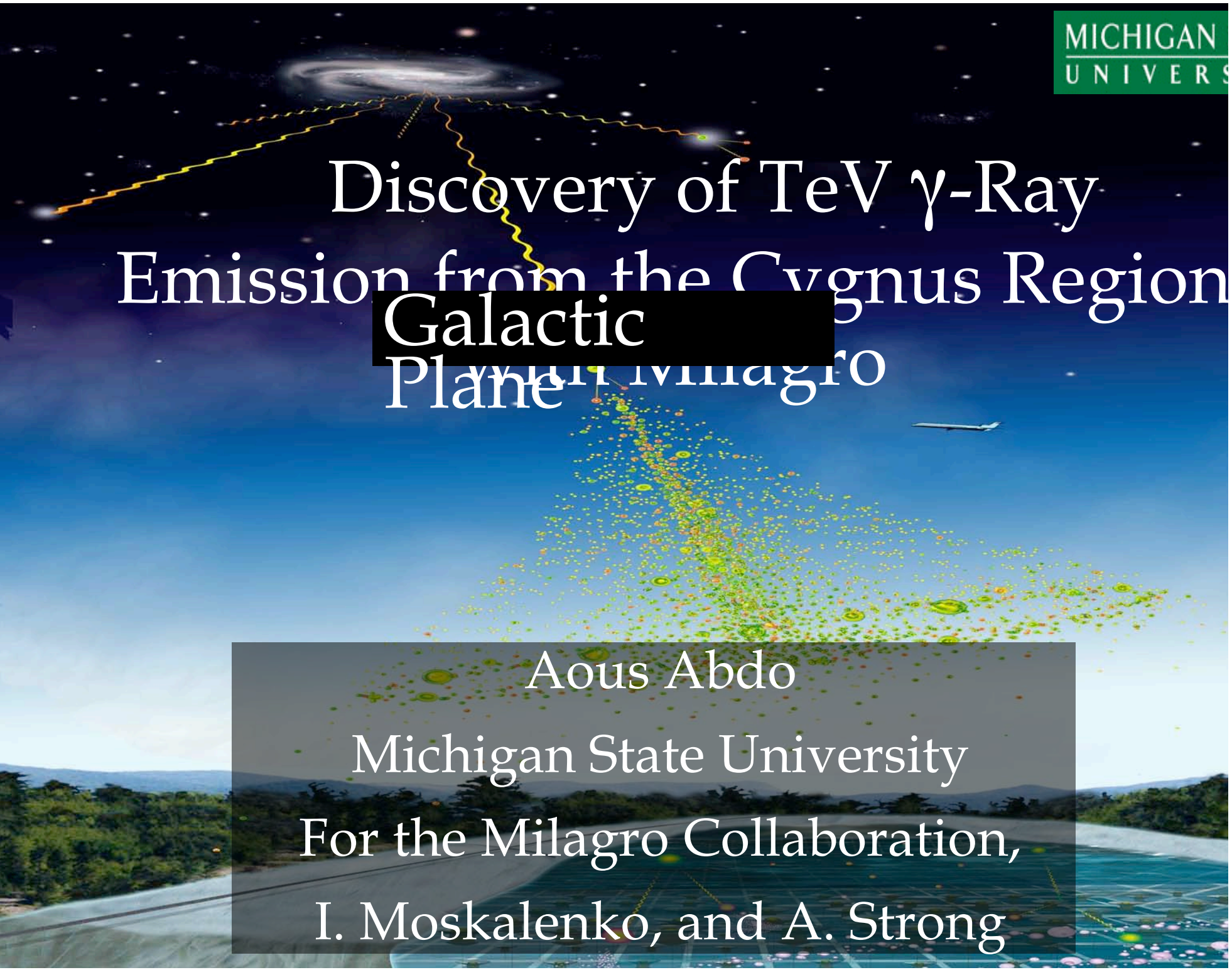


Discovery of TeV γ-Ray Emission from the Cygnus Region of the Galactic Plane with Milagro

