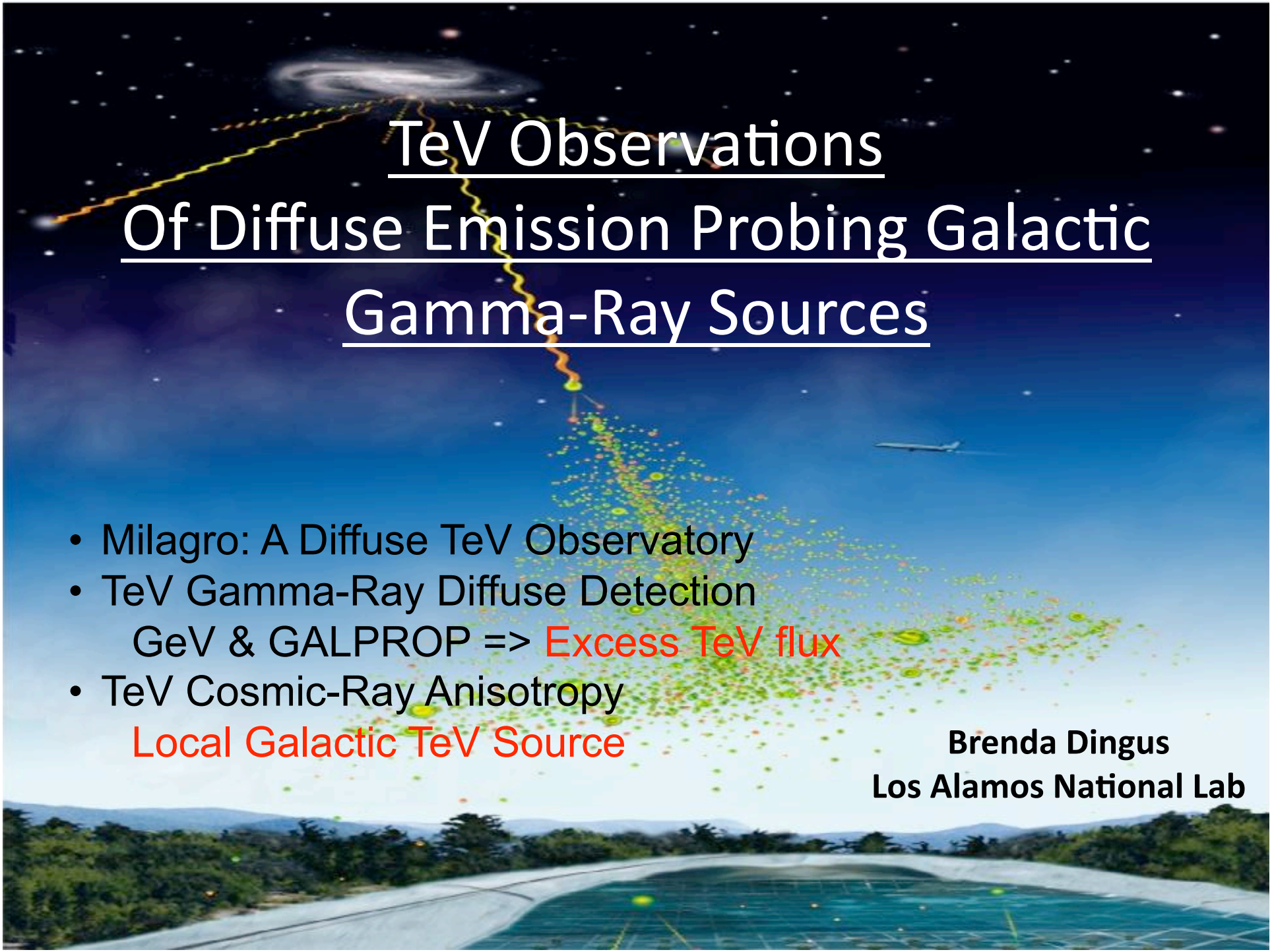


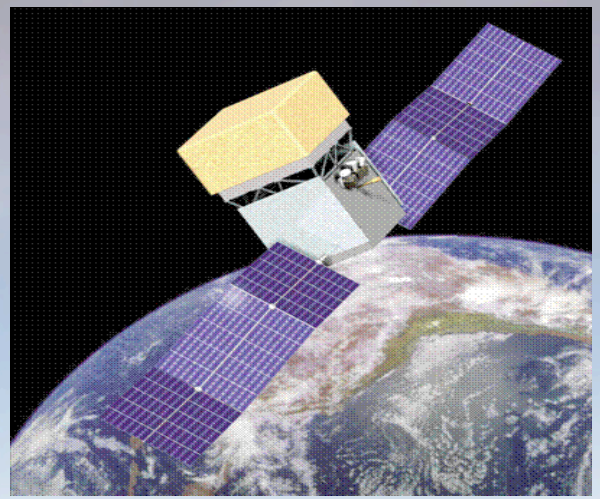
TeV Observations Of Diffuse Emission Probing Galactic Gamma-Ray Sources

- Milagro: A Diffuse TeV Observatory
- TeV Gamma-Ray Diffuse Detection
  GeV & GALPROP => Excess TeV flux
- TeV Cosmic-Ray Anisotropy
  Local Galactic TeV Source

Brenda Dingus
Los Alamos National Lab

Gamma-Ray Detectors

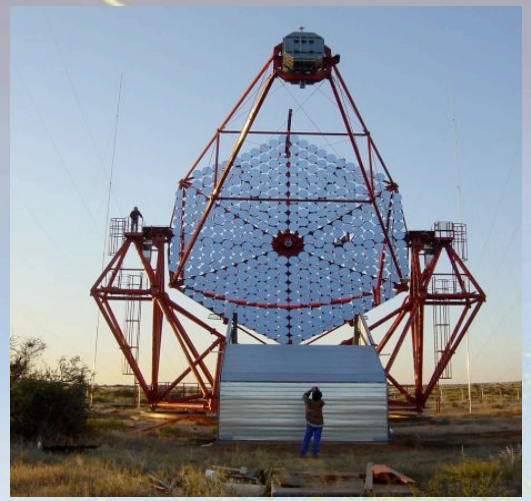
Low Energy Threshold
EGRET, AGILE, Fermi



Space-based (Small Area)
"Background Free"
Large Duty Cycle/Large Aperture

Sky Survey (< 10 GeV)
AGN Physics
Transients (GRBs) < 100 GeV

High Sensitivity
HESS, MAGIC, VERITAS



Large Effective Area
Excellent Background Rejection
Low Duty Cycle/Small Aperture

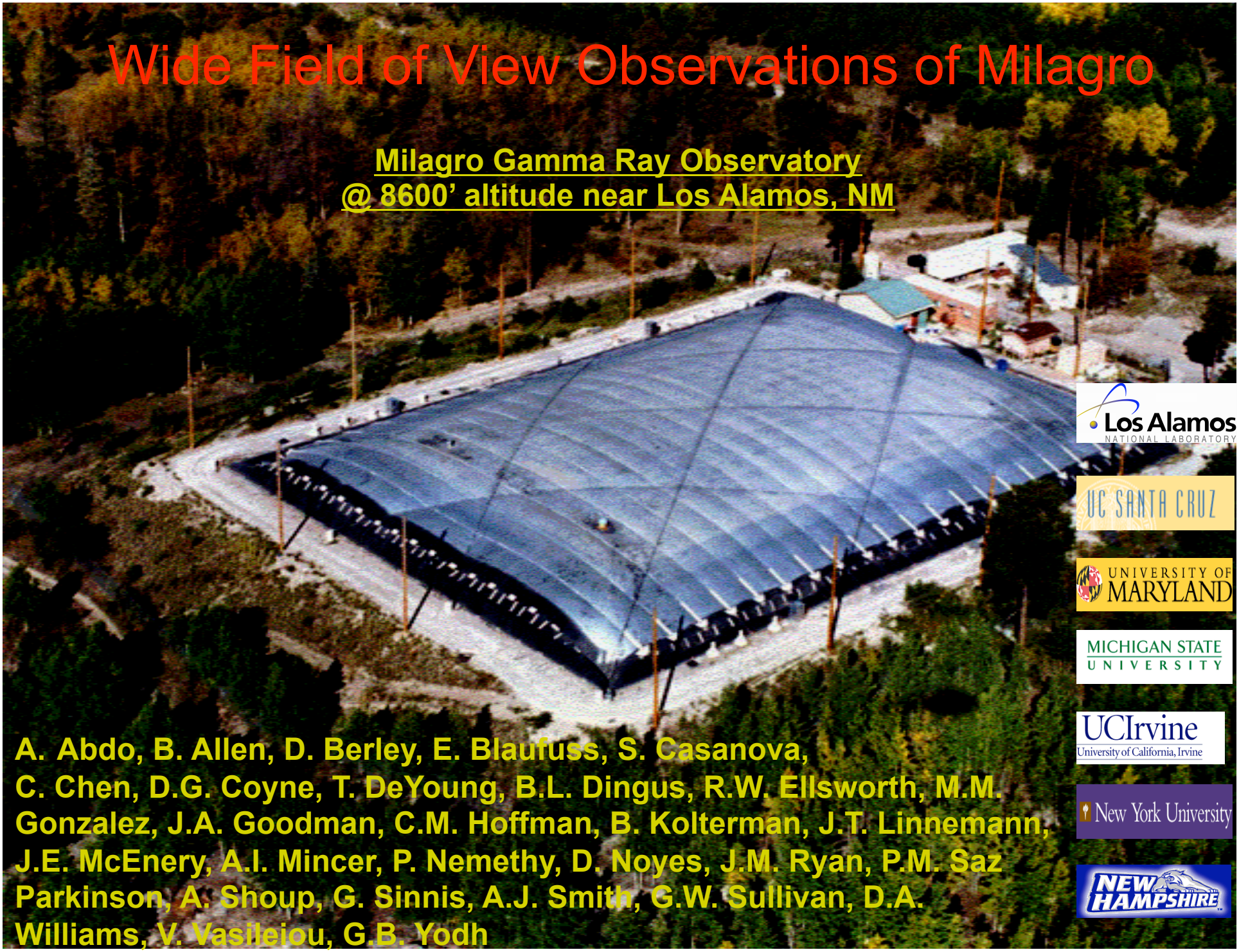
High Resolution Energy Spectra
Studies of known sources
Surveys of limited regions of sky

Large Aperture/High Duty Cycle
Milagro, Tibet, ARGO, HAWC

Moderate Area
Good Background Rejection
Large Duty Cycle/Large Aperture

Unbiased Sky Survey
Extended sources
Transients (GRB's)

Wide Field of View Observations of Milagro

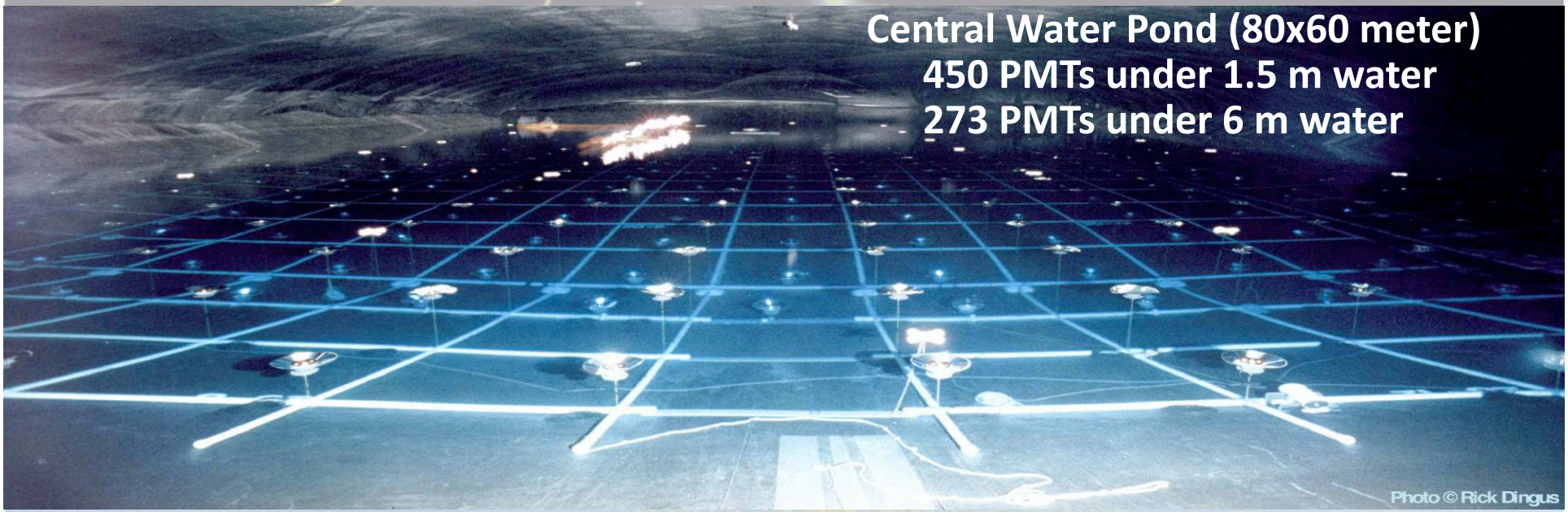


Milagro Gamma Ray Observatory
@ 8600' altitude near Los Alamos, NM

A. Abdo, B. Allen, D. Berley, E. Blaufuss, S. Casanova, C. Chen, D.G. Coyne, T. DeYoung, B.L. Dingus, R.W. Ellsworth, M.M. Gonzalez, J.A. Goodman, C.M. Hoffman, B. Kolterman, J.T. Linnemann, J.E. McEnery, A.I. Mincer, P. Nemethy, D. Noyes, J.M. Ryan, P.M. Saz Parkinson, A. Shoup, G. Sinnis, A.J. Smith, G.W. Sullivan, D.A. Williams, V. Vasileiou, G.B. Yodh

