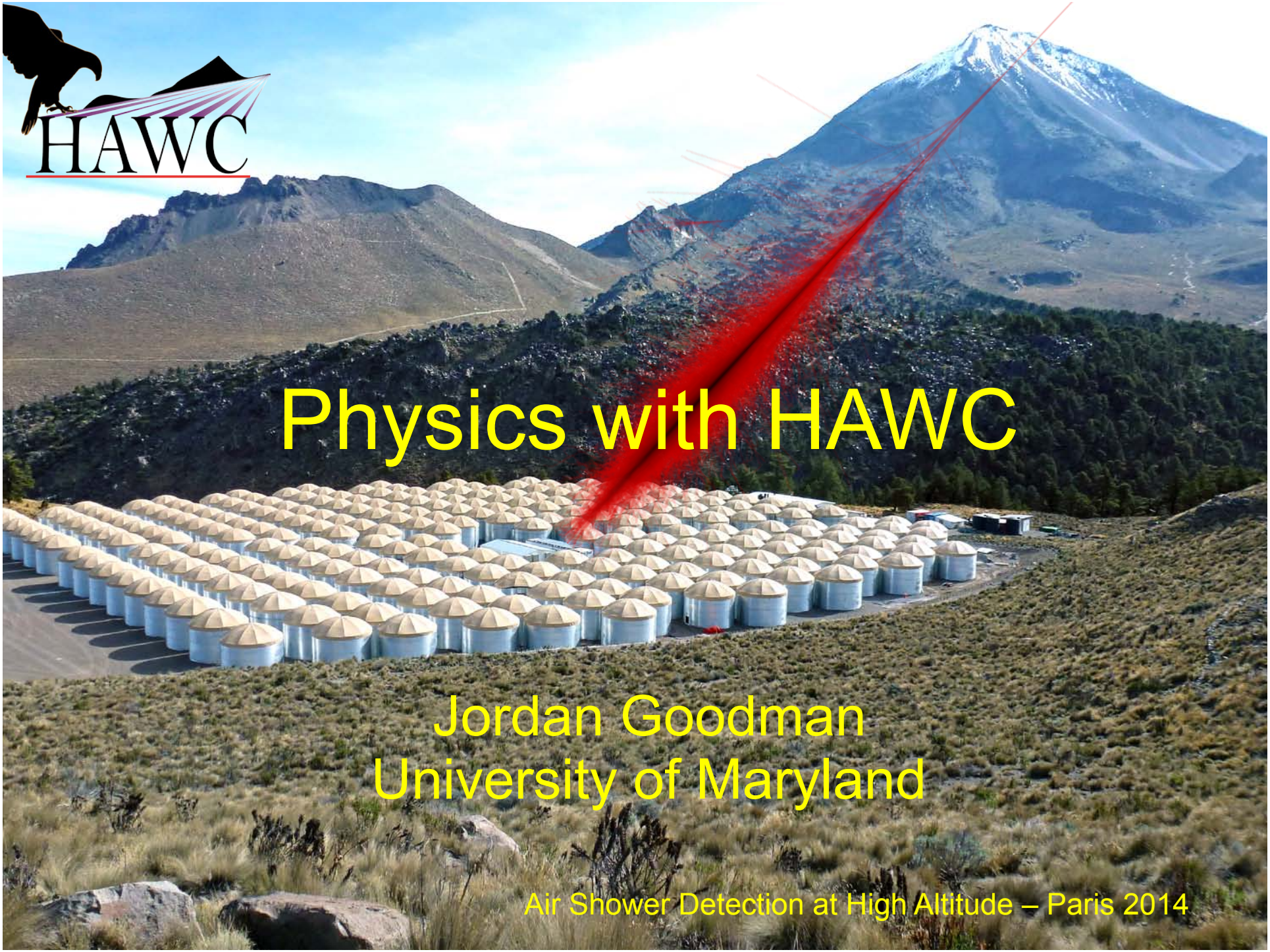
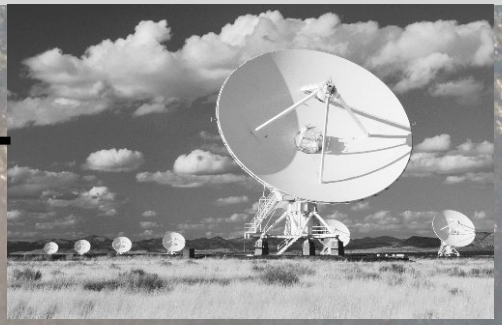

HAWC
Physics with HAWC
Jordan Goodman
University of Maryland
Air Shower Detection at High Altitude – Paris 2014


USA
The HAWC Collaboration
Mexico
HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory
HAWC Collaboration Meeting, February 25-27, 2014
Universidad Autónoma del Estado de Hidalgo
Pachuca, Hidalgo

Observatories

Radio



Infrared

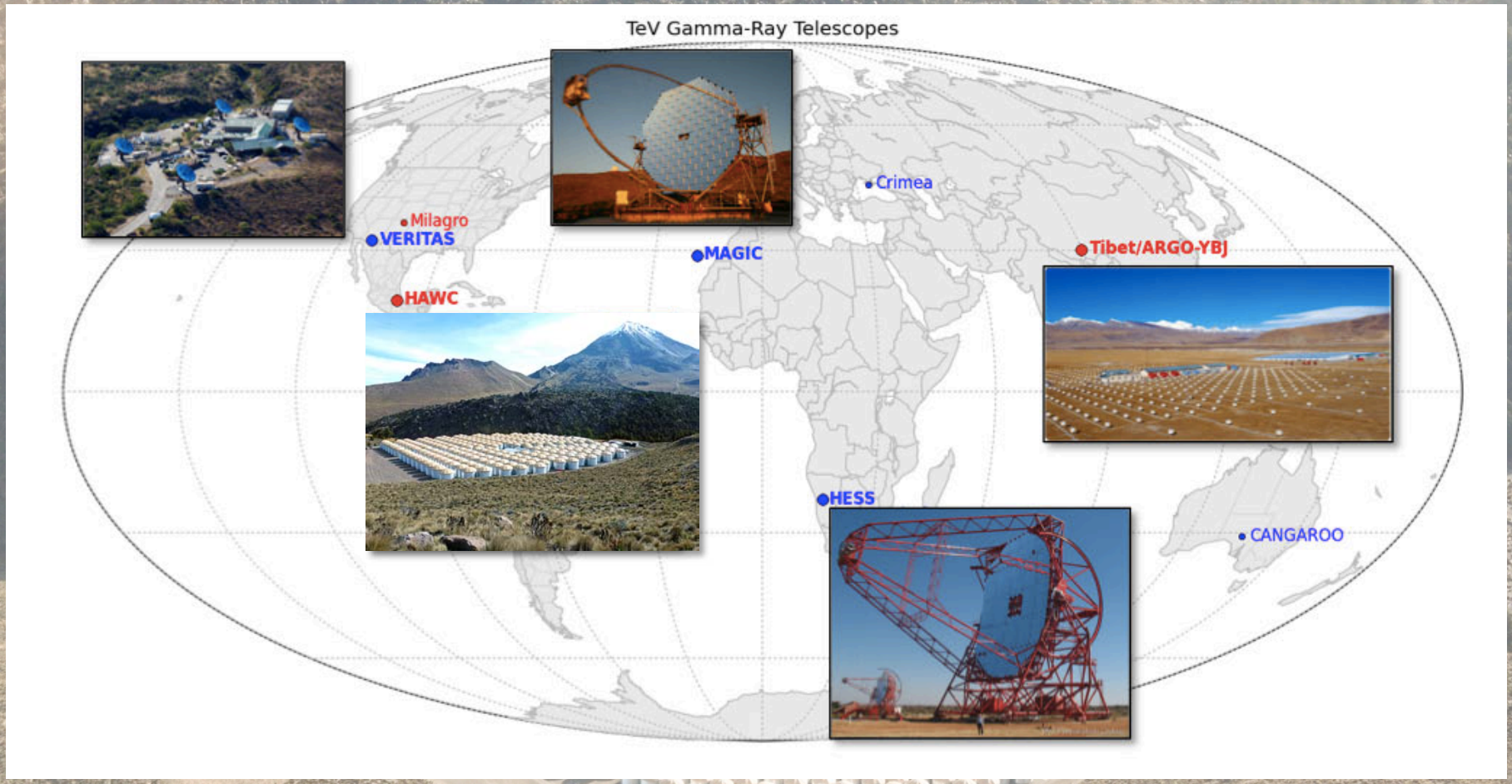
Optical

X-ray

Gamma-ray

TeV Gamma-ray

TeV Observatories



- IACT: low uptime, small FOV, excellent bkg rejection and angular resolution
-> deep surveys, point sources, high-resolution energy spectra
- Arrays: high uptime, large FOV, good background rejection and angular resolution
-> unbiased surveys, transients, extended/diffuse emission,
cosmic rays and solar physics

