More on Milagro Observations of TeV Diffuse Emission in Cygnus

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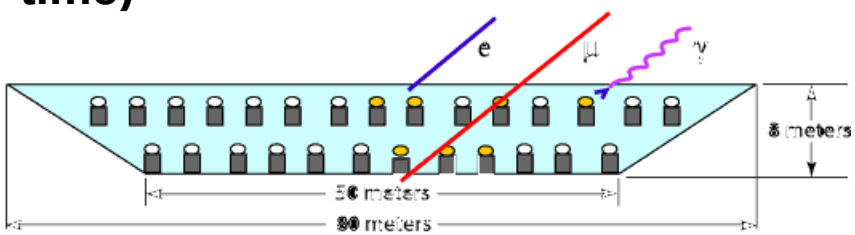
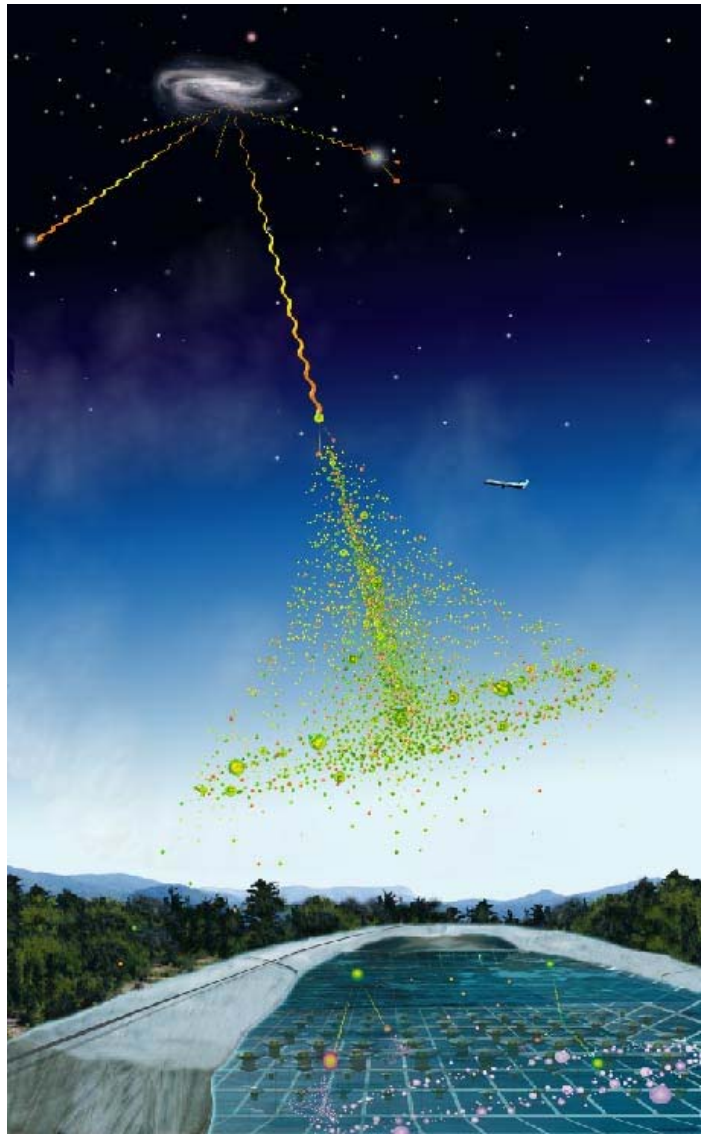
What is Milagro?

- A Water Cherenkov Extensive Air Shower Array at Los Alamos
- Can reconstruct directions of showers from primary gamma rays
  - 0.75° resolution; now 0.45° with 175 4000-liter 'outriggers' (septic tanks)
- Can at least give a hint about the energy (threshold ~>1 TeV)
- Can discriminate against cosmic-ray primaries fairly well
- In essentially continuous operation since 1999 (taking data >90% of the time)





Milagro collaboration web sites, e.g., http://www.lanl.gov/milagro/
See also Julie McEnery's GLAST lunch talk at
http://www.slac.stanford.edu/exp/glast/ground/GlastScience/year2005/