Los Alamos NATIONAL LABORATORY
UC SANTA CRUZ
UNIVERSITY OF MARYLAND
MICHIGAN STATE UNIVERSITY
UCIrvine University of California, Irvine
New York University
NEW HAMPSHIRE

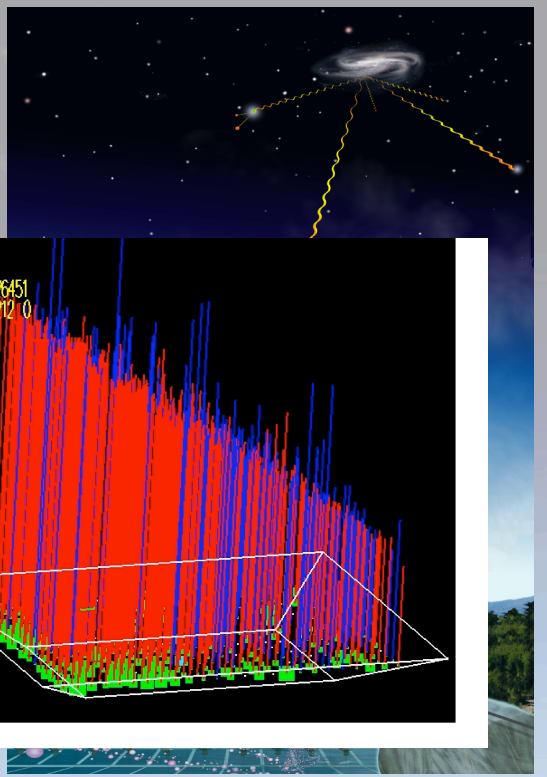
Milagro Water Cherenkov TeV Observatory

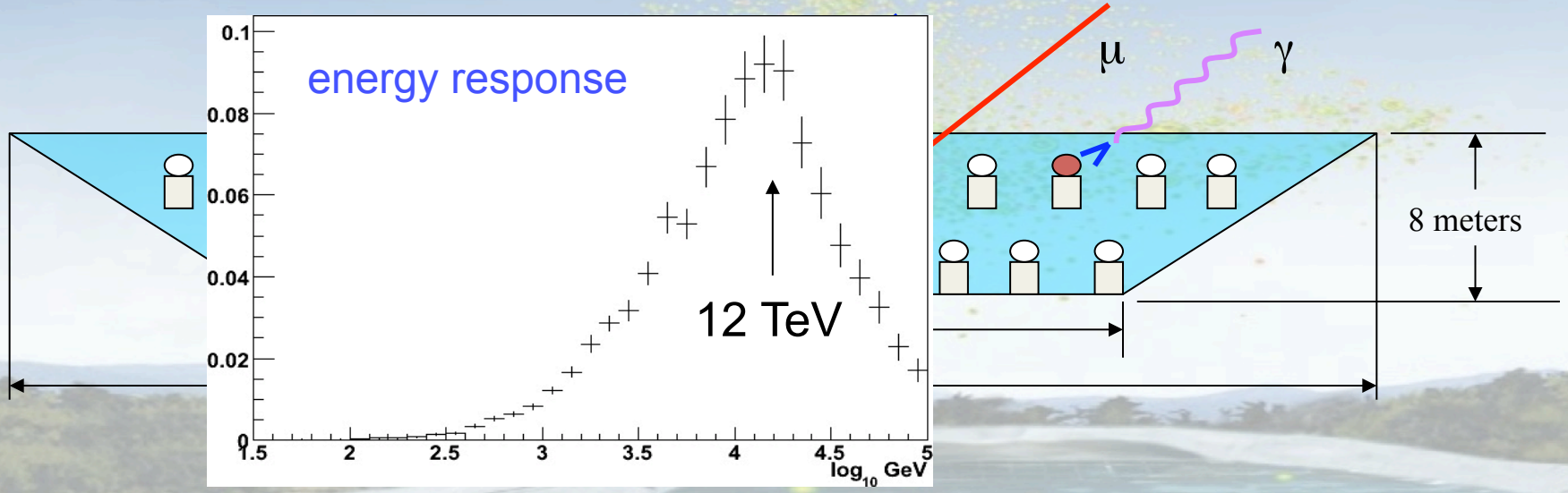


- 4000 m^2 pond surrounded by 40000 m^2 array of outriggers
- Located 2640 meters a.s.l. near Los Alamos, NM
- Operated from 2000-2008
- Operated 2004-2008 with outriggers (2x sensitivity)

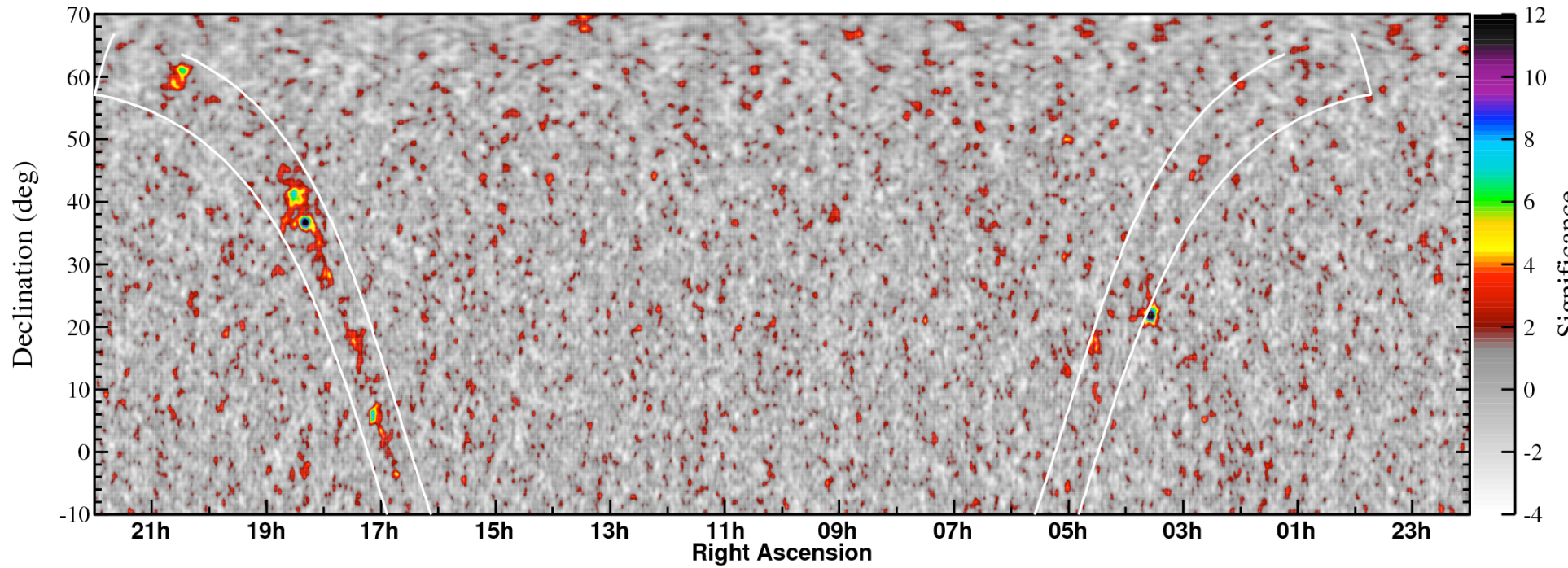
How Does Milagro Work?

- Detect Particles in Extensive Air Showers from Cherenkov light created in 60m x 80 m x 8m pond containing filtered water
- Reconstruct shower direction to ~0.5° from the time different PMTs are hit
- 1700 Hz trigger rate mostly due to Extensive Air Showers created by cosmic rays
- Field of view was ~2 sr and the average duty factor was >90%