Aous Abdo

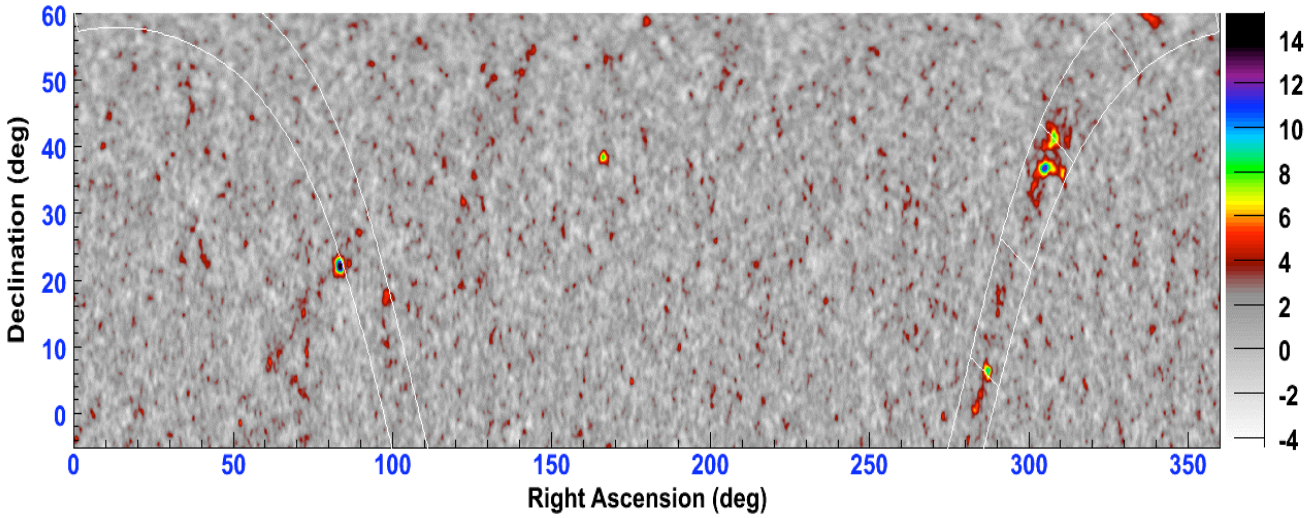
Michigan State University

For the Milagro Collaboration,

I. Moskalenko, and A. Strong

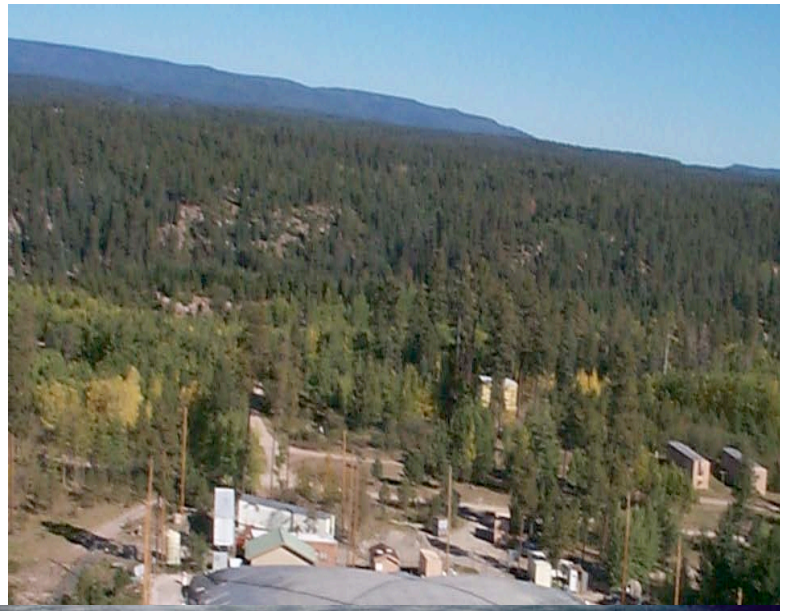
Outline

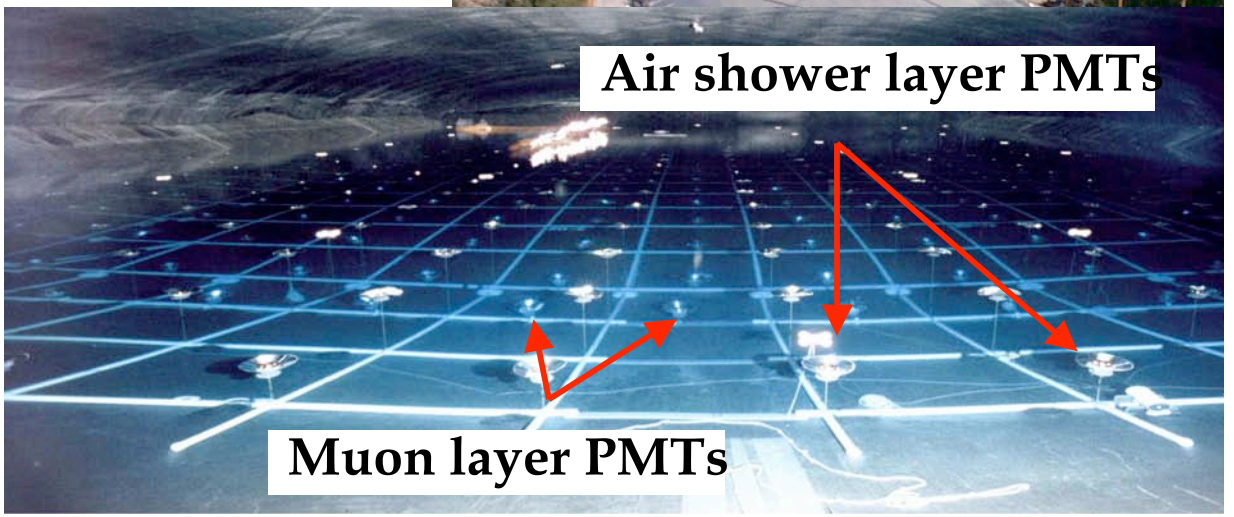
- Brief Description of Milagro
  - New Background Rejection Technique
- New results From Milagro Sky Survey
  - Galactic Plane
  - Cygnus Region of the Galaxy
  - Diffuse Galactic γ-Ray Emission



The Milagro TeV γ-ray Detector:

- Water Cherenkov detector Located in Jemez Mountains near Los Alamos NM
- Elevation: 2630 m
- Central pond: 80m X 60m X 8m (depth) (5000 m^2)
  - Air shower layer: 450 PMTs under 1.4 m
  - Muon layer: 273 PMTs under 6 m
- Outrigger array: 175 4000 L water tanks ~ 40,000 m^2
- 2 Steradians field of view
- 1700 Hz trigger rate
- > 90 % duty cycle
- 0.6-0.3 degree PSF





Background Rejection in Milagro

Hadronic EAS out number Gamma Ray EAS by 10,000:1

Hadronic Showers

- Contain many more muons than those for gamma ray EAS
- ➔ Result in a bright, compact clusters of light in the Muon layer

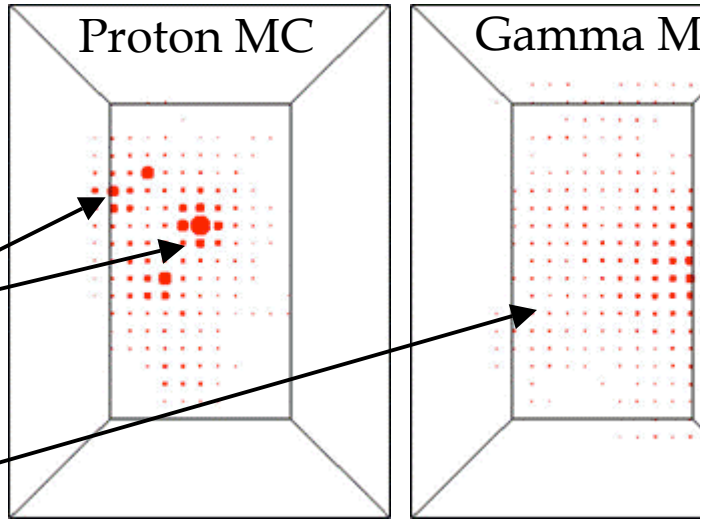
Gamma Ray Showers

- Gamma EAS illuminate the Muon layer uniformly, with small hits

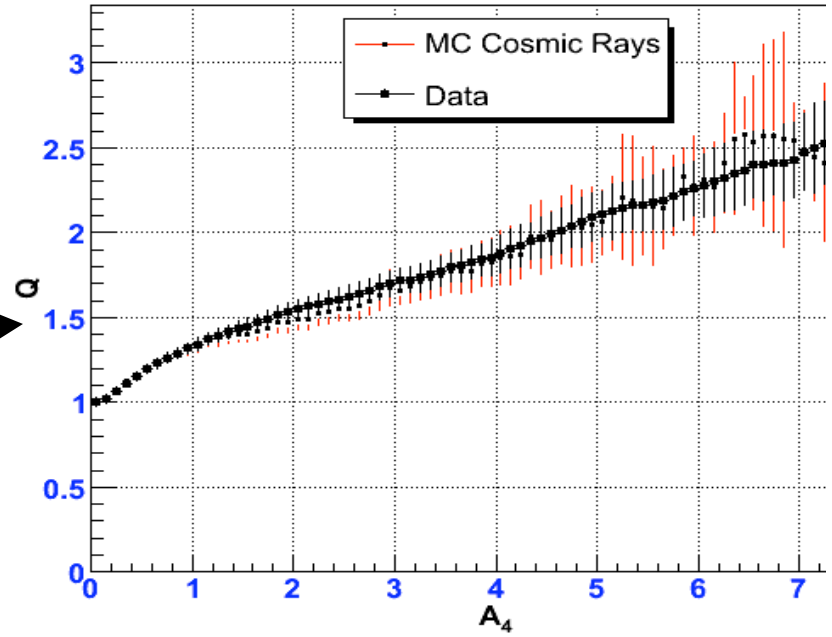
A_4 is a new gamma-hadron separation variable that has been developed

- Apply a cut on A_4 to reject hadrons: $A_4 > 3$ rejects 99% of Hadrons and keeps 18% of Gammas
- S/B increases with A_4.

