Astrophysics Prospects with the High Altitude Water Cherenkov Observatory

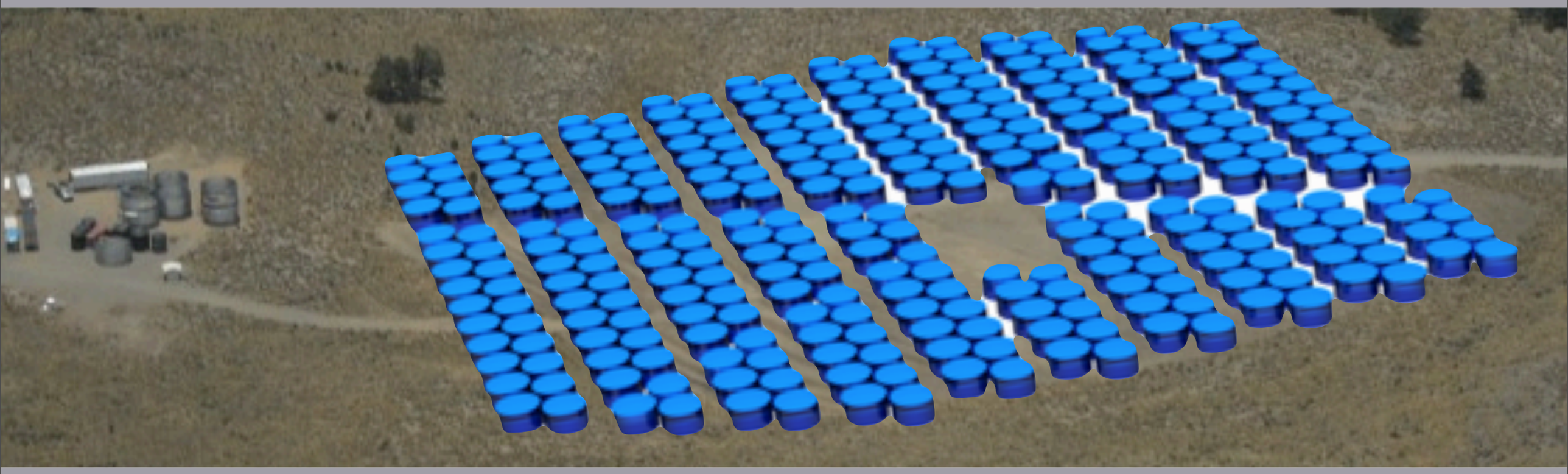
Miguel

Guillermo Haro 2011 Workshop - July 4 - 15, 2011

Outline

- Intro to **HAWC** and motivation
- Milagro results
- **HAWC** expected performance
- Astrophysical prospects with **HAWC**

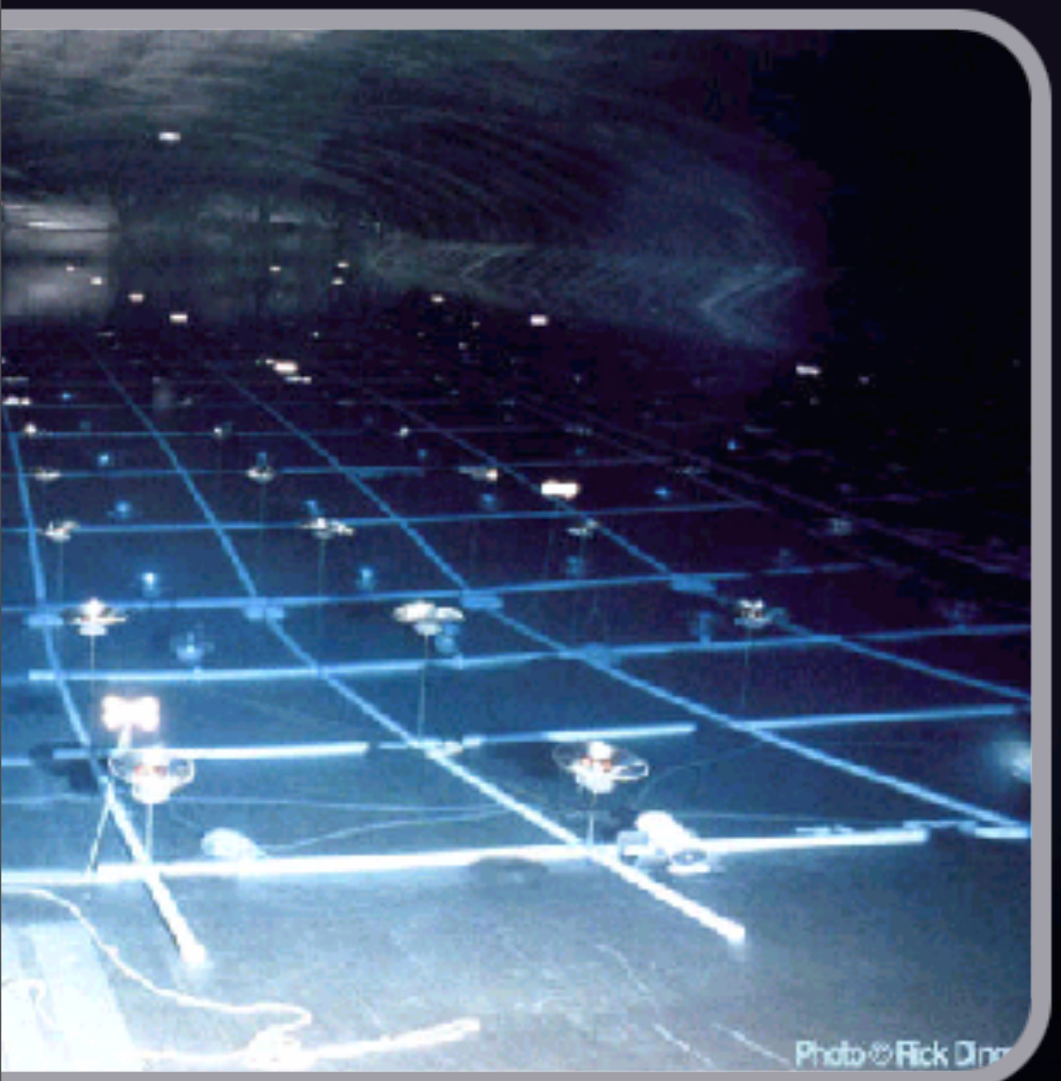
HAWC



300 - 7 m x 5 m steel Water Cherenkov Detectors (a.k.a. *tanks*) with 3 PMTs at 4,100 m a.s.l. in Mexico

Scientific Motivation

- Constrain the **origin of cosmic rays** by measuring gamma-ray **spectra to 100 TeV**.
- Probe **particle acceleration** in astrophysical jets with **wide field of view, high duty factor** observations.
- Explore **new physics** with an **unbiased survey** of the **TeV sky**.



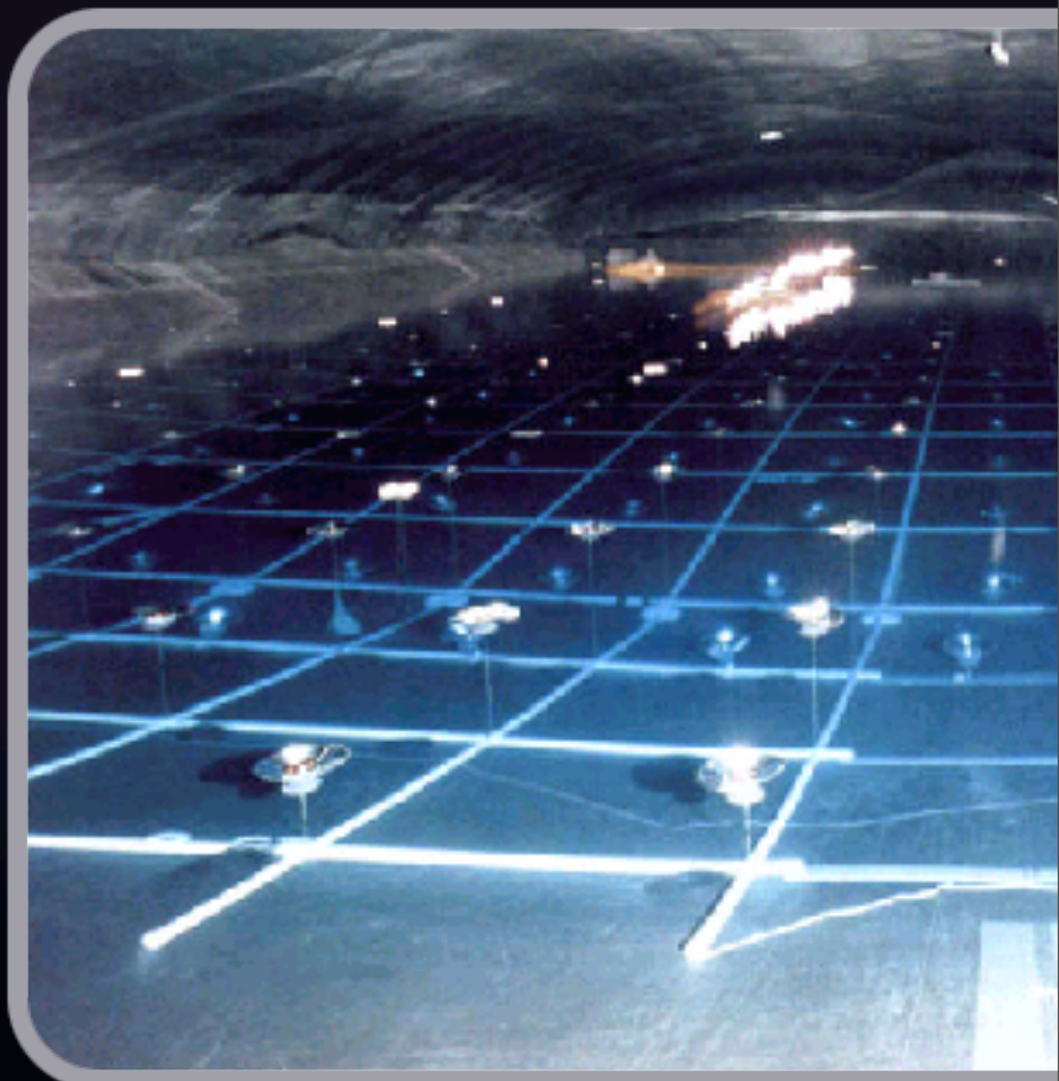
Milagro

- water Cherenkov detector
- threshold ~300 GeV
- wide angle
- γ/hadron separation
- 24 hour - all year operation

A first generation wide-field γ-ray detector

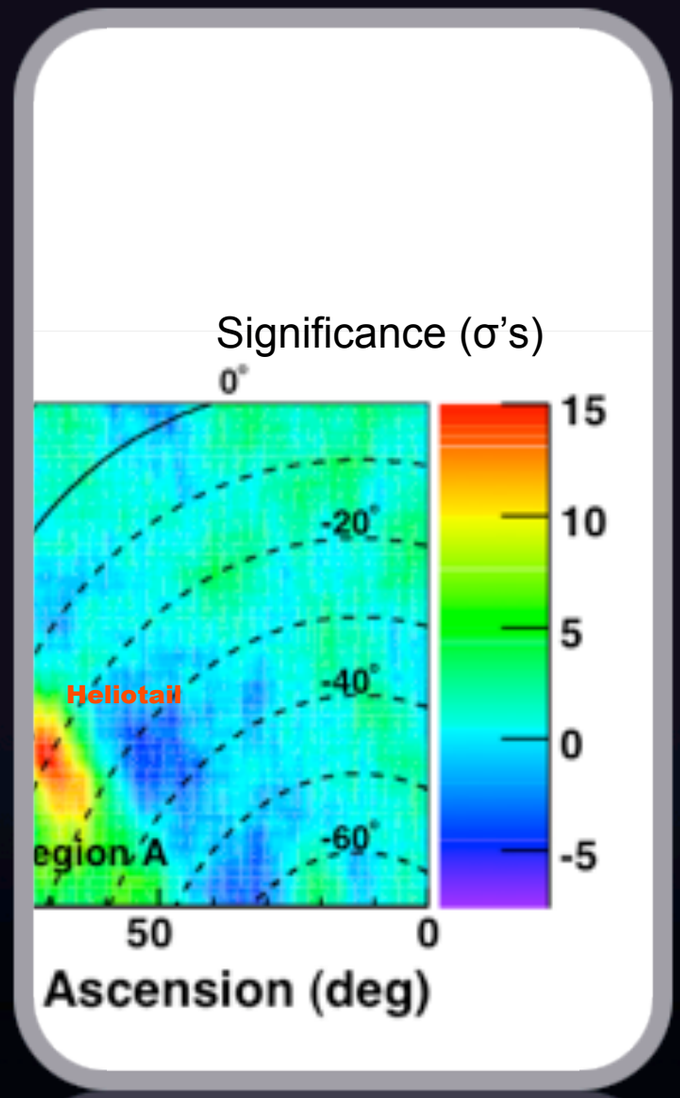
Milagro site

- Los Alamos, NM
- 8,650 ft in elevation
- 60 m x 80 m x 8 m covered pond



Milagro Results

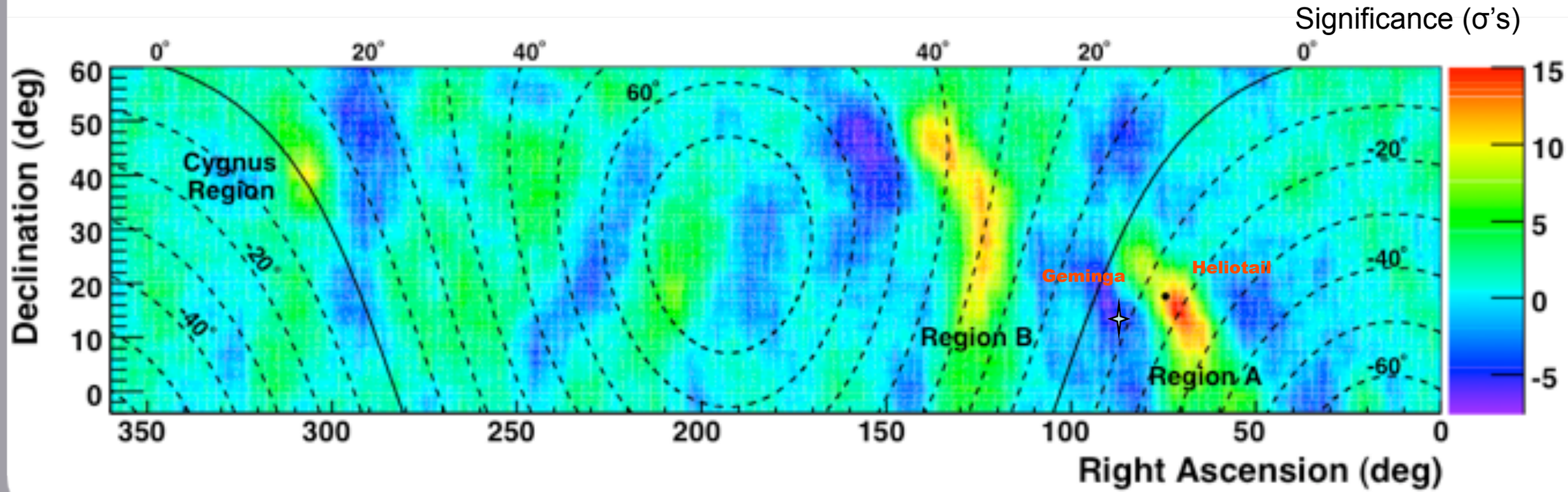
Discovery of Localized Regions of Excess 10 TeV Cosmic Rays



Physical Review Letters **101** (2008) 221101

Milagro Results

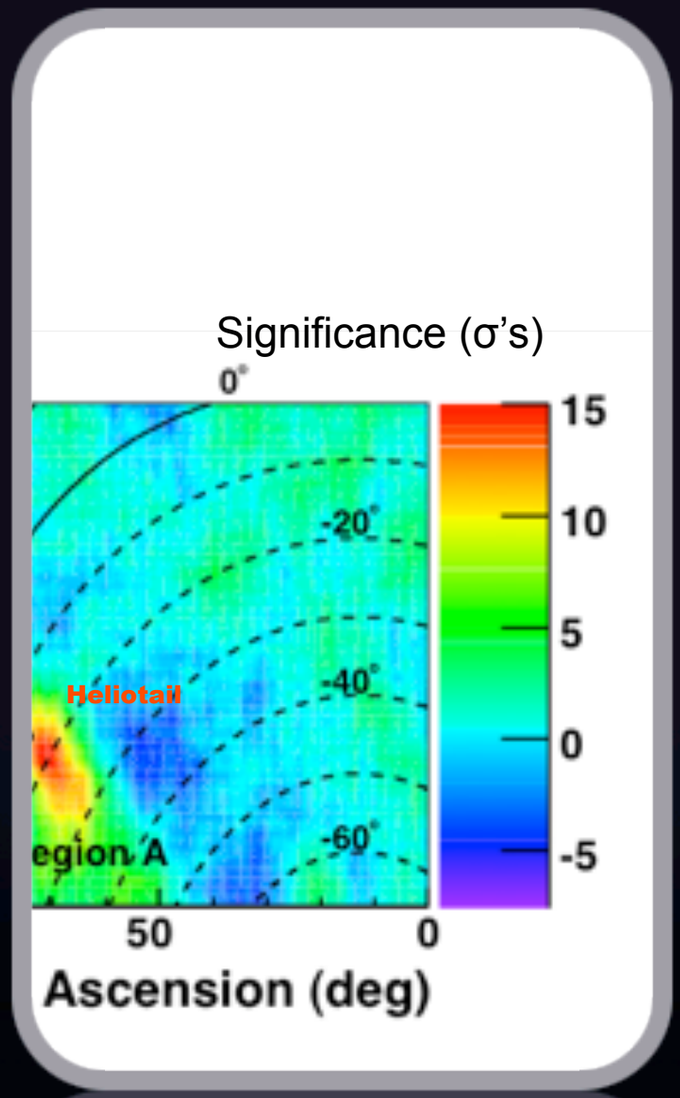
Map of significances for the Milagro (cosmic rays) data set



Physical Review Letters **101** (2008) 221101

Milagro Results

Excess emission on angular scales of ~10º has been found in two localized regions of unknown origin with greater than 12σ significance.



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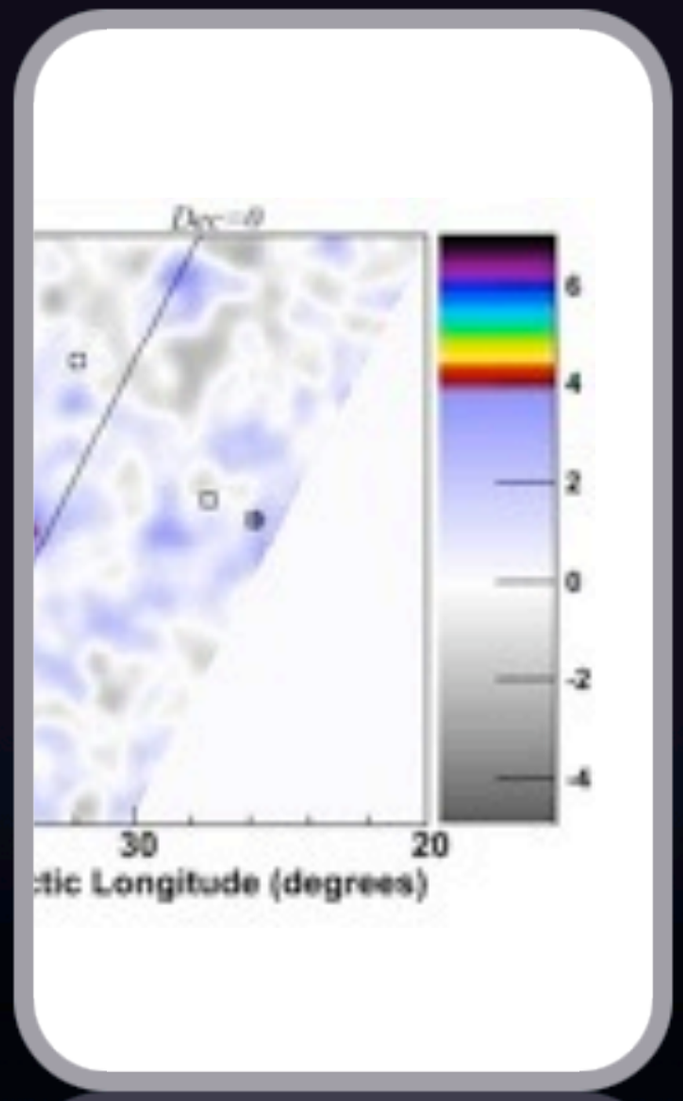
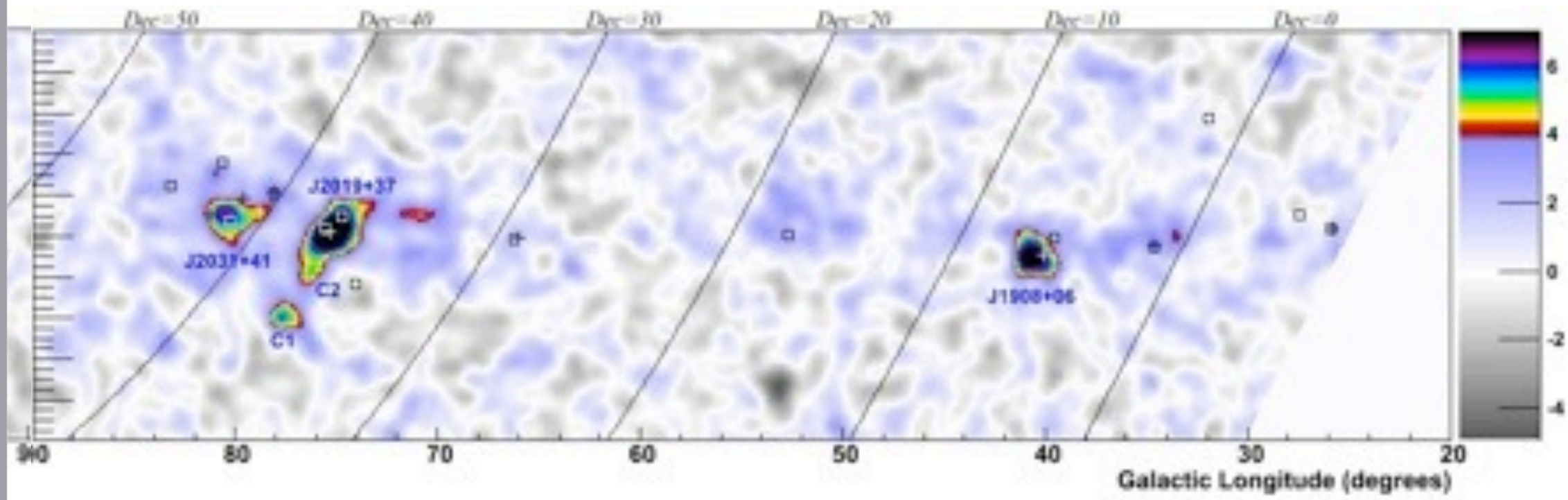


Excess emission on angular scales of ~10º has been found in two localized regions of unknown origin with greater than 12σ significance.

Deepest survey of Galactic gamma-ray sources at a median energy of ~ **20 TeV**.

The Astrophysical Journal **664** (2007) L91-L94

Milagro Results



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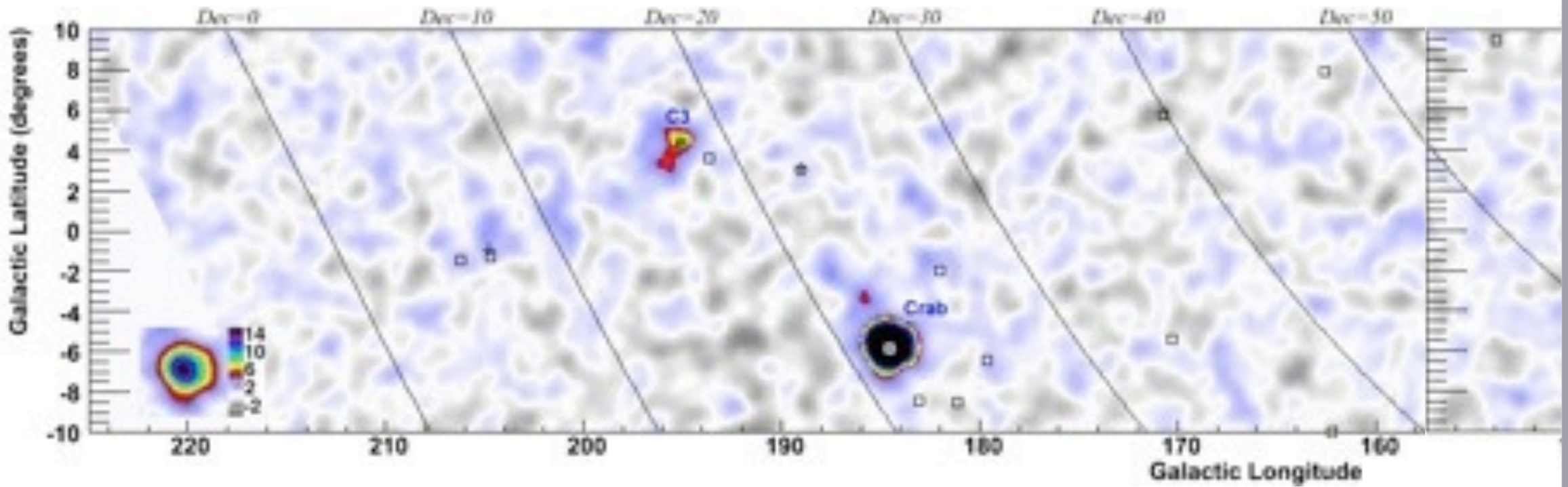

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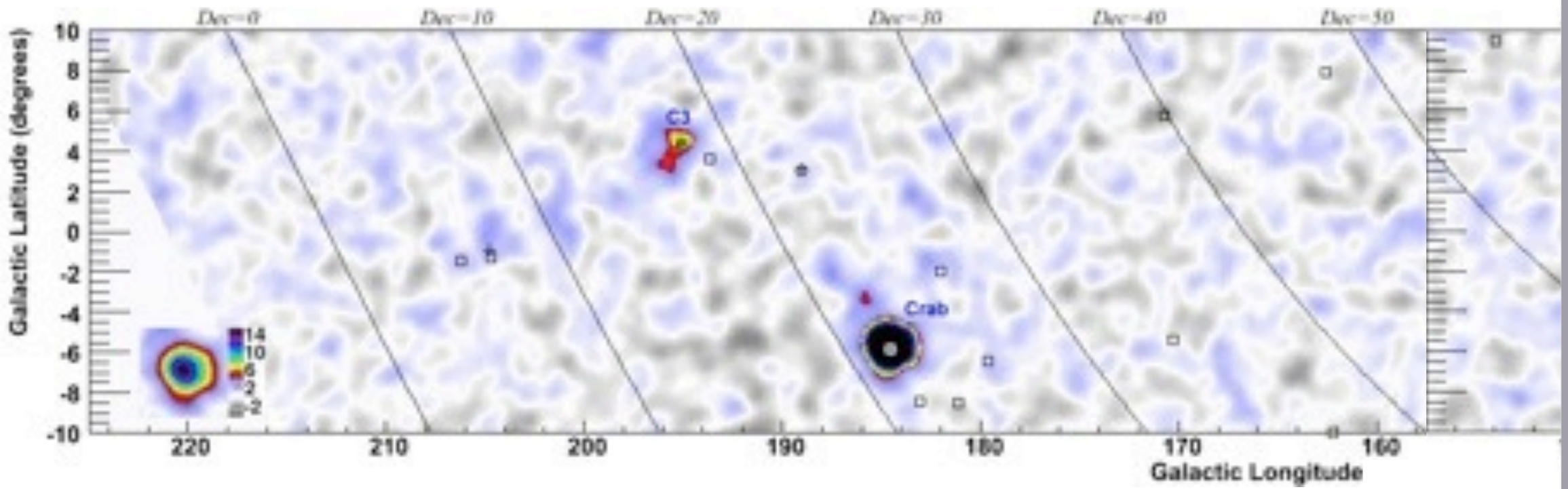
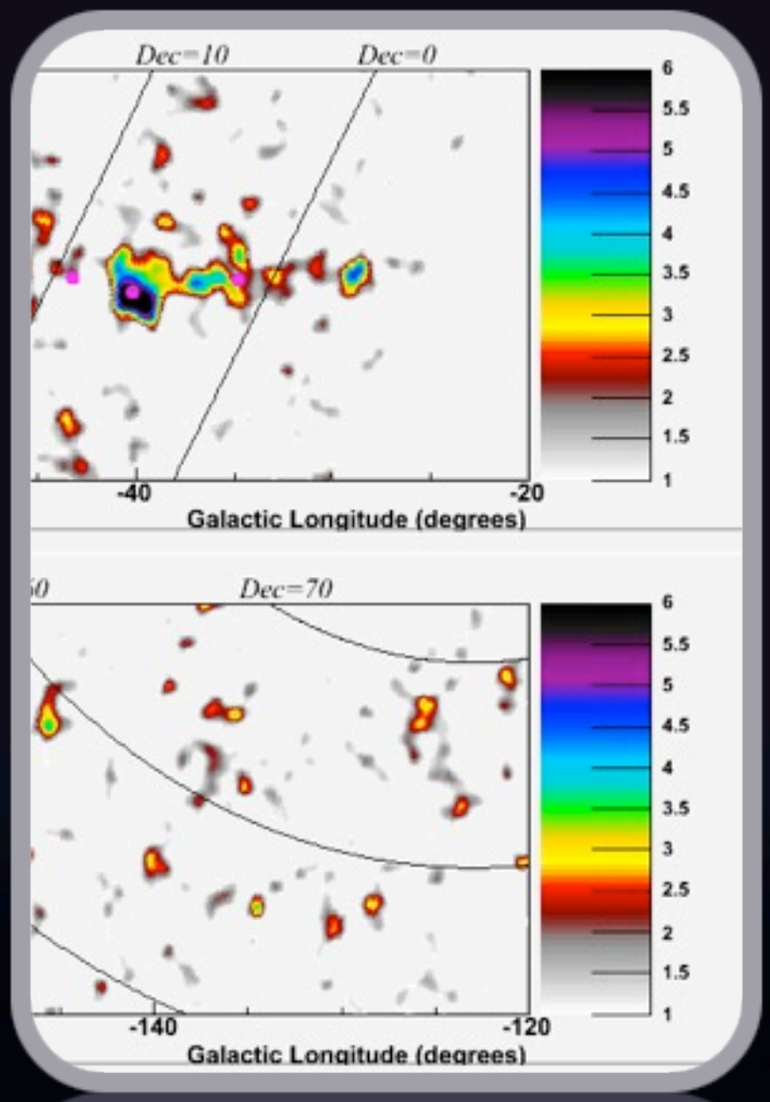


Eight sources of TeV emission were identified with significance > 4σ (after accounting for trials).