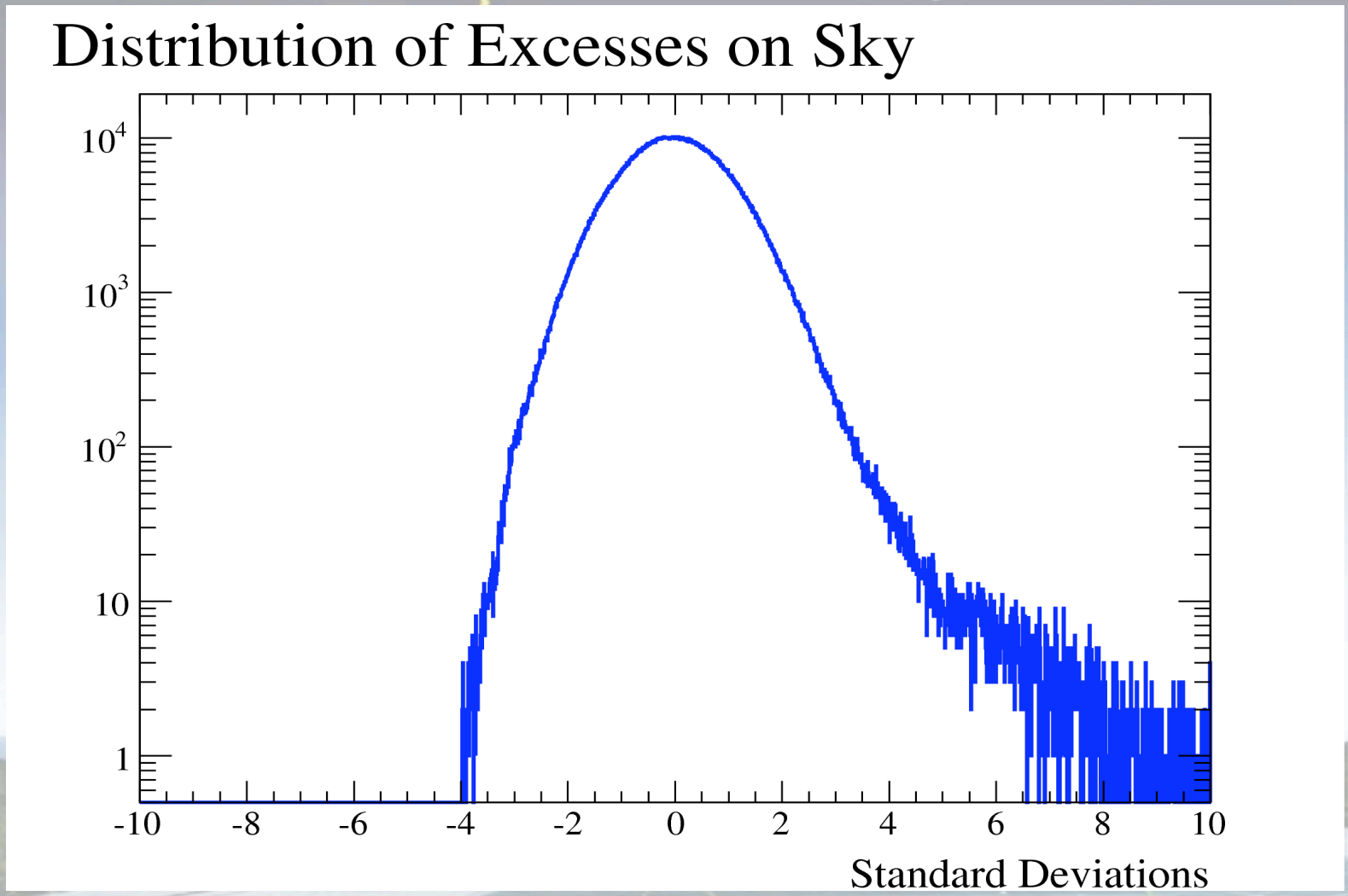




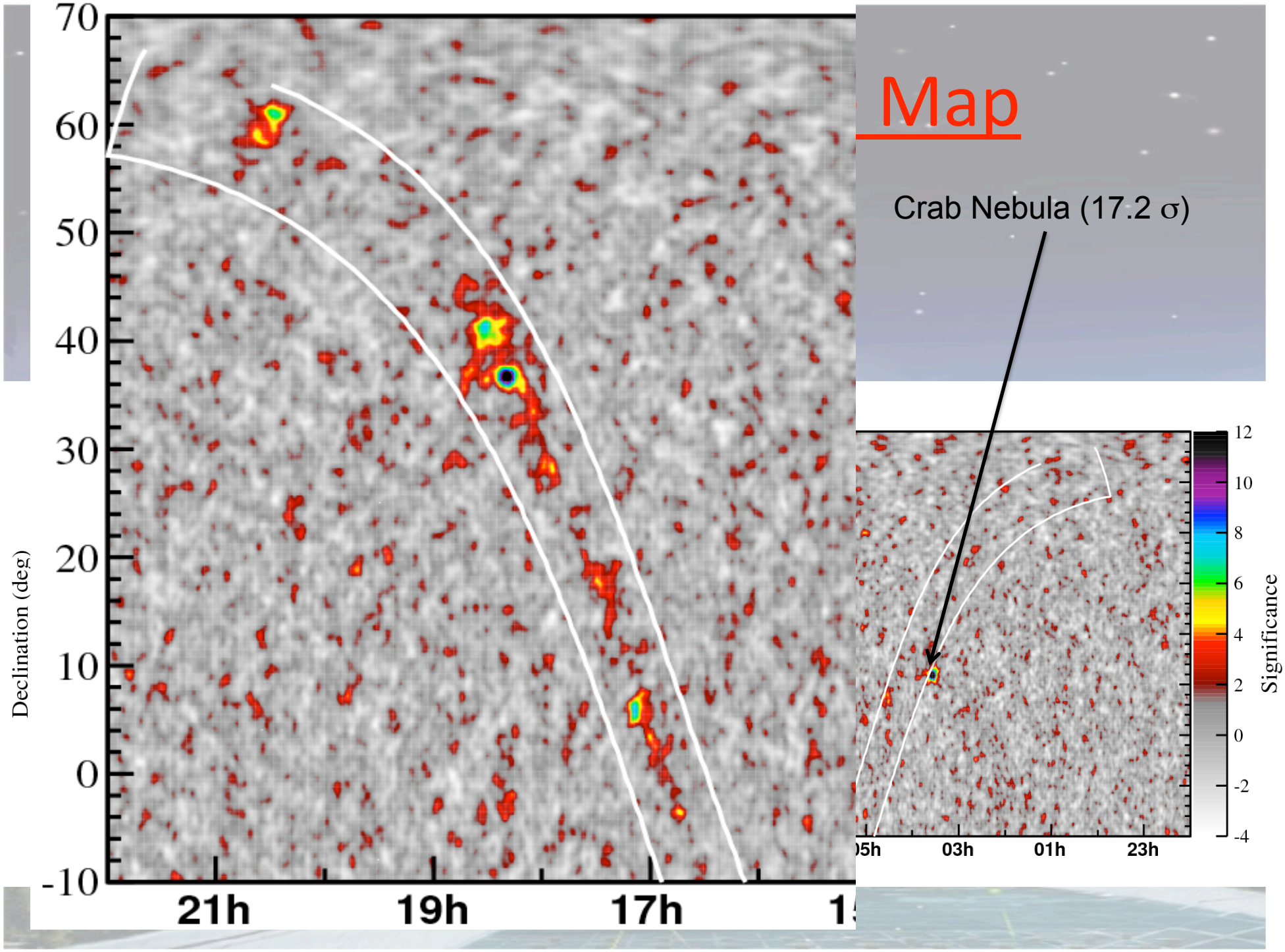
Milagro Significance Map



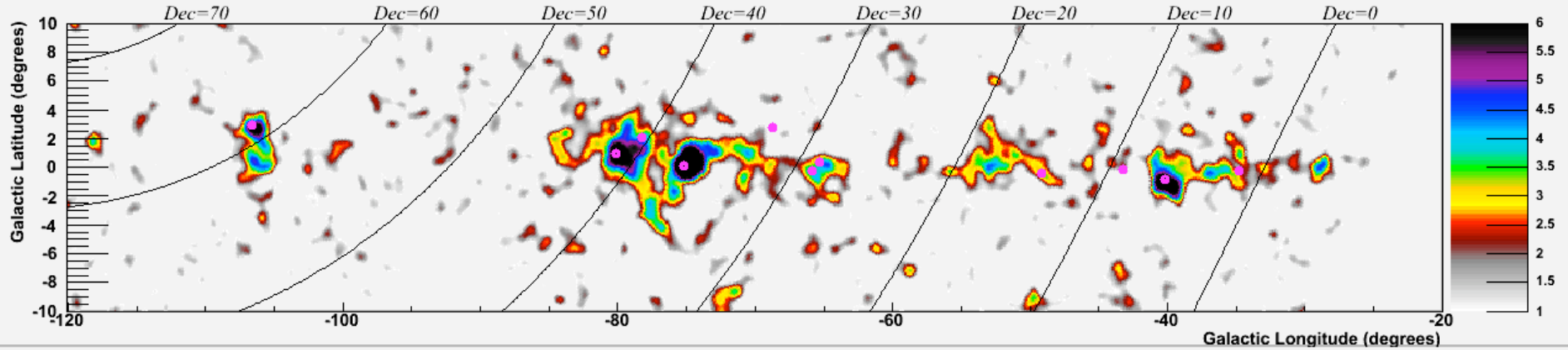
Distribution of Significances from Previous Map

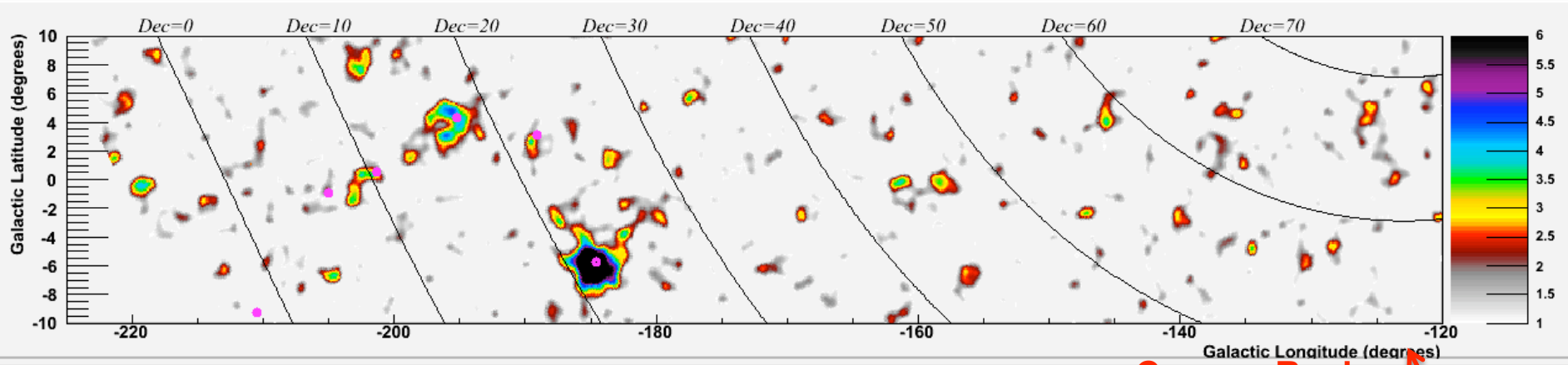


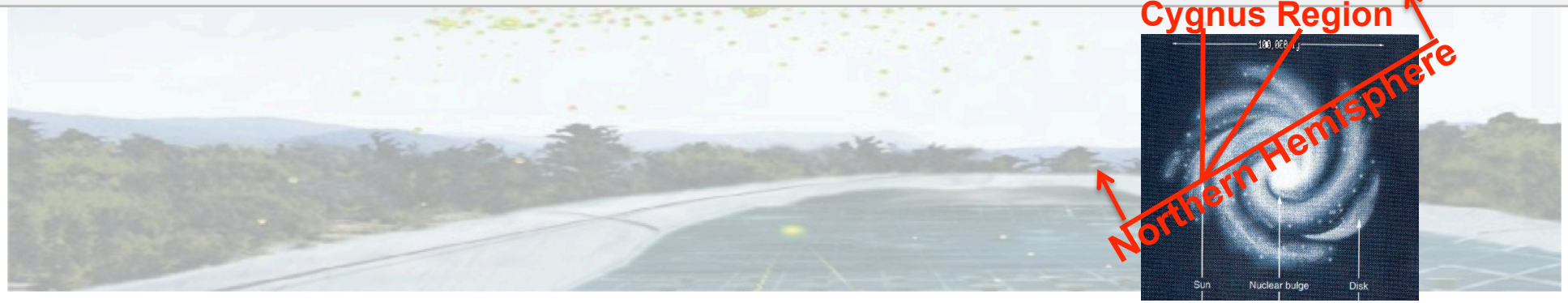
Map


Crab Nebula (17.2 σ)
70
60
50
40
30
20
10
0
-10
Declination (deg)
21h
19h
17h
03h
01h
23h
12
10
8
6
4
2
0
-2
-4
Significance

Milagro's Galactic Plane

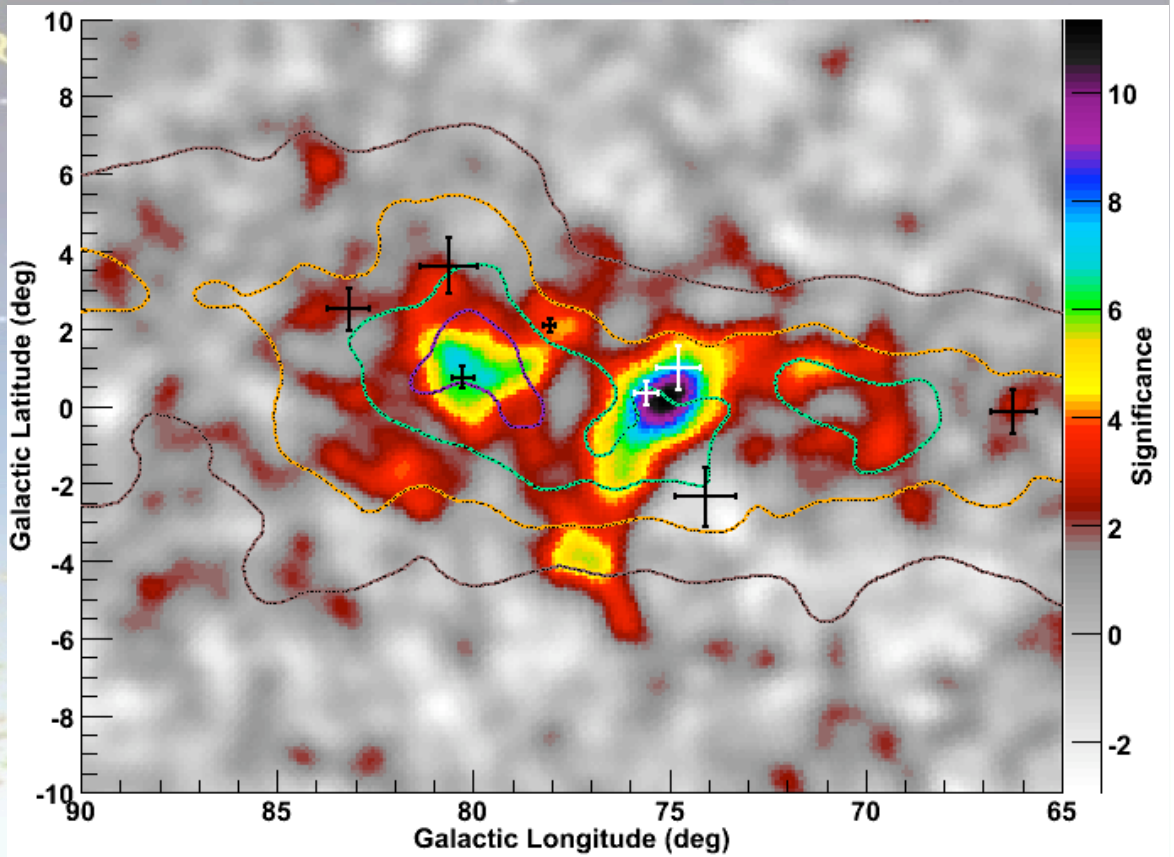




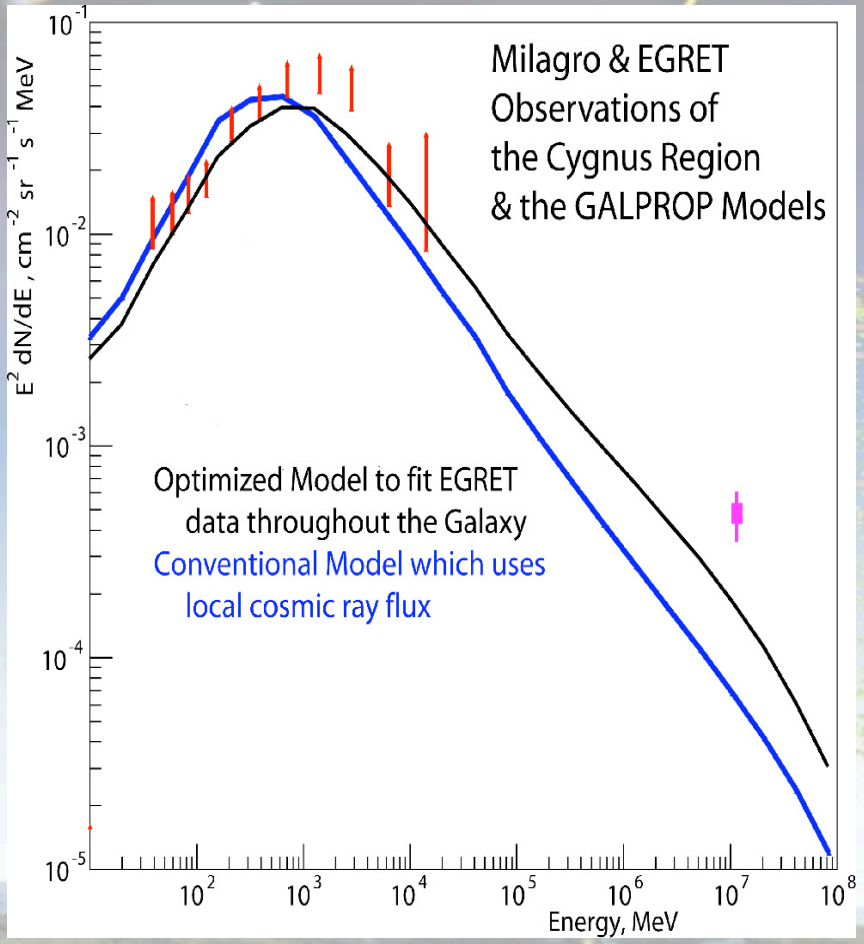


Cygnus Region Spatial Morphology

- Crosses are EGRET GeV sources
- Contours are Molecular (Dame et al, 2001) and Atomic Hydrogen (Kalberla et al, 2005)
- TeV flux correlated with matter density