Milagro threshold

- **Calorimetry is hard**

Median Energy vs. Dec and Spectral Index

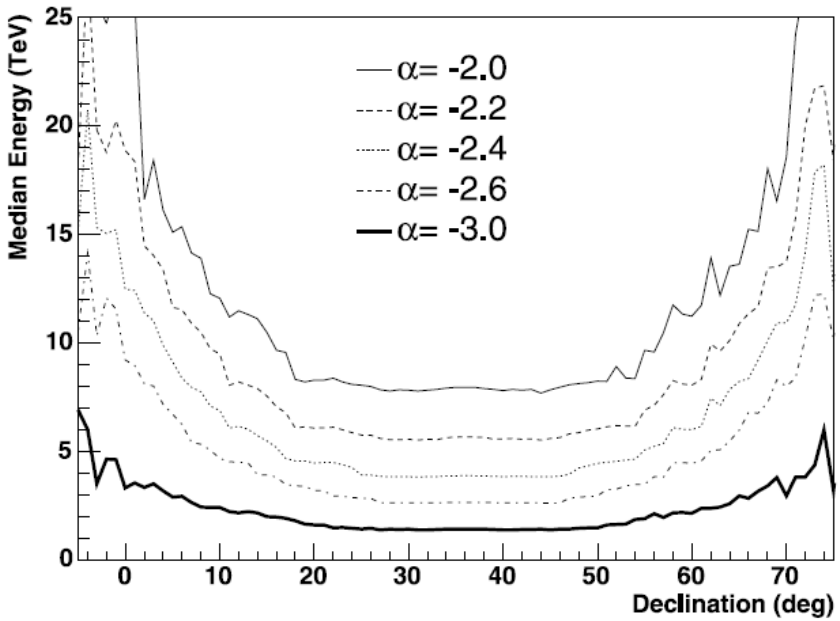


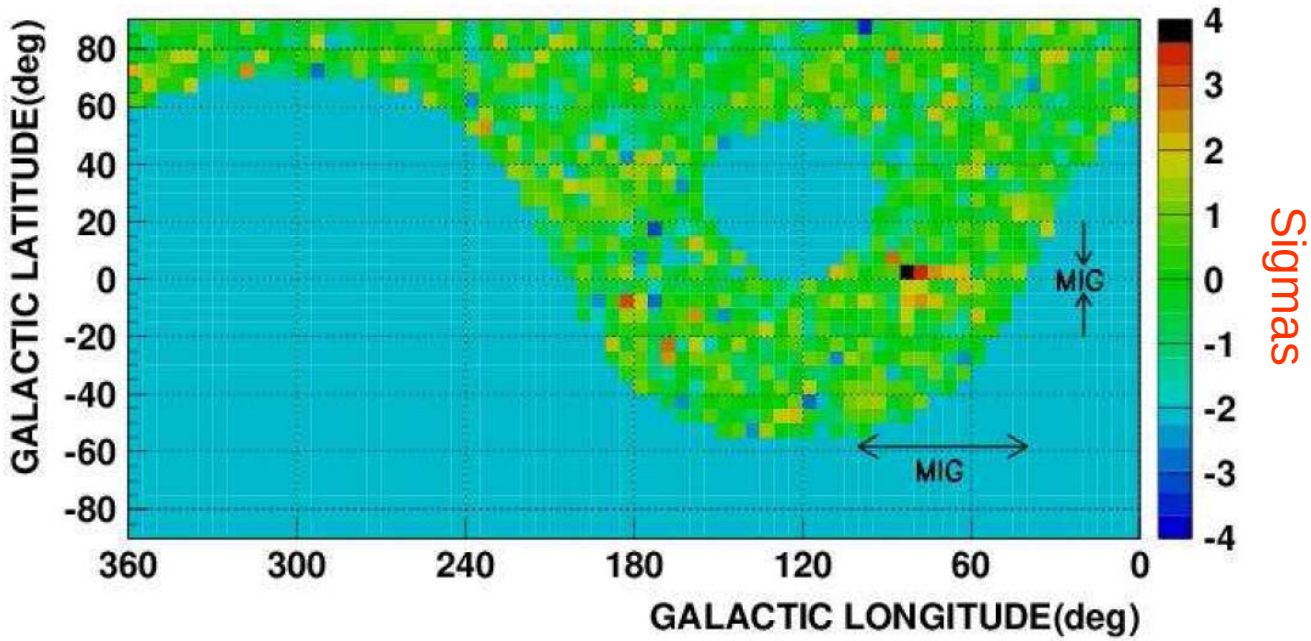
FIG. 3.—Median energy of gamma-ray events that trigger Milagro, pass the compactness cut, and are reconstructed within 1°.2 of their true direction as a function of source declination (this is equivalent to the 2.1 deg^2 bin used in the search). The response of Milagro is averaged over a complete source transit (i.e., 1 day of observation) and the source differential spectral index α for each curve is given in the figure.