The Astrophysical Journal **664** (2007) L91-L94

Milagro Results

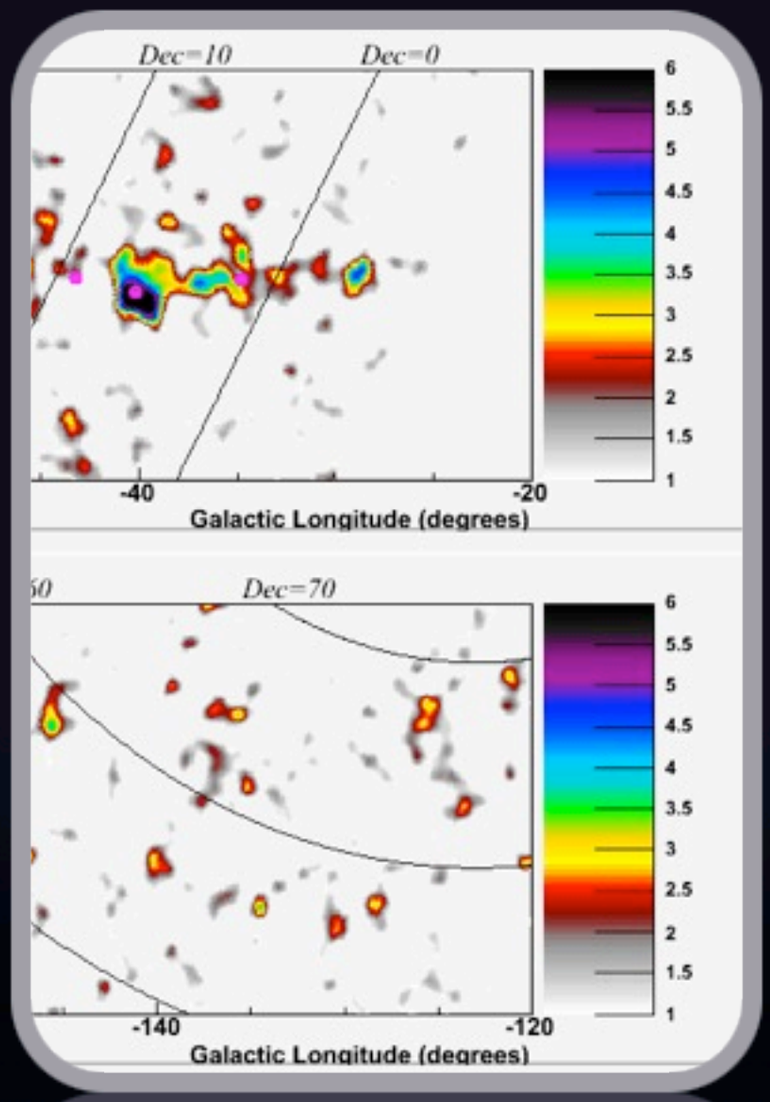
Multi-TeV emissions from Galactic Sources!



The Astrophysical Journal **700** (2009) L127-L131

Milagro Results

16 TeV-associations out of 34 Fermi Galactic sources



The Astrophysical Journal **700** (2009) L127-L131

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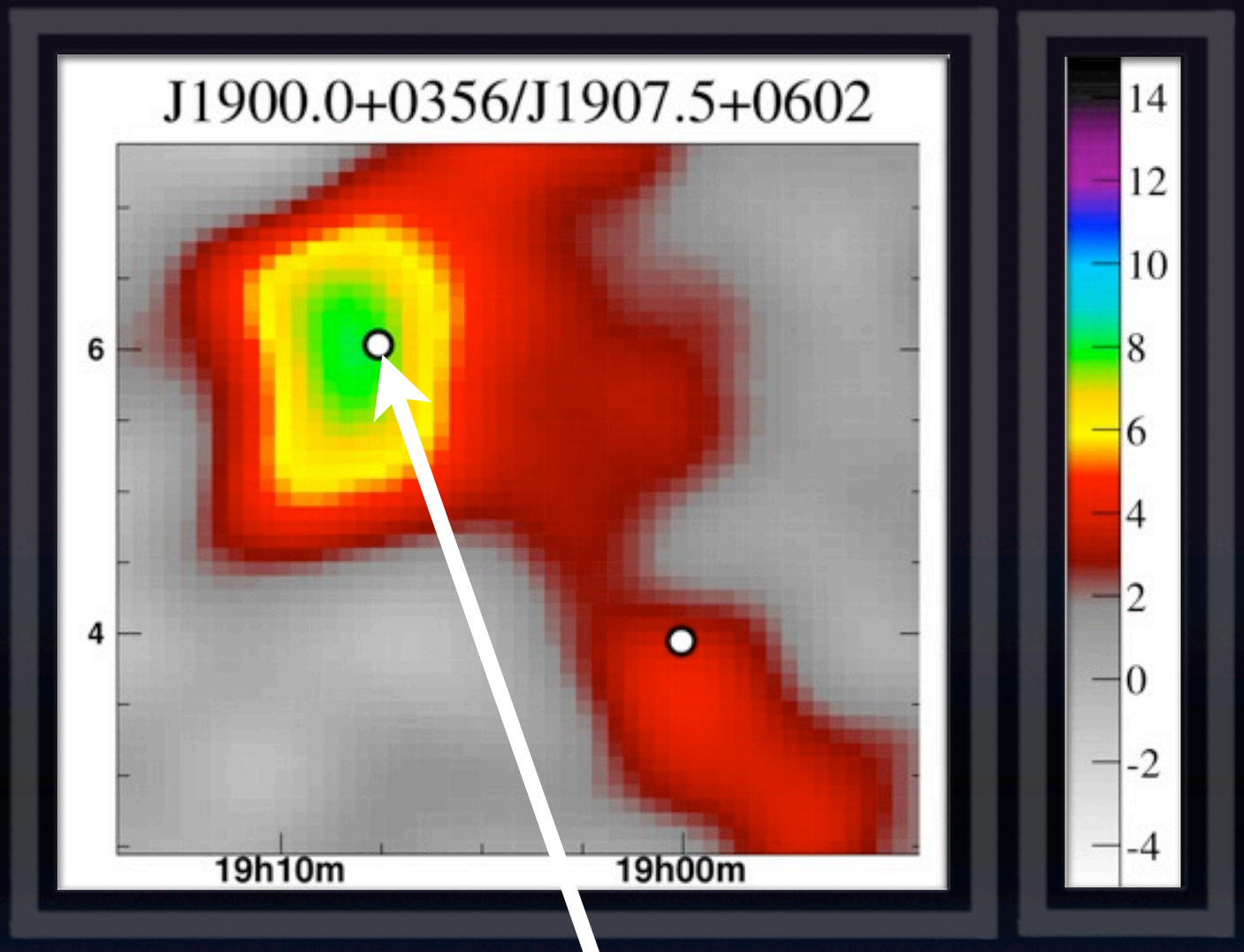
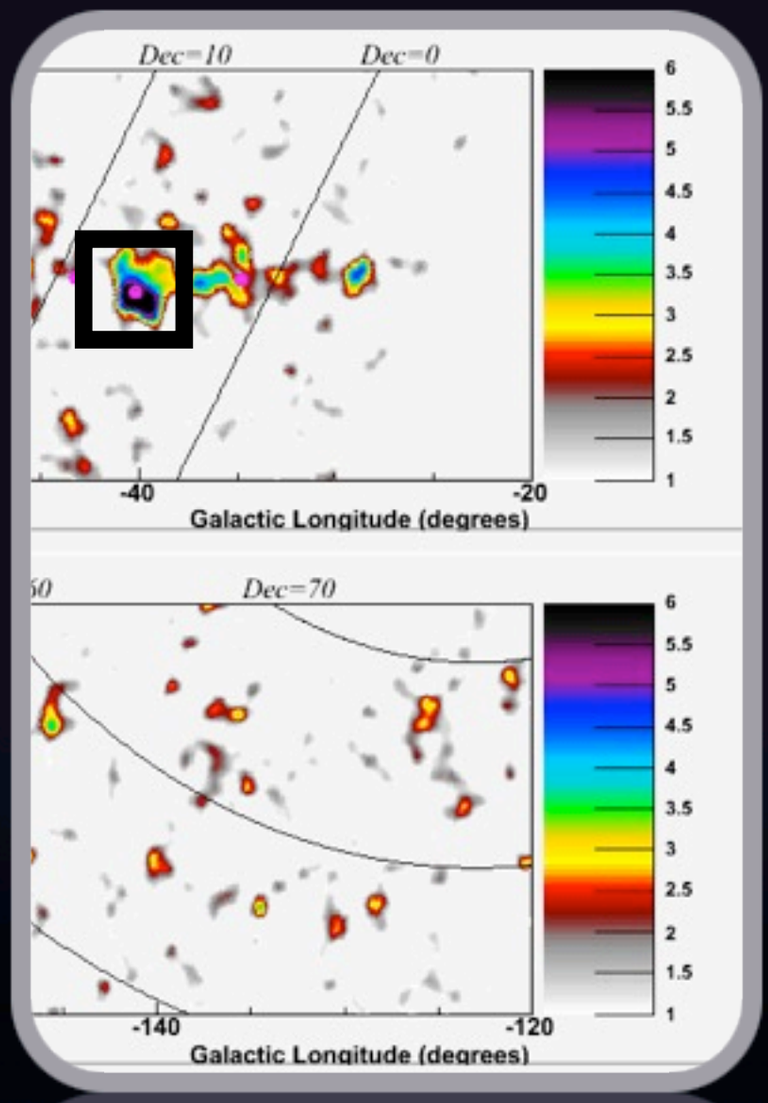
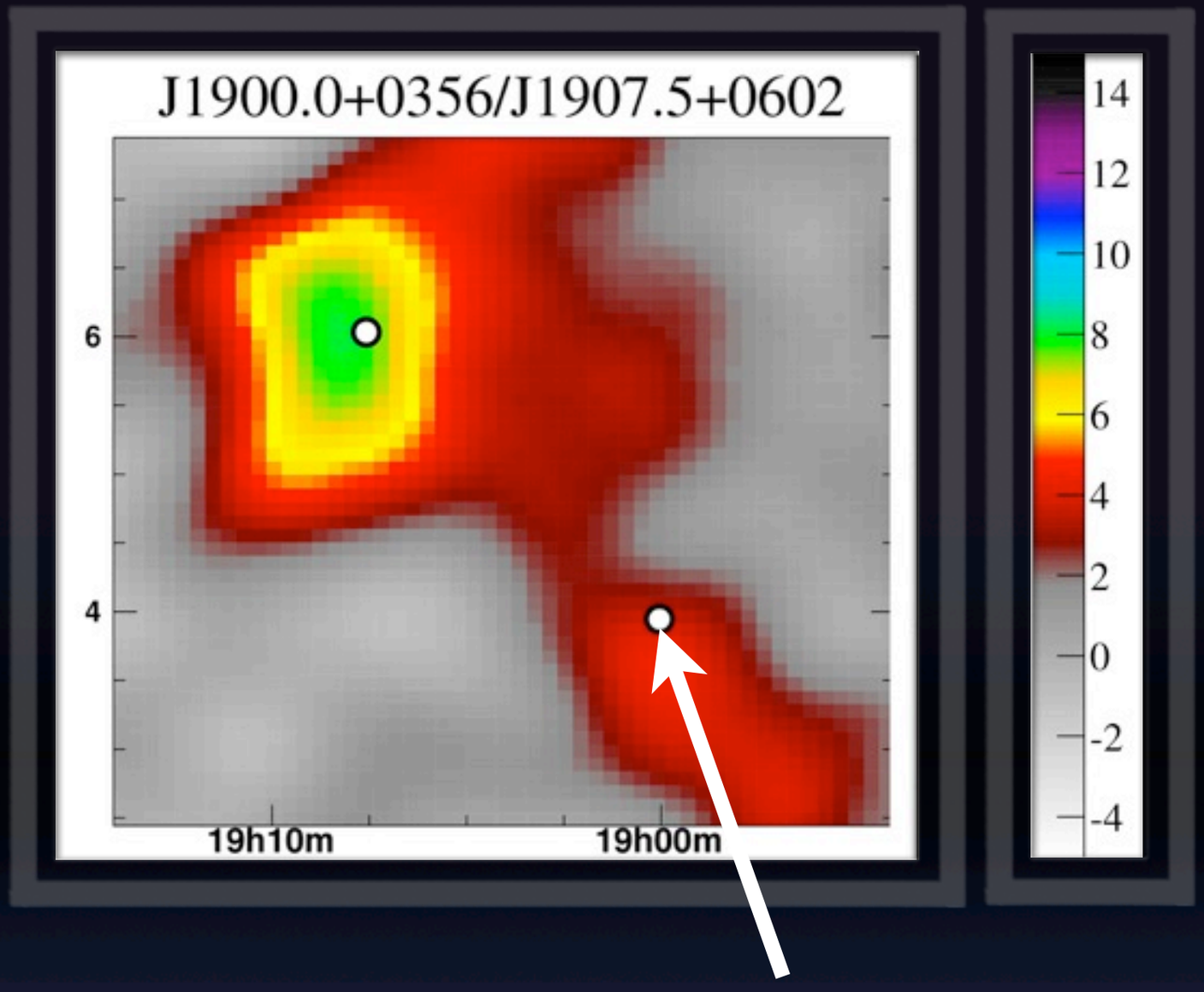


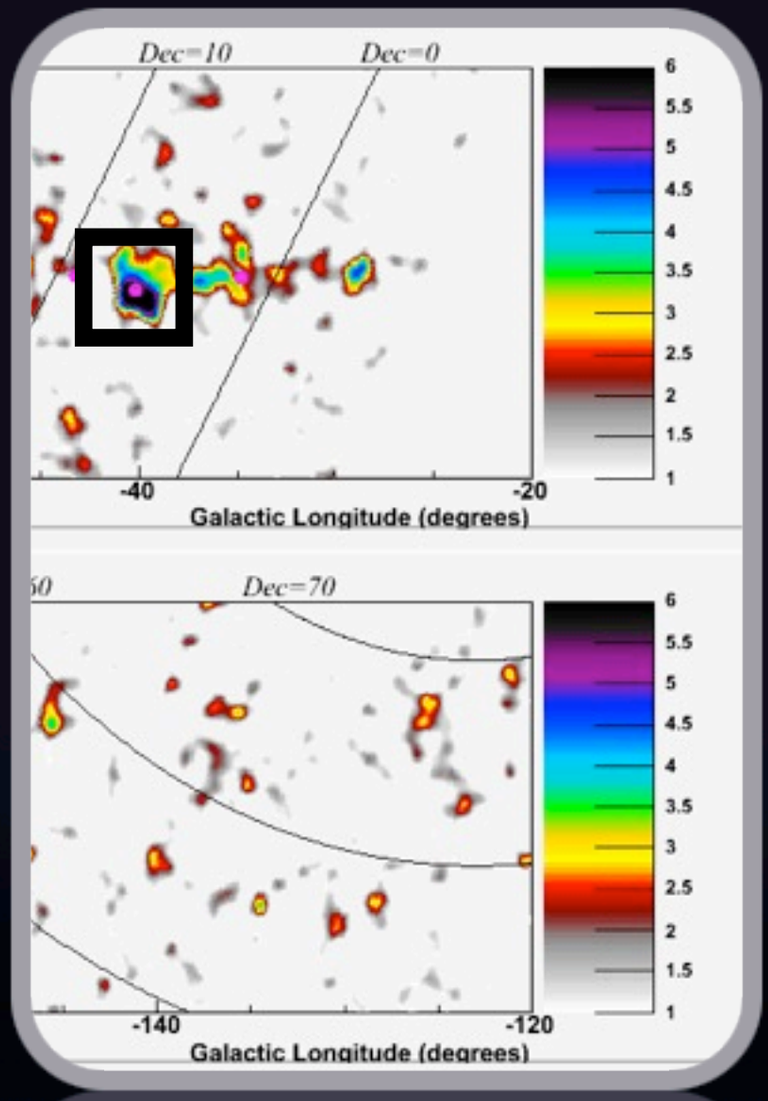


Associated with **MGRO J1908+06**

The Astrophysical Journal **700** (2009) L127-L131

Milagro Results



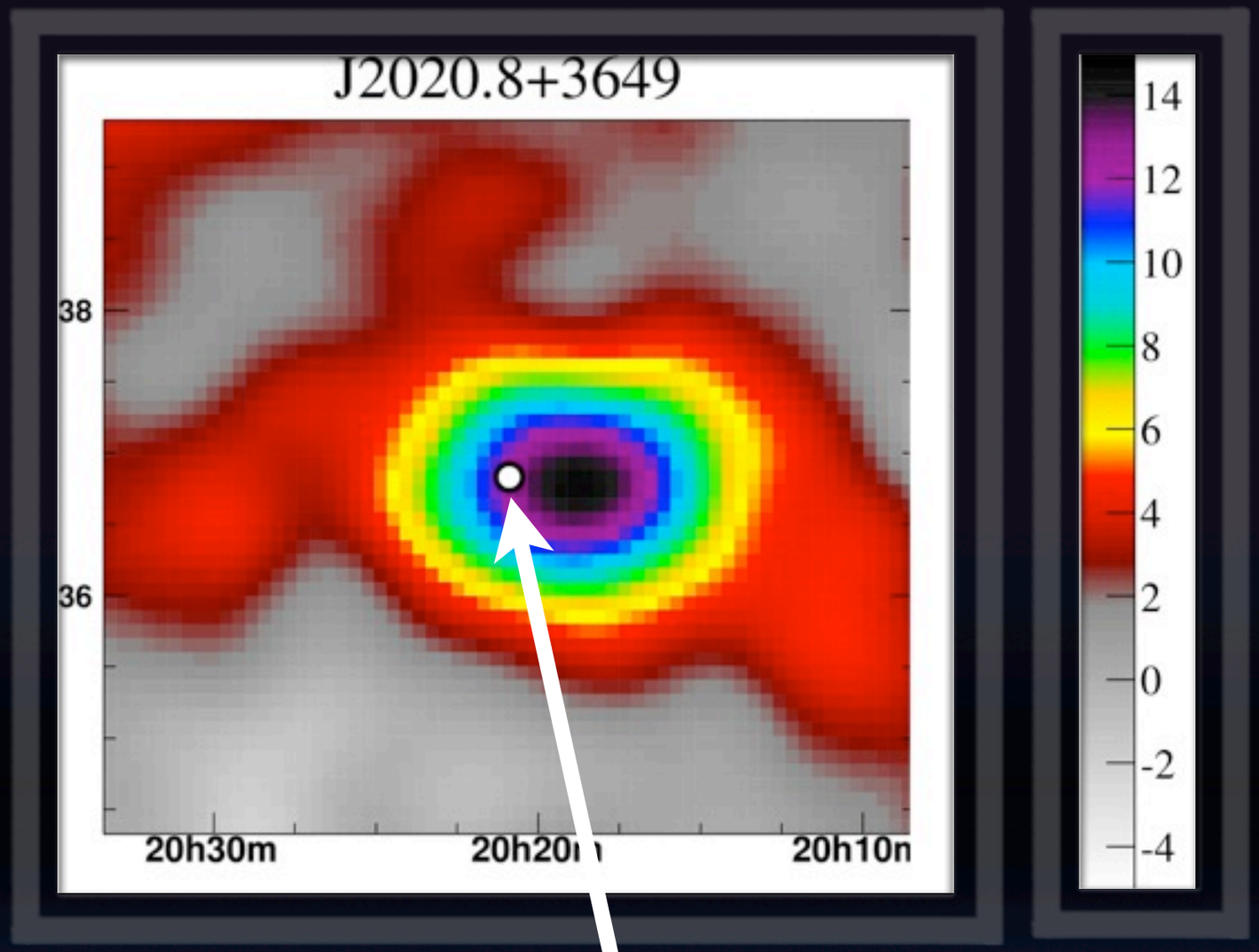


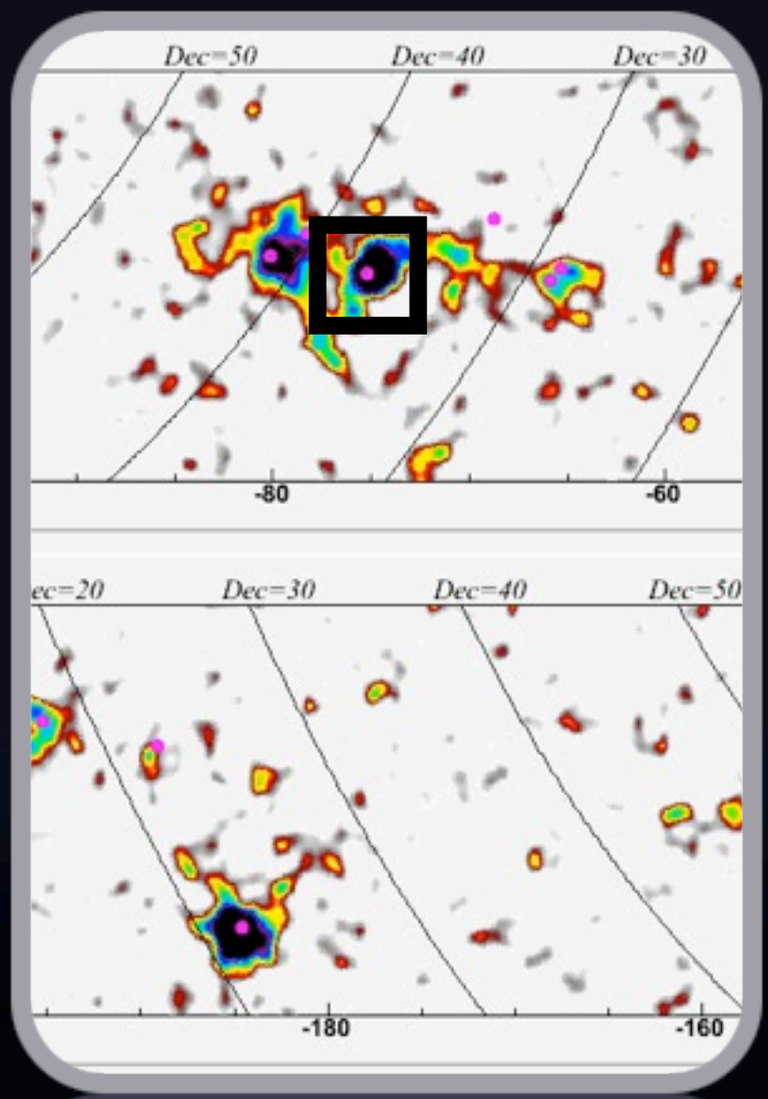
J1900.0+0356 has **NO** known association.

Previously not reported in TeV.

The Astrophysical Journal **700** (2009) L127-L131

Milagro Results

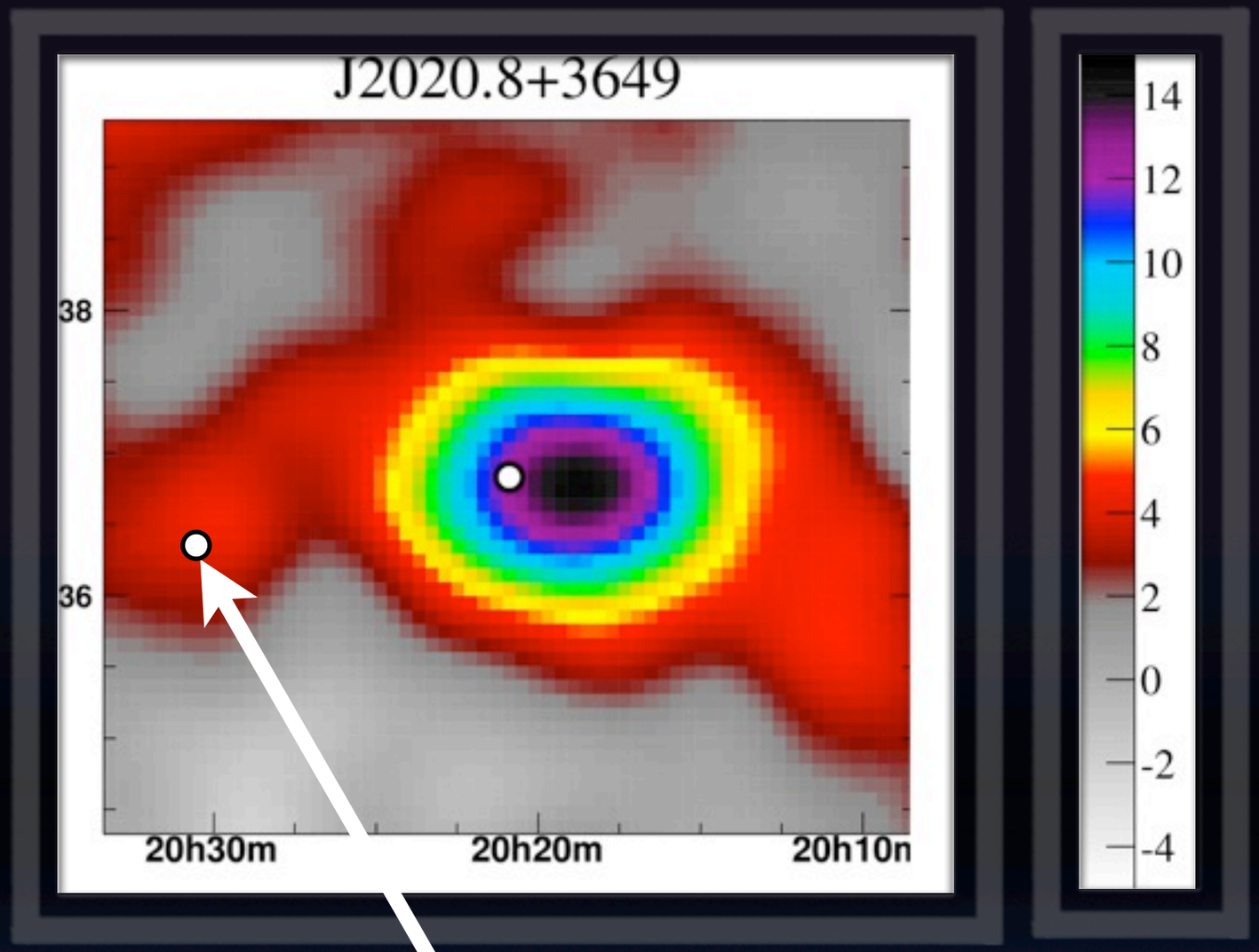


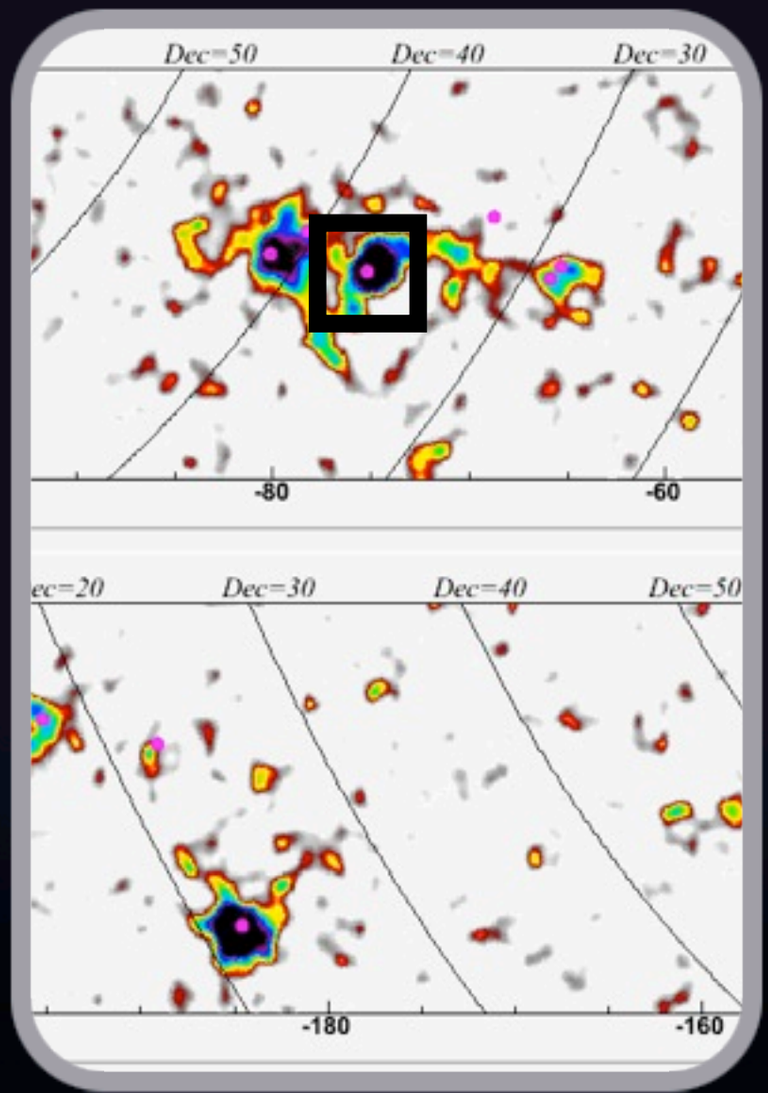


Associated with previously reported **MGRO J2019+37**

The Astrophysical Journal **700** (2009) L127-L131

Milagro Results





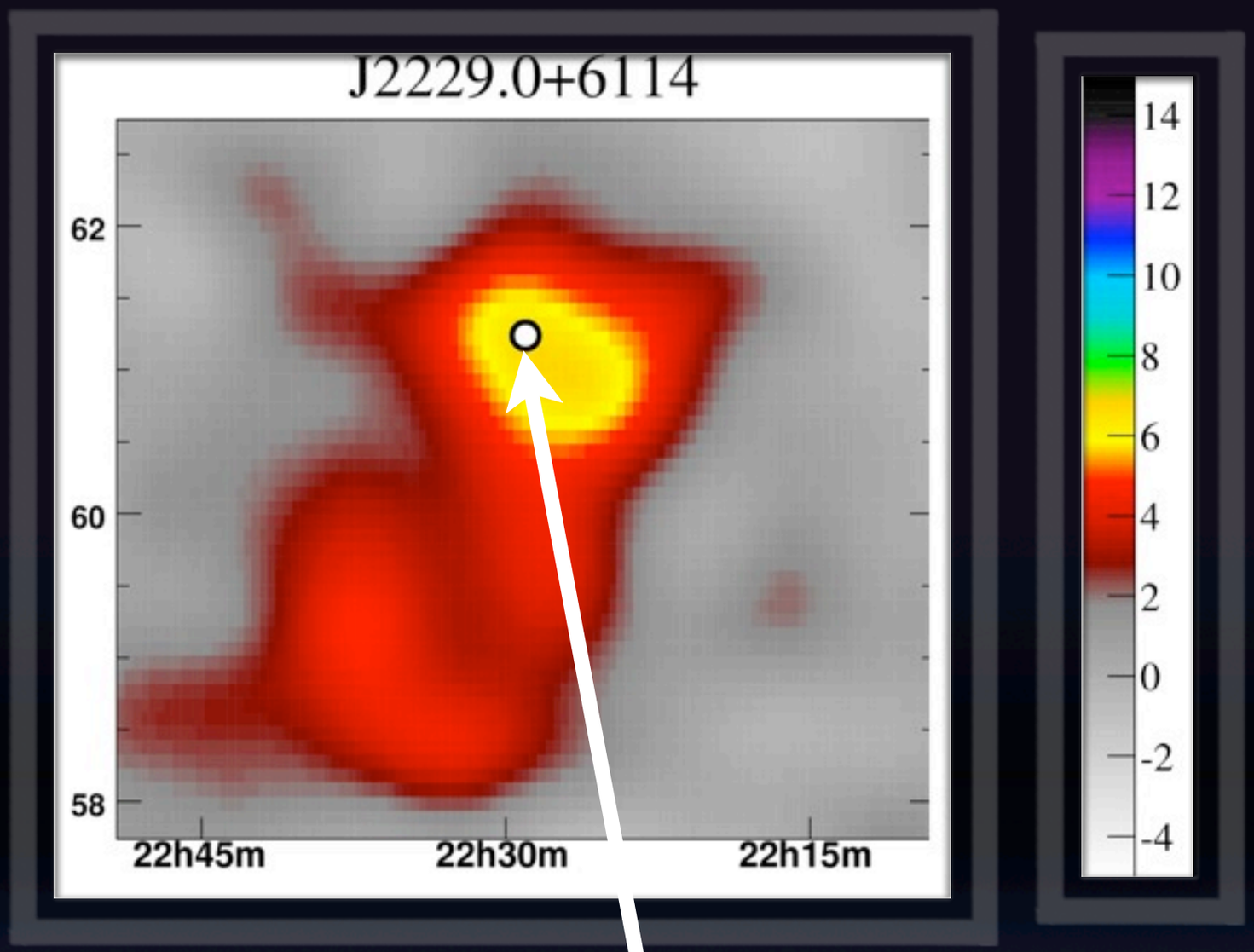
NEW!

