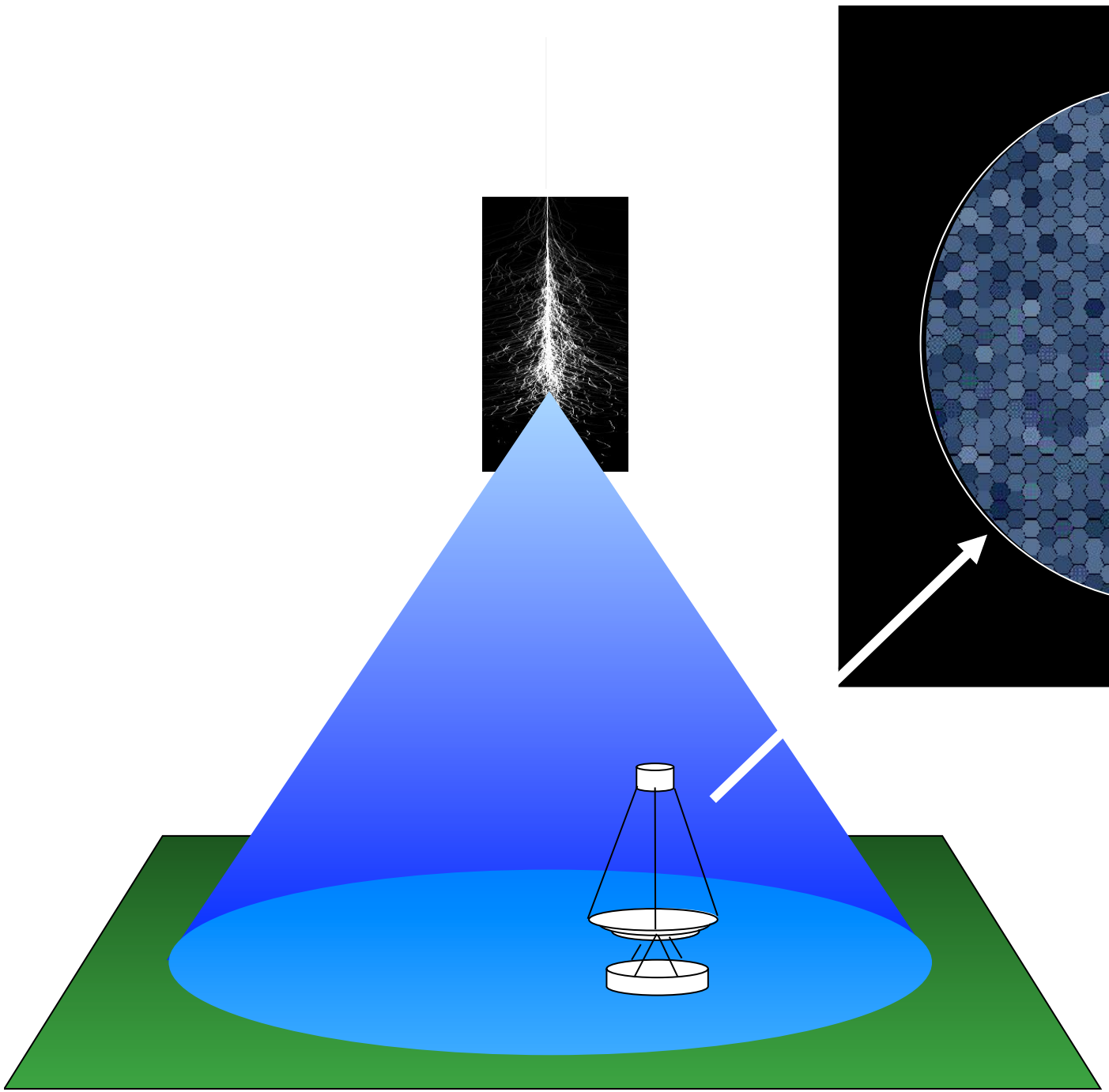
A telescope placed inside the (huge) Cherenkov light pool can obtain an image of the development of the shower above the bkg fluctuations

Observation tecnique



Detection of TeV gamma rays

using Cherenkov telescopes



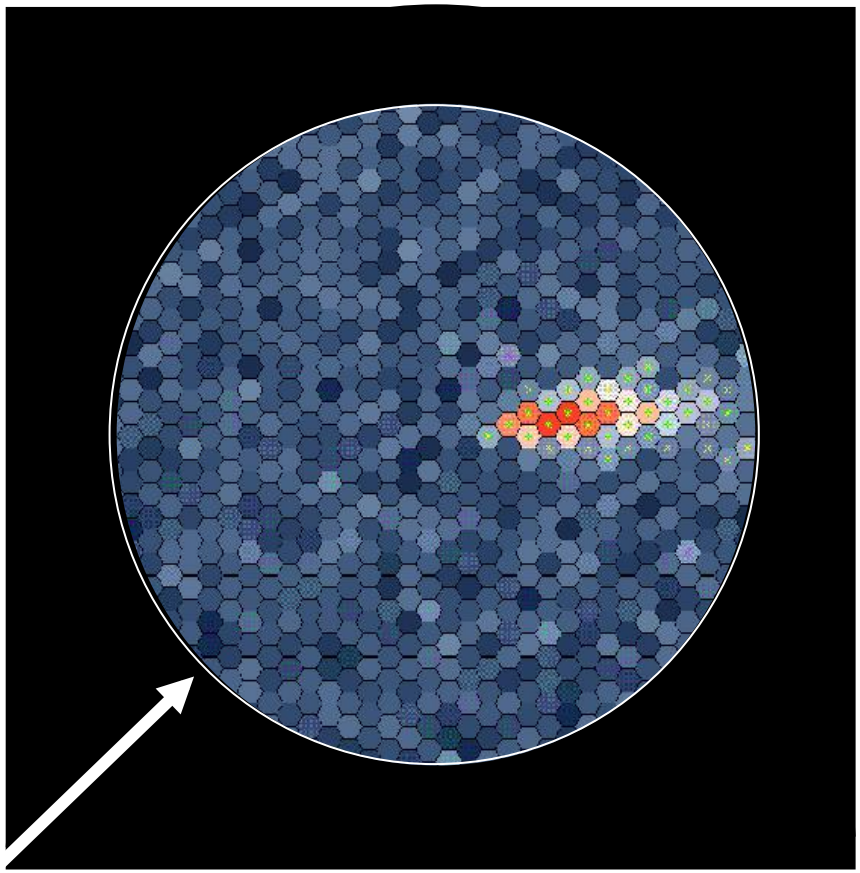
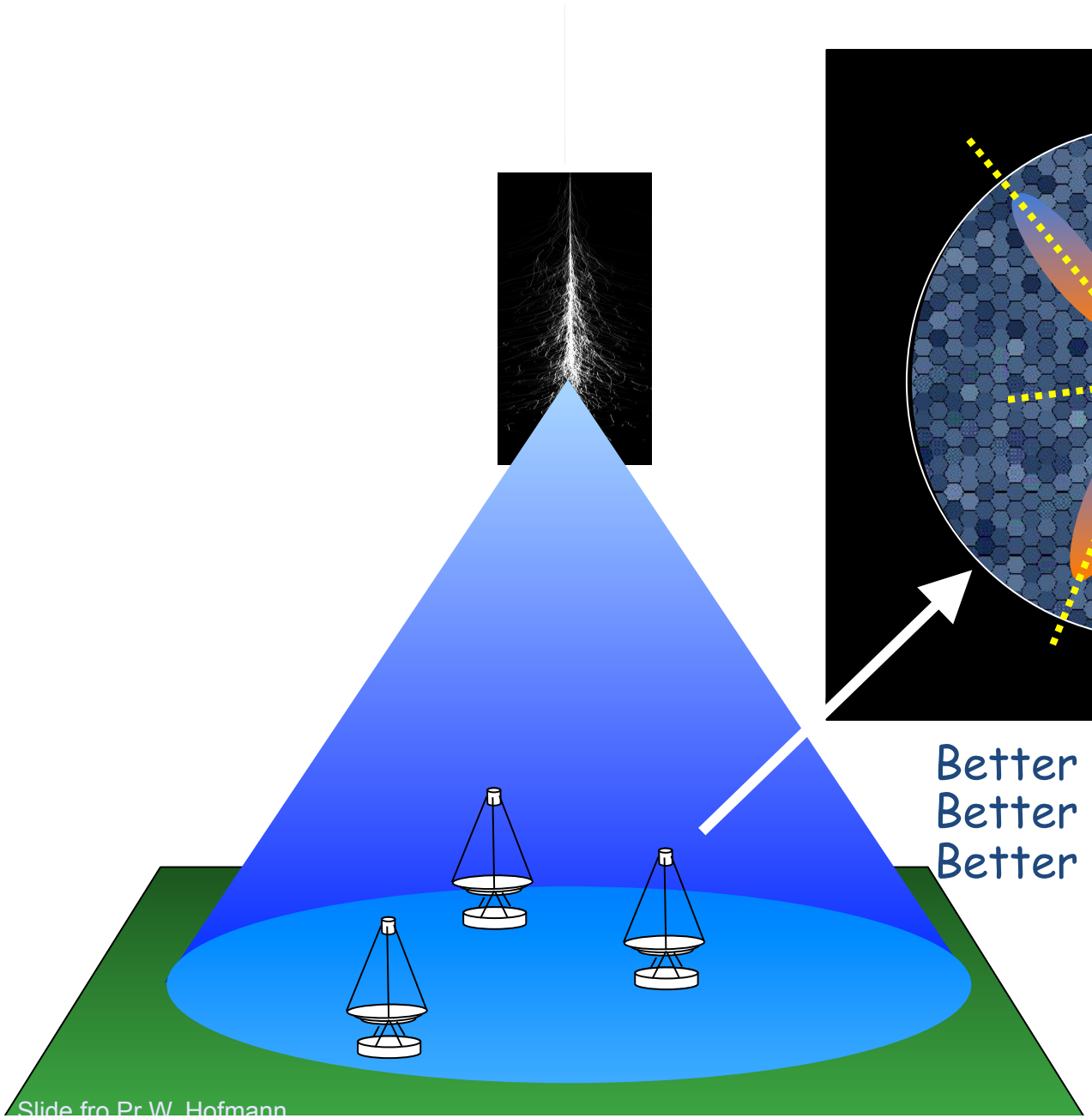
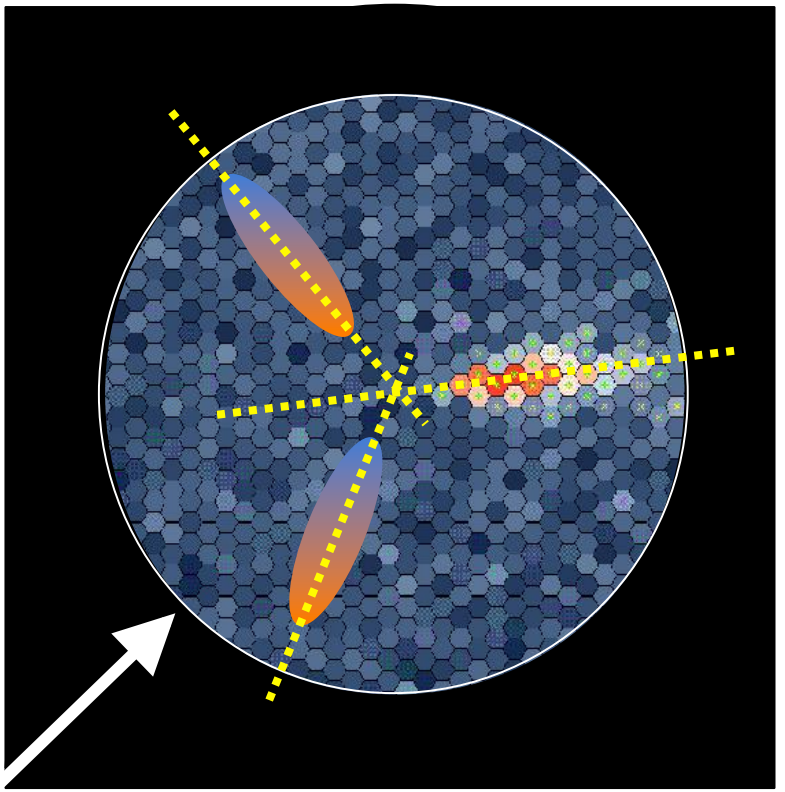


Image intensity
➔ Shower energy

Image orientation
➔ Shower direction

Image shape
➔ Primary particle



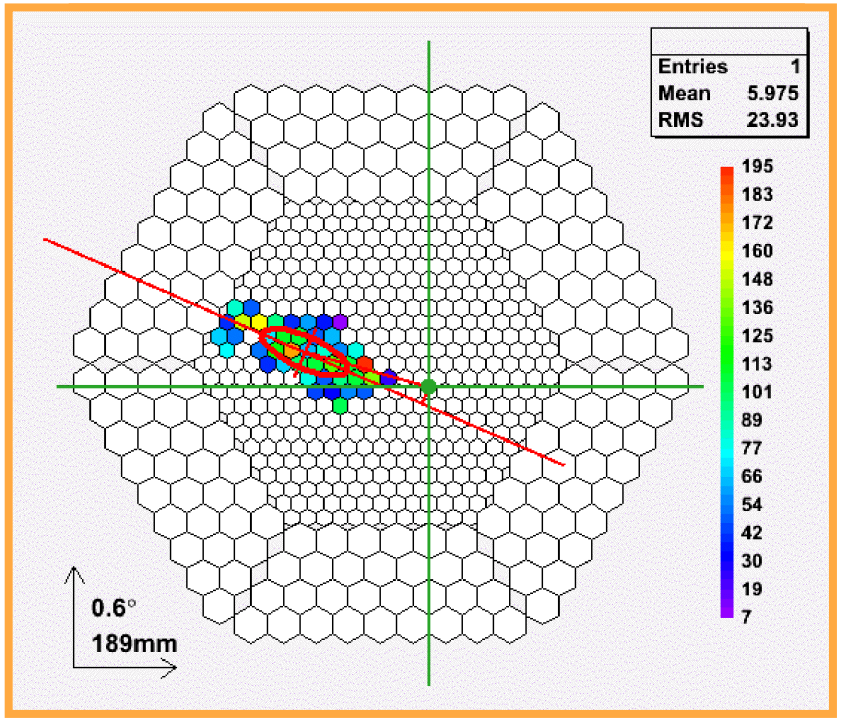


Better bkgd reduction
Better angular resolution
Better energy resolution

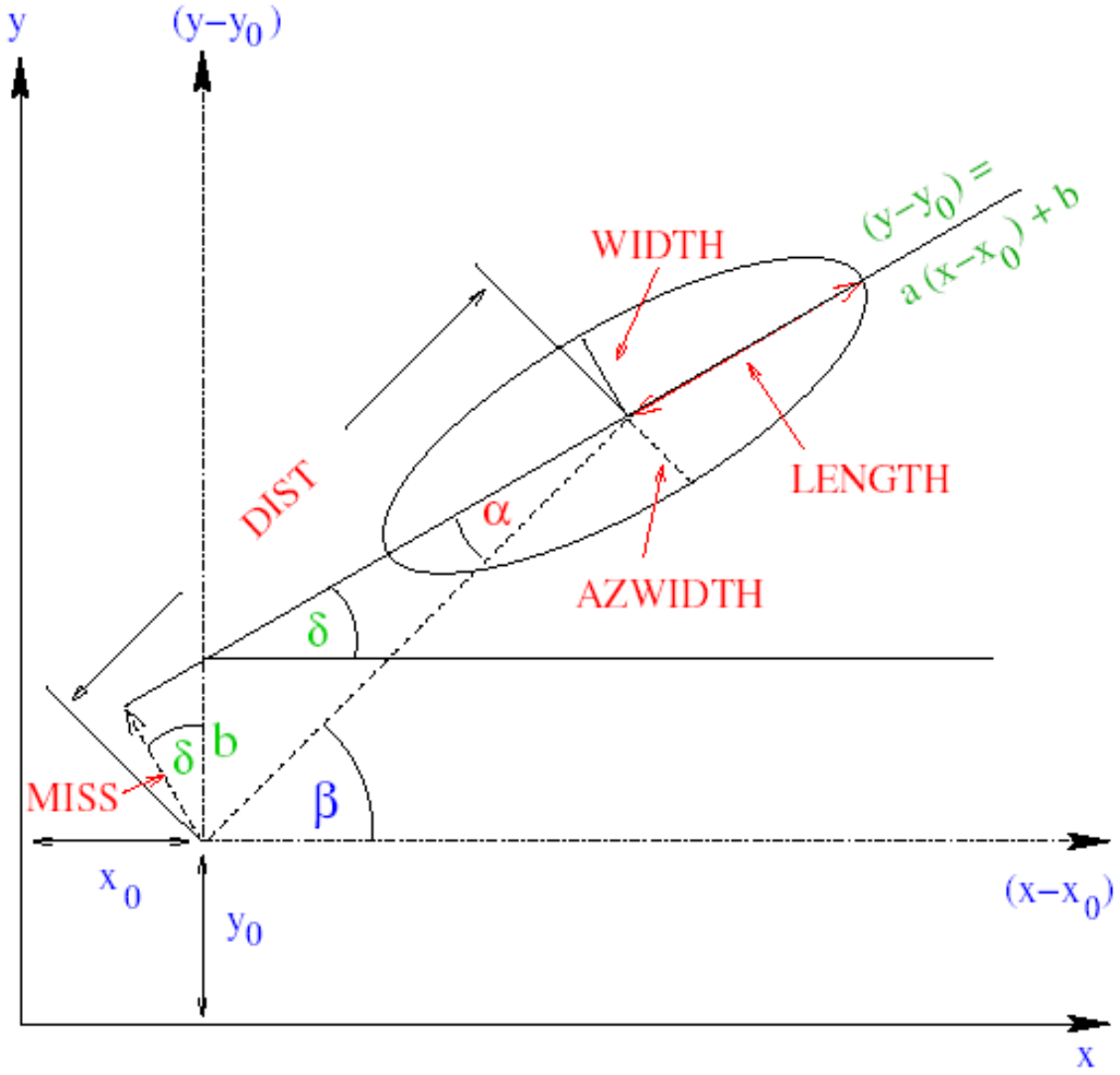
Slide fro Pr W. Hofmann

IACT image reconstruction

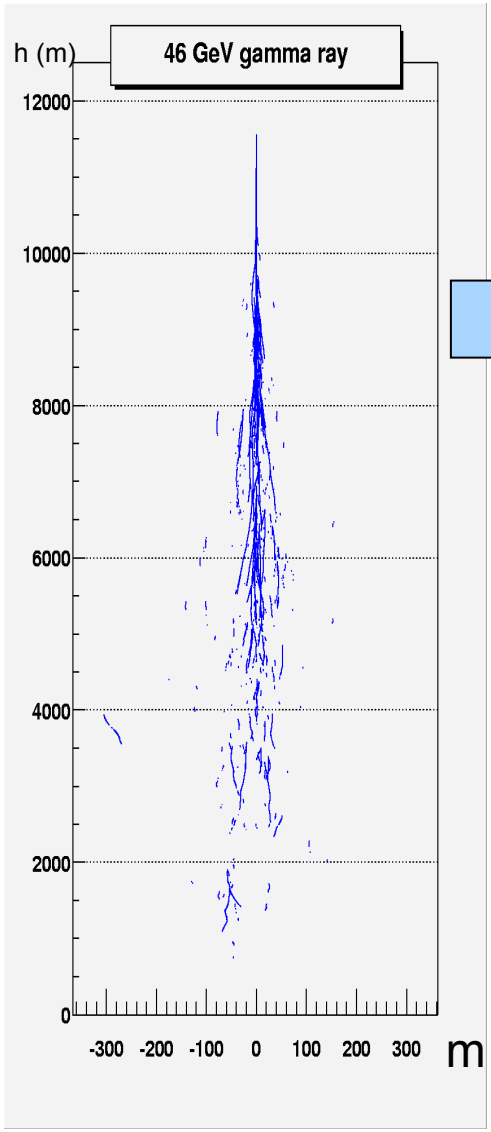
- Primary γ parameters reconstruction by particle shower image analysis
- Different primary particles give different image shapes
- Possible γ-hadron separation
- Reconstructed parameters of primary γ: energy, direction, arrival time
- Signal estimation
- Spectrum calculation
- Lightcurve