Atkins et al. (2004)

Milagro source catalog

- Crab Nebula and Mrk 421 as point sources (Atkins et al. 2004)
- Recently reported evidence for an extended source or two
  - Milagro Inner Galaxy – primarily Cygnus – 5.5 σ (or more)
  - Flux ~1.5 Crab

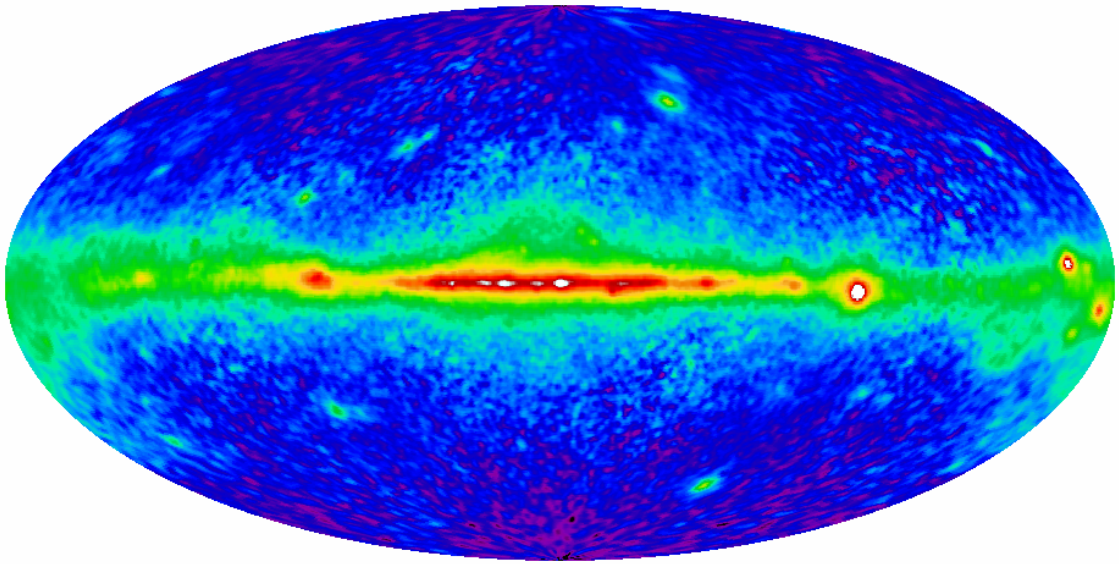
Map of *Signficances* in 5×5° Bins



Atkins et al. (2005)

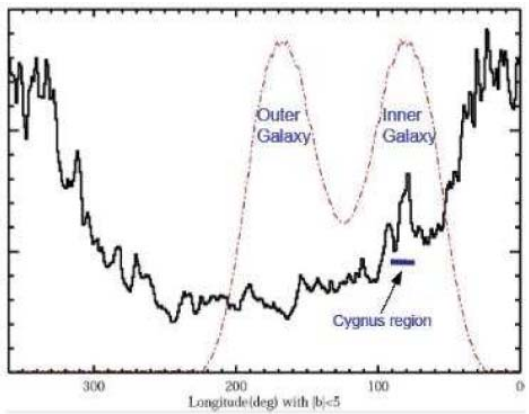
WWES?

- **What would EGRET see if it pointed only at $\delta = 36°$ and had the Milagro Aeff profile?**