Milagro

2630 m altitude

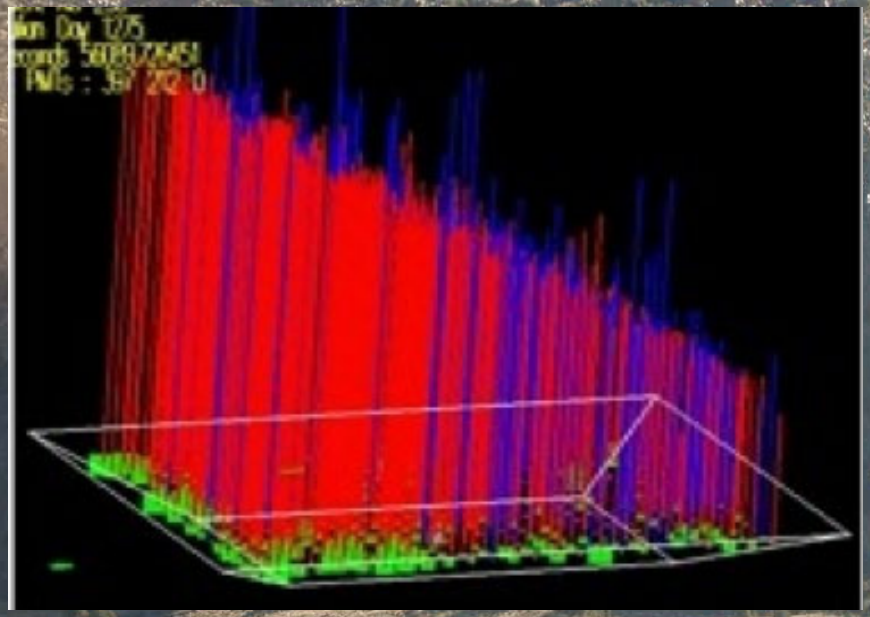
Pond: 80 m x 60 m

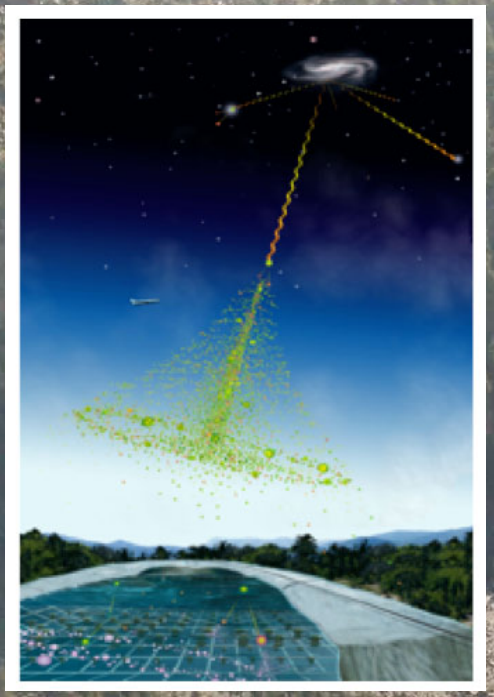
8 m deep

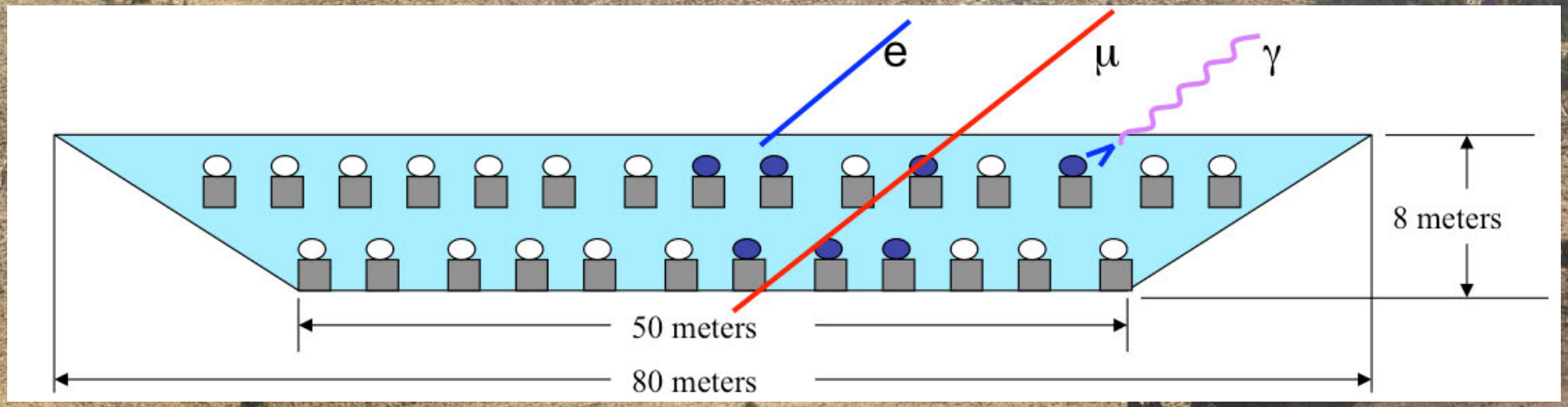
175 outriggers

The Milagro Pond

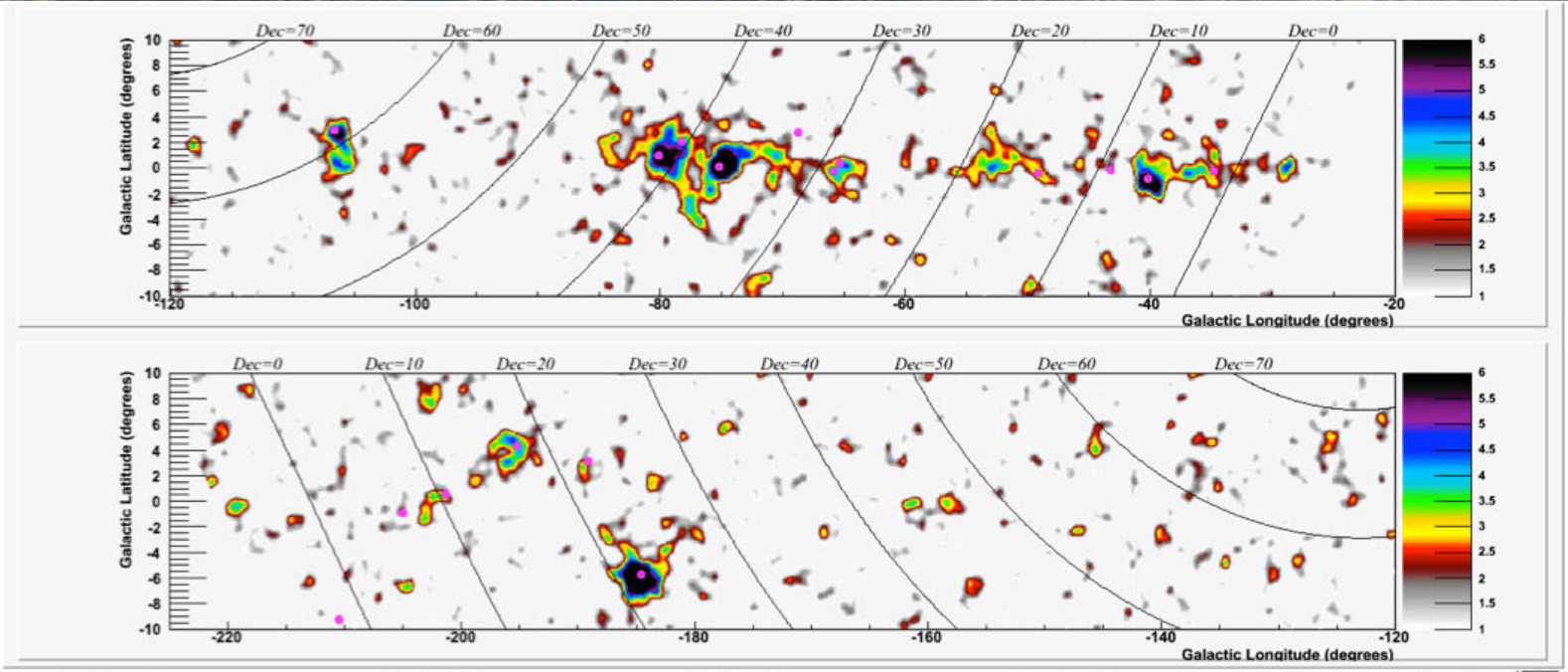
Air Shower Detection

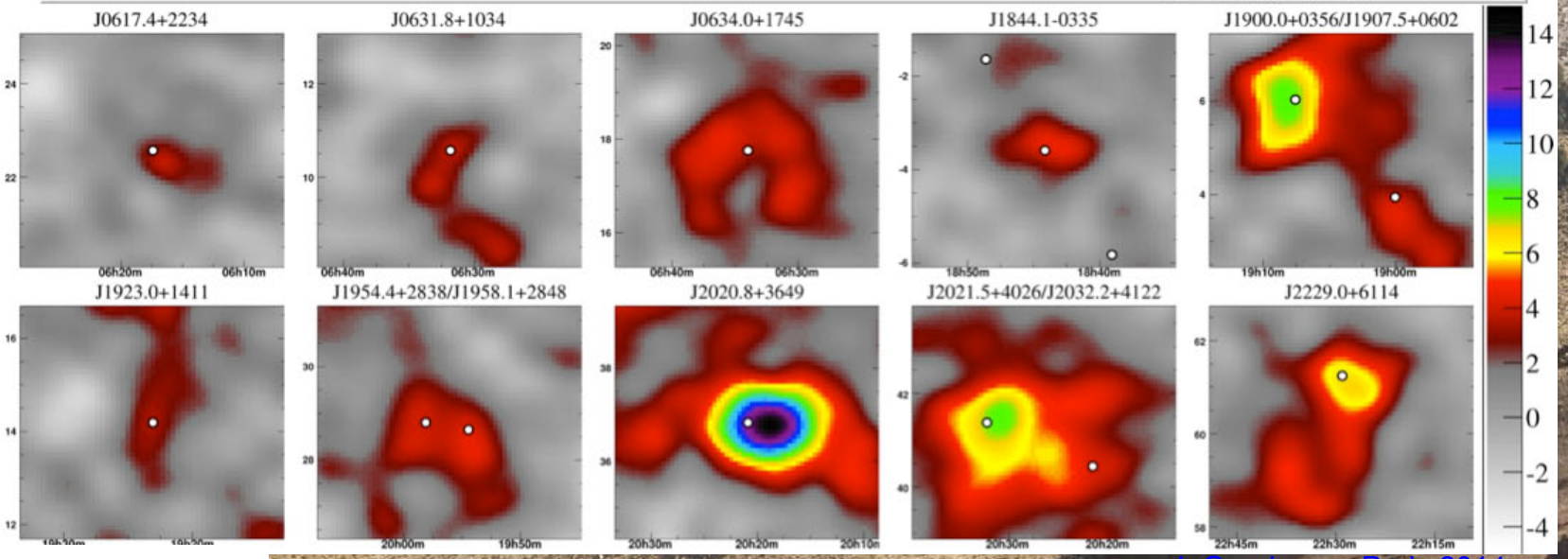




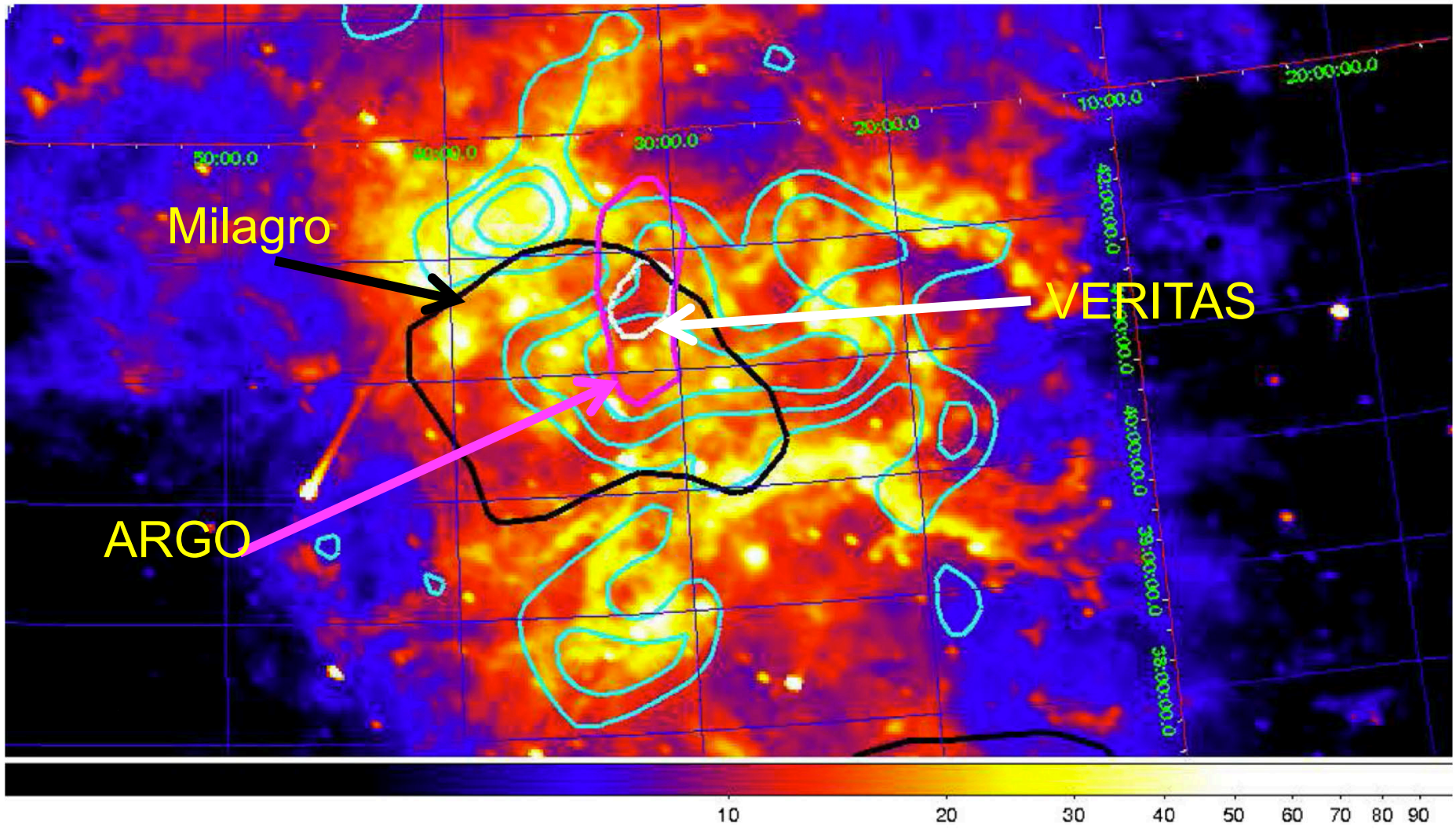


Milagro TeV Sources



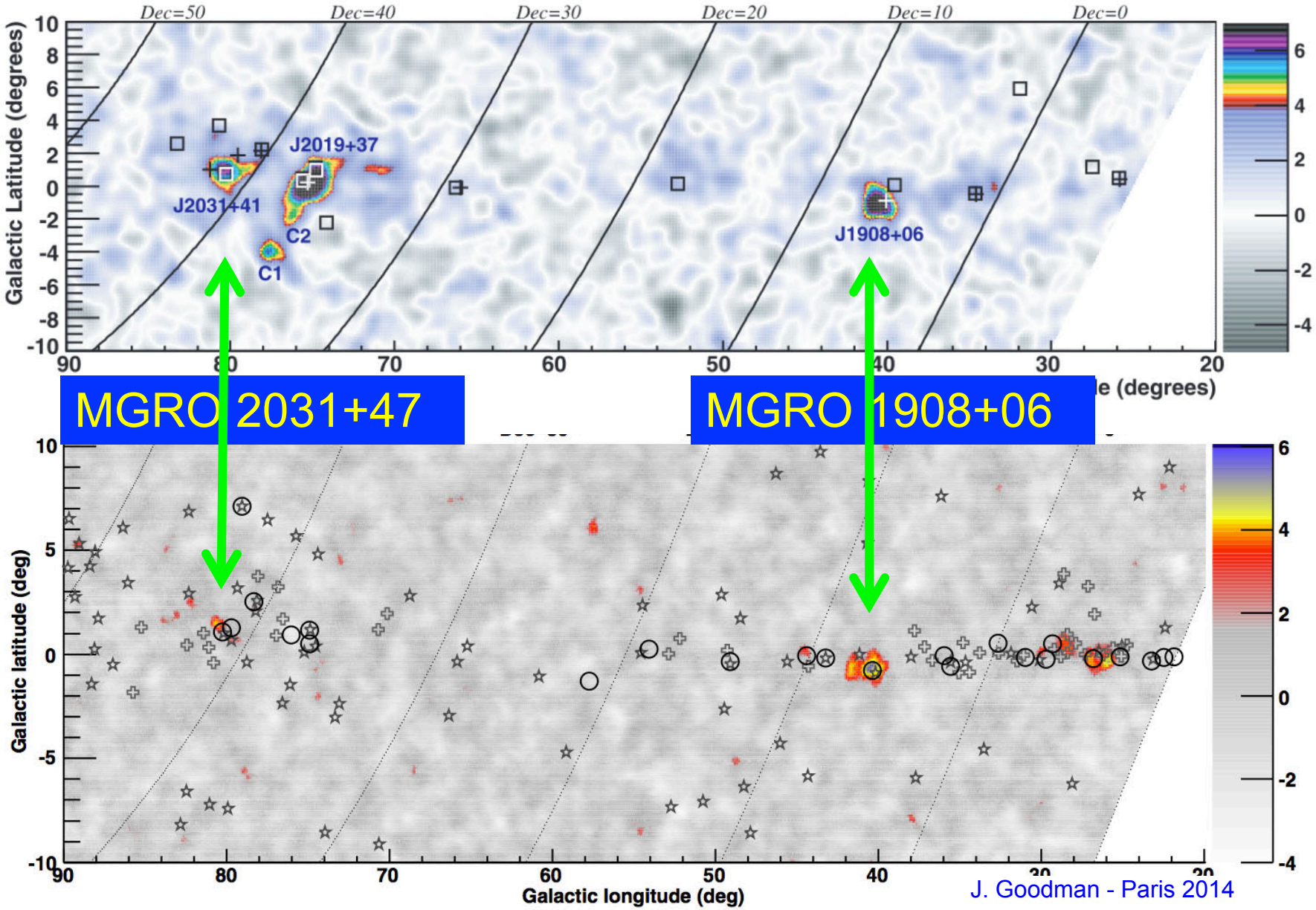


VERITAS-ARGO- Milagro J2032+41

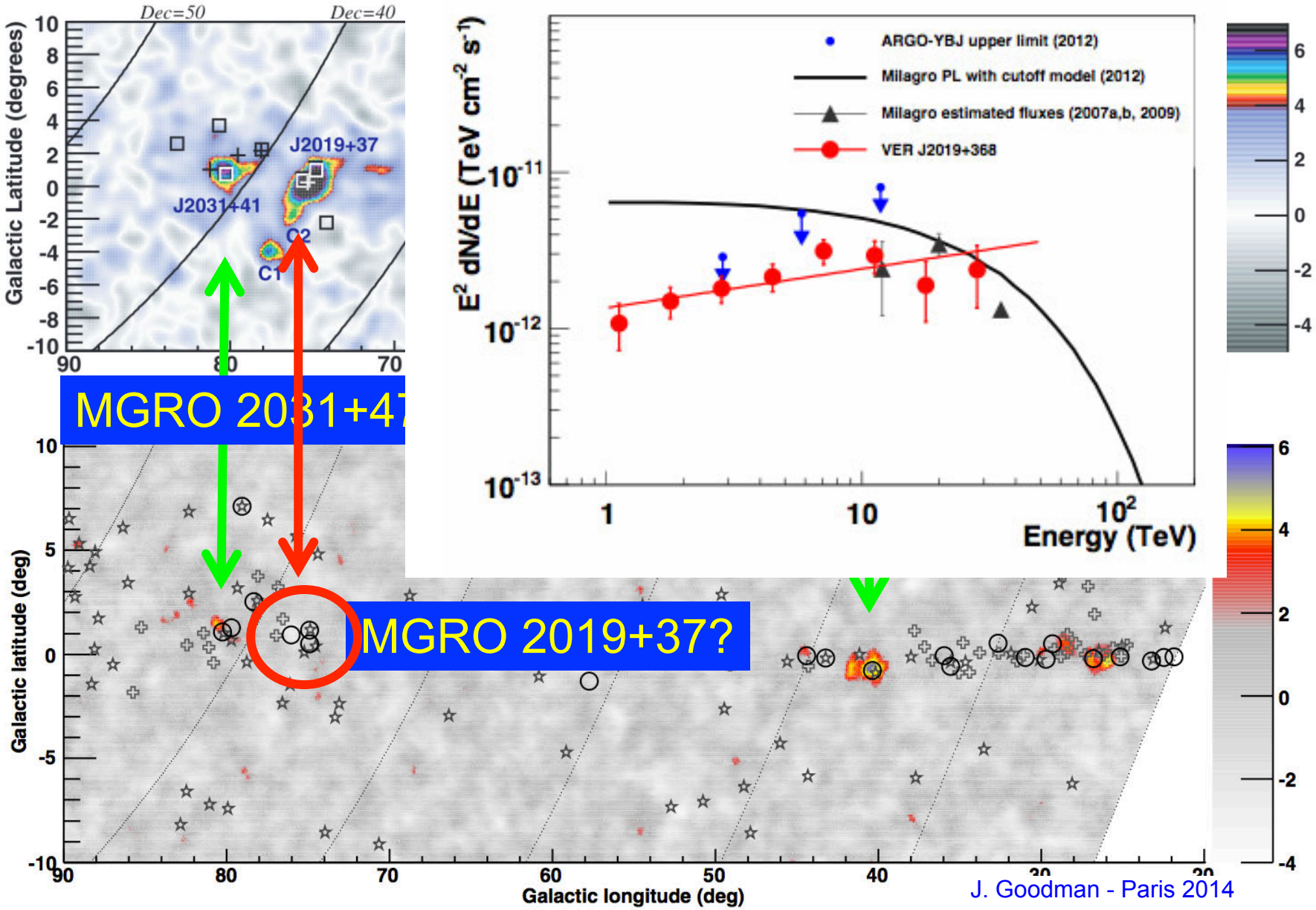


http://adsabs.harvard.edu/abs/2014arXiv1404.7185A

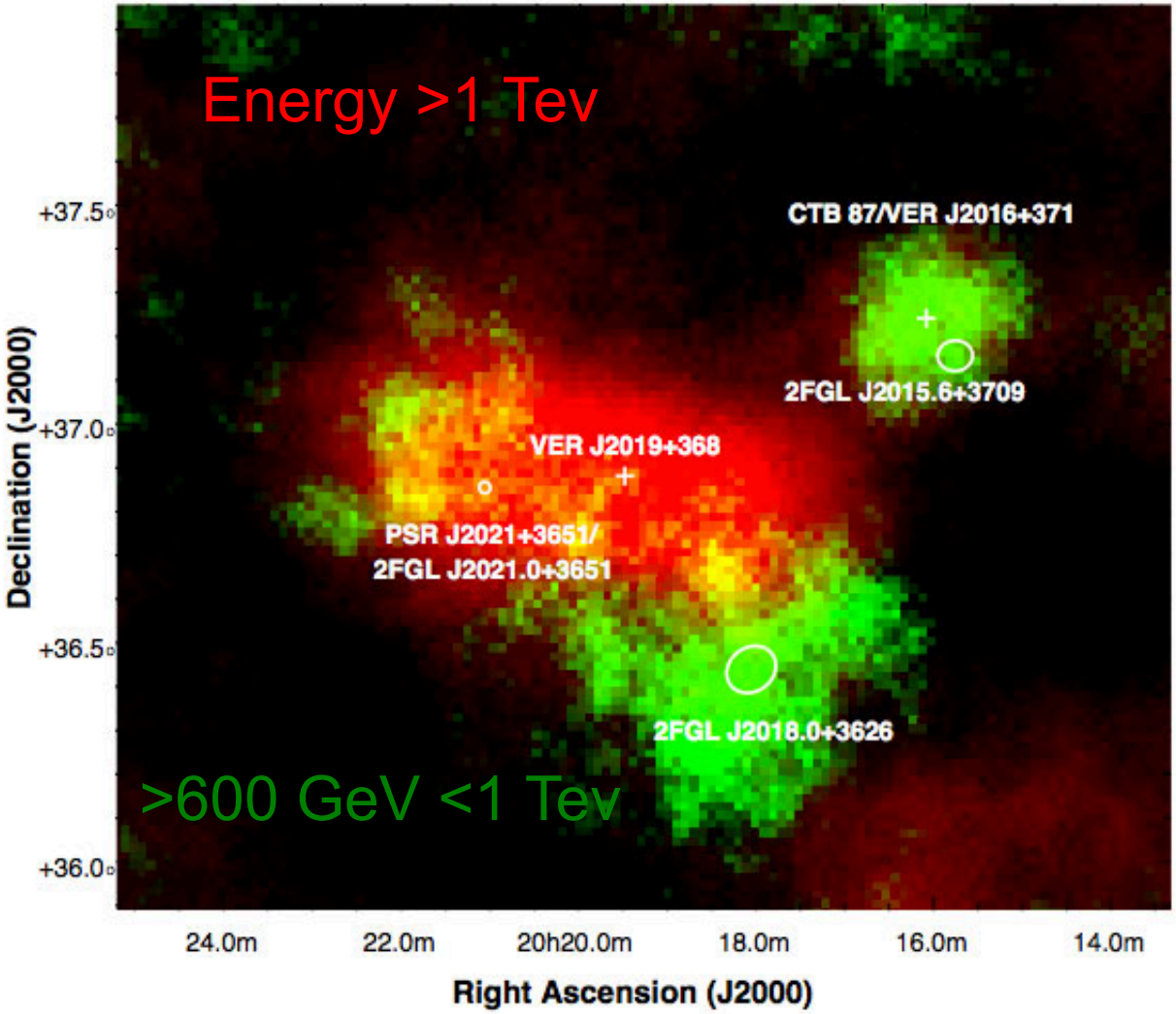
Milagro - ARGO Sky Map



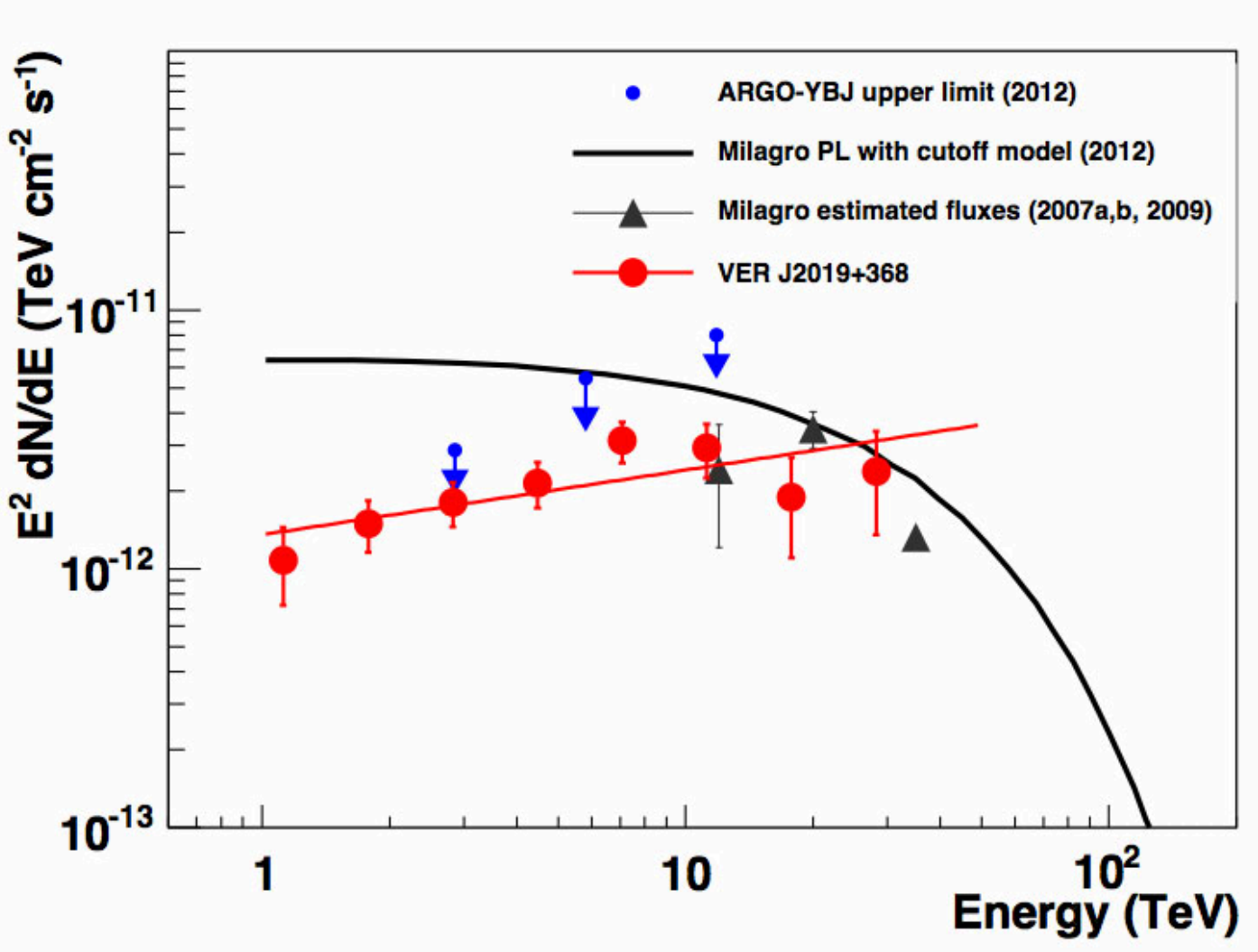
J. Goodman - Paris 2014


Dec=50
Dec=40
Galactic Latitude (degrees)
J2019+37
J2031+41
C2
C1
MGRO 2031+47
ARGO-YBJ upper limit (2012)
Milagro PL with cutoff model (2012)
Milagro estimated fluxes (2007a,b, 2009)
VER J2019+368
E² dN/dE (TeV cm⁻² s⁻¹)
Energy (TeV)
MGRO 2019+37?
Galactic latitude (deg)
Galactic longitude (deg)