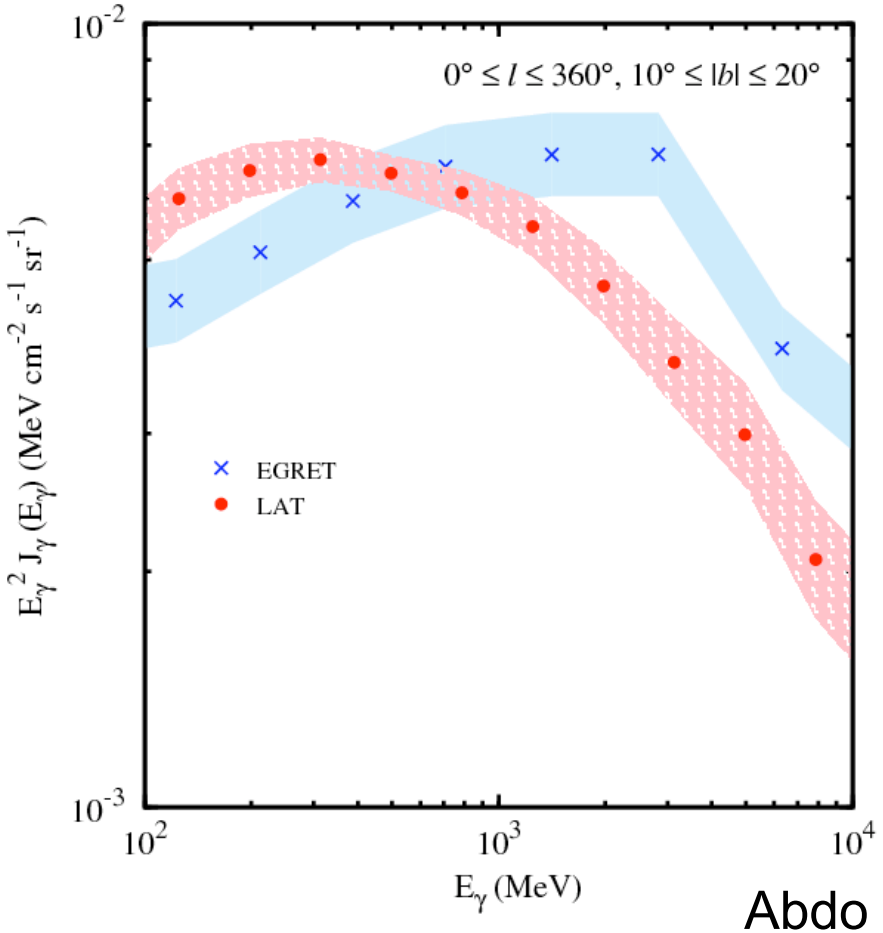
TeV Diffuse Emission

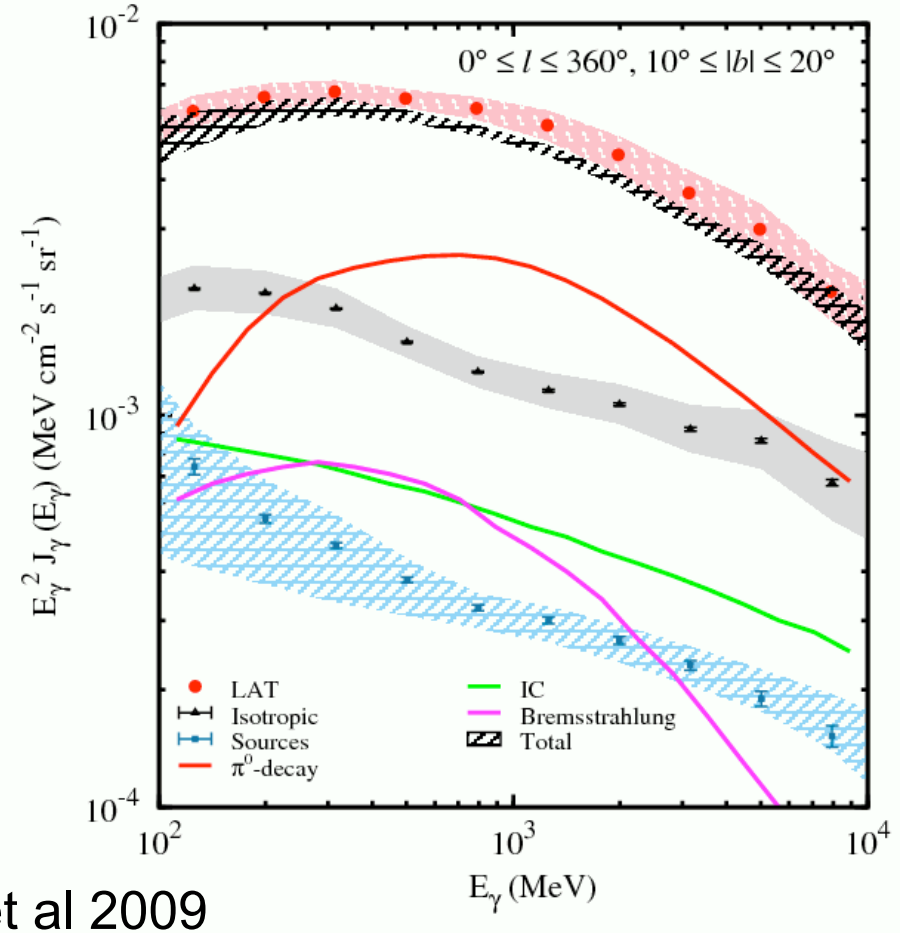


- GALPROP model of the cosmic ray production, propagation, matter, and radiation fields in the Galaxy
  - "Conventional" model uses local cosmic-ray flux
  - "EGRET Optimized" model increases cosmic-ray flux to match EGRET
- 'EGRET Optimized model' disfavored by Fermi

GeV Mid Latitude Diffuse Emission

- Fermi & EGRET disagree
- Fermi matches GALPROP "conventional" model
  - Assumes that the local cosmic ray flux is typical

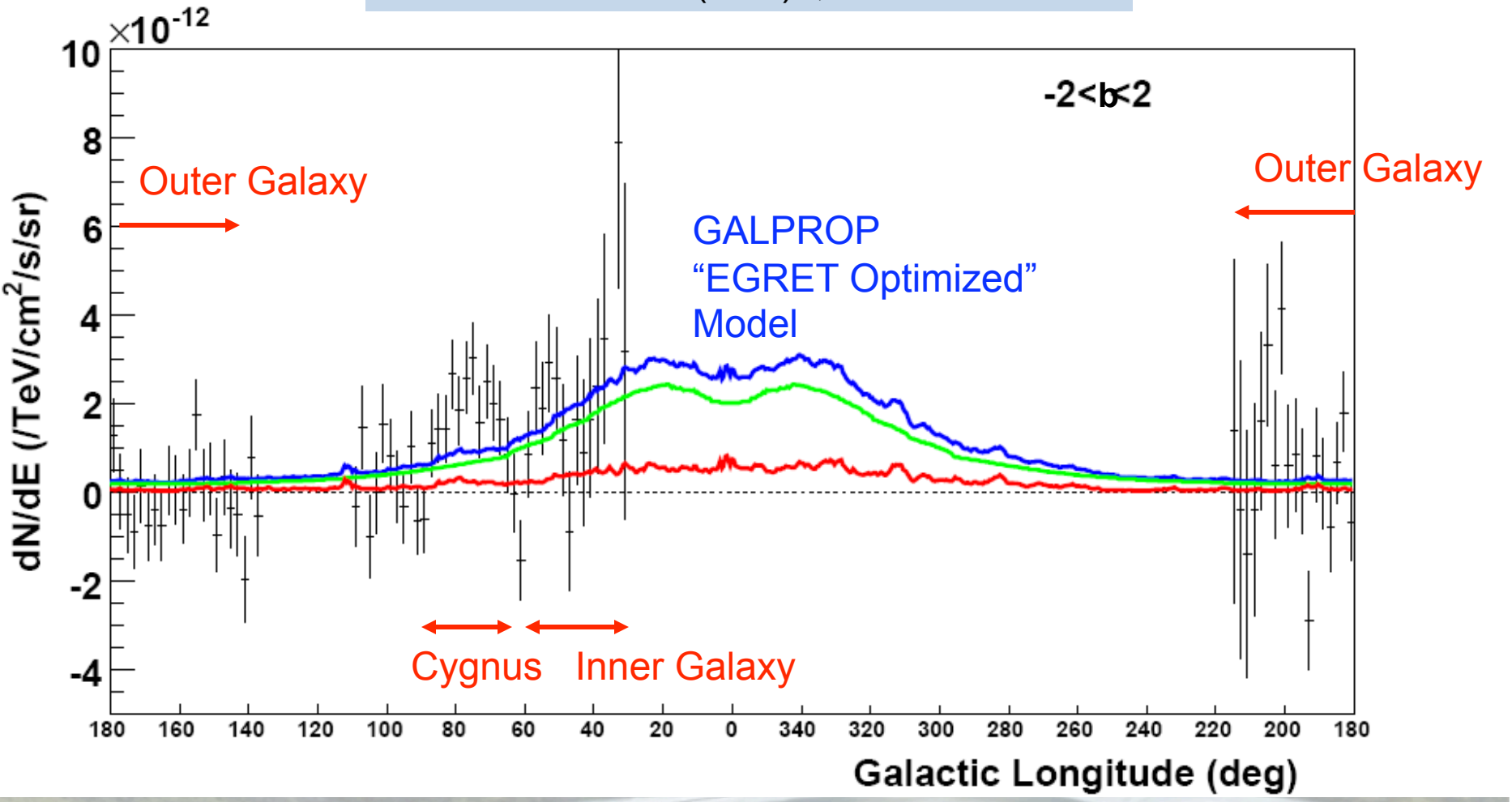




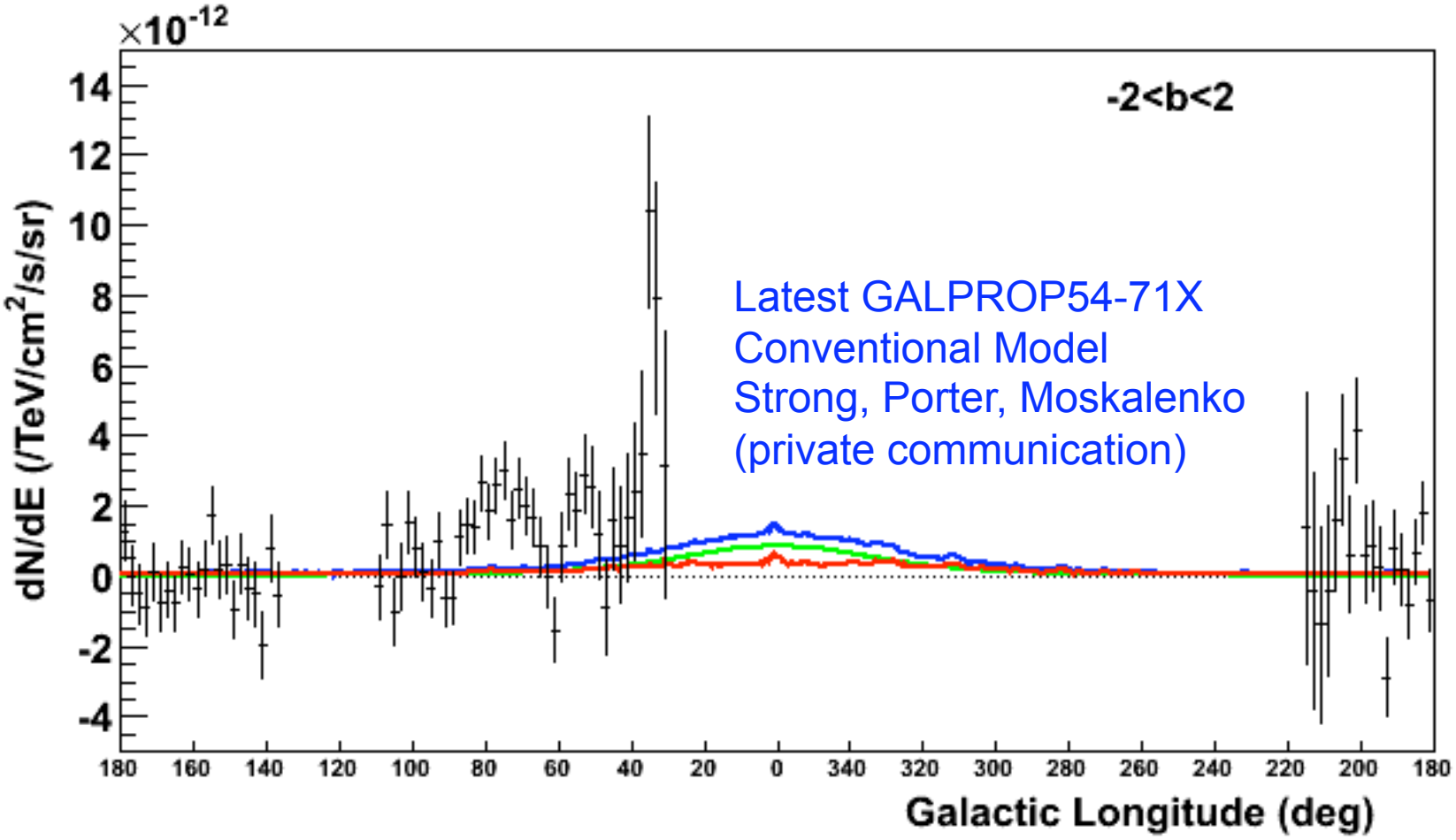
Abdo et al 2009

Flux Profiles: Galactic Longitude

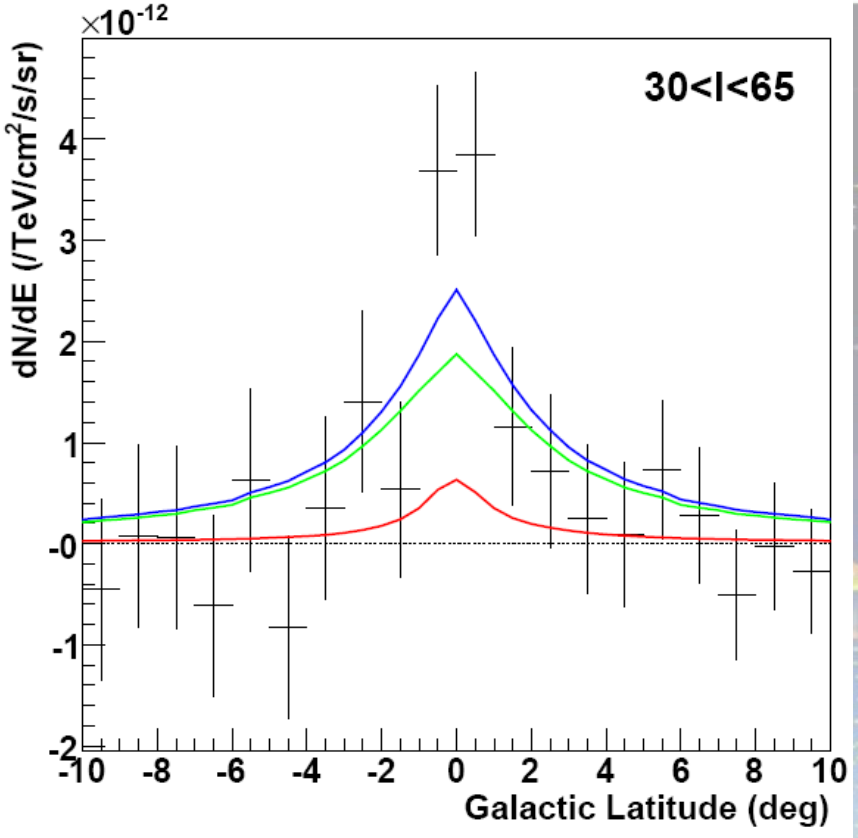
Flux ratio Inner Galaxy to Cygnus region:
data: 1.1 ± 0.2 (stat.) ; model: 2.0

