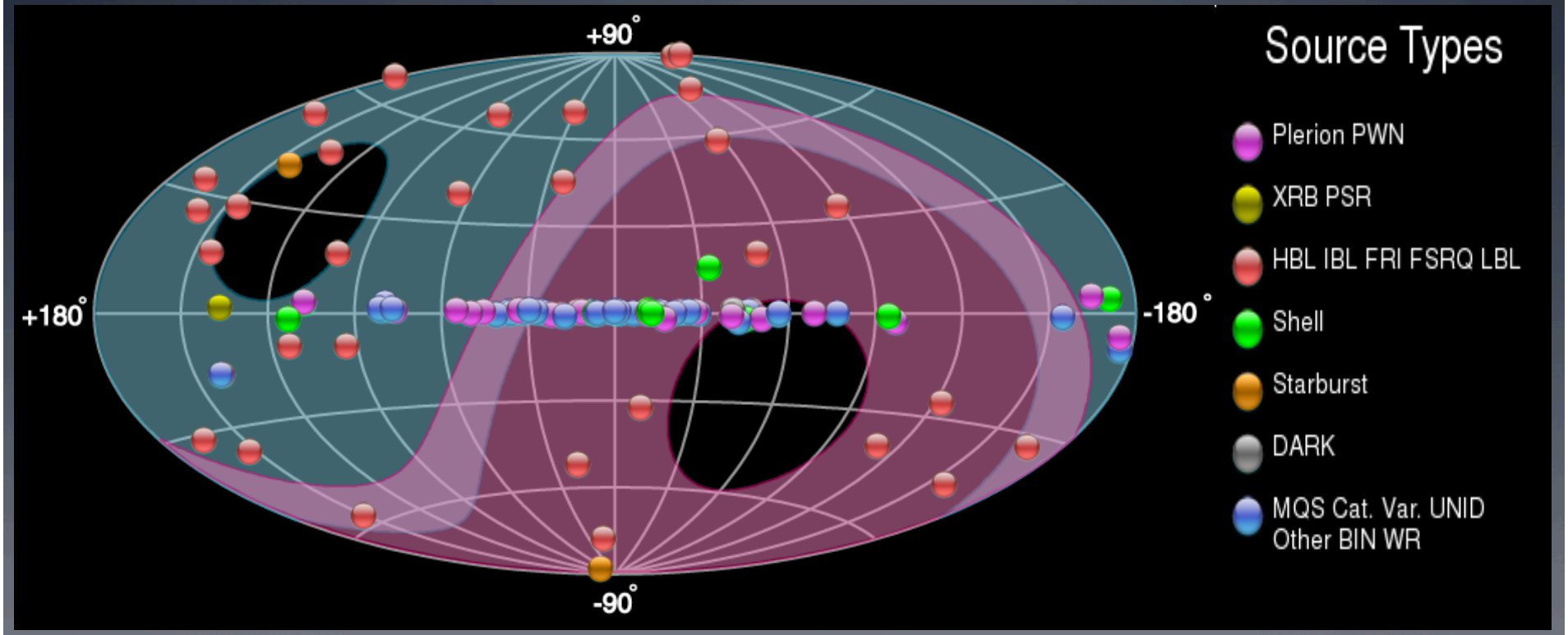
Extended Sources in TeV and GeV Energies

Tülün Ergin, CfA

Gamma-ray Astronomy Nomenclature

Energy Range	Nomenclature	Detection Technique
10 - 30 MeV	Medium	Satellite Detector
30 Mev - 30 GeV	High (HE)	Satellite Detector
30 GeV - 30 TeV	Very High (VHE)	Ground-based (Air/Water Cherenkov)
30 TeV - 30 PeV	Ultra High (UHE)	Ground-based (Particle Detector)
30 PeV - EeV	Extremely High (EHE)	Ground-based (Particle Detector)
EeV - ZeV	EHE	Ground-based (Air-fluorescence)