Muon Layer Images



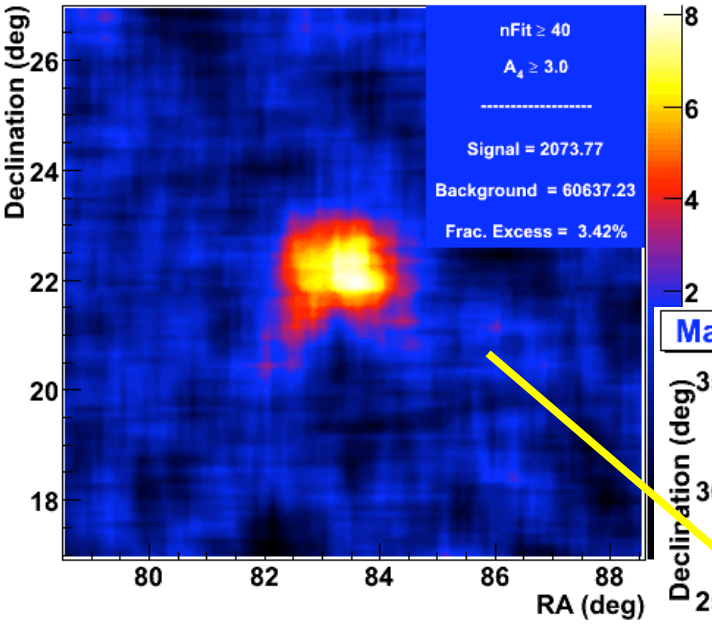
Q-Factor as a function of A_4



A_4 Weighting Analysis on the Crab Nebula

Combine A_4 with the weighting Analysis on 2 Years of Data

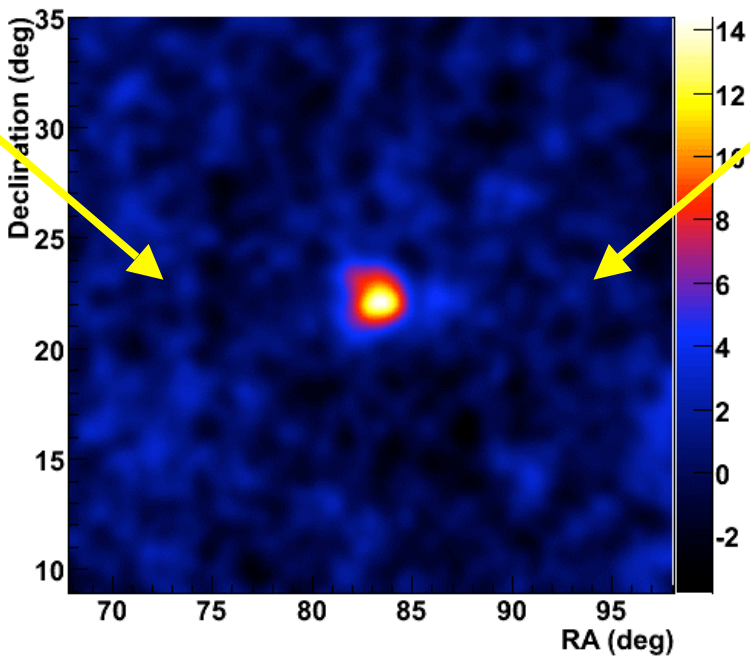
$A_4 > 3.0$



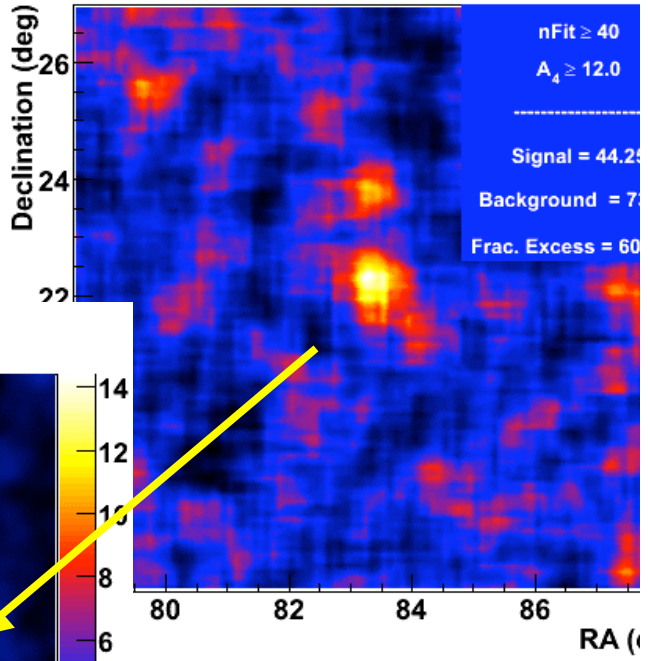
Excess Signal = 2,074
Background = 60,637
S/B = 3.4%

