



Measuring TeV Gamma-Ray Diffuse Emission from the Galactic Plane with Milagro

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Abstract: Diffuse gamma radiation produced in the interaction of cosmic-ray particles with matter and radiation in the Galaxy can be used for probing the origin of cosmic rays. With its large field of view and long observation time the Milagro Gamma-Ray Observatory – a water Cherenkov detector in New Mexico, USA – is an ideal instrument for surveying large regions of the Northern Hemisphere sky and for detecting diffuse gamma ray emission at the highest energies. In my presentation, I will discuss the diffuse emission from the galaxy as visible from the Northern Hemisphere. In this region, the experiment has previously observed eight sources or source candidates respectively at a median energy of 20 TeV with a pre-trials significance of > 4.5 standard deviations [2]. The fluxes of these locations have been measured and can be subtracted from the total flux measured in the Galactic Plane region to estimate the amount of diffuse emission. The resulting diffuse emission will be reported and compared to predictions of the GALPROP program, which calculates the expected gamma-ray emissivity due to cosmic-ray interactions with matter.

Introduction

The Galactic diffuse γ -ray emission is recognized as one of the most promising probes to study the origin of cosmic rays, since it is believed that it is caused by interactions of cosmic rays with the matter and the radiation fields in the Galaxy. The main production mechanisms of diffuse emission are electron non-thermal Bremsstrahlung, Inverse Compton scattering off the radiation fields and pion decay processes in inelastic collisions of nuclei and matter. However, the measured emission above 1 GeV [10, 12, 13] from the plane exceeds what one predicts based on the the accepted matter density in the plane and cosmic-ray intensity and spectrum measurements. There have been many suggestions to explain this discrepancy, including the contribution of unresolved sources, a varying cosmic-ray spectrum or intensity across the Galaxy [12, 13], or the addition of new production mechanisms such as the annihilation of dark matter particles [8].

At TeV energies, Milagro has previously published an observation of diffuse emission from a large region of the Galactic Plane (Galactic longitudes $40^\circ < l < 100^\circ$) [7] measuring the integral flux

above 3.5 TeV. This measurement has been argued to also be in excess of the predicted diffuse gamma radiation [11]. The most recent publication by Milagro on the subject of diffuse emission studied the Cygnus region [1]. The γ -ray flux from this region measured by Milagro at a median energy of 12 TeV was compared to predictions from the GALPROP model, which calculates the gamma-ray emissivities in every spatial grid point using the propagated spectra of cosmic-rays, leptons and nucleons, the interstellar radiation field, and the gas densities [12, 13]. Even if the GALPROP model is tuned to match EGRET diffuse emission data for the whole sky and reproduces the GeV excess by relaxing the constraints from the local cosmic-ray proton and electron measurement, it clearly underestimates the flux as measured by Milagro [1].

With the observation of TeV gamma-ray sources from a survey of the Galactic Plane with Milagro [2] we are closer to disentangling the truly diffuse emission from that produced by unresolved sources. In our presentation at this conference we will report the diffuse fluxes in various regions after subtracting the fluxes of the newly observed Milagro sources and source candidates. We will

then compare these to predictions of the GALPROP model.

The Milagro Experiment and Data Analysis

Milagro [5] is a water-Cherenkov detector at an altitude of 2650 m capable of continuously monitoring the overhead sky and is composed of a central $60 \text{ m} \times 80 \text{ m}$ pond with a sparse $200 \text{ m} \times 200 \text{ m}$ array of 175 “outrigger” tanks surrounding it. The pond is instrumented with two layers of photomultiplier tubes. The top “air-shower” layer consists of 450 PMTs under 1.4 m of purified water while the bottom “muon” layer has 273 PMTs located 6 m below the surface. The air-shower layer allows the accurate measurement of shower particle arrival times used for direction reconstruction and triggering. The greater depth of the muon layer is used to detect penetrating muons and hadrons. The outrigger array improves the core location and angular resolution of the detector by providing a longer lever arm with which to reconstruct events. The angular resolution improves from $\sim 0.75^\circ$ to $\sim 0.45^\circ$ when outriggers are used in the reconstruction. Milagro’s large field of view ($\sim 2 \text{ sr}$) and high duty cycle ($> 90\%$) allow it to monitor the entire overhead sky continuously, making it well-suited to measuring diffuse emission. In this survey of the Northern Galactic Plane, only events with zenith angle less than 45° are included, which covers declinations north of $\delta = -7^\circ$. In Galactic coordinates, a region of longitude $l \in [30^\circ, 216^\circ]$ and latitude $b \in [-10^\circ, 10^\circ]$ has been studied. The detector accepts events over a wide energy range with most events coming in at the median energy of 20 TeV in this analysis.

The Milagro data were analyzed using the method described in [1]. The event excess is calculated using the background estimation method described in [6] with the modification that each event is now weighted based on the gamma/hadron separation parameter (A_4). The event excess is converted to a flux with a Monte Carlo simulation of extensive air showers using CORSIKA [9] and of the Milagro detector using GEANT4 [3]. By this the changing sensitivity of the Milagro detector with declination is taken into account. The flux from the diffuse

emission in the studied region and the Crab flux are calculated assuming a differential photon spectrum of a power law with spectral index $\alpha = -2.62$ without a cutoff. The fluxes of the seven other sources/source candidates are computed assuming a differential photon spectrum of a power law with spectral index $\alpha = -2.3$ without a cutoff. This is the average spectrum for Galactic sources observed by HESS [4]. The flux of these sources can then be subtracted from the diffuse flux in the Galactic plane region. Since, as mentioned above, 20 TeV is approximately the median energy of the gamma rays detected by Milagro, all fluxes are quoted at this energy.

Preliminary Results

We find that the Cygnus Region is the brightest region of the sky seen by Milagro. In this region the TeV gamma flux is seen with a significance of > 10 standard deviations above the background outside the Galactic Plane. The measured Cygnus flux was compared to the GALPROP prediction and found to be greater than the GALPROP predicted flux for diffuse emission. The GALPROP parameters were chosen to agree with the EGRET diffuse GeV measurements for the plane [12]. The flux measured by Milagro for a region of longitude $l \in [30^\circ, 100^\circ]$ and latitude $b \in [-2^\circ, 2^\circ]$ is also higher than the GALPROP prediction. The source-subtracted diffuse flux and significances in the various regions as well as flux profile plots will be shown in our upcoming presentation.

Acknowledgments

We thank Scott Delay, Michael Schneider, and Owen Marshall for their dedicated efforts on the Milagro experiment. We also gratefully acknowledge the financial support of the National Science Foundation (under grants PHY-0245234, -0302000, -0400424, -0504201, -0601080, and ATM-0002744), the Department of Energy (Office of High Energy Physics), Los Alamos National Laboratory, the University of California, and the Institute for Geophysics and Planetary Physics at Los Alamos National Laboratory.

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