TeV Gamma Ray Observations with Milagro and HAWC

John Pretz – Los Alamos National Lab
RICAP 2009
Milagro Collaboration

Milagro Detector

- Central Water Pond (80x60 meter)
  - 450 PMTs under 1.5 m water
  - 273 PMTs under 6 m water
- Outriggers
  - 2.4 meter diameter
  - 1.4 meter tall
  - 175 PMTs in outrigger tanks
- Water Cherenkov Detector
- 2600 meters altitude
- 4000 m² pond / 40000 m² outrigger coverage
- 1700 Hz Trigger Rate
- 0.4° – 1.0° angular resolution
- Sensitivity 100 GeV – 100 TeV Median energy 10 – 40 TeV (depending on cuts, weights etc)
Gamma/Hadron Discrimination

- Penetrating component of Hadronic air showers illuminates the bottom layer.
Gamma/Hadron

- Penetrating component of Hadronic air showers illuminates the bottom layer.
The Cosmic Ray Picture

Astrophysical Source

‘Old’ CR Interacts.

‘Young’ CR Interacts.

Direct propagation
Open Questions

• What are sources of cosmic rays?
• How do the accelerators work?
• What is the source of the TeV Galactic diffuse emission?
• Is there a nearby source of cosmic rays?
Diffuse Gamma-ray Emission
TeV Diffuse Emission from the Galactic Plane with Milagro (Abdo et al. 2008)
Inner Galaxy and Cygnus Region Compared to Galprop

- 8 times the conventional flux
- 4.7 times the conventional flux

- **Total Galprop Prediction**
- **Pion Decay**
- **Electron Inverse Compton**

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Petra Huentemeyer

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• Unresolved Sources
  – Extrapolating HESS source population model can account for a substantial fraction of the excess (Casanova & Dingus. Astropart. Phys. 2008.)

• Unmodeled ‘young’ cosmic rays interacting near their sources
  – For instance, HESS observation of emission along the Galactic Center Ridge (Aharonian et al. Nature. 2006.)

• Dark Matter

• There is more to see.
Discrete Gamma-Ray Sources
Fermi-LAT Bright Source List

- Sensitivity from 100 MeV to hundreds of GeV
- 205 $10\sigma$ sources in 3 months of data
- Blazars, pulsars identified by their variability.
- Several new pulsars (pulsations discovered in the GeV first)
- Deeper survey than entire EGRET dataset
- Angular resolution $< 0.1^\circ$ at the higher energies

Abdo et al. arXiv:0902.1340
Survey of the Galactic Plane

Boomerang PWN

MGRO J2019+37

MGRO J2032+41

MGRO J1908+06

Geminga

Crab
Milagro Search for TeV emission from Galactic sources

- 34 / 205 BSL sources are possibly Galactic and in Milagro’s field of view ($\delta > -5^\circ$)
  - 16 pulsars
  - 1 x-ray binary
  - 5 SNR
  - 12 unknown
- 14/34 are observed at 3\(\sigma\) or more in Milagro data
- Probability of a single 3\(\sigma\) detection in 34 trials is only 4%
- 6/14 have been reported by Milagro before
- 9/14 are pulsars (all 6 previous Milagro sources are now associated with pulsars)
- 3/14 are SNR
- ‘Most’ of the 3\(\sigma\) sources are true TeV detections, but cannot be claimed individually
- All of these will be observable with 3 months of HAWC data

arXiv:0904.1018
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The 3σ Locations

arXiv:0904.1018
The $3\sigma$ Locations

- Most Significant source in BSL
- Old (300 kyr) and nearby (169 pc)
- $3.5\sigma$ at the location of Geminga
- $6.3\sigma$ when assuming $1^\circ$ extended source
- Fitted $2.2^\circ$ extent, consistent with IACT observations of more distant PWN
The 3σ Locations

- Associated with LAT-identified pulsar
- Originally reported by Milagro as an 3° extended source.
- Source confusion with 0FGL J2021.5+4026?
The $3\sigma$ Locations

- Boomerang PWN
- $6.6\sigma$ at the pulsar location.
- Associated with known radio pulsar
- Extended source or additional source to the south.
Milagro Gamma-Ray Sources

- Milagro’s strongest sources are very likely TeV PWN. Typical TeV source is a PWN.
- TeV emission is quite commonly associated with MeV-GeV Pulsars.
- Spectrum to connect Milagro measurements to Fermi measurements are universally softer than 2.3.
- There is much more to see!
High Altitude Water Cherenkov detector (HAWC)

- Move Milagro PMTs to high-altitude site at Sierra Negra, Mexico
- One layer representing 10x the area of Milagro’s bottom layer
- Tanks can distinguish muons from EMS particles.
  - Better gamma/hadron separation.
- Overall 15x sensitivity improvement over Milagro.
- See sources 225x faster.
  - See 1 Crab every day.
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Gamma-Hadron Separation in HAWC
Status of HAWC

• ~1M USD from NSF, UMD, and Mexican funding institutions for construction of nano-HAWC.
  – Three small test tanks at the site.
• Tank selection in progress
• Permission to build a road to the site (yesterday)
• Data acquisition with 3-tank array has occurred.
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Conclusions

• Milagro decommissioned in June 2008 and analysis of final dataset is underway. Exhibits the need for an all-sky survey instrument.
  • Gamma-rays:
    _List of sources and potential TeV emitters is growing. Appear to be mostly TeV PWN associated with MeV-GeV pulsars.
    _High-confidence TeV detection from Geminga and Boomerang PWN
    _How much Galactic Diffuse emission is explainable this way is an open question. Remaining Fermi data will help.
• HAWC
  _15x increase in Milagro sensitivity
  _Engineering progressing with 1M USD MRI
  _“Shovel Ready”