Weight each event by Expected S/B

Map of Significances

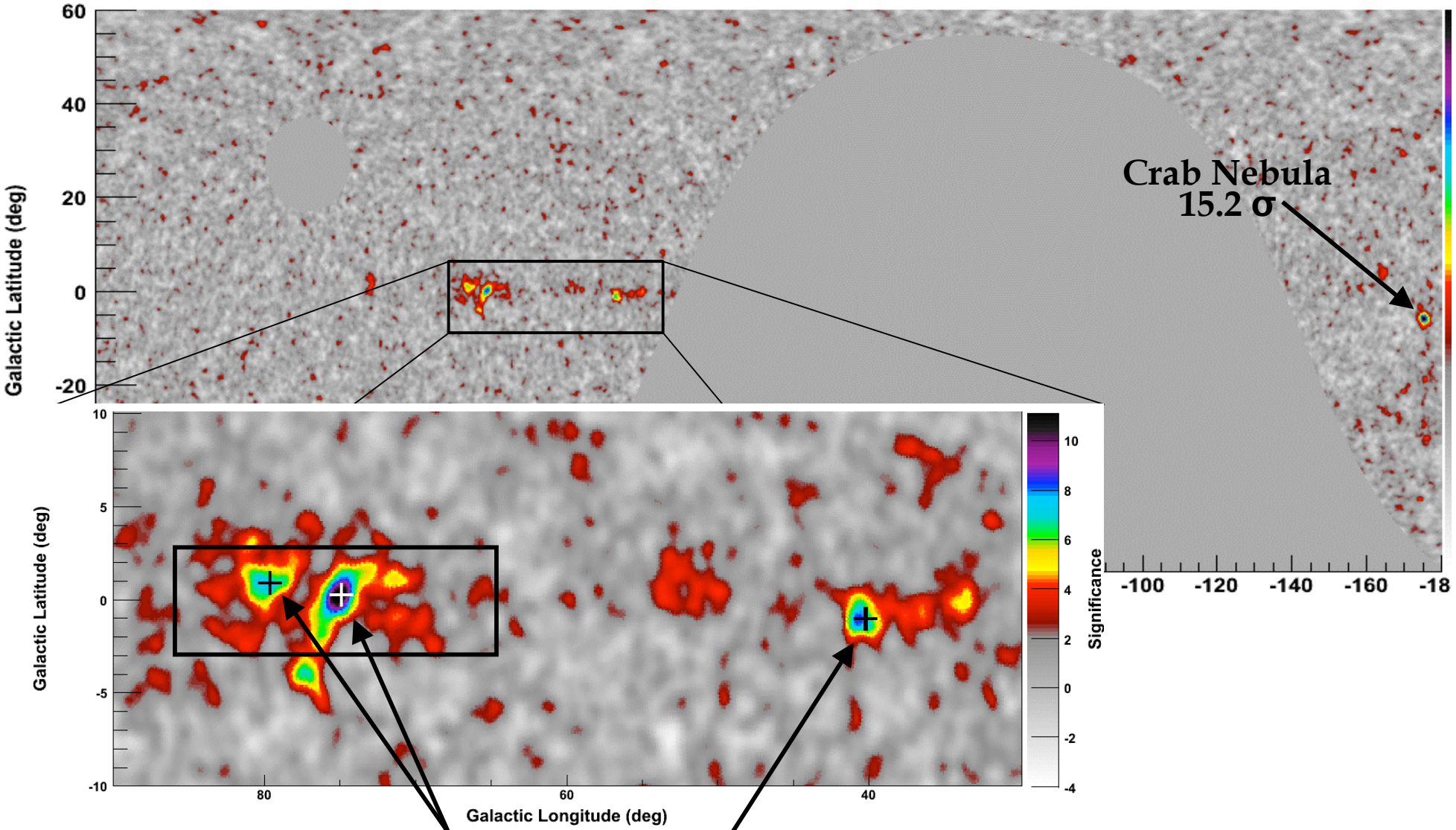


$A_4 >$ 12.0



Excess Signal = 44
Background = 74
S/B = 60%

A Closer Look at the Galactic Plane

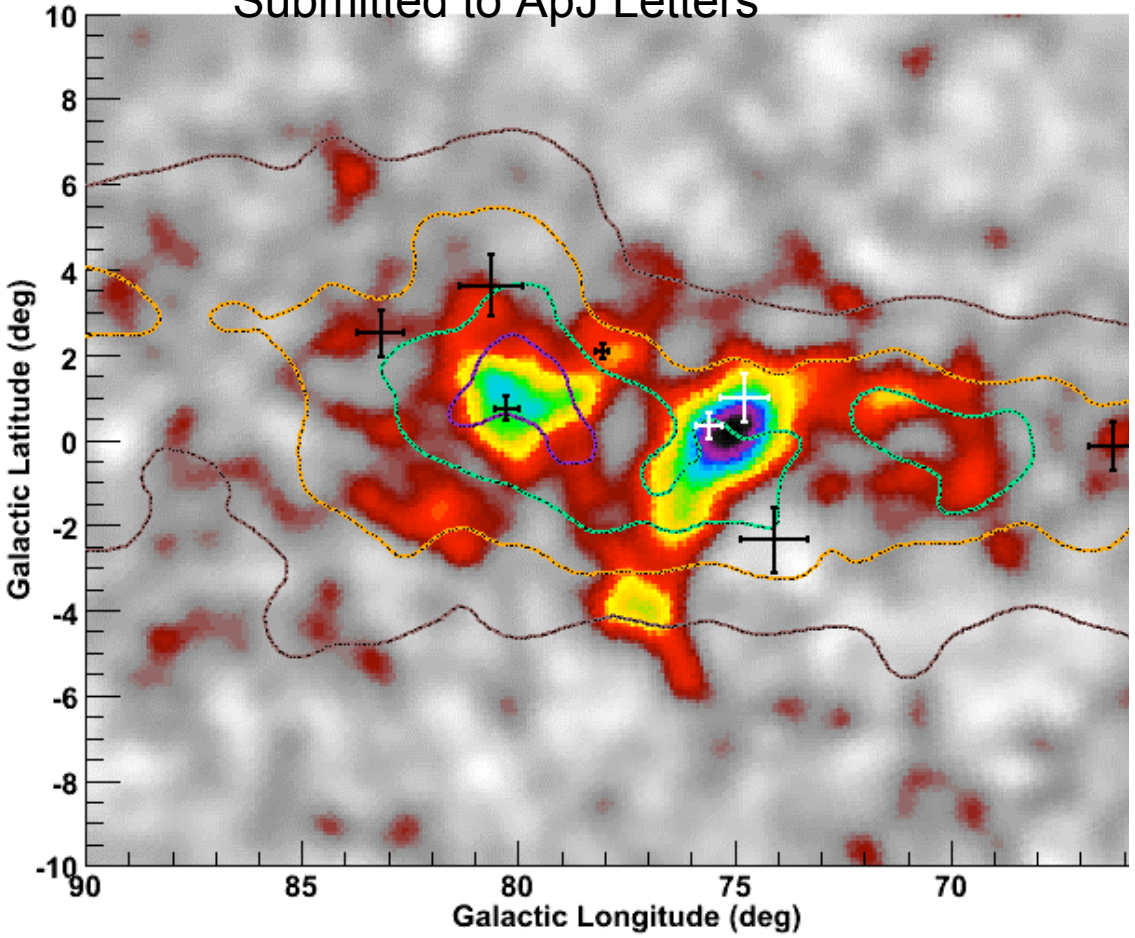


- Cygnus region shows two new TeV gamma-ray sources
- Diffuse emission from Cygnus region
- A new TeV source at low declinations

Cygnus Region Spatial Morphology

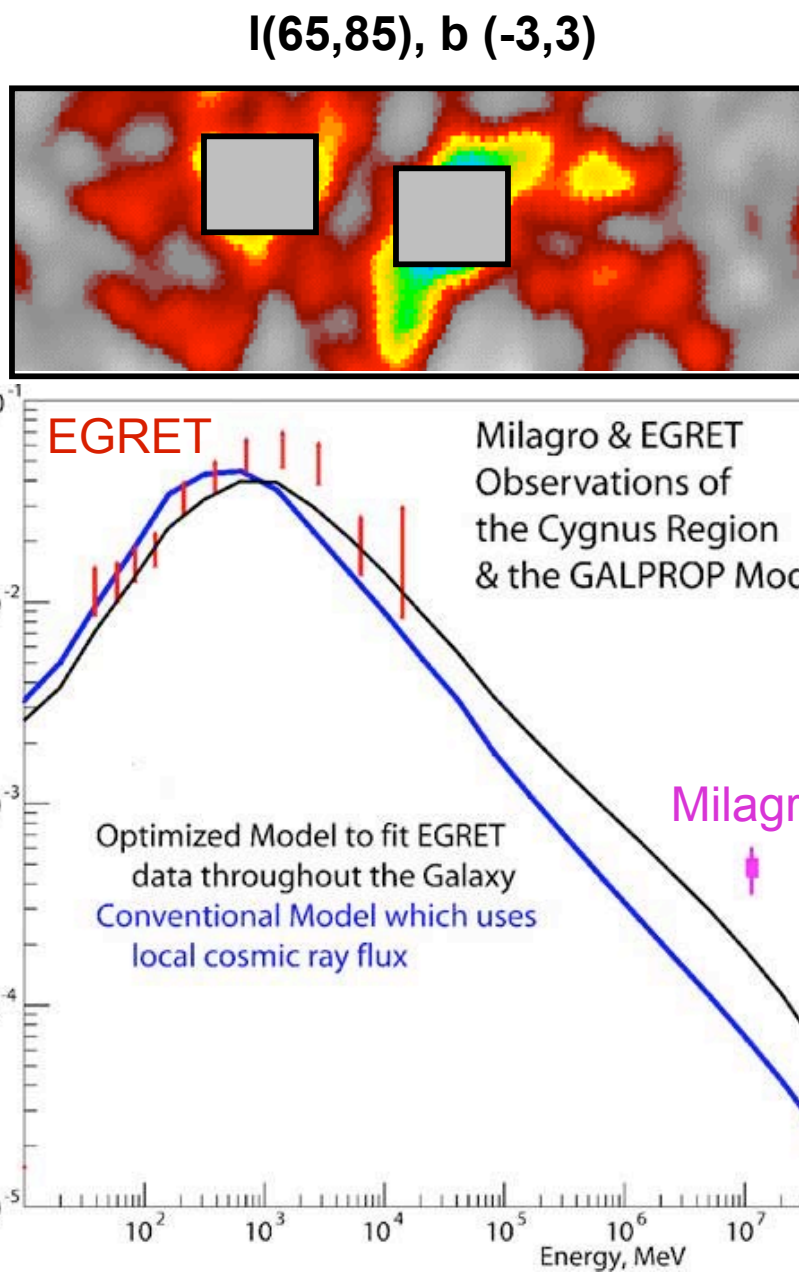
A. A. Abdo *et al.*, arXiv:astro-ph/0611691
Submitted to ApJ Letters

- Crosses are EGRET sources
- Contours are Molecular (Dame et al, 2001) and Atomic Hydrogen (Kalberla et al, 2005)
- TeV/matter correlation good in Galactic latitude



Diffuse Emission from Cygnus Region

- Exclude a region of 3°×3° around MGRO J2019+37 and MGROJ2033+42
  - Diffuse flux ($\times 10^{-14}$ TeV^{-1} cm^{-2} s^{-1}) = $8.3 \pm 1.3_{stat} \pm 2.7_{sys}$ ~ 2× Crab flux
- Strong & Moskalenko Galprop model
  - Milagro flux ~ 7x conventional model of Galprop
  - Milagro flux ~3x optimized model
- Hard spectrum cosmic ray sources?
- Unresolved point sources?