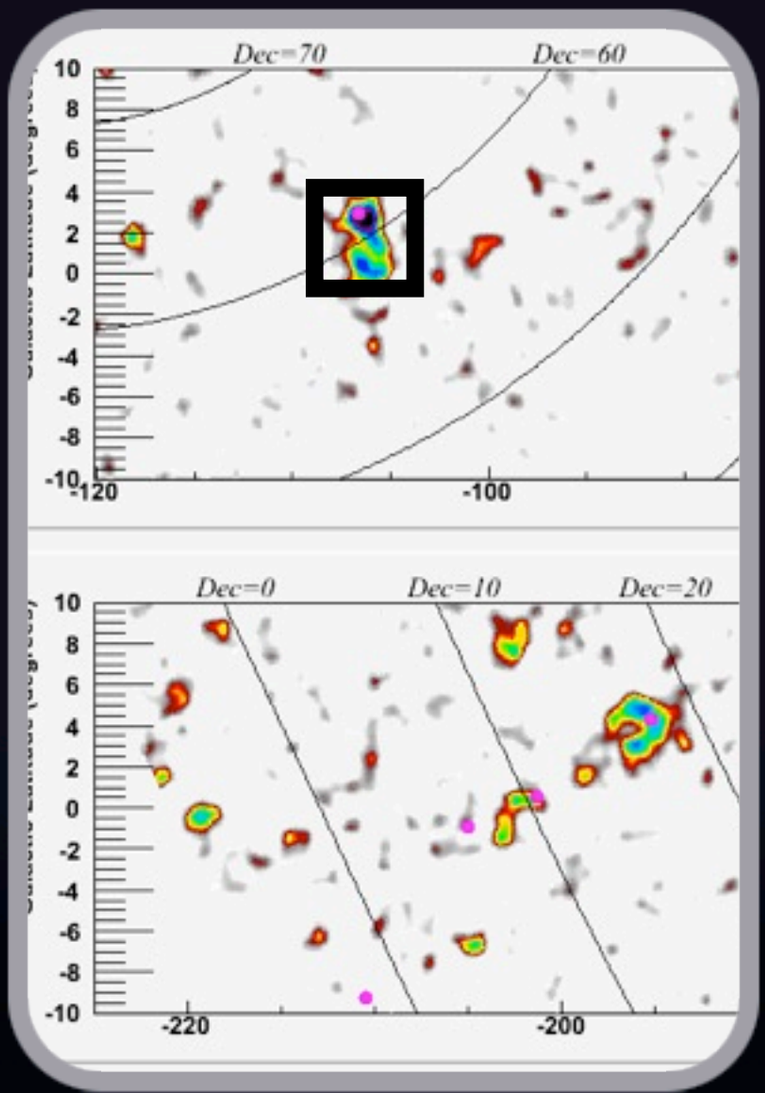
Fermi reports now **PSR J2030+3641**

A. A. Abdo *et al.* 2010 *ApJS* ***188*** *405*

The Astrophysical Journal **700** (2009) L127-L131

Milagro Results

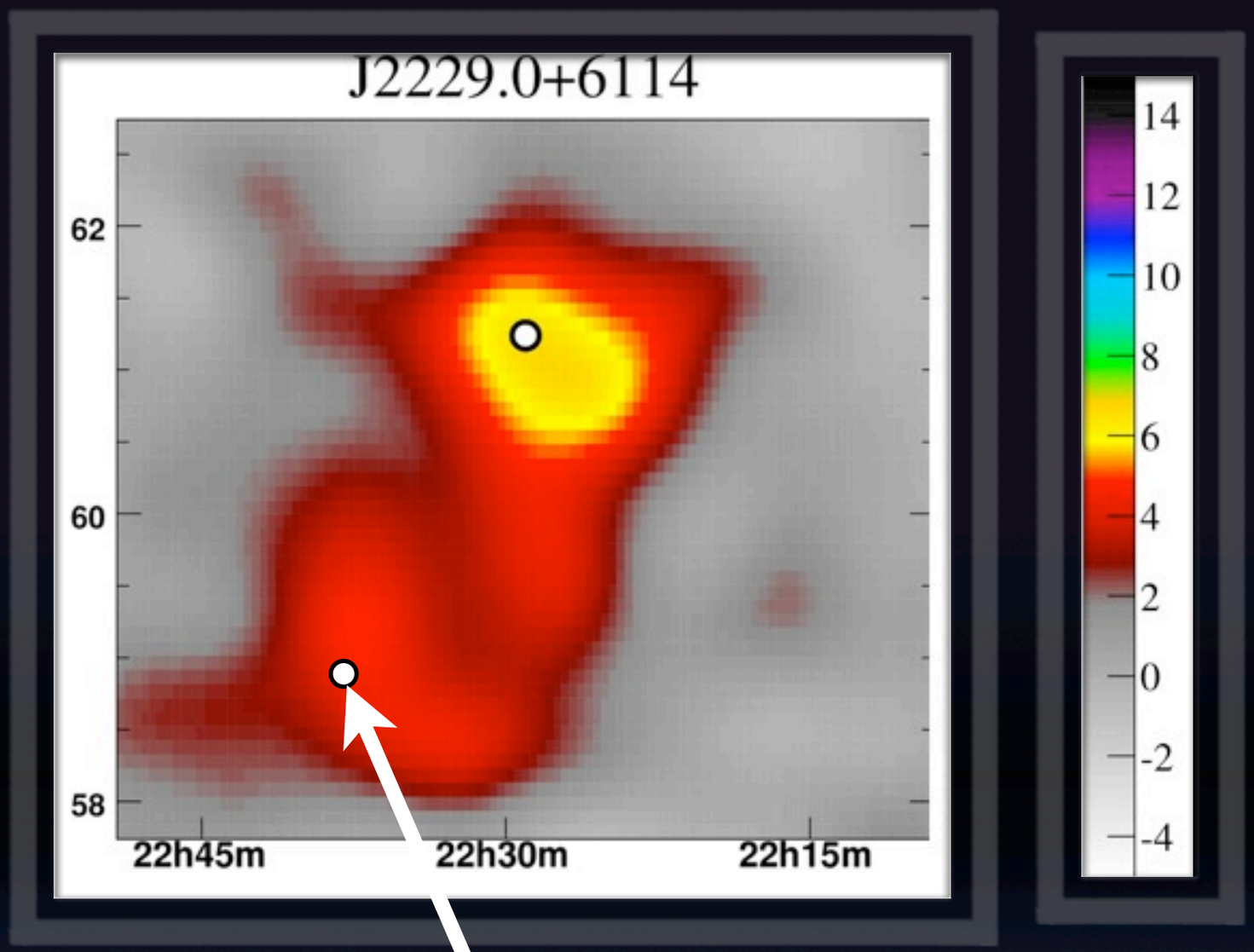


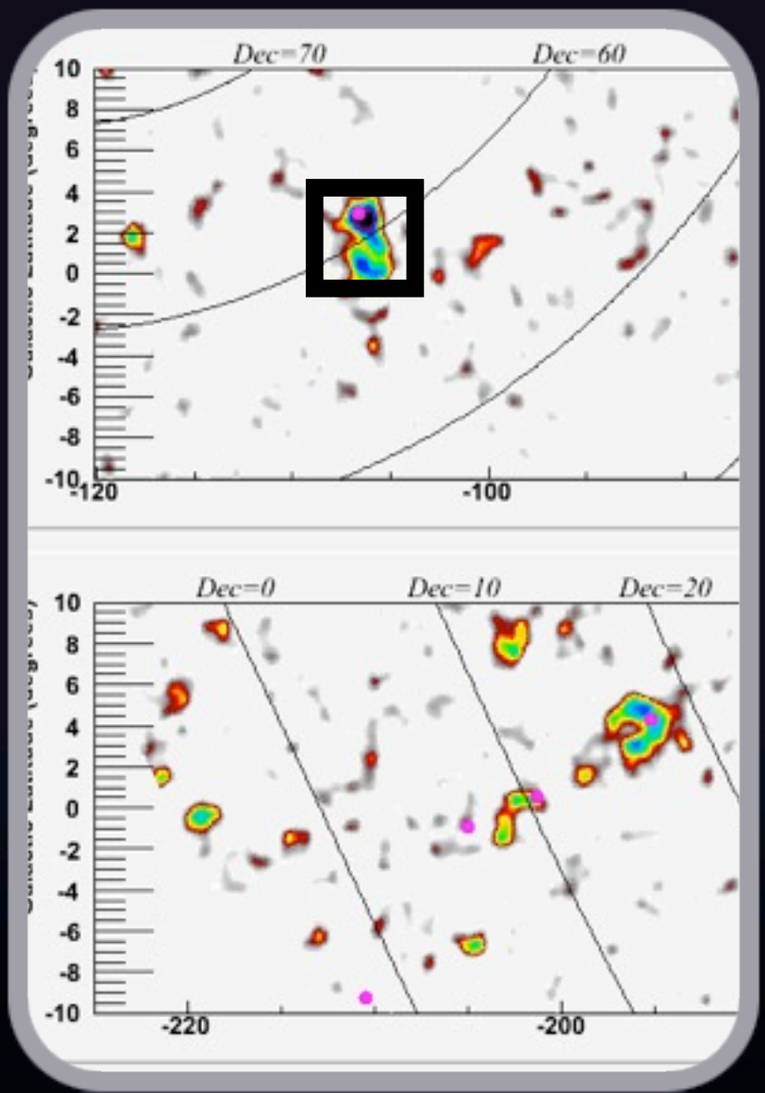


"Boomerang" PWN
Associated with **radio pulsar J2229+6114**

The Astrophysical Journal **700** (2009) L127-L131

Milagro Results



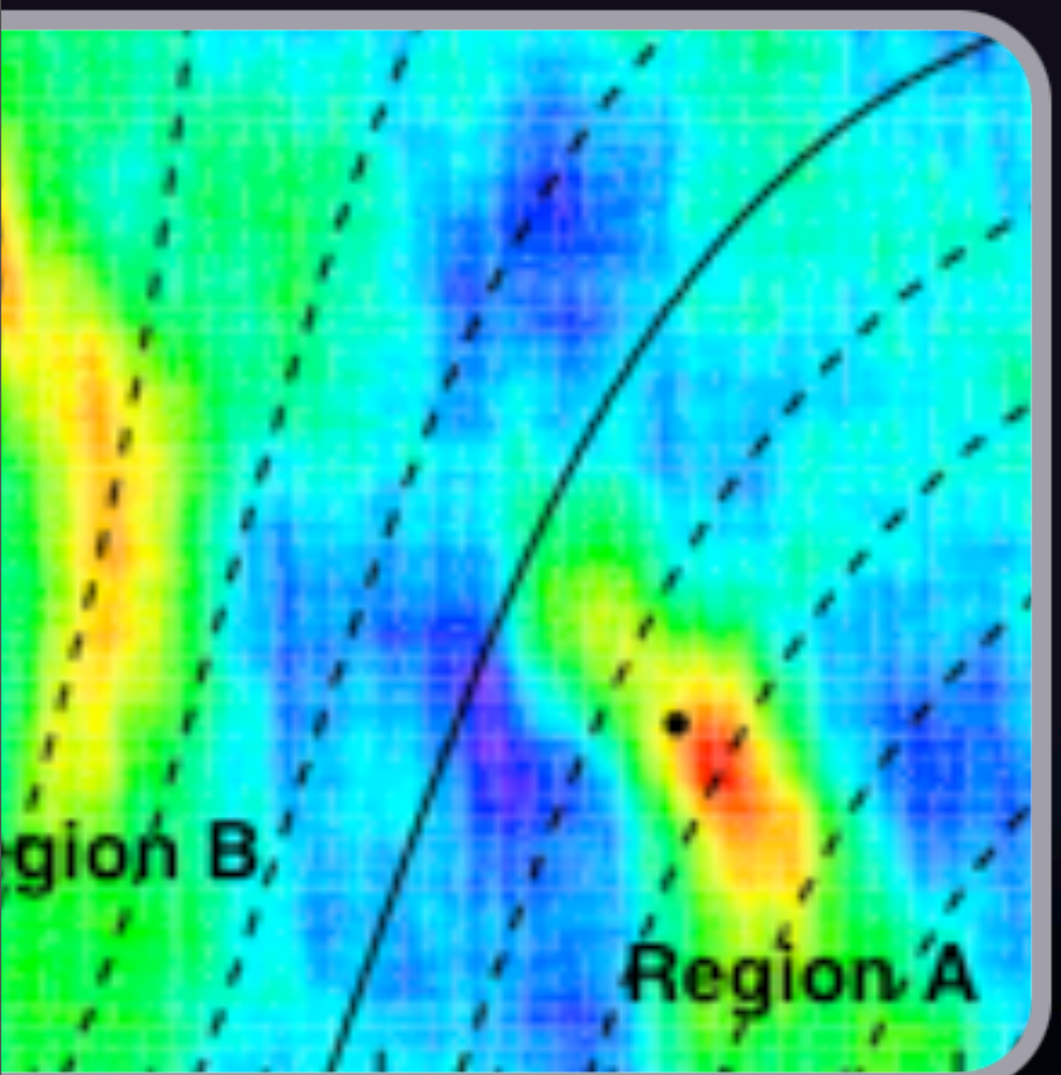


Fermi pulsar **in the Milagro 5σ region**

A. A. Abdo *et al.* *Science* **325** (5942) 848-852

The Astrophysical Journal **700** (2009) L127-L131

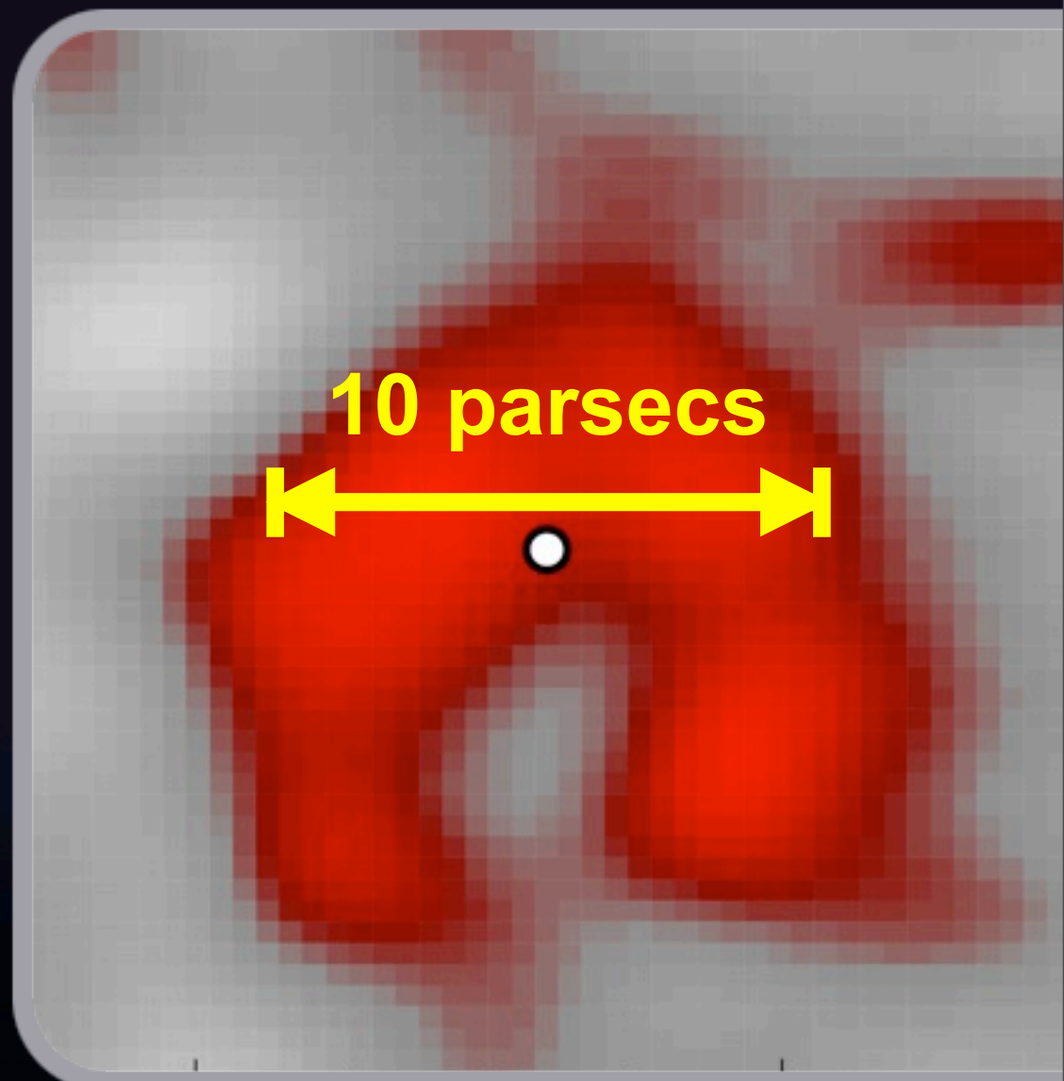
Milagro Discoveries



- over a dozen **TeV sources**
- **diffuse TeV emission** from the Galactic plane
- directional **excess of cosmic rays**

Milagro Achievements

- Most bright Galactic GeV sources **extend to TeV**
- Best instrument for **hard spectrum** and **extended sources**

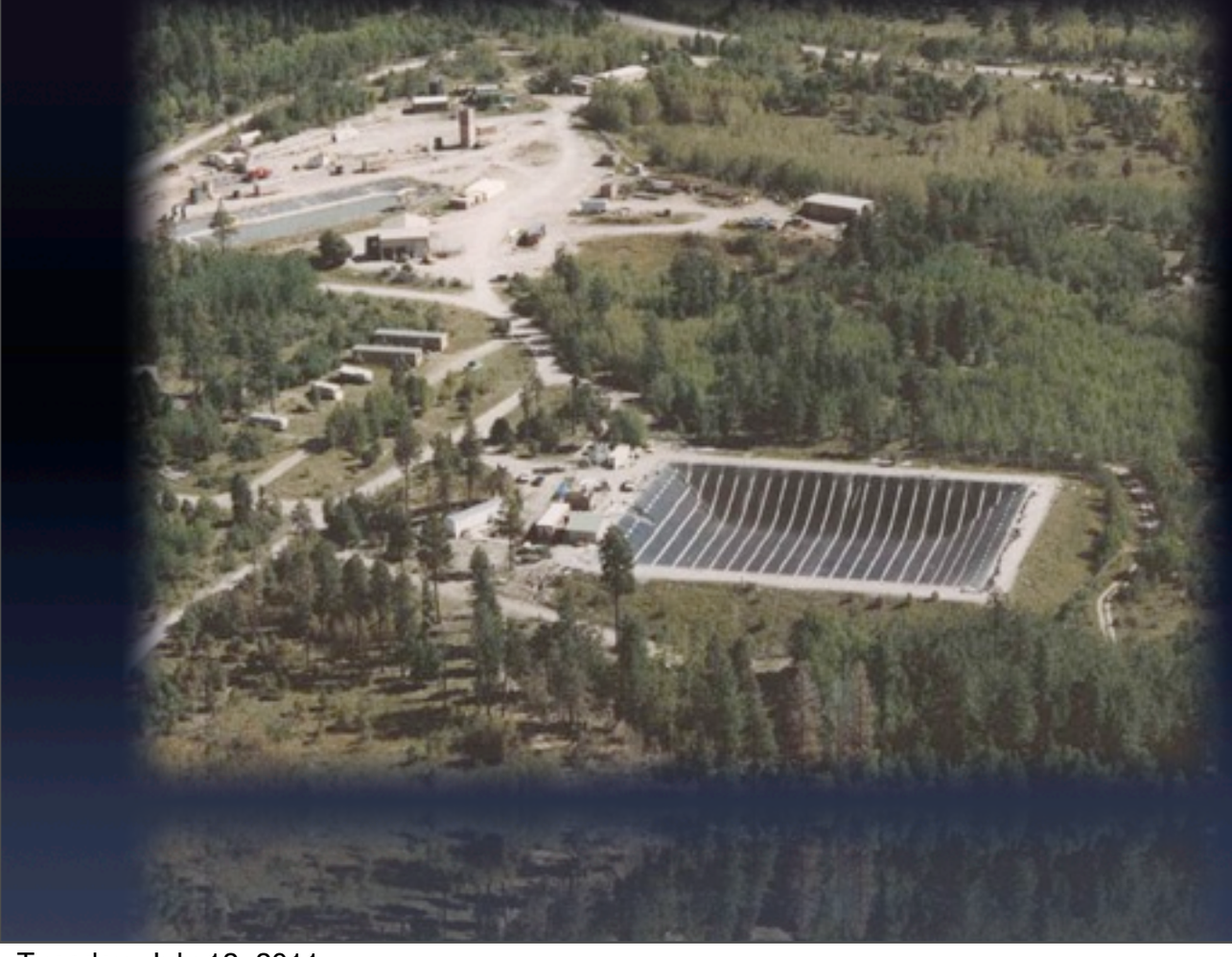


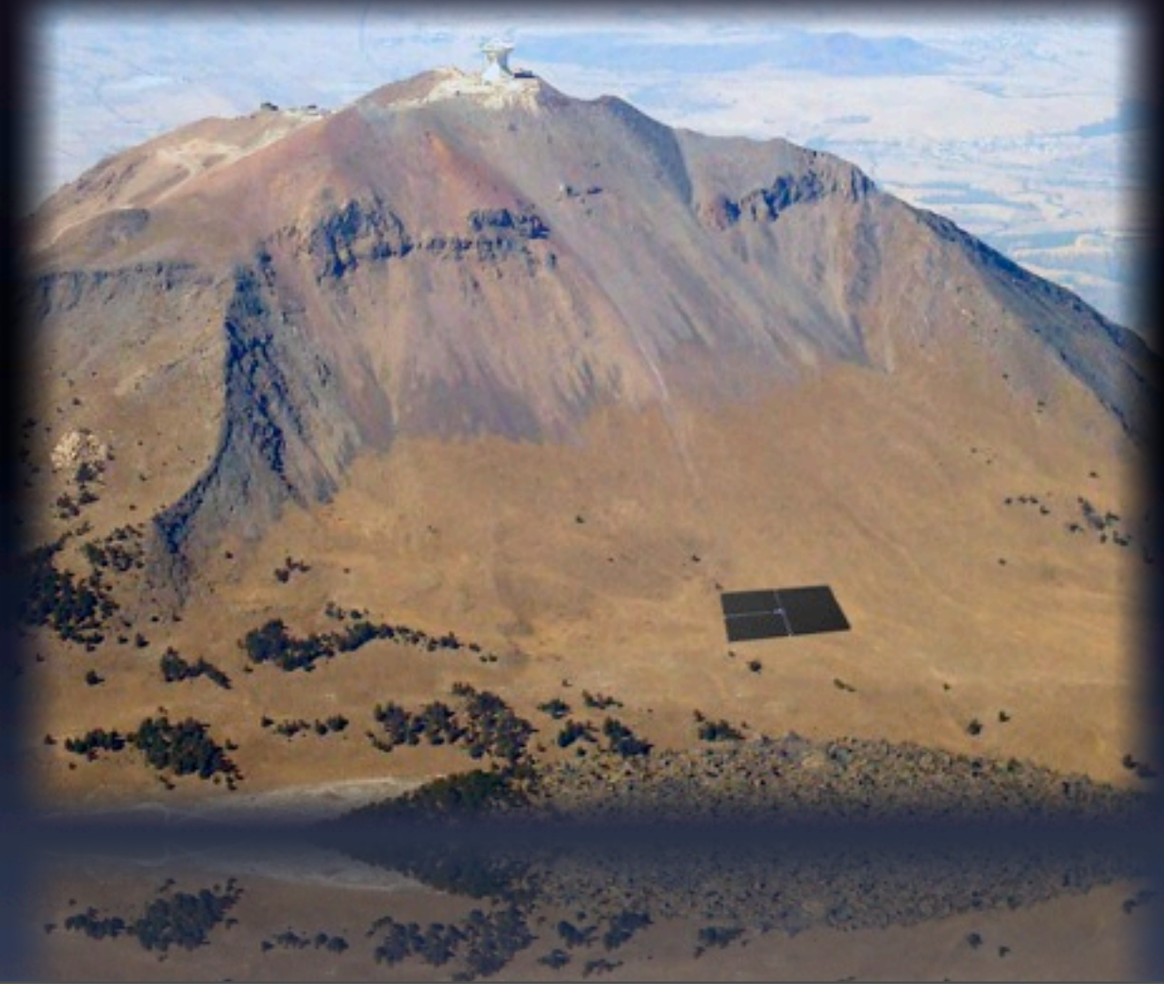
How do you make Milagro better?