TeV Sources 2010

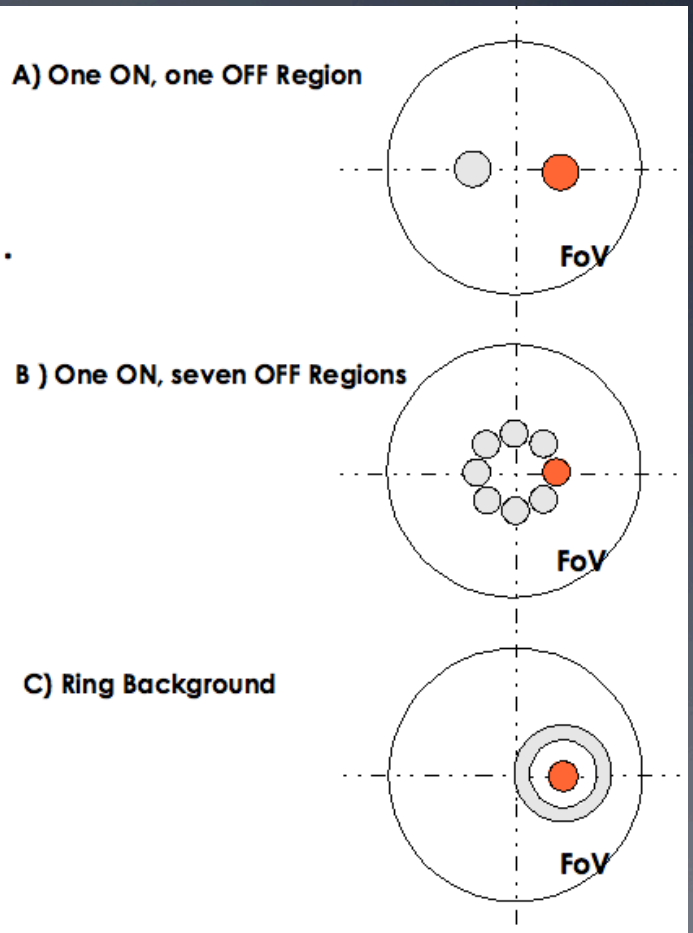


TeV Signal Extraction

$$N_S = N_{ON} - \nu \cdot N_{OFF} \ , \ N_B = \nu \cdot N_{OFF} \ .$$

$$\nu = \frac{A_{ON}}{A_{OFF}} \ .$$

- N_{ON}: # of events counted from signal (ON-) region
- N_{OFF}: # of events counted from background(OFF-) region(s)
- A_{ON}: area of signal region.
- A_{OFF}: area of background region.



TeV Source Detection Significance

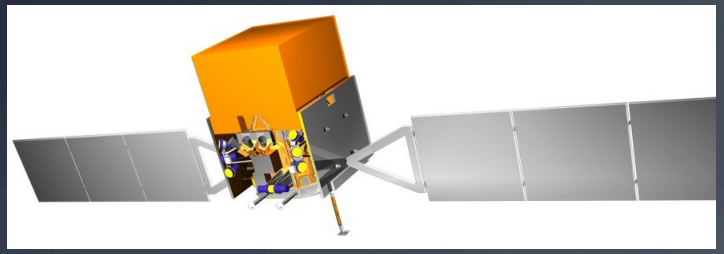
- Li &Ma Method

$$S = \sqrt{2}\left[N_{ON} \cdot \ln\left((1+\nu) \frac{N_{ON}}{\nu (N_{ON} + N_{OFF})} \right) + N_{OFF} \cdot \ln\left((1+\nu) \frac{N_{OFF}}{(N_{ON} + N_{OFF})} \right) \right]^{\frac{1}{2}}$$

Li, T.P. & Ma, Y.Q., ApJ 272, 317-324 (1983)

Extension measured using simple Gauss fit.

The 1st Year Catalog of Fermi Sources



Quote from Fermi Workshop in Boston in Jan 2010:

"*The Galactic ridge (|lat| < 1°, |lon| < 60°) has serious difficulties: sources are close to each other, are not high above the background below 3 GeV, and the Galactic diffuse model is very uncertain there. This even affects sources statistically very significant (TS > 100).*"

From Fermi Workshop in Boston in Jan 2010: 1451 Sources

- Typical 95% error radius is 10 arcmin
- About 250 sources show evidence of variability
- About half the sources are associated mostly with blazars and pulsars
- Other classes of sources exist in small numbers (XRB, PWN, SNR, starbursts, globular clusters, radio galaxies, narrow-line Seyferts)
- Uncertainties due to the diffuse model, particularly in the Galactic ridge, should be kept in mind for low-latitude and local cloud studies