VERITAS Observation of 2019+37

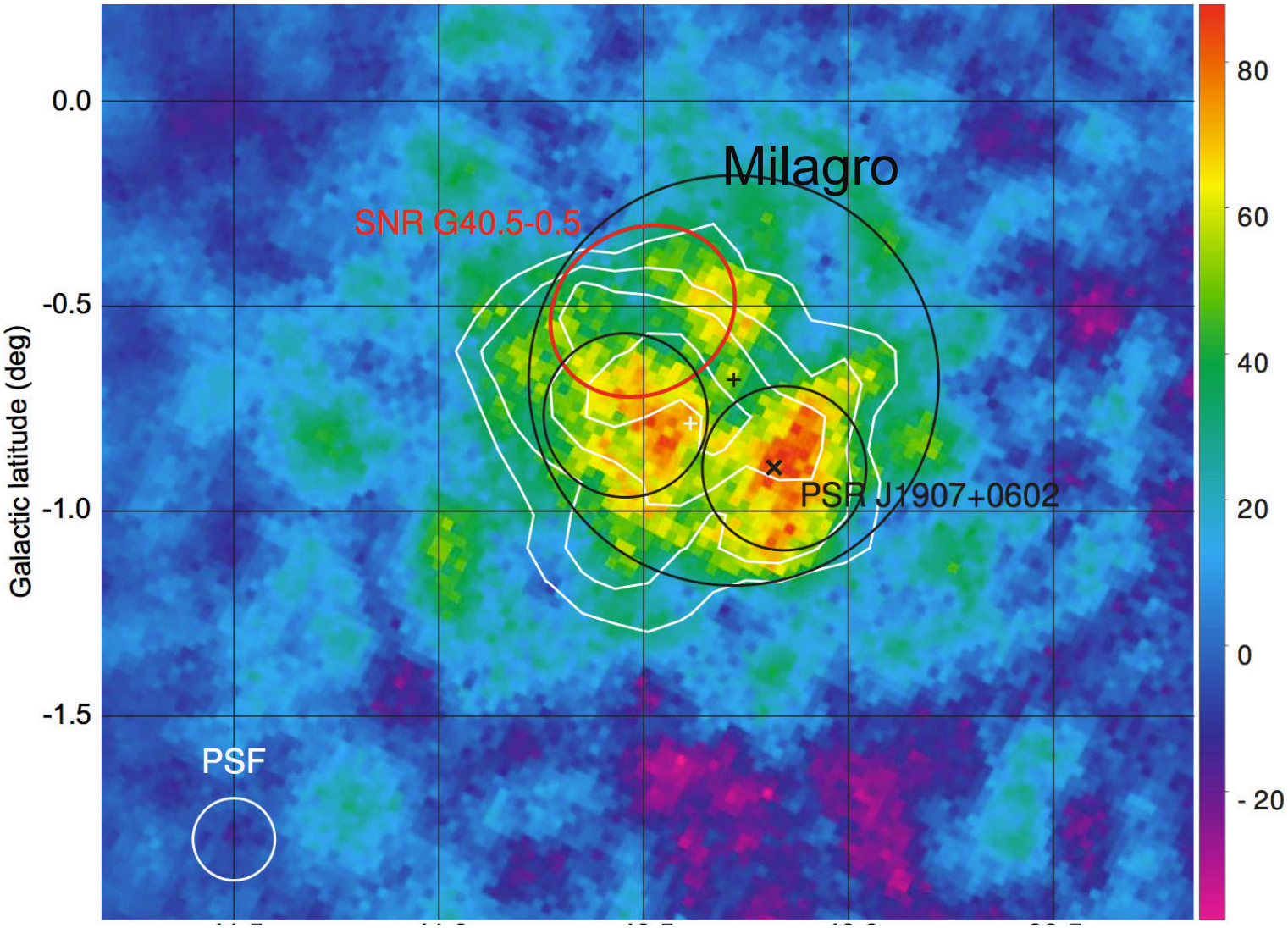


VERITAS Spectrum 2019+37



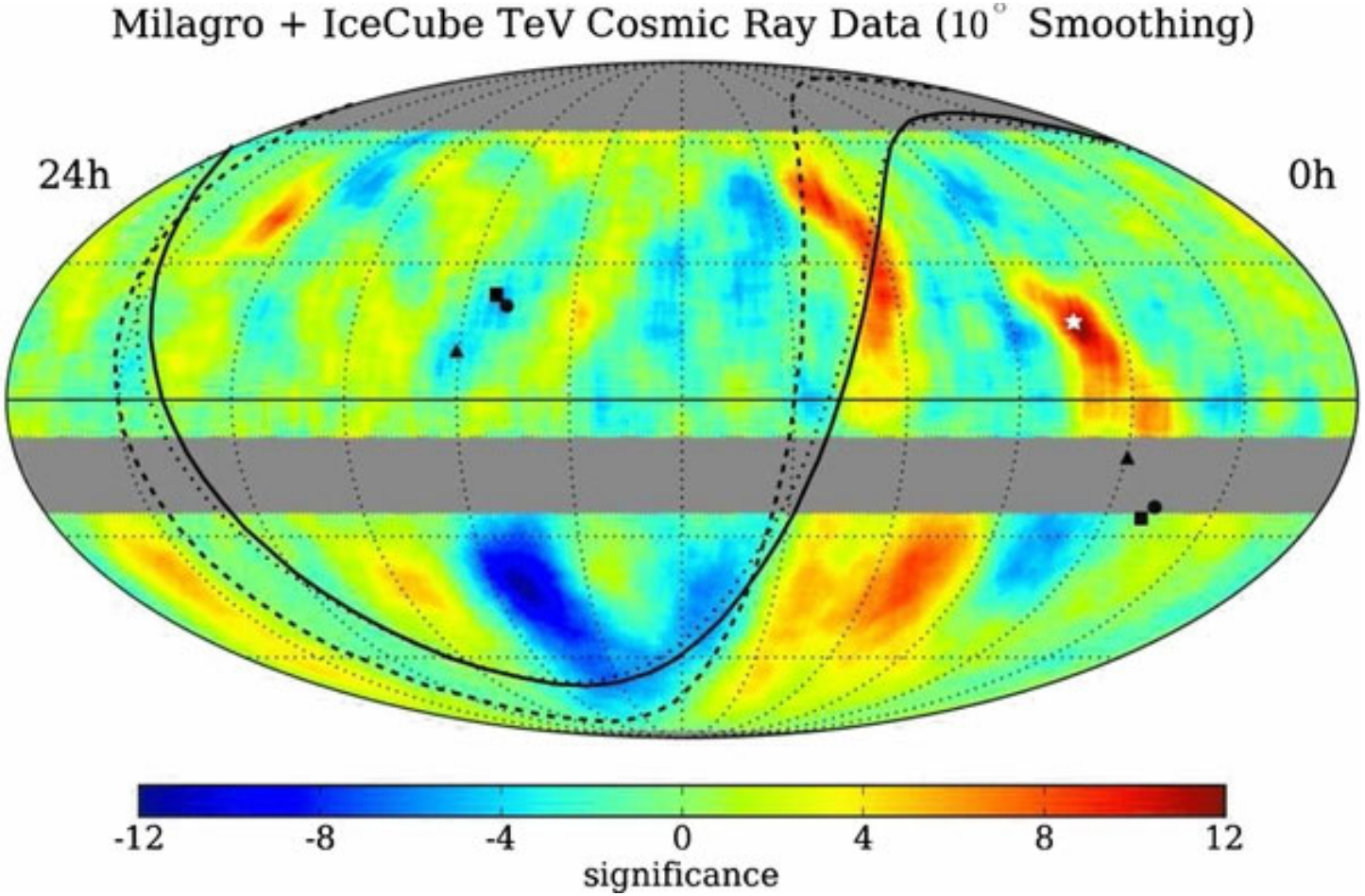
http://arxiv.org/pdf/1404.1841v1.pdf

VERITAS Results on 1908+06



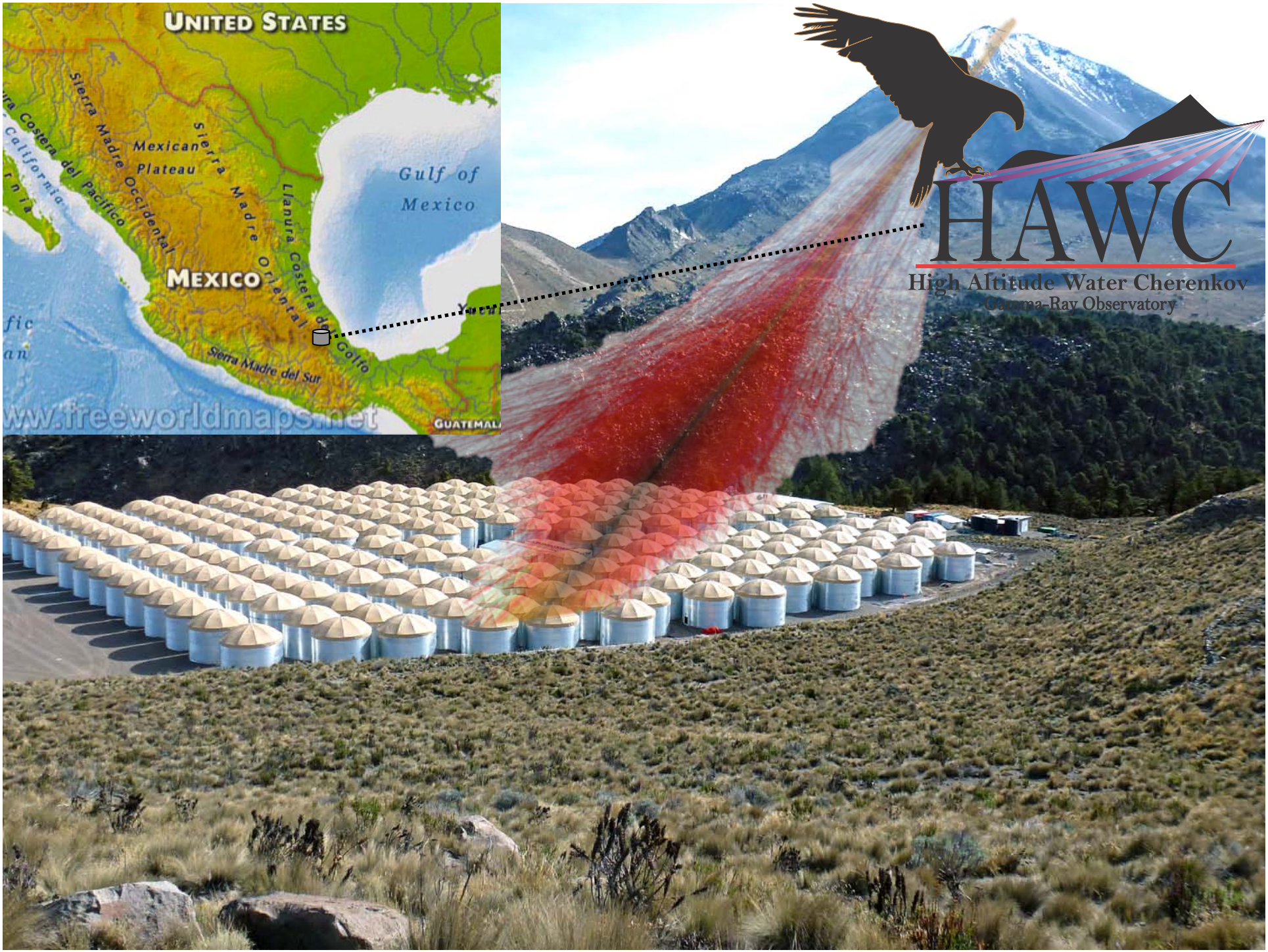
http://arxiv.org/pdf1404.7185v1.pdf

Small Scale Anisotropy



Milagro + IceCube

ApJ 740, 16 (2011)


UNITED STATES
Sierra Madre Occidental
Mexican Plateau
Sierra Madre Oriental
Llanura Costera del Golfo
Gulf of Mexico
MEXICO
Sierra Madre del Sur
www.freeworldmaps.net
HAWC
High Altitude Water Cherenkov
Gamma-Ray Observatory

HAWC

High altitude(4100m) site at Sierra Negra, Mexico.
2nd generation of technique developed for Milagro (2000-2008).
Large tanks of water covering 22,000 m^2 area.
Each contains 3-8”PMTs and1 central 10” PMT.
Sensitive from 100 GeV to 100 TeV.
Angular resolution 1.0–0.1 degrees.
2sr instantaneous field of view.
>90% duty cycle.
Overall 15x improvement in sensitivity over Milagro.
See the Crab at over 5σ everyday.

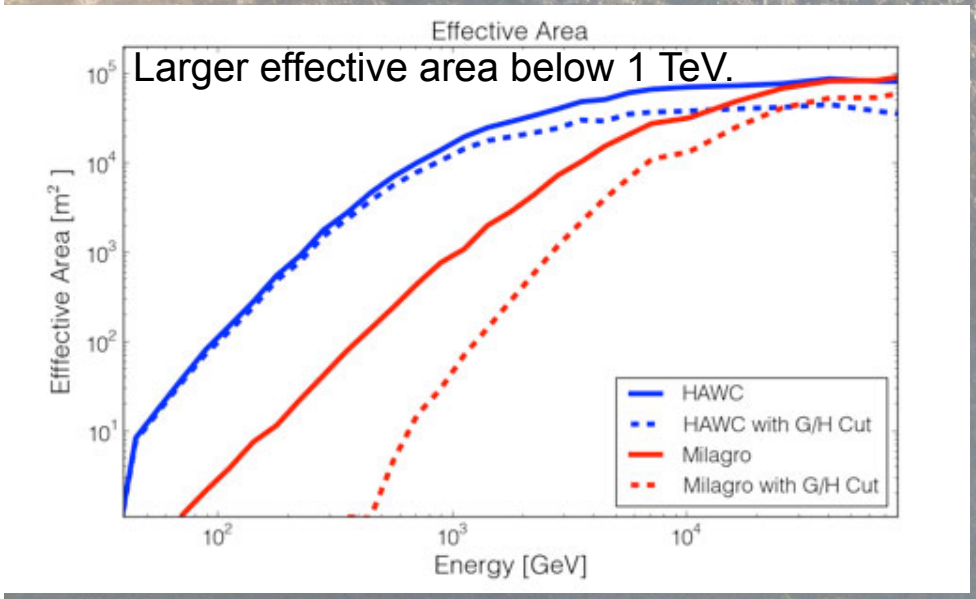
trengths:

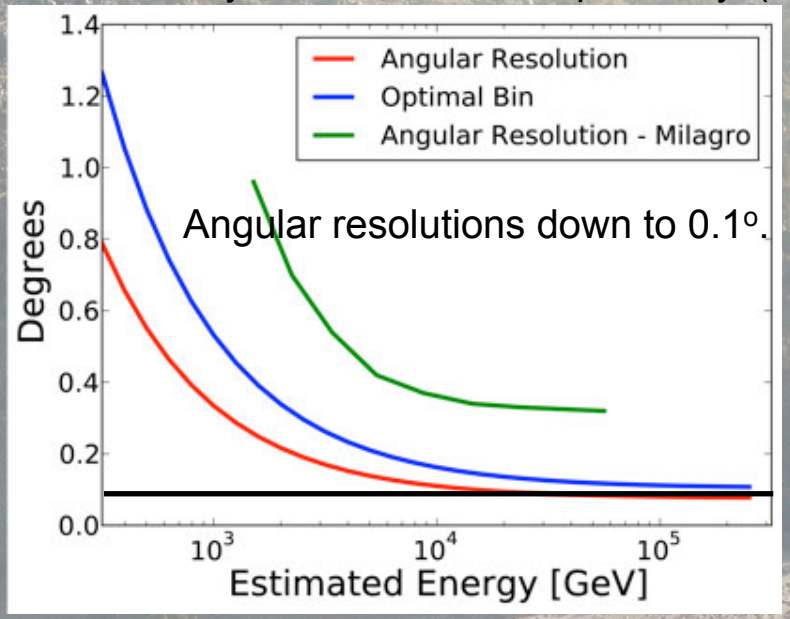
Extreme high-energy reach.

