DISSECTING THE GALACTIC TeV EXCESS

J. PETROVIĆ[1], T. PRODANOVIĆ[1] and M. KOVAČEVIĆ[2]
[1]*Department of Physics, Faculty of Sciences, University of Novi Sad, Trg Dositeja Obradovi ca 4, 21000 Novi Sad, Serbia*
E–mail: jovana.petrovic@df.uns.ac.rs, prodanvc@df.uns.ac.rs

[2]*Department of Physics and ICRA, Sapienza University of Rome, Piazzale Aldo Moro 5, 00185 Rome, Italy*
E–mail: Milos.Kovacevic@icranet.org

Abstract. Diffuse gamma-ray emission has been studied in detail by the Fermi LAT telescope. Most of the emission comes from the interactions of galactic cosmic rays with the interstellar gas, as well as interactions with fields. However, at least a portion of the emission belongs to unresolved point sources. Another eye-on-the-sky in the past years, focusing on the high energy range (TeV), was the Milagro Cherenkov telescope and its last report of the diffuse Galactic disk emission for the region $30^\circ \leq l \leq 65^\circ, -2^\circ \leq b \leq 2^\circ$ states a gamma-ray differential flux differential flux of $F_{\gamma,\mathrm{diff,MGO}} = 4.1 \pm 1.0 \times 10^{-12}$ photons $\mathrm{TeV}^{-1}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}\,\mathrm{sr}^{-1}$ on 12 TeV, adopting a spectral index of 2.62. We compare this value to the Fermi LAT diffuse model and find an excess in gamma-rays dubbed the TeV excess. After removing all known point sources found in catalogues, such as the Fermi LAT and TeVCat catalogues, the TeV excess remains. Our goal was to give possible explanation of this excess by modeling point source candidates - pulsars and supernova remnants, that are still unresolved.

1. INTRODUCTION

Diffuse gamma emission from our galaxy - the Milky Way, has been measured in the recent years using several telescopes. Most of the measured emission above 1 GeV originates from cosmic ray interactions with the interstellar medium, resulting in neutral pion production and latter decay into two gamma rays. Another dominant source of gamma rays is from leptonic cosmic ray interactions via the inverse Compton scattering and Bremsstrahlung emission. Last guaranteed contributing source are the unresolved point sources. There are still open questions concerning the gamma-ray sky such as the galactic centre gamma-ray excess, as well as the high energy Milagro excess - still unexplained emission of gamma rays in the Milky Way.

Our goal was to give possible explanations for the unresolved excess measured at 12 TeV by the Milagro telescope, taking into account the newest diffuse gamma ray data from the Fermi LAT telescope, as well as all recorded point sources in the area of the sky that was observed by this Cherenkov telescope ($30^\circ \leq l \leq 65^\circ, -2^\circ \leq b \leq 2^\circ$) by modeling point source populations - supernova remnants and pulsars/pulsar wind nebulae.

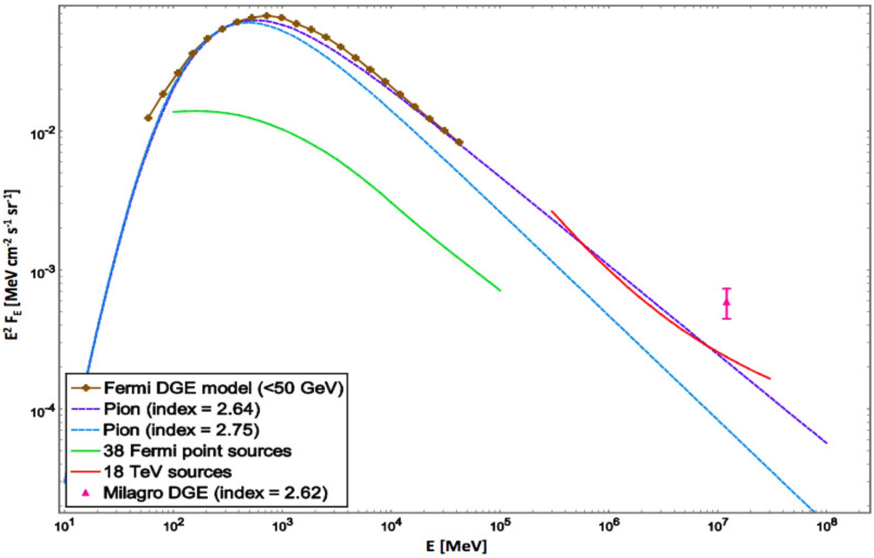

Figure 1: All selected data for the $30° \leq l \leq 65°, -2° \leq b \leq 2°$ sky region, including the Fermi LAT diffuse emission model, 38 Fermi point sources, 18 TeV TeVCat sources and the Milagro 12 TeV data point.