Fermi and VERITAS

	EGRET	GLSAT-LAT	VERITAS
Energy Range	35 MeV – 30 GeV	20 MeV - 300 GeV	100 GeV – 20 TeV
Energy Resolution	< 15%	< 10%	15 - 20%
Angular Resolution	0.5deg @ 10 GeV	0.1 deg @ 10 GeV 0.42 deg @ 1 GeV	0.1 deg above 100 GeV
Field of View	0.5 sr	2.2 sr	3.5 deg
Effective Area	$0.3 m^2$	$1 m^2$	$10^5 m^2$
Point Source Sensitivity	1.2×10^{-8} cm^2 s^{-1} For E > 1 GeV	1.5×10^{-10} cm^2 s^{-1} For E > 1 GeV	10^{-11} cm^2 s^{-1} For E > 100 GeV
Duty Cycle	100%	100%	12%

GeV Source Detection Significance

- Binned/unbinned maximum likelihood analysis (position and energy) is used to determine source significance assuming power-law spectra on top of standard diffuse model
- TS = 2 Δlog(likelihood) is defined by comparing models with and without the source. TS = 25 corresponds to about 4 σ or 2.5E-5 probability (4 degrees of freedom including source position).

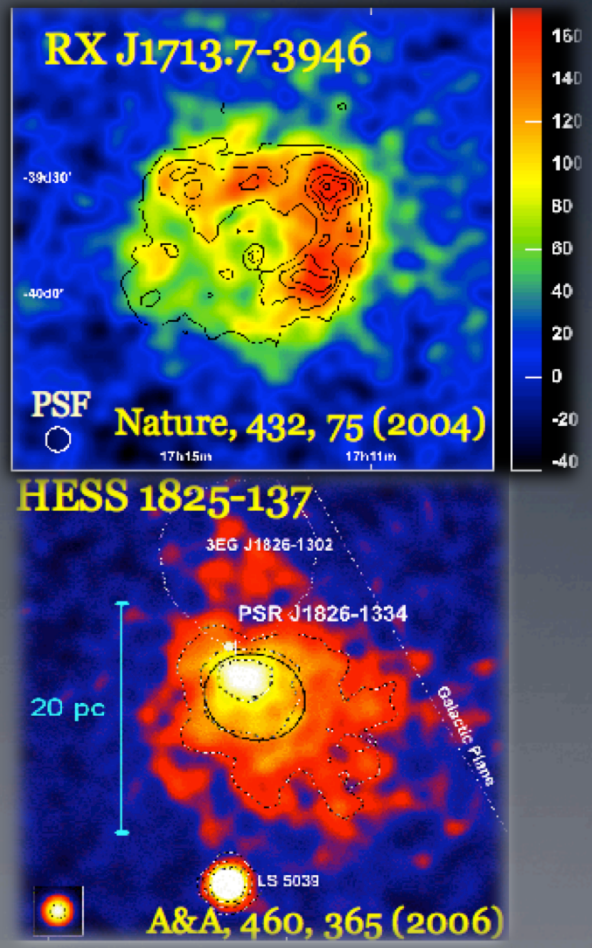
Source Extension

- Extension of the sources are energy dependent
- Symmetric 2D Gaussian fit to calculate the extension
- Size and location of Gaussian is varied and resulting likelihood value with respect to the likelihood value of a point source in the same energy band is evaluated to get the best likelihood ratio. Example: SNR W28
- Alternatively, a flat disk can be fitted on the source, assuming the shape is independent of energy. Vary spatial template to get the systematic errors. Example: SNR W51C