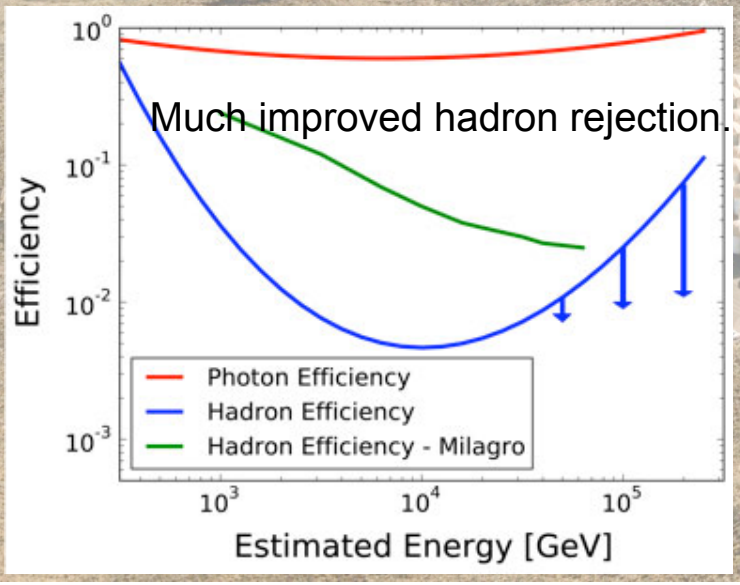
- ***Wide field-of-view: ideal for transients and extended objects.***

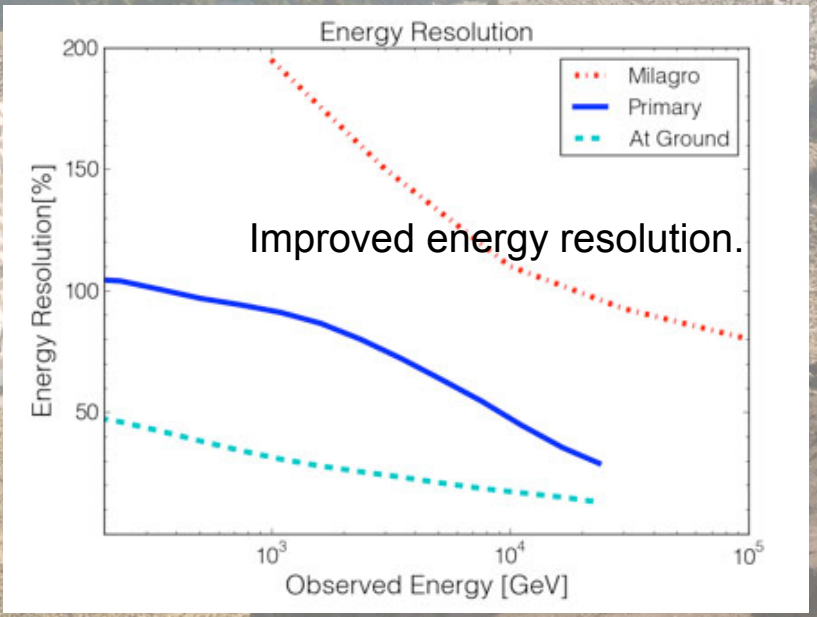
HAWC Performance

Abeysekara et al., Astropart. Phy. (2013)

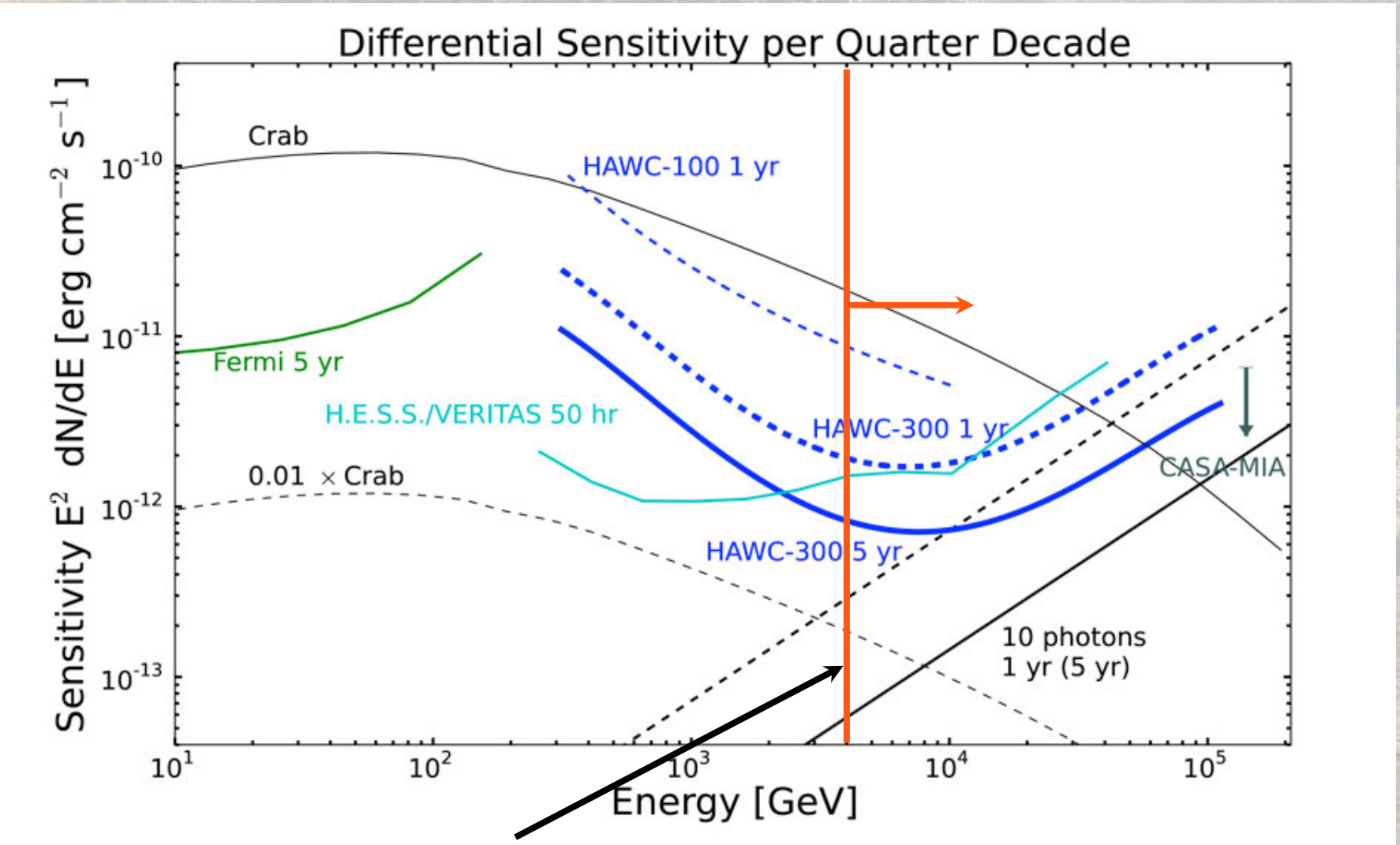






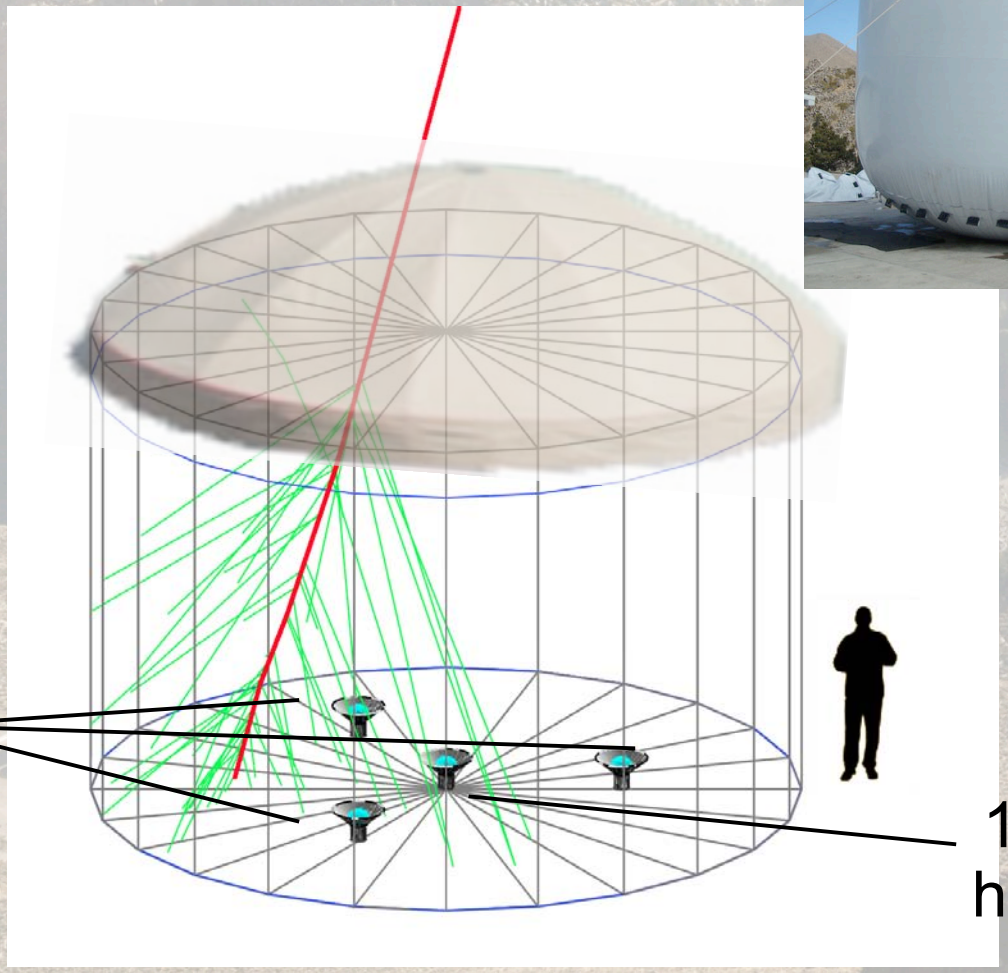


HAWC Performance



Equivalent of a 50-hour observation above 4 TeV on **every source** in 1 year.

HAWC Design



3 8-inch PMTs
(reused from Milagro)

10-inch high QE PMT

HAWC

Important Dates

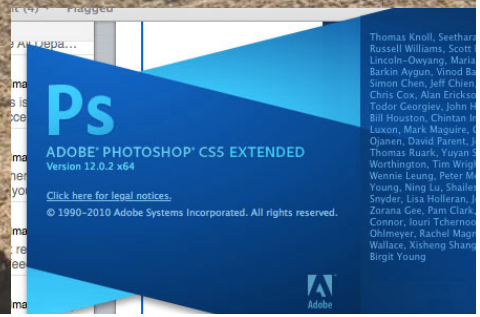
- $13M project funding began Feb 2011
- Operations with 100 water Cherenkov detectors in Aug 2013
- 250 WCD array complete in Aug 2014


January 2014


250th WCD tank constructed May 15, 2014

HAWC Operations

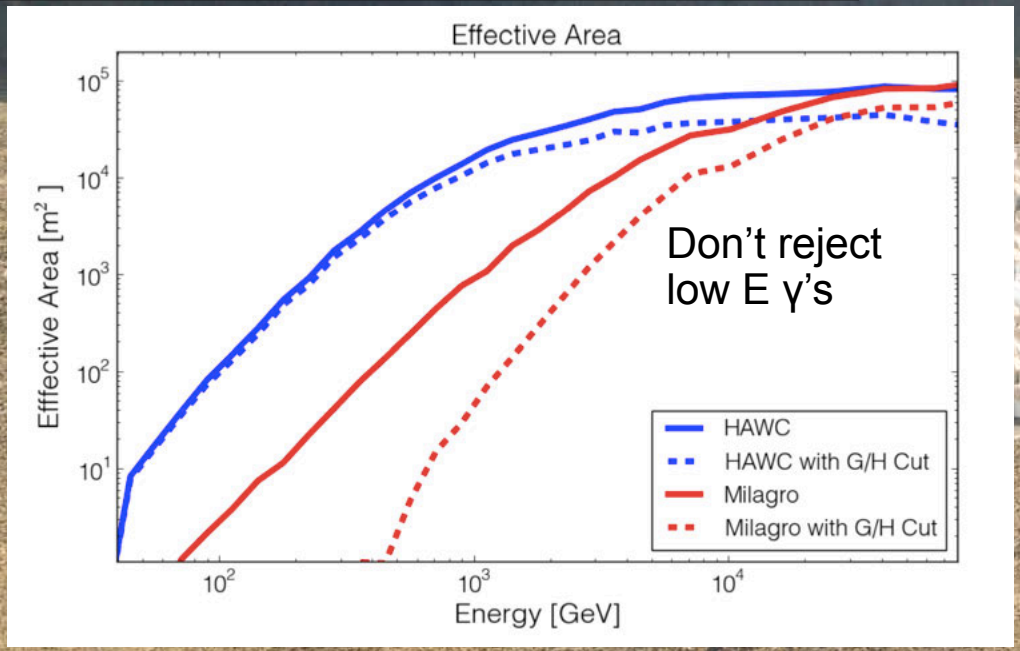
HAWC-300

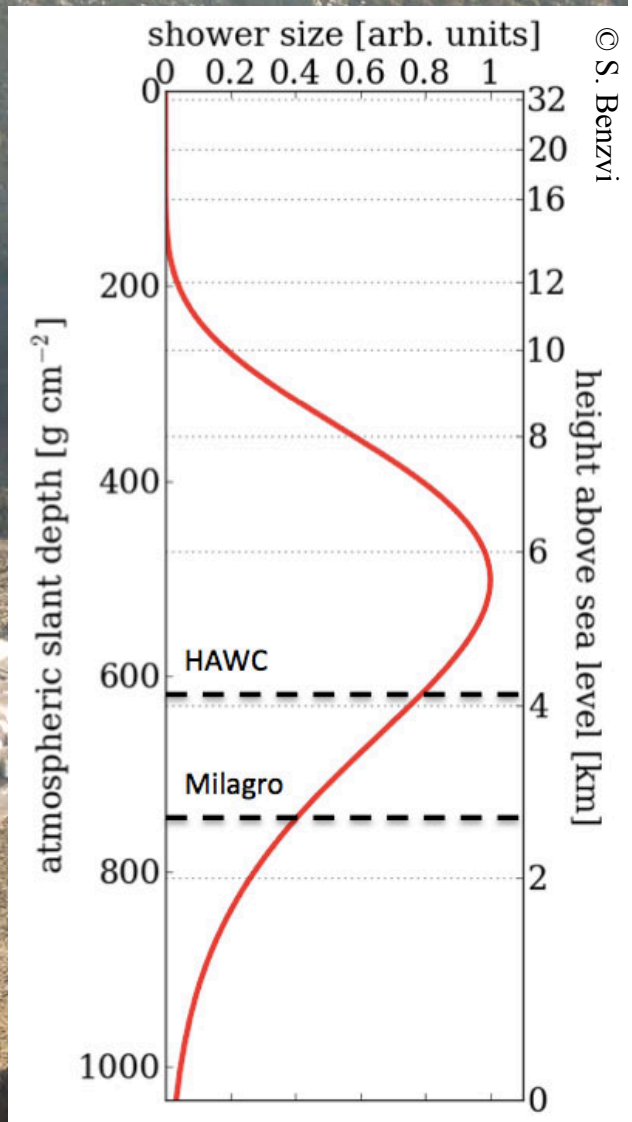


How can HAWC be so much more sensitive than Milagro with the same number of PMTs?

Three main reasons:

1. High Altitude = Statistics
   - >5x # of detectable shower particles relative to Milagro





© S. Benzvi

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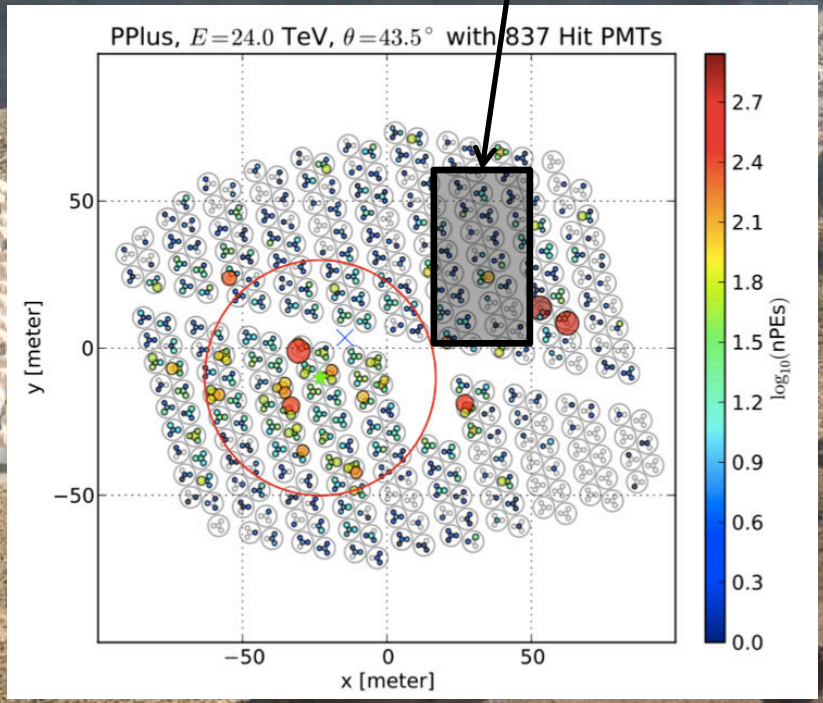
   - 10x Larger muon detection area (~22,000m^2)
   - 4x Larger dense sampling region

Milagro bottom layer size



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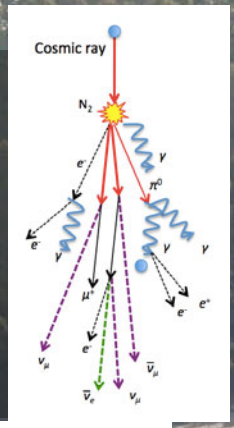
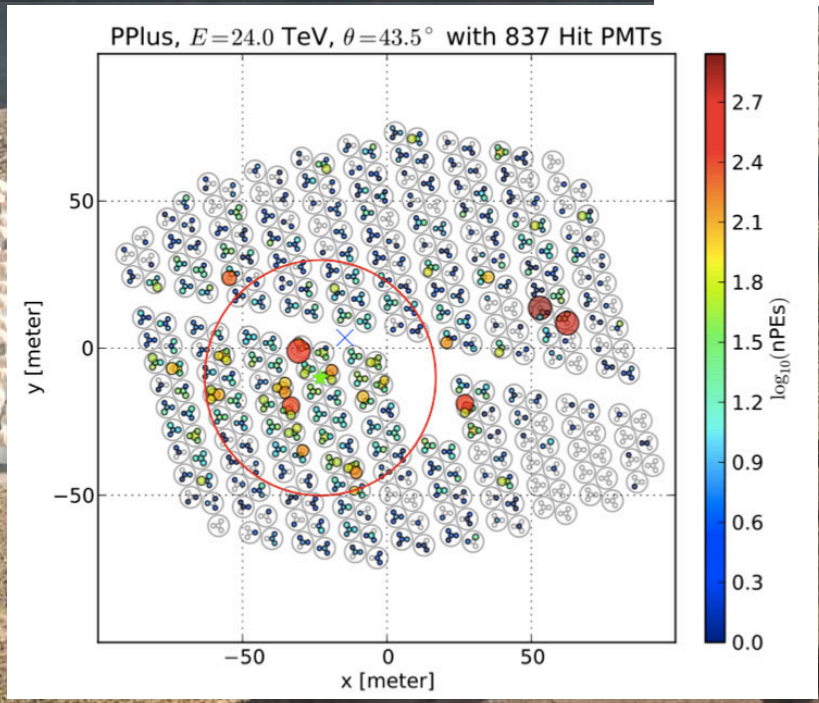
Proton Tagging:
Look for high-amplitude hits far (>40 m) from the reconstructed core location: 99% @ 10 TeV





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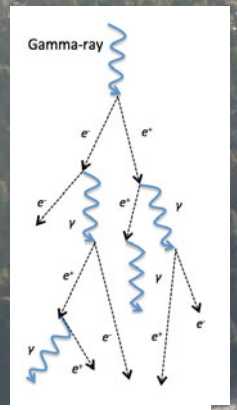
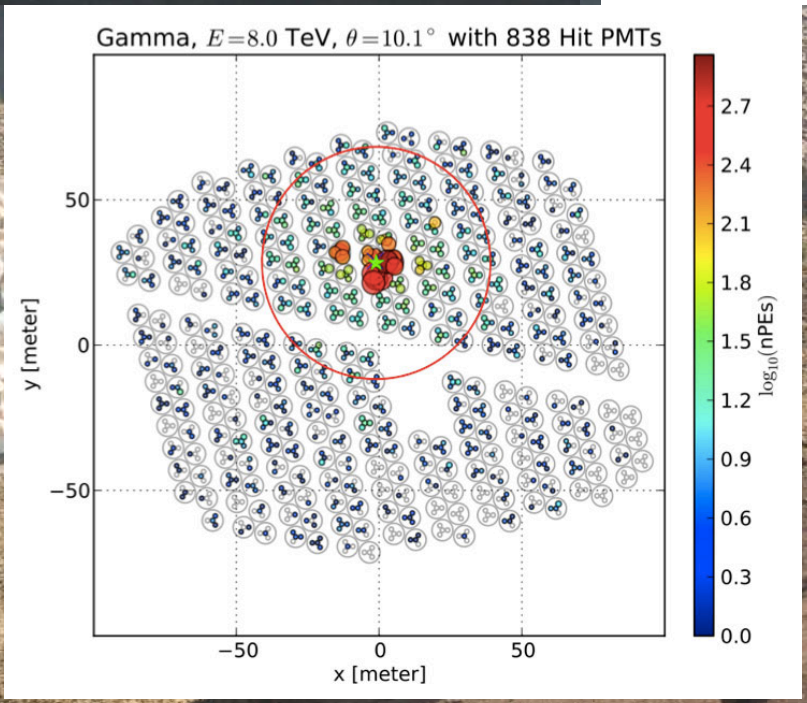
Gamma-Ray Tagging:

Proton cut: removes 50% of gammas.