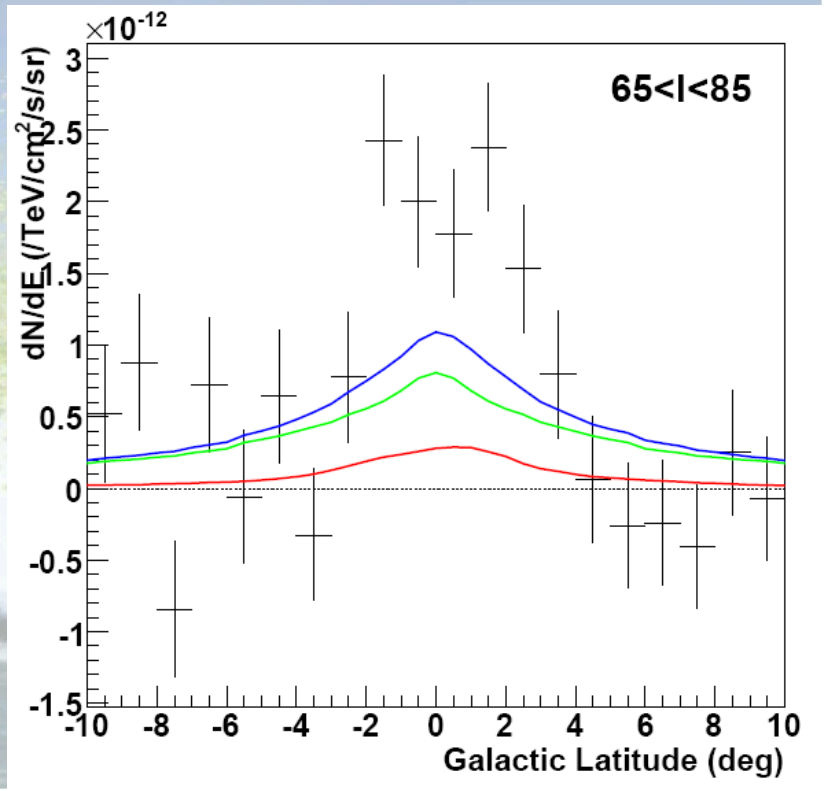


Latest GALPROP



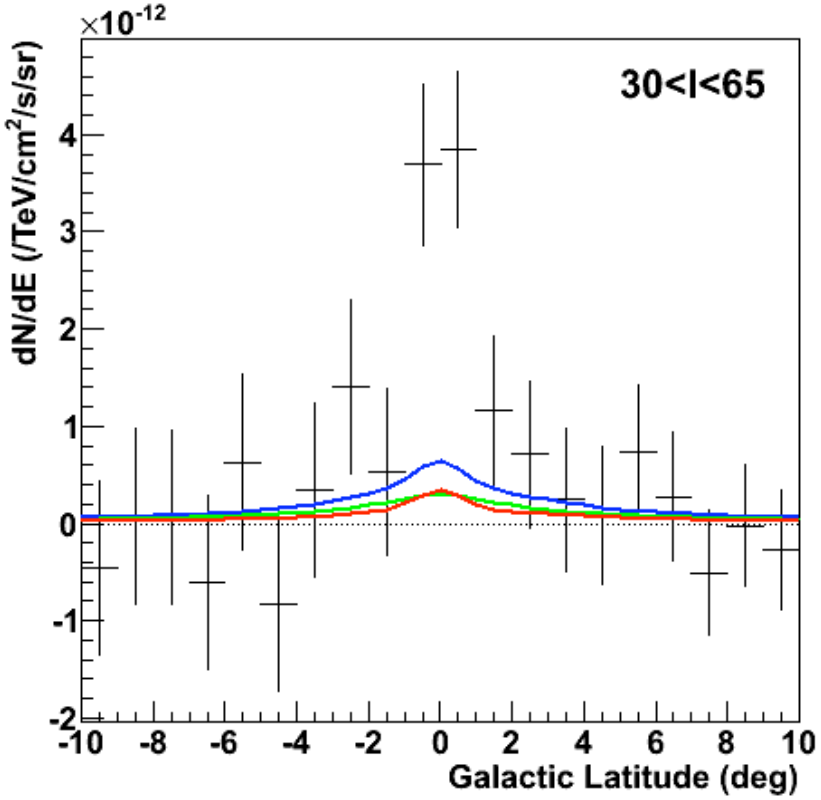
Flux Profiles: Galactic Latitude

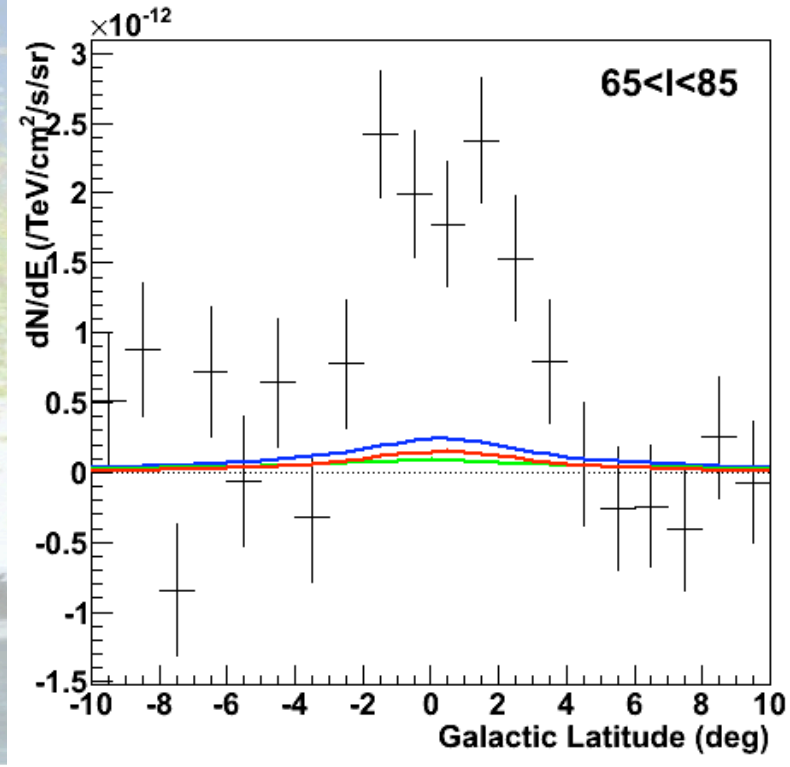




Can Improve the fit by increasing pion contribution (red), but then violate antiproton measurements

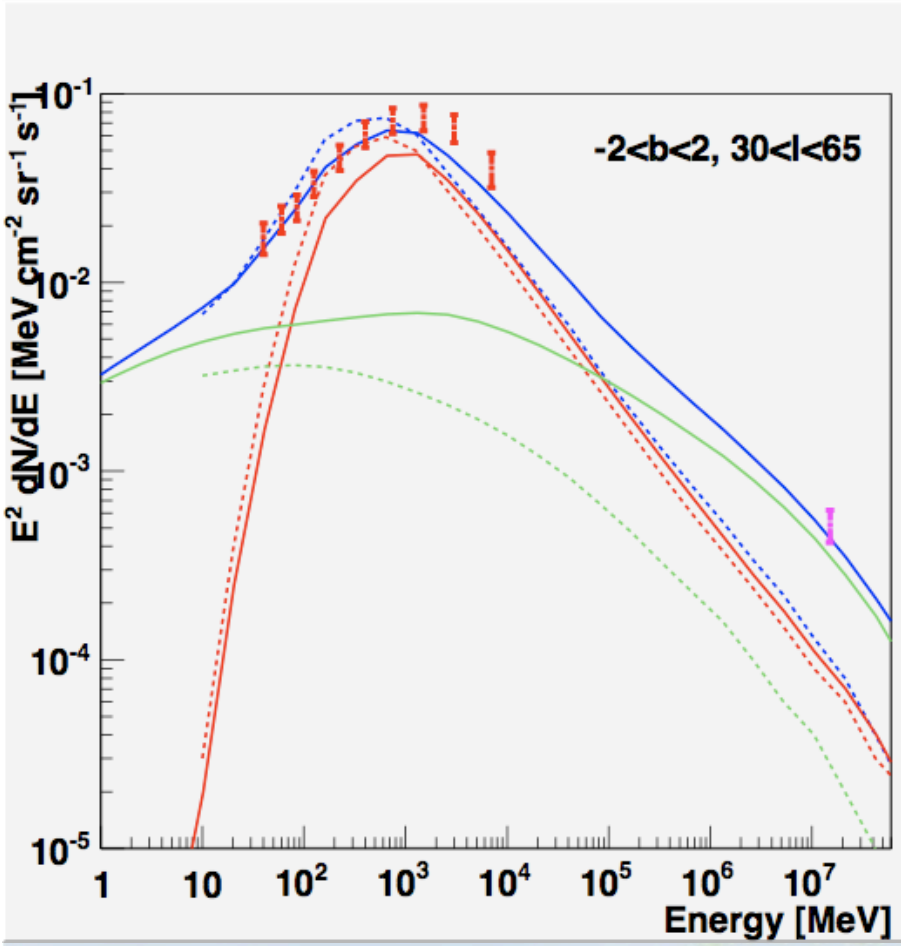
Flux Profiles: Galactic Latitude

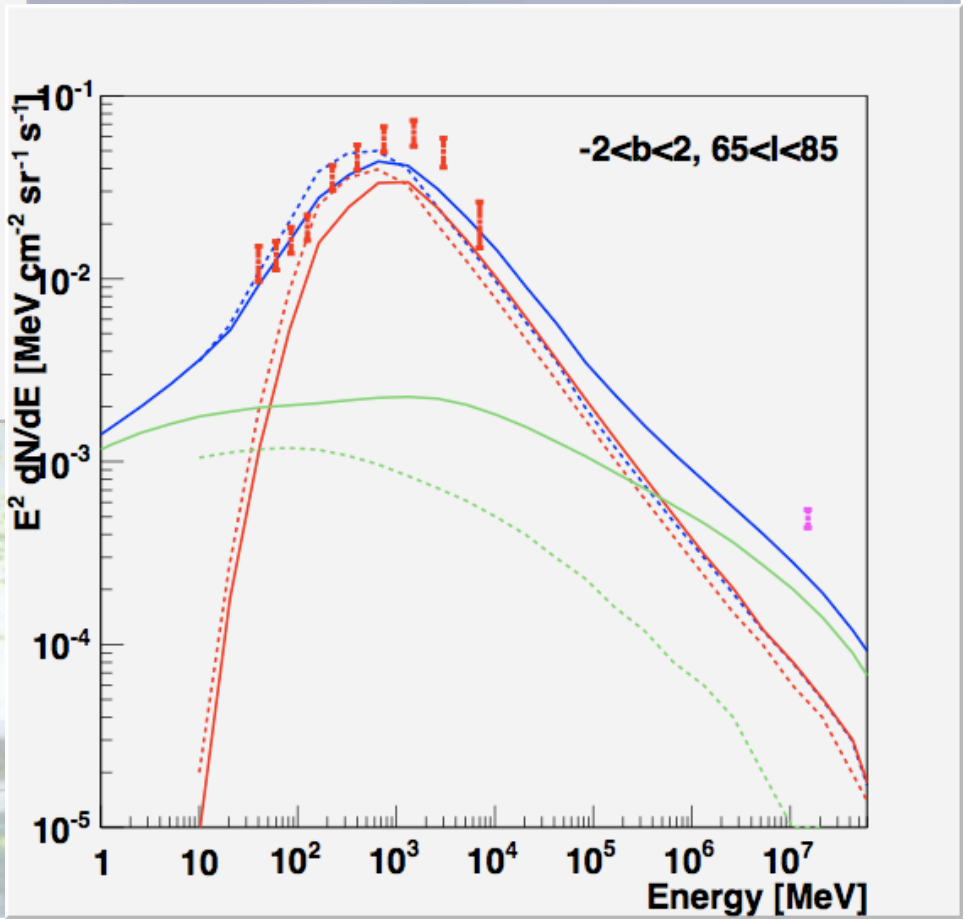




Can Improve the fit by increasing pion contribution (red), but then violate antiproton measurements