Intensity >100 MeV

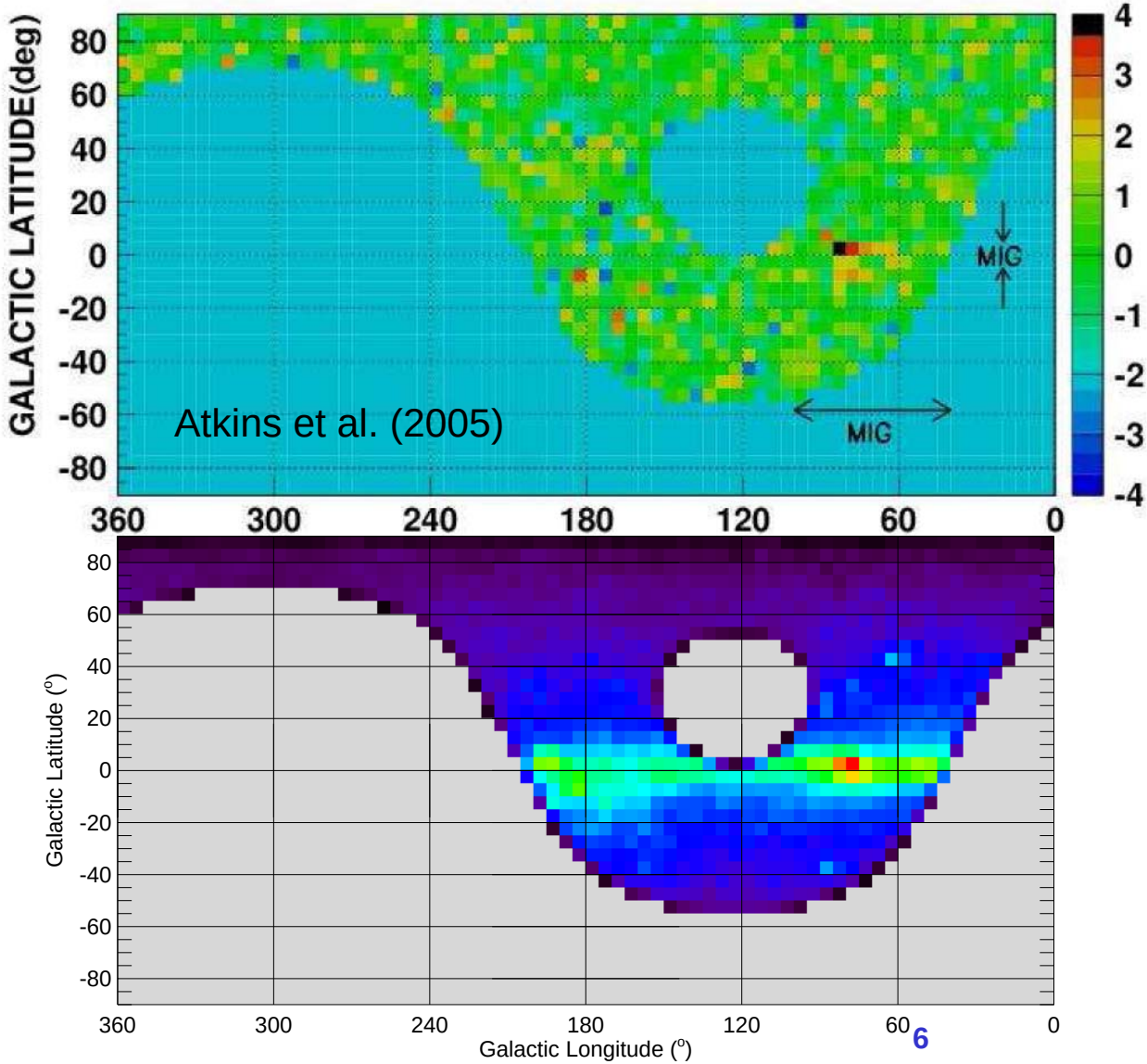
×



Parkinson et al. (2005)

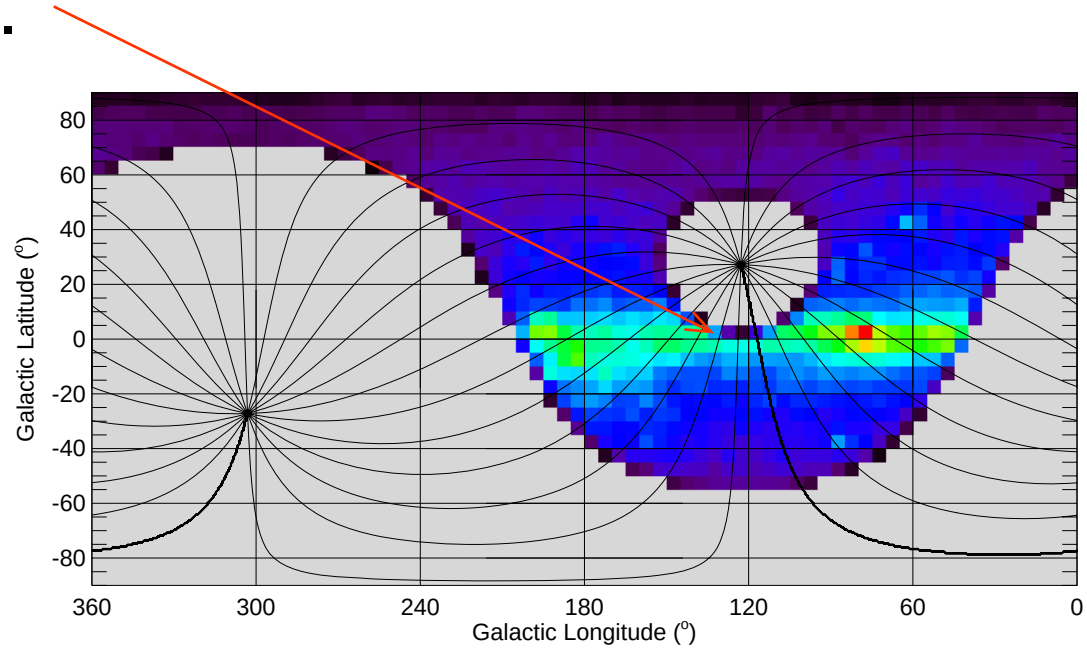
Approximate comparison with EGRET sky

- Comparison not quantitative, obviously
  - And assumes a uniform spectrum for extrapolation by 10^4 in energy
- Cygnus is the brightest part of the plane, but EGRET image does suggest that the plane in general should show up