Above a few TeV Signal/bg >1





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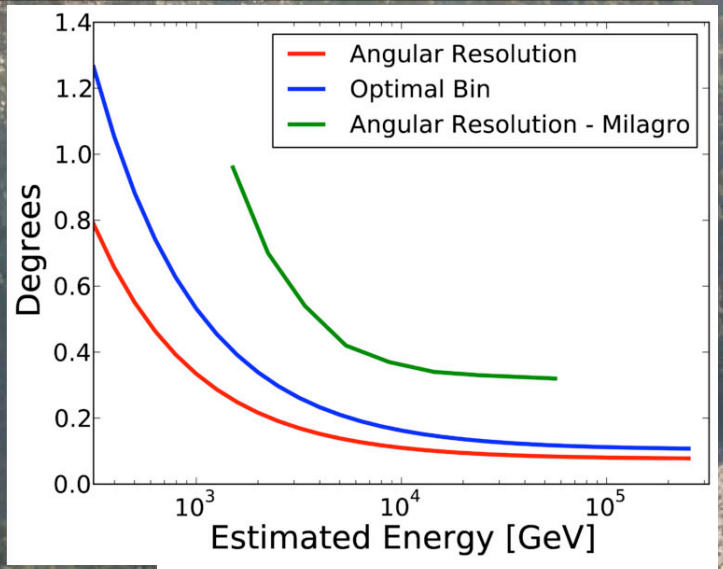
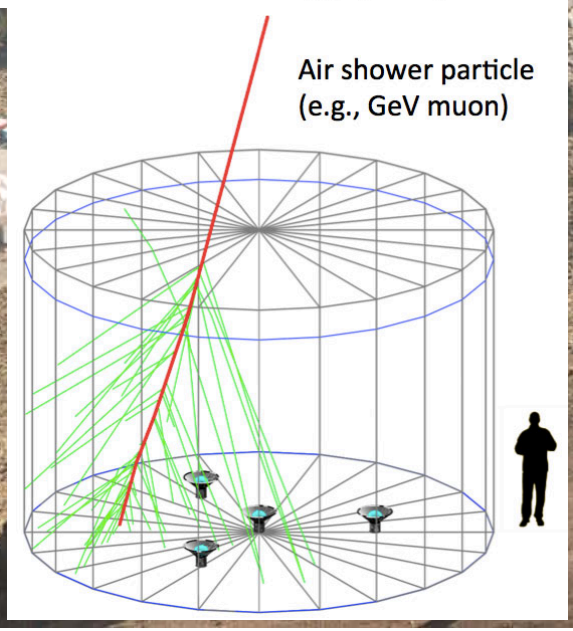
   - 4x Larger dense sampling region
3. Improved Angular & Energy Resolution
   - Optical isolation of detector elements





HAWC Sky Coverage

Same sky viewed by IceCube

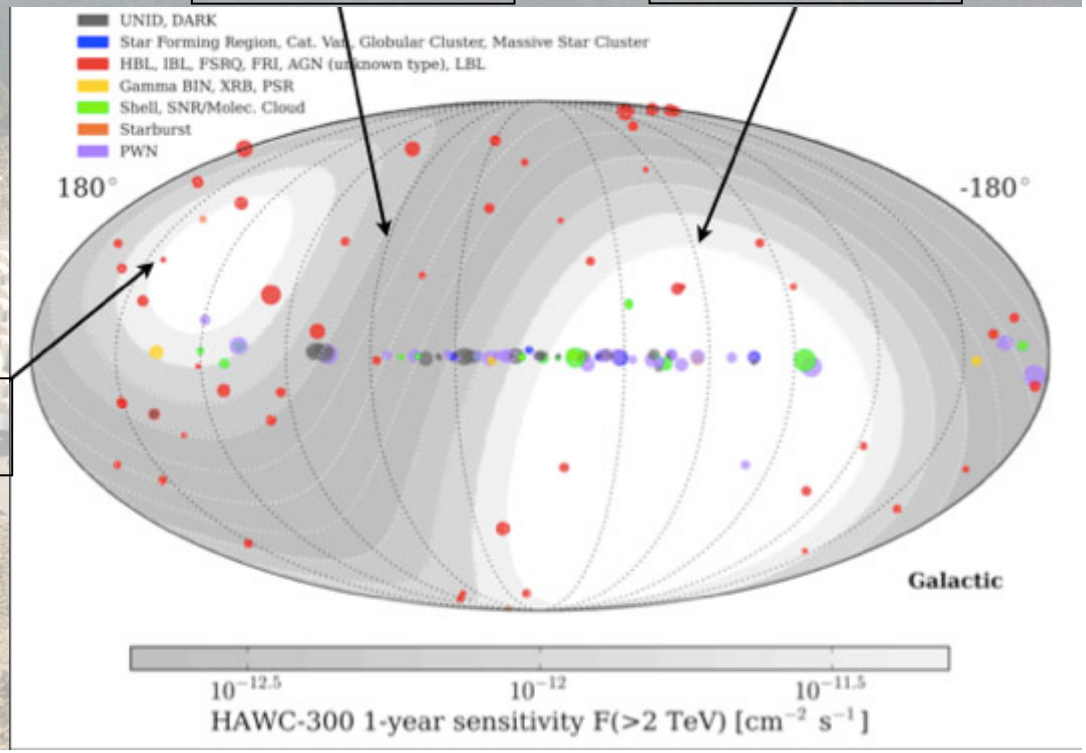
Simultaneous sky with VERITAS

Synoptic survey, combined analysis with Fermi

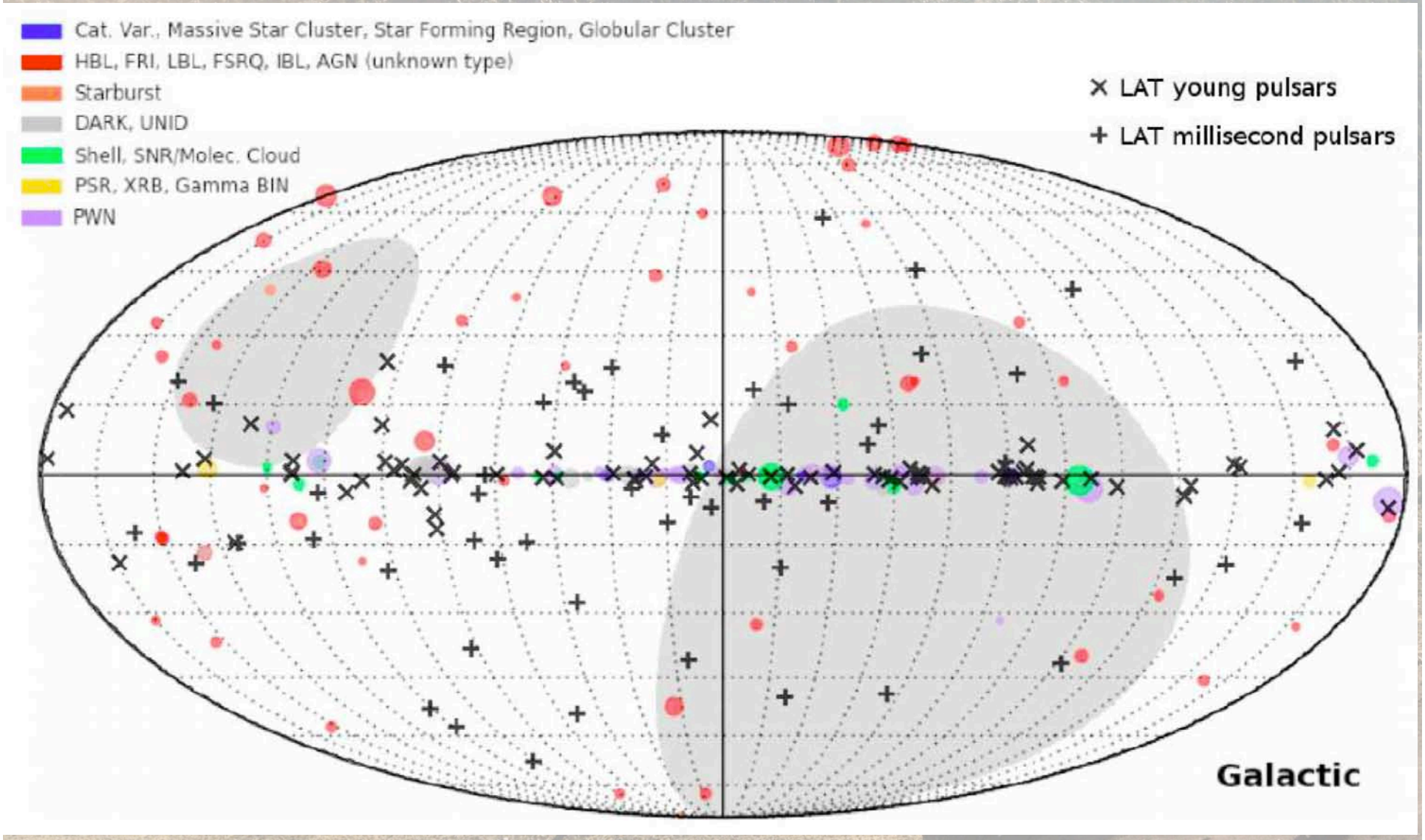
(Study point sources from MeV-TeV)

Crab Nebula overhead,
(so is Geminga)

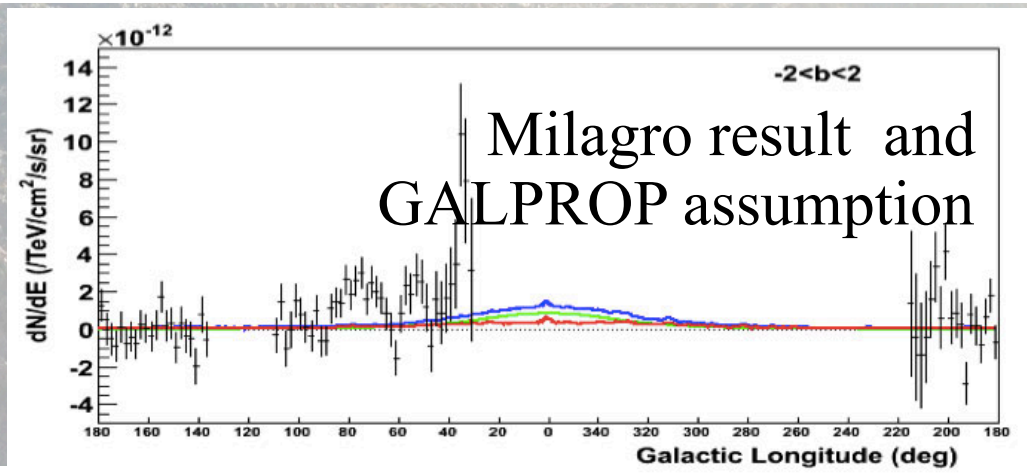
Galactic center visible
(~45^o transit)