By building **HAWC**... *duh!*

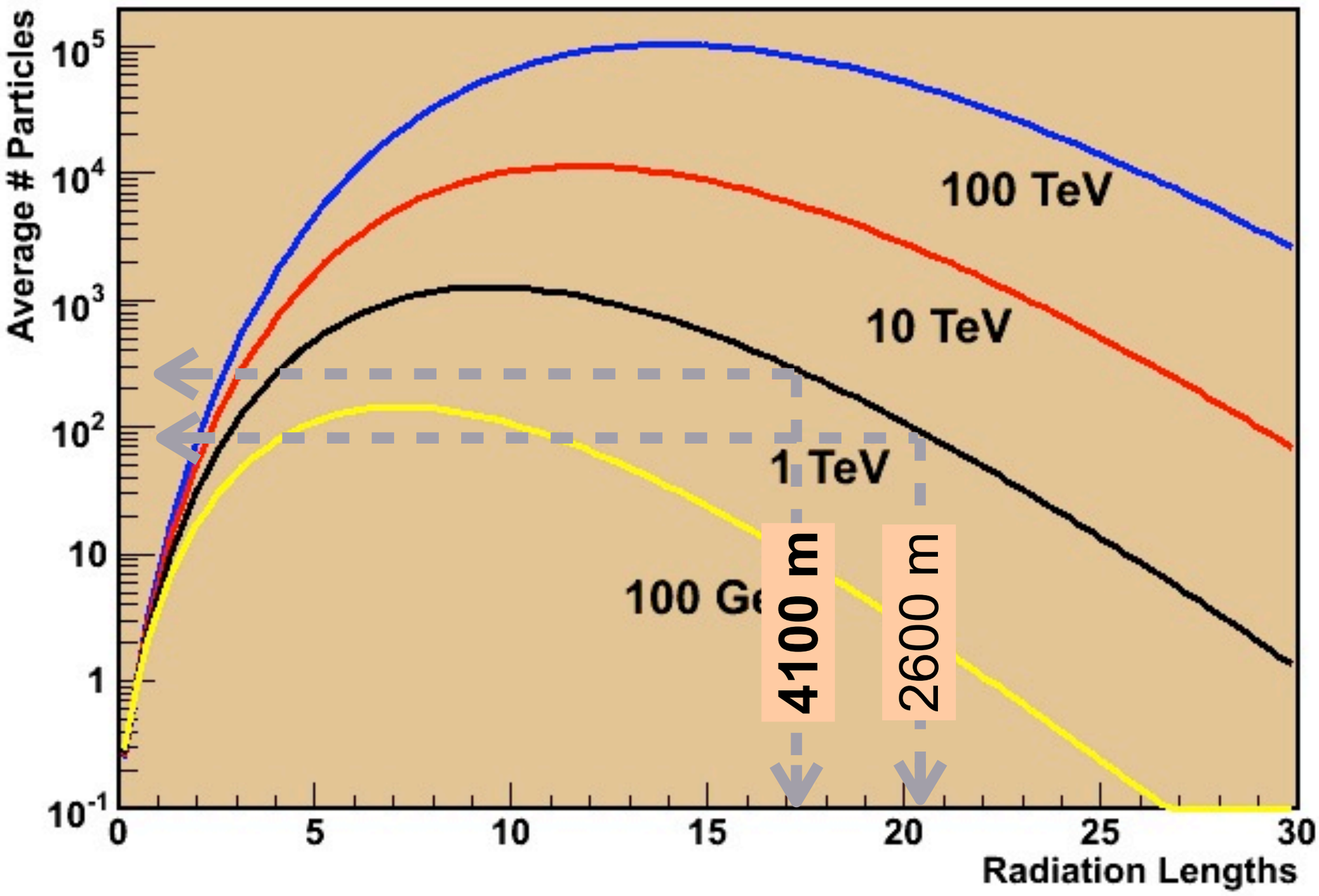
Go higher

Milagro	HAWC
2,650 m a.s.l.	**4,150 m a.s.l.**



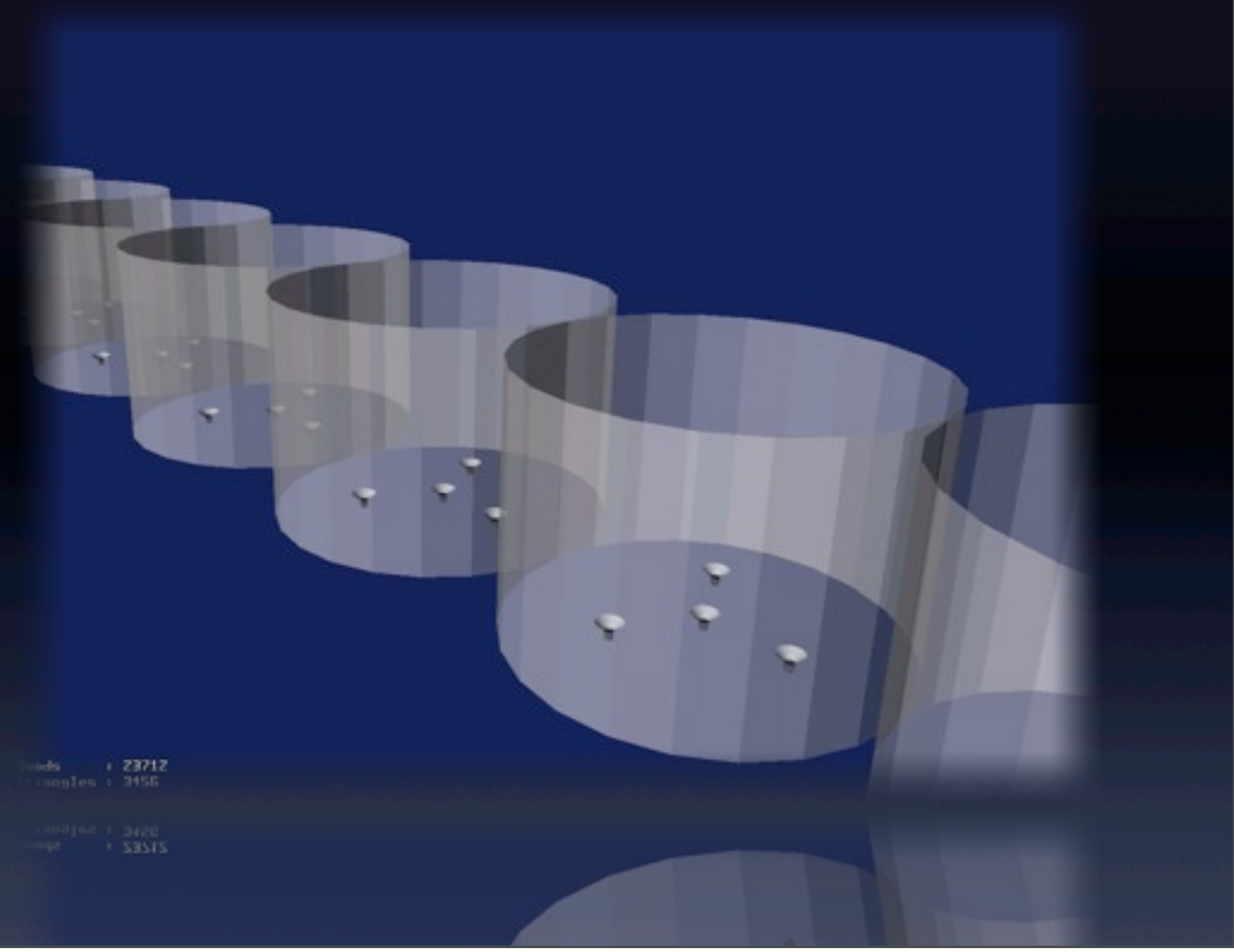


closer to shower max

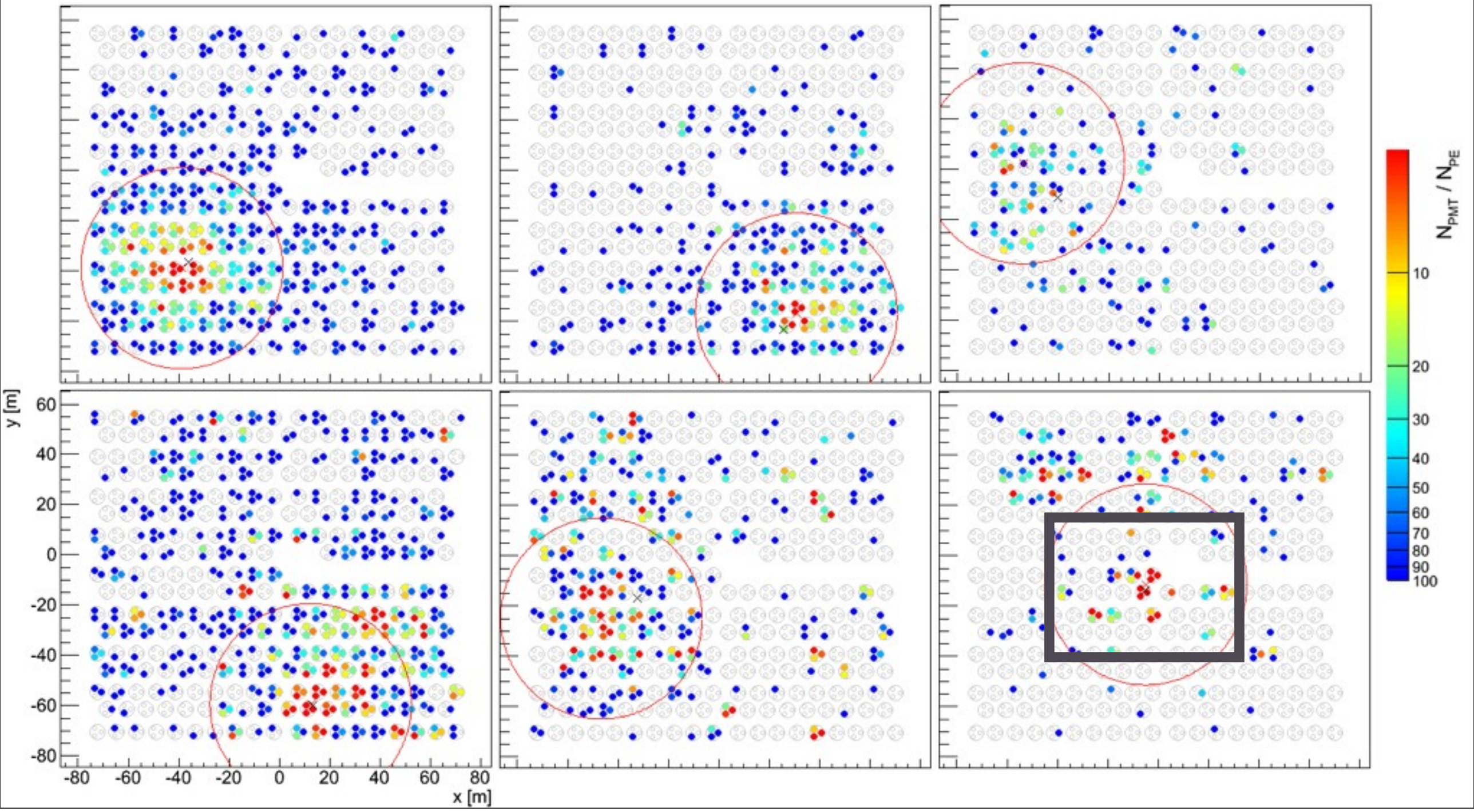


Improve optical separation

Milagro	HAWC
one big pond	**individual tanks**

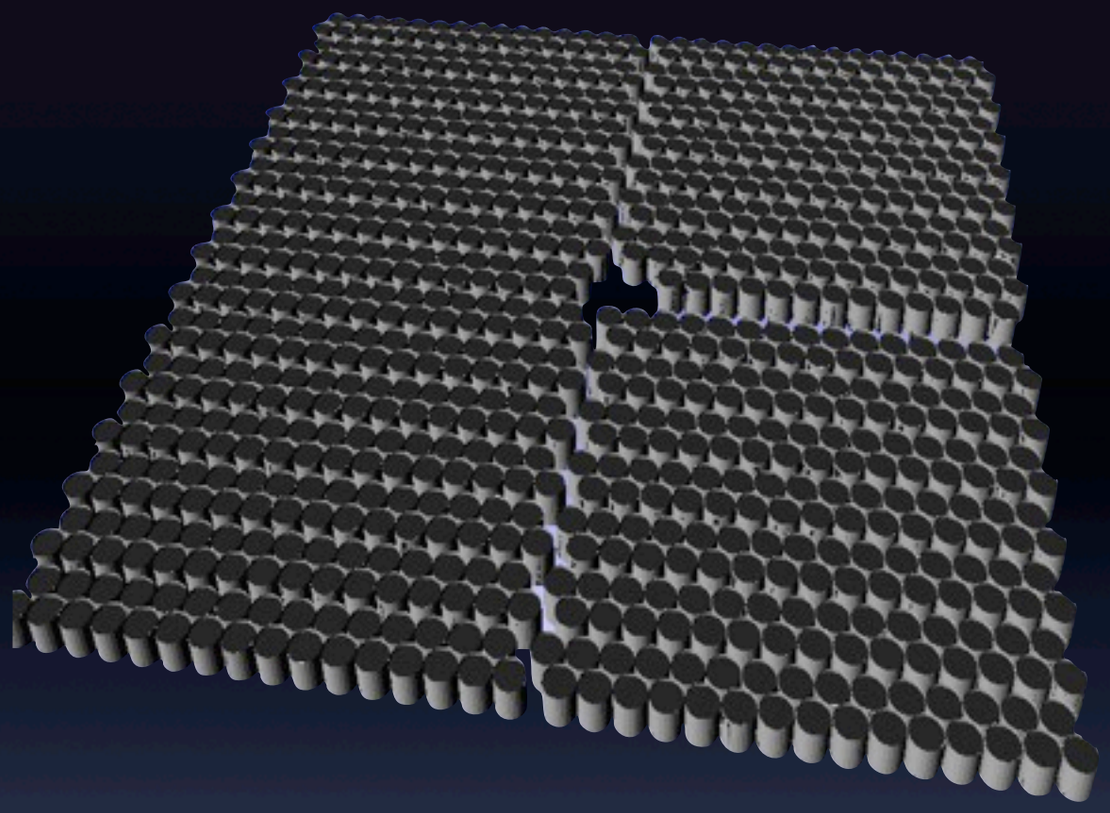


γ/h separation

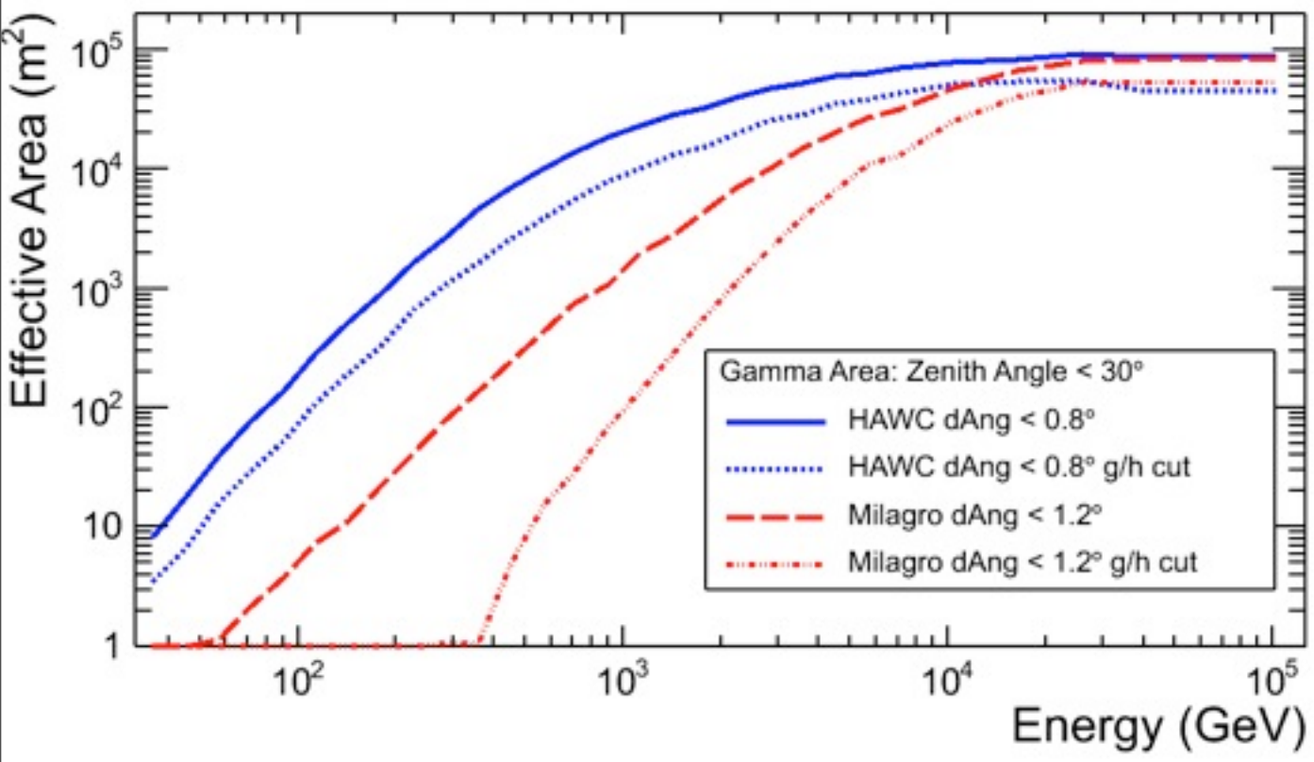


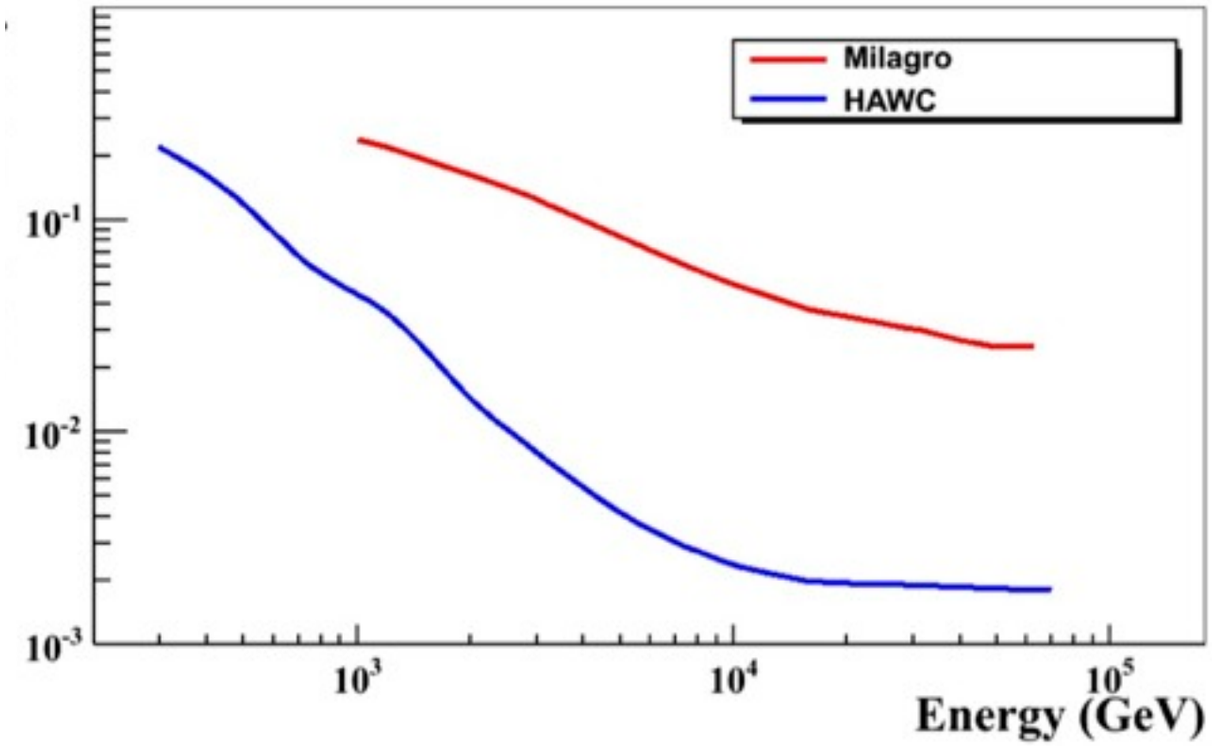
Go bigger

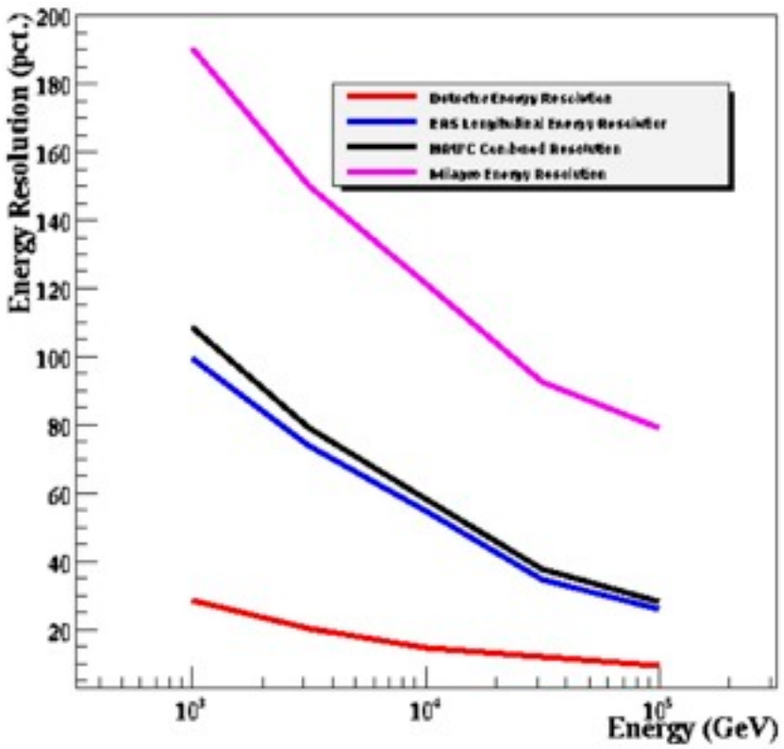
Milagro	HAWC
4,000 m^2	**20,000 m^2**

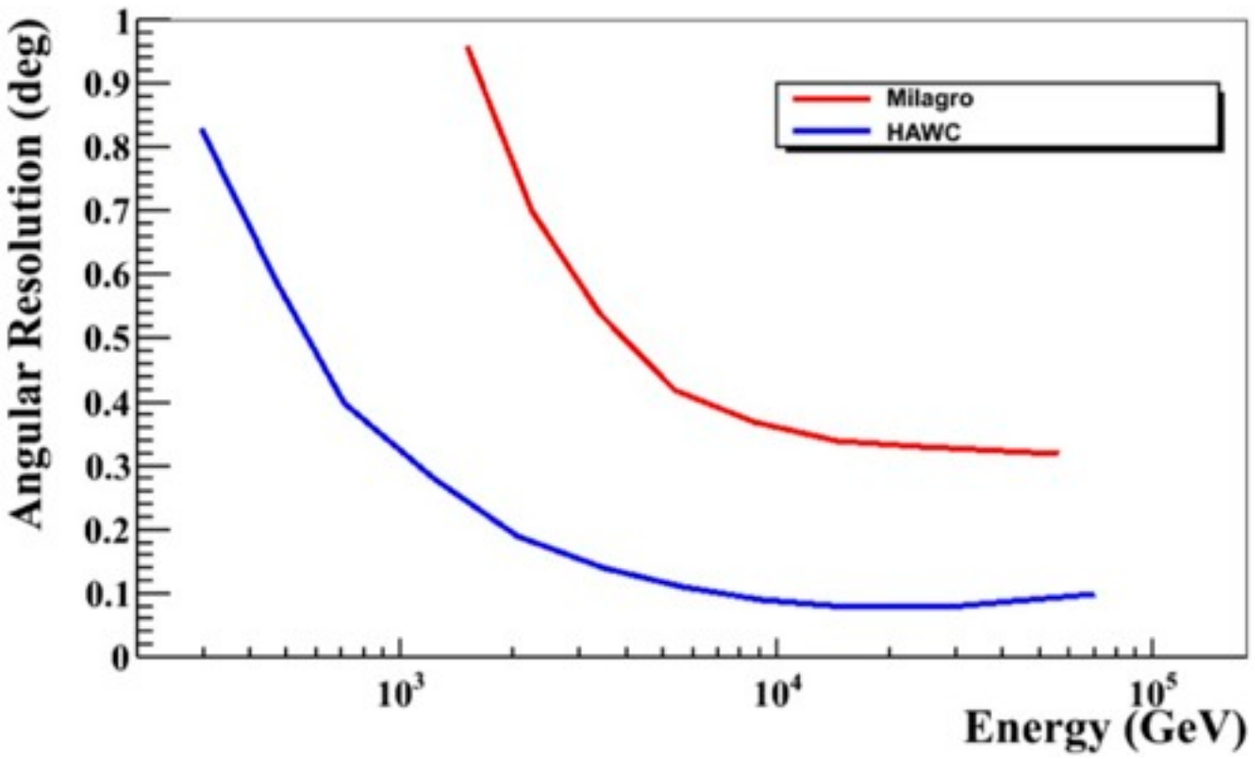


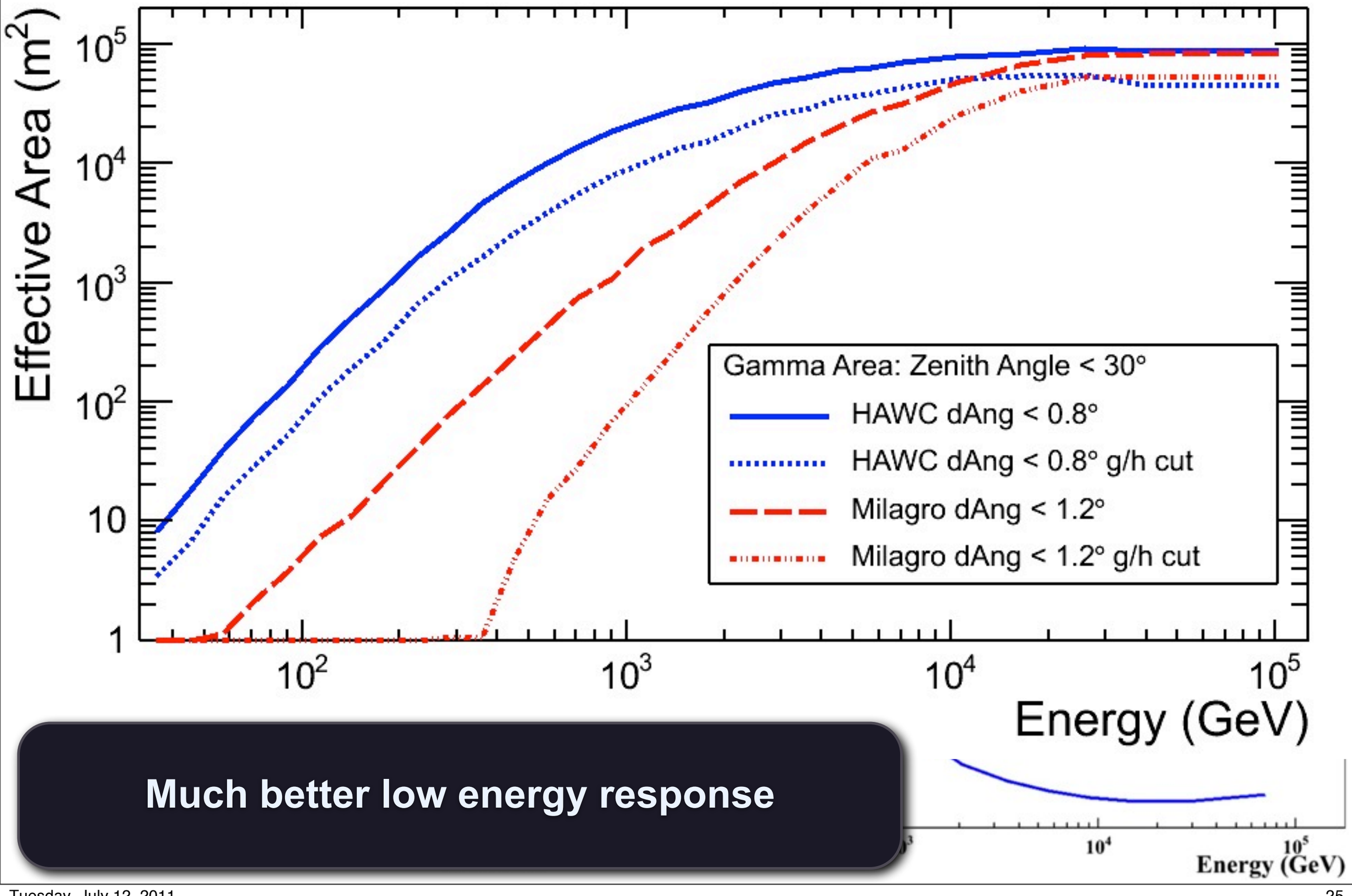
HAWC performance

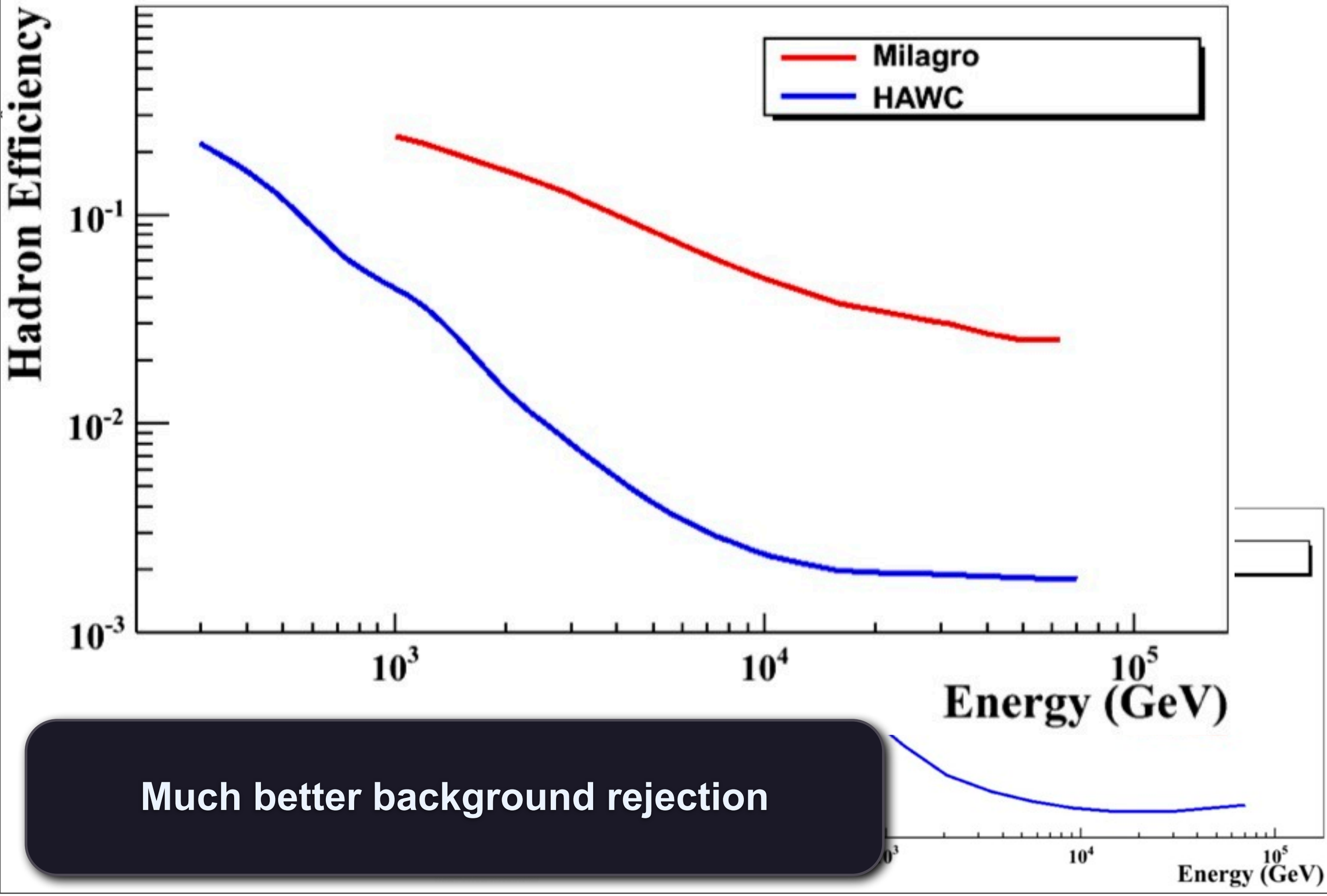




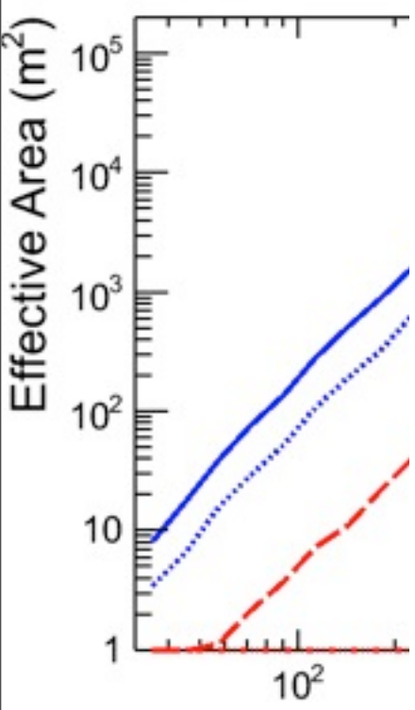


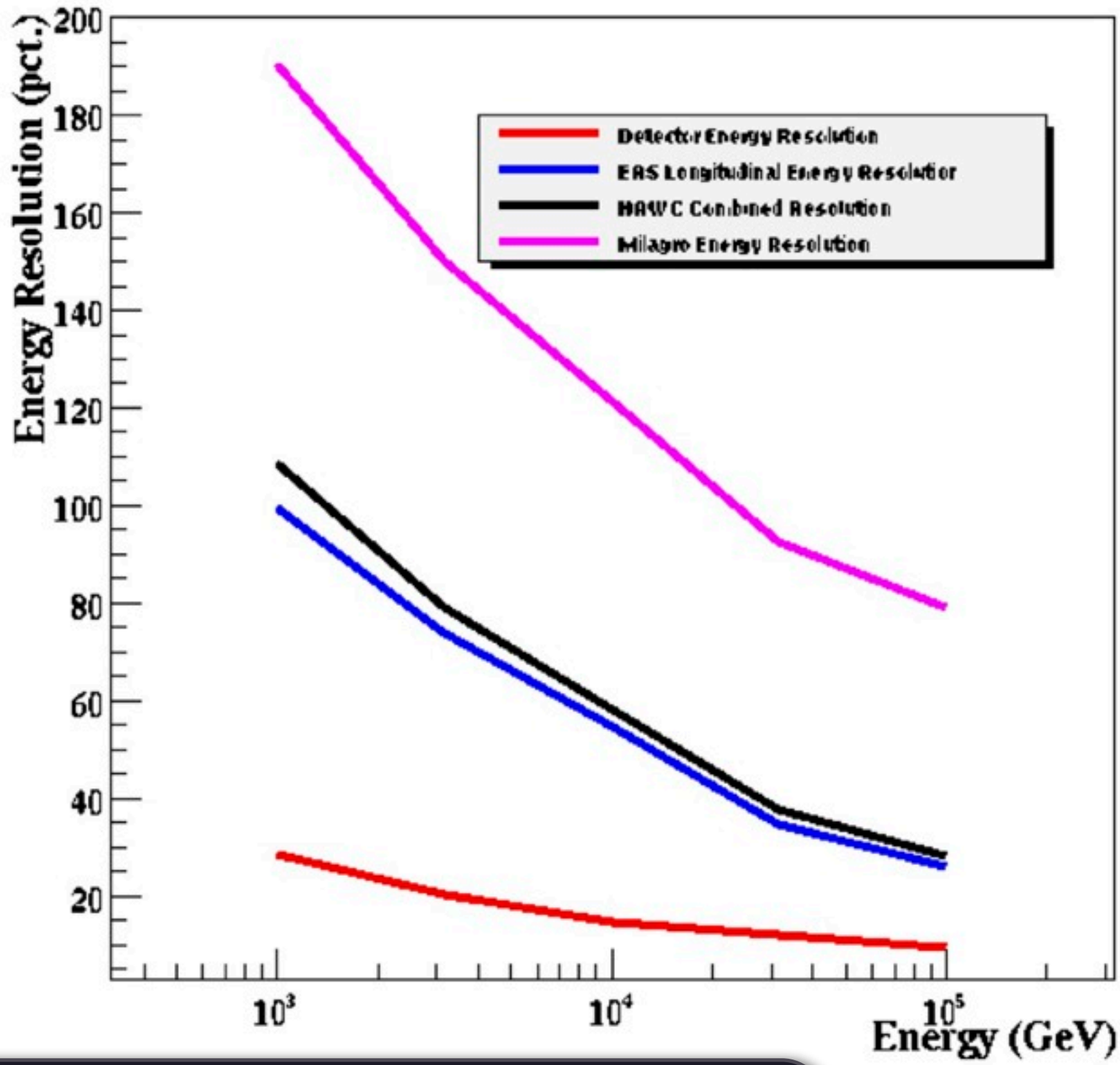


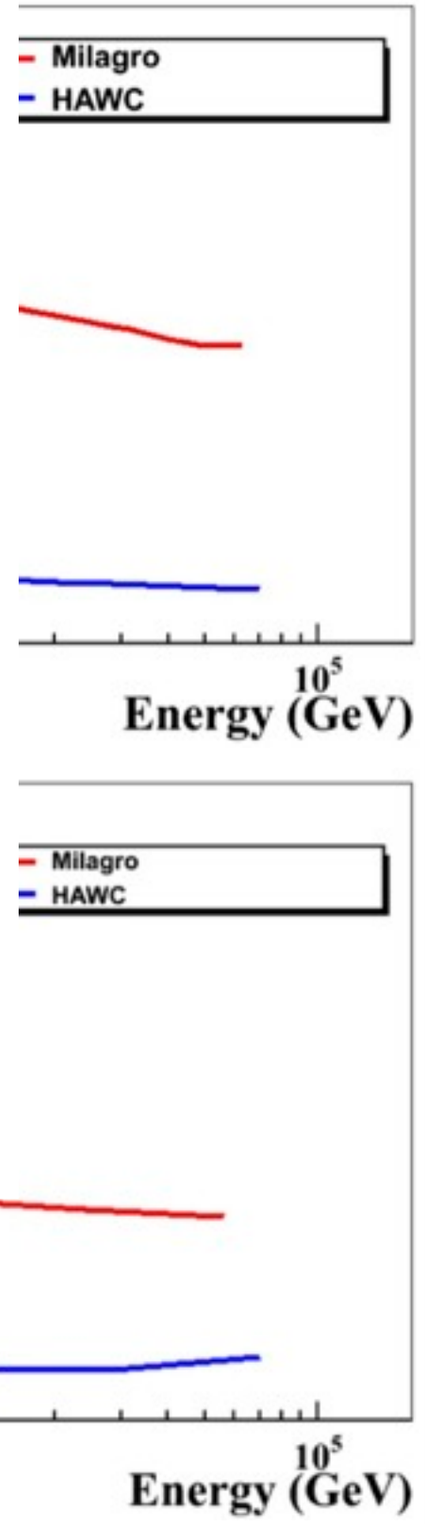

Effective Area (m^2)
10^5
10^4
10^3
10^2
10
1
10^2
10^3
10^4
10^5
Energy (GeV)
Gamma Area: Zenith Angle < 30°
HAWC dAng < 0.8°
HAWC dAng < 0.8° g/h cut
Milagro dAng < 1.2°
Milagro dAng < 1.2° g/h cut
Much better low energy response
10^4
10^5
Energy (GeV)



