

The Galactic Center region, as seen by Fermi-LAT

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Abstract. The Galactic Center is among the richest and most complex regions in the Galaxy, due to the number of possible sources and the difficulty to correctly model the diffuse emission due to cosmic ray interaction with the local molecular clouds complex. Despite detection in the GeV (EGRET) and TeV range (H.E.S.S.), an accurate description of the high-energy emission in that region still eludes us.

The Fermi Gamma-ray Space observatory (hereafter Fermi) has been successfully launched on June 11 2008, and is currently performing a one-year all sky survey. We report here on the observation of the Galactic Center region with Fermi Large Area Telescope (LAT), a pair conversion detector designed to study the gamma-ray sky in the energy range 20 MeV to more than 300 GeV, with unprecedented sensitivity and resolution.

In this talk we describe Fermi measurements of diffuse GeV-band gamma-ray emission from the Galactic Center region, including the search for dark-matter annihilation signals.

Keywords: Dark Matter, Gamma Rays, Galactic Center

I. THE LARGE AREA TELESCOPE

The Fermi Gamma-ray Space Telescope is an observatory for the study of gamma-ray emission from astrophysical sources. Fermi has two main instruments:

- 1) the Large Area Telescope (LAT), a gamma-ray imager operating in the energy band between 20 MeV and 300 GeV;
- 2) the Gamma Ray Burst Monitor (GBM), a detector covering the 8 keV-40 MeV energy range, devoted to the study of the Gamma Ray Bursts.

A detailed description of Fermi, which was previously known as GLAST, is [2] and [1].

Previous studies of the gamma-ray sources in the LAT energy band were performed with the Energetic Gamma Ray Experiment Telescope (EGRET) onboard of the Compton Gamma Ray Observatory between 1991 and 2000. EGRET detected 271 sources [3], an half of which unidentified, mainly because of the relatively large errors associated with the source location. The majority of the identified EGRET sources are pulsars (spinning neutron stars, with powerful magnetic field, capable to accelerated particles up to the high energy regime) or Flat Spectrum Radio Quasars and Blazars (active galactic nuclei, with relativistic jets of plasma). Furthermore diffuse galactic and extra-galactic gamma-ray emission was detected with EGRET.

The LAT instrument has an effective area \approx five times larger and a much better angular resolution, if compared with EGRET, then Fermi has a sensitivity \approx 30 times better than its predecessor. Fermi has several scientific objectives, which span many topics of astrophysics and fundamental physics:

- 1) the detailed study of pulsar (for example [4] and [5]), AGNs (for example [6]), diffuse emissions and gamma-ray emission from nearby bodies;
- 2) the study of Gamma Ray Bursts, up to GeV energies with the LAT and in the better studied keV- MeV range by means of the GBM (for example [7]);
- 3) the search for new classes of gamma-ray emitters;
- 4) the possible signals of new physics. The indirect search for Dark Matter particles and the investigation of their nature are major research topics for Fermi;

An international collaboration was set up in order to build and operate Fermi. This collaboration is made of more than 300 members, both astrophysicists and particle physicists, coming from institutions of France, Germany, Italy, Japan, Sweden and United States of America. Fermi was launched the 11th June of 2008, with a Delta II 7920H rocket, and it is foreseen to be operated for 10 years.

II. THE INDIRECT SEARCH FOR DARK MATTER FROM THE GALACTIC CENTER

The estimated Universe energy content [9] is : 4% of baryonic *ordinary* matter, 23% of *Dark Matter* (DM) and 73% of *Dark Energy*. DM is gravitationally coupled with ordinary matter, other details of DM nature are unknown. There are several evidences of the DM existence: galaxies rotation velocities [10]; galaxies orbital velocities within clusters[11]; gravitational lensing [12]; the cosmic microwave background [13]; light elements abundances [14]; and large scale structures [15]. Non-gravitational DM couplings are studied with: (1) the search for DM scattering on ordinary matter; (2) the indirect study of DM annihilation via the secondary products, both charged and neutral (e^+ , \bar{p} , \bar{d} , ν , γ rays and lower frequency electro-magnetic radiation), if DM particles self-annihilate and produce quarks, leptons and gauge bosons.

The annihilating DM γ -ray flux, from the Galactic Center (GC) can be expressed as:

$$\Phi_{DM} = \sum b_i \frac{dN_{\gamma,i}}{dE_{\gamma}} \frac{\sigma v}{8\pi m_X^2} \int_{los} \rho^2(l) dl$$

where $\langle \sigma v \rangle$ is the DM annihilation cross section times the relative particles velocities, m_X = DM particle mass, $\rho(r)$ = DM density as a function GC distance, the integral is performed along the line-of-sight, $\frac{dN_\gamma}{dE_\gamma}$ = annihilation γ -ray yield and b_i the branching ratio. Another possibility is to have gamma-rays from decaying dark matter (for example see [16]). In such a scenario the gamma-ray flux will scale as the density, not the density squared.