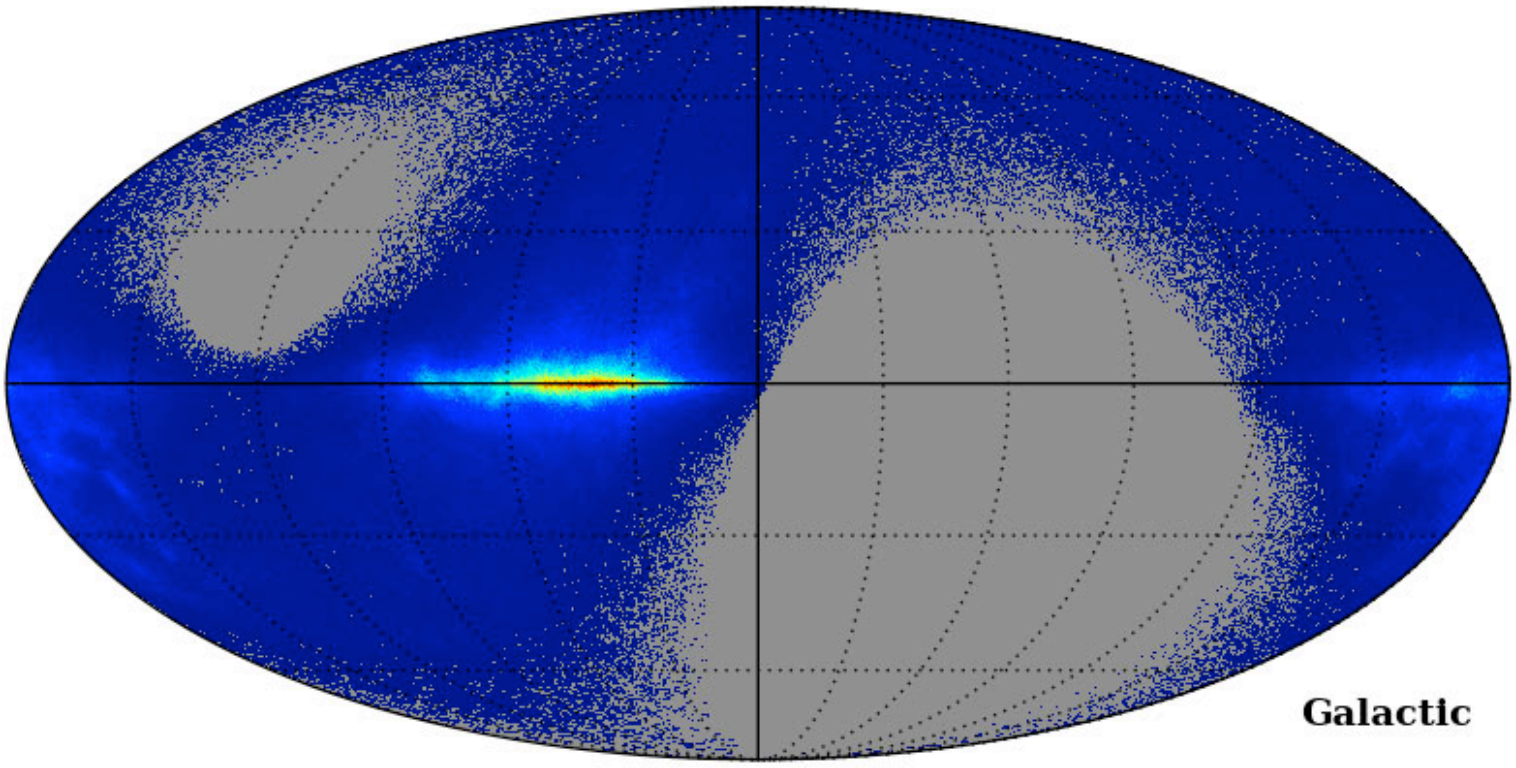


Sources in the HAWC Field of View



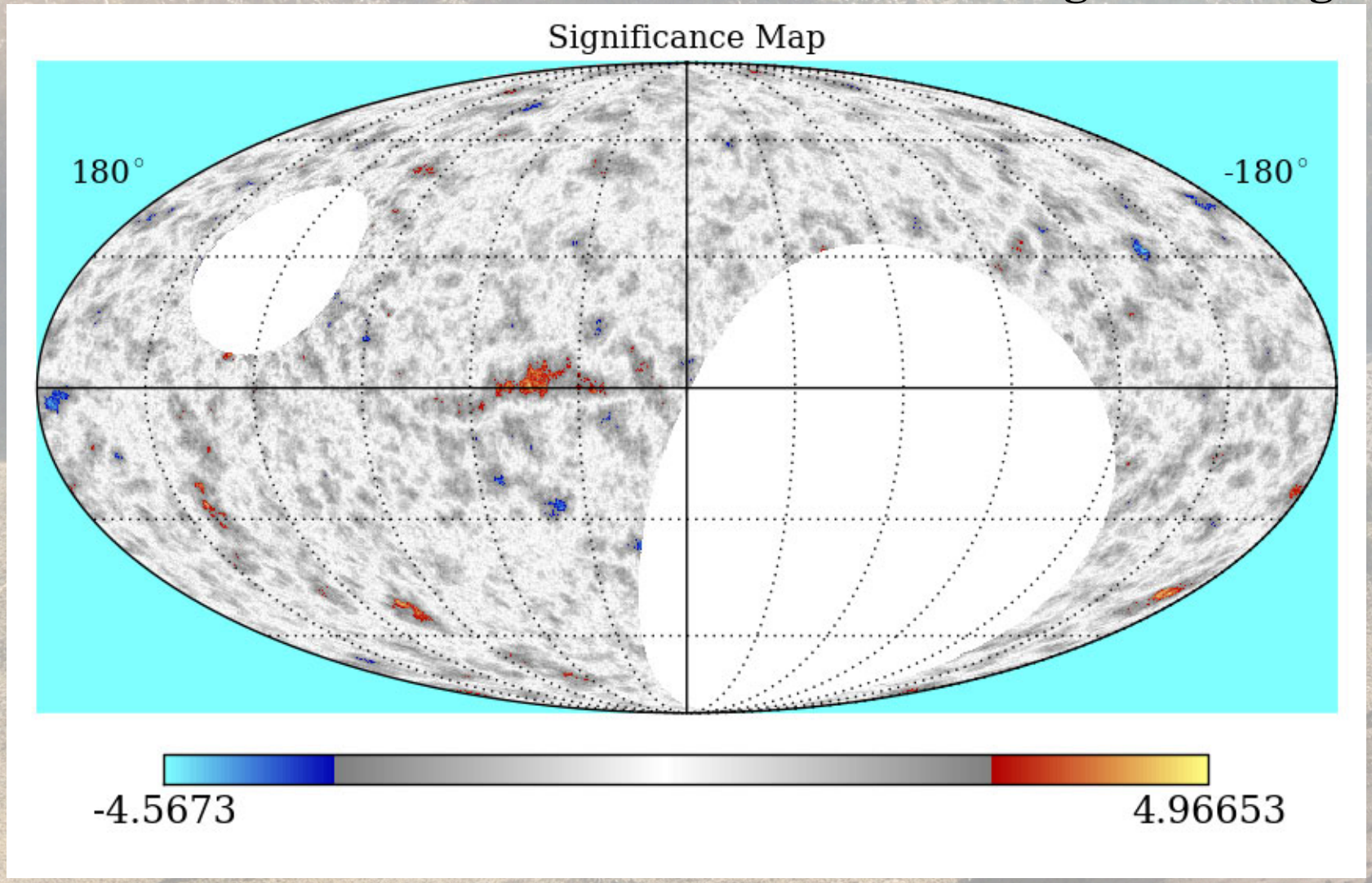
HAWC Diffuse Sky
1 Year





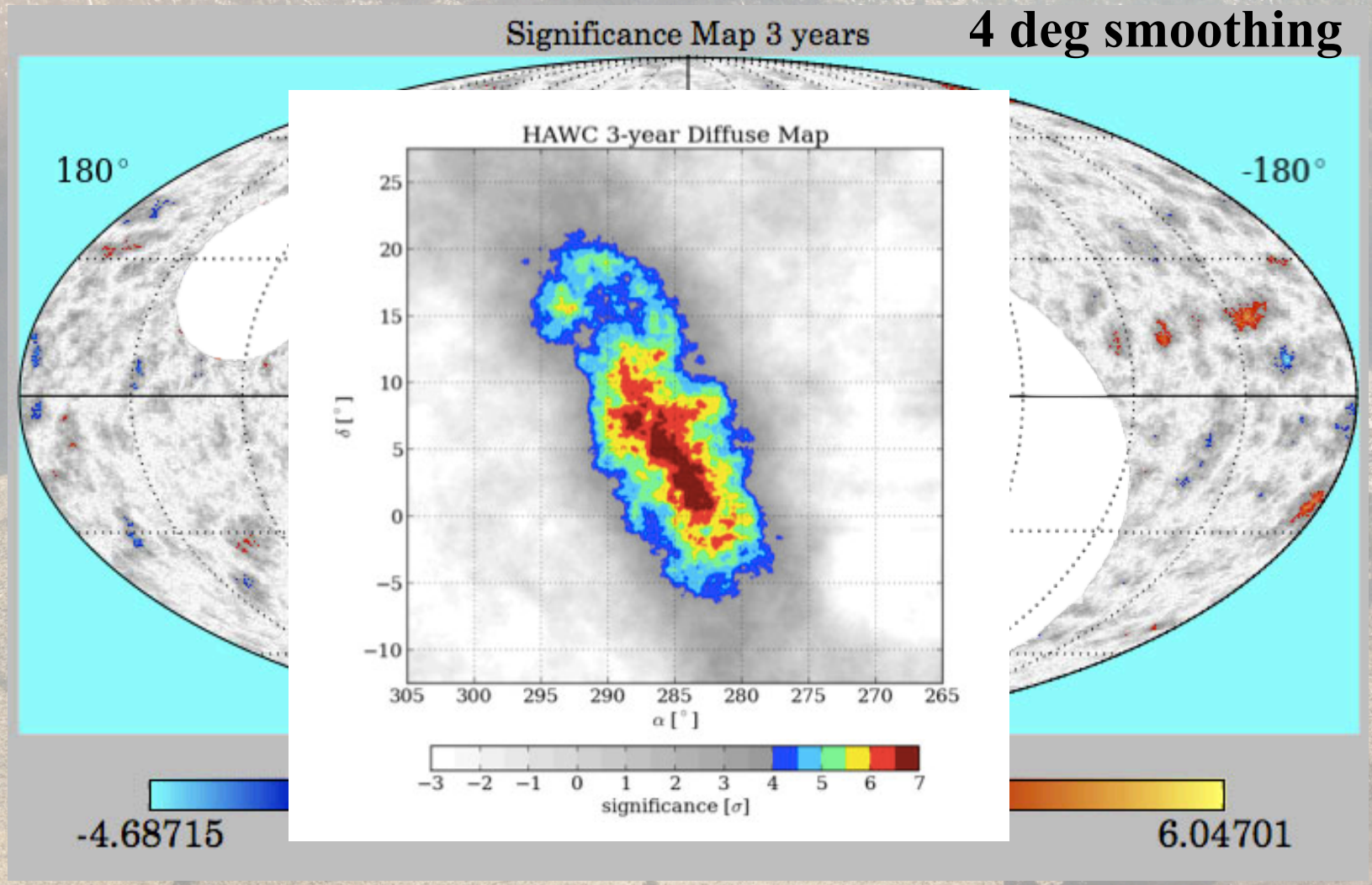
HAWC Diffuse Sky 1 Year

GALPROP assumption
4 deg smoothing



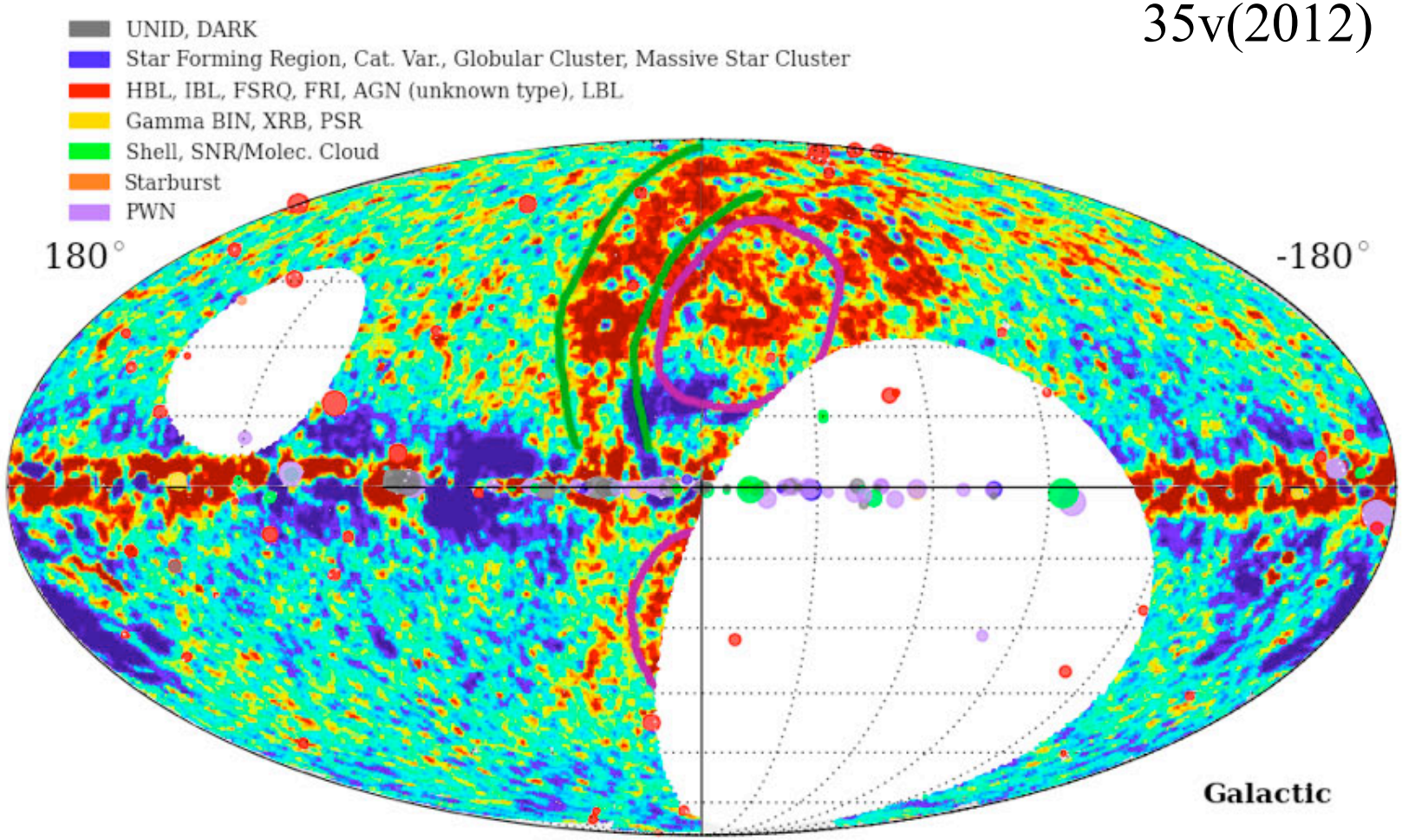
HAWC Diffuse Sky 3 Year

GALPROP assumption
4 deg smoothing

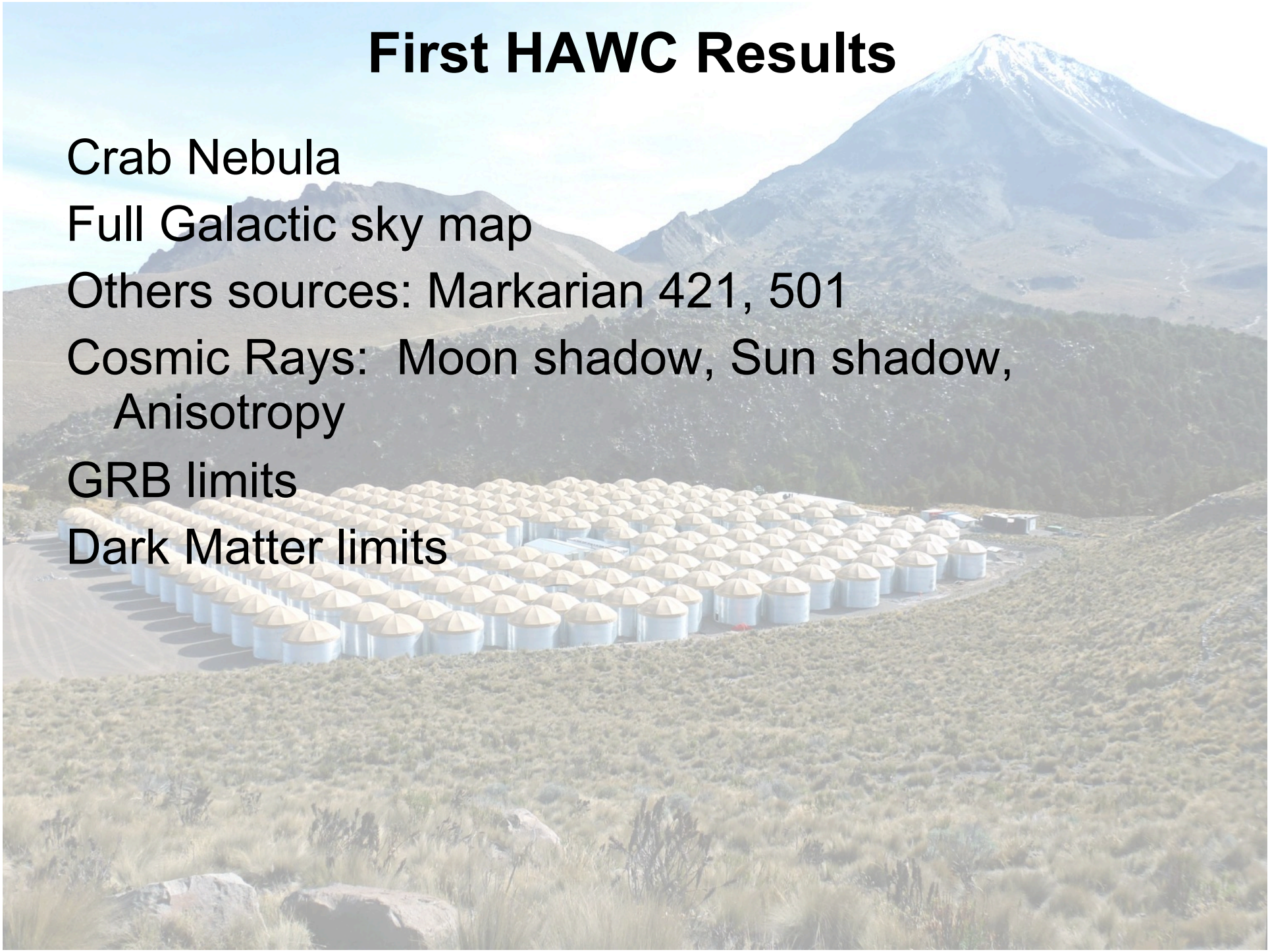


Fermi Bubbles – With Fermi

ApJ, 750, 35v(2012)

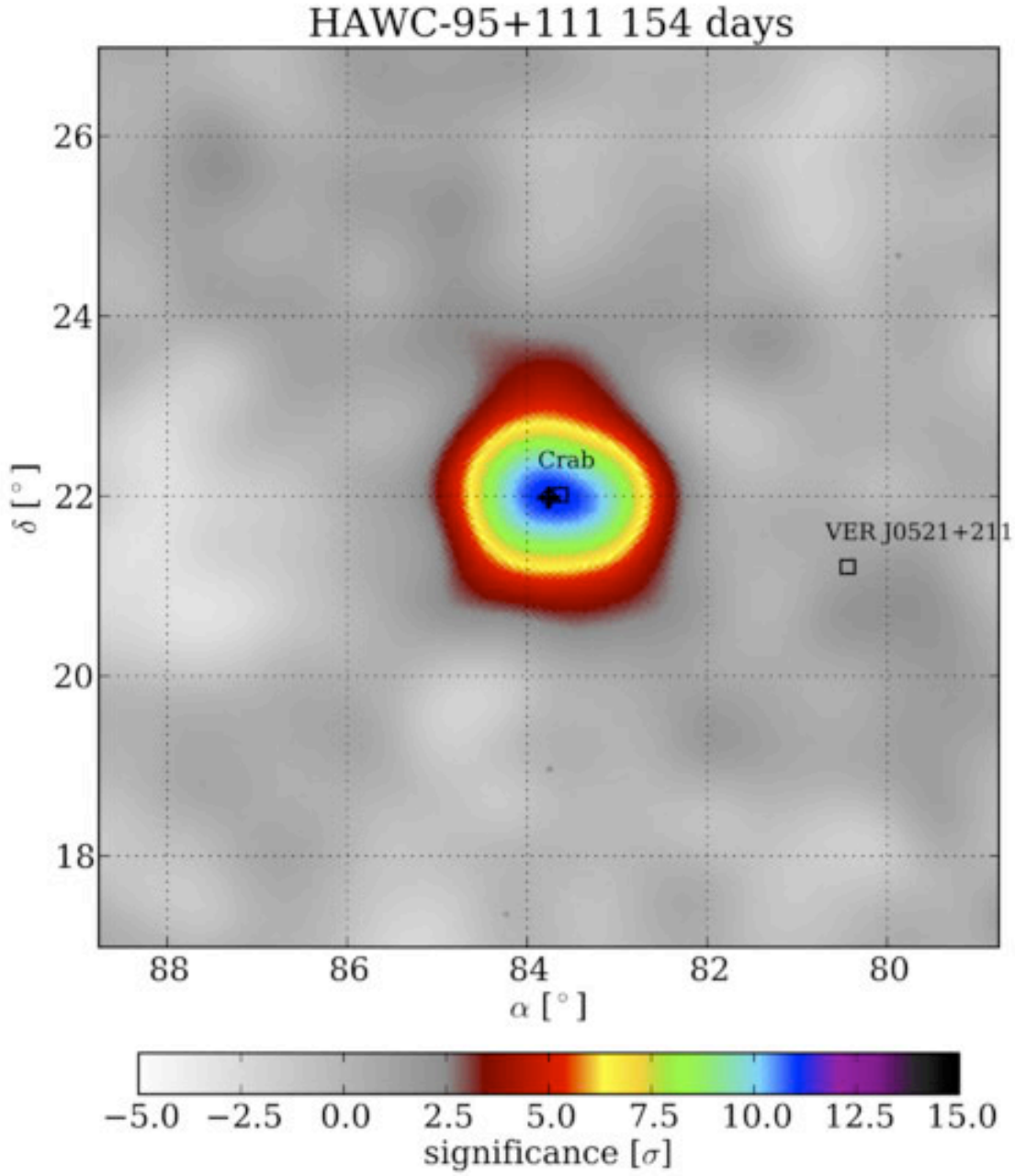


First HAWC Results

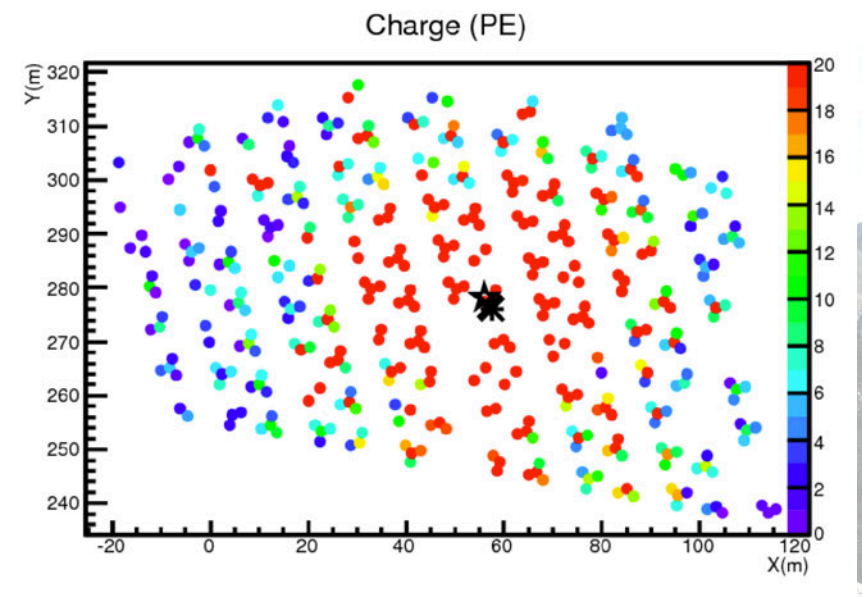


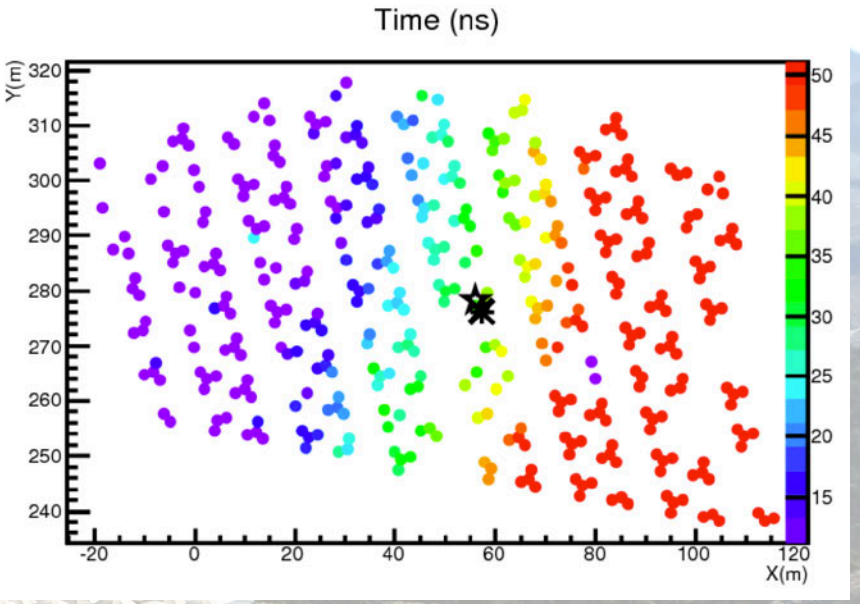
- Crab Nebula
- Full Galactic sky map
- Others sources: Markarian 421, 501
- Cosmic Rays: Moon shadow, Sun shadow, Anisotropy
- GRB limits
- Dark Matter limits