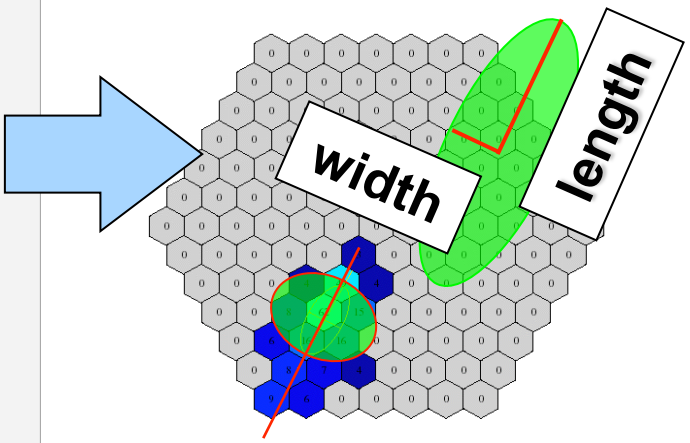
Hillas parameters



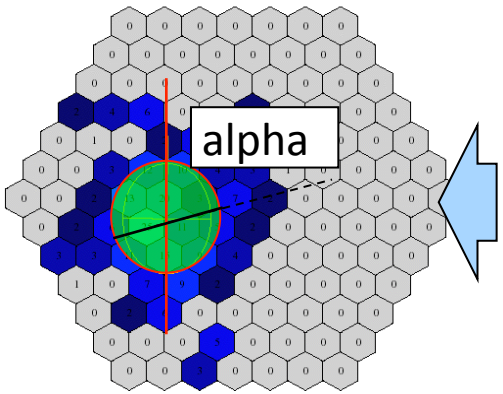
Gamma / hadron separation

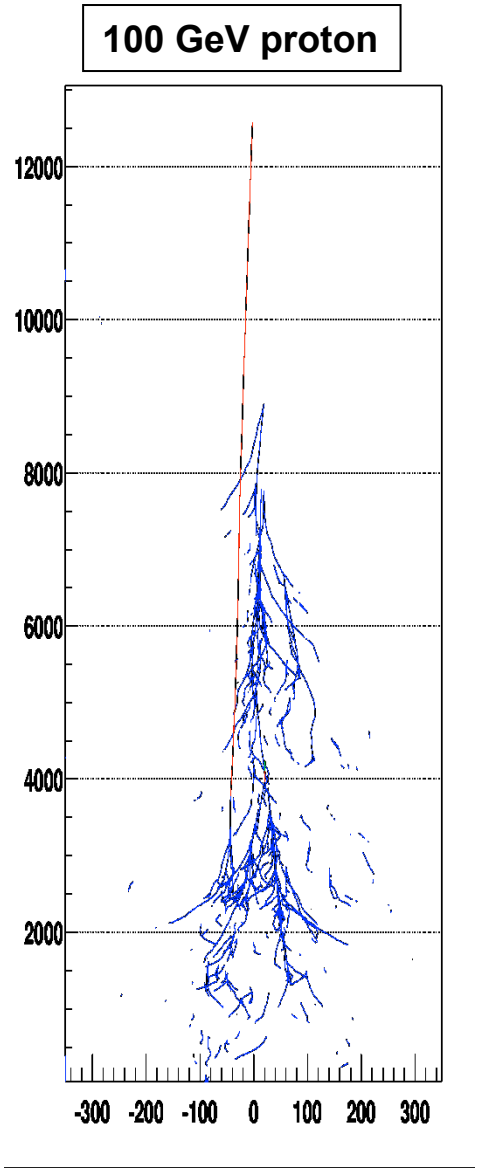


Gamma shower
(narrow, points to source)

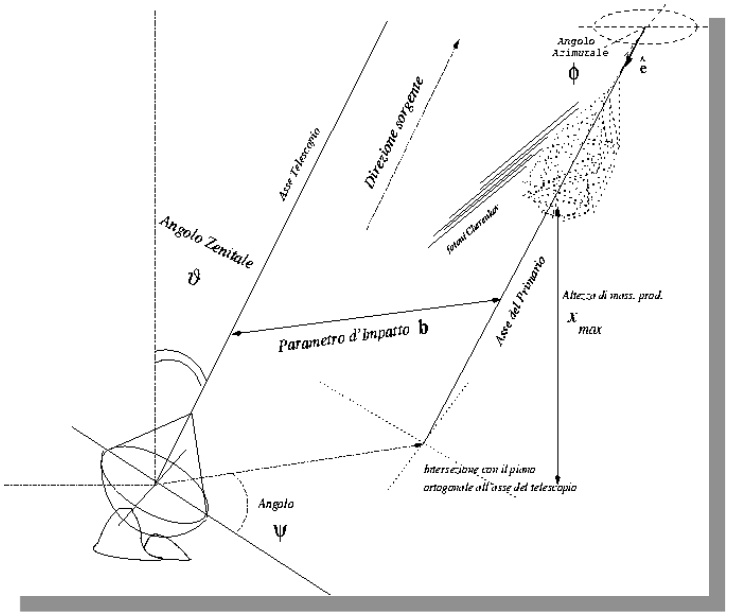


Proton shower
(wide, points anywhere)

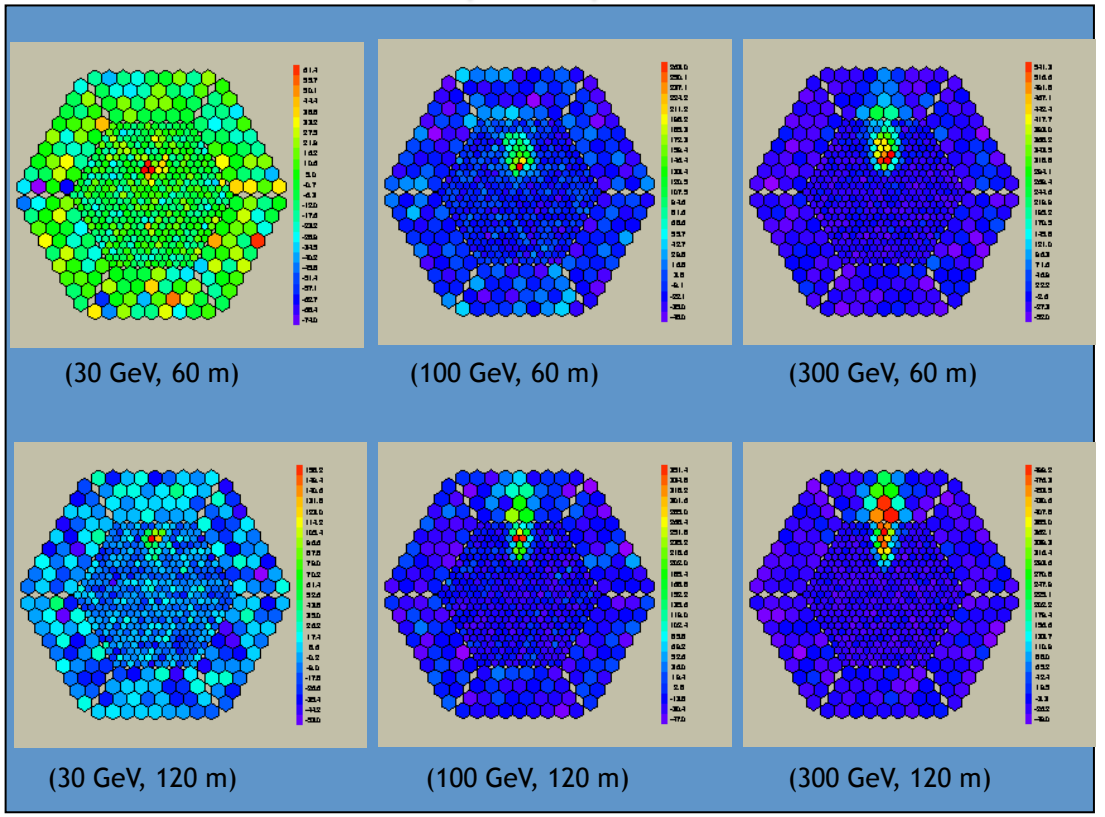




Imaging Atmospheric Cherenkov Telescopes



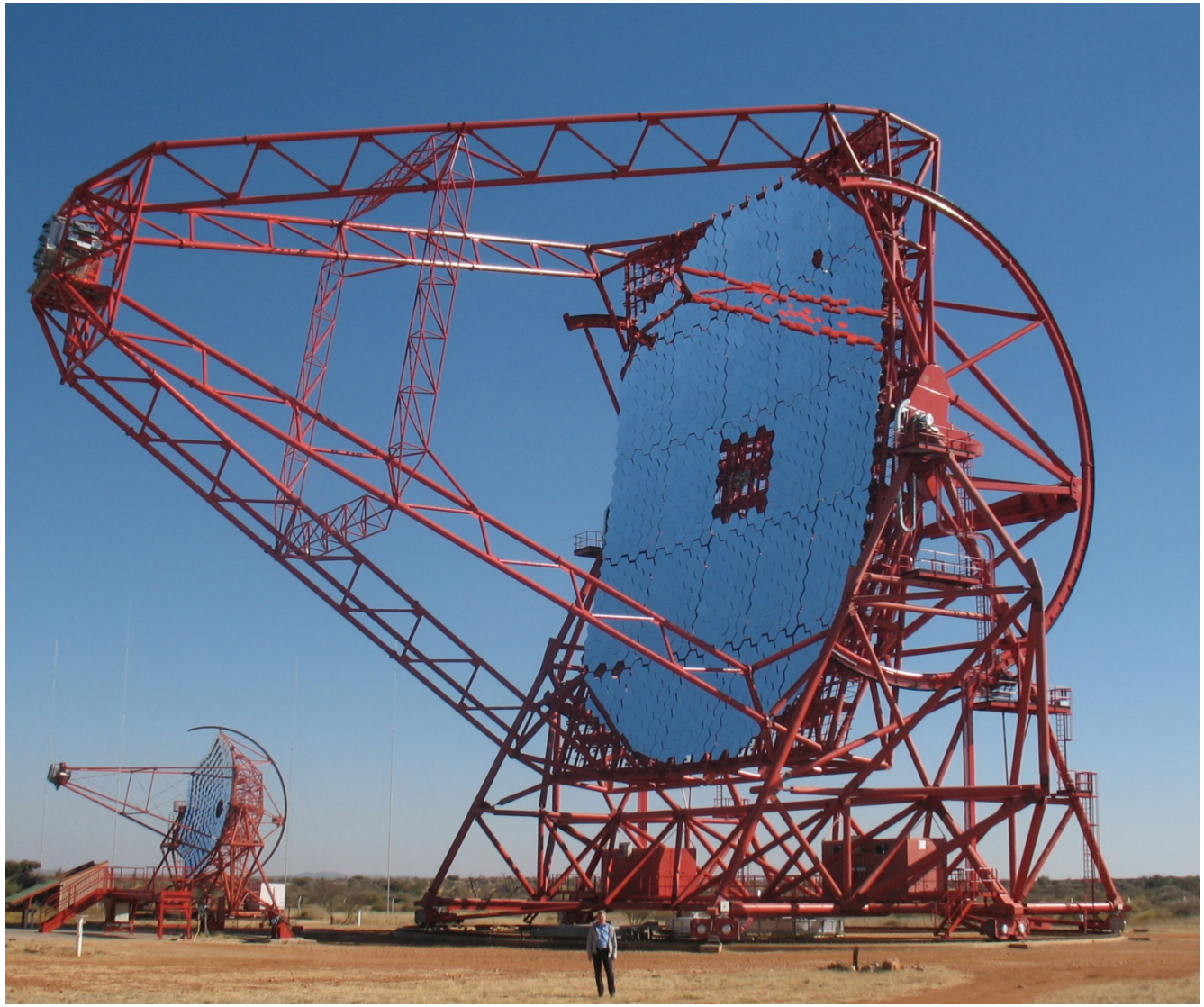
Typical γ shower images simulated with different energy and different impact parameter



Geometric relations between a shower and the Cherenkov Telescope optics

HESS

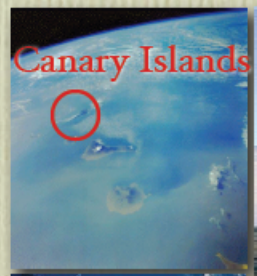
HESS-II

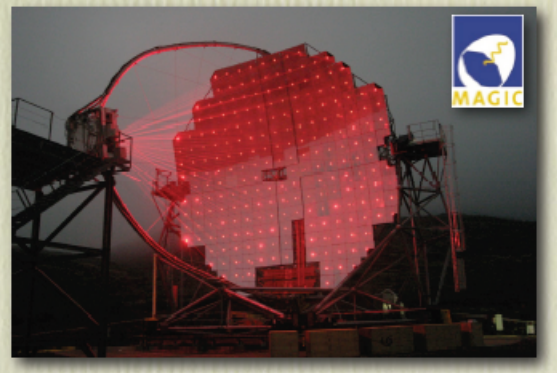


The MAGIC Telescope

Major Atmospheric Gamma Imaging Cherenkov telescope

Located at the Roque de los Muchachos on La Palma, Canary Islands (Spain) at ~2200 m *asl*





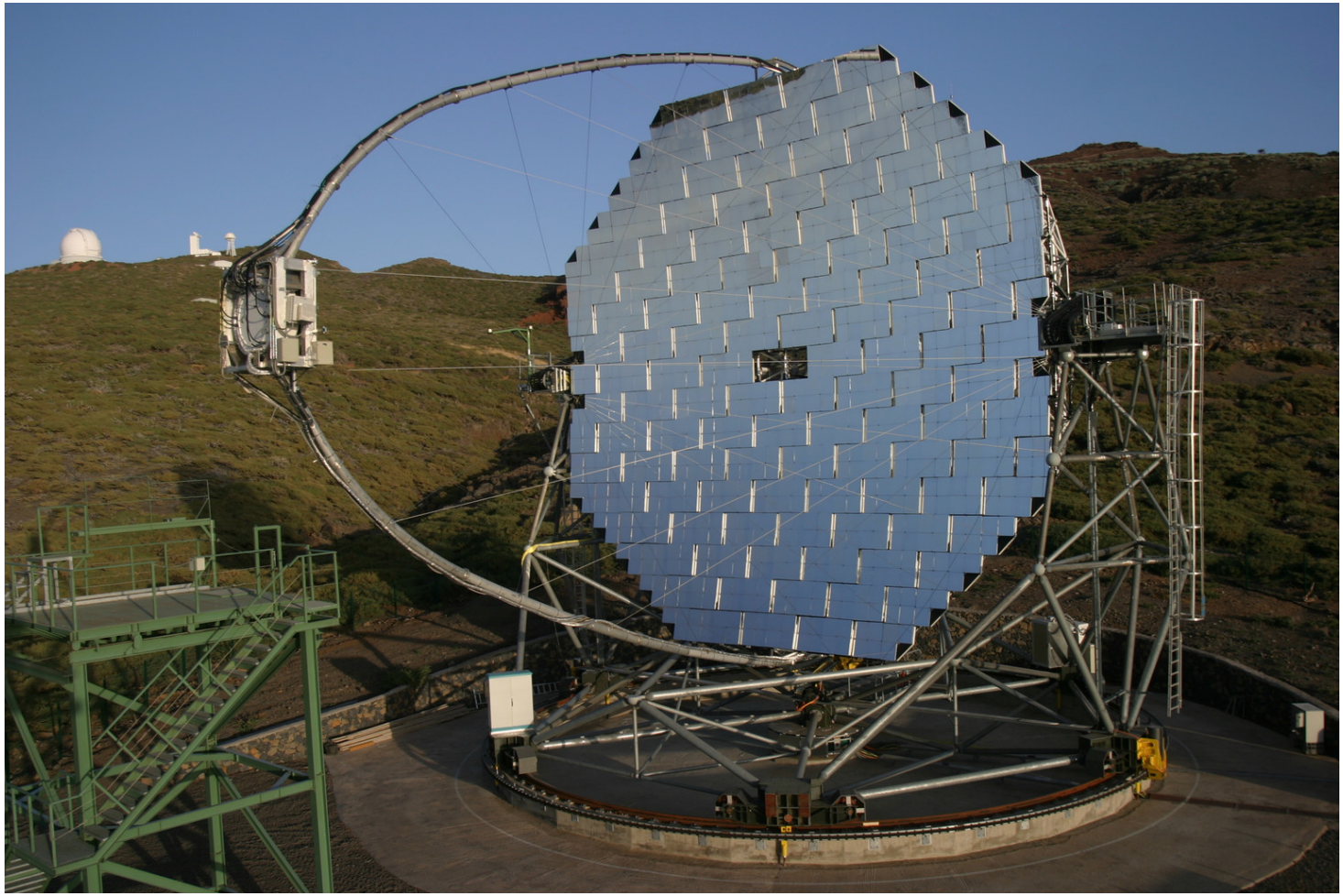
Largest imaging Cherenkov telescope for γ-ray astronomy

Designed for:

