



TeV Gamma-Ray Emission from the Cygnus Region with Milagro

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Abstract: Analysis of diffuse TeV gamma-ray emission can provide clues about the origin of VHE galactic cosmic rays. Previous studies of the galactic diffuse flux with Milagro show an excess of gamma-rays when compared to cosmic ray propagation models in certain regions of the galactic plane. One of these regions is the Cygnus region, which has four known TeV gamma-ray sources in addition to a significant excess of diffuse gamma-rays. In order to better understand this excess, a new analysis technique was used to reconstruct the TeV spectrum of the gamma-rays from the Cygnus region between 1 TeV and 100 TeV for the first time. This technique is based on the fraction of PMTs in the detector that show a significant signal from air shower particles. In this presentation, the analysis technique as well as the resulting spectra in the Cygnus region will be discussed.

Keywords: acceleration of particles–cosmic rays–gamma rays: observations–Cygnus region, Gamma ray emission, MGRO 2019+37

1 Introduction

The Cygnus region is a region in our Galaxy of active massive star formation and destruction and has been studied at different wavelengths, including radio, X-ray, GeV and TeV gamma-ray, and in cosmic rays. At GeV up to multi-TeV energies, the Cygnus region is the brightest diffuse gamma-ray source in the northern hemisphere [1, 2, 3]. Most recently, the Fermi and VERITAS observatories have presented new results of their surveys of this region [4, 5]. Between 2007 and 2008, the Milagro experiment published the discovery of two unidentified TeV sources in the region, MGRO 2019+37 and MGRO 2031+41. The location of MGRO 2019+37 was found to be consistent with two EGRET pulsars, while the best fit position for MGRO 2031+41 was near two EGRET sources and the HEGRA unidentified source TEV 2032+41 [2, 3]. In a correlation study connecting TeV sources discovered by Milagro with sources detected at $\geq 10\sigma$ by the Fermi telescope (the so-called Bright Source List, BSL) the two aforementioned brightest Milagro sources in the region could be again associated with two GeV pulsars, and two additional associations were found in the Cygnus region, specifically defined in Galactic coordinates as $l \in [65^\circ, 85^\circ]$ and $b \in [-2^\circ, +2^\circ]$ [6]. Figure 1 shows a significance map of this region, that from now on will be referred to as the Cygnus region, based on data collected with the fully operational Milagro detector after 2004 (906 days of operation). The positions of the four Milagro excesses that are associated with Fermi BSL sources are indicated by different markers.

One of the challenges when analyzing the Cygnus region at TeV energies is the proper separation of the gamma-ray flux that is attributed to the point or extended sources in the region or to the diffuse emission. The Milagro experiment with its wide field of view capability previously measured the diffuse excess from the Cygnus region and found a 2 to 3 times higher flux than expected from the EGRET optimized GALPROP model and an about 8 times higher flux than expected from the conventional GALPROP model [2, 3]. In the earlier approach [2], an area of $3 \times 3 \text{ deg}^2$ centered on the positions of MGRO 2019+37 was excluded to calculate the diffuse emission in the region. In the later approach [3], the event excesses from the sources in the region were modeled as a two-dimensional Gaussian plus a constant. The source location (R.A., decl.), the amplitude and radial width of the Gaussian, and the constant were determined using a χ^2 minimization. The excess from each source was then calculated bin by bin using the resulting Gaussian function and subtracted from the total excess in the 0.1° by 0.1° bin event excess map.

Measurements by the Fermi LAT detector rule out the EGRET optimized cosmic ray propagation model, at least at intermediate latitudes [7], motivating the present reanalysis of gamma-ray emission from the Cygnus region using the last three years of data collected with the Milagro experiment, an improved gamma-hadron separation and a newly developed technique that allows to reconstruct the energy spectrum of gamma-rays from the Cygnus region. This includes a reconstruction of the spectrum of MGRO 2019+37, a source with a post trial significance in excess of 12σ between 1-100 TeV [2]. We will compare the spectral