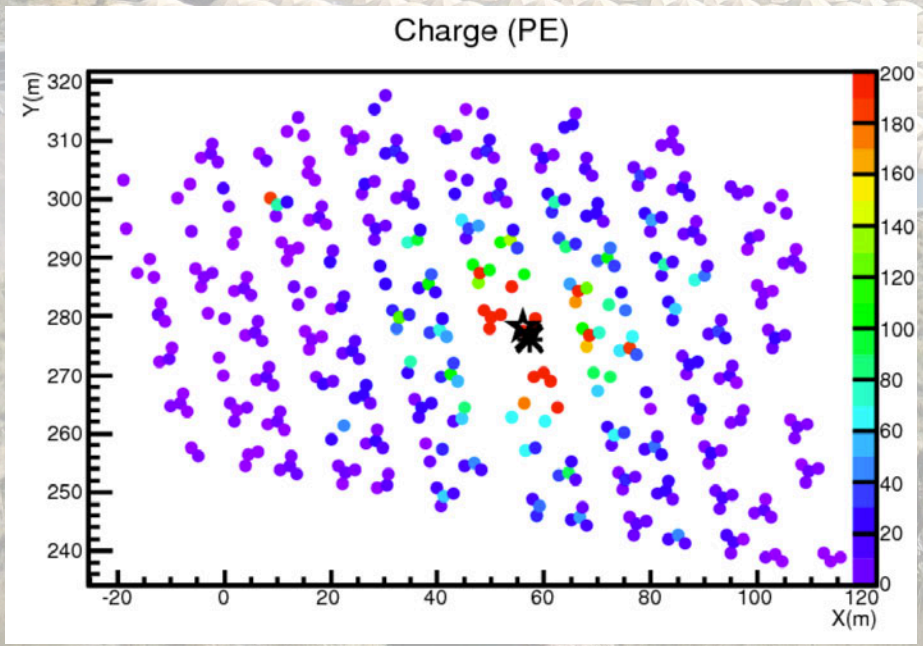
The Crab

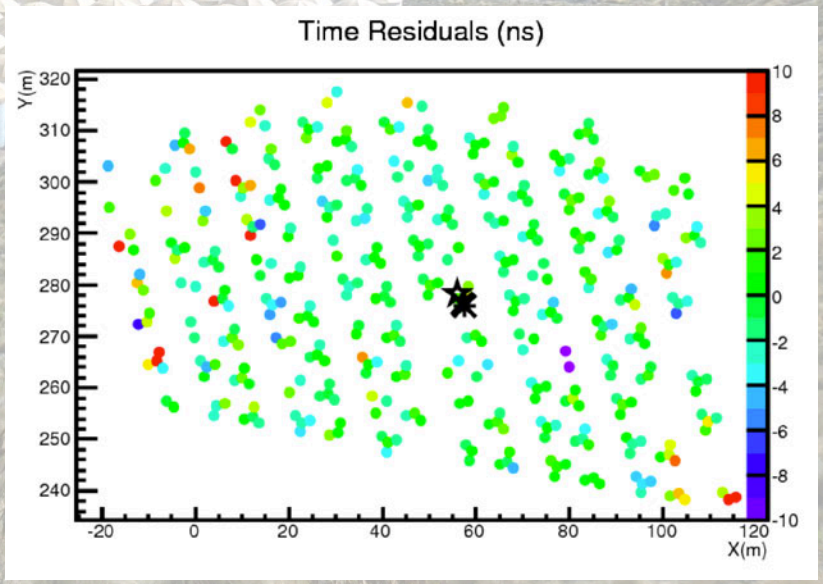

HAWC-95+111 154 days
26
24
22
20
18
δ [°]
Crab
VER J0521+211
88
86
84
82
80
α [°]
−5.0 −2.5 0.0 2.5 5.0 7.5 10.0 12.5 15.0
significance [σ]