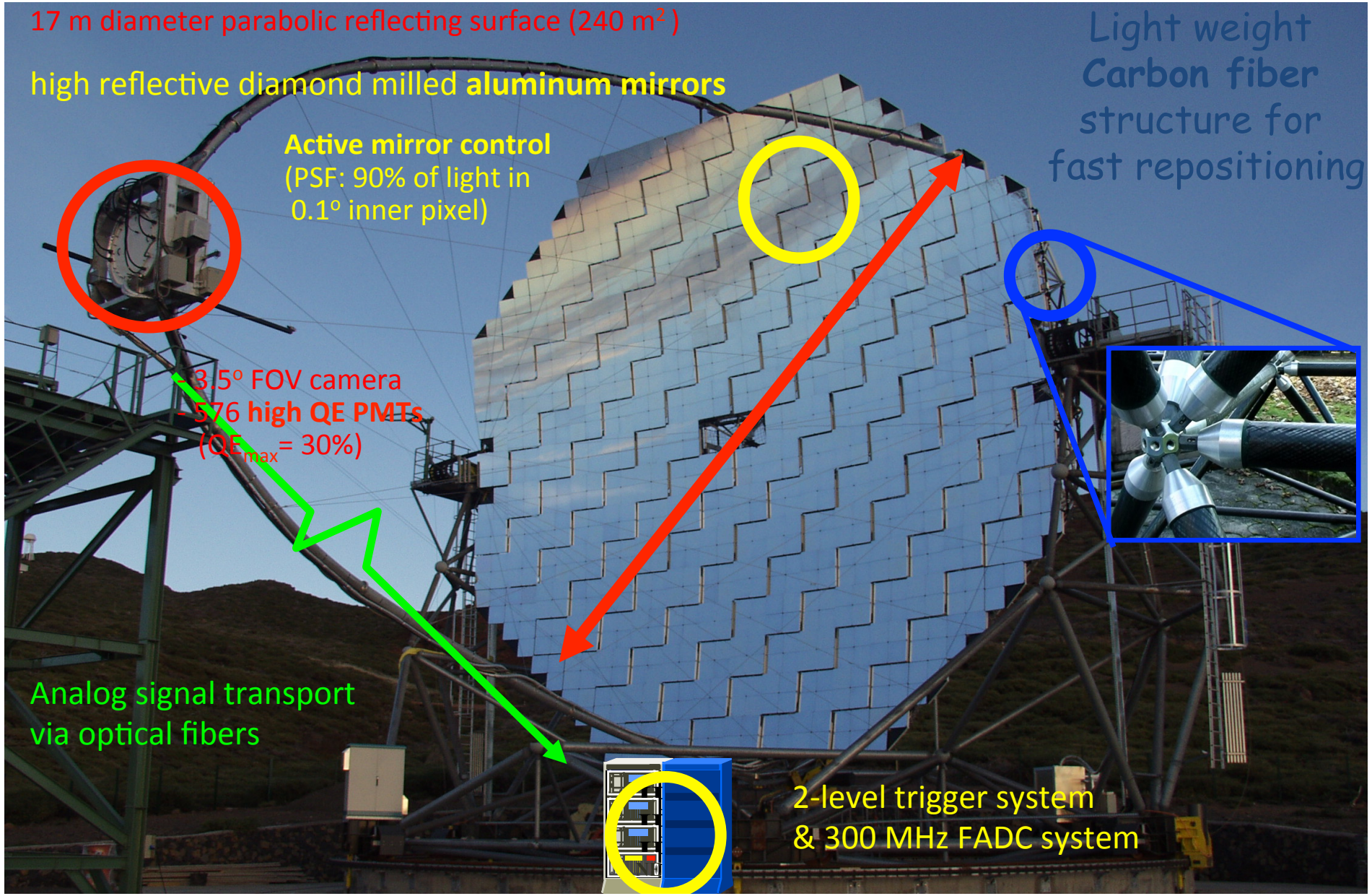
- Low energy threshold $E_{th} \approx 50$ GeV
- Fast repositioning in < 30 s

Construction 2001-2003
Inauguration 10/10/2003
Commissioning 2004
Cycle I 2005-2006

MAGIC



Key technological elements for MAGIC

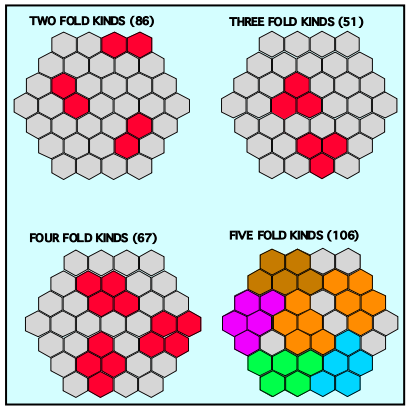


The trigger architecture

The trigger is split into two stages: level 1 (L1) and level 2 (L2). The L1 is a fast coincidence device (2-5 ns) with simple patterns (n-next-neighbor logic) while L2 is slower (50-150 ns) but can do a more sophisticated patter recognition.

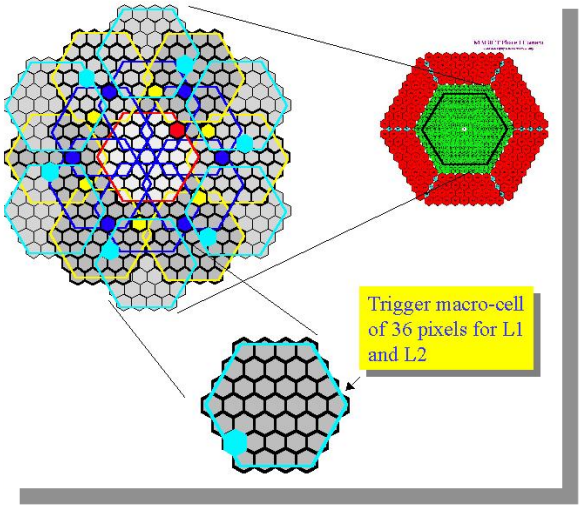
Discriminators L0

Choose the **number of photoelectrons** per pixel you want to use in the trigger



Level 1 L1

Make a **tight time coincidence** on simple pattern of compact images and **enable L2**



Level 2 L2

Make an **advanced pattern recognition** to use topological constraint:

- pixel counting in a given region of the detector
- mask hot spots like bright stars
- rough center of gravity of the image…etc…..

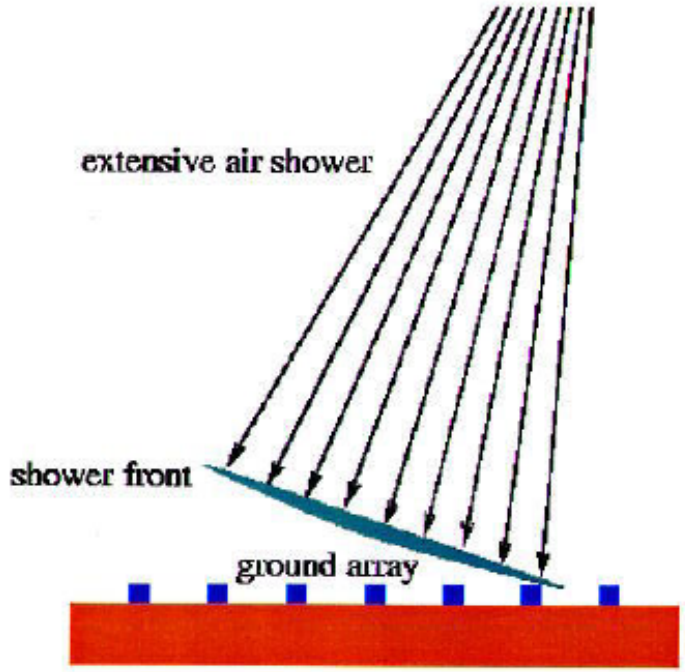
To FADC

MAGIC telescopes

VERITAS

TeV detectors

Air Shower Arrays



Reconstruction of the γ direction with the particles arrival times

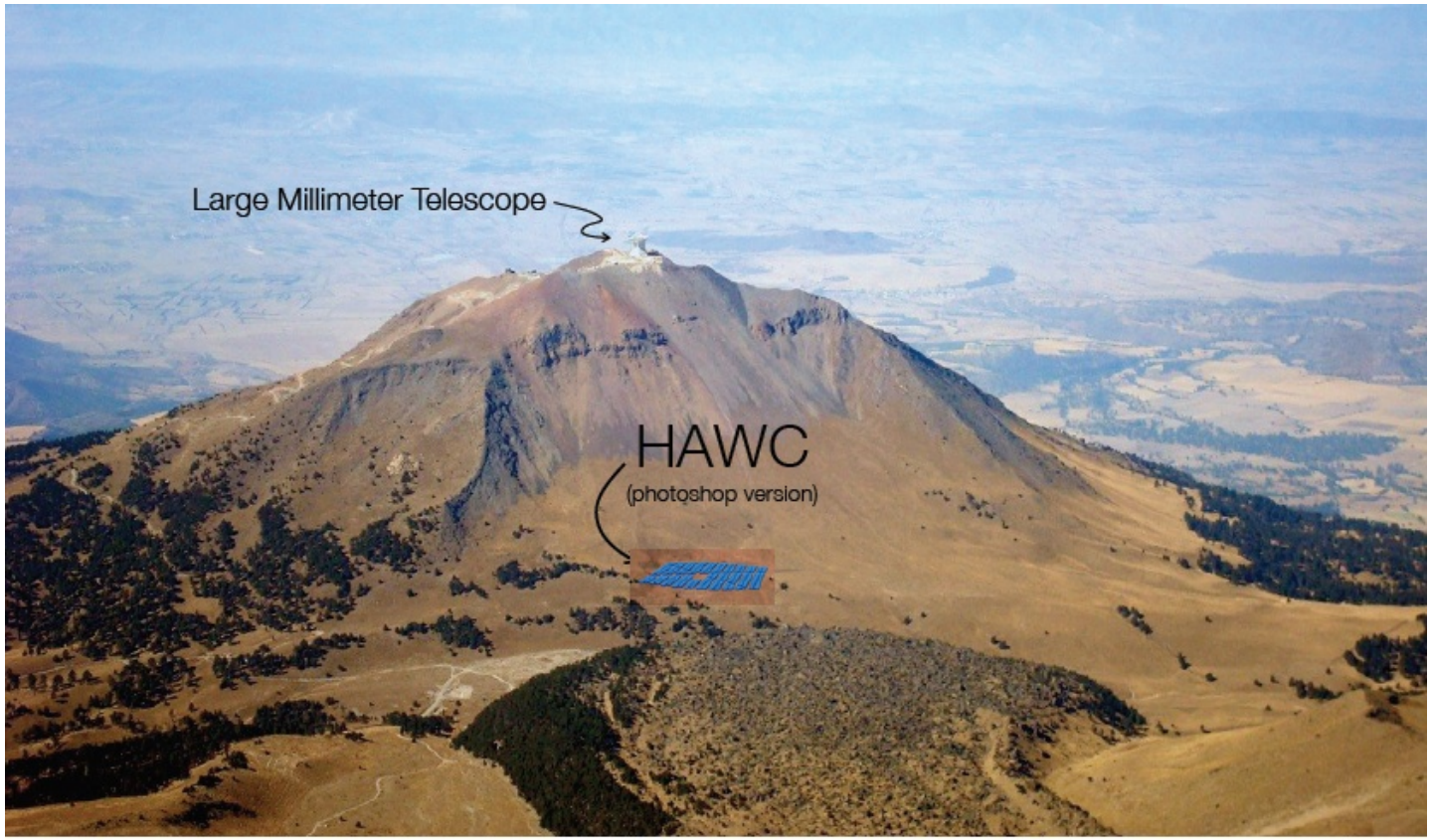
Large field of view: ~ π sr

Duty cycle ~ 100%

Gamma-hadrons discrimination:

μ-poor showers

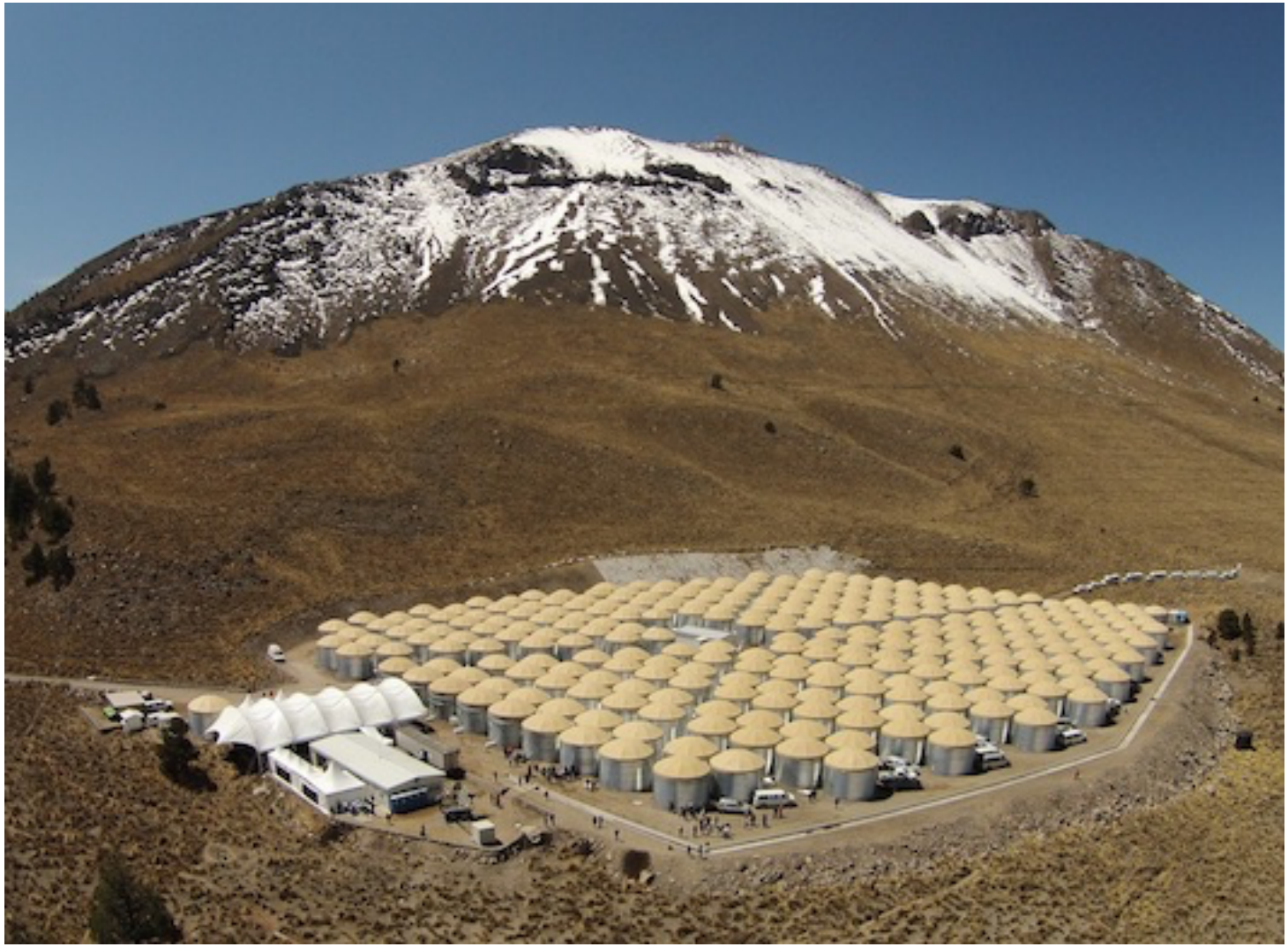
HAWC



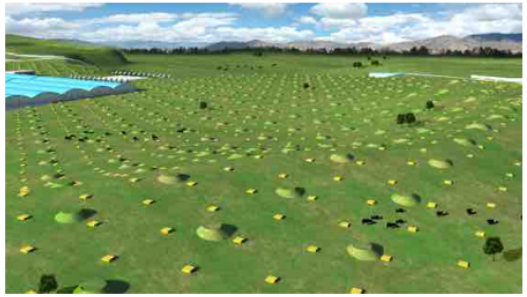
HAWC

Pico de Orizaba, altitude 4100 m, latitude 18° 59' N
Two hours drive from Puebla, four from México City
Site of Large Millimeter Telescope (existing infrastructure)