Sources of Interest

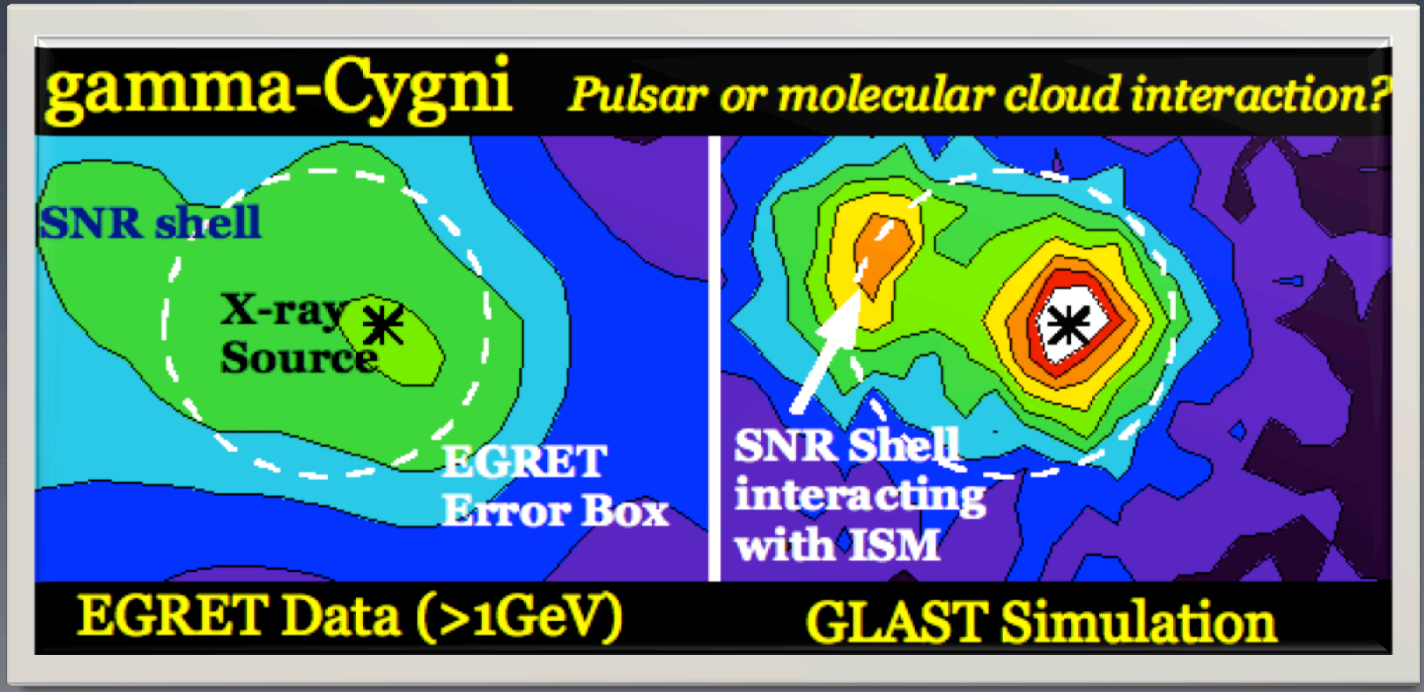
Supernova Remnants & Pulsar Wind Nebulae

- Shell-type SNRs : The shells of the SNRs are the sites of acceleration
- Separate shell-emission from PWN emission by MW studies in GeV, TeV and X-ray energy regimes
- PWNe : Extended emission of gamma-rays from GeV to TeV energies
- Possible scenarios of the extended emission?
- In some PWN the pulsar is asymmetrically positioned
- Ultra-relativistic particles lose energy to Synchrotron and IC-emission as they move away from the pulsar