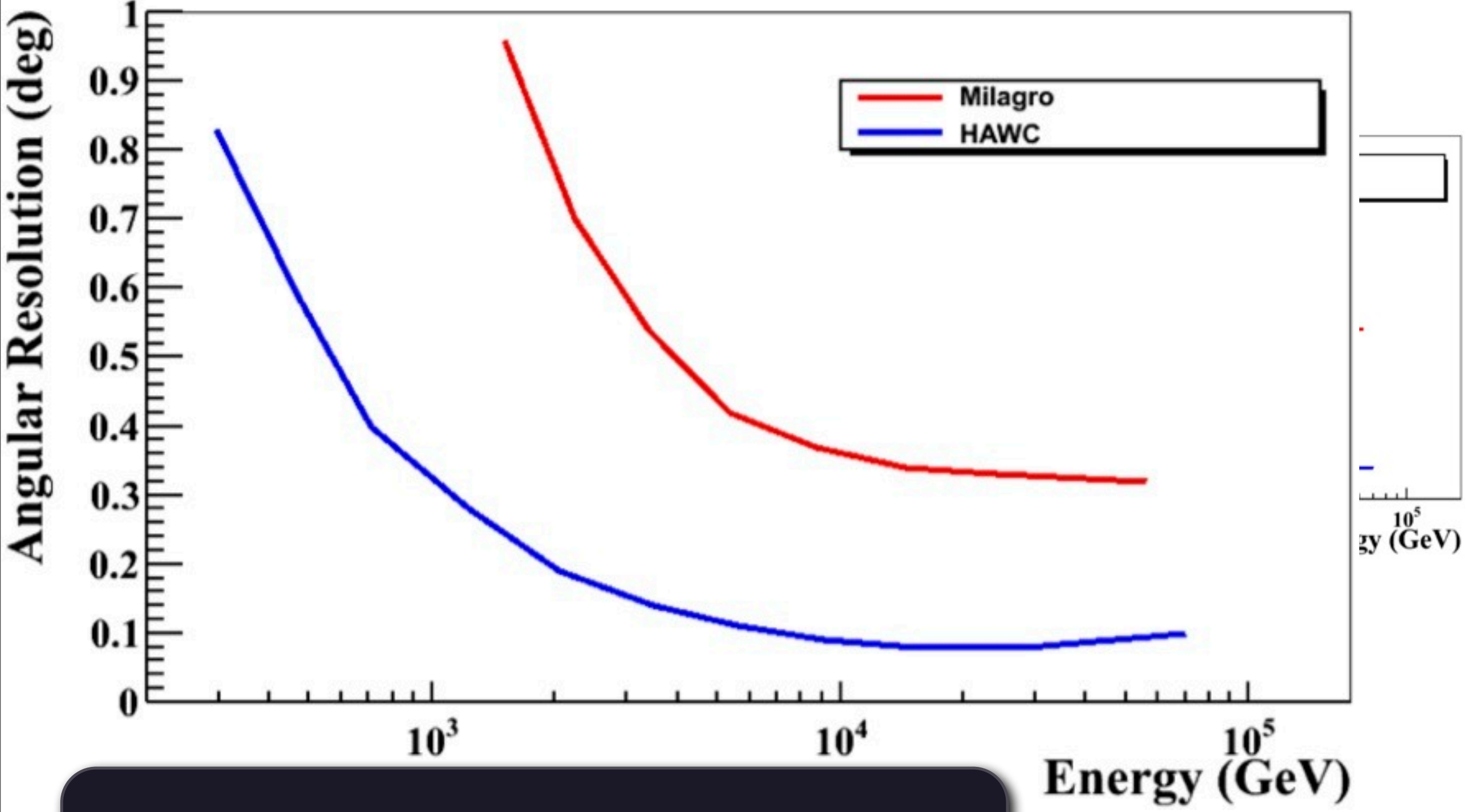
Much better background rejection





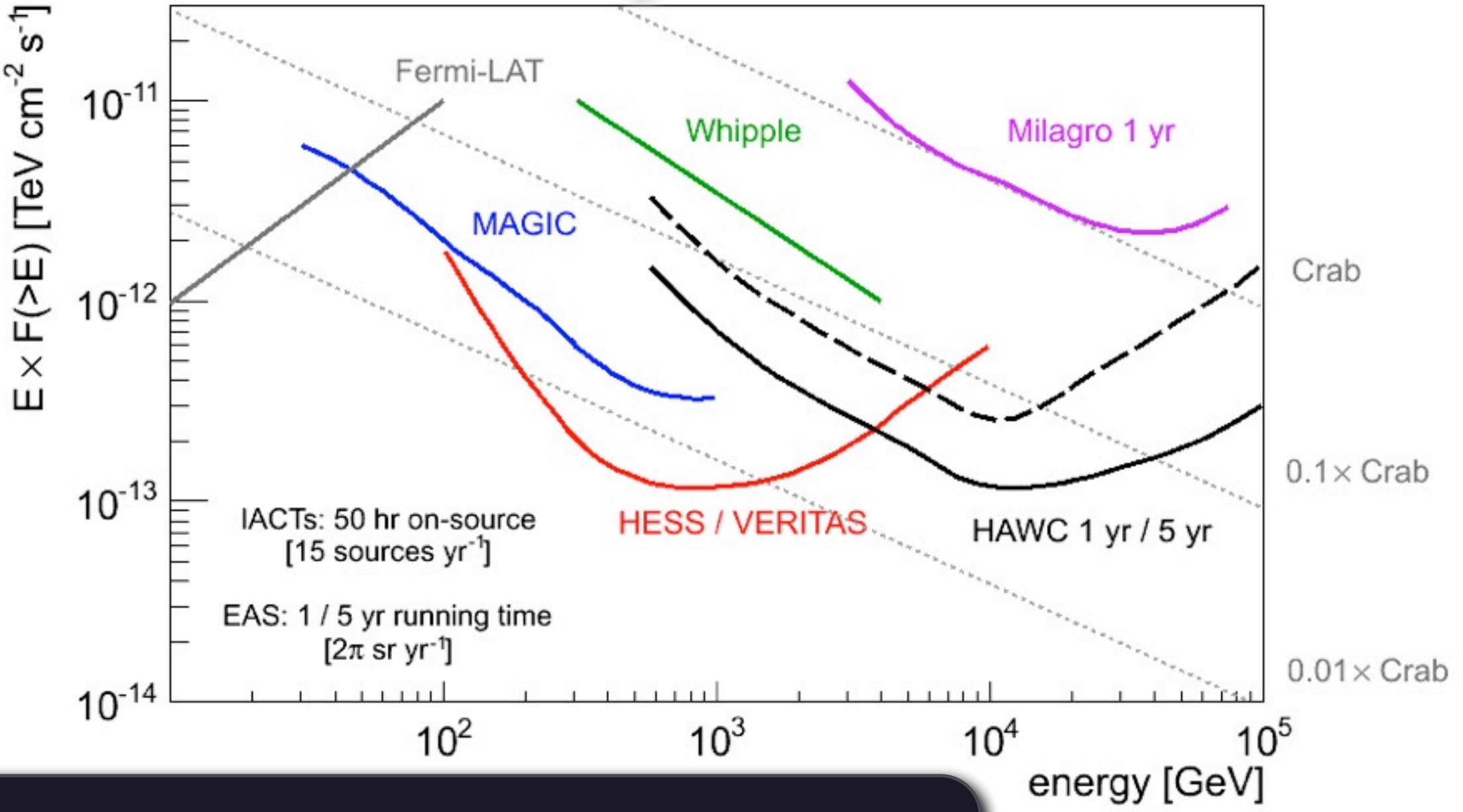


Better energy resolution



Better angular resolution

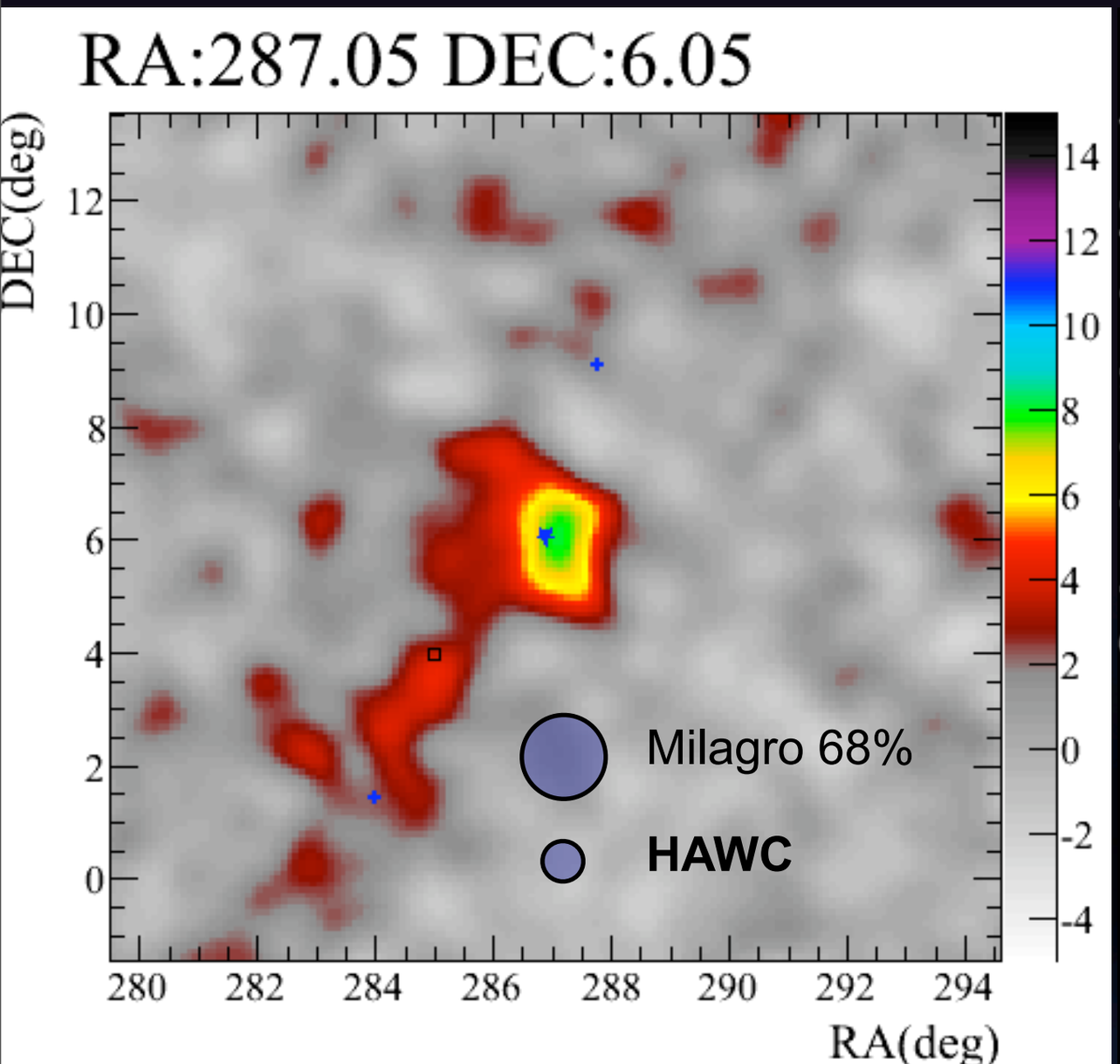
HAWC performance

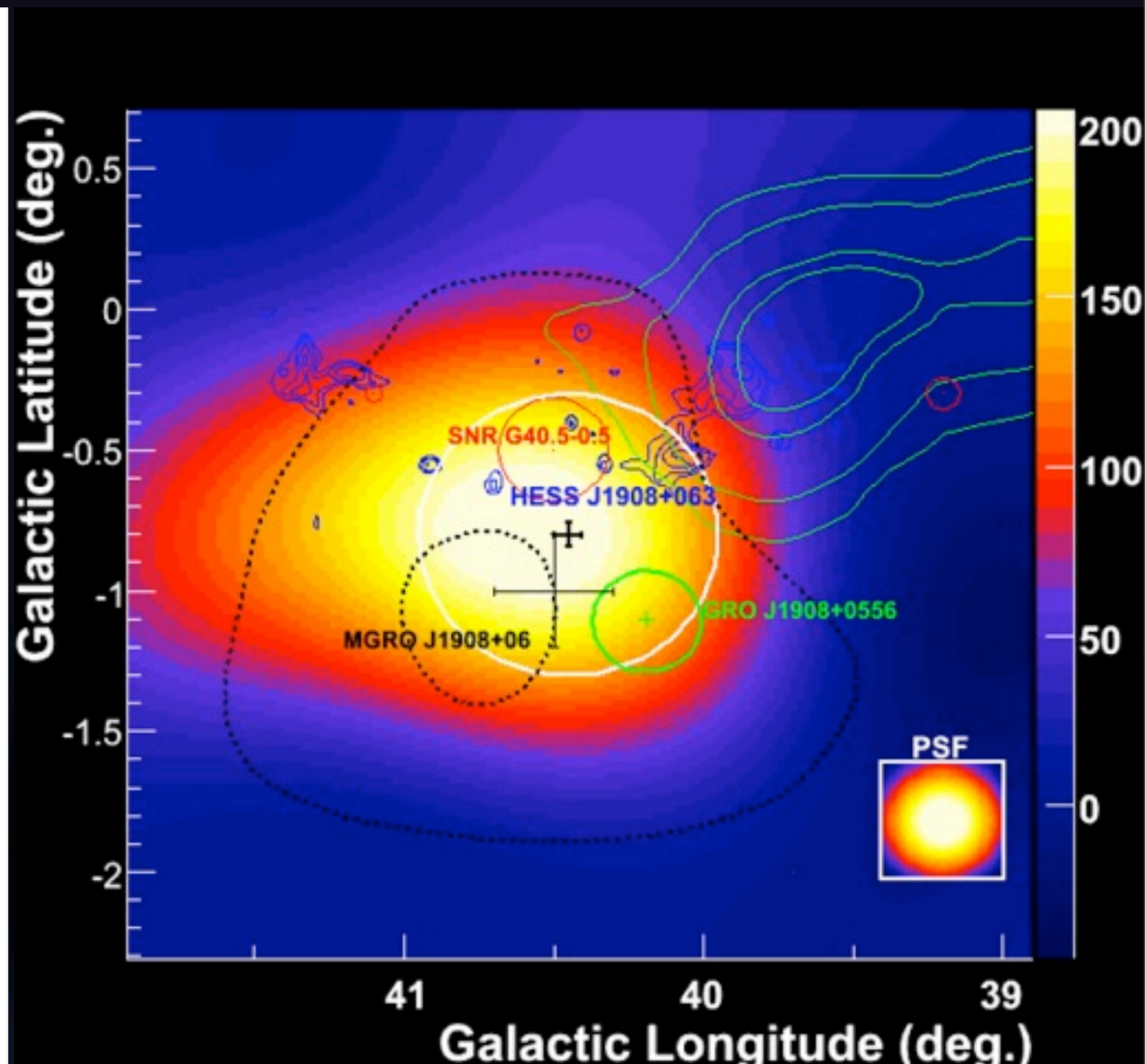


Overall x15 more sensitive than Milagro

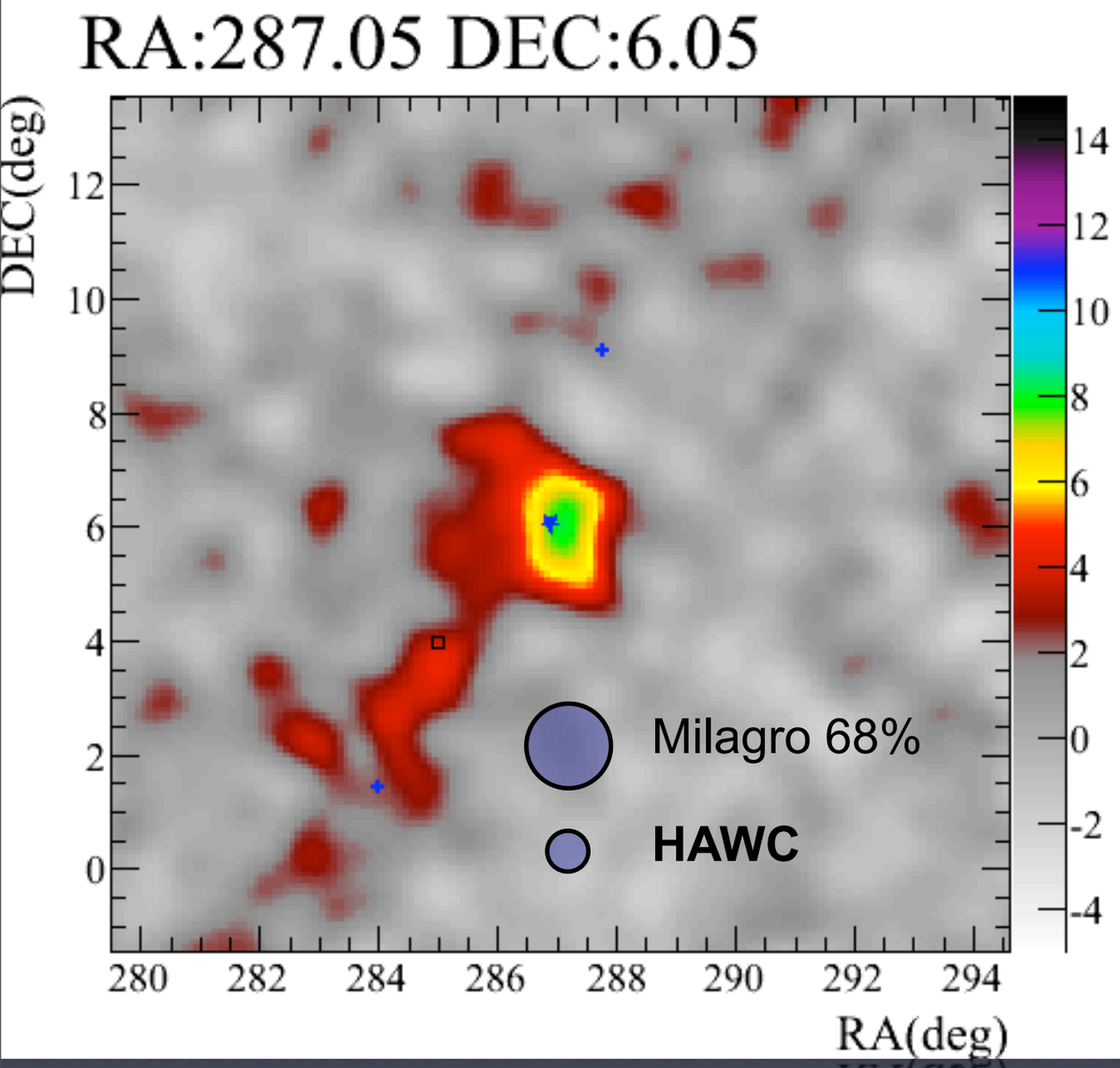
What can you do with HAWC?

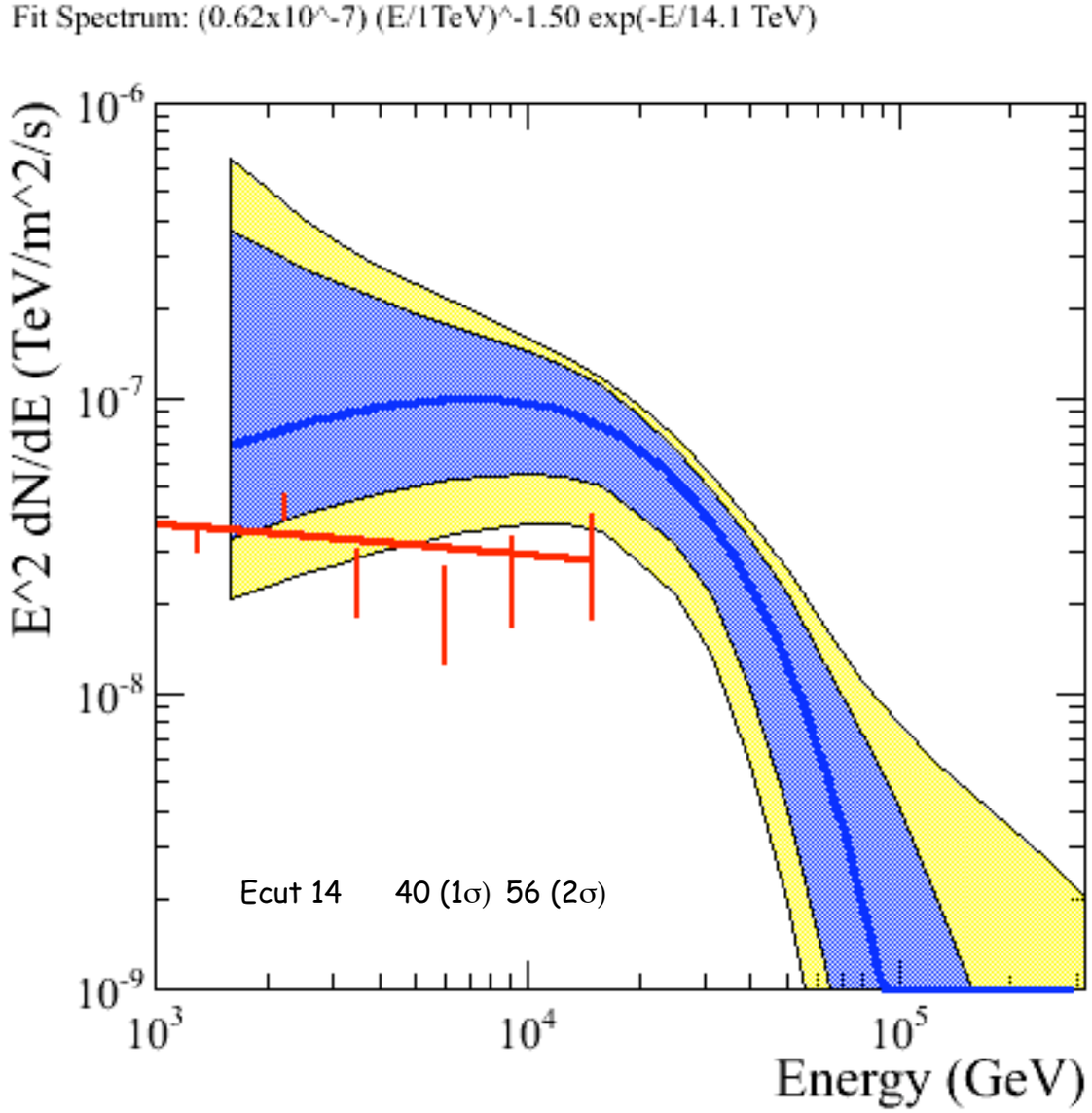
MGRO J1908+06





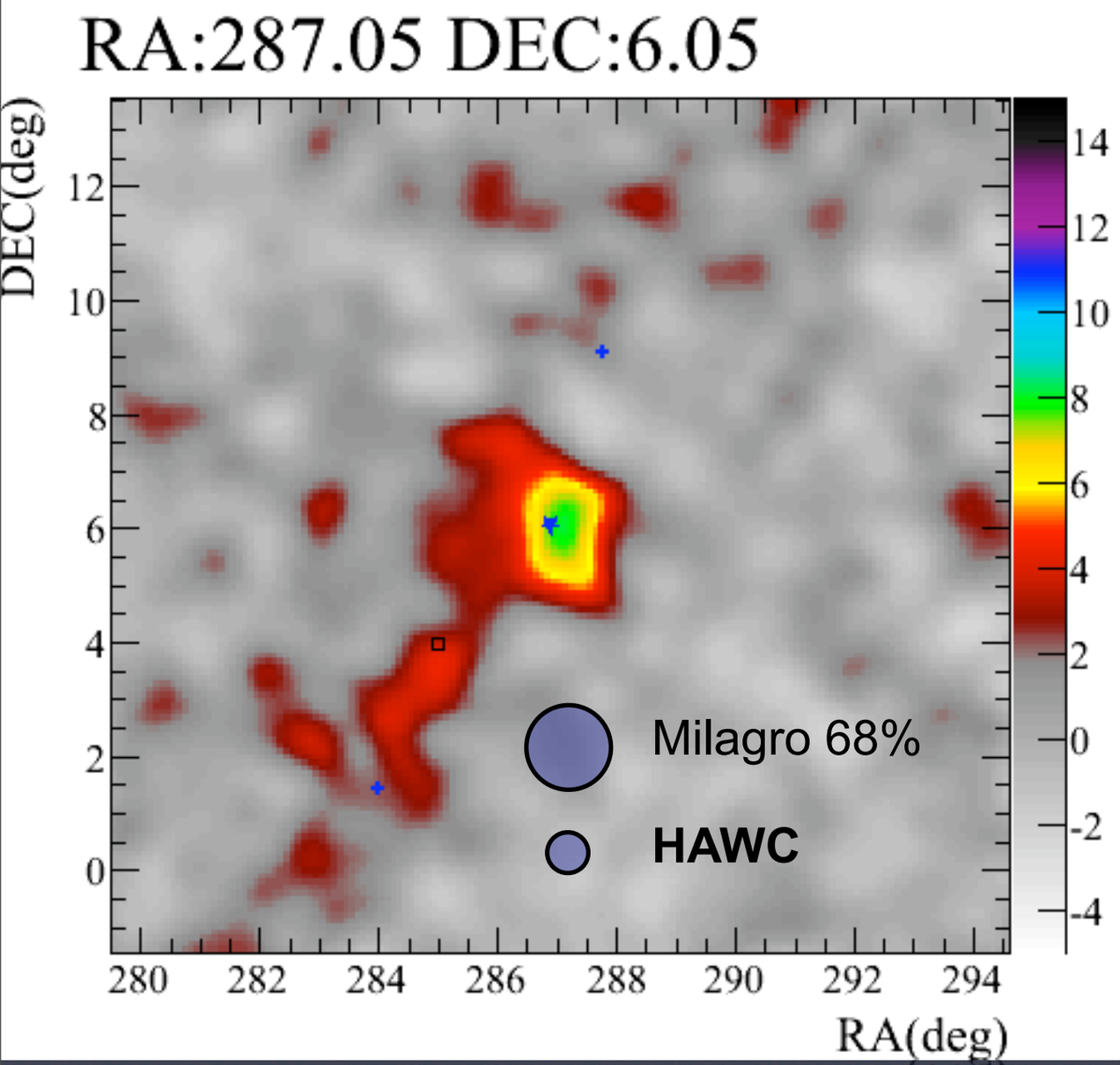
MGRO J1908+06

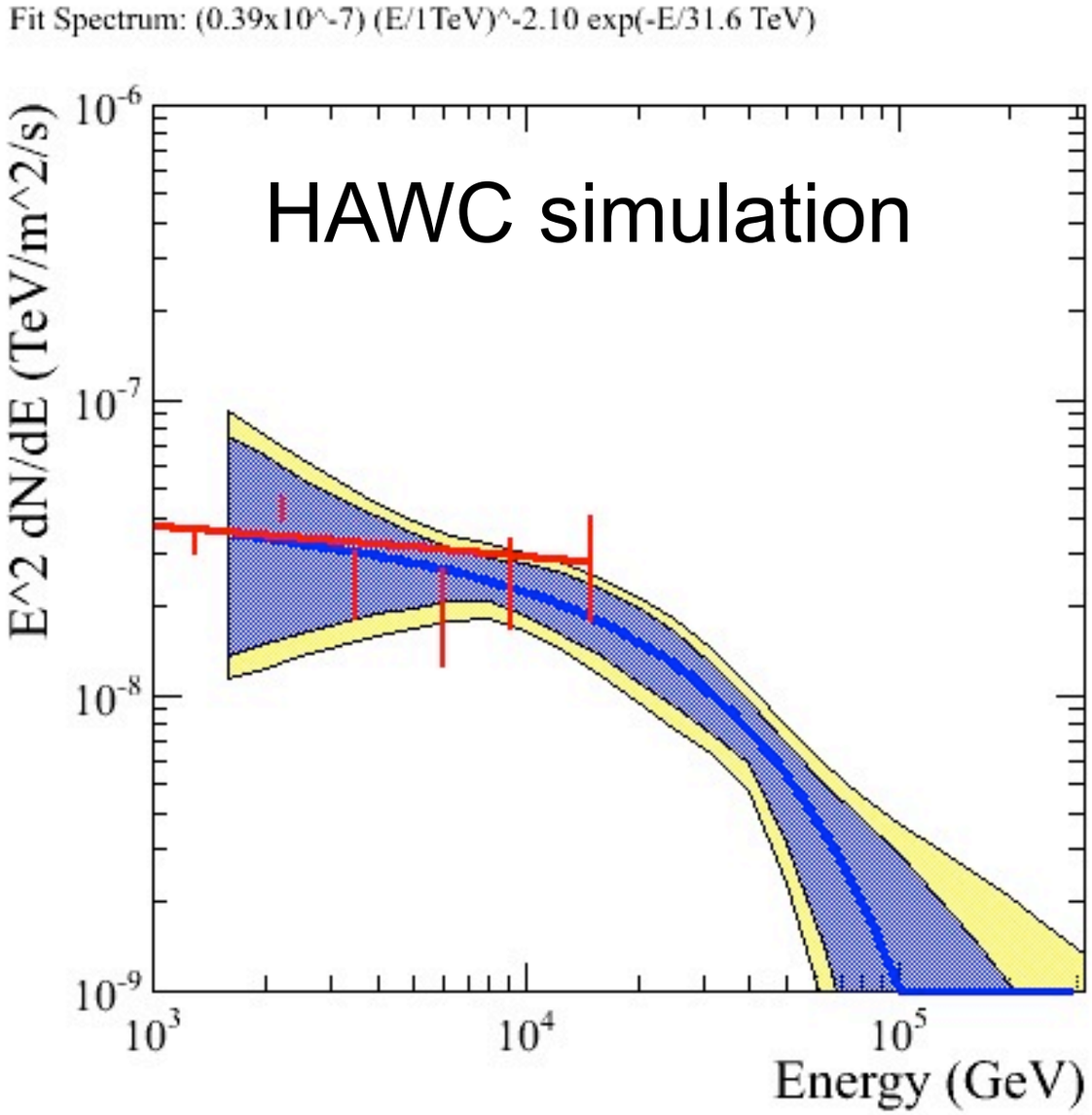




Milagro 3σ source detected at **20σ HAWC** (**3 months**)