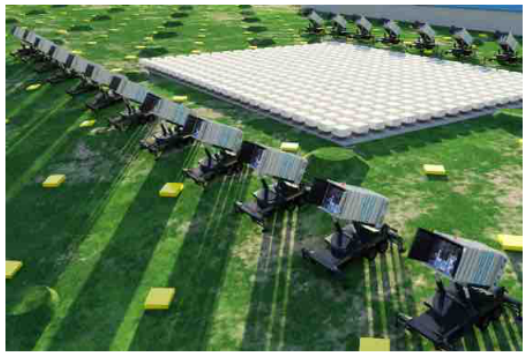
HAWC



LHAASO main components

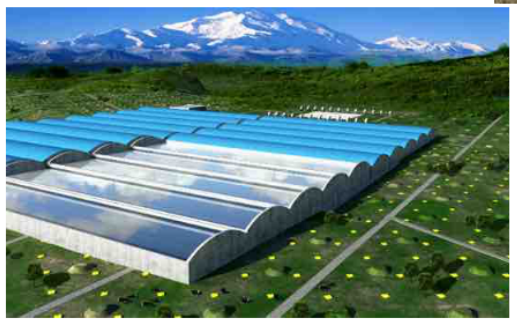


1 KM2A:
5635 EDs
1221 MDs



WFCTA:
24 telescopes
1024 pixels each

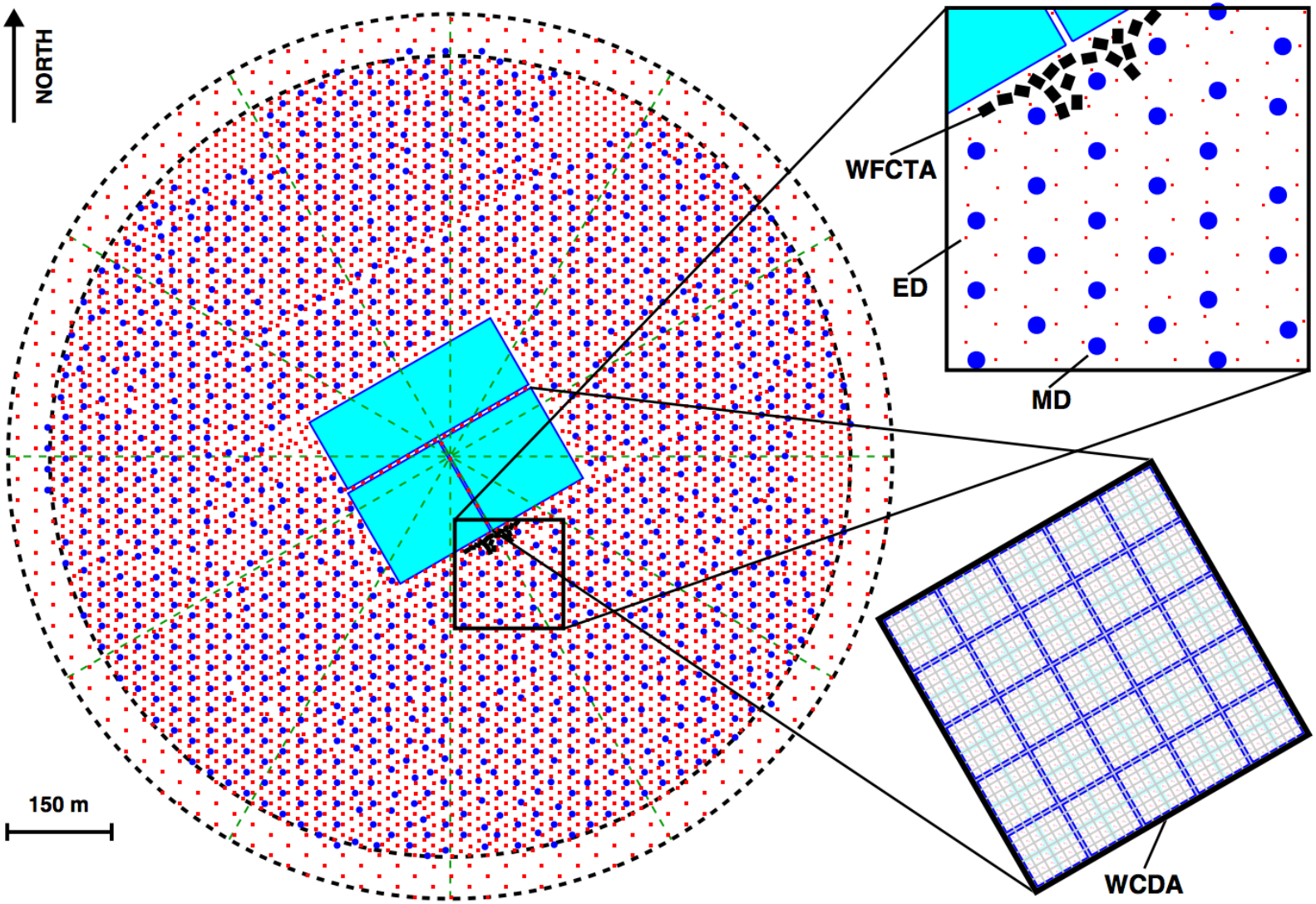
WCDA:
3600 cells
90,000 m^2



Coverage area: 1.3 km^2

SCDA:
452 detectors

LHAASO

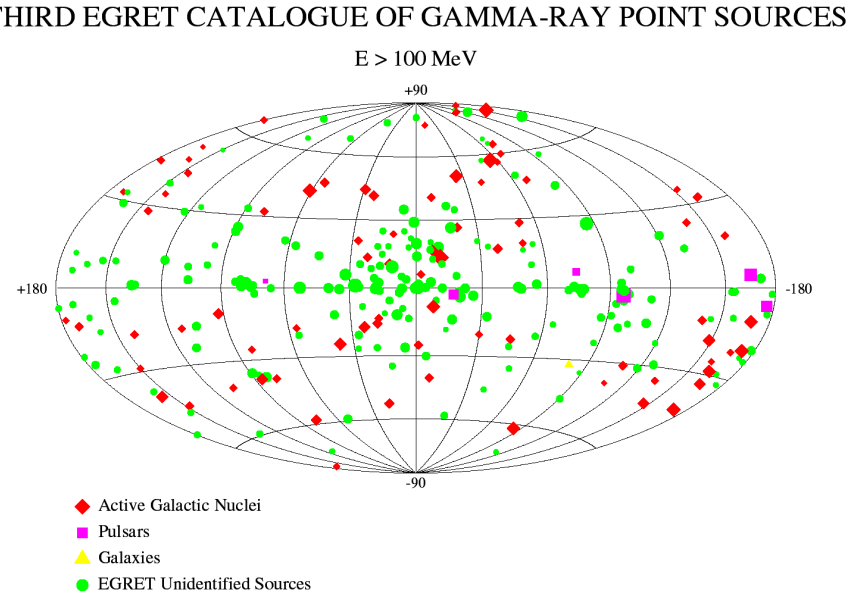


Astrofisica Nucleare e Subnucleare

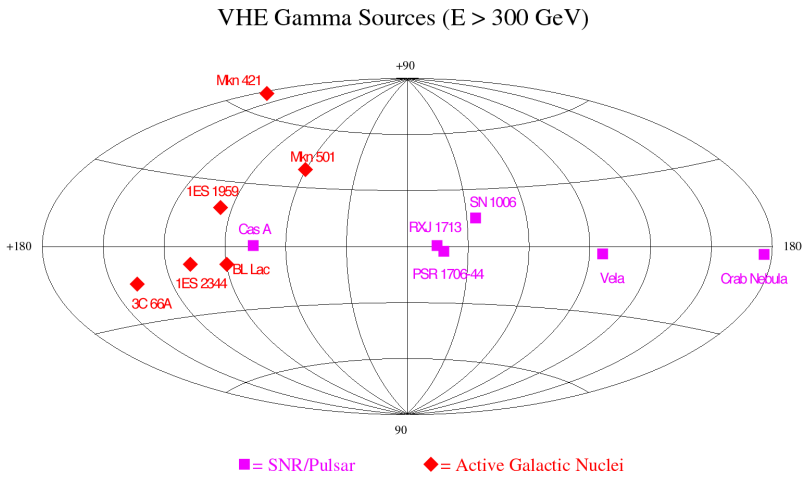
VHE Gamma Astrophysics

The unexplored spectrum gap

- Satellites give a nice crowded picture of energies up to 10 GeV.



- **Ground based experiments show very few sources with energies > ~300 GeV.**



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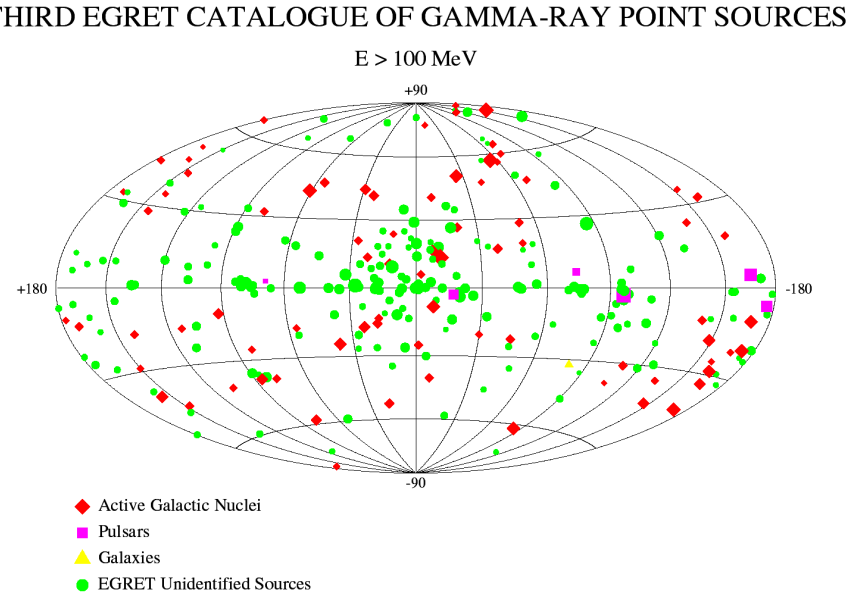

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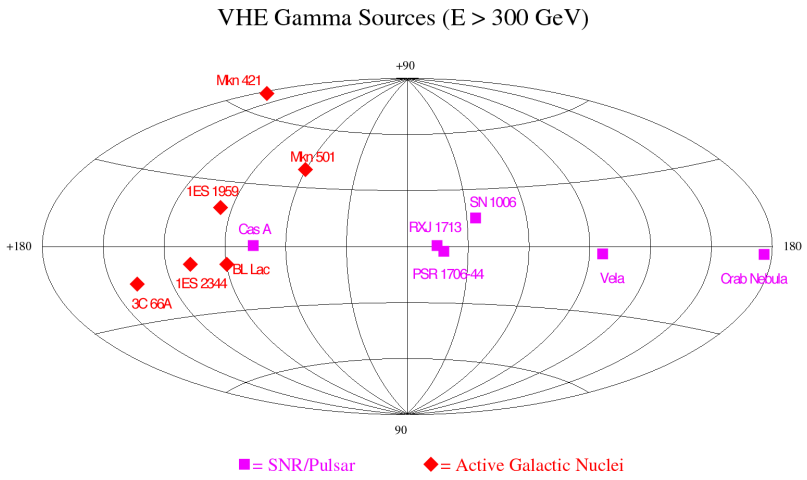
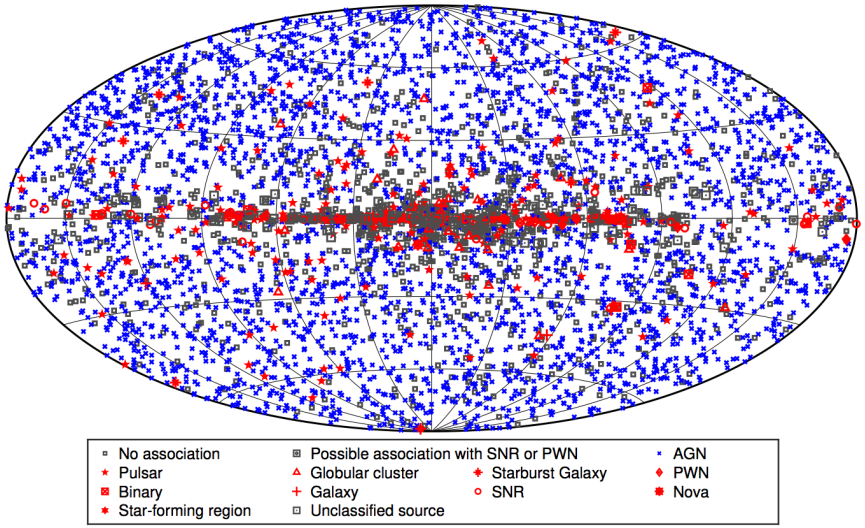
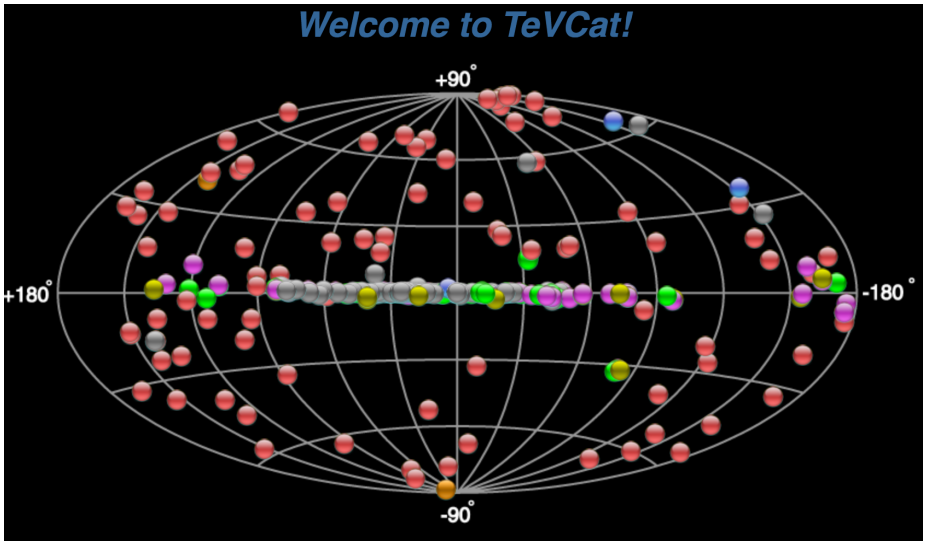


VHE sky

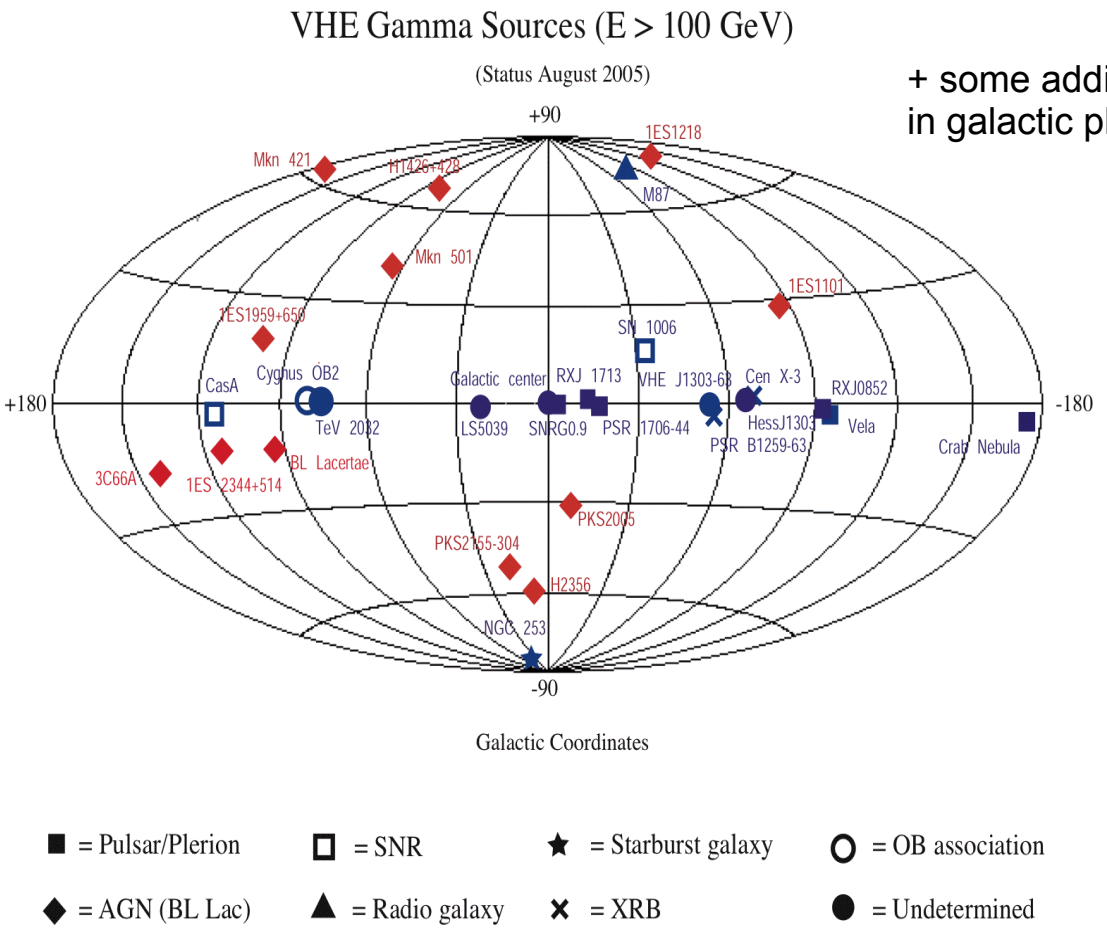
- The HE sky up to 100 GeV.
- The VHE sky from 50 GeV.





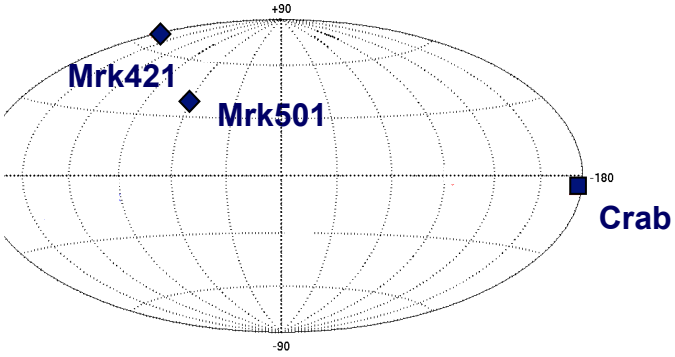
The VHE γ ray sky

2005



+ some additional sources in galactic plane.