2. DIFFUSE AND POINT SOURCE GAMMA RAY DATA

In our analysis we have used the latest Milagro collaboration data for the Galactic region$30° \leq l \leq 65°, -2° \leq b \leq 2°$ observed above 12 TeV, from where the measured differential gamma ray flux at 12 TeV was derived to be $F_{\gamma,\text{diff,MGO}} = 4.1 \pm 1.0 \times 10^{-12}$ photons $\text{TeV}^{-1}\,\text{cm}^{-2}\,\text{s}^{-1}\,\text{sr}^{-1}$, assuming a spectral index of 2.62. Spectral indices we use are are linked to the gamma-ray flux as $F_{\gamma,\text{diff,MGO}} \sim -\Gamma$, thus taking only positive values. The Fermi LAT Pass 7 Galactic Diffuse Model [1] has been adopted from the Fermi collaboration, and extrapolated over 50 GeV, selecting the data with in the Milagro field of view and our region of interest.

From the measured diffuse flux, we subtract the smoothed contribution of all measured gamma ray point sources in out ROI from the Fermi LAT 4-year Point Source Catalog (3FGL) [2] and the eVCat catalog of TeV sources [3].

In Figure 1. we plot all the data we selected - the Fermi LAT diffuse emission model, 38 Fermi point sources, 18 TeV TeVCat sources and the Milagro 12 TeV data point after subtracting all known point sources (the Milagro excess data point).

[1] http://fermi.gsfc.nasa.gov/ssc/data/access/lat/BackgroundModels.html
[2] https://fermi.gsfc.nasa.gov/ssc/data/access/lat/4yr_catalog/
[3] http://tevcat.uchicago.edu

It can be concluded, that even after subtracting all known sources of gamma rays at high energies, the 12 TeV Milagro data point still stays well above all modeled gamma rays emission coming from diffuse and point source contributions, meaning it still stays unexplained.

3. SOURCE POPULATIONS AS TEV EXCESS EXPLANATIONS

We move to investigating the possibility that the explanation for this excess can be found in the population of unresolved galactic point sources. One of the most commonly identified sources in the Milky Way, that are a good candidate for the Milagro excess explanation, would be unresolved supernova remnants (see e.g. Wakely & Horan 2008).

For Galactic distribution of supernova remnants we take the distribution given in Green 2015, while for their fluxes we adopt a function from Pfrommer and Ensslin 2003, and their luminosity ($L_\gamma \sim -\Gamma + 1$) from the 3FGL Fermi LAT collaboration paper.

We do not at this stage assume any luminosity function but rather leave luminosity as a free parameter doing the analysis with maximal and minimal luminosity take for all sources, that we adopt from what has already been measured for Galactic supernova remnants by Fermi LAT in 3FGL. We also leave spectral index Γ as a free parameter.

We adopt their galactic distributions and luminosity functions, leaving the spectral indices in both cases as a free parameter in order to cover a larger range of potential sources.

