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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 this paper, we 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 [1]. The event excesses of these locations have been measured and can be subtracted from the total event excess measured in the Galactic plane region to estimate the amount of diffuse emission. The resulting diffuse exess of events is converted to a diffuse flux. This flux is 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 [2, 3, 4] 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 [3, 4], or the addition of new production mechanisms such as the annihilation of dark matter particles [5].

At TeV energies, Milagro has previously published an observation of diffuse emission from a large region of the Galactic Plane (Galactic longitudes $40^o < l < 100^o$) [6] measuring the integral flux above 3.5 TeV. This measurement has been argued to also be in excess of the predicted diffuse gamma radiation [7]. The most recent publication by Milagro on the subject of diffuse emission studied the Cygnus region [8]. 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 [3, 4]. 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 Milago [8].

With the observation of TeV gamma-ray sources from a survey of the Galactic Plane with Milagro [1] we are closer to disentangling the truly diffuse emission from that produced by unresolved sources. We report the diffuse fluxes in various regions after subtracting the fluxes of the newly observed Milagro sources and source candidates. We then compare these to predictions of the GALPROP model.

The Milagro Experiment and Data Analysis

Milagro [9] 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 m $\times$ 80 m pond with a sparse 200 m $\times$ 200 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° to $\sim$0.45° when outriggers are used in the reconstruction. Milagro's large field of view ($\sim$2 sr) and high duty cycle ($> 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 $\delta = -7°$. In Galactic coordinates, a region of longitude $l \in [30°, 216°]$ and latitude $b \in [-10°, 10°]$ 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 [8]. The event excess is calculated using the background estimation method described in [10] with the modification that each event is now weighted based on the gamma/hadron separation parameter (A_4). The event excess distributions around the locations of the previously detected eight sources/source candidates [1] are fit to a two-dimensional Gaussian on top of a constant offset. The source location (RA, δ), the amplitude and radial width of the Gaussian, as well as the constant offset are parameters determined through a χ^2 minimization procedure. The excess from each source is calculated from the integral of the resulting Gaussian function and subtracted from the total excess in the Galactic plane region. The resulting diffuse event excess is converted to a flux with a Monte Carlo simulation of extensive air showers using CORSIKA [11] and of the Milagro detector using GEANT4 [12]. 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 is calculated assuming a differential photon spectrum of a power law with spectral index $\alpha = -2.62$ without a cutoff. 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 total TeV gamma flux is seen with a significance of > 10 standard deviations above the background outside the Galactic Plane. The measured diffuse Cygnus flux is compared to the GALPROP [3] prediction and found to be greater than the GALPROP predicted flux for diffuse emission. This can be seen in Figure 1, which shows the measured flux profile by Milagro after source subraction and the predictions from the GALPROP model versus Galactic longitude for a region of latitudes $b \in [-2°, 2°]$. The optimized GALPROP flux profile is also shown in Figure 1. For the optimized model, the GALPROP parameters were chosen to agree with the EGRET diffuse GeV measurements for the plane. The optimized model matches the Milagro data well, except for the region of longitudes $l \in [30°, 85°]$, which includes the Cygnus region. The excess in the data may be an indication for unresolved sources.

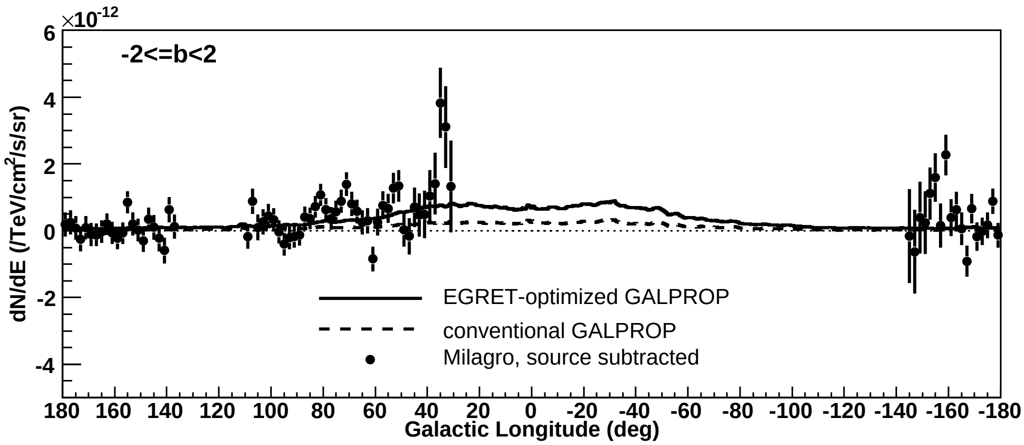

Figure 1: Flux profiles in the Galactic plane as measured by Milagro and predicted by GALPROP

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References

[1] A. A. Abdo, et al., TeV Gamma-Ray Sources from a Survey of the Galactic Plane with Milagro, Astrophys. J. 664 (2007) L91–L94.

[2] S. D. Hunter, et al., Egret observations of the diffuse gamma-ray emission from the galactic plane, Astrophys. J. 481 (1997) 205.

[3] A. W. Strong, I. V. Moskalenko, O. Reimer, A new determination of the extragalactic diffuse gamma-ray background from egret data, Astrophys. J. 613 (2004) 956–961.

[4] A. W. Strong, I. V. Moskalenko, O. Reimer, S. Digel, R. Diehl, The distribution of cosmic-ray sources in the galaxy, gamma-rays, and the gradient in the co-to-h2 relation, Astron. Astrophys. 422 (2004) L47–L50.

[5] W. de Boer, C. Sander, V. Zhukov, A. V. Gladyshev, D. I. Kazakov, Egret excess of diffuse galactic gamma rays as tracer of dark matter, Astron. Astrophys. 444 (2005) 51.

[6] R. W. Atkins, et al., Evidence for tev gamma-ray emission from the galactic plane, Phys. Rev. Lett. 95 (2005) 251103.

[7] T. Prodanovic, B. D. Fields, J. F. Beacom, Diffuse gamma rays from the galactic plane: Probing the 'gev excess' and identifying the 'tev excess', Astropart. Phys. 27 (2007) 10–20.

[8] A. A. Abdo, et al., Discovery of tev gamma-ray emission from the cygnus region of the galaxy, Astrophys. J. 658 (2007) L33–L36.

[9] R. W. Atkins, et al., Milagrito, a tev air-shower array, Nucl. Instrum. Meth. A449 (2000) 478–499.

[10] R. W. Atkins, et al., Observation of tev gamma rays from the crab nebula with milagro using a new background rejection technique, Astrophys. J. 595 (2003) 803–811.

[11] D. Heck, G. Schatz, T. Thouw, J. Knapp, J. N. Capdevielle, Corsika: A monte carlo code to simulate extensive air showersFZKA-6019.

[12] S. Agostinelli, et al., Geant4: A simulation toolkit, Nucl. Instrum. Meth. A506 (2003) 250–303.