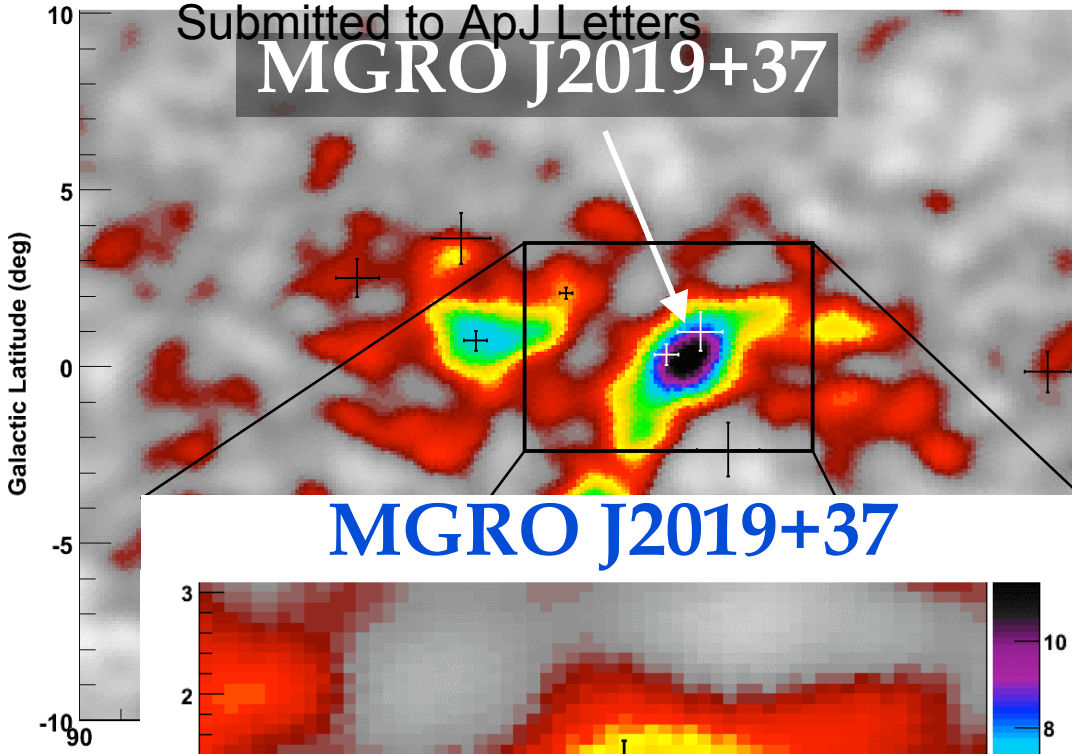


A. A. Abdo *et al.*, arXiv:astro-ph/0611691
Submitted to ApJ Letters

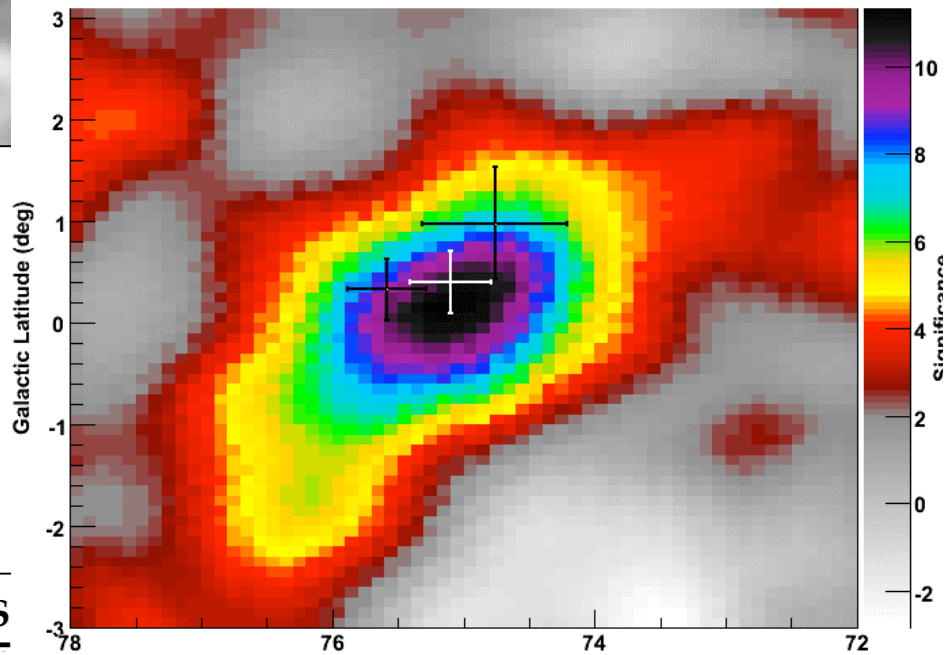
MGRO J2019+37

- **MGRO J2019+37 New Extended TeV Gamma-ray source**
  - Statistical Sig. 11.3 σ
  - Coincident with 2 EGRET sources (unidentified)
    3EG J2016+3657
    3EG J2021+3716 (PWN G75.2+0.1[19])
  - Flux ($\times 10^{-14}$ TeV^{-1} cm^{-2} s^{-1})
    $2.4 \pm 0.4_{stat} \pm 0.7_{sys}$
    ~ 500 mCrab
- Gaussian Width = $0.32^o \pm 0.12^o$
- Location:
  $l = 75.1^o \pm 0.1^o_{stat} \pm 0.3^o_{sys}$
  $b = 0.3^o \pm 0.1^o_{stat} \pm 0.3^o_{sys}$