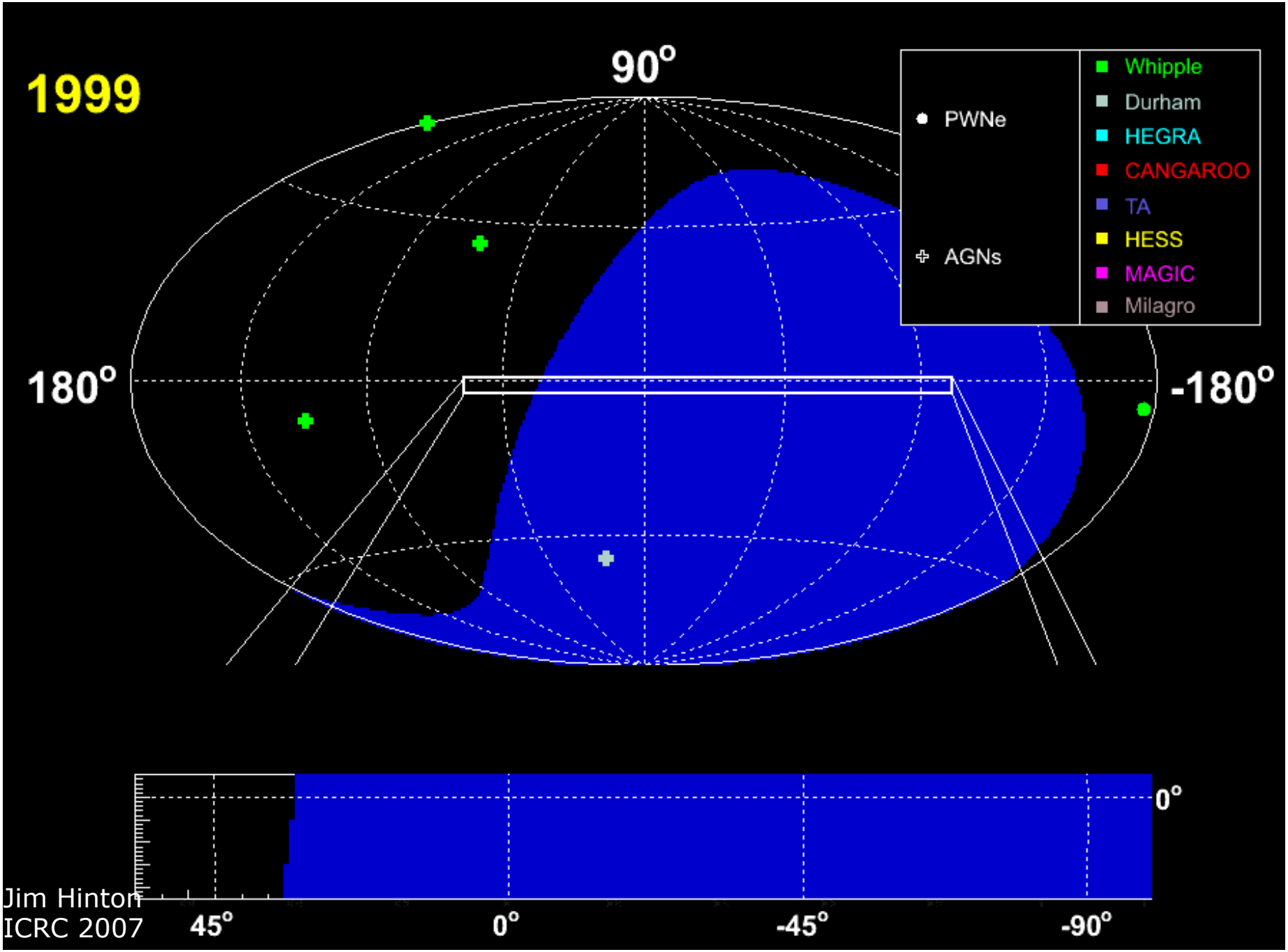
1995



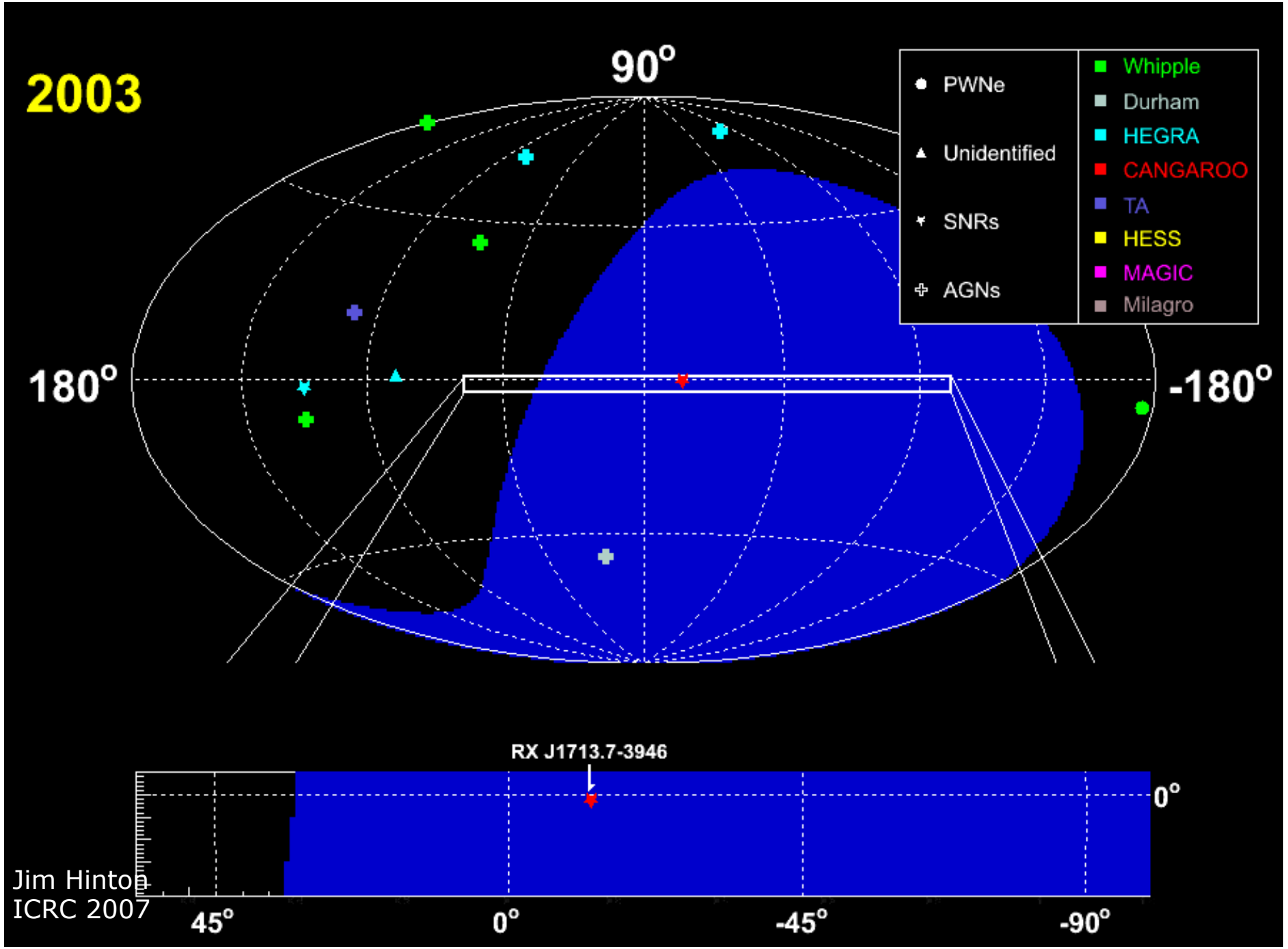
■ = Pulsar/Plerion ◻ = SNR ★ = Starburst galaxy ○ = OB association

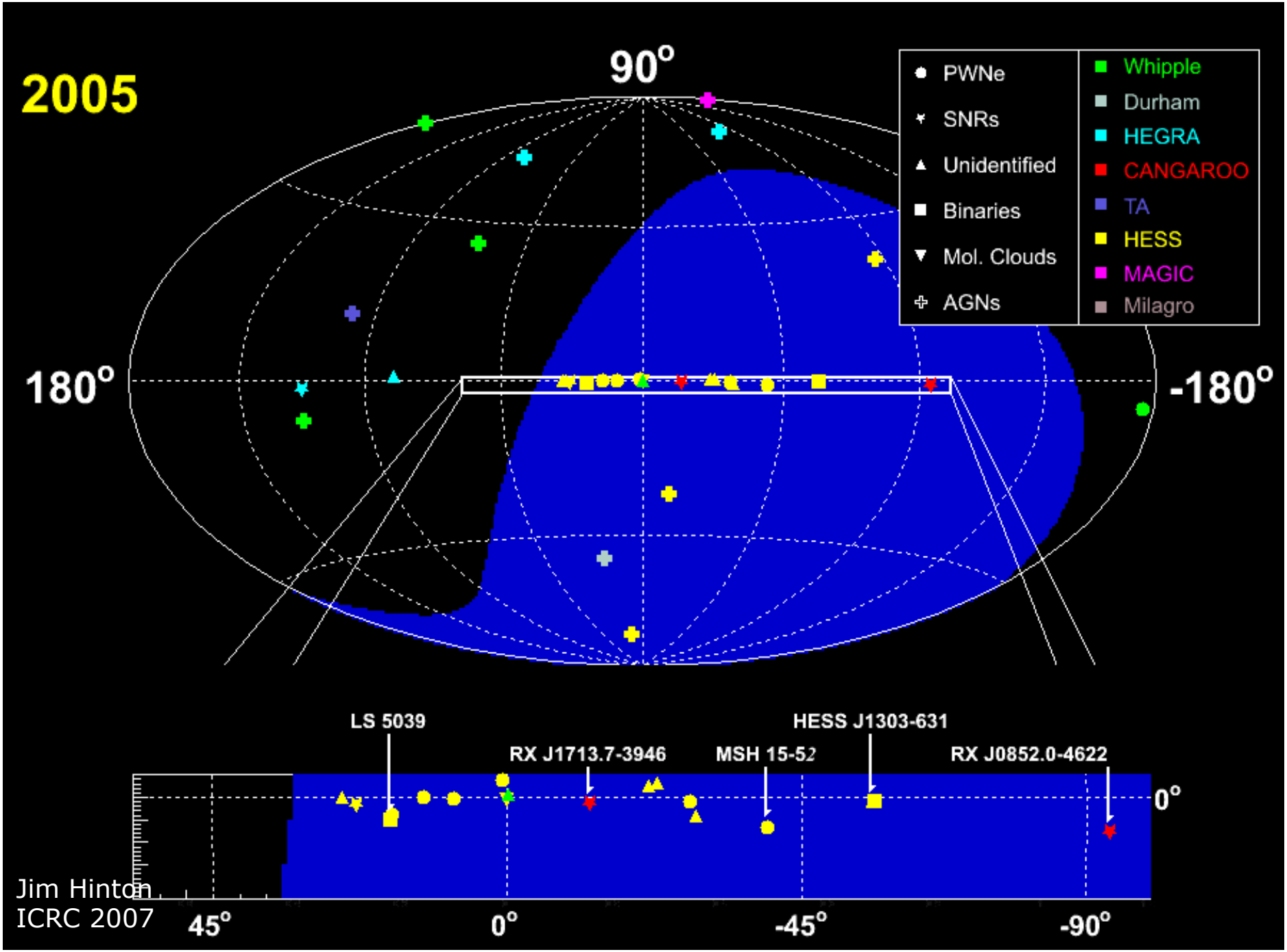
◆ = AGN (BL Lac) ▲ = Radio galaxy ✕ = XRB ● = Undetermined

■ **Pulsar** ◆ **AGN**

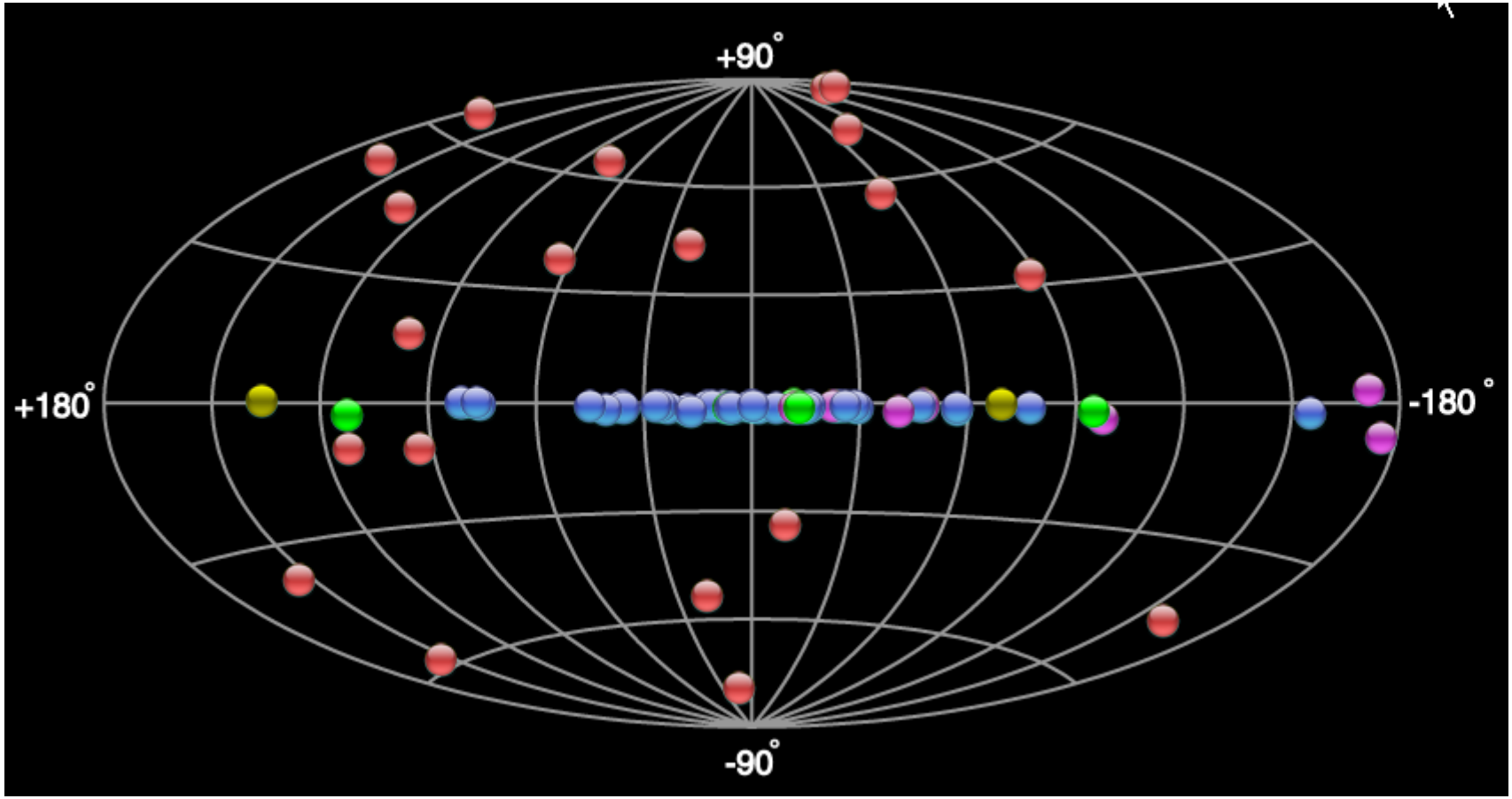


Jim Hinton
ICRC 2007


2003
90°
180°
-180°
PWNe
Unidentified
SNRs
AGNs
Whipple
Durham
HEGRA
CANGAROO
TA
HESS
MAGIC
Milagro
RX J1713.7-3946
0°
45°
0°
-45°
-90°
Jim Hinton
ICRC 2007

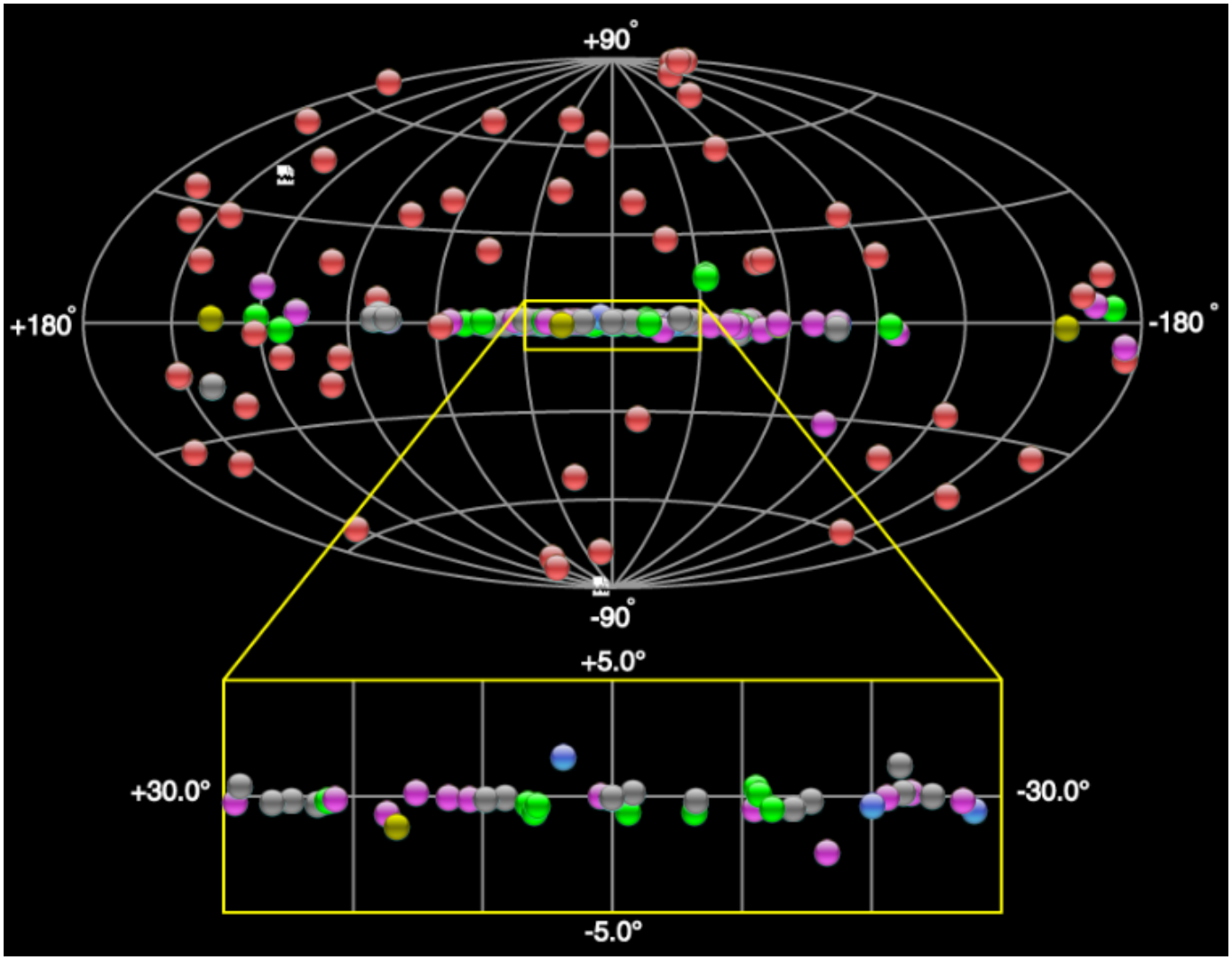

2005
90°
180°
-180°
PWNe
SNRs
Unidentified
Binaries
Mol. Clouds
AGNs
Whipple
Durham
HEGRA
CANGAROO
TA
HESS
MAGIC
Milagro
LS 5039
RX J1713.7-3946
MSH 15-52
HESS J1303-631
RX J0852.0-4622
0°
45°
0°
-45°
-90°
Jim Hinton
ICRC 2007