Complication of background subtraction

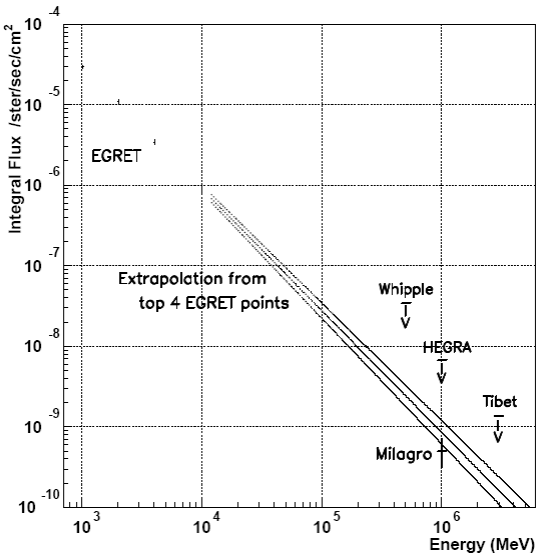
- Data are mostly background – trigger rate ~1.5 kHz and flux from Crab is measured in γ-rays per day
- Background subtraction in Milagro analysis of Atkins et al. is over a range of 2 hours in RA
- Near 120° longitude in the plane, RA is nearly perpendicular to longitude.



Cygnus but not Taurus?

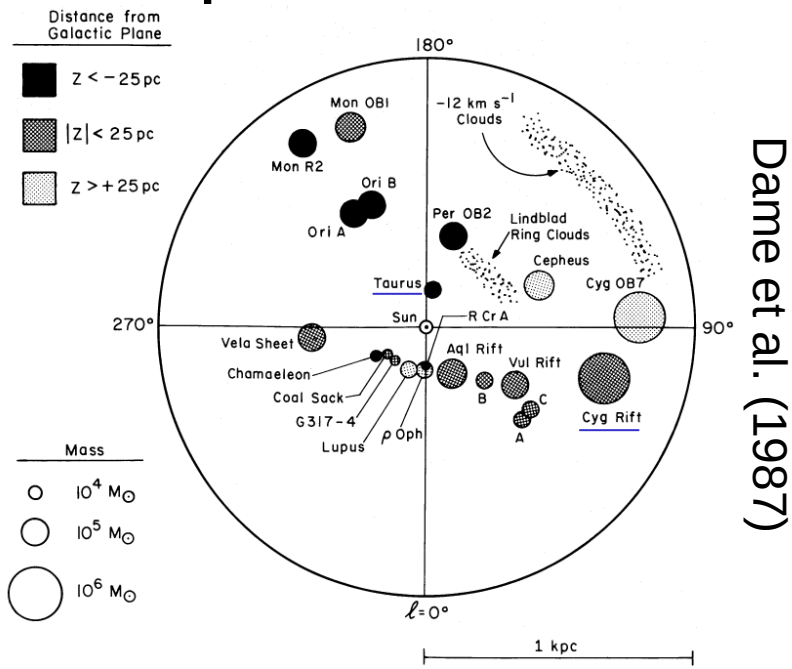
Hillas et al. (1998)

- **Luminosity of the diffuse source at >TeV energies is ~1.5 × (2.1 × 10^{-11} cm^{-2} s^{-1}) × 4π × (2 kpc)^2 ~ 1.4 × 10^{34} γ s^{-1} ~ 6 × 10^{34} erg s^{-1} (~15 L_{sun})**
- **This is not inconsistent with what might be expected from diffuse emission (pion decay) with no special enhancement of CR density**



Atkins et al. (2005)

FIG. 5: Integral flux results of Milagro and EGRET, with 99% c.l. upper limits from Whipple ($l \in (38.5°, 41.5°)$, $|b| < 2°$) [8], HEGRA ($l \in (38°, 43°)$, $|b| < 5°$) [9], and Tibet ($l \in (20°, 55°)$, $|b| < 5°$) [10].

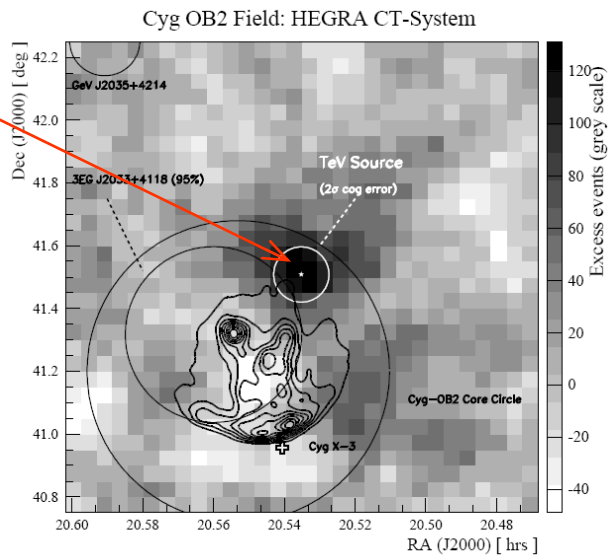


Dame et al. (1987)