A. A. Abdo *et al.*, arXiv:astro-ph/0611691
Submitted to ApJ Letters

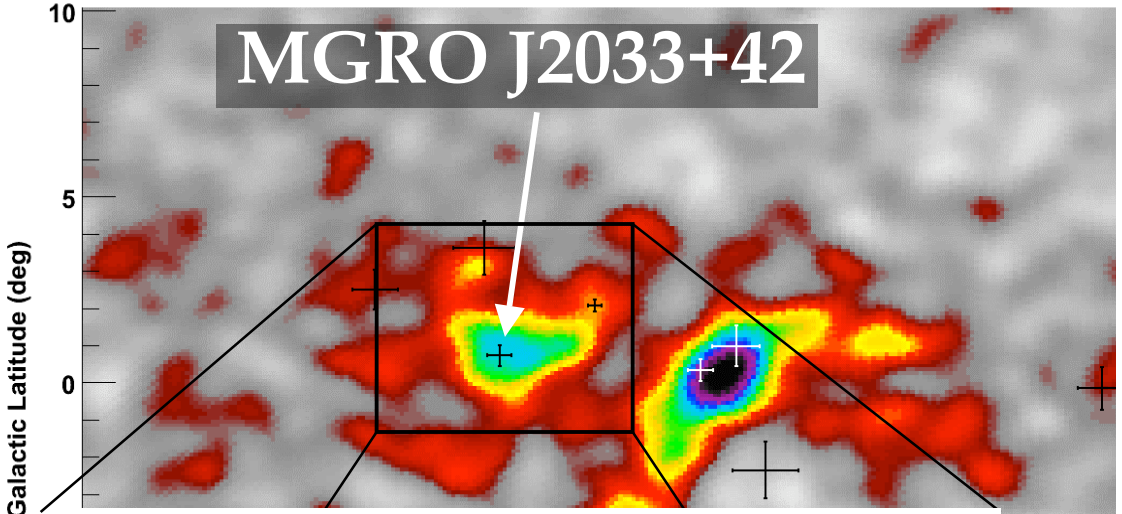


MGRO J2019+37

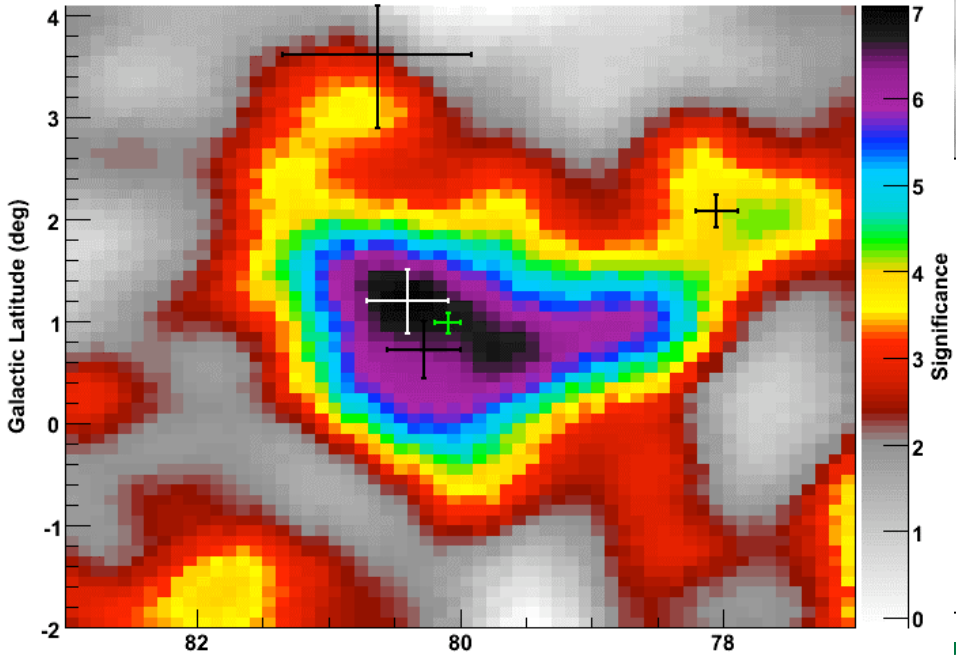


MGRO J2033+42

- Milagro's Latest Discovery: **MGRO J2033+42**:
  - Statistical Sig. 7.1 σ
  - Coincident with:
    HEGRA TeV J2032+4130
    EGRET 3EG J2033+4118
  - Flux ($\times 10^{-14}$ TeV^{-1} cm^{-2} s^{-1})
    $1.7 \pm 0.4_{stat} \pm 0.5_{sys}$
    ~ 350 mCrab
    ~ 3× TeV J2032+4130
  - Location:
    $l = 80.4^{o} \pm 0.4^{o}_{stat} \pm 0.3^{o}_{sys}$
    $b = 1.0^{o} \pm 0.3^{o}_{stat} \pm 0.3^{o}_{sys}$

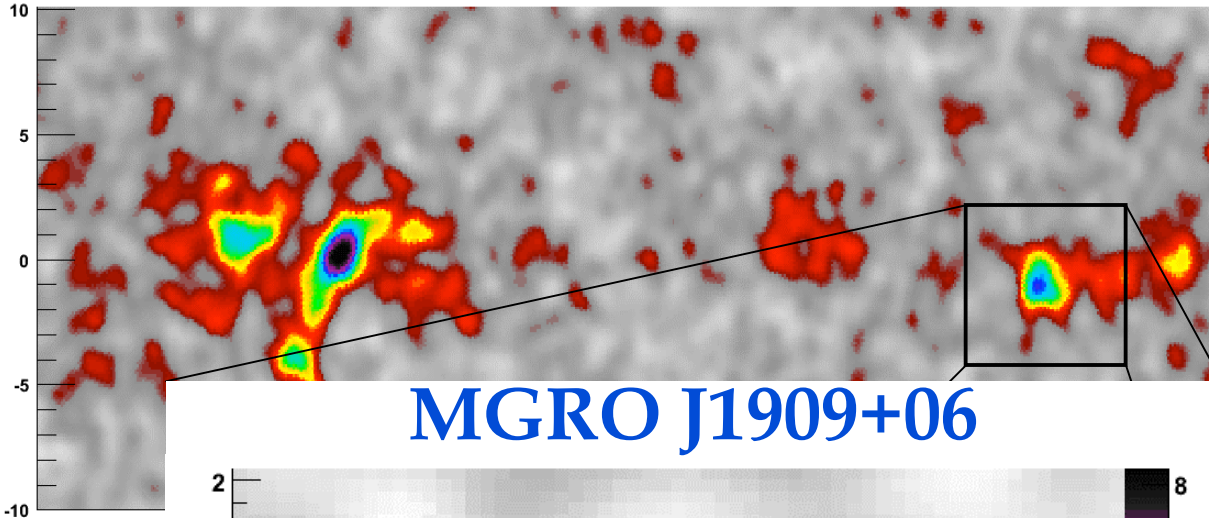


MGRO J2033+42

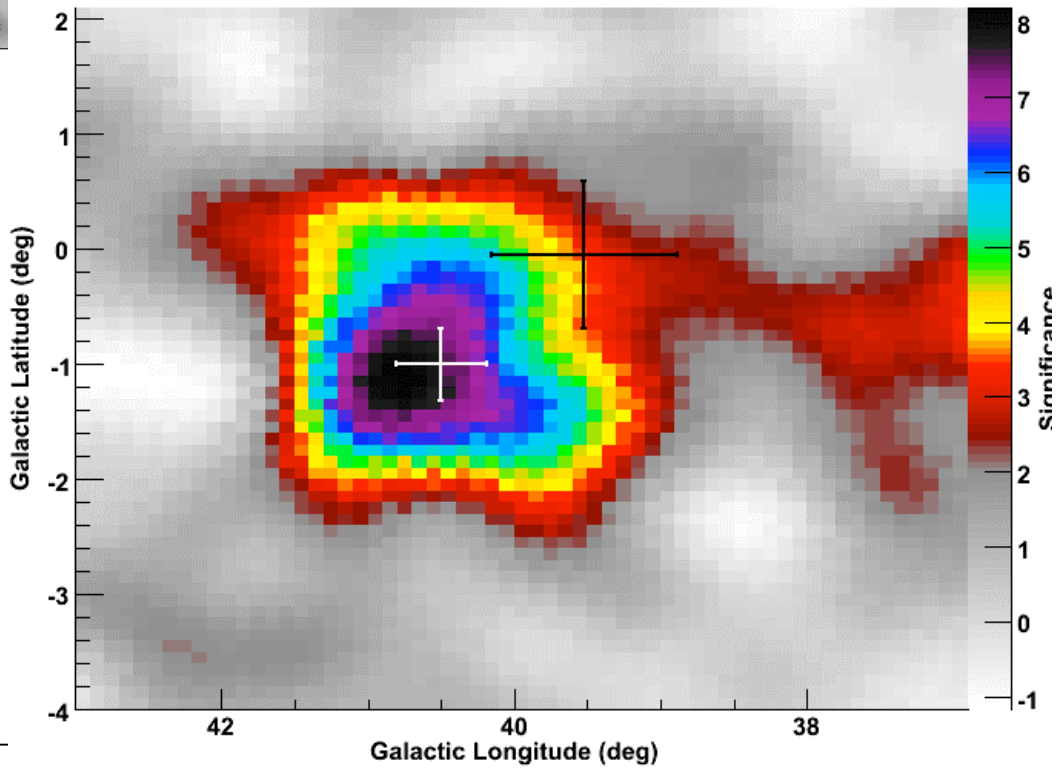


MGRO J1909+06

- Milagro's Latest Discovery: **MGRO J1909+06**:
  - Statistical Sig. 8.2 σ
  - Flux ($\times 10^{-14}$ TeV^{-1} cm^{-2} s^{-1})
    $4.1 \pm 0.9_{stat} \pm 1.2_{sys}$
    ~ 850 mCrab
  - Location:
    $l = 40.5^{o} \pm 0.1^{o}_{stat} \pm 0.3^{o}_{sys}$
    $b = -1.0^{o} \pm 0.1^{o}_{stat} \pm 0.3^{o}_{sys}$