MGRO J1908+06





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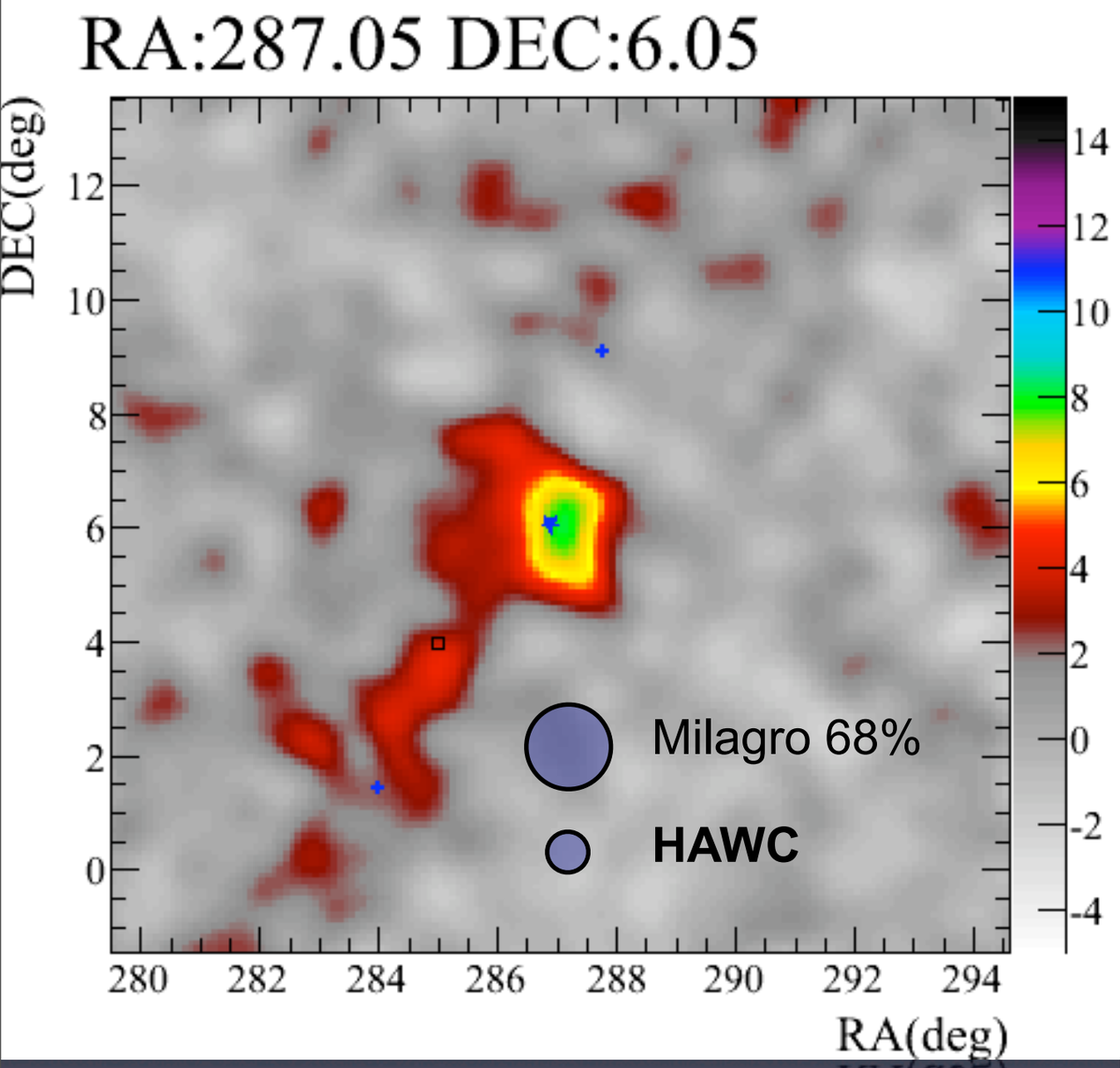
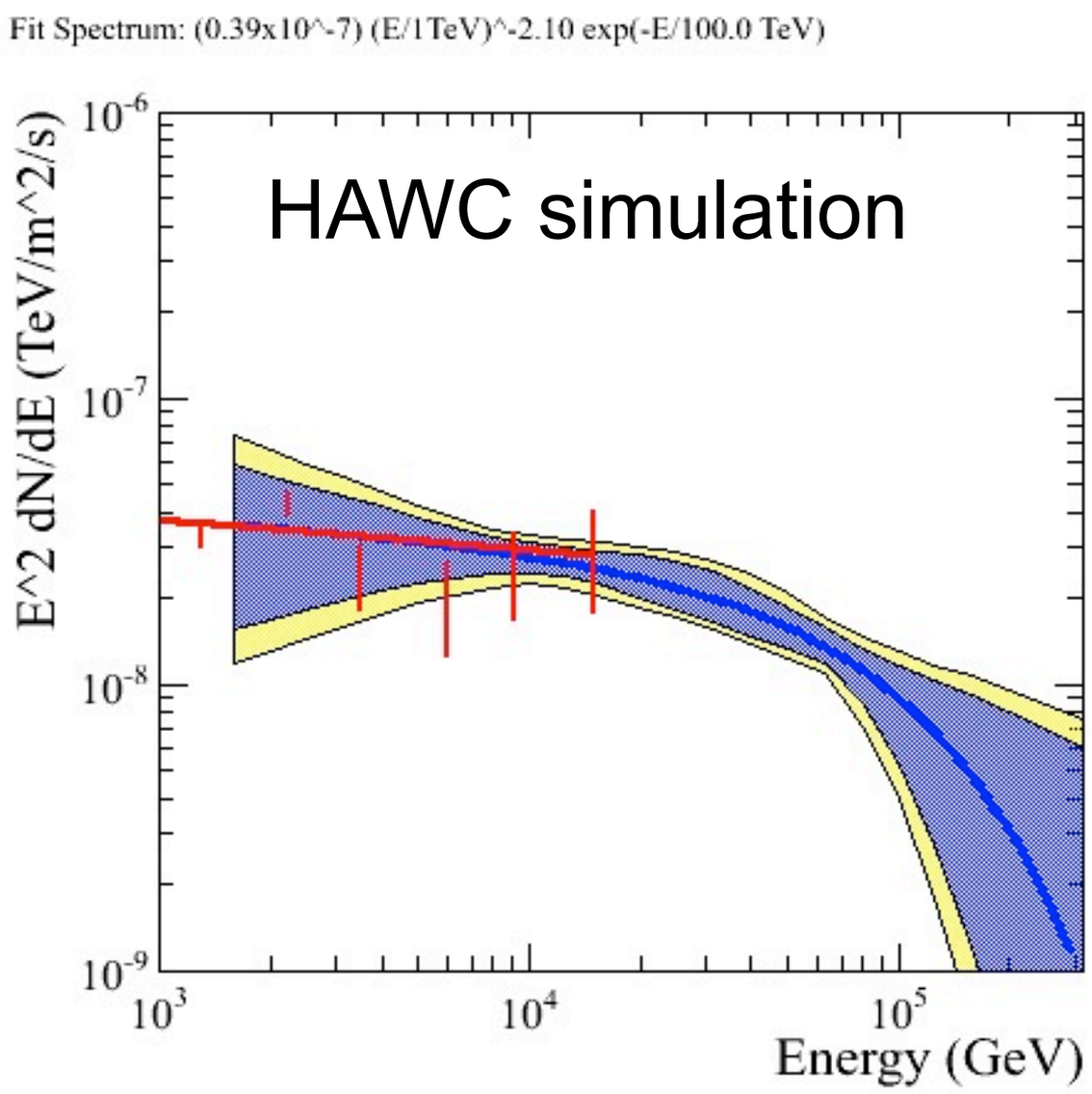
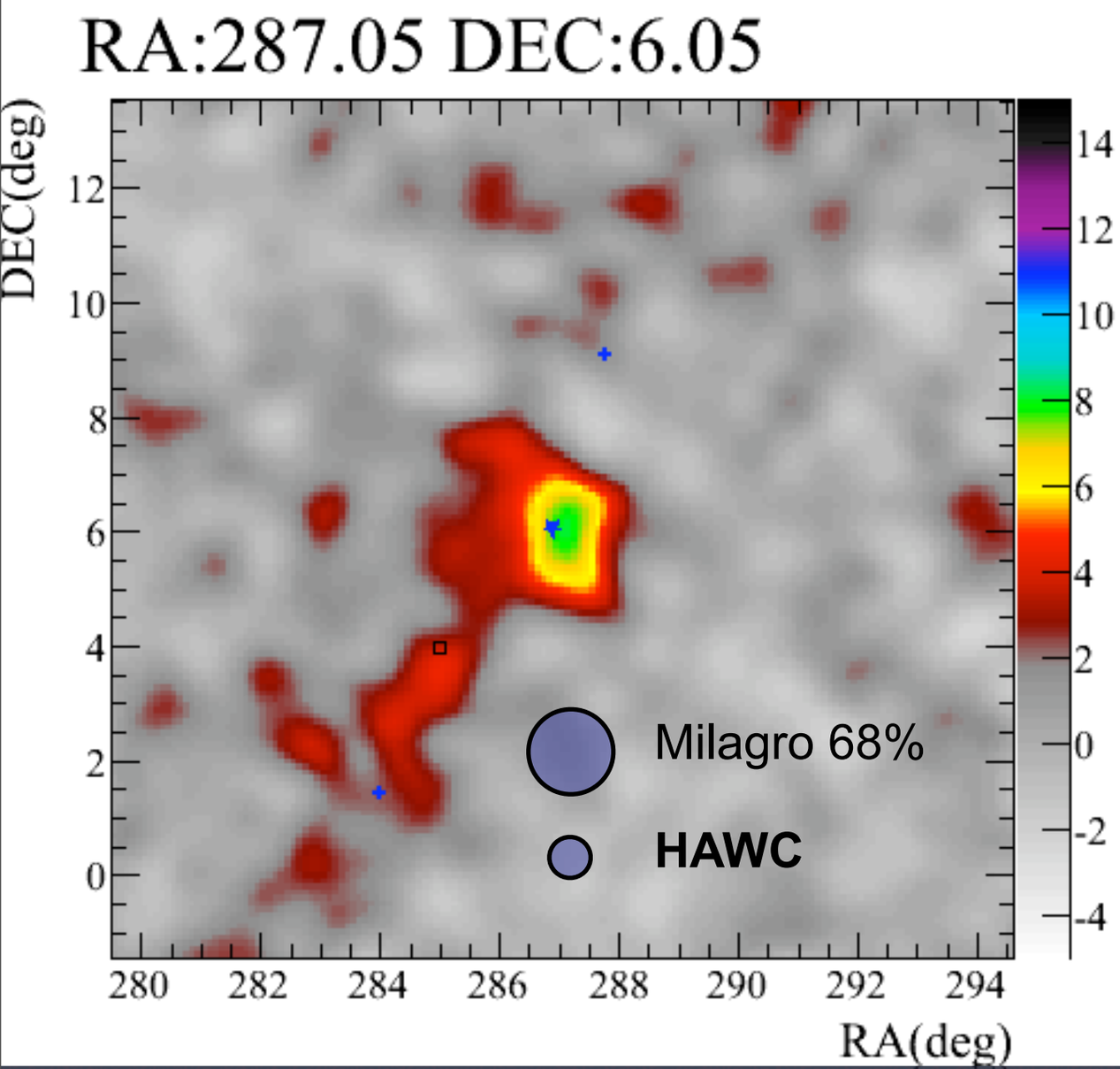
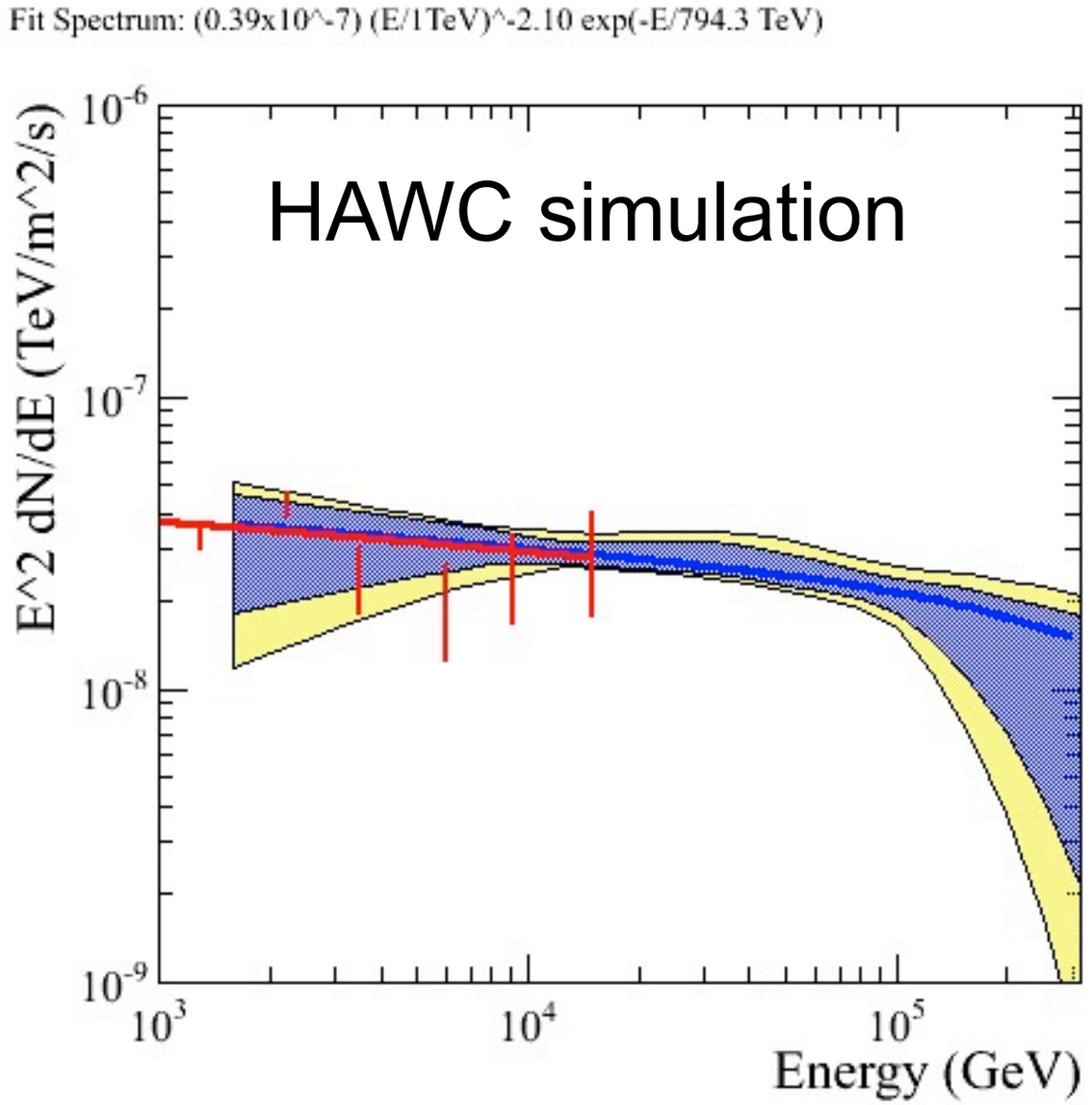




Milagro 3σ source detected at **20σ HAWC** (**3 months**)

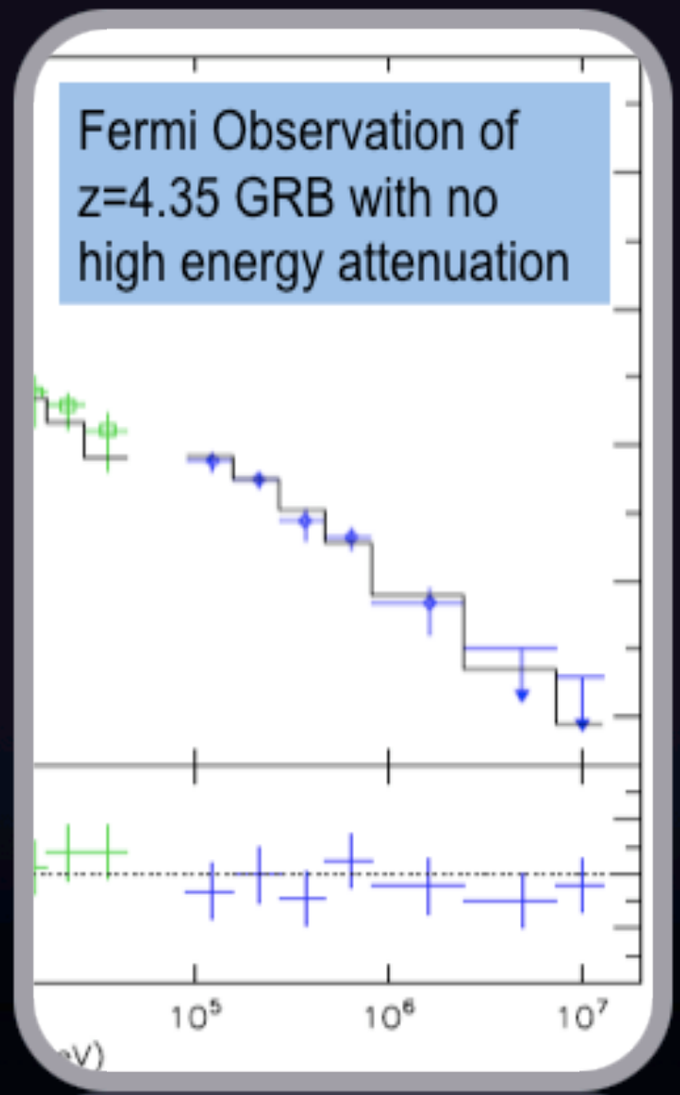
MGRO J1908+06





Milagro 3σ source detected at **20σ HAWC** (**3 months**)

Gamma Ray Bursts

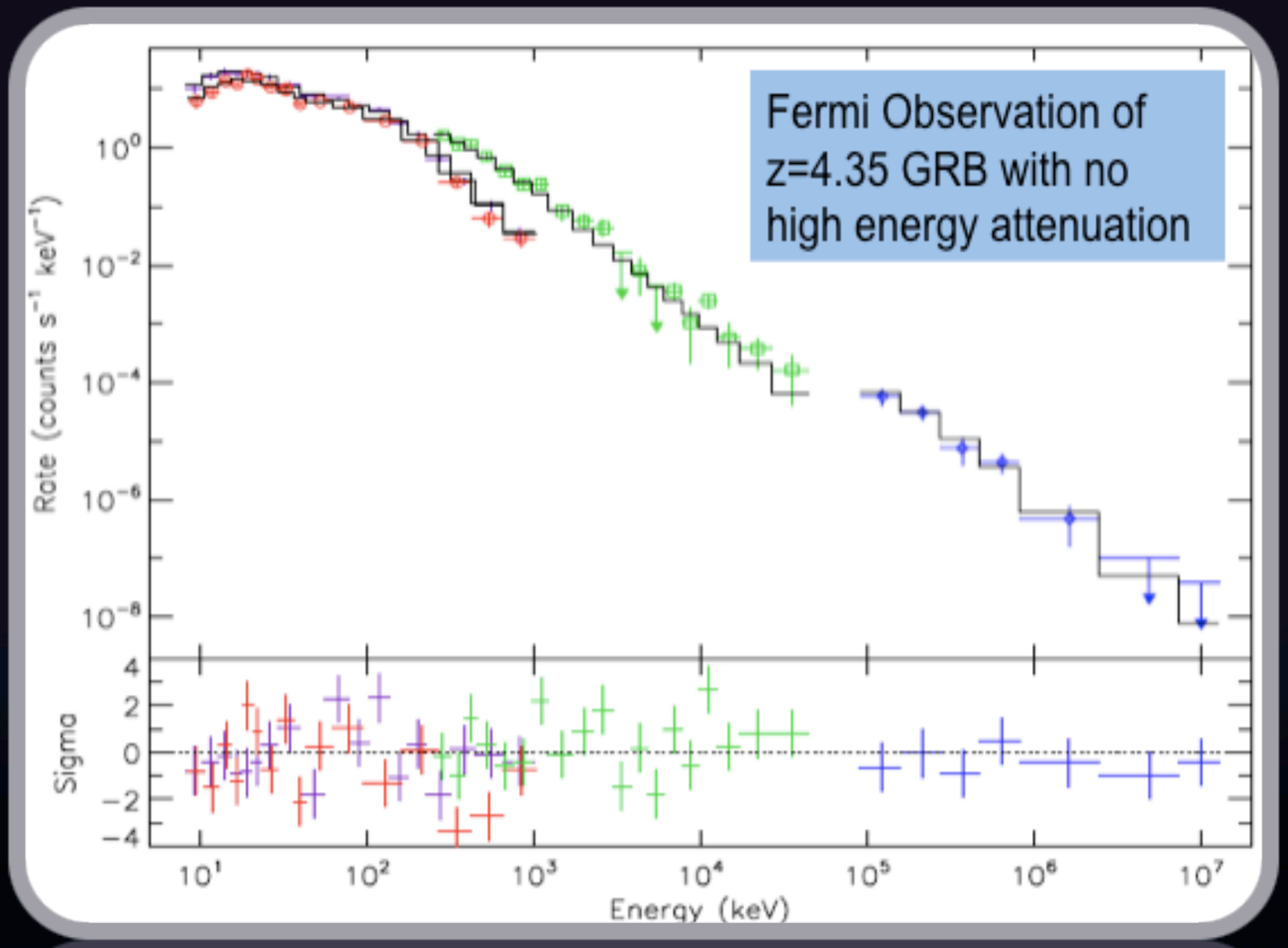


Highest energy gamma-ray detected from **GRB080916** (right) was emitted at 70 GeV

HAWC's effective area at 100 GeV is ~ **100 times** larger than Fermi's.

Gamma Ray Bursts

Fermi's observations indicate that both long and short GRBs emit **GeV γ-rays**

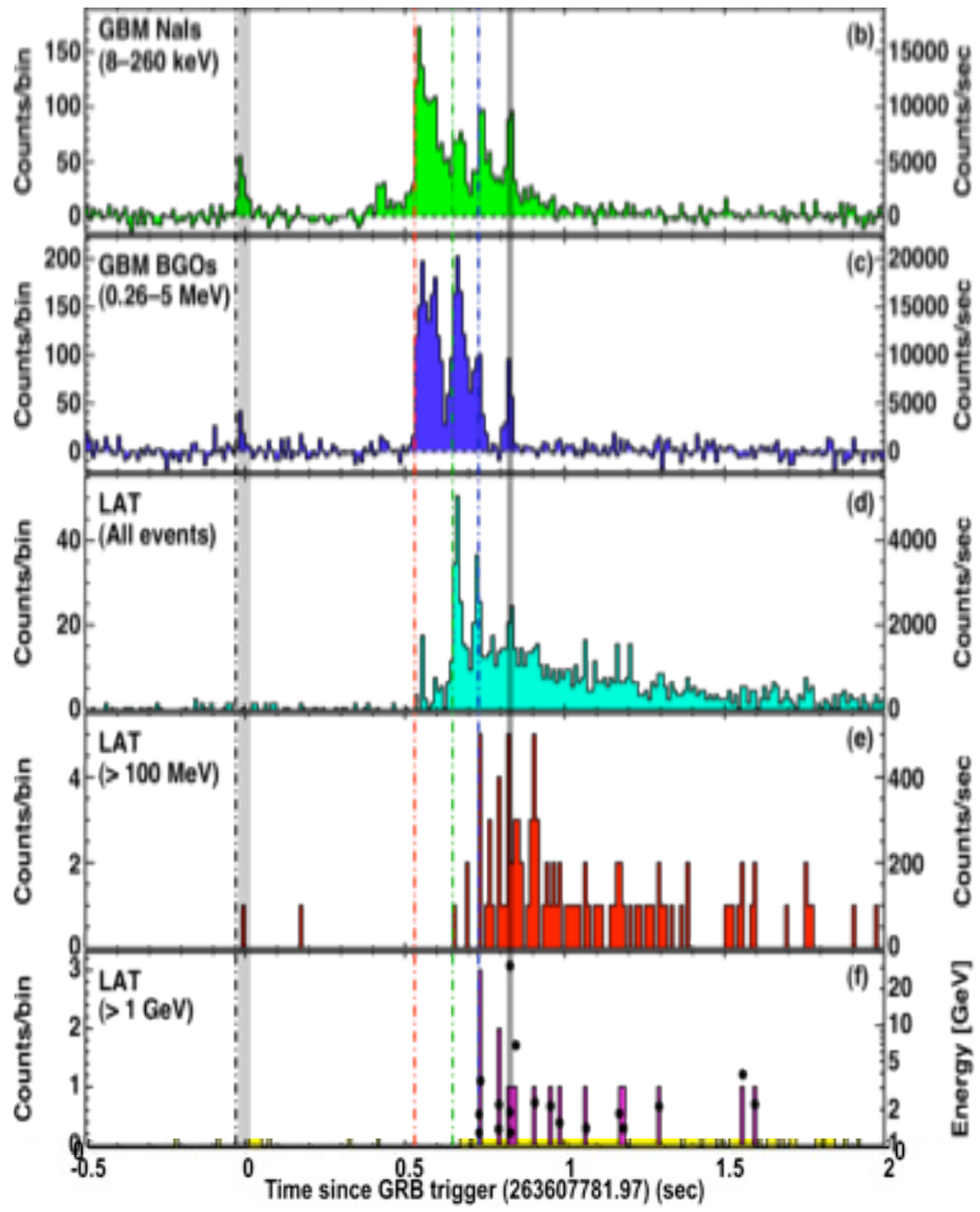


HAWC's effective area at 100 GeV is **~ 100 times** larger than Fermi's.

GRBs

- Bursts have energies up to at least **~100 GeV**.
- The brightest 4 bursts were emitted at energies of 70, 60, 94, and 61 GeV.

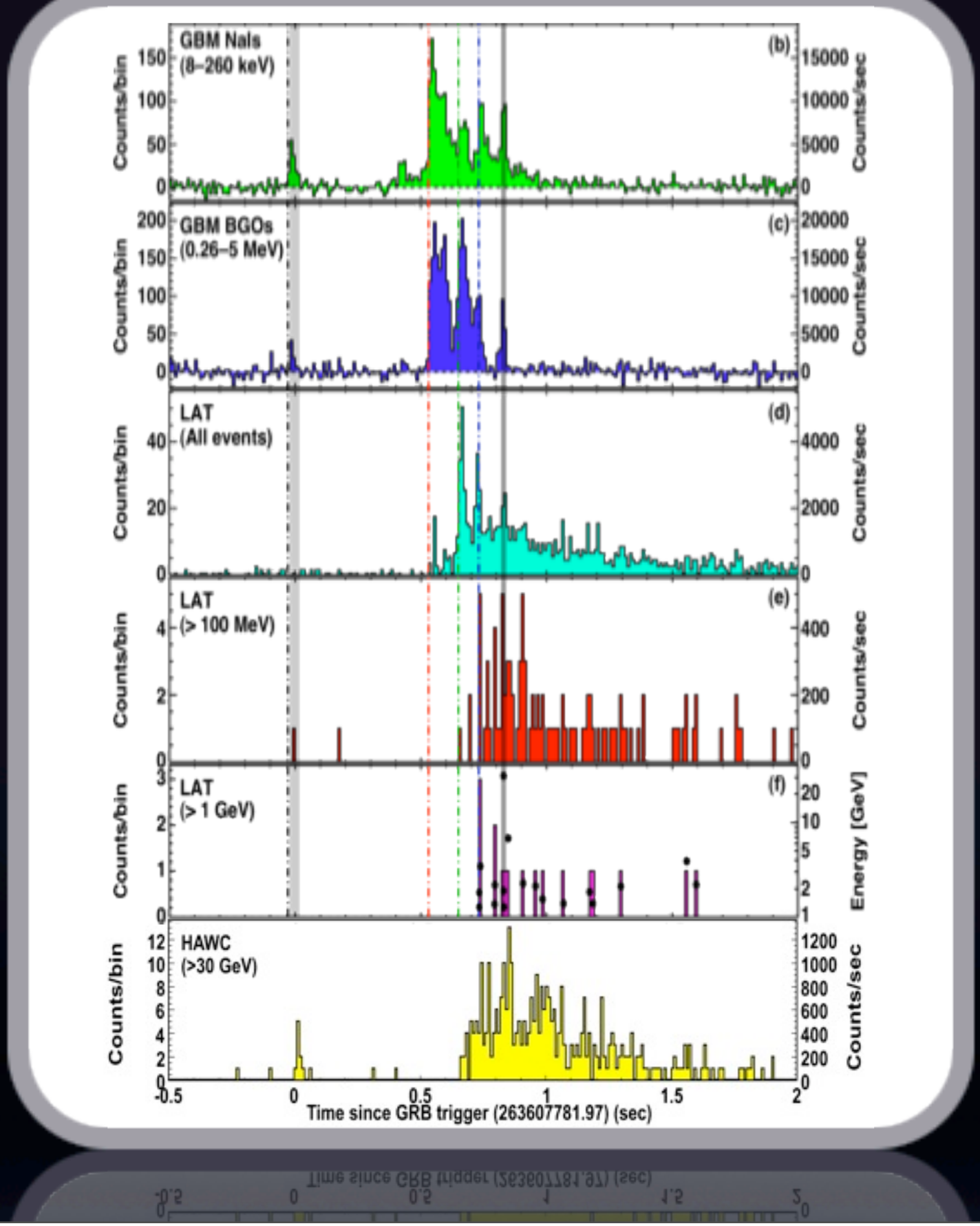
Fermi observation of **GRB090510** at *z* = *0.9*



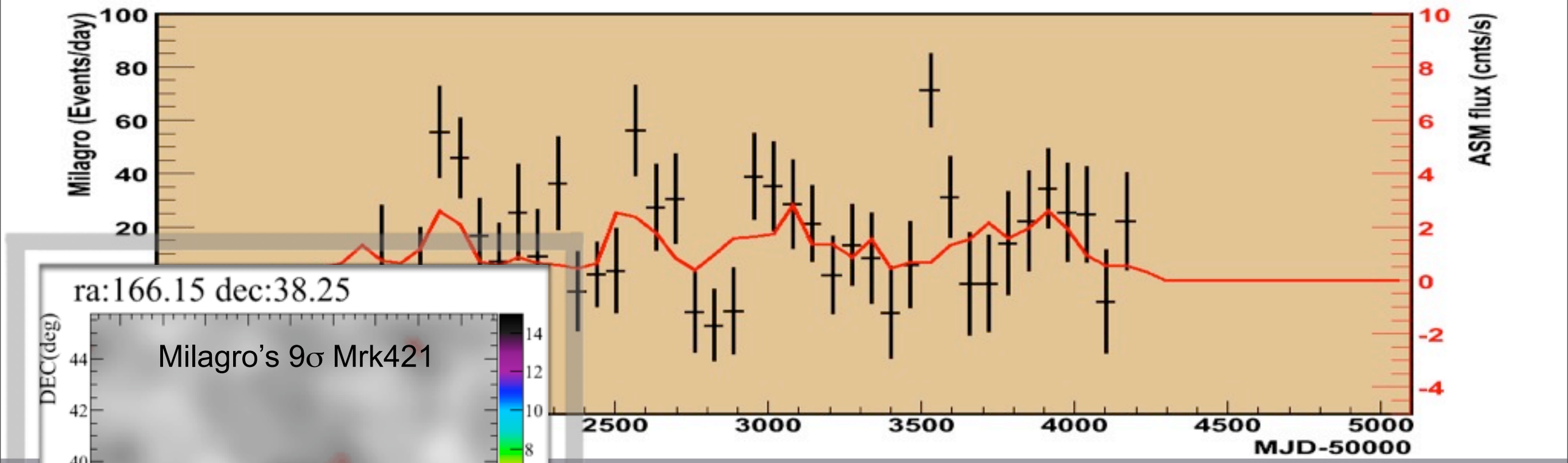
Fermi observation of **GRB090510** at *z* = *0.9*

GRBs

- Bursts have energies up to at least **~100 GeV**.
- The brightest 4 bursts were emitted at energies of 70, 60, 94, and 61 GeV.
- HAWC should see these signals even if they cut off at 100 GeV.