GALPROP Spectra with EGRET and Milagro Data





Dashed is Conventional Model and
Solid is Optimized Model

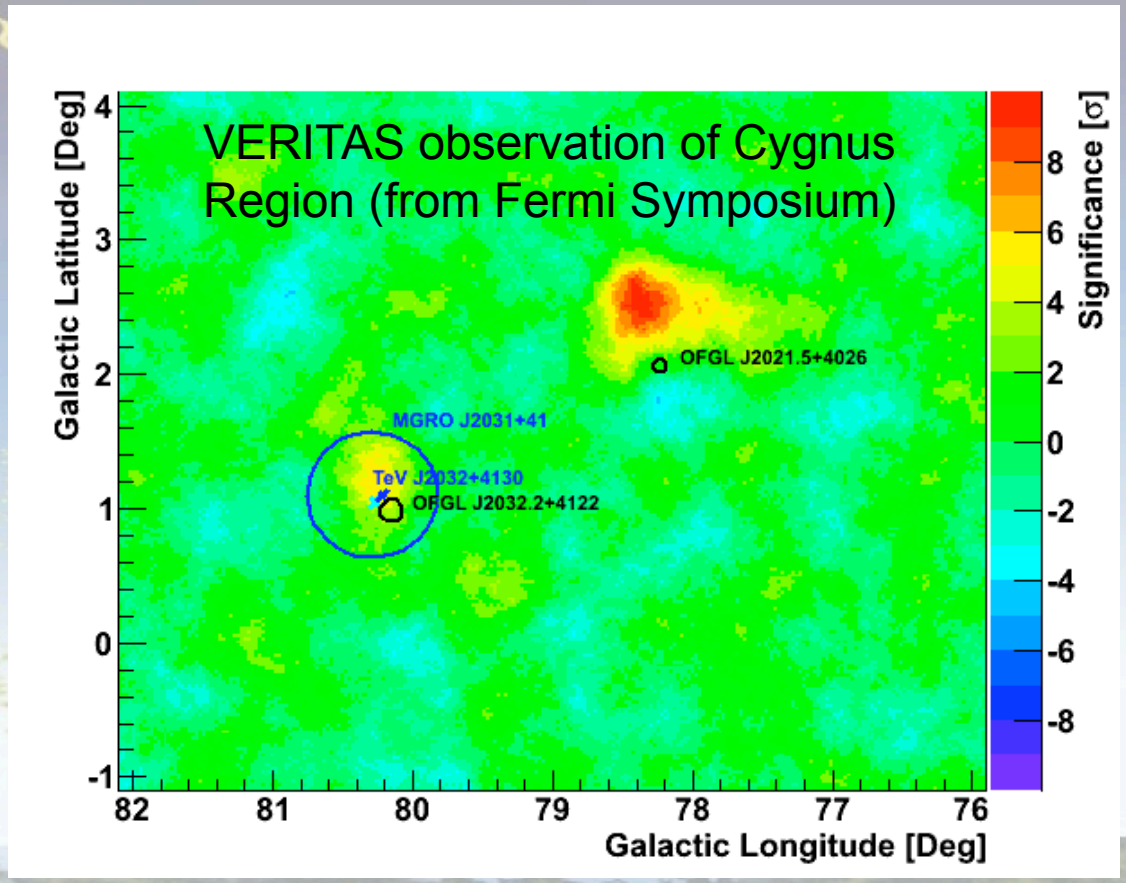
Contribution of TeV Sources

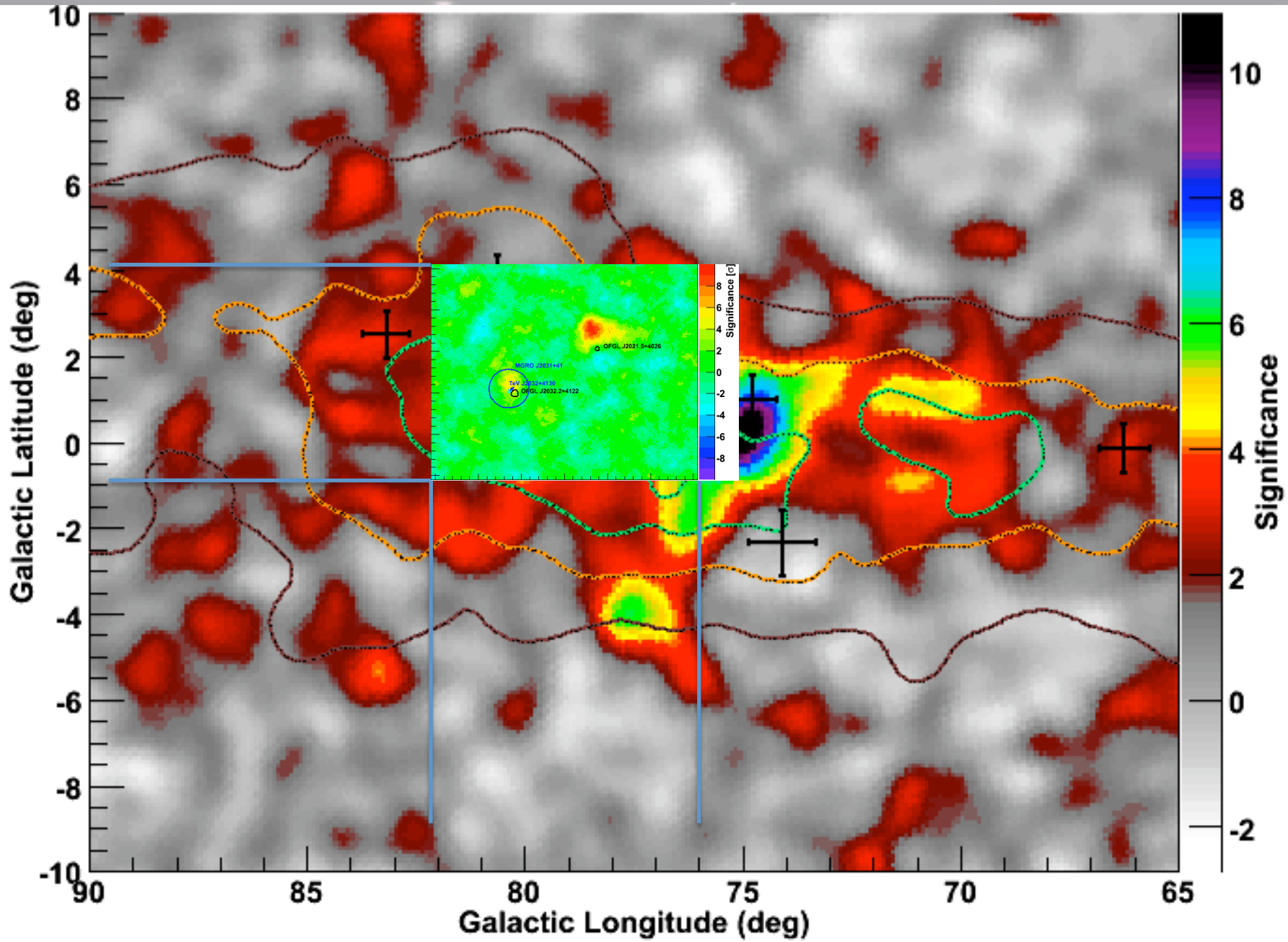
- Milagro resolved sources are subtracted
  - Weaker Milagro excesses (which are corellated with Fermi sources) reduce diffuse flux by <15%
- Deep surveys with ACTs will resolve weaker sources, but this is difficult because
  - Milagro observations are at higher energies
  - Nearby regions (e.g. Cygnus) have very angularly extended sources
- Where does an extended source end and a diffuse source begin???

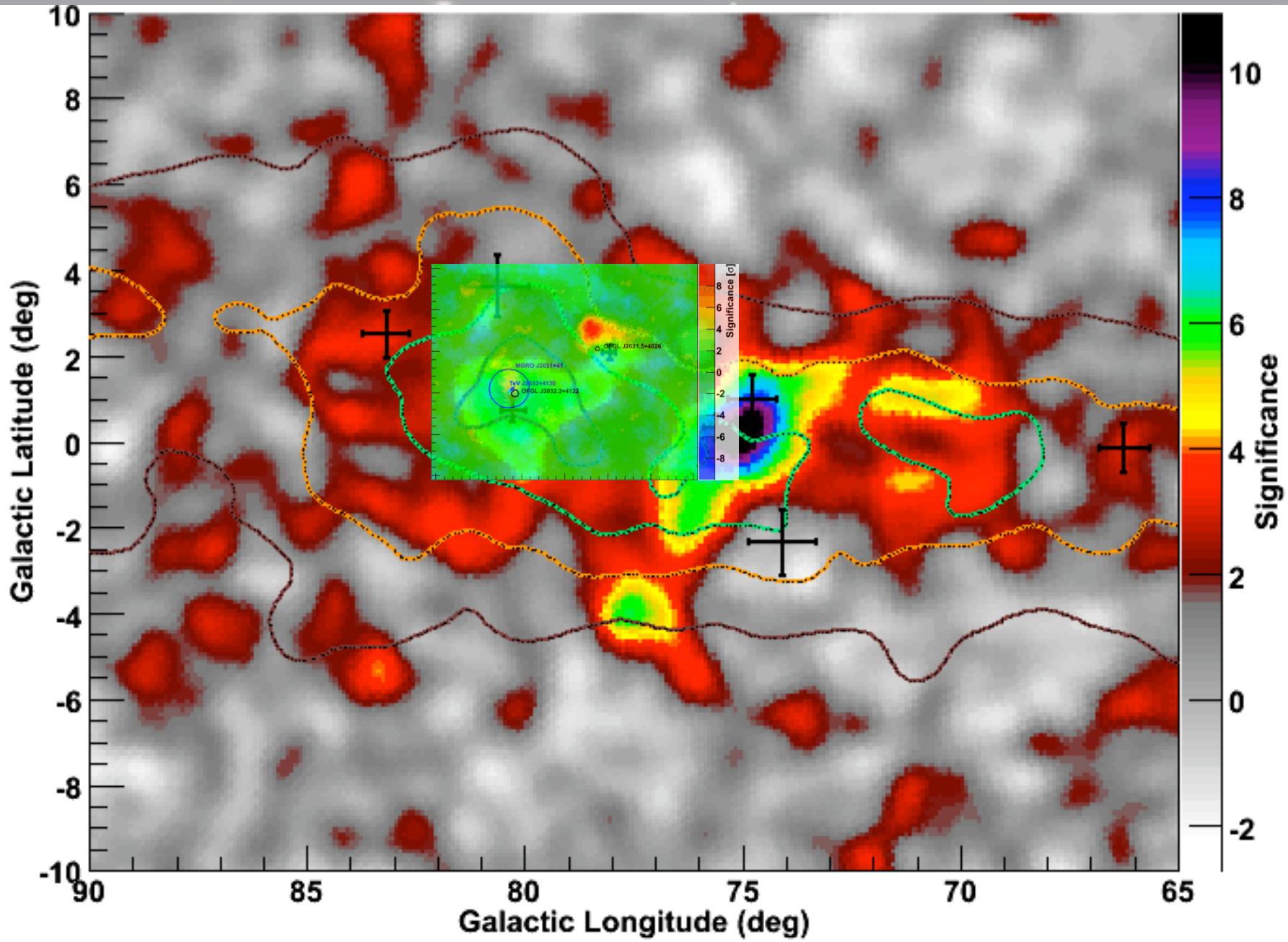
Some VERITAS Results from Survey of Cygnus Region