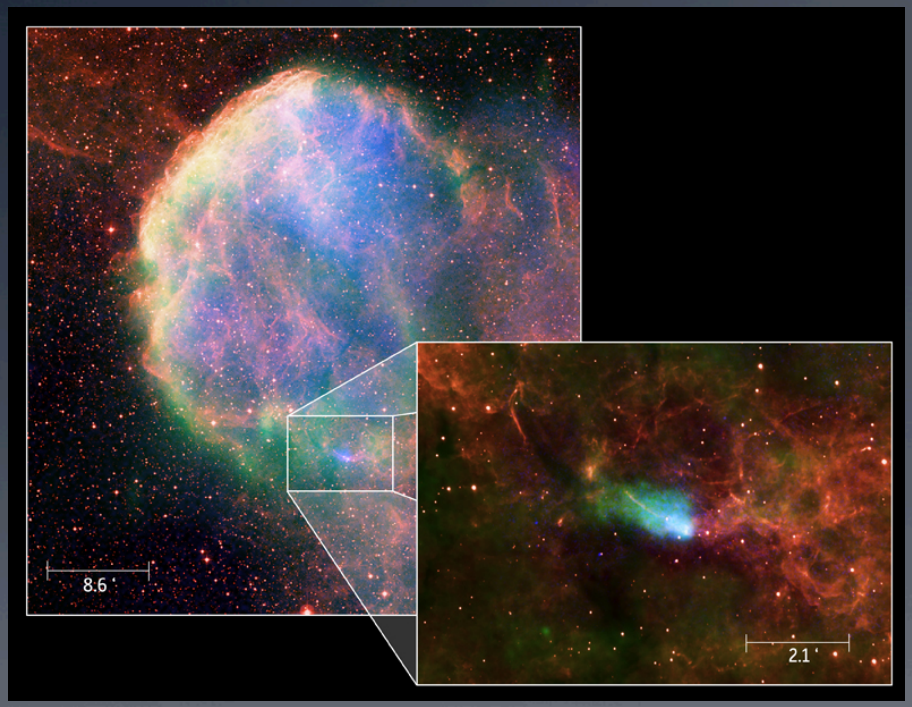


SNRs Interacting with Molecular Clouds

Spatial correlations with molecular clouds give hint about interactions of SNR shell with molecular clouds and the hadronic origin of gamma rays
Candidates: W44, IC443, W28, W51 etc.



IC 443: A Good Example of Confusion

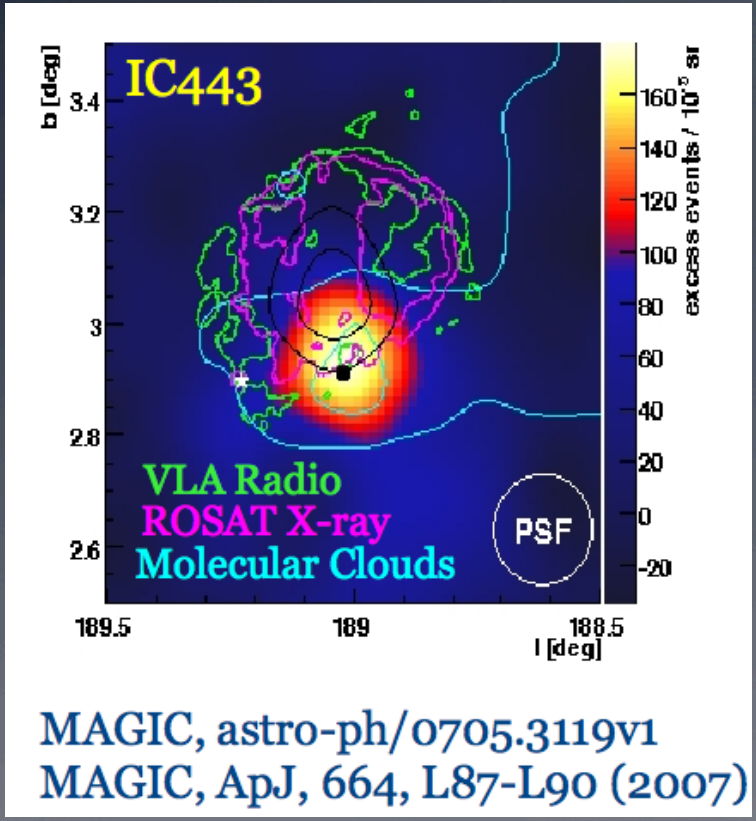


- An SNR within dense molecular cloud region and some OB associations
- Distance = 1.5 kpc, Age = 3-30 kyrs
- Strong X-ray source
- SNR shell diameter is 20 pc (45' for 1.5 kpc)
- Associated with neutron star CXOU J061705.3+222127.
- Associated with an unidentified EGRET source (E > 100 MeV)