DM forms halos with central density enhancements and the Milky Way is embedded in one of such structures. The galactic density profile is commonly parametrized as

$$\rho(r) = \frac{\rho_0}{(r/R)^\gamma (1 + (r/R)^\alpha)^{(\beta-\gamma)/\alpha}}$$

with $R \approx 20$ kpc as scale radius, ρ_0 fixed such as the DM density = 0.3 GeV/cm^3 in the Sun region. The other three parameters are defining the profile type: Navarro-Frenk-White (NFW, [17]) has $\alpha=1, \beta=3, \gamma=1$; Moore profile [18] has $\alpha=1.5, \beta=3, \gamma=1.5$. Recently other possible Dark Halo density profiles were suggested ([19] and references therein). The density profile is essential for the DM indirect study in the γ -ray channel as:(1) the γ -ray flux goes as ρ^2 and can be above or below the detection threshold as function of the profile type; (2) some density profiles might be detected as extended sources.

III. ANALYSIS METHODS FOR THE DARK MATTER INDIRECT SEARCH WITH FERMI

Before the launch of Fermi, the estimate of the LAT sensitivity to the detection of annihilating Dark Matter emission, was based on detailed MonteCarlo simulations of the detector and of the Dark Matter source. General assumptions on the possible Dark Matter particle candidates were used.

Experimental data, with large statistics are available, after the beginning of satellite operation. The standard analysis for the LAT data can be applied for a basic study of the Galactic Center region in order to: (1) detect the γ -ray sources in the region; (2) try to identify them; (3) study the diffuse γ -ray emissions.

Main steps of such an analysis are:

- to select data of high quality (selection cuts on events energy, zenith angle, reconstruction and classification quality);
- to build a emission model of the region, based on the previous knowledge and experimental evidence of new excesses with enough statistical significance;
- to apply the likelihood analysis to the data and the considered model.

A further step is the search for γ -ray emission which might be originated by annihilating Dark Matter. The signatures, suggested by the current theories on the Dark Matter are then exploited (see for example [20], [29] and references therein).

A. Pre-launch Expectations

The Fermi Gamma Ray Satellite sensitivity for DM indirect searches was investigated in [21]. For the GC the DM mass was considered between 10 and 1000GeV, while the $\langle \sigma v \rangle$ parameter between 0.5 and $100 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1}$. The Galactic diffuse emission (both conventional and optimized GALPROP models, see ref. in [21]) was assumed as background and a χ^2 analysis was applied. Some of the obtained results for the GC are reported in table 1.

TABLE I
LAT SENSITIVITY IN THE $\langle \sigma v \rangle$ VS ENERGY PLANE. IN THIS TABLE THE MINIMUM DETECTABLE $\langle \sigma v \rangle$, WITH 3 STANDARD DEVIATIONS CONFIDENCE LEVEL AND IN 5 YEARS OF LAT OPERATION, AS A FUNCTION OF THE ENERGY, ARE REPORTED. RESULTS FROM FIGURES 5, 6, 7 OF [21].

Annihilation Channel	DM Mass (GeV)	$\langle \sigma v \rangle$ $10^{-26} \text{ cm}^3 \text{ s}^{-1}$
$b\bar{b}$	10	0.7
$b\bar{b}$	100	4
$t\bar{t}$	100	10
$t\bar{t}$	1000	80
W^+W^-	100	15
W^+W^-	650	90
$\tau^+ \tau^-$	100	10

B. Preliminary MonteCarlo Study

The γ -ray events, expected from annihilating Dark Matter, were calculated by means of a preliminary MonteCarlo study [22].

For this study the Galactic Diffuse emission and the all the known astrophysical γ -ray sources were included in the background model. Furthermore the Maximum Likelihood Analysis was applied, because this analysis type is sensitive to the source spatial distribution.

The Dark Matter γ -ray spectrum was obtained with the DarkSusy code. Dark Matter particles with mass = 50, 241 and 500GeV were considered. Both the Navarro-Franck-White [17] and the Adiabatic NFW [37] Dark Matter density profile were used, for the source spatial distribution. The $\langle \sigma v \rangle$ value was fixed at $3 \times 10^{-26} \text{ cm}^3 \text{ s}^{-1}$, and the $b\bar{b}$ annihilation channel was assumed. The simulations and the likelihood analysis were performed by means of the Fermi *ScienceTools*, which were developed by the Fermi LAT collaboration.

For each DM source realization the absolute number of detected γ rays was obtained (Fig 1 and 2). For example in 30Ms, a DM source with DM mass = 50GeV and NFW profile (DM50NFW) yielded 280 counts, a DM source with DM mass = 500GeV and Adiabatic NFW profile (DM500ADB) yielded 2136. In the same time 19710 background counts were detected.

The likelihood was applied to single components and in a second time to the GC region with all the simulated emission components. The fit parameters of the main sources were fixed. With real data, the DM search requires thorough understanding of the involved astrophysical backgrounds. Some of the benchmark DM