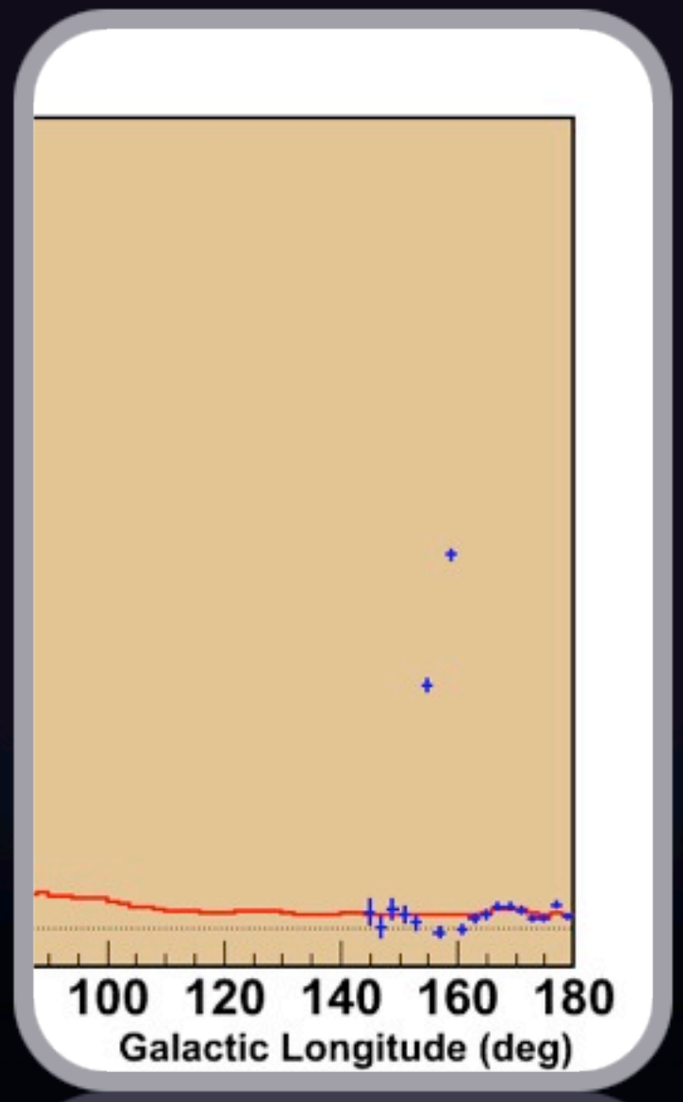
AGN flares



- continuously monitor flares
- notify mutli-wavelengths observers
- discover orphan TeV flares

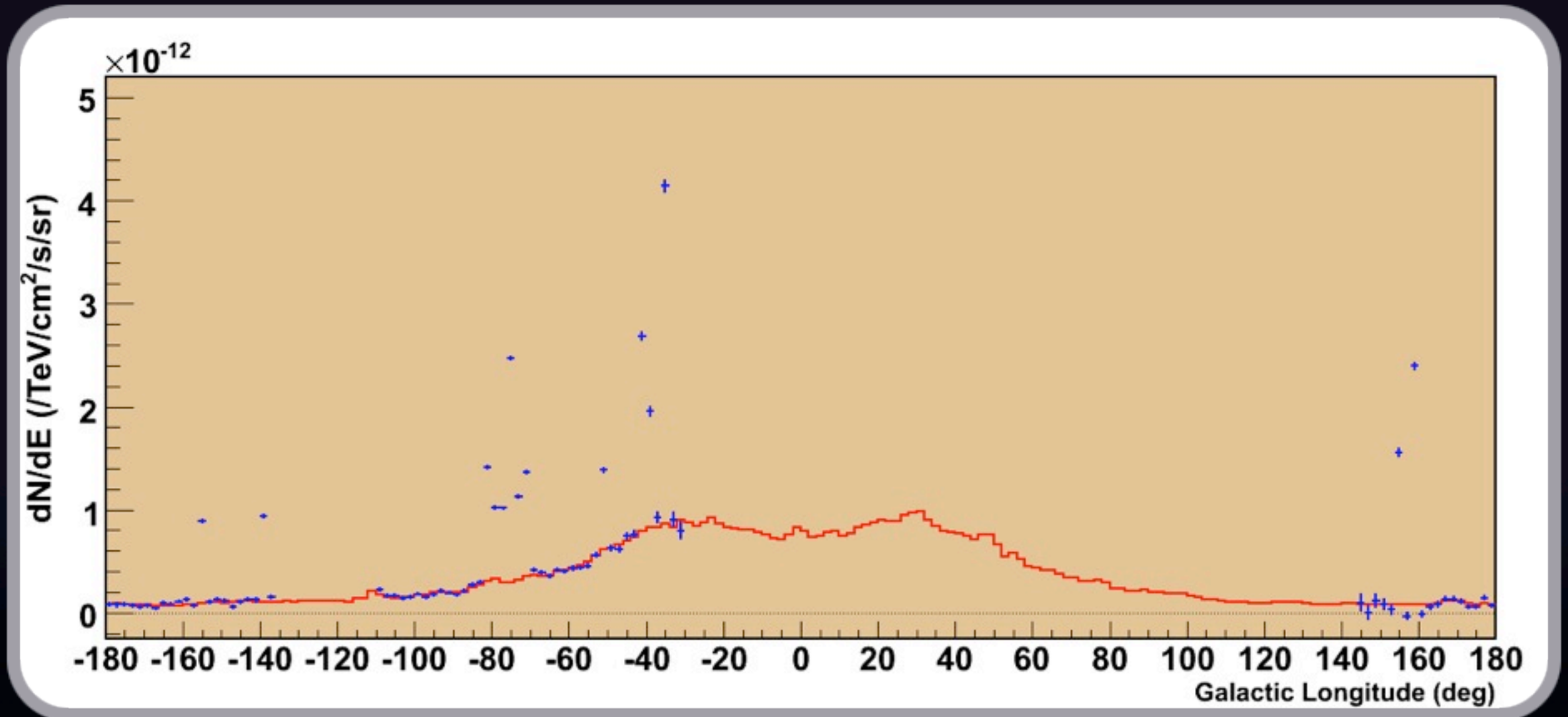
TeV diffuse emission

Unresolved sources?



HAWC can map TeV diffuse emission with **2º** longitude resolution.

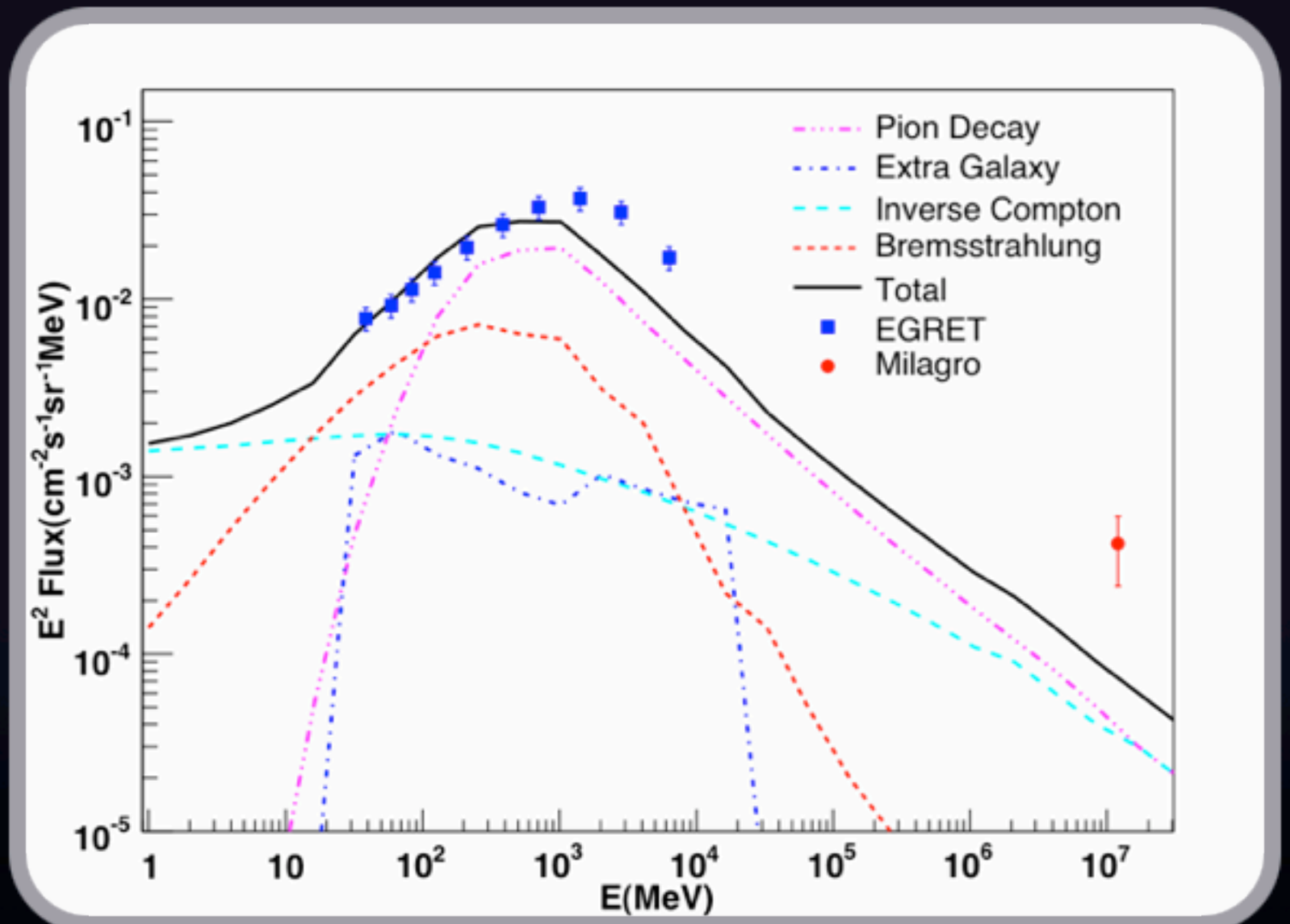
TeV diffuse emission



HAWC can map TeV diffuse emission with **2º** longitude resolution.

TeV diffuse emission

Whether or not there is a GeV excess, Milagro sees a **TeV excess**.

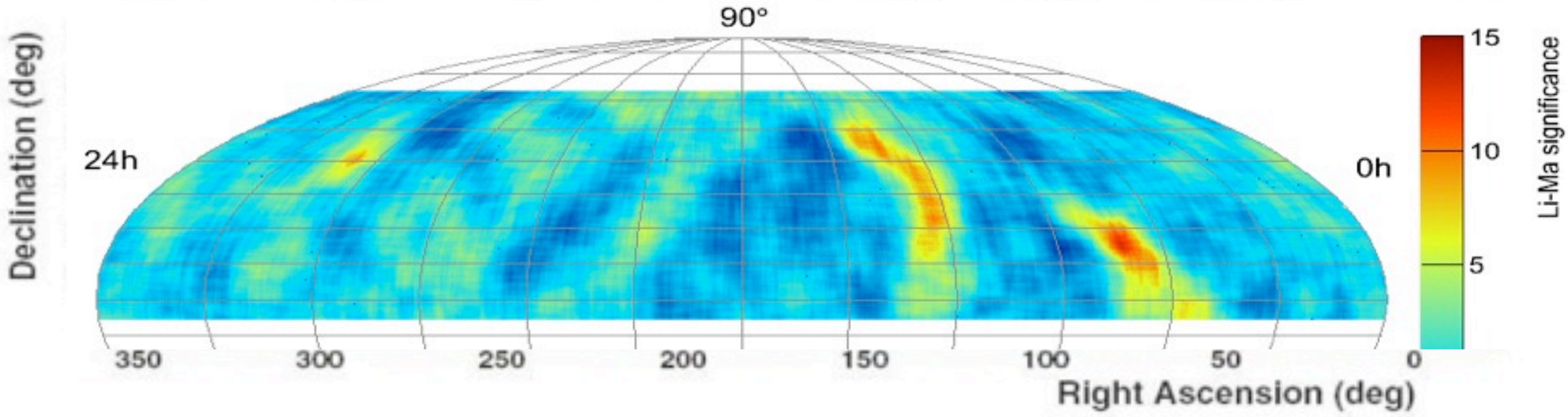


HAWC can map TeV diffuse emission with **2º** longitude resolution.

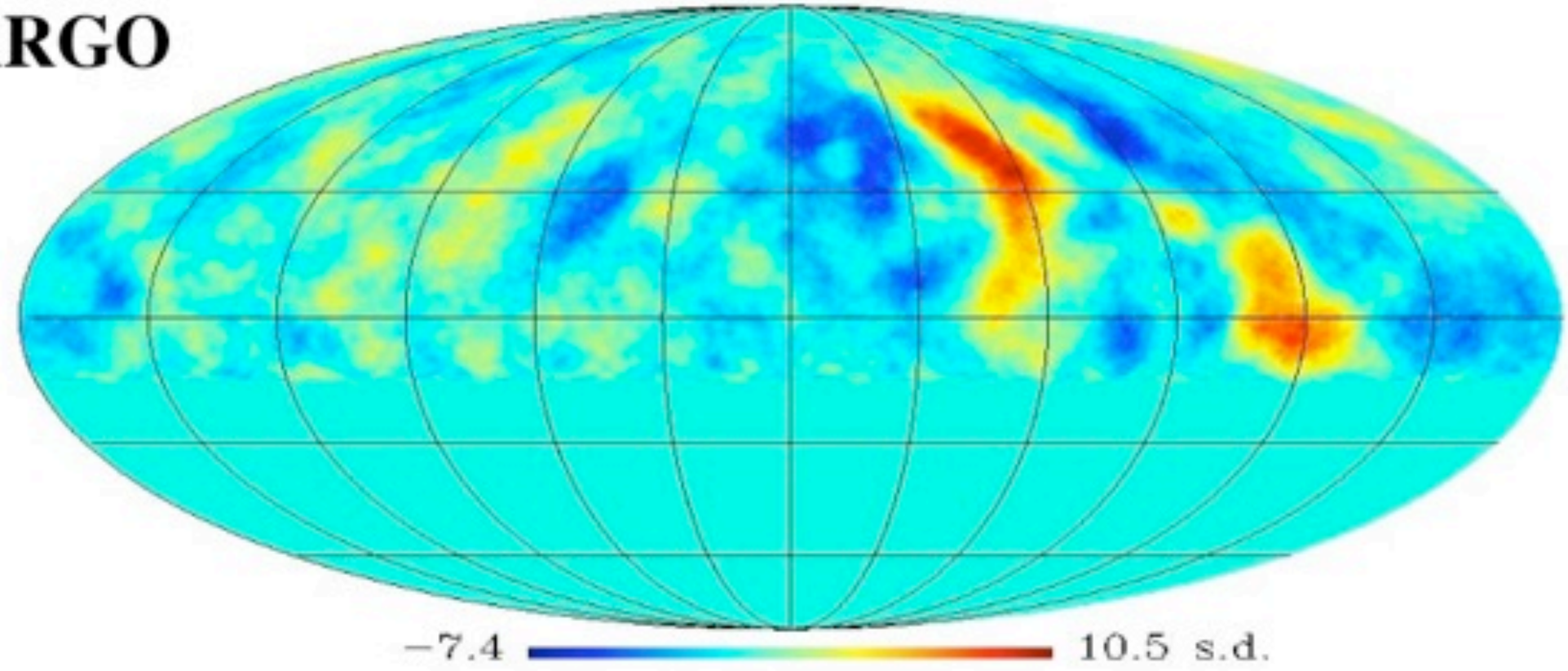
The Astrophysical Journal **688** (2008) 1078-1083

Expect the unexpected!

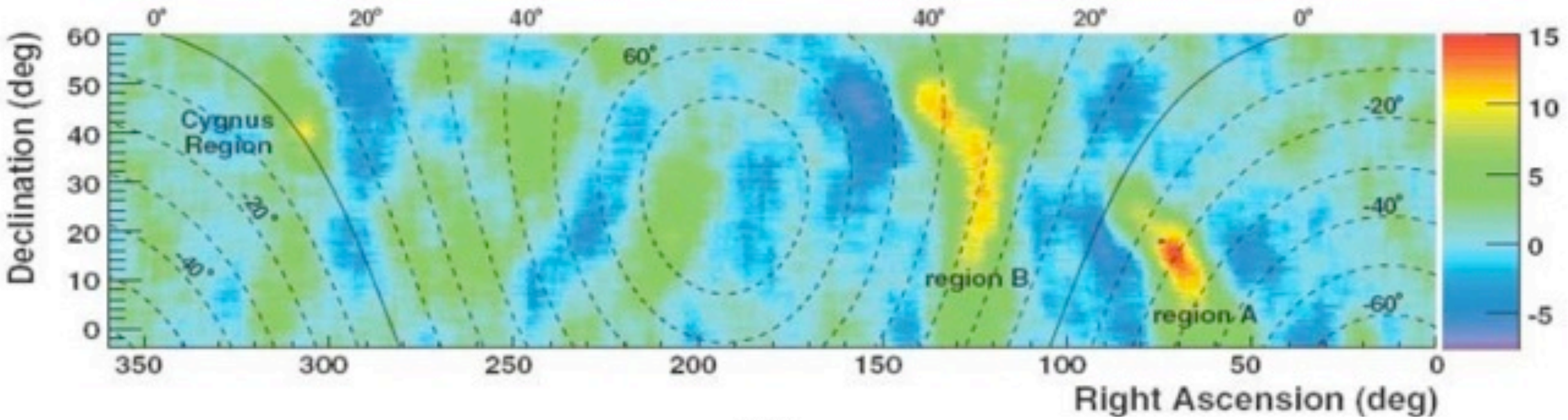
Milagro



ARGO

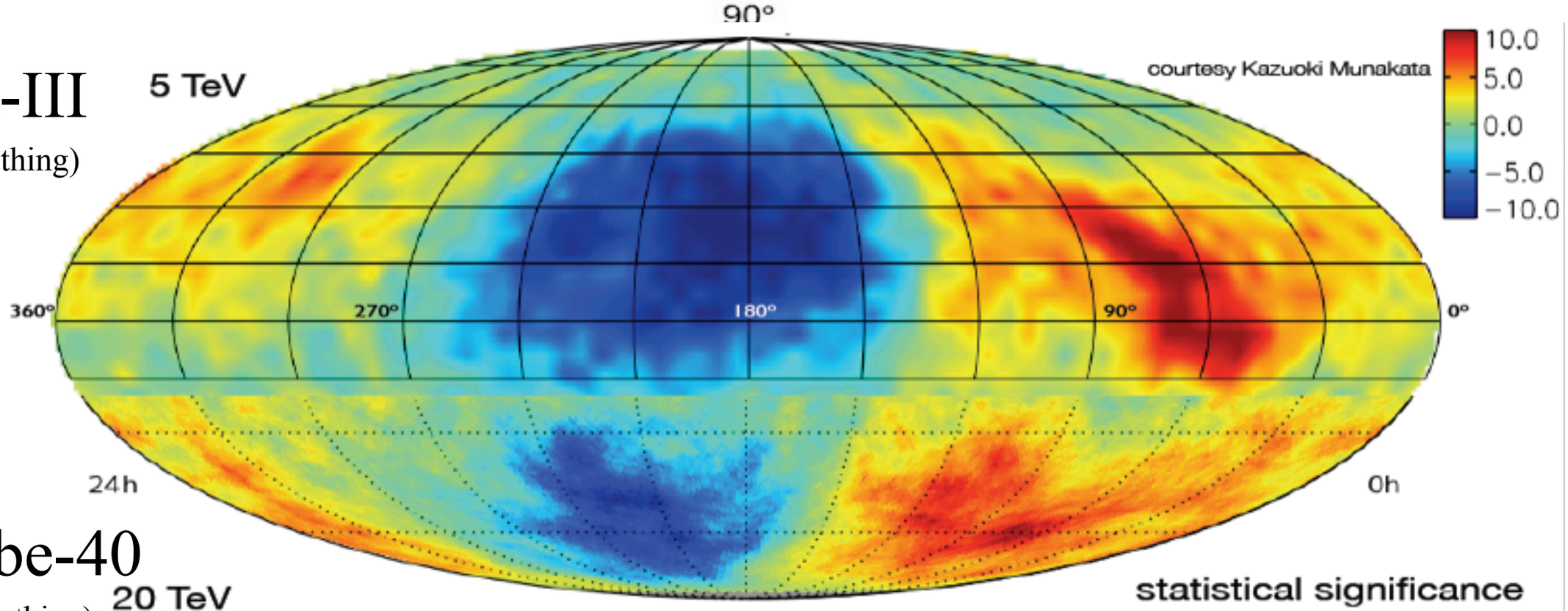


Milagro



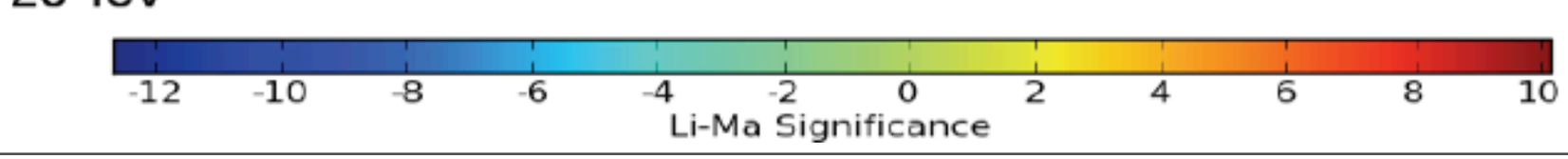
Tibet-III

(5° smoothing)

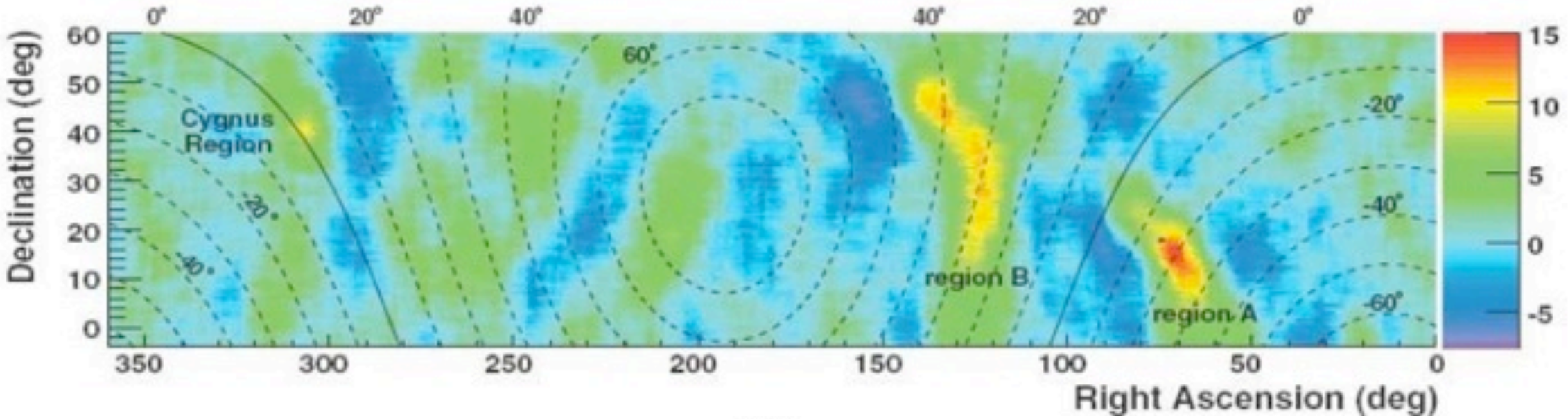


IceCube-40

(3° smoothing)

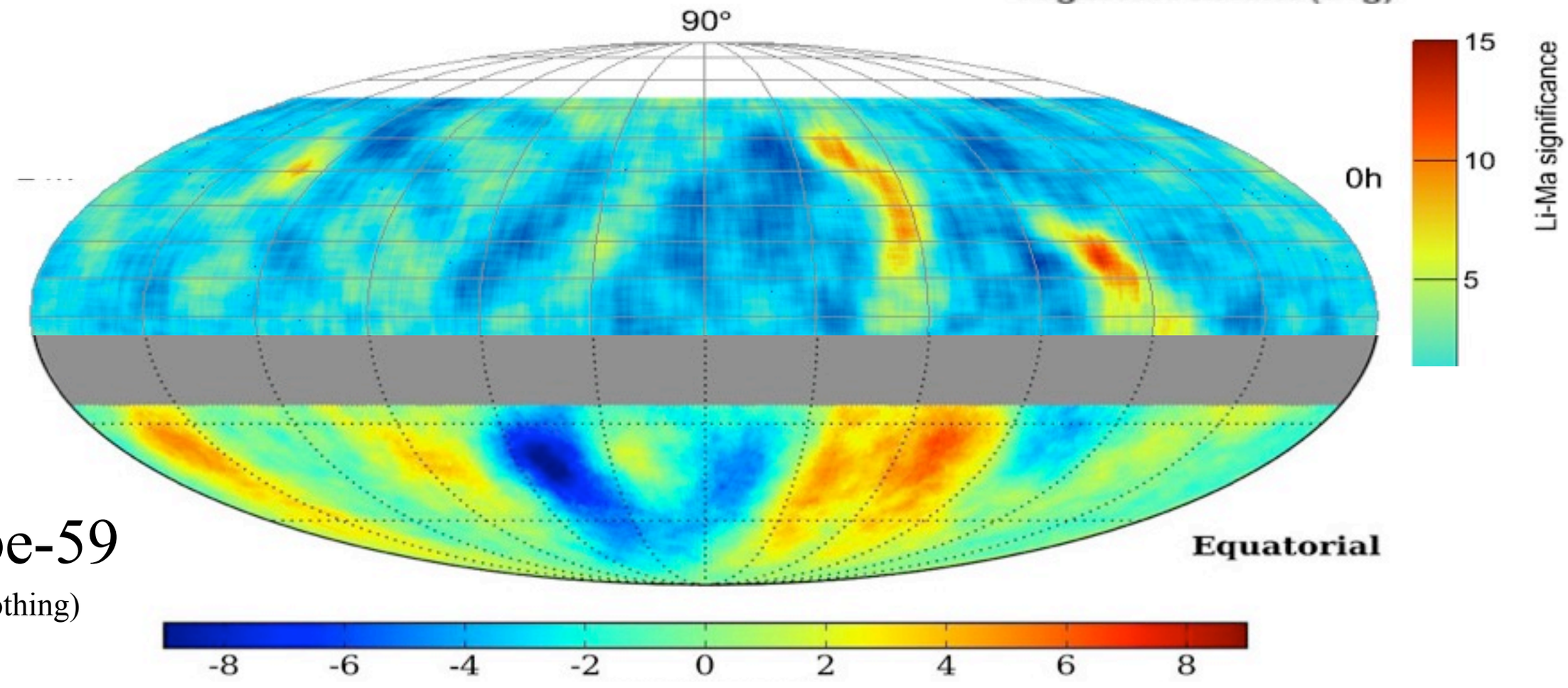


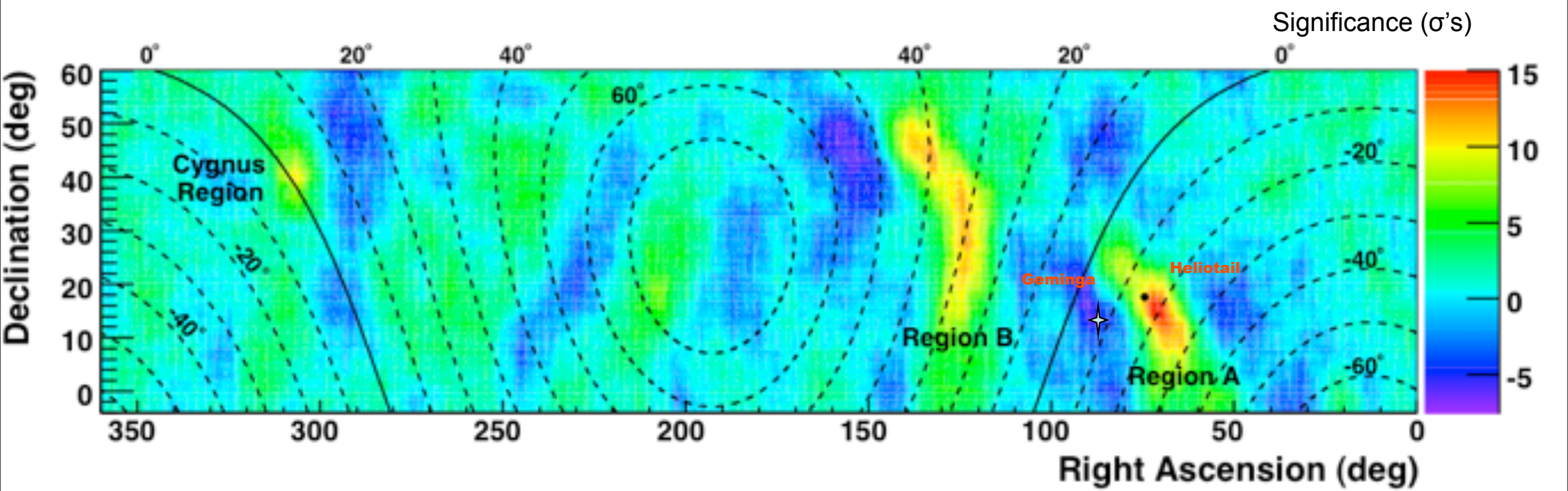
Milagro



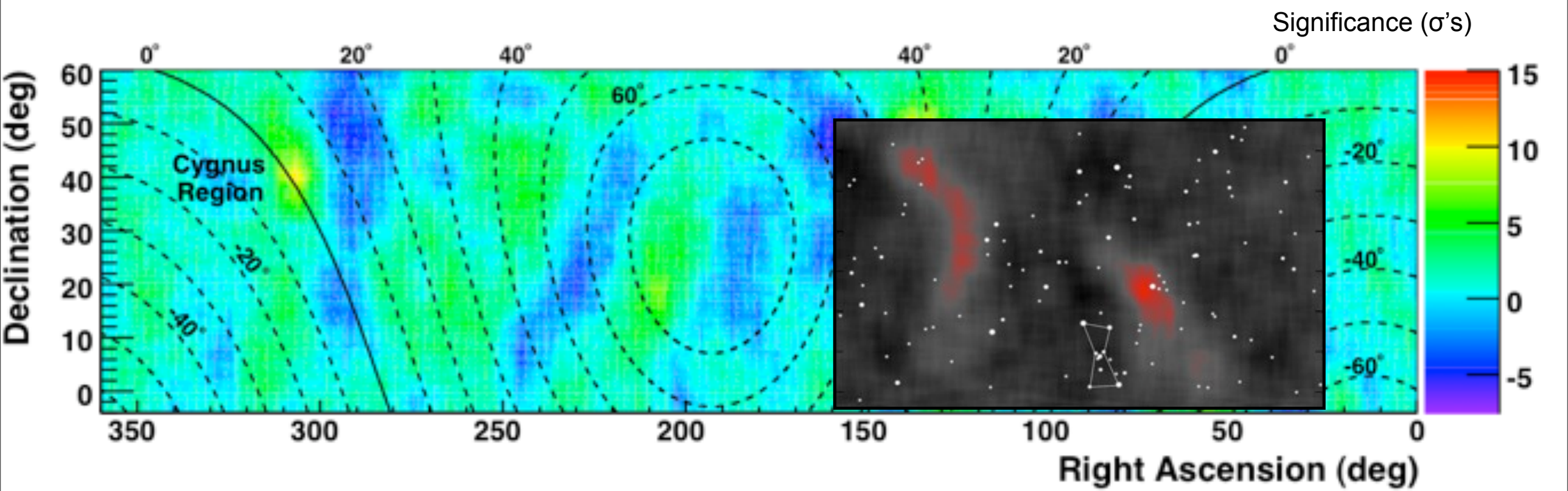
IceCube-59

(10° smoothing)





Milagro observes anisotropy in **10 TeV** cosmic rays.
HAWC will have **better energy resolution** plus a **higher rate**