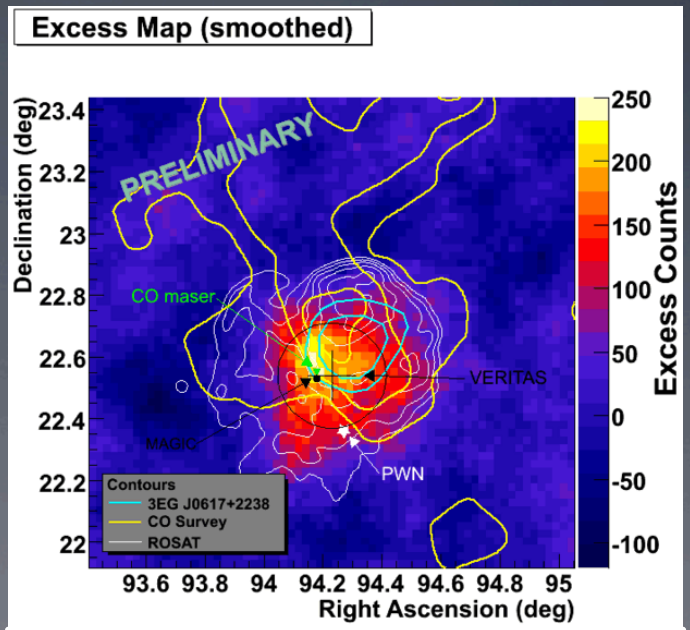
X-ray/CHANDRA Optical Radio

IC 443: TeV Gamma Rays

MAGIC Detection: MAGIC J0616+225, 5.7 sigma
VERITAS Detection: VER J0616.9+2230, 7.5 sigma,
Extension: 0.16 deg from a simple Gauss fit.



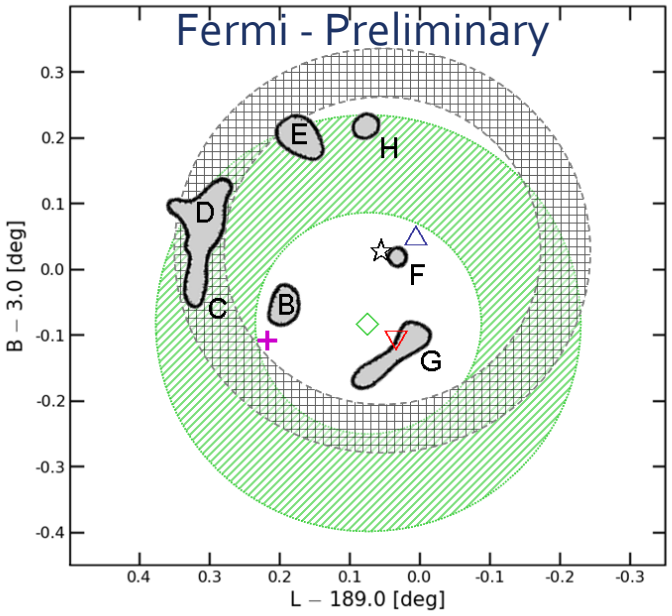
MAGIC, astro-ph/0705.3119v1
MAGIC, ApJ, 664, L87-L90 (2007)



VERITAS, astro-ph/0905.3291
VERITAS, ApJL,L133-L137 (2009)

IC 443: GeV Gamma Rays

- IC 443 is detected at ~ 86 sigma level in the 200 MeV – 50 GeV energy range.
  - → GeV extension=0.27 deg.
  - → GeV Extension overlaps with VERITAS result
  - → Location inconsistent with the pulsar
- SED fits to a broken power -law with a energy break at 3.25 GeV.
- *The MeV–TeV SED can be reproduced by a purely pionic component with a broken power -law proton spectrum breaking at ~ 70 GeV*
  - → *Except for E < 200 MeV where bremsstrahlung may contribute*
- More statistics is needed to show association or non -association with molecular clouds and/ or the PWN