TeV Source Catalog

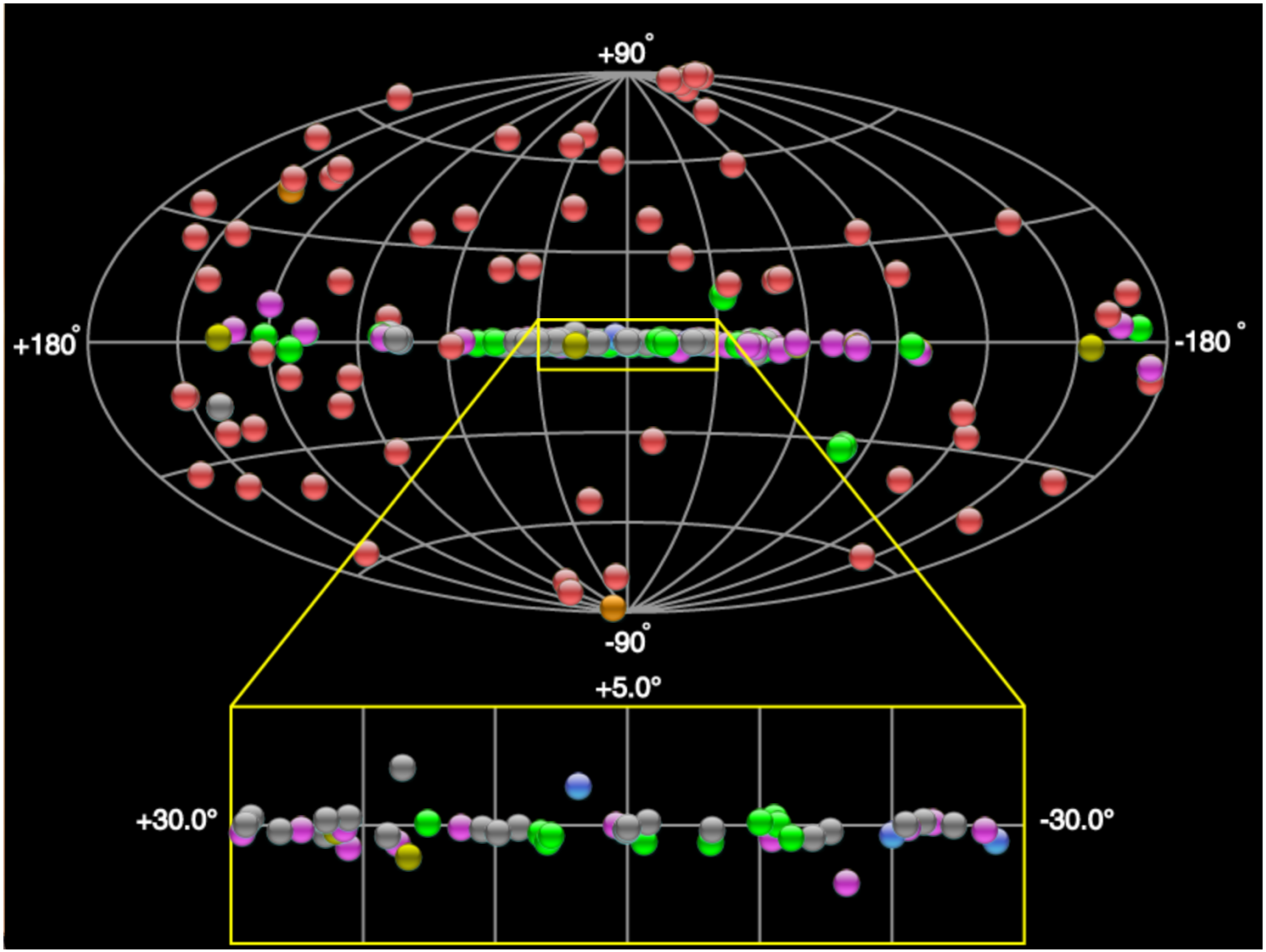


http://tevcat.uchicago.edu/

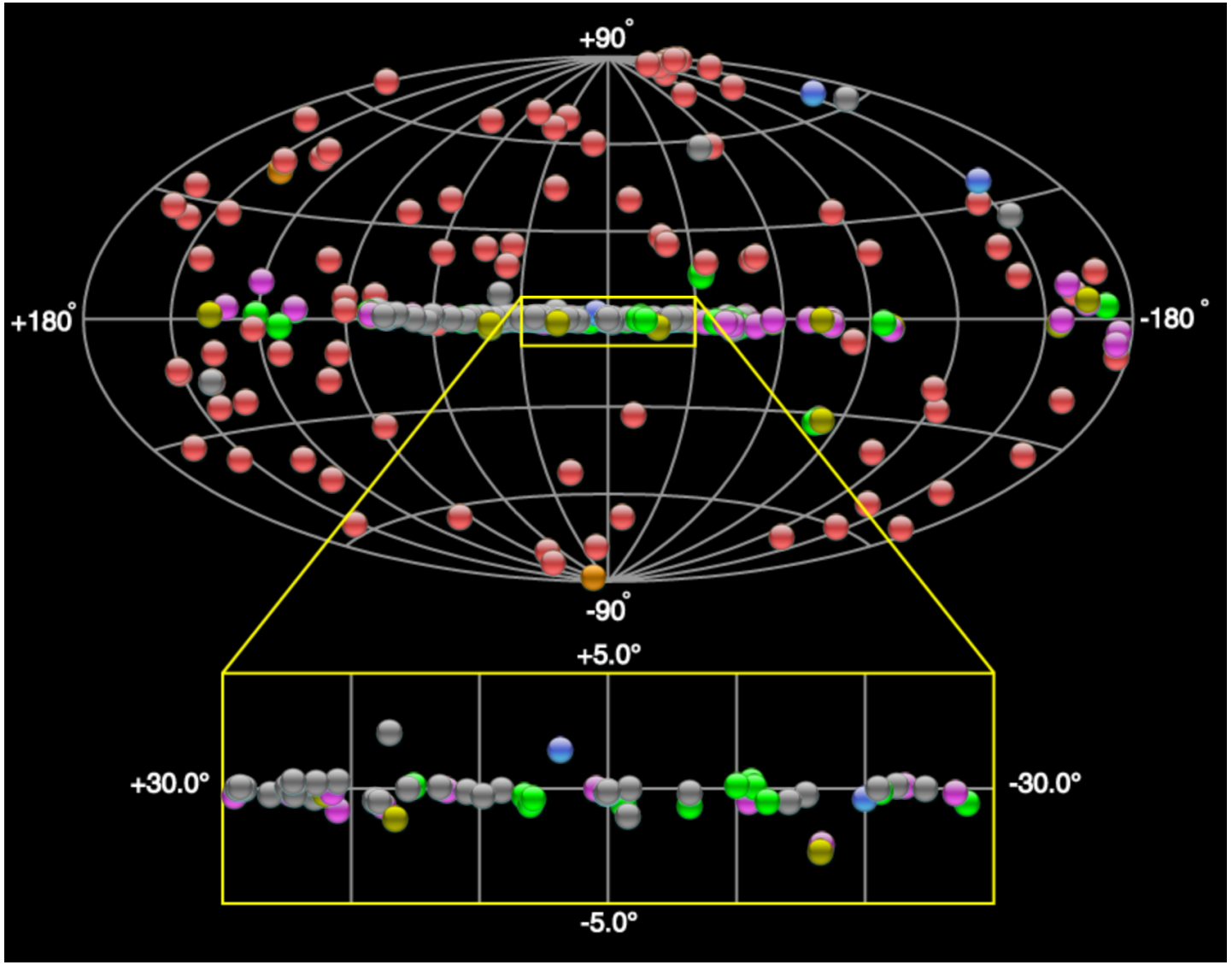
The TeV Catalog 2012



The TeV Catalog 2016

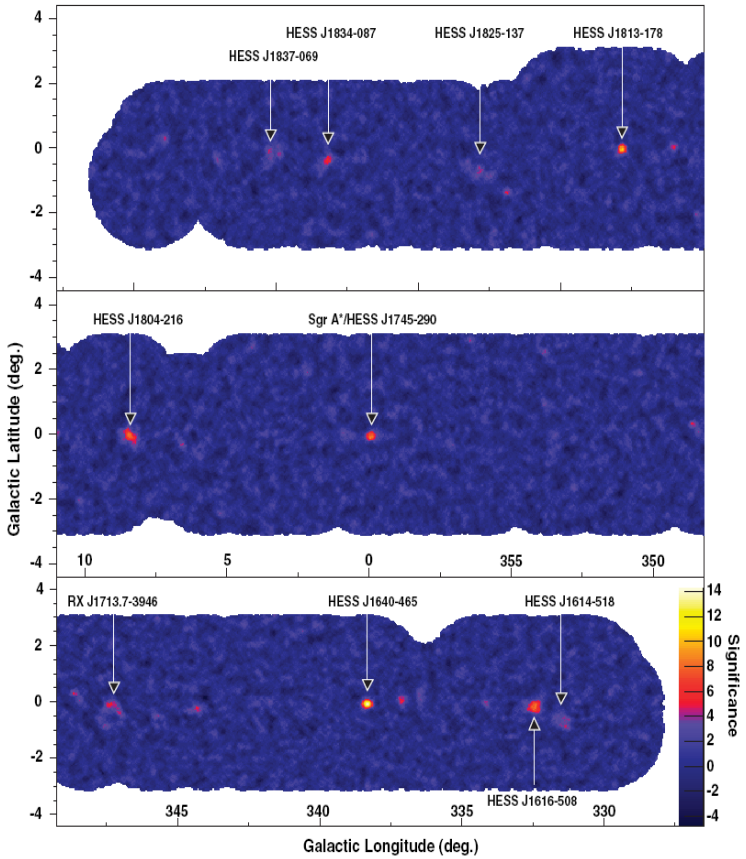


The TeV Catalog 2021

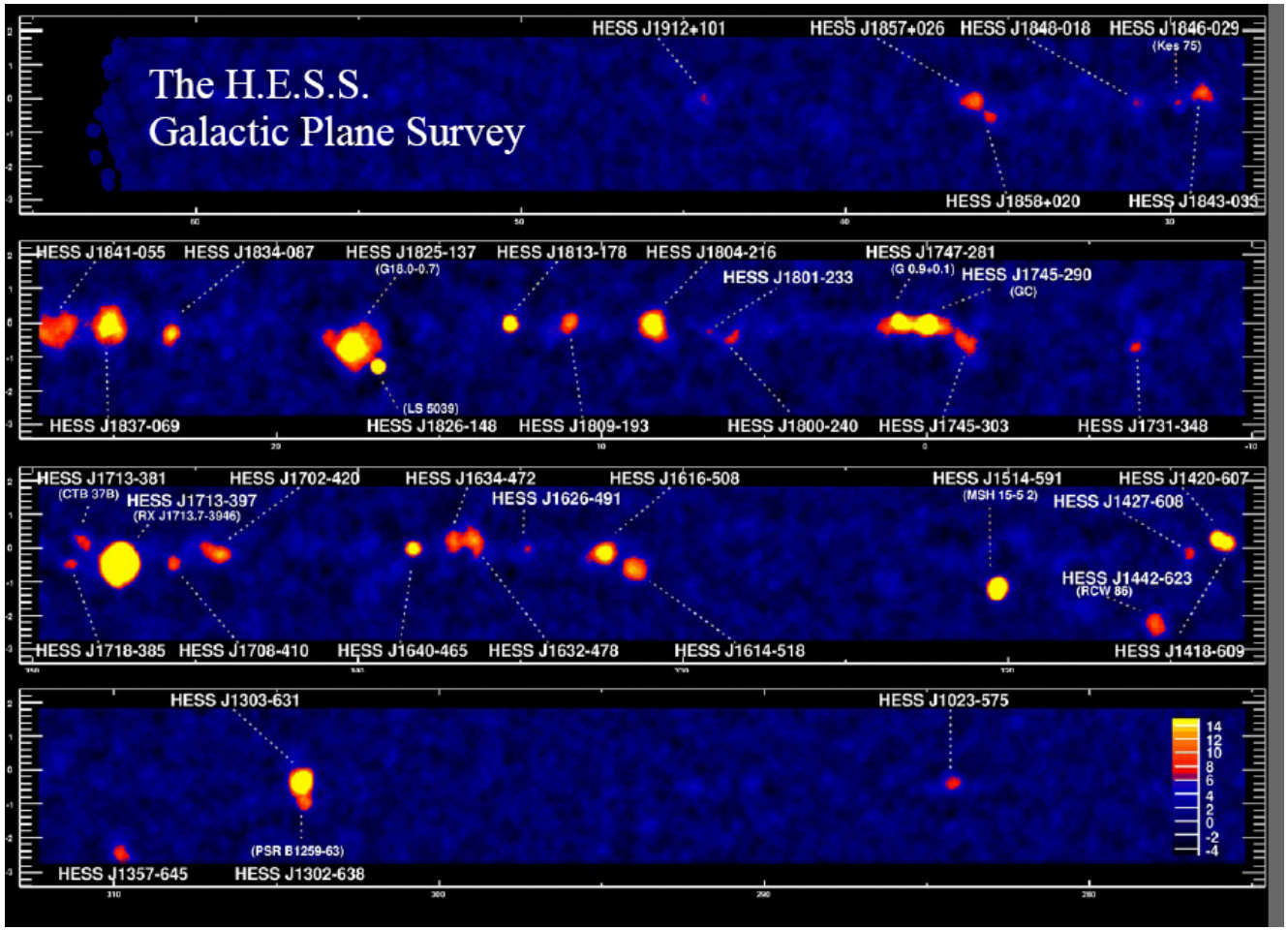


TeV Sky Survey

- HESS Galactic plane survey sees many new TeV sources (Aharonian et al. 2005)
  - This might possibly inform a detailed model of the distribution of CR sources, although the distribution is so confined to the plane that the sources (probably plerions and SNR) are at least several kpc distant