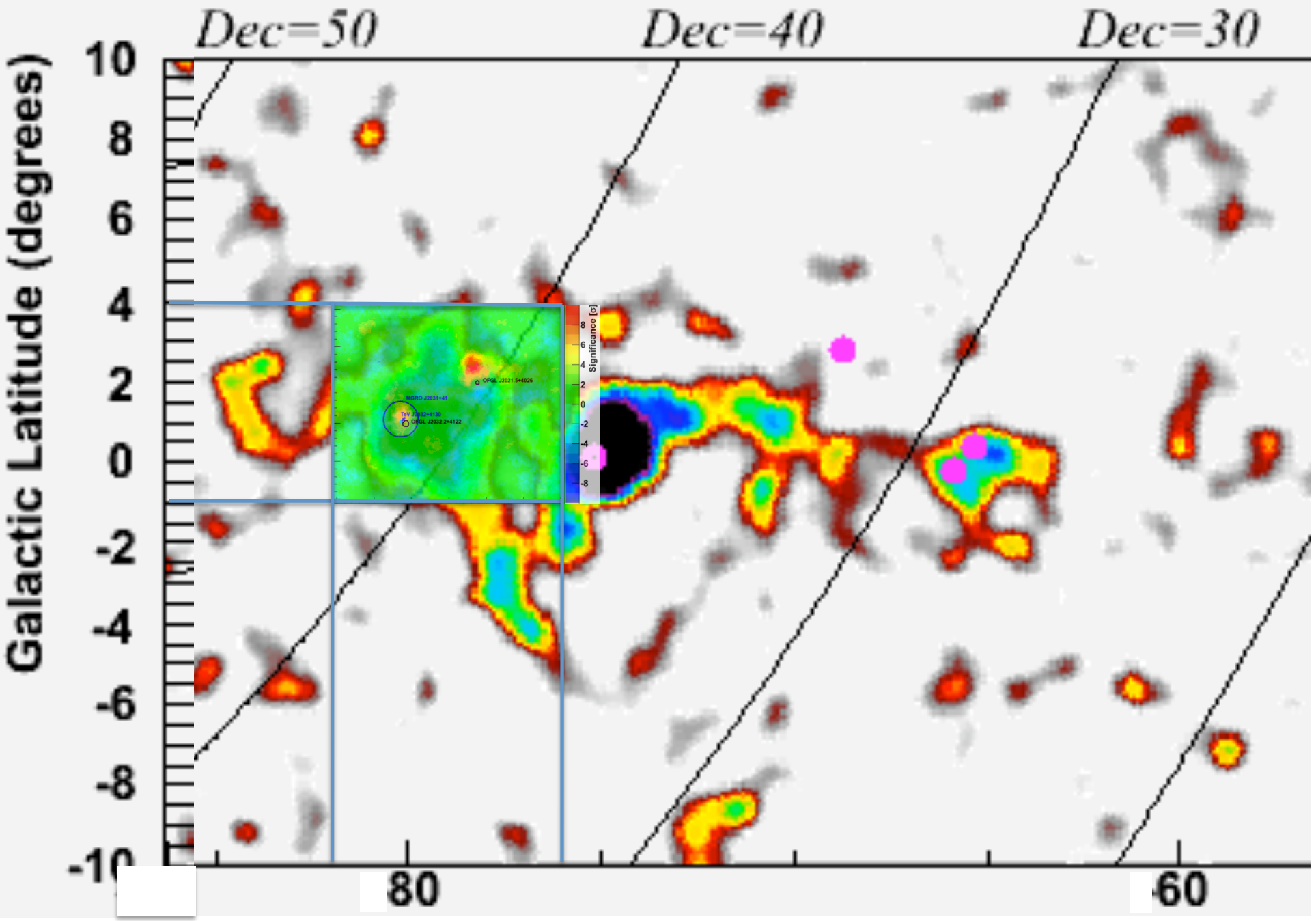
Two sources

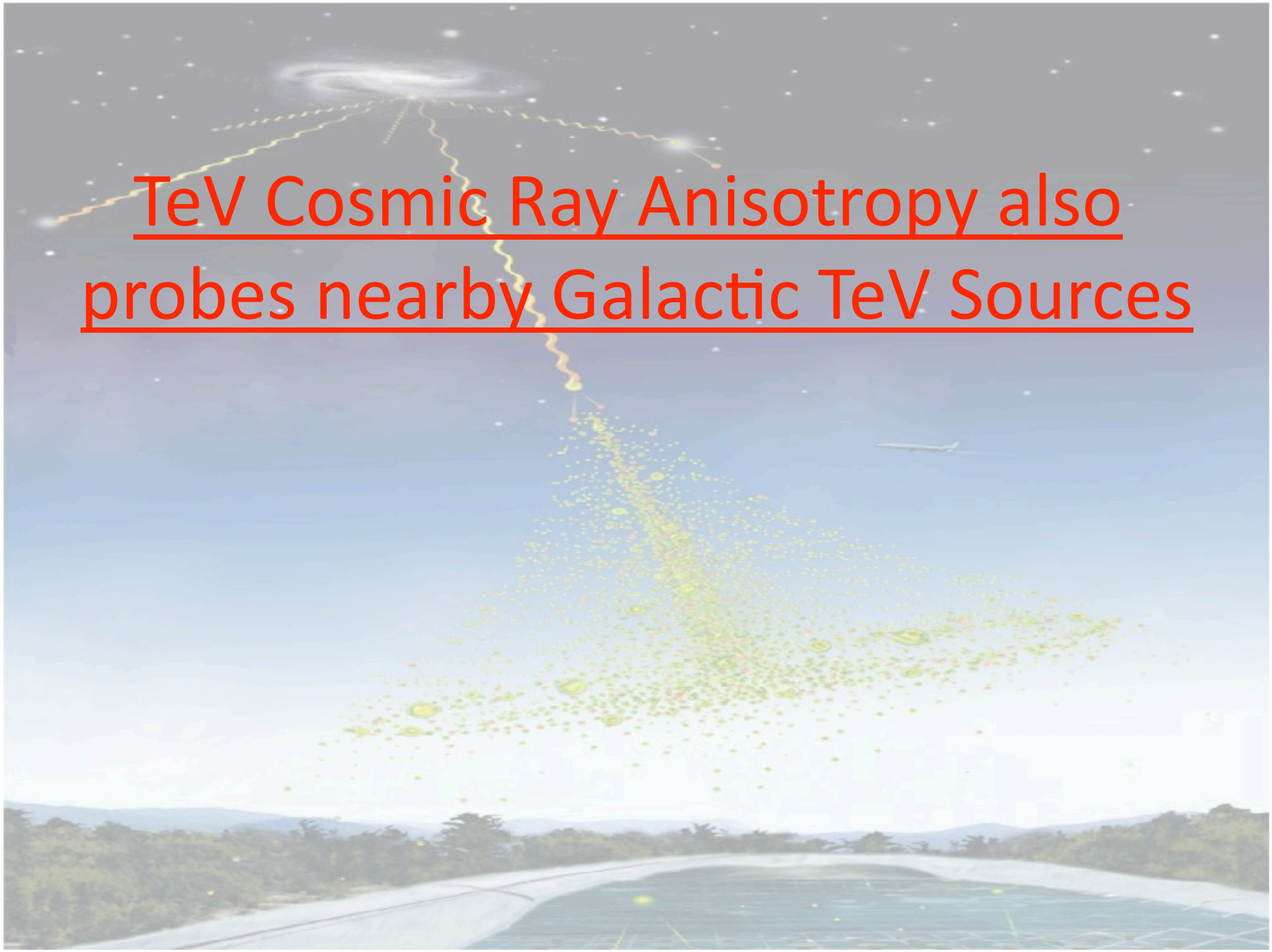
- Near gamma-Cygni
  - Offset from Fermi source
  - Coincident with Radio map
  - Not coincident with molecular cloud
  - 2-5% of Crab Flux
- TeV J2032 +4130, Fermi and Milagro



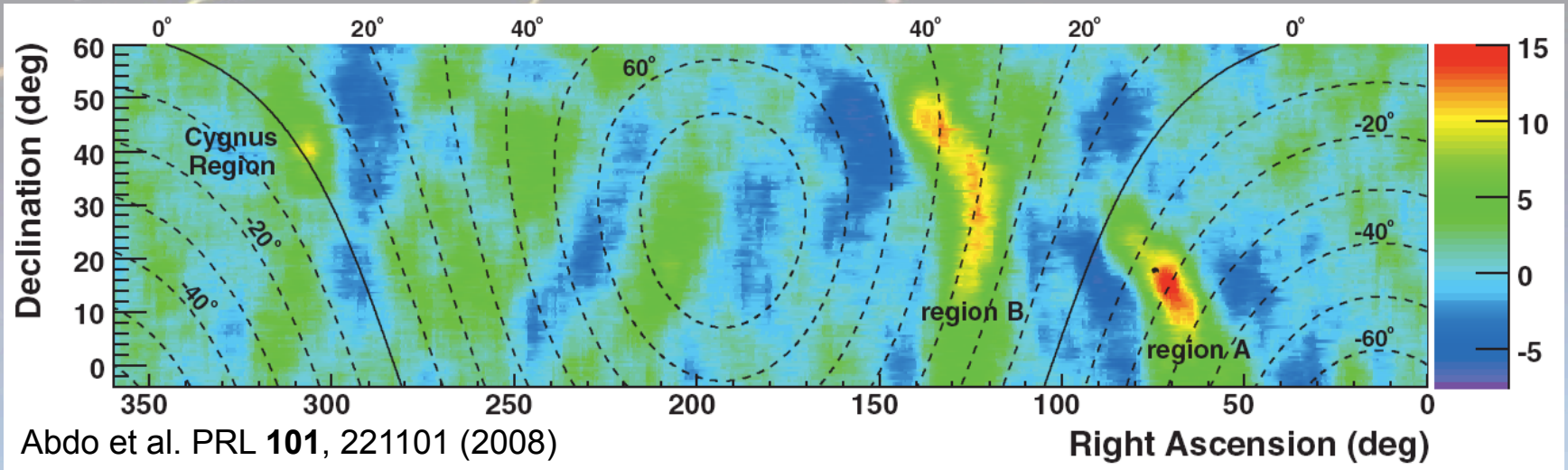

Galactic Latitude (deg)
Galactic Longitude (deg)
Significance
Significance [σ]
OFGL J2021.5+4026
MGRO J2031+41
TeV J2032+4130
OFGL J2032.2+4122


Galactic Latitude (deg)
Galactic Longitude (deg)
Significance
10
8
6
4
2
0
-2
-4
-6
-8
-10
90
85
80
75
70
65
Significance [σ]
MGRO J2031+41
TeV J2032+4130
0FGL J2032.2+4122
0FGL J2021.5+4026

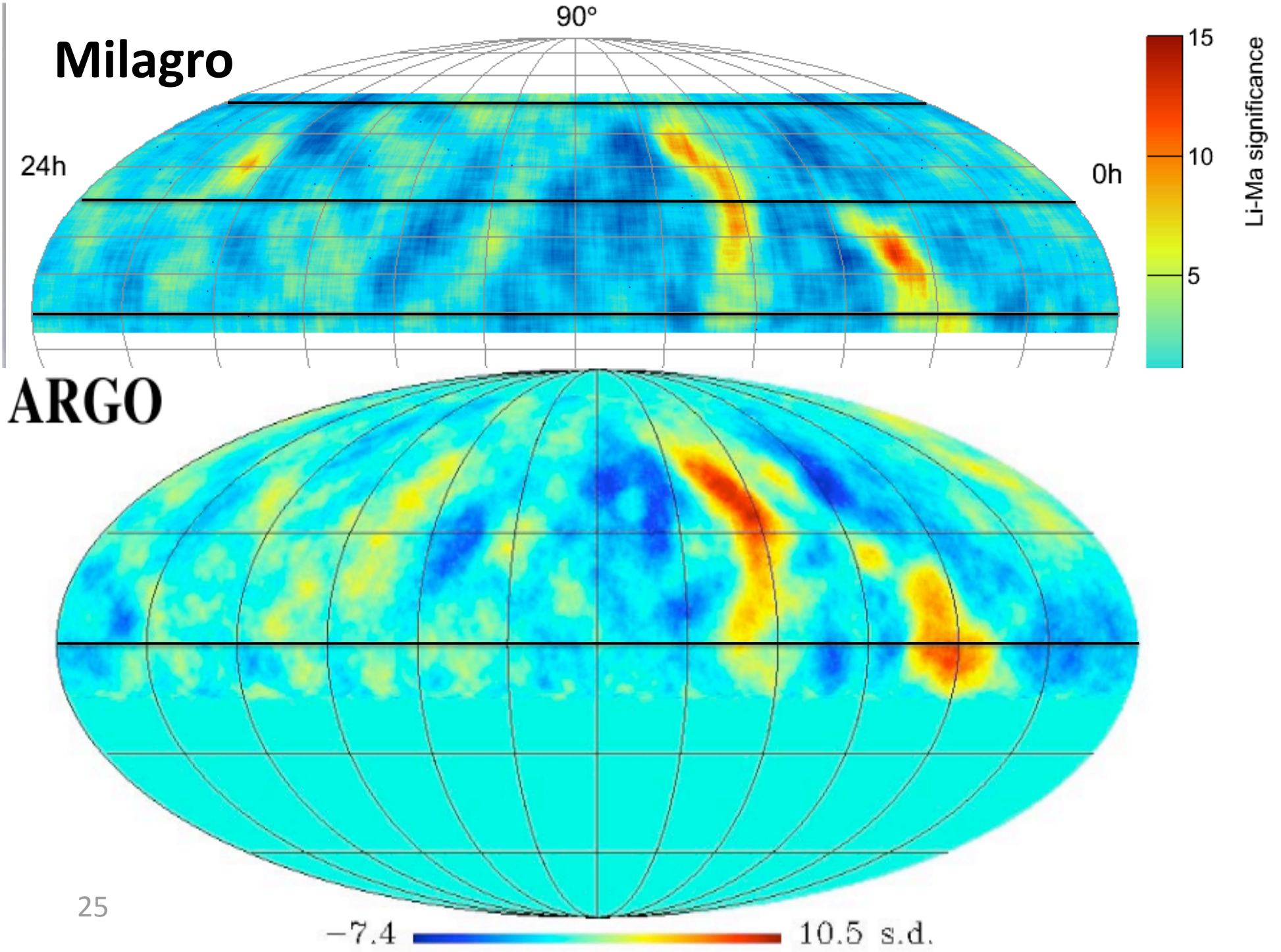

Dec=50
Dec=40
Dec=30
Galactic Latitude (degrees)
10
8
6
4
2
0
-2
-4
-6
-8
-10
80
60
Significance [σ]
8
6
4
2
0
-2
-4
-6
-8
MGRO J2031+41
TeV J2032+4130
OFGL J2032.2+4122
OFGL J2021.5+4026


TeV Cosmic Ray Anisotropy also
probes nearby Galactic TeV Sources

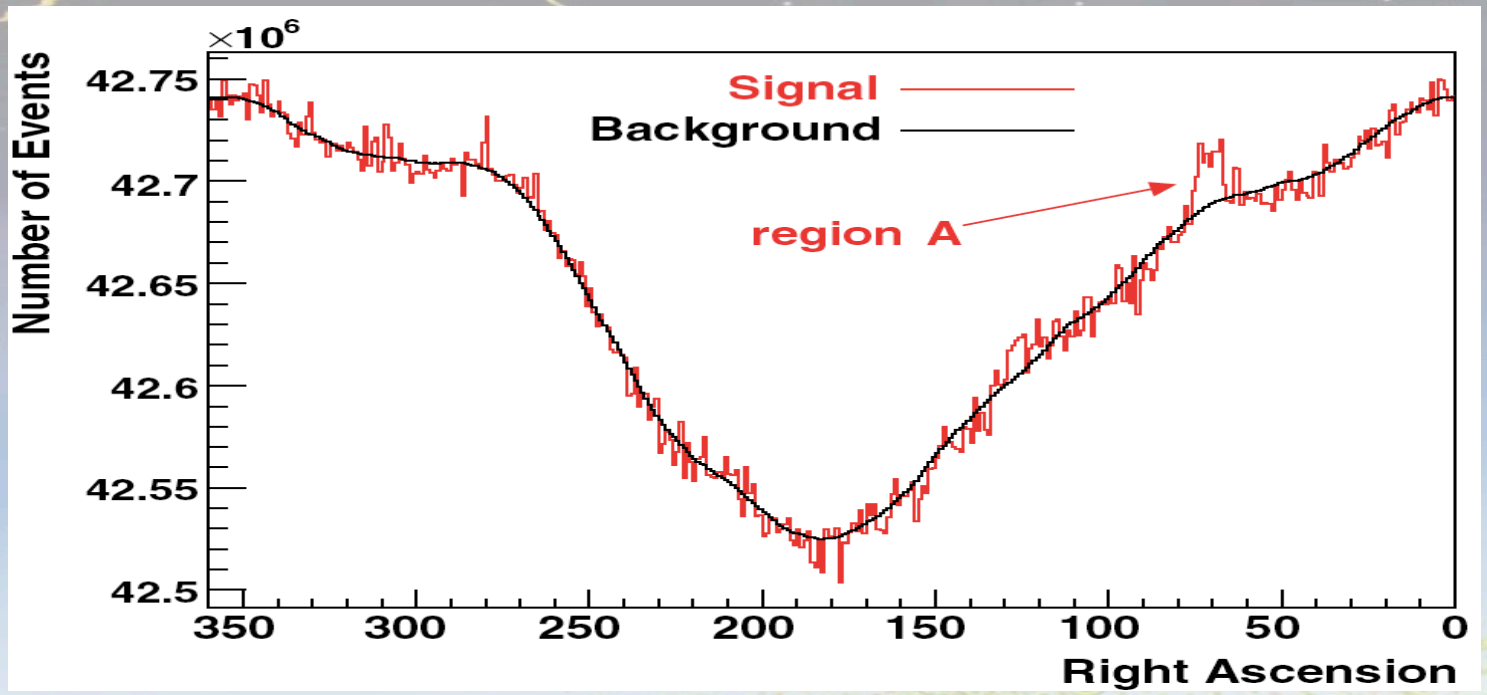
Milagro Cosmic Ray Observations



- Data is dominated by cosmic rays. 100 billion detected.
- 10^{o} smoothing, looking for large angular features.
- Two regions of excess 15.0σ and 12.7σ. Fractional excess of 6×10^{-4} (4×10^{-4}) for region A(B).
- Tibet AS Gamma and ARGO confirm these excesses


Milagro
90°
24h
0h
15
10
5
Li-Ma significance
ARGO
−7.4
10.5 s.d.