MGRO J1909+06

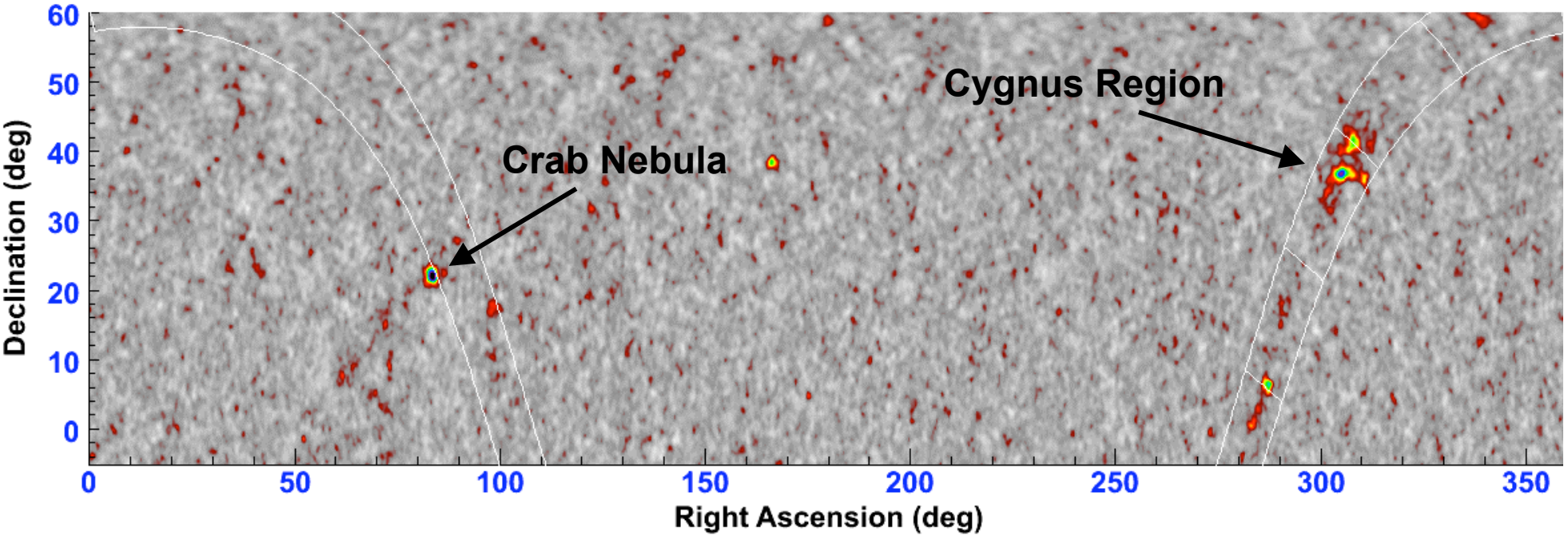


Conclusions

- Milagro has proven its capabilities as a survey instrument for TeV gamma-rays:
  - Discovery of diffuse TeV gamma-ray emission from th Cygnus region of the Galactic plane
  - Discovery of Three TeV gamma-ray sources in the Galactic plane:
    - **MGRO J2019+37 at > 10.2 σ post-trials in Cygnus regic**
    - **MGRO J2033+42 at > 5.2 σ post-trials in Cygnus Regio**
    - **MGRO J1909+06 at > 6.5 σ post-trials at low declinations**

Backup Slides

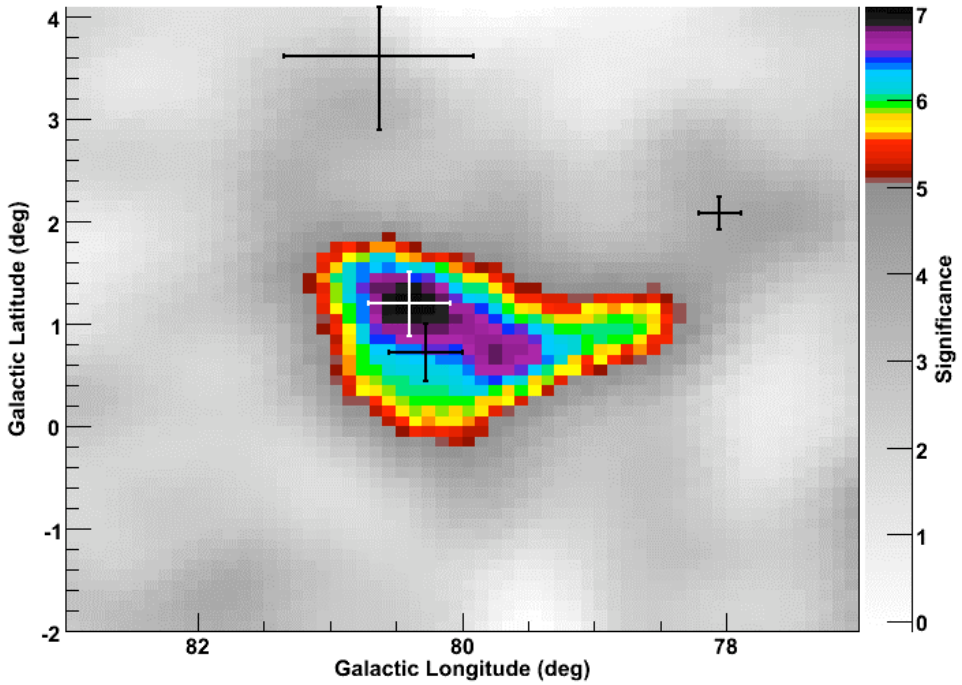
2007 Milagro Sky Survey At 12 TeV



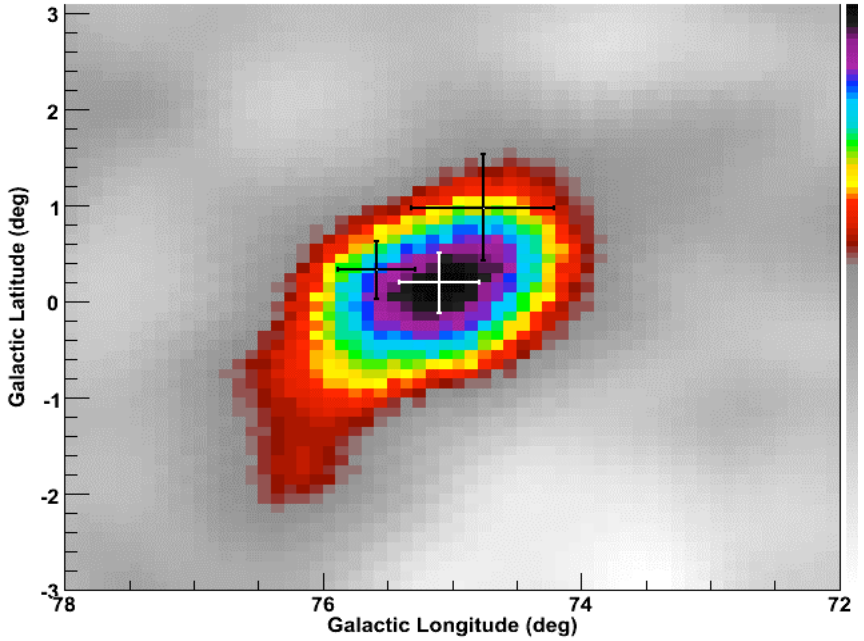
- Crab Nebula Statistical Significance ~ 15.2 σ
- Galactic Ridge clearly visible:
- Three New TeV Gamma-Ray Sources:
  - **MGRO J2019+37 in Cygnus region**
  - **MGRO J2033+42 in Cygnus Region**
  - **MGRO J1909+06 at low declinations**
- **Diffuse Emission from the Cygnus Region**