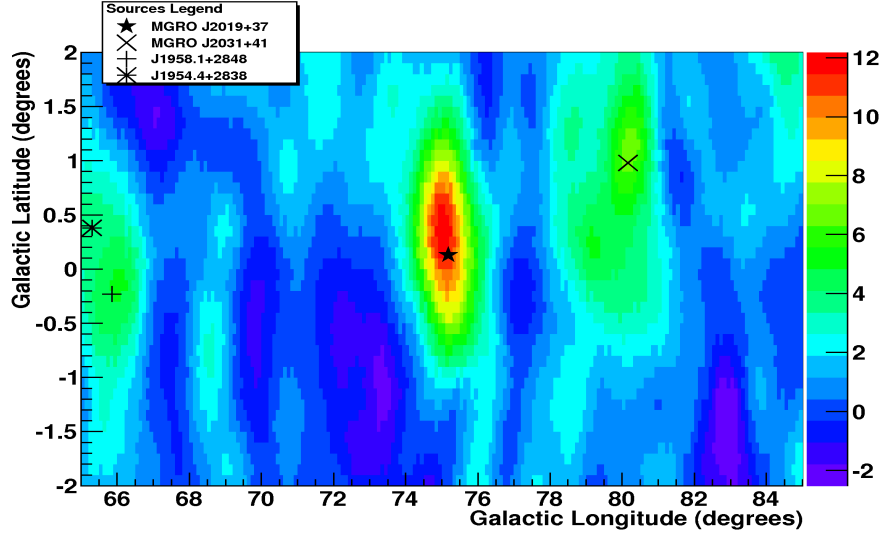


Figure 1: Significance map of the Cygnus region, assuming a simple power law with a differential photon index of $\alpha = 2.6$, based on 906 days of data collected with the Milagro detector after 2004 until the shutdown of the experiment in 2008.

shape of this source with the average differential spectrum of gamma rays in the Cygnus region.

2 Energy Reconstruction

The Milagro Observatory was a large field of view water-Cherenkov detector that was located at 2630 m in the Jemez Mountains near Los Alamos, New Mexico, measuring gamma and cosmic-ray from the northern hemisphere sky with declinations of $\delta \geq -7^\circ$ [8]. Since 2004 the observatory consisted of two components: 1. a central pond instrumented with two layers of photomultipliers (PMTs), a shallow air shower layer of 450 PMTs, and a deep muon layer of 273 PMTs; 2. an array of 175 water tanks where each tank contained one downward pointing PMT. The tank array surrounded the pond and covered an area of about 200 m by 200 m. Only data collected in this detector configuration is used in the present analysis. In Monte Carlo studies it is found that the sum of two fractions, the fraction of photomultipliers in the air shower layer detecting signals from a given air shower, and the fraction of PMTs in the tank array detecting signals from the same air shower, strongly correlates with the original energy of the cosmic or gamma ray:

$$f = \frac{N_{AS}}{N_{AS}^{live}} + \frac{N_{TA}}{N_{TA}^{live}}.$$

Here, N_{AS} and N_{TA} are the number of PMTs with an air shower signal, and N_{AS}^{live} and N_{TA}^{live} are the number of all functional PMT channels, in the air shower layer and the tank array, respectively.

In order to reconstruct the spectrum of the cosmic particles f distributions are simulated for two spectral assumptions,

a simple power law,

$$\frac{dN}{dE}(I_o, \alpha, E_{cut}) = I_o \left(\frac{E}{10 \text{ TeV}} \right)^{-\alpha}$$

and a power law with an exponential cut-off

$$\frac{dN}{dE}(I_o, \alpha, E_{cut}) = I_o \left(\frac{E}{10 \text{ TeV}} \right)^{-\alpha} \exp\left(\frac{-E}{E_{cut}}\right)$$

for a range of values of I_o , α , and E_{cut} . The various simulated f distributions of are then compared to the data distribution by calculating

$$\chi^2(I_o, \alpha, E_{cut}) = \sum_{i=f-bins} \frac{(P_i(I_o, \alpha, E_{cut}, \delta) - M_i)^2}{(dP_i)^2 + (dM_i)^2}.$$

The set of values for I_o , α , and E_{cut} that produces the minimum value of χ^2 represents the energy spectrum that best fits the Milagro data. Subsequently an F-test is performed to determine if one and which of the two spectral assumptions is preferred. The fitting procedure is tested by determining the spectrum of the cosmic ray background using Milagro data and comparing the result to measurements of balloon experiments. The same algorithm is also used for the reconstruction of the spectrum of TeV gamma rays emitted by the Crab Nebula.

Figure 2 shows an example of f distributions for the Cygnus source MGRO 2019+37. The data distribution is plotted in blue, the Monte Carlo distribution of the best spectral fit assumption in case of a simple power law is plotted in yellow.

3 Results

We will present the average gamma-ray spectrum measured in the Cygnus region and compare it with the spectral

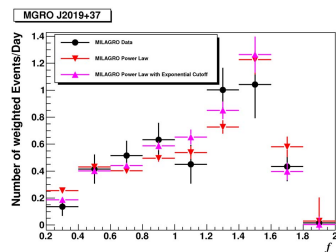


Figure 2: f distributions of MGRO 2019+37. The simulated distribution was derived for power law with an exponential cut-off.

shape of the most significant source in the region MGRO 2019+37. The shape of the spectrum of MGRO 2019+37 will shed more light onto the nature of its gamma-ray emission. A relatively hard spectrum would support the argument that the emission from this object is associated with a pulsar wind nebula. Finally, the event excess map of the area around MGRO 2019+37 will be optimized for the spectral shape that fits the Milagro data best and the map will be compared to measurements at other wavelengths.

4 Acknowledgements

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