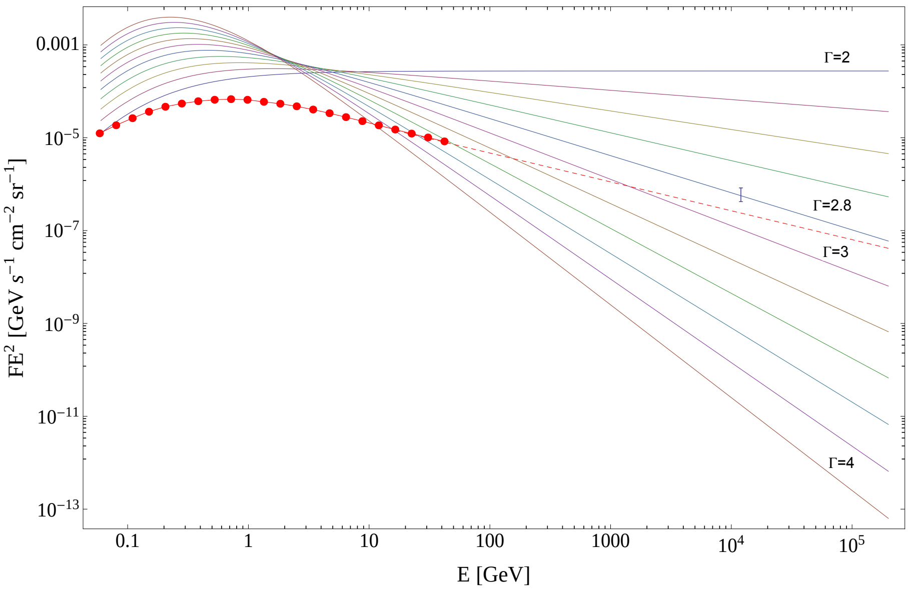

Figure 2: Modeled gamma ray flux for a population of supernova remnants with the maximal luminosity, where the spectral index takes values in the range $2 \leq \Gamma \leq 4$. Red points are the Pass 7 galactic diffuse emission measurement adopted from the Fermi LAT, and extrapolated to higher energies (dashed red), the blue data point is the Milagro 12 TeV excess.

In Figures 2. and 3. we present our results for supernova remnants where we implement the highest and lowest values for their luminosities that we adopt from the 3FGL catalogue of sources. We assume that the production of gamma rays from these sources is purely hadronic in nature and leave the spectral index Γ as a free parameter.

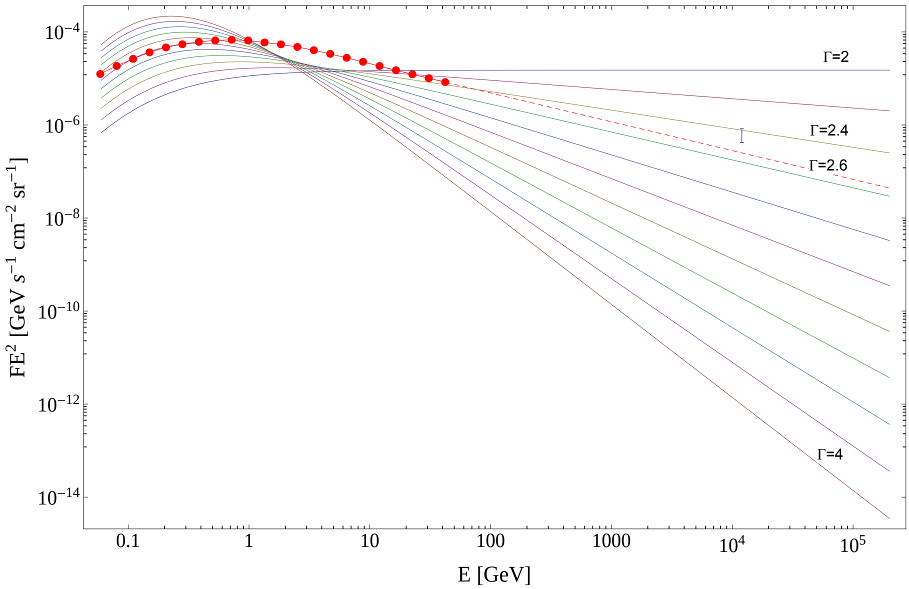

Figure 3: Modeled gamma ray flux for a population of supernova remnants with the minimal luminosity, where the spectral index takes values in the range $2 \leq \Gamma \leq 4$. Red points are the Pass 7 galactic diffuse emission measured by the Fermi LAT, and extrapolated to higher energies (dashed red), the blue data point is the Milagro 12 TeV excess.

As can be concluded from the Figures 2. and 3. above, for certain values of luminosity (minimal luminosity value) and spectral indices ($\Gamma = 2.4$ and $\Gamma = 2.6$), the Milagro excess data point (the Milagro derived flux at 12 TeV from which we subtract all known point sources) is reached by our modeled population of supernova remnants, while not overshooting the measured Fermi LAT diffuse foreground. Therefore we conclude that the Milagro excess could be explained by point sources - in this case supernova remnants, that remain undetected.

We have confirmed the existence of the Milagro gamma-ray TeV excess in the light of the most recent data from both the Milagro collaboration, the Fermi LAT Pass 7 diffuse galactic emission and 3FGL, as well as TeVCat point source data. We then modeled a population of sources that could potentially explain this excess in gamma rays - supernova remnants adopting their Galactic distribution and fluxes, varying the luminosity function value and spectral indices. We see that for some choices of the free parameters supernova remnants can indeed reach, and thus explain, the Milagro excess data point at 12 TeV.

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