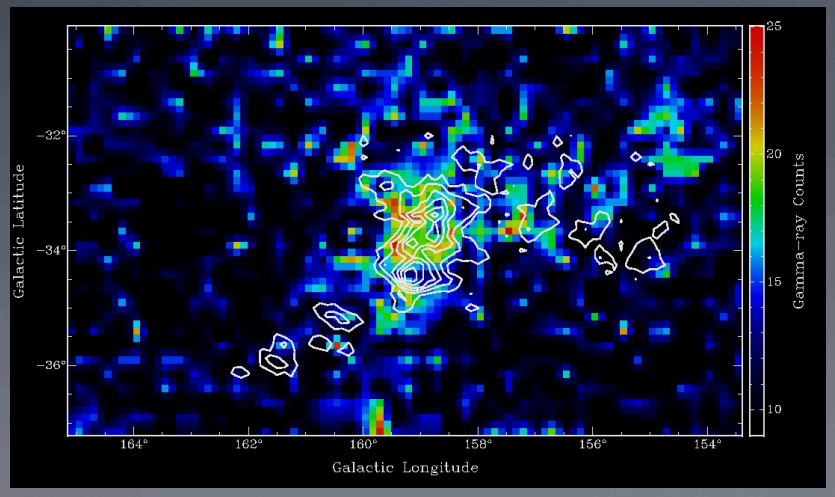


H. Lee, 2nd Fermi Symposium (2009)

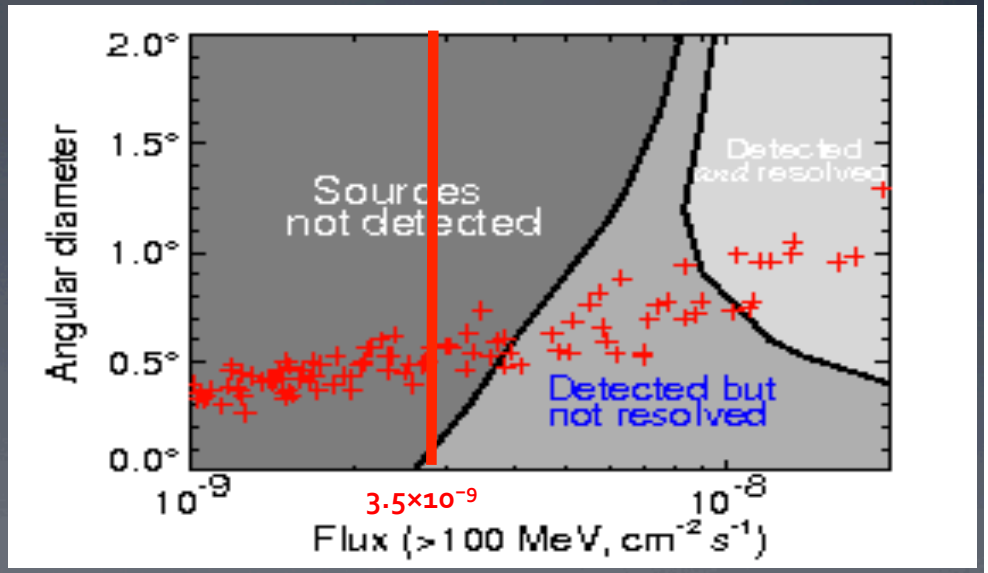
High Latitude Molecular Clouds

Interstellar gas clouds are sources of diffuse GeV gamma rays produced from the decay of pions.

Most of the molecular clouds at |b|> 10 deg lie in a thin layer of 87 pc within 1 kpc of the Sun.



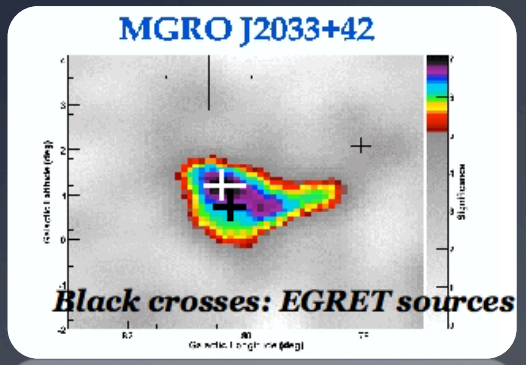
The limiting gamma-ray fluxes of the sources with given angular extend to be detected and/or resolved by Fermi. Plot taken from Torres, Dame, and Digel (2005).