Milagro observes anisotropy in **10 TeV** cosmic rays.
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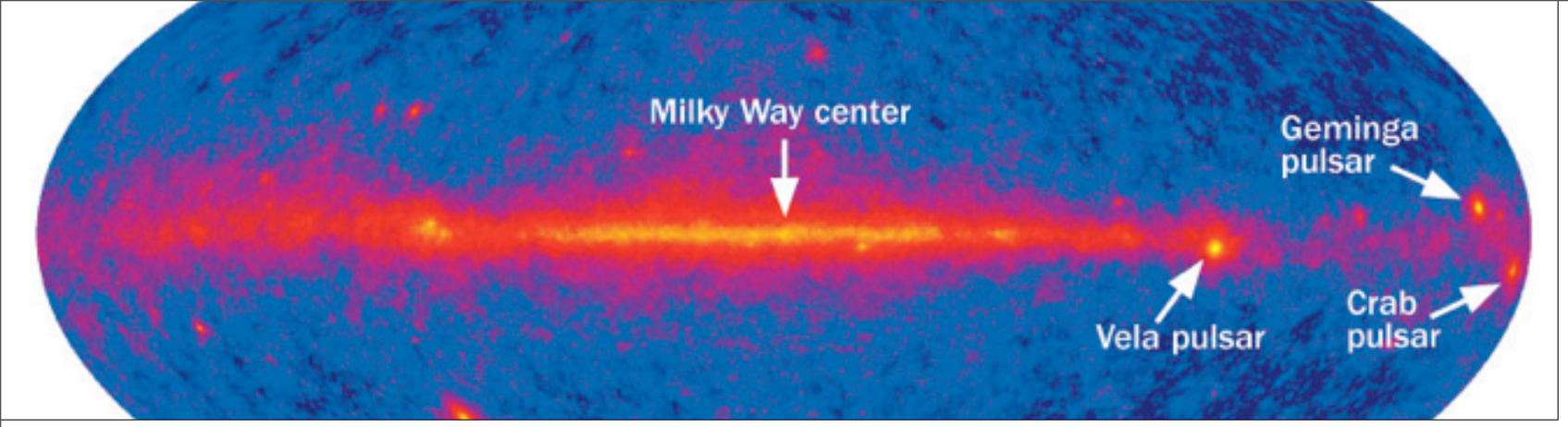
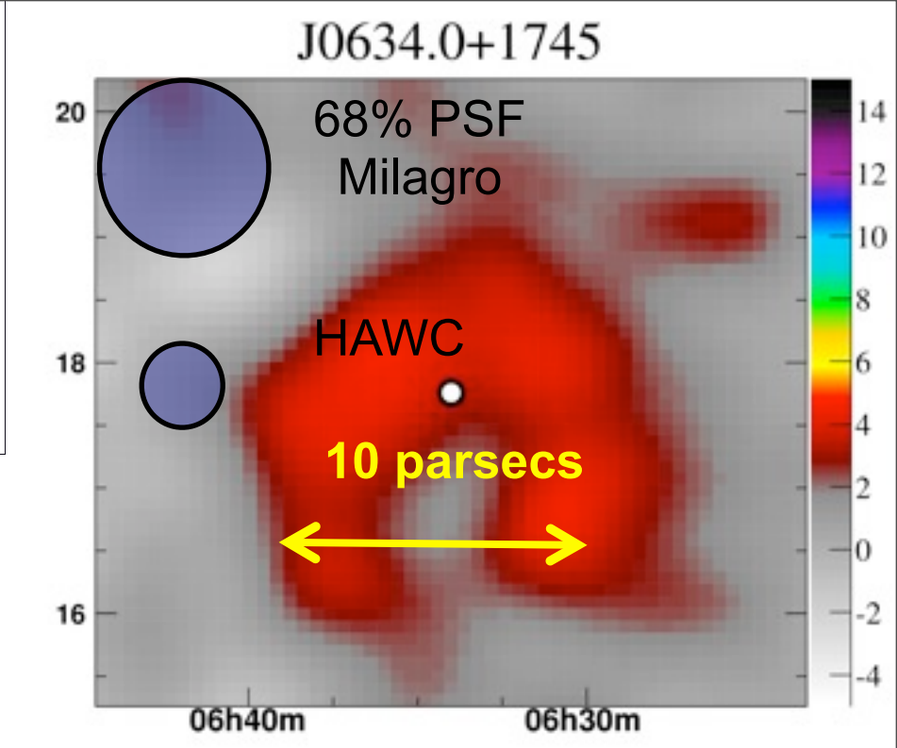
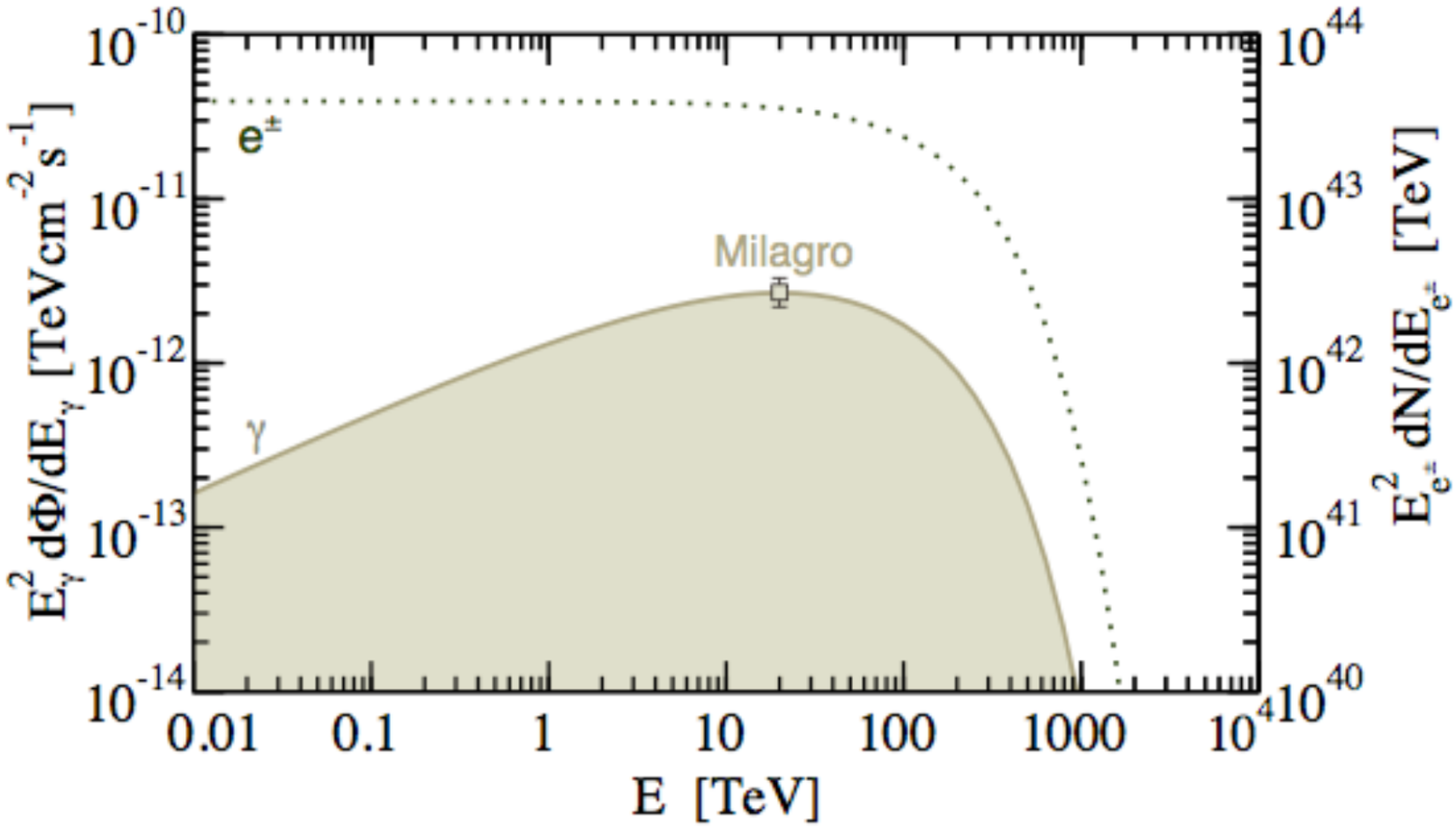
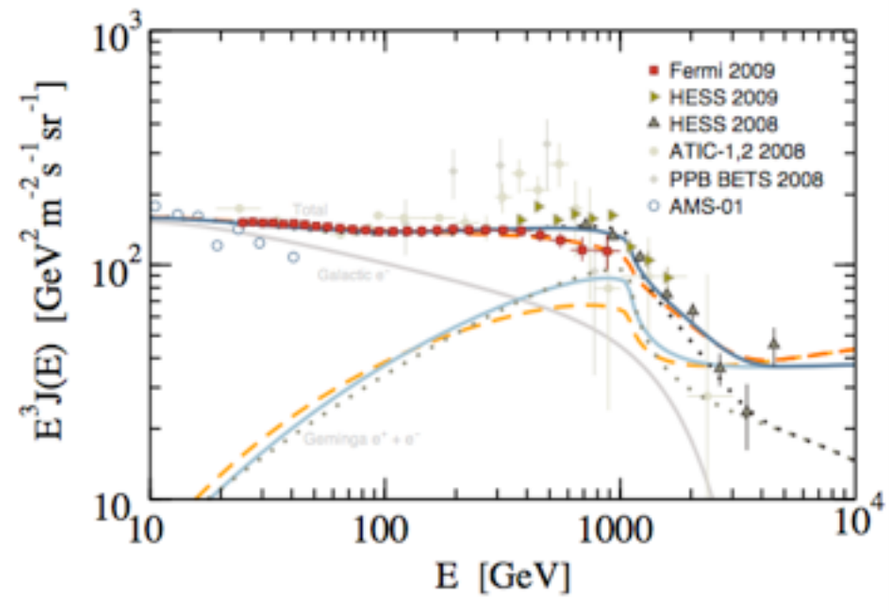




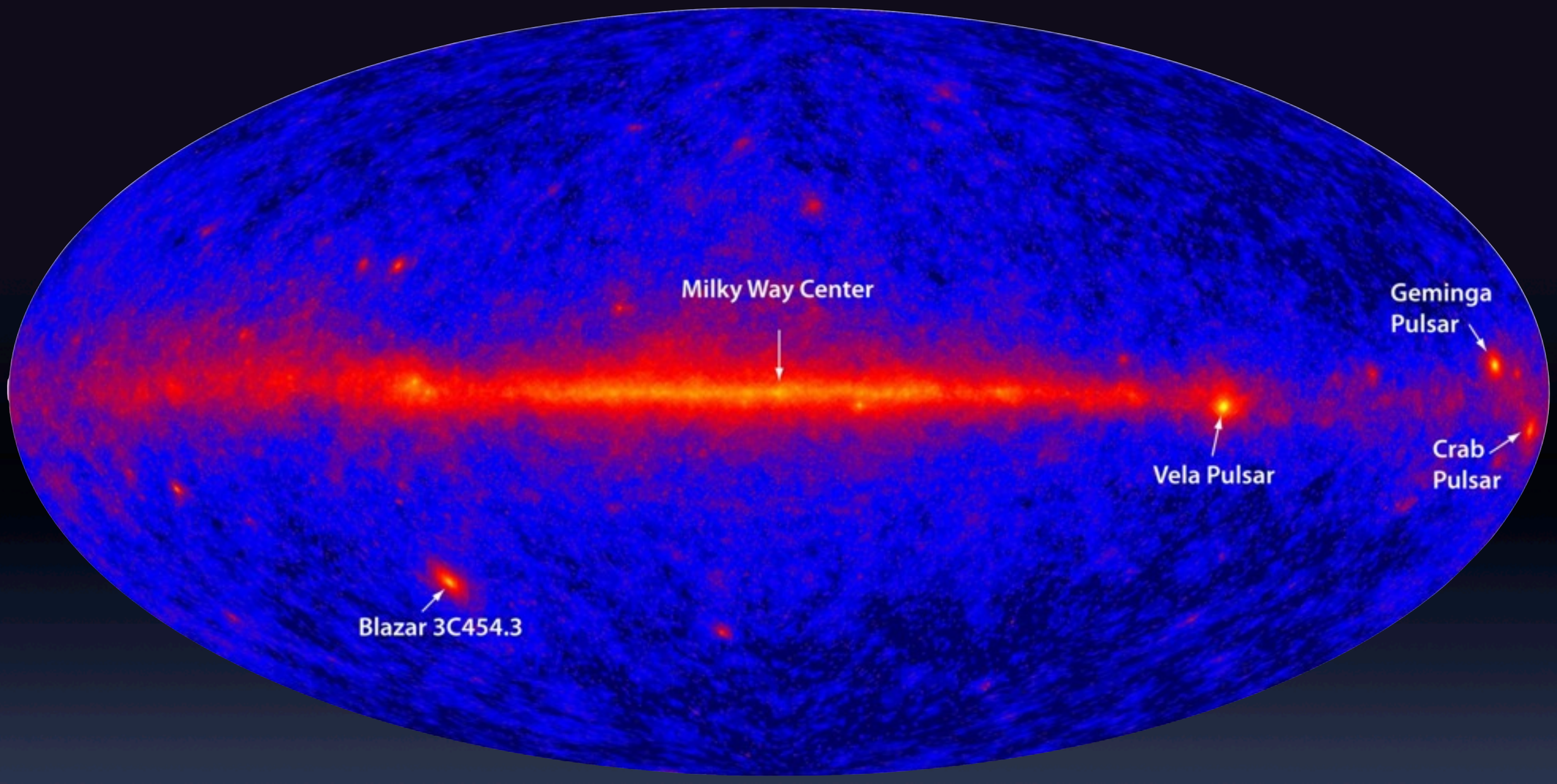




- Yuksel, Kistler and Stanev explain the **Pamela excess** and Milagro data with Geminga as the source.

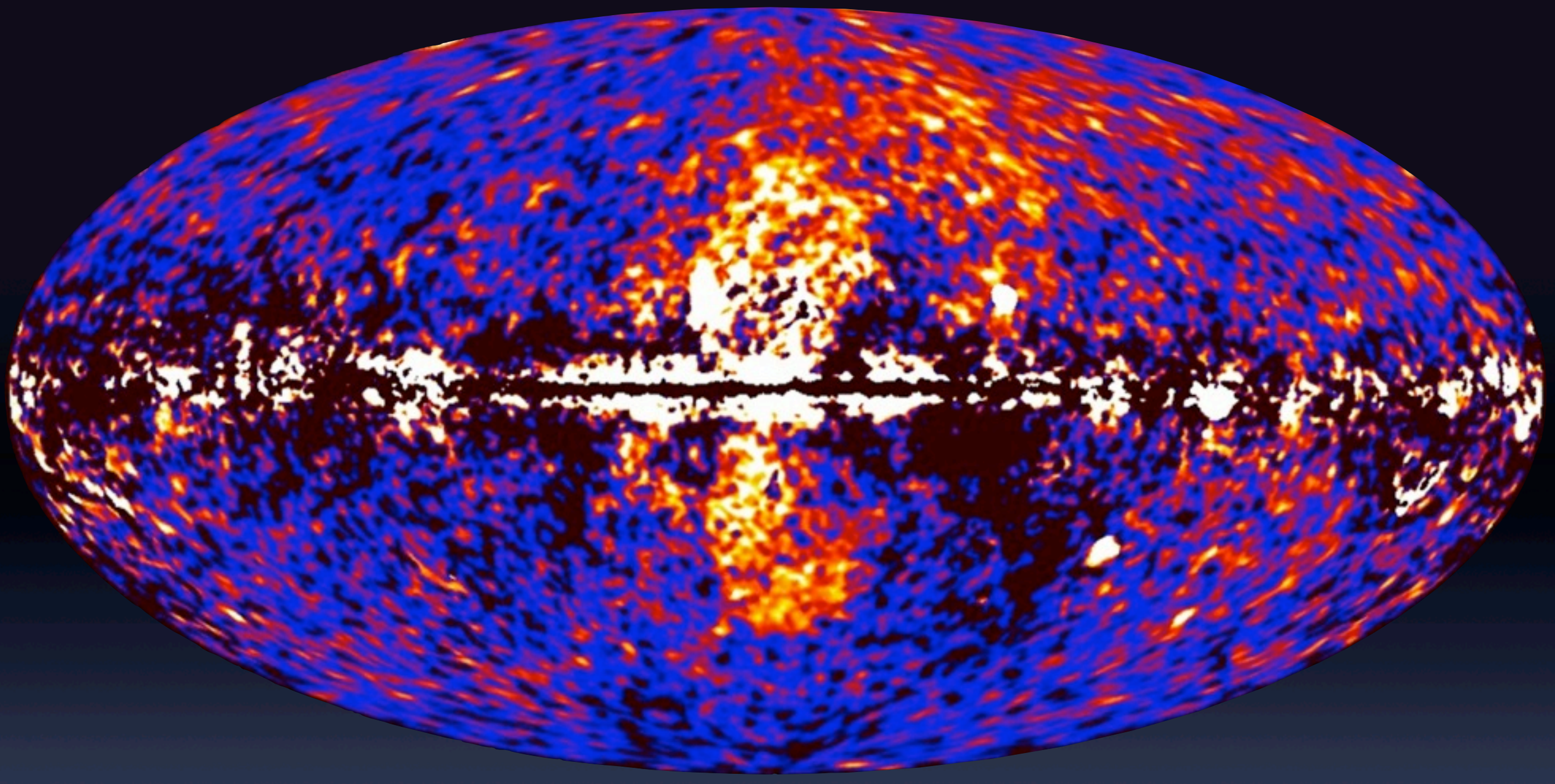
Physical Review Letters **103** (2009) 051101

Fermi *Bubbles*



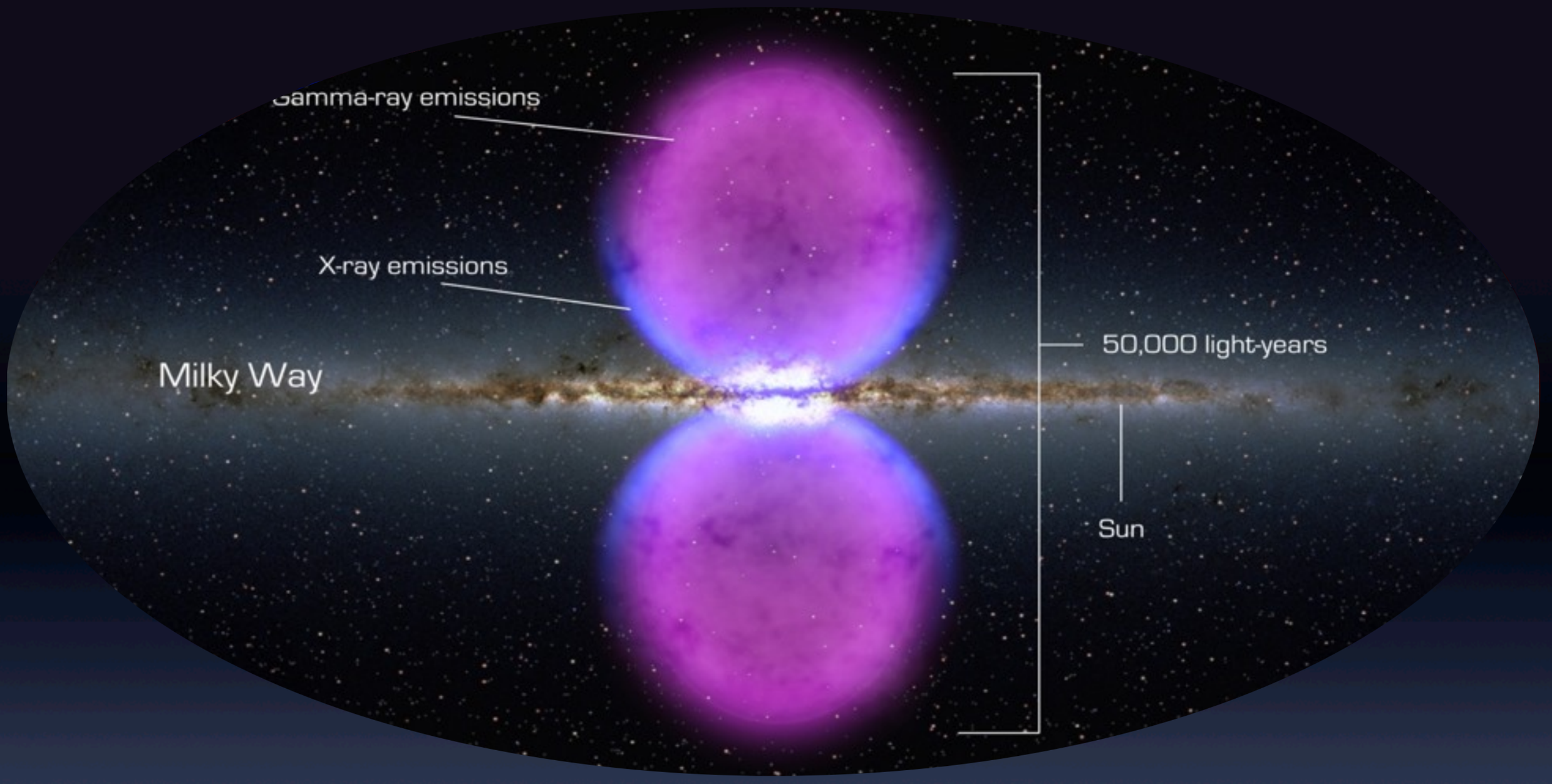
Credit: NASA/DOE/Fermi LAT

Fermi *Bubbles*



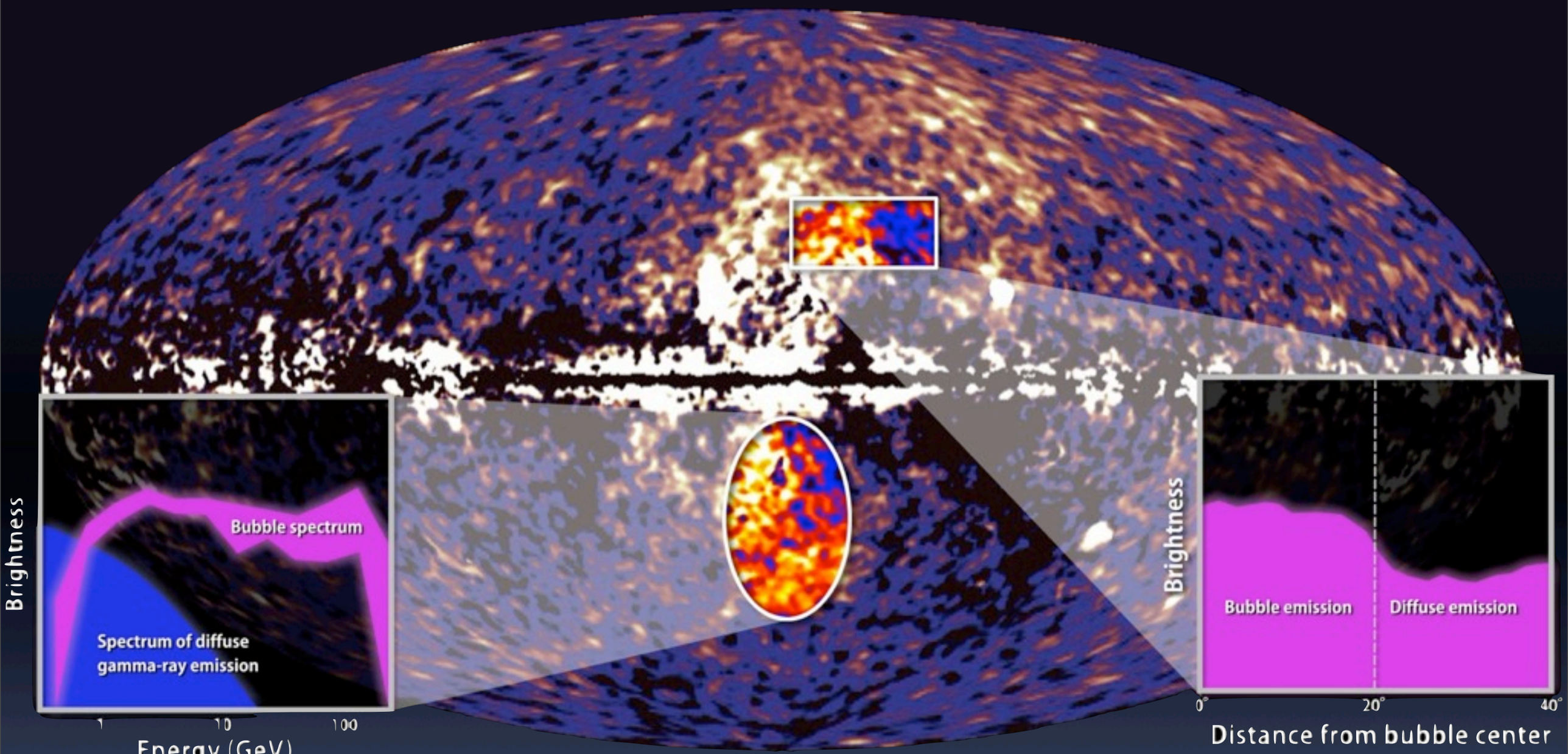
Credit: NASA/DOE/Fermi LAT/ D. Finkbeiner et al.

Fermi *Bubbles*



Credit: NASA/DOE/Fermi LAT/ D. Finkbeiner et al.

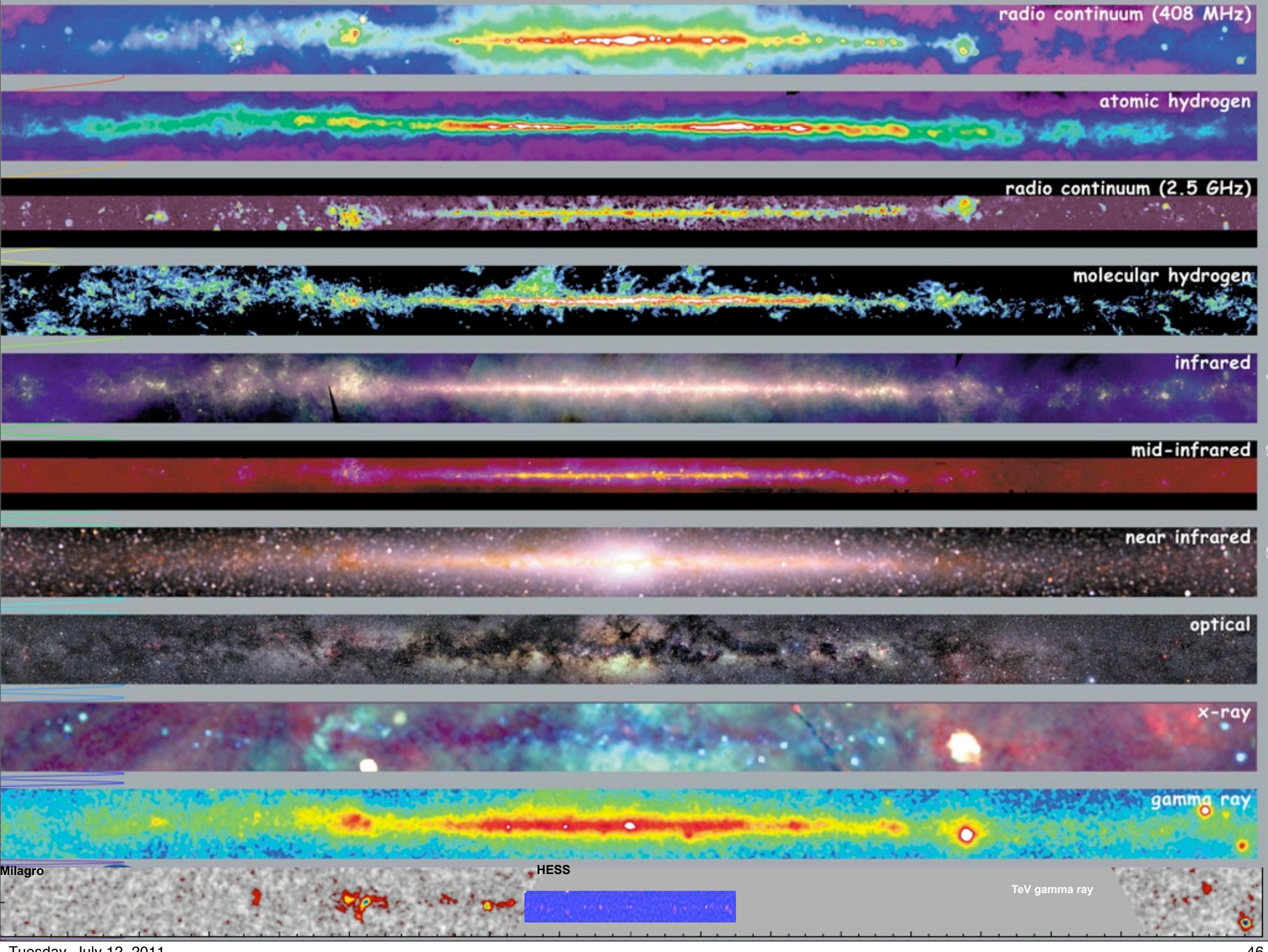
Fermi *Bubbles*



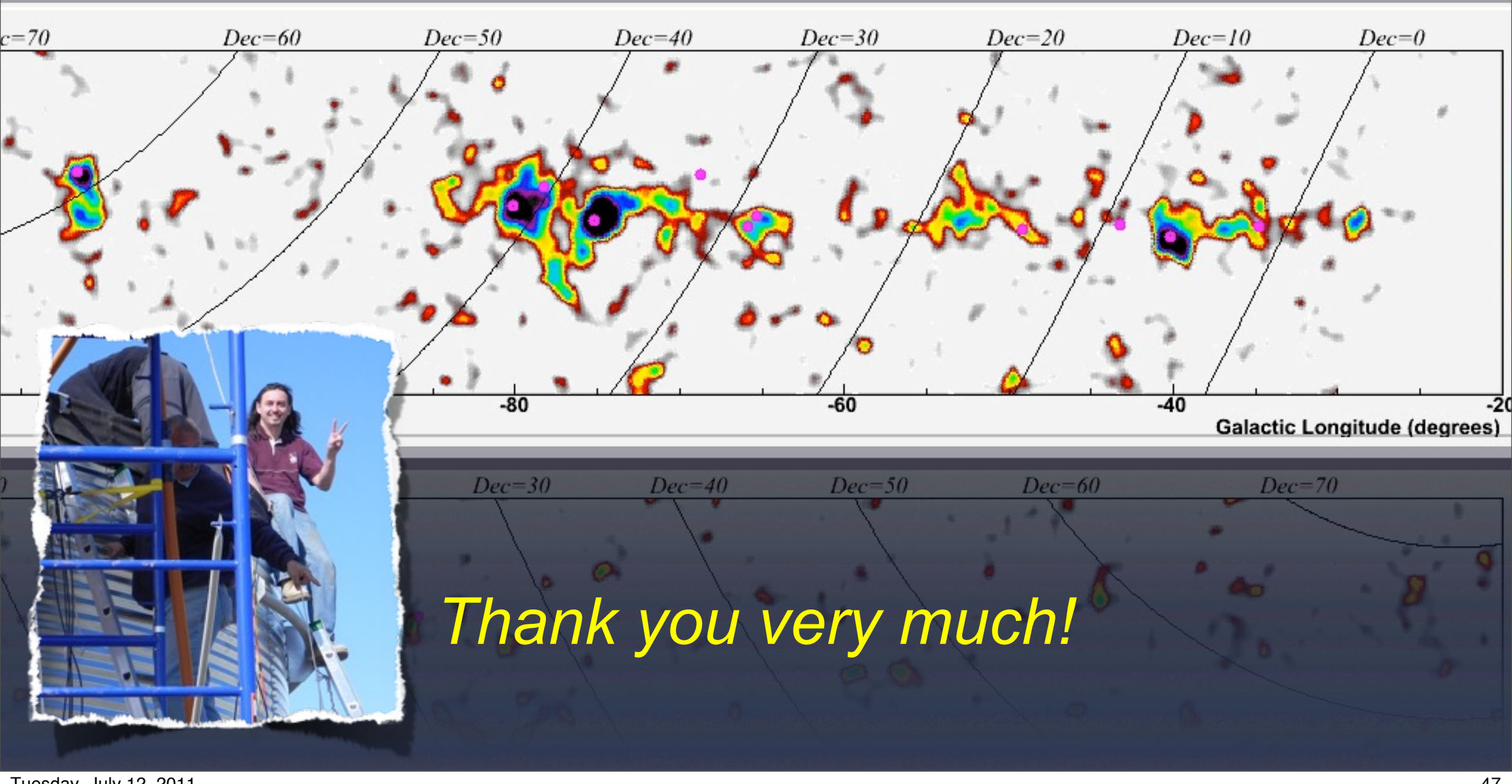
Credit: NASA/DOE/Fermi LAT/ D. Finkbeiner et al.

HAWC Science

- Discover the **origin of cosmic rays** via **HAWC's observations of γ-rays up to 100 TeV** from discrete sources and the Galactic plane.
- Understand **particle acceleration** in astrophysical jets with **HAWC's** (wide field of view, high duty factor) **observations of transient sources**, such as gamma ray bursts and supermassive black holes.
- Explore **new TeV physics** via **HAWC's unbiased survey** of ½ the sky.


radio continuum (408 MHz)
atomic hydrogen
radio continuum (2.5 GHz)
molecular hydrogen
infrared
mid-infrared
near infrared
optical
x-ray
gamma ray
Milagro
HESS
TeV gamma ray

HAWC will open the TeV window to the Universe!



Thank you very much!