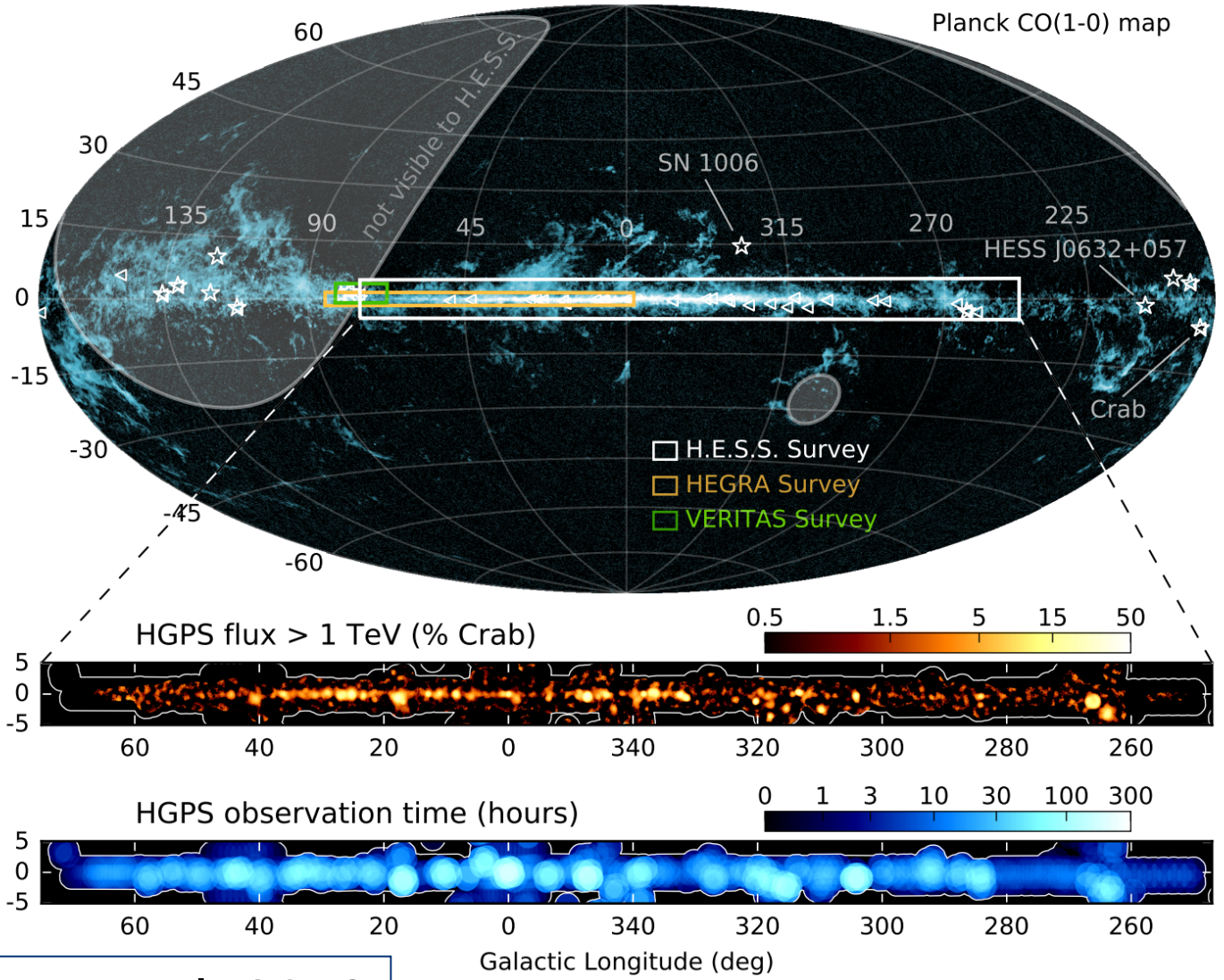


The Galactic Plane survey



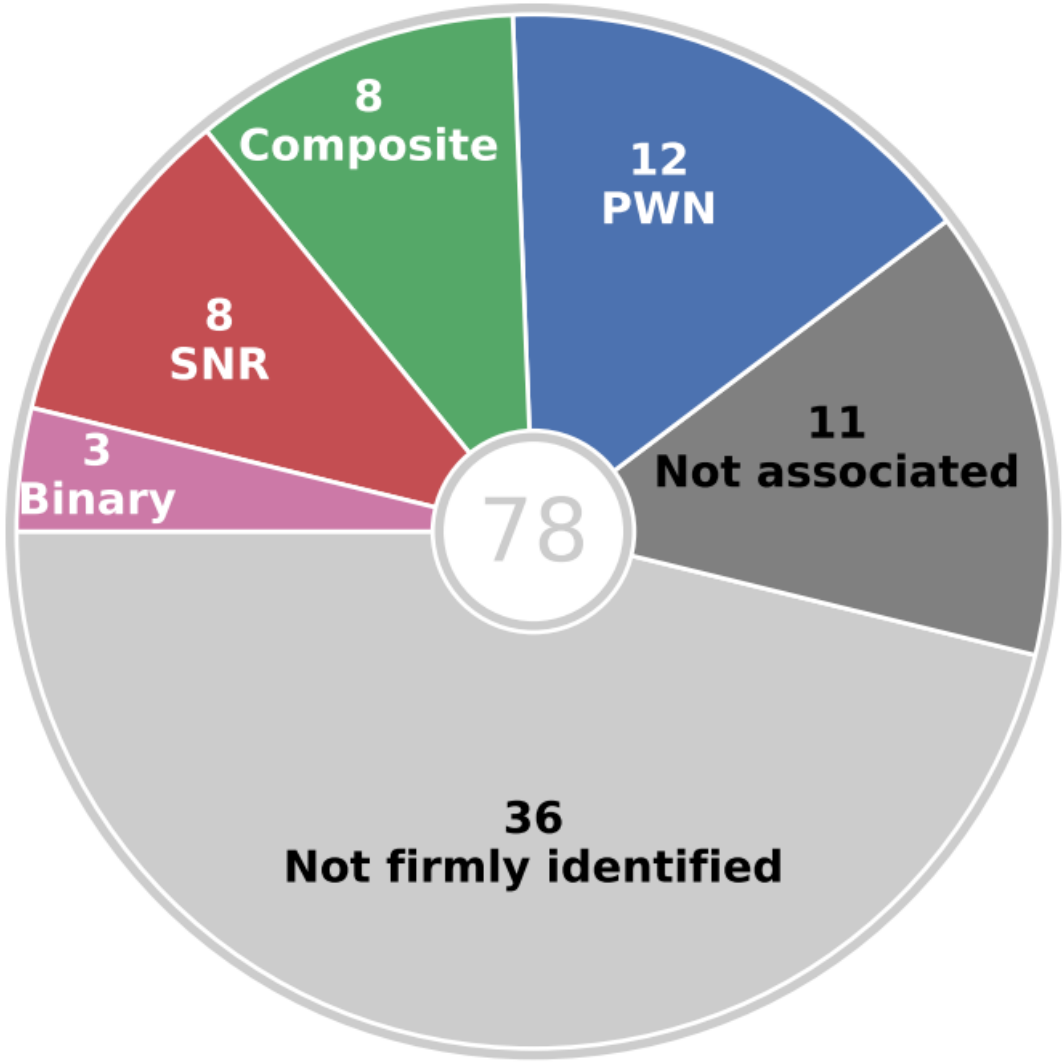
Aharonian et al. 2006

The Galactic Plane survey



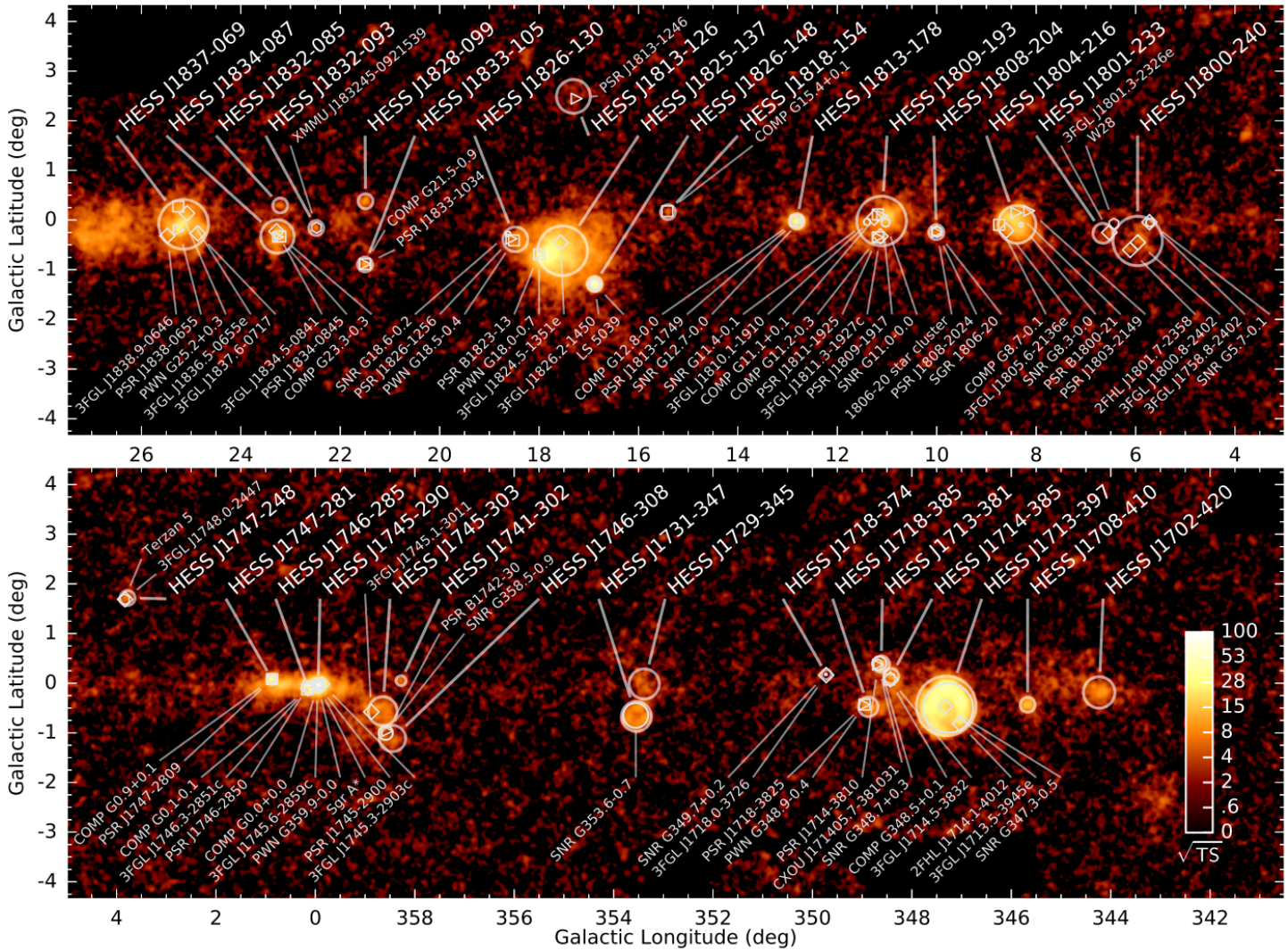
Aharonian et al. 2018

The Galactic Plane survey



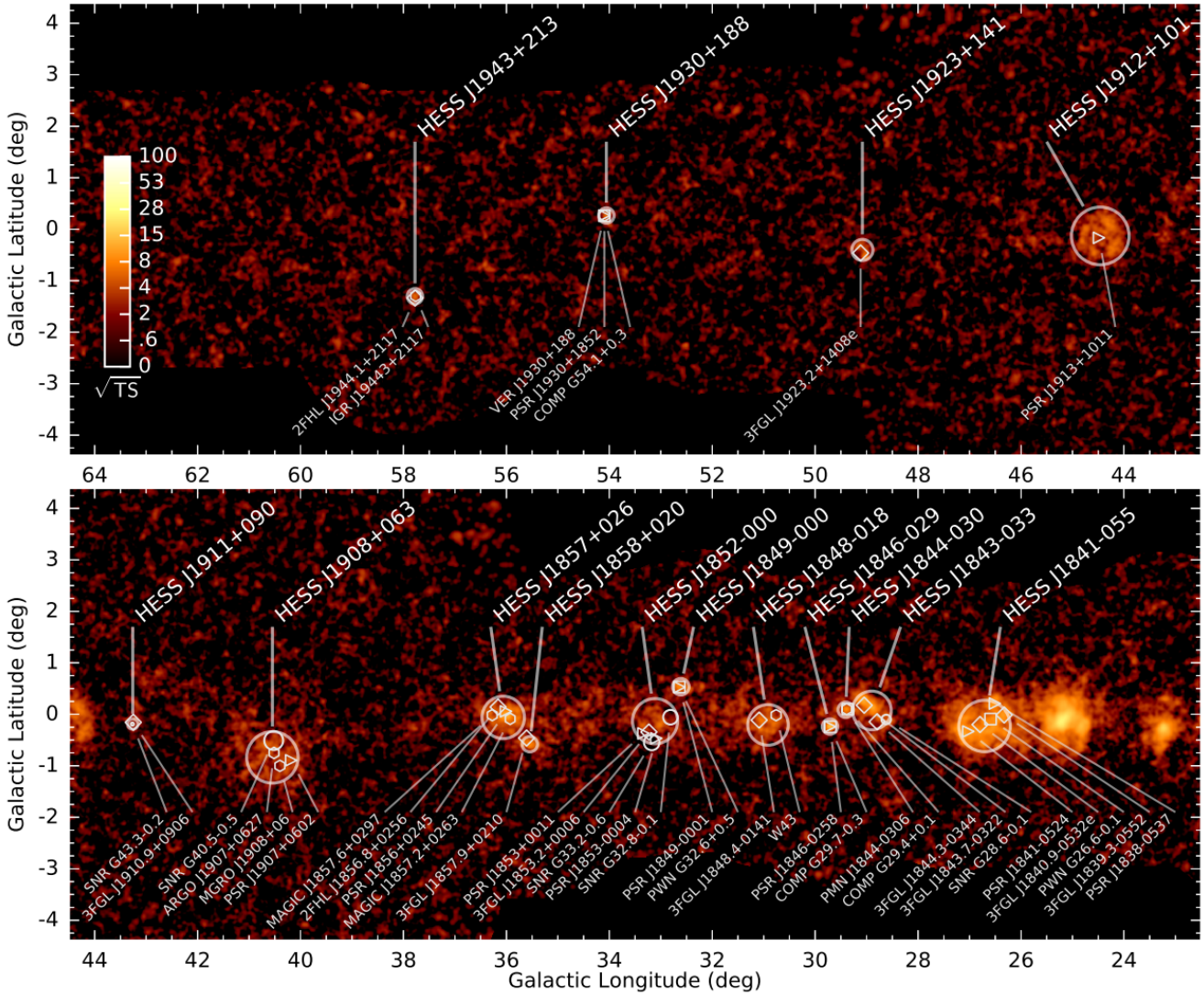
Aharonian et al. 2018

The Galactic Plane survey



Aharonian et al. 2018

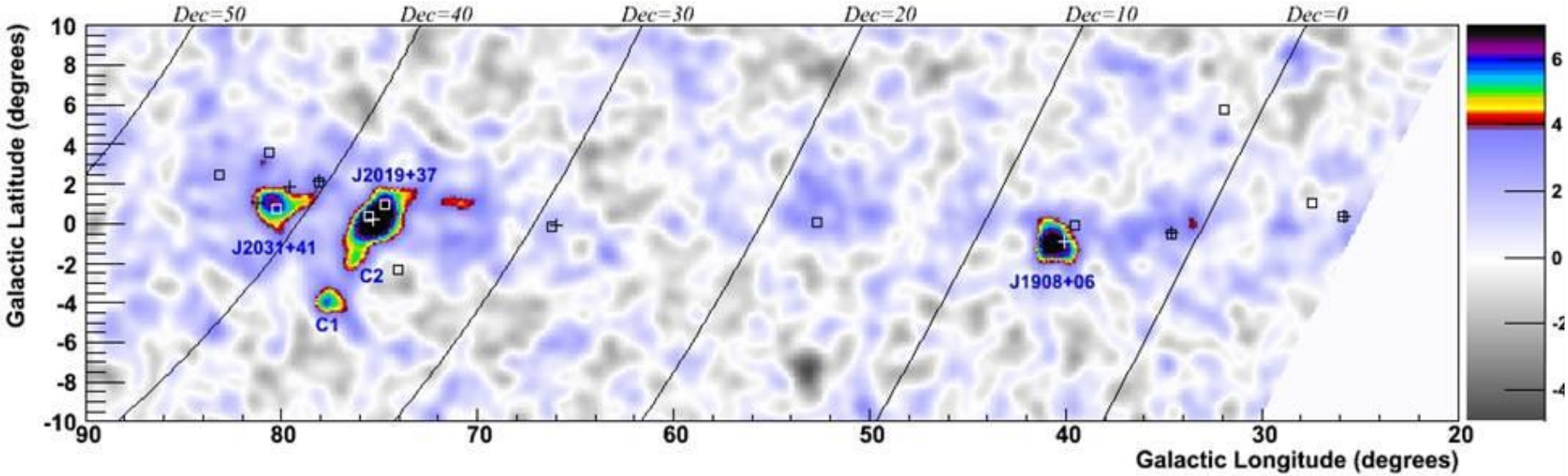
The Galactic Plane survey



Aharonian et al. 2018

MILAGRO Sky Survey

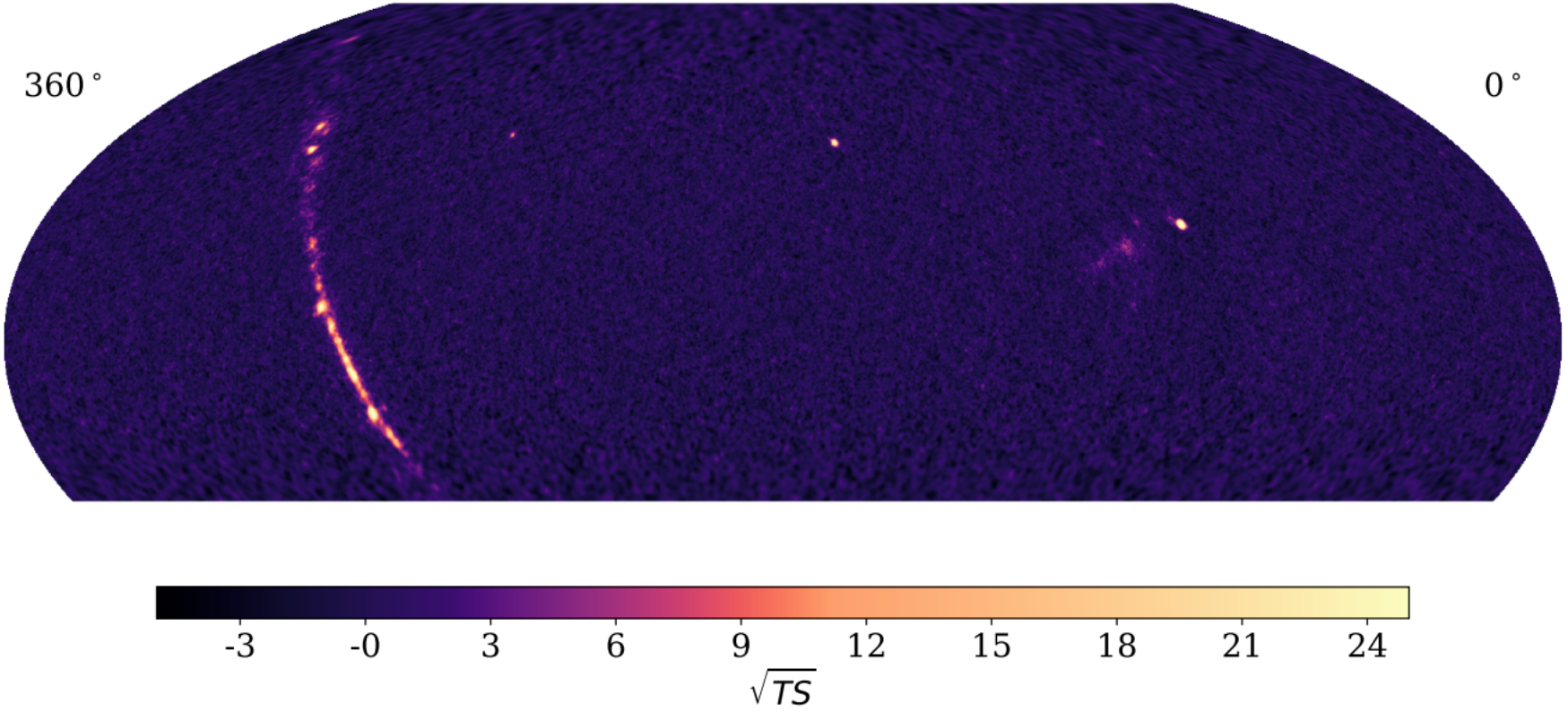
- Milagro reports detecting the diffuse emission of the Milky Way at >1 TeV energies (Abdo et al 2008)