Additional Plots

MGRO J2033+42

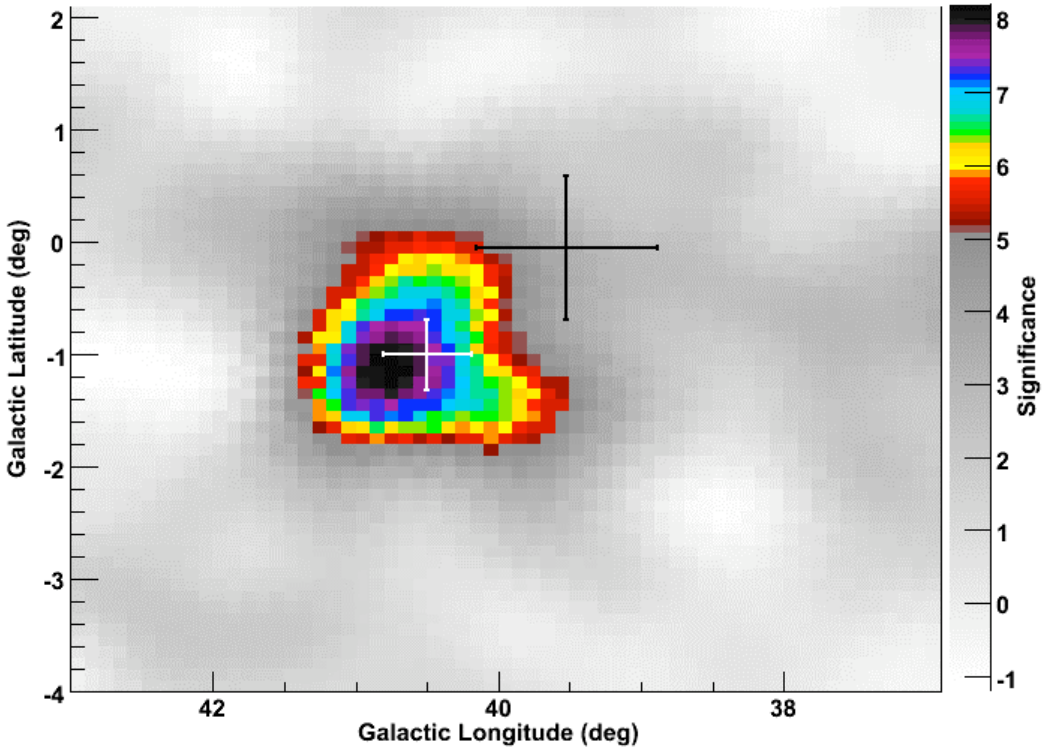


MGRO J2019+37

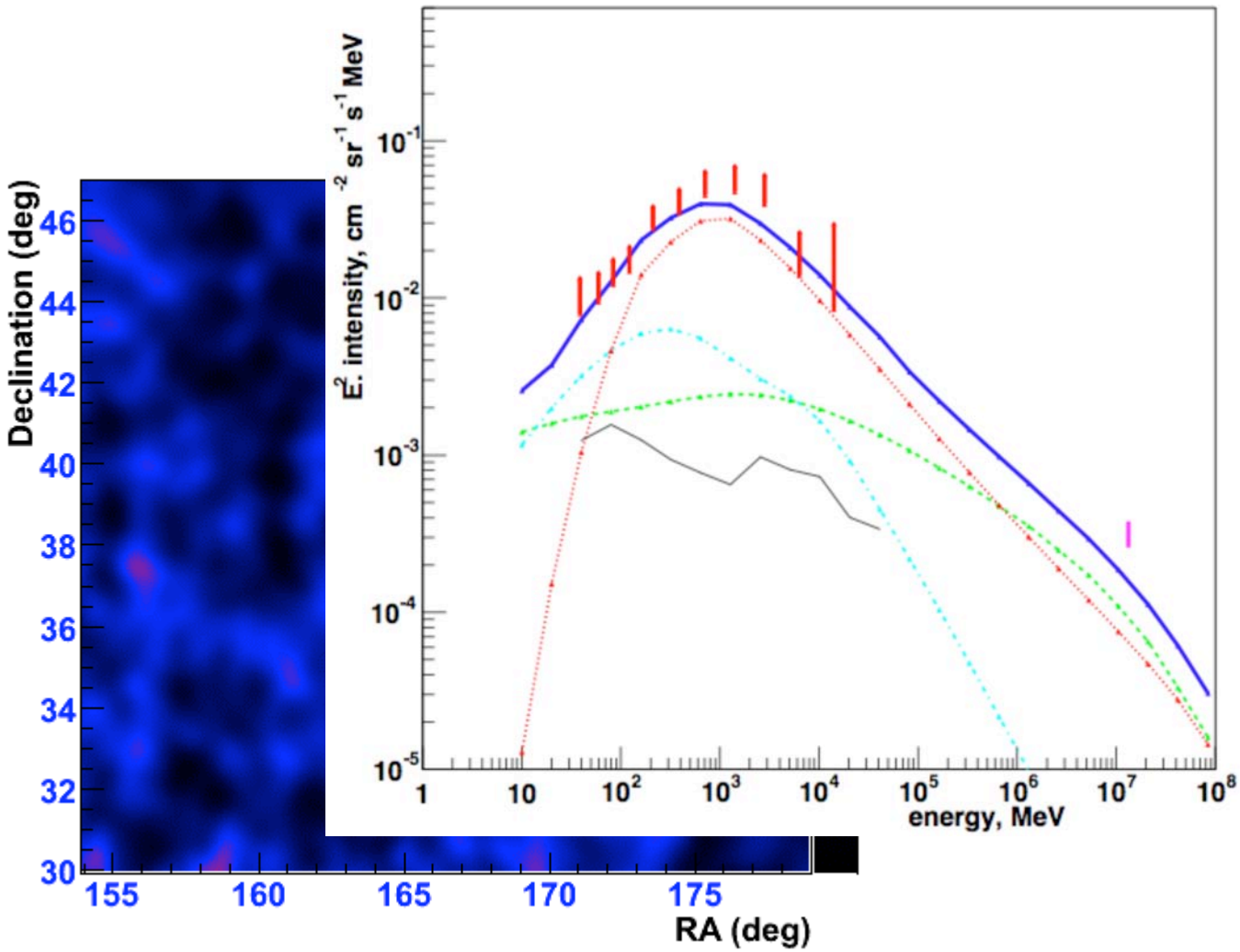


Additional Plots

MGRO J1909+06



Additional Plots



Additional Plots