Cosmic Ray Observations



- Gamma-ray origin excluded to high confidence.
- Appear harder than background cosmic-rays with a cutoff at ~10 TeV.

PRL **101**, 221101 (2008)

What are these features?

- Of note:
  - Gyroradius of 10 TeV proton in 2μG magnetic field is 0.005 pc = 1000 AU
  - 10 TeV neutron will live 0.1 pc
  - No plausible sources out to 100 pc
  - Brightest Region is in the direction of the heliotail

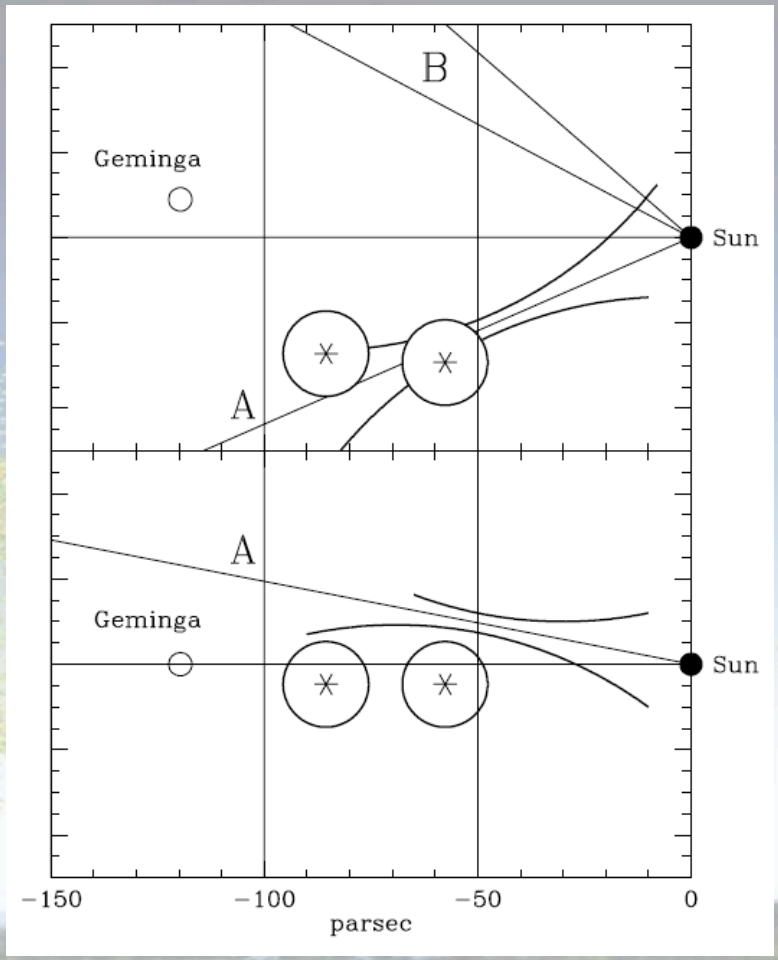
What are these features?

- Heliospheric?
  - Not enough energy in solar B field. (Salvati and Sacco)
- Neutron production in clump of ISM matter gathered at the heliotail.
  - Flux too low by factor of 10^6. (Drury and Aharonian)
- Dark Matter?
  - Data fits a line-spectrum at 10 TeV fairly well, but it's hadronic

Salvati and Sacco. A&A 485, 527-529 (2008)
Drury and Aharonian. Astropart. Phys. 29 420-423 (2008)

Nearby Cosmic-Ray Accelerator?

- "Bullets" not "smoking gun".
- Requires non-standard cosmic-ray diffusion and a nearby source (Geminga supernova? < 90 pc away in the past?)
- Some coherent magnetic structure connecting us to the source.
- Need to understand cosmic-ray propagation better.

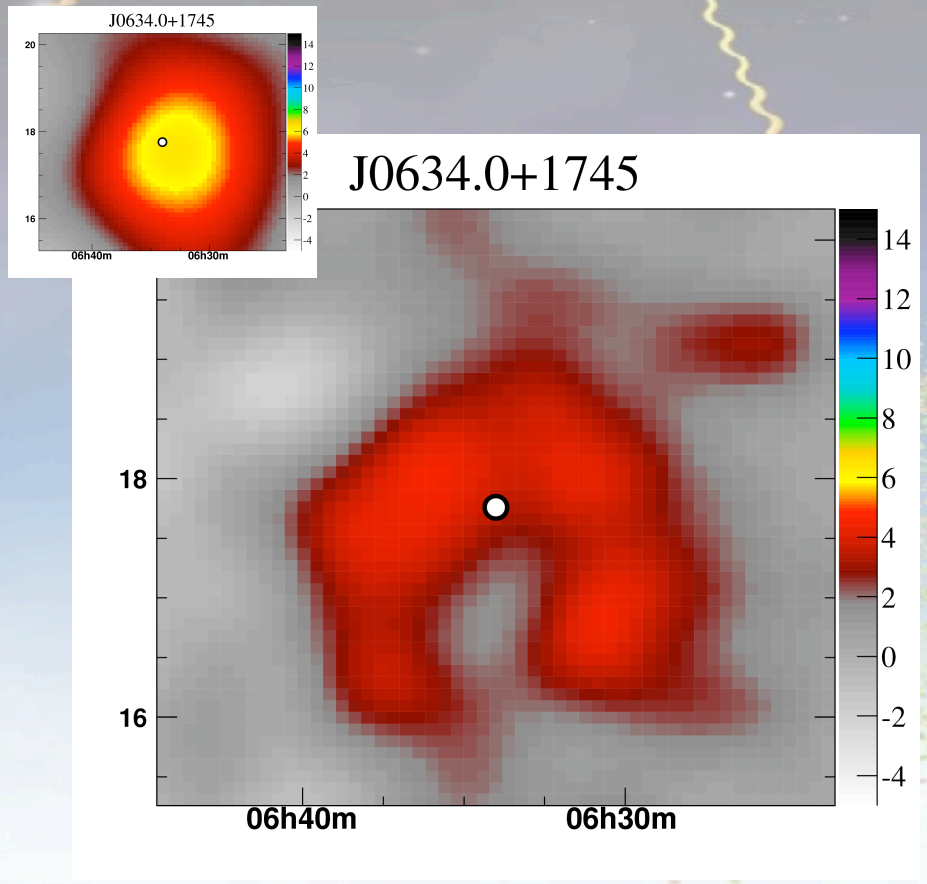


From: Salvati and Sacco. A&A 485, 527-529 (2008)

Open Questions

- Excess TeV gamma-ray Diffuse Emission
  - Increase more TeV electron contribution suggested by GALPROP?
  - Increase TeV hadronic contribution without violating cosmic ray secondary observations?
  - Limit on unresolved sources due to luminosity function of TeV sources?
- Localized Excess of TeV hadronic emision
  - Astrophysical Galactic Source nearby?
  - Ordered local magnetic field?

Geminga (J0634.0+1745)



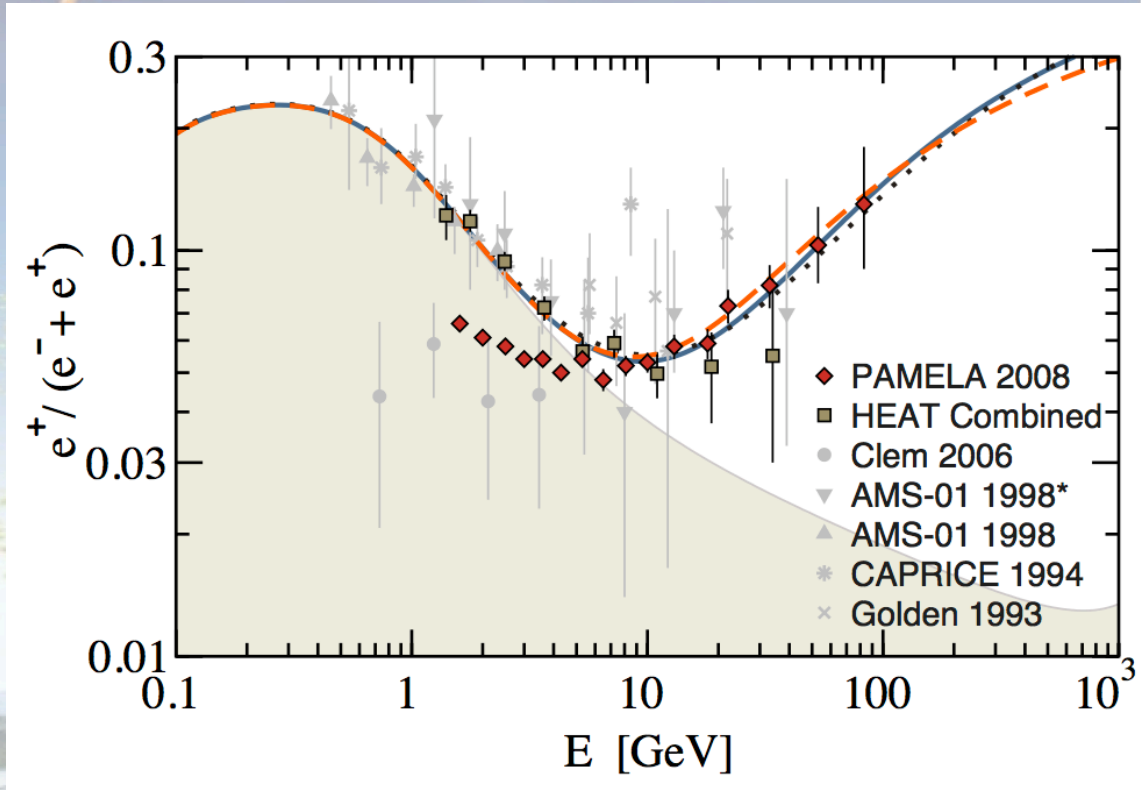
- Most Significant GeV source of 34 searched is Geminga
- Old (300 kyr) PWN and nearby (250 pc)
- Fitted Gaussian profile gives sigma of 1.1° (4.9 pc) extent which is similar to HESS observations of more distant PWN

Geminga as a Local Cosmic Ray Source

- *The confirmed presence of a nearby, ancient source of high-energy electrons and positrons immediately suggests an explanation for the positron excess.*

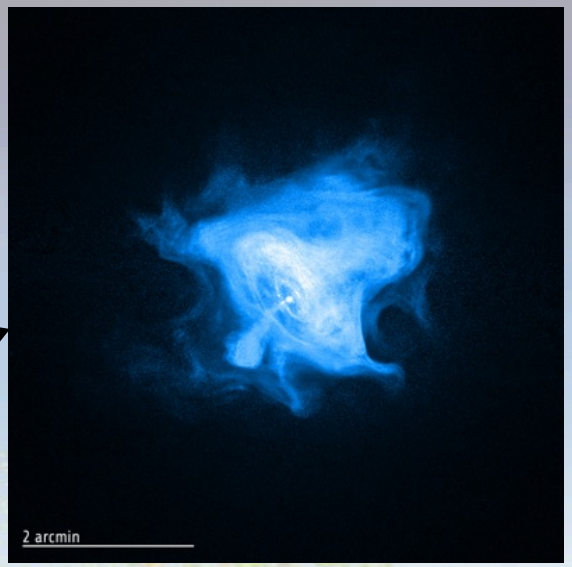
  -Yüksel, Kistler, Stanev Phys Rev Lett 2009

PAMELA's positron excess is well fit given Milagro's flux from Geminga



GeV Pulsars are Coincident with TeV sources

GeV Emission is pulsed & due to rotation axis misaligned with Magnetic Dipole of ~10^{12} G



TeV Emission is produced by particles further accelerated in the shock interacting with the ambient medium.

IMPLICATIONS

- GeV emission has broad beam
  - Because TeV PWN are unbeamed
  - And bright TeV sources are coincident with GeV pulsars
- TeV PWN are prevalent in GeV pulsars