Abdo et al. 2008

HAWC Sky Survey

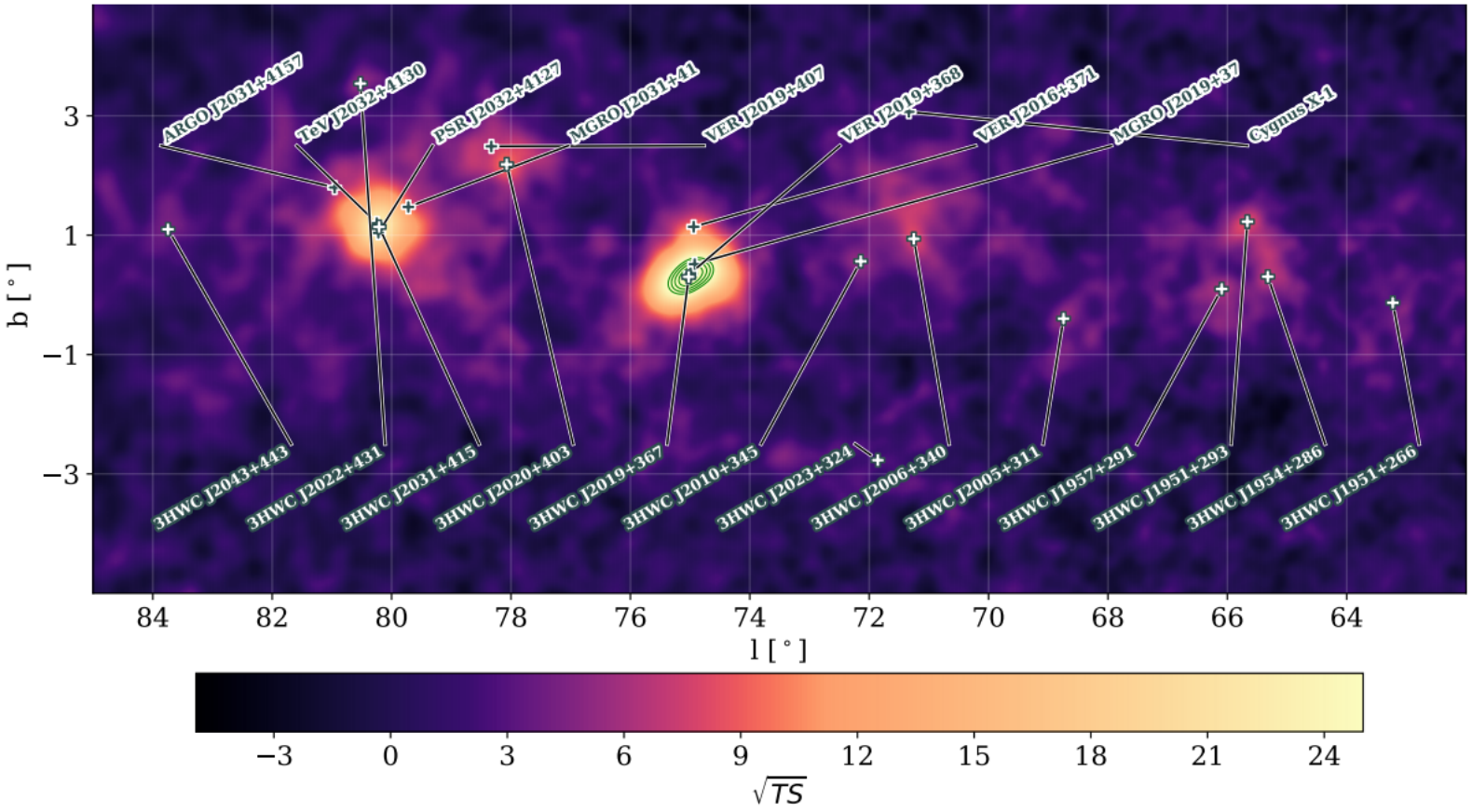
- HAWC 3rd catalog of Gamma Ray sources



Albert et al. 2021

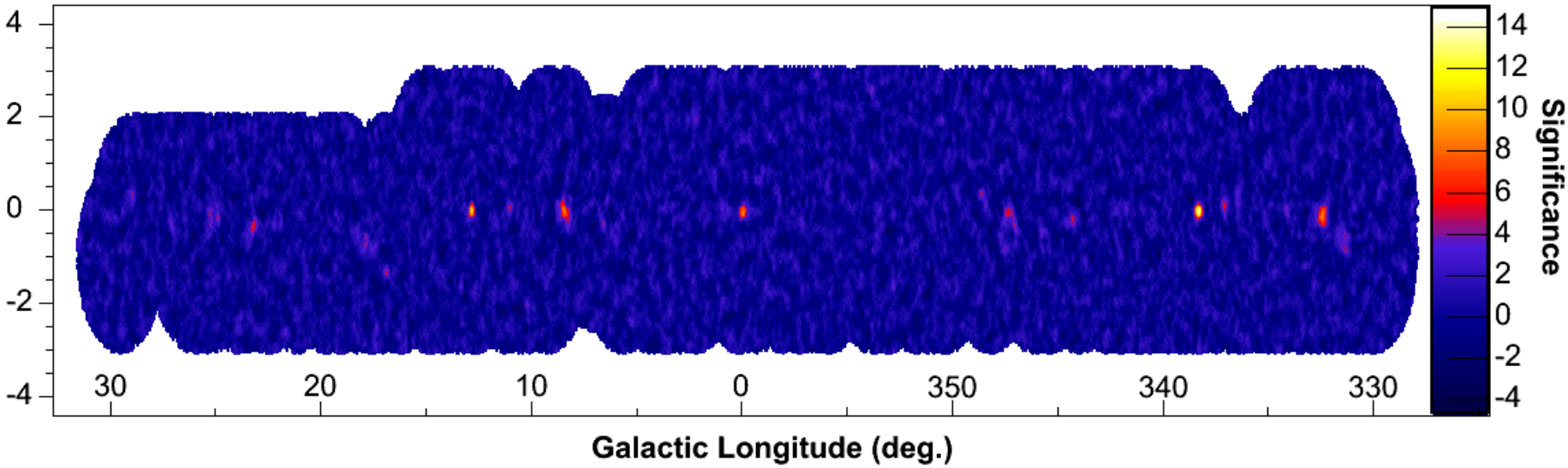
HAWC Sky Survey

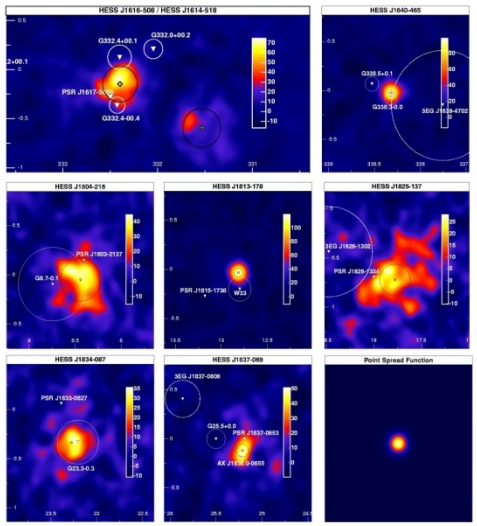
- HAWC 3rd catalog of Gamma Ray sources



Albert et al. 2021

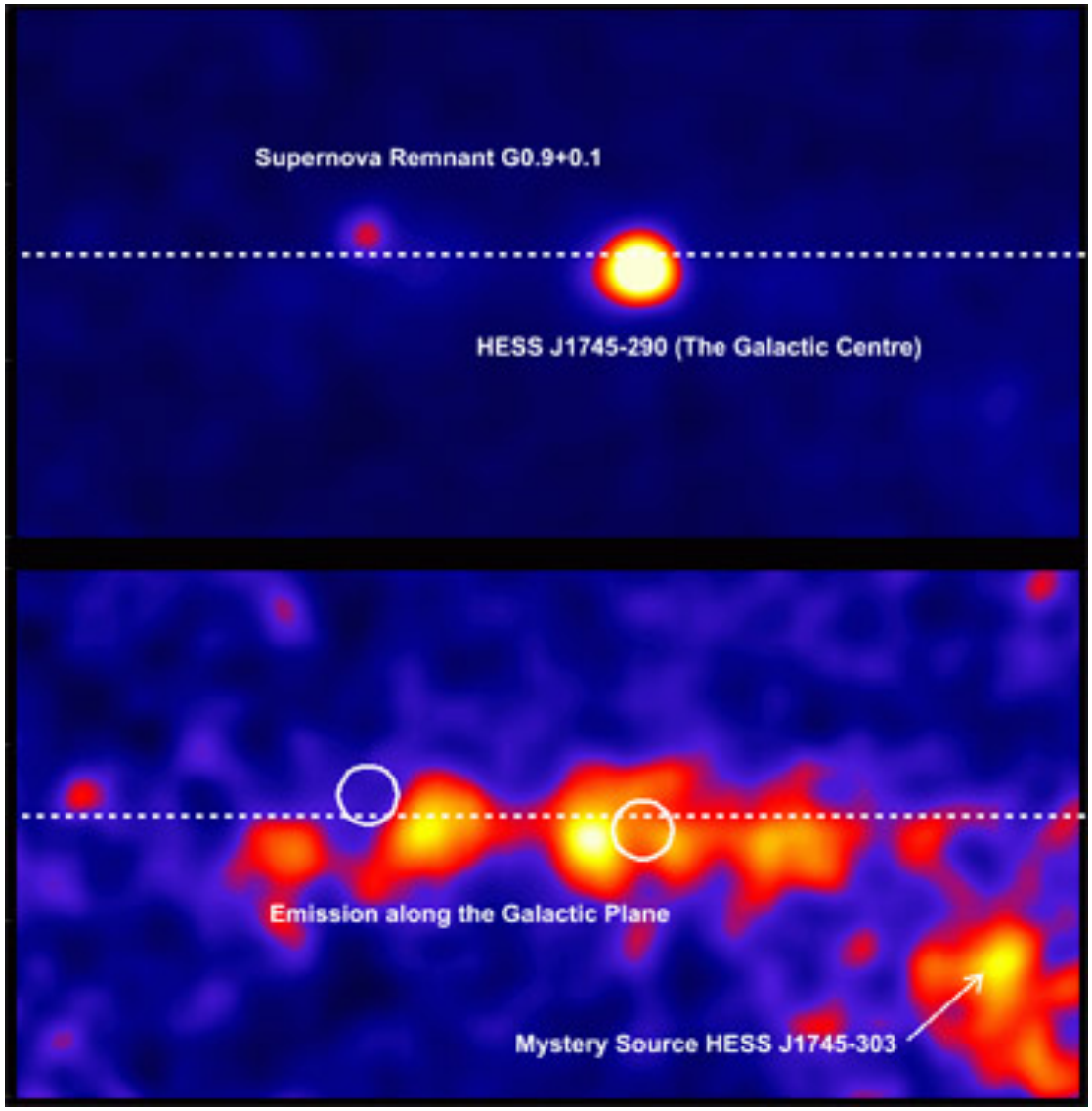
HESS "new" sources



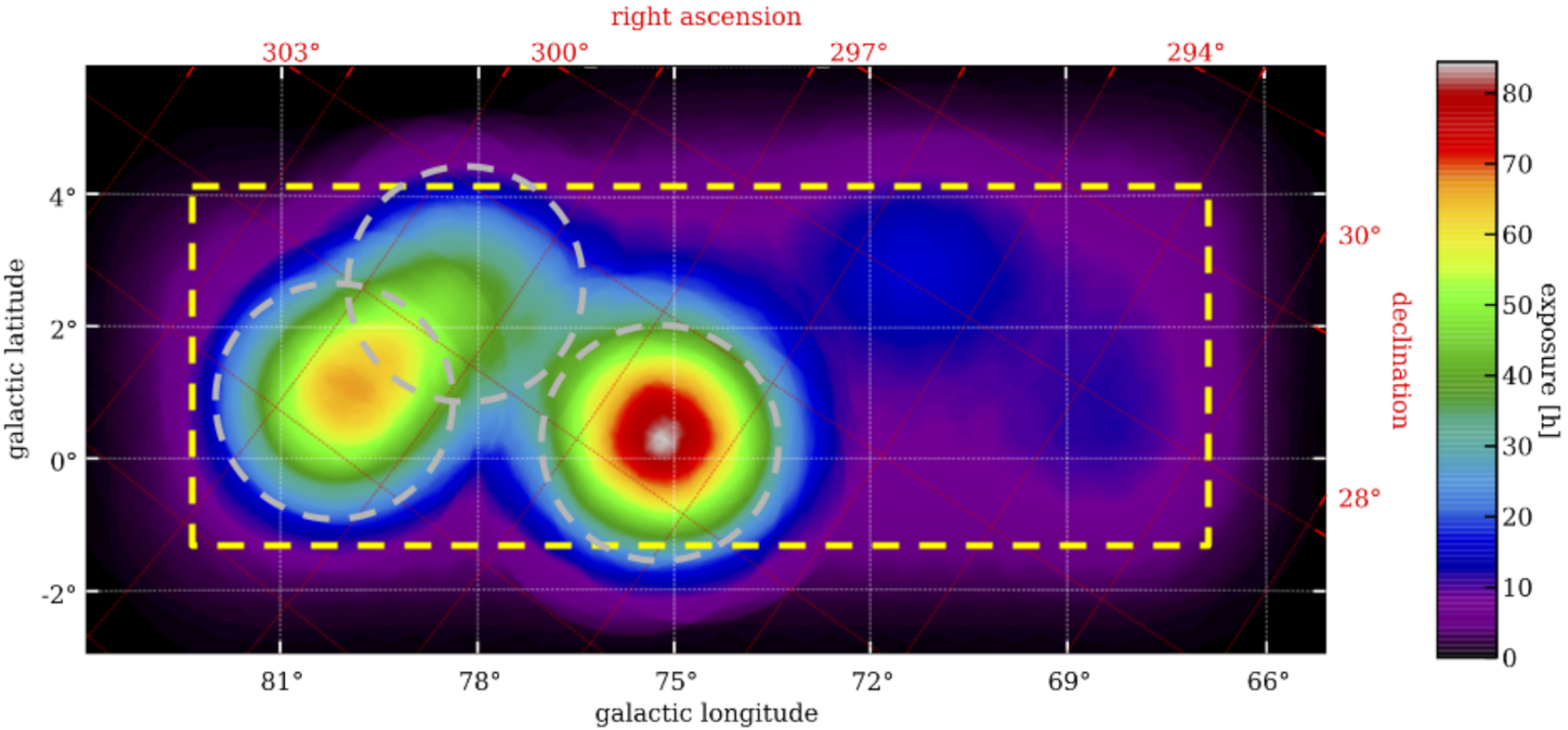


Close-up view of the new sources, discovered in the Galactic plane scan. Shown as white circles are close-by supernova remnants , that are known to be sources of very high energy gamma-rays (with the radius of the circle representing the size of the supernova remnant). Also shown in white are close-by pulsars, another class of sources of very high energy gamma-rays.

HESS Diffuse Gamma-Ray

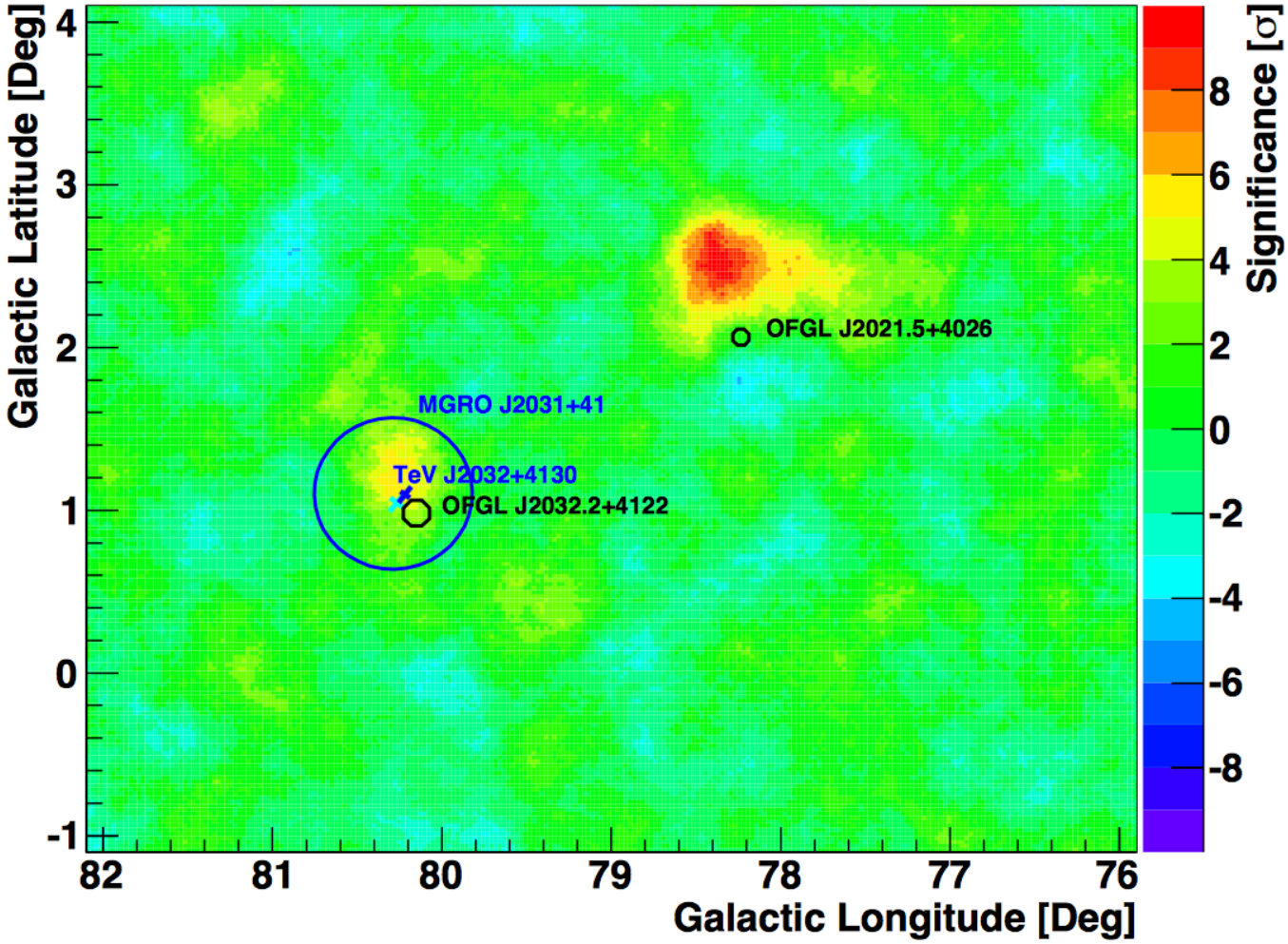


VERITAS Cygnus Survey



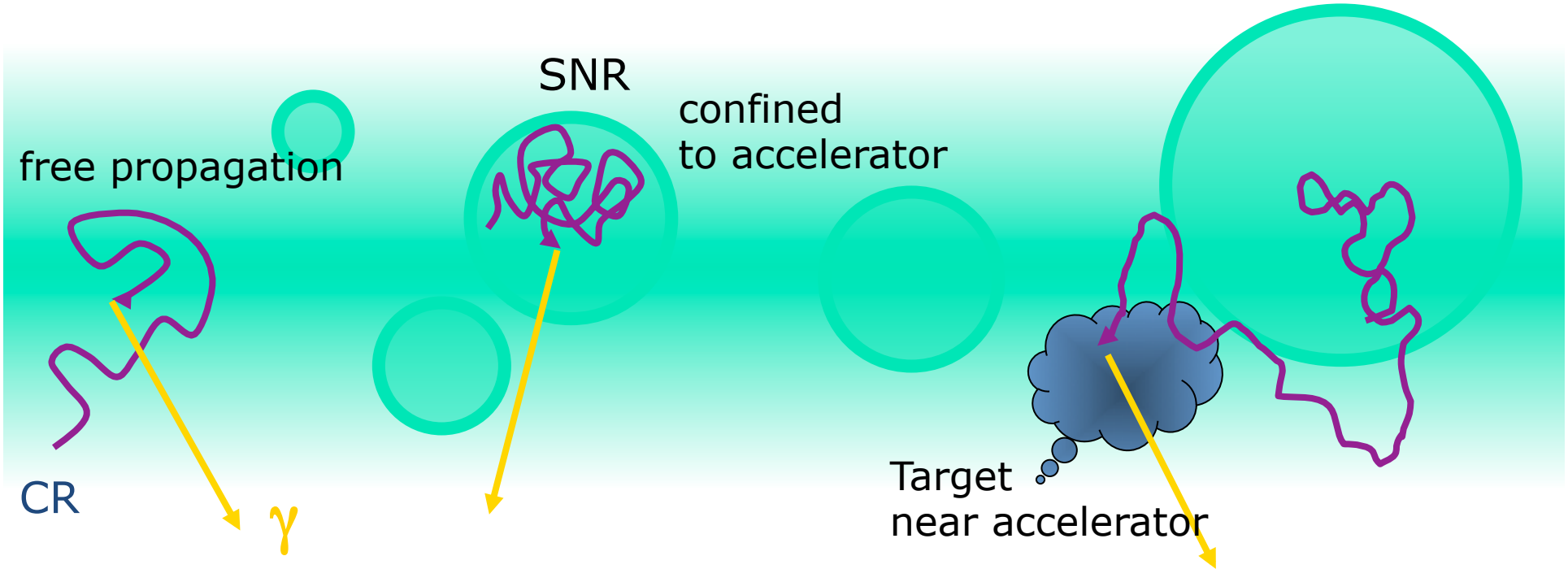
http://arxiv.org/abs/1508.06684

VERITAS Cygnus Survey



http://arxiv.org/abs/0912.4492

CR origin and propagation



VHE gamma rays from secondary interactions:

p: π^o production and decay

e: Inverse Compton scattering and Bremsstrahlung

Trace beam density x target density