But in a Mass/Distance^2 sense, regions like Taurus should have similar diffuse fluxes

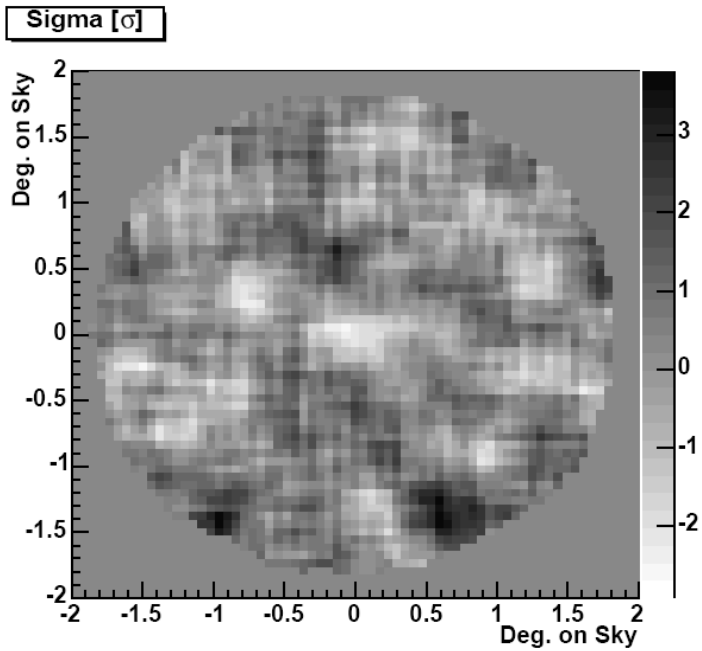
So is it really diffuse?

- **Apparently: the angular size is ~5° – at least not detected with, say, 2.1° bins, flux ~1.5 Crab**
- **And a source with this size is hard to verify with IACTs**
- **Certainly IACTs are looking for point sources in the field**
  - **Serendipitous HEGRA source in Cygnus – Aharonian et al. (2002); only ~3% of the Crab**



Is it really diffuse? (2)

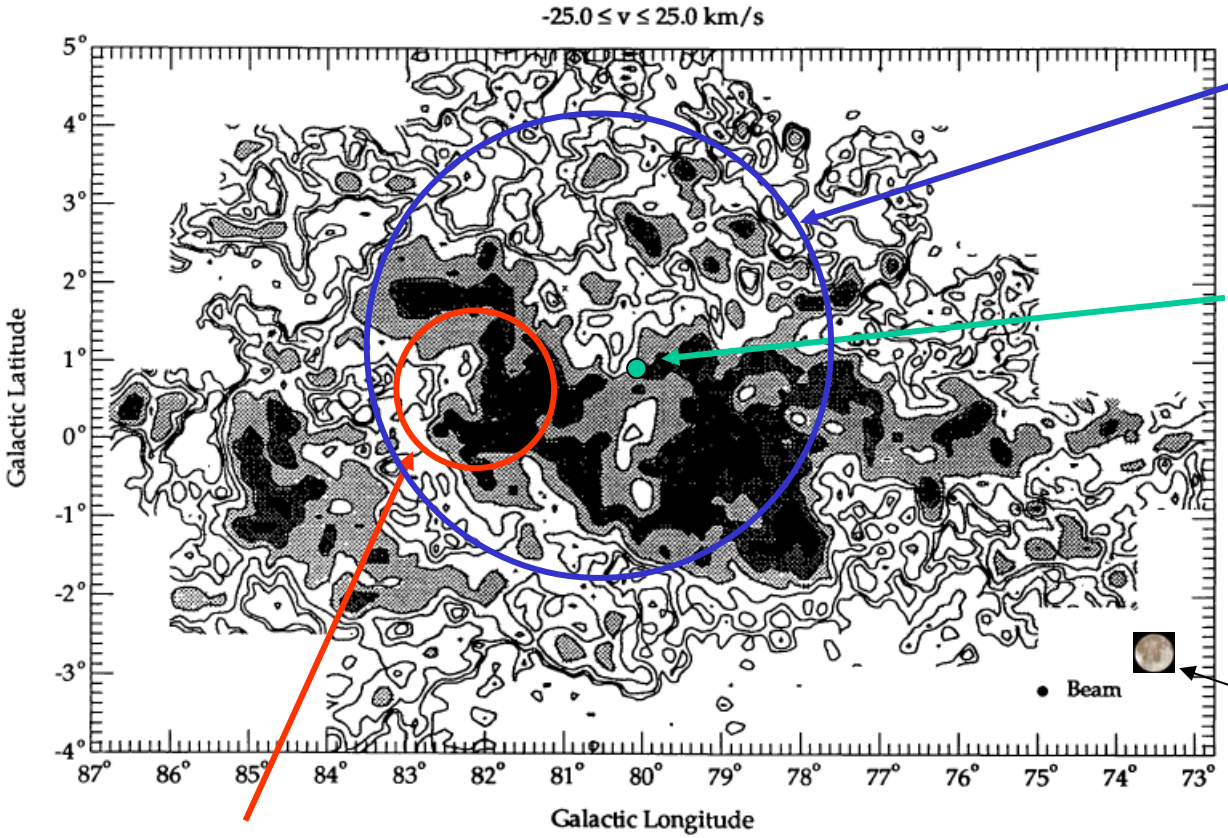
- **Whipple follow-up observations (Atkins et al., astro-ph/0507446): upper limits of 3-4% of Crab for *point source* in inner 1° radius**