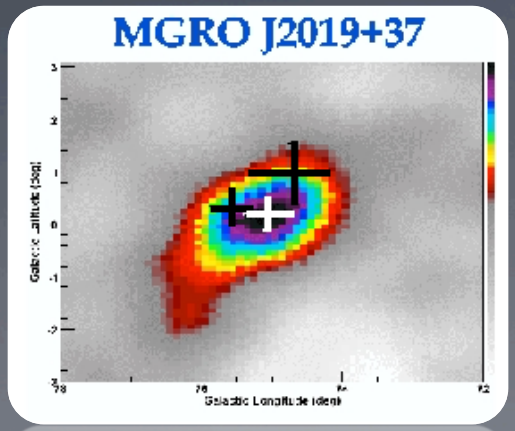


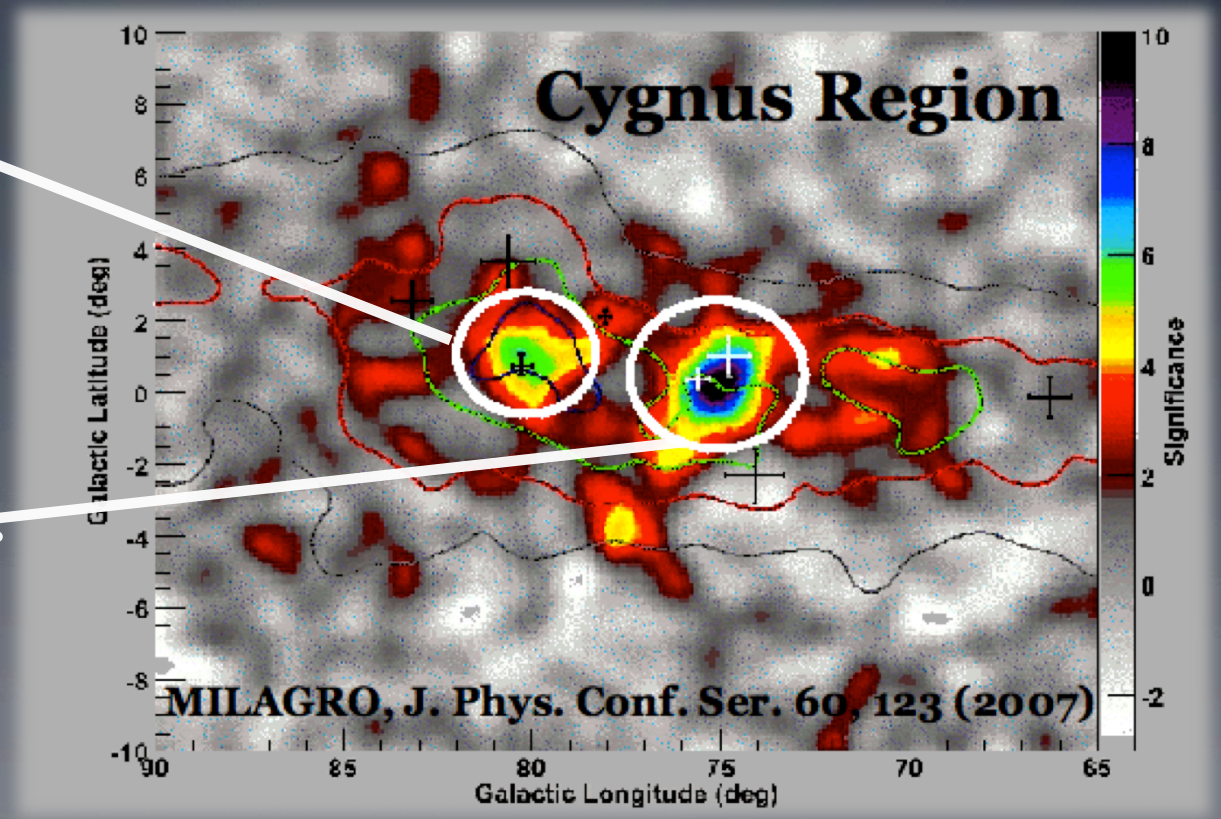
Most of the emission is weak and extended!

Unidentified Sources

Resolve the gamma-ray emission (e.g. in Cygnus region) and clarify the unidentified EGRET - TeV source associations







Conclusions

- TeV gamma-ray emission does not have any source confusion from the diffuse emission
- But if source extended, it is not clear if it is multiple unresolved sources that cause the emission, or maybe a diffuse source
- Many sources with asymmetric shape
- Multi-wavelength data is needed or new methods to localize the emission regions if the source is weak (low duty cycle) or asymmetric
- Angular resolution at lower energies is large, although pulsar identification possible
- Angular resolution better at higher energies, but statistic counts are low
- Uncertainties in the diffuse model make it difficult to resolve multiple source confusions near galactic plane
- Diffuse sources have a nonsymmetrical structure
- Methods needed that can work in low stat regions to measure extension more accurately