Gamma-like Events near Crab

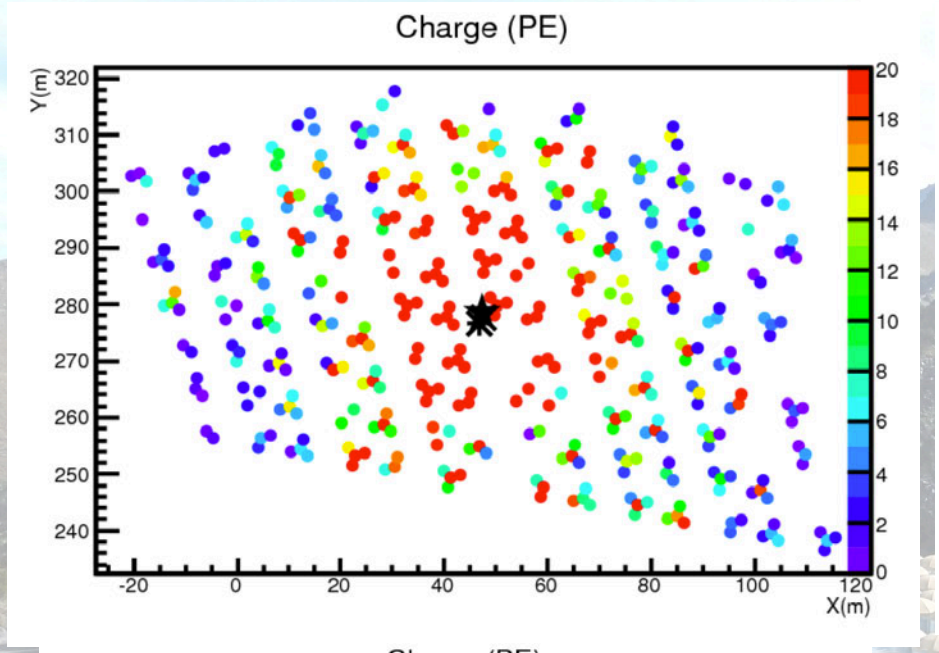


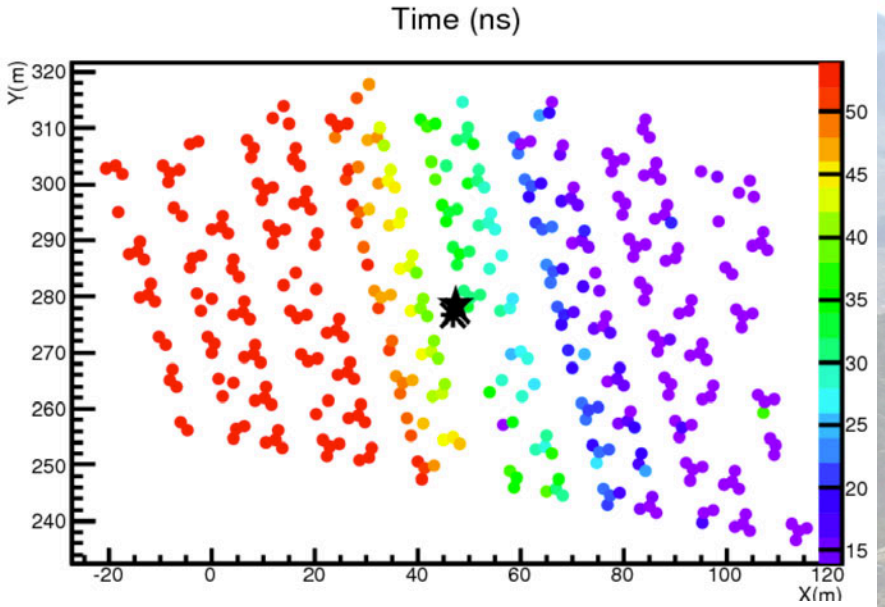


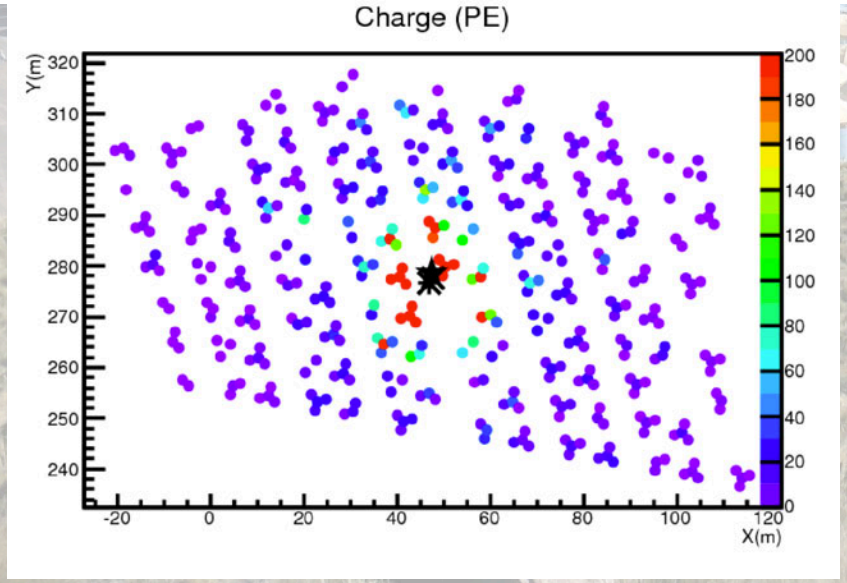


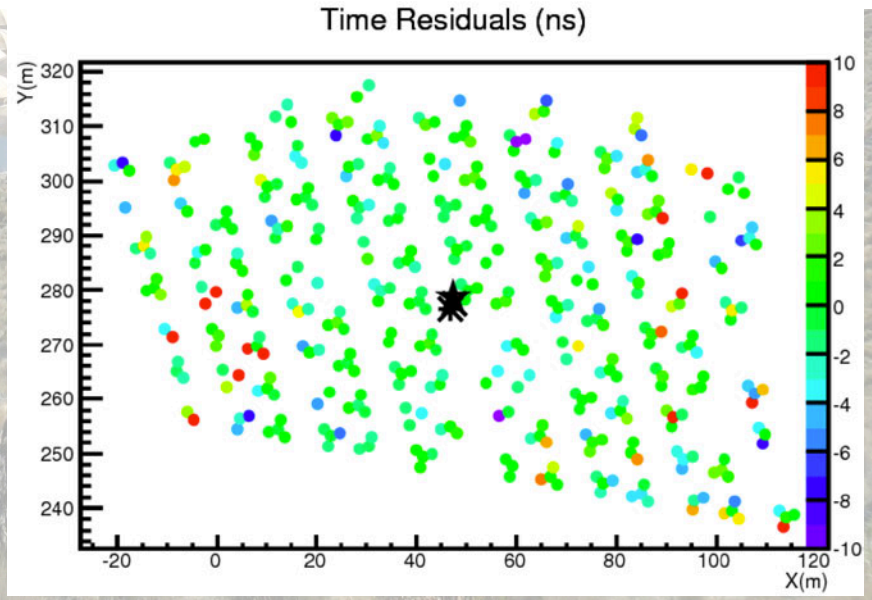


Gamma-like Events near Crab



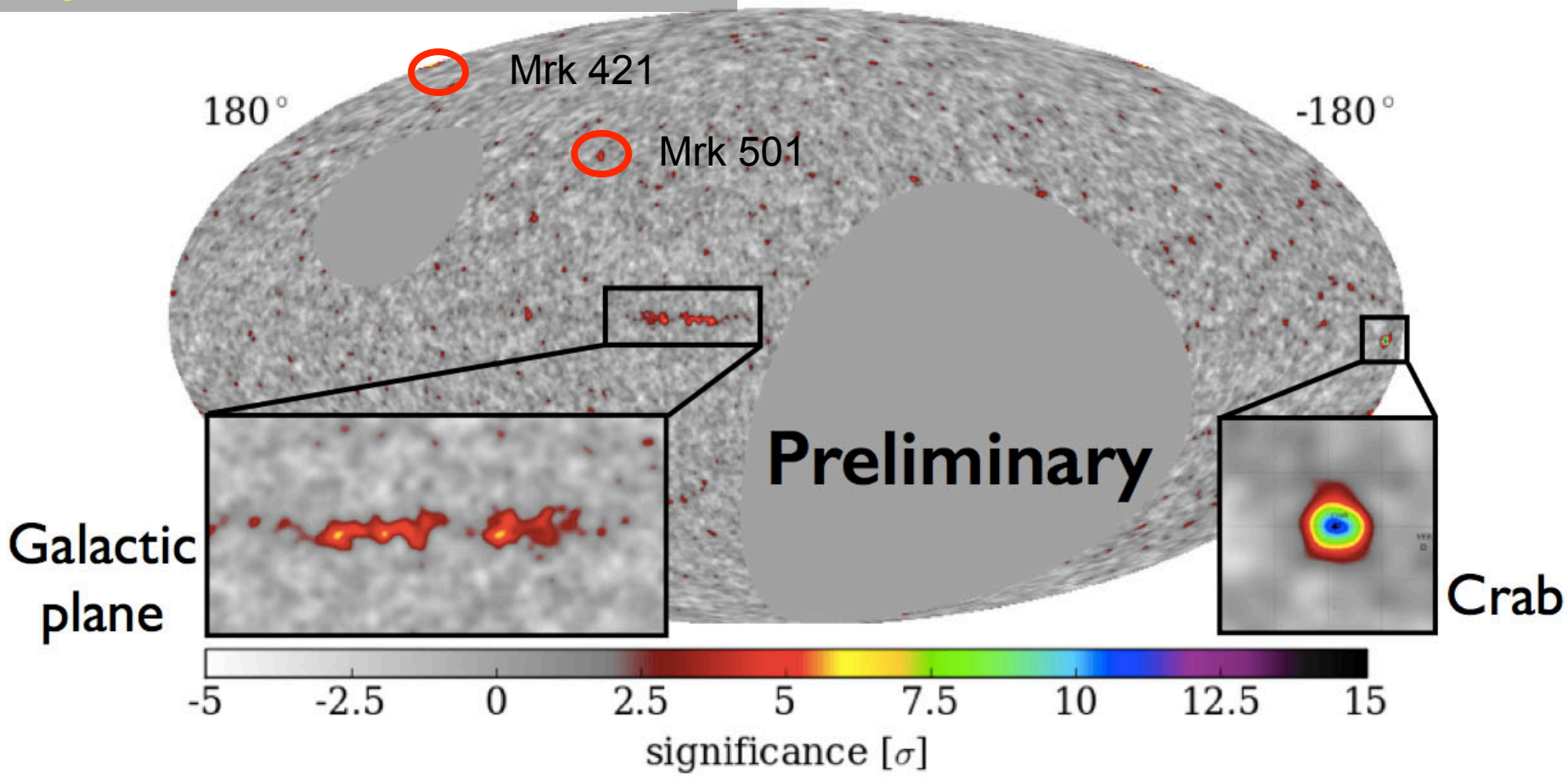






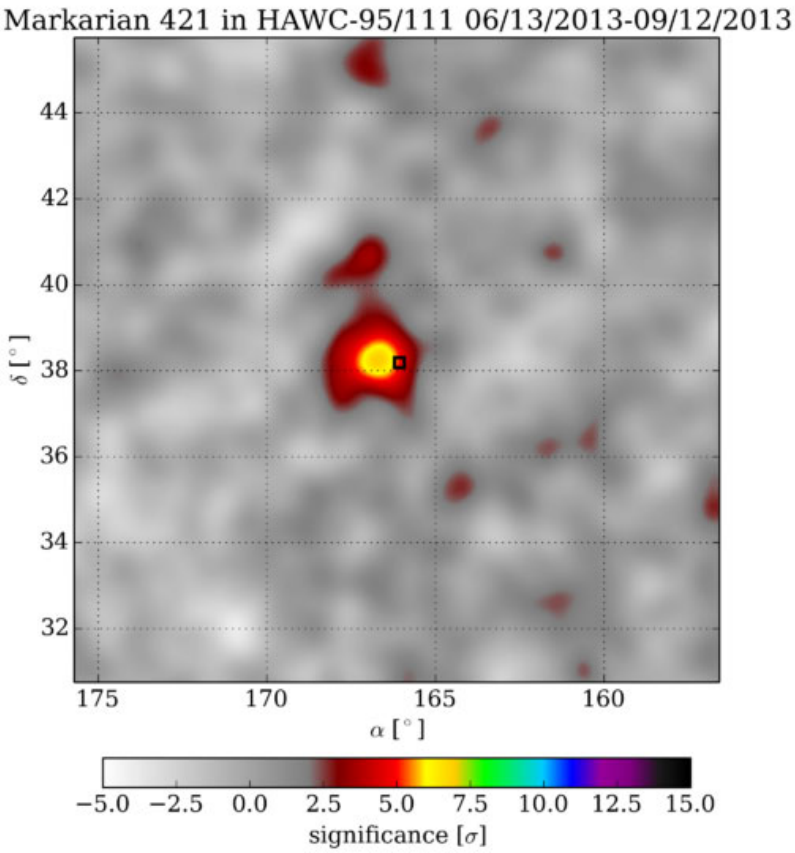
The HAWC Sky*: TeV Gamma Rays

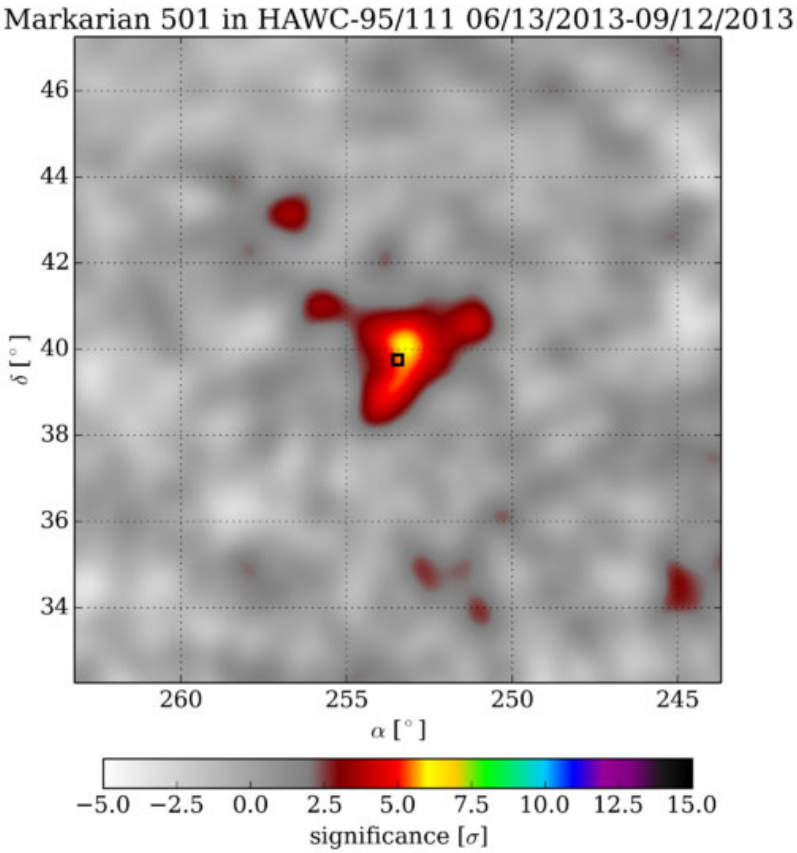
The origin of Cosmic Rays



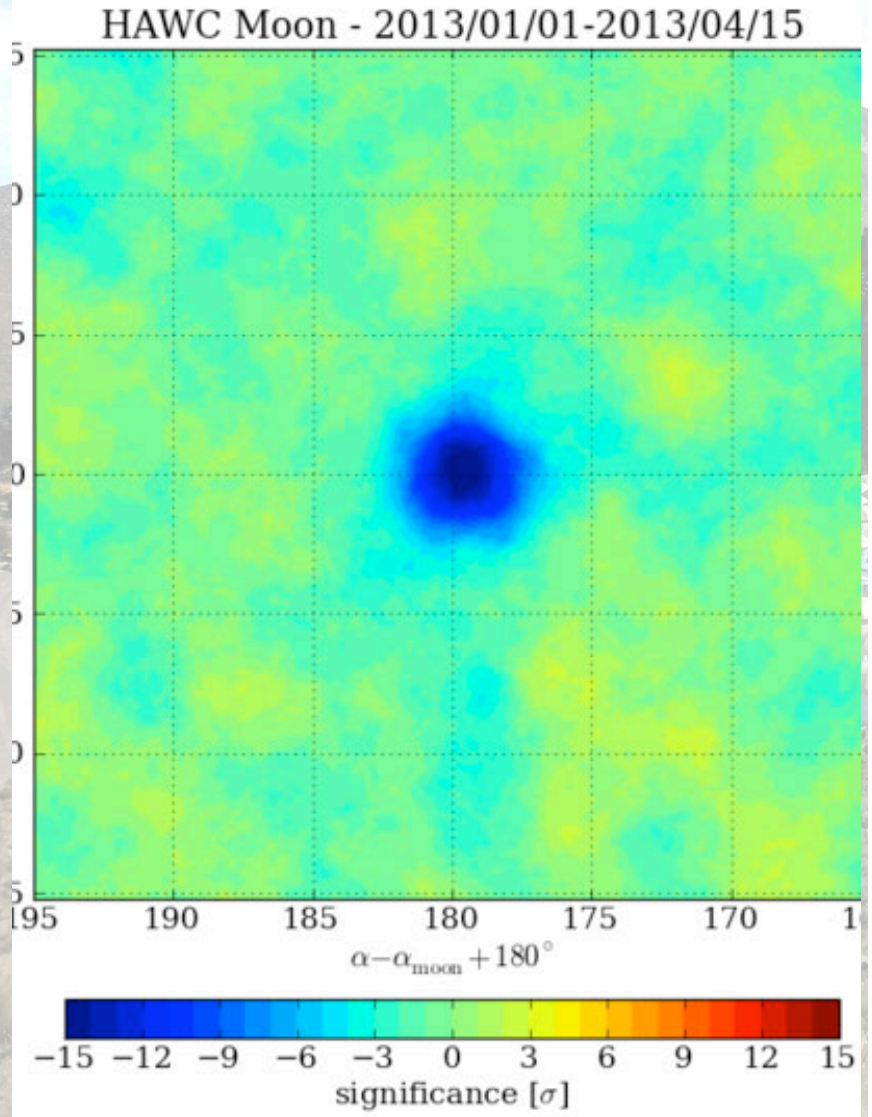
* *3 months of data, 3rd of array*

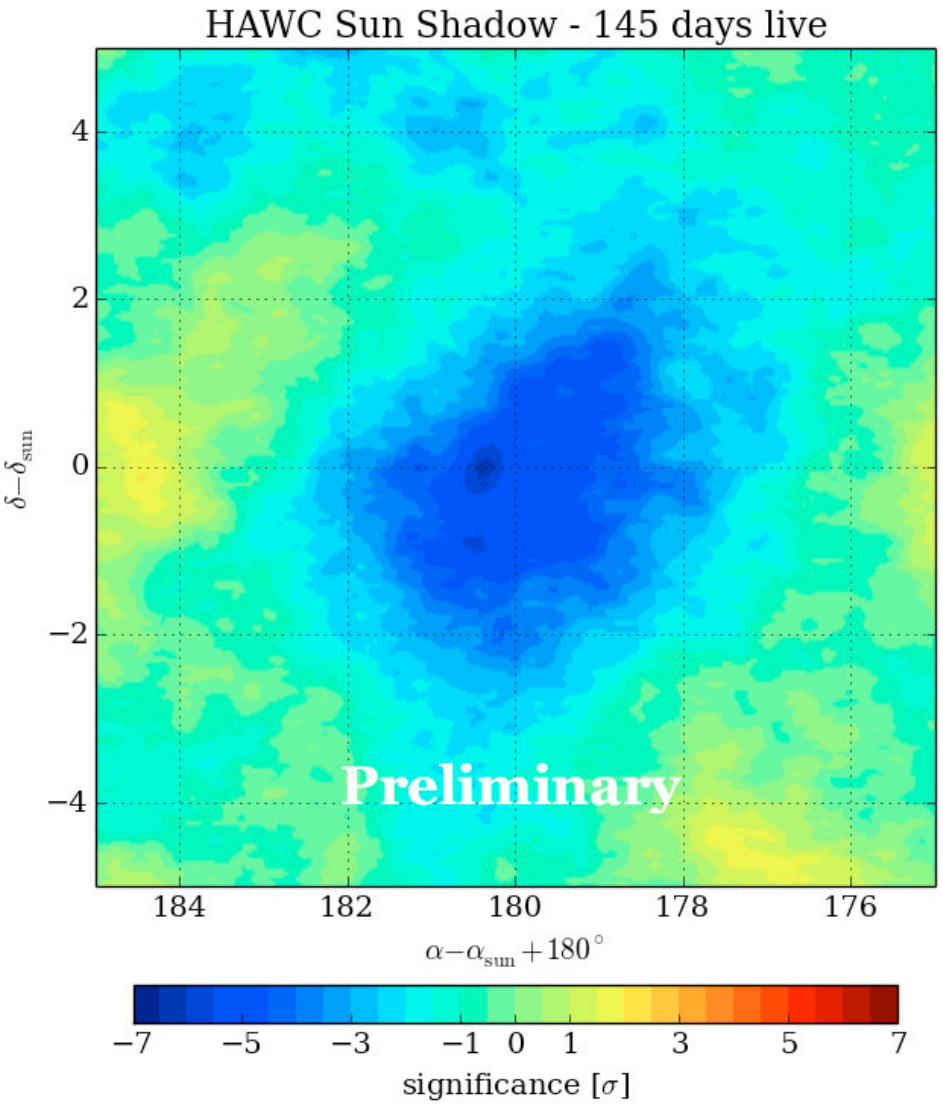
The Markarians



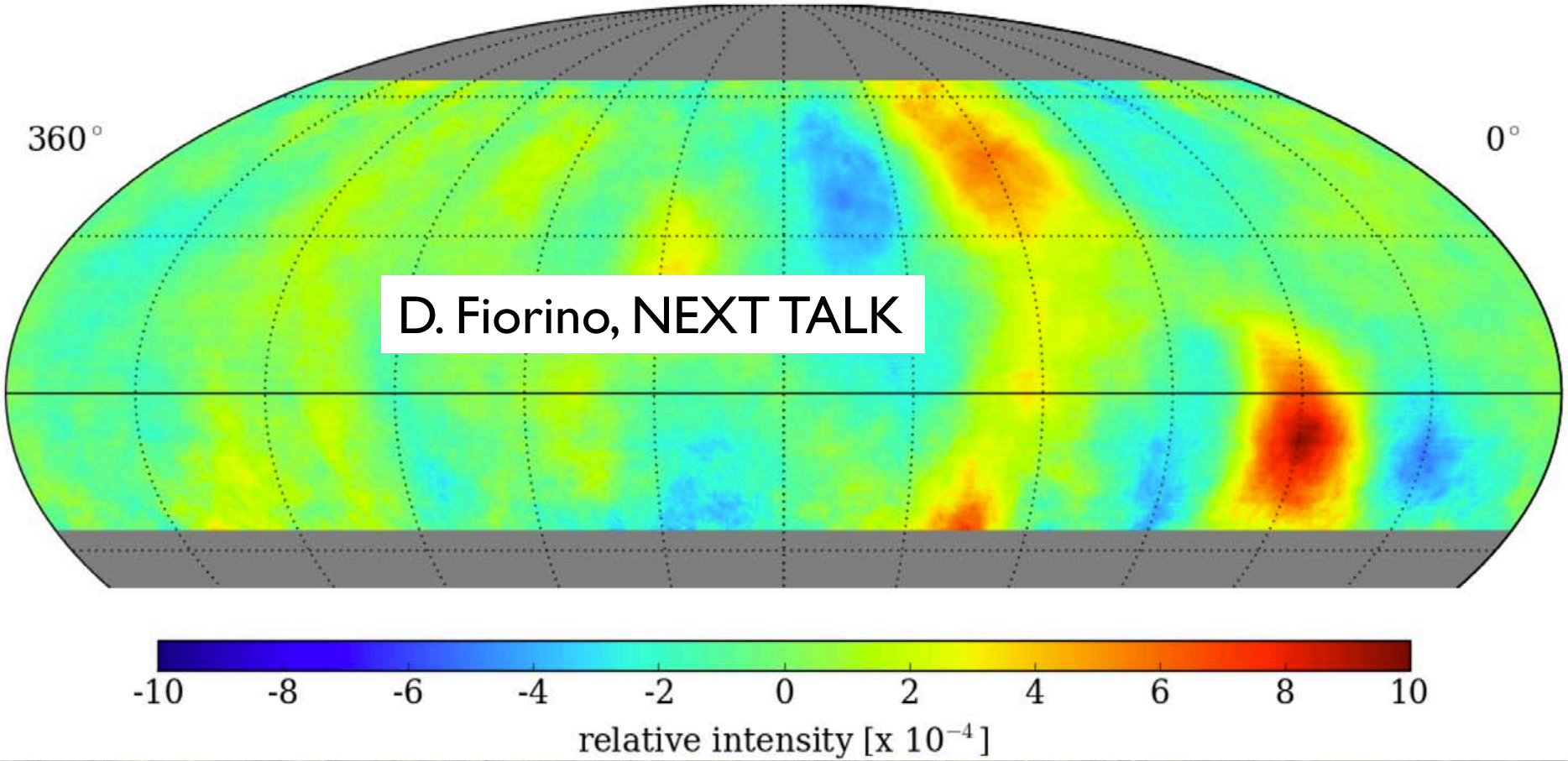


The Moon and Sun





The HAWC Sky: TeV Cosmic Rays



GRB 130427A

Misfortune 1

- The main DAQ was offline
- Luckily, the scaler DAQ was taking data

➡ Monitoring the rate of 29 tanks (HAWC 30) with 112 PMTs

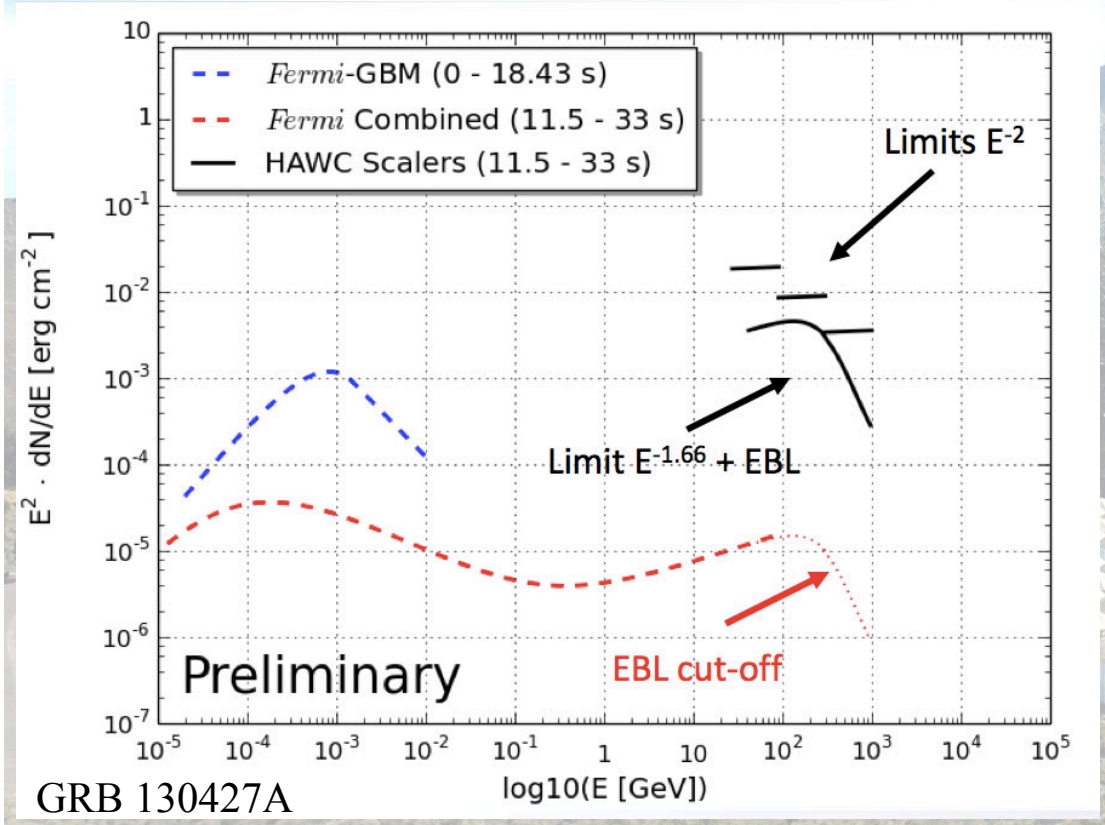
Misfortune 2

- The GRB had an elevation of only 33° in the HAWC field of view

➡ Sensitivity is about 2 orders worse than at zenith

➡ Increased energy threshold

Gamma-Ray Burst (130427A) with HAWC

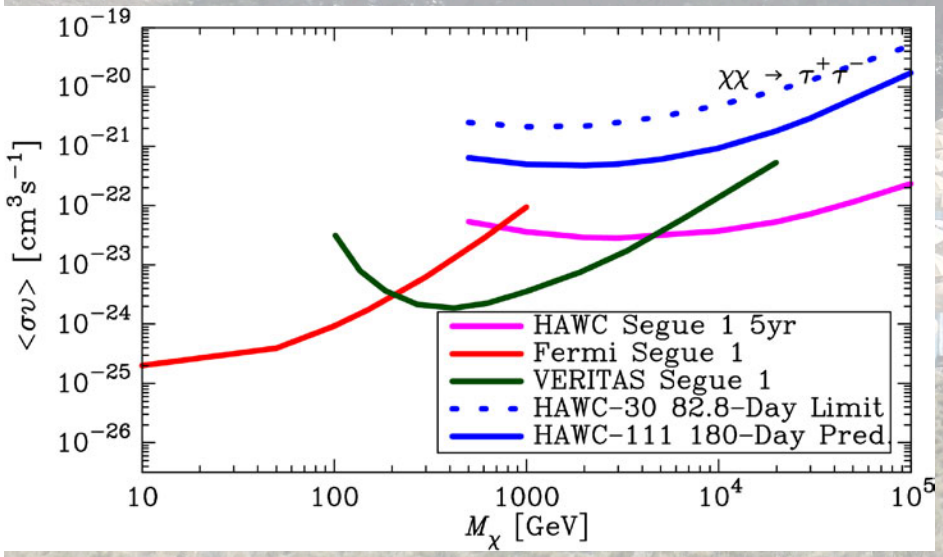


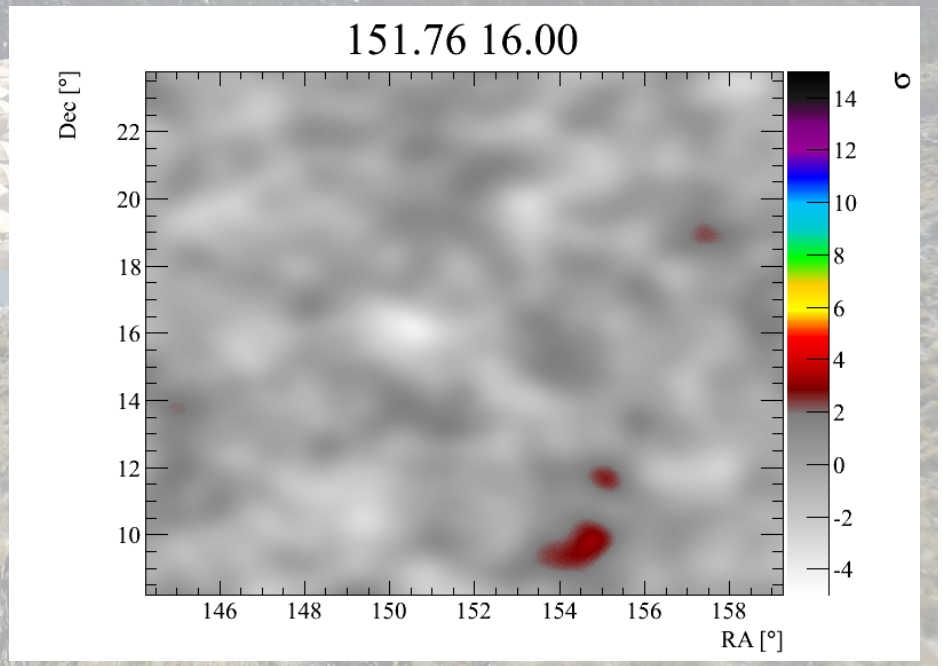
GRB 130427A

- Searches with two independent systems:
  - Triggered ("Main")
  - DAQ, Scaler DAQ
- Were able to set limits with scaler DAQ

Dark Matter Searches

Segue 1 , preliminary





This is Just the Beginning!

Data collection with full array starts this year

Physics include:

Cosmic Rays:

- Origin, evolution, acceleration and anisotropy

Gamma Rays:

- Study of known sources: Supernova remnants, pulsar wind nebulae, binary systems, gamma ray bursts, active galactic nuclei
- Discover unknown sources and structures

Particle Physics:

- Dark matter, Q-Balls, Primordial Black Holes, Intergalactic Magnetic Fields

Petabytes of data streaming in and to be mined in the coming years. Stay tuned!