Center of field at (α, δ) = (310.03°, 42.66°)

Getting oriented re: TeV sources in Cygnus

Intensity distribution of CO in Cygnus



Milagro source

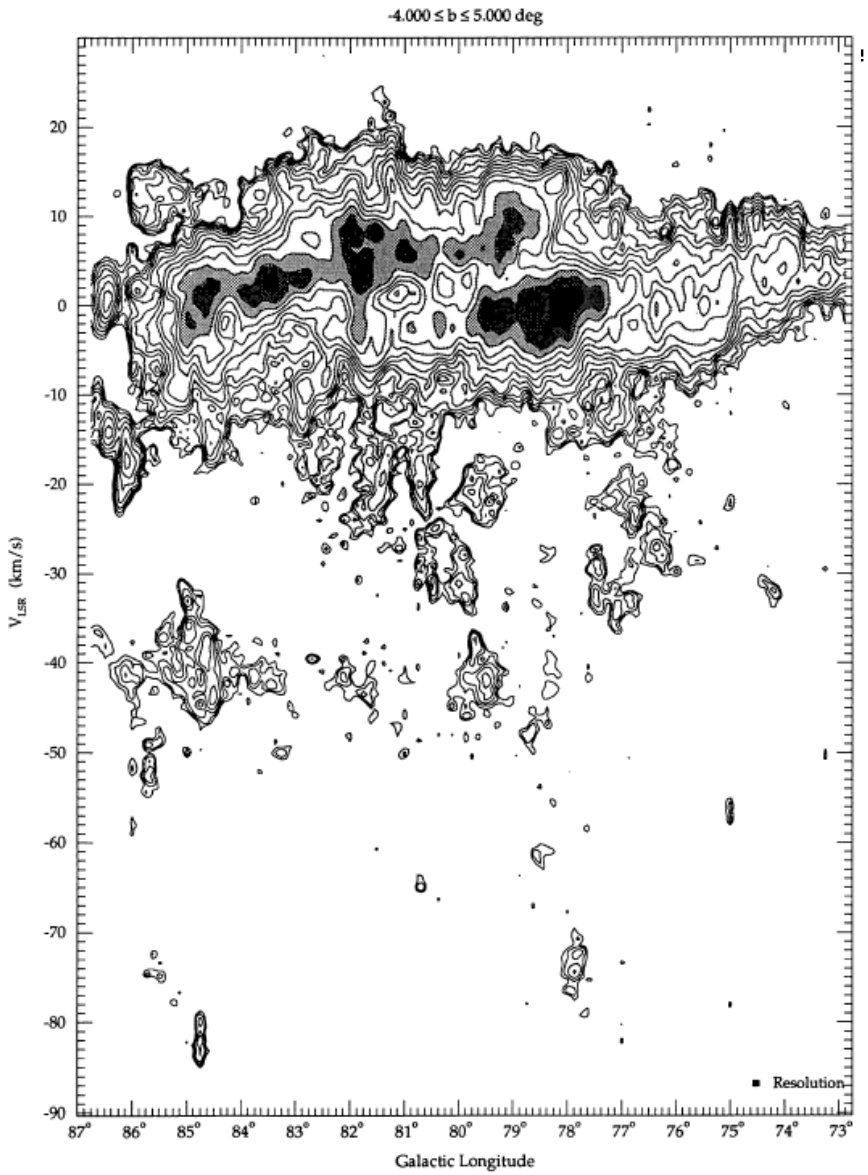
HEGRA source

MOON (Clementine image)

Whipple field

Leung & Thaddeus (1992)

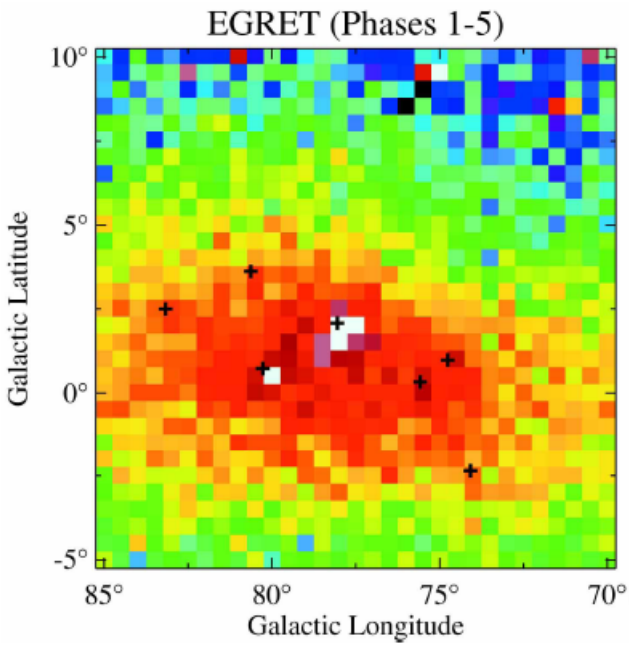
Longitude-velocity distribution of CO in Cygnus

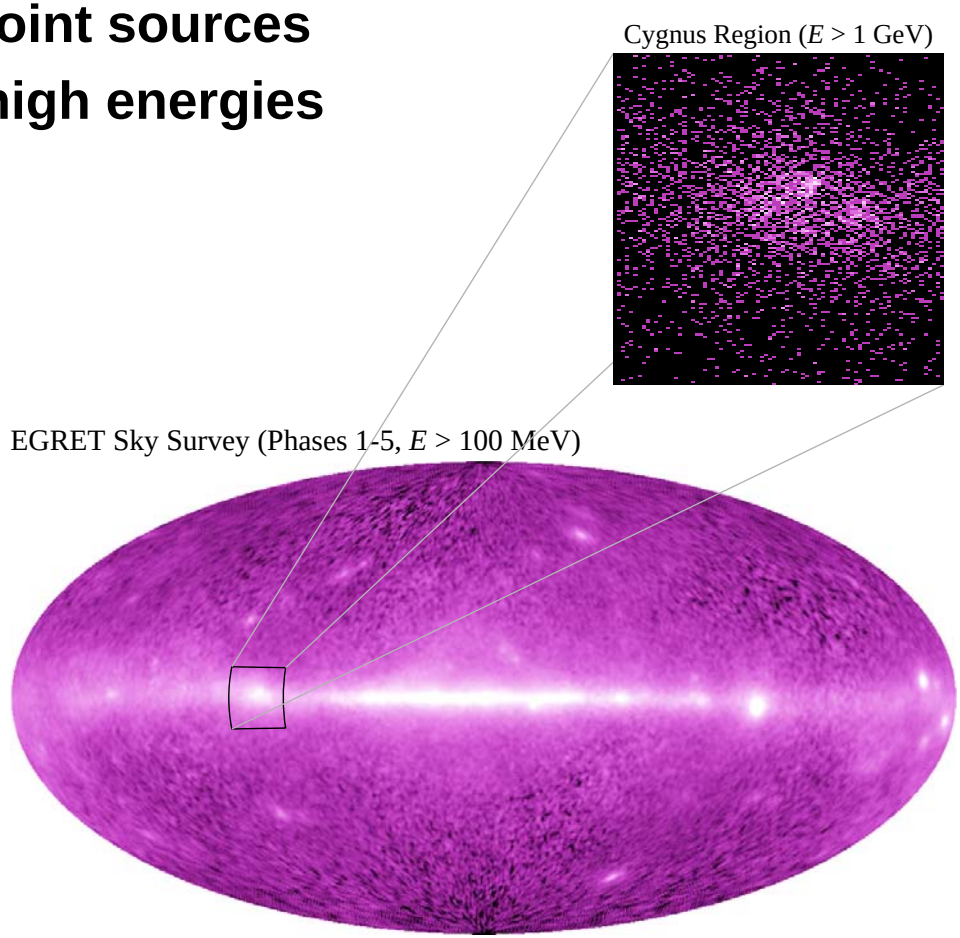


Leung & Thaddeus (1992)

What did EGRET see in Cygnus?

- Diffuse emission + 7(!) point sources
- Not a lot of statistics at high energies





What did EGRET see? (2)

- More quantitatively
- The suggestion from EGRET data is that the Milagro source is probably mostly truly diffuse
  - Although the spectral index of the diffuse emission at high energies is ~-2.7, softer than all of these sources

3EG (Hartman et al. (1999)	10^{-7} cm^{-2} s^{-1} (>100 MeV)	α
J2016+3657	3.5	2.09
J2020+4017	12.4	2.08
J2021+3716	5.9	1.86
J2022+4317	2.5	2.31
J2027+3429	2.6	2.28
J2033+4118	7.3	1.96
J2035+4441	2.9	2.08
Total 3EG	36.7	
Total diffuse+3EG	165.8	
Crab	22.6	2.19

What will GLAST see?

- I don’t know, but here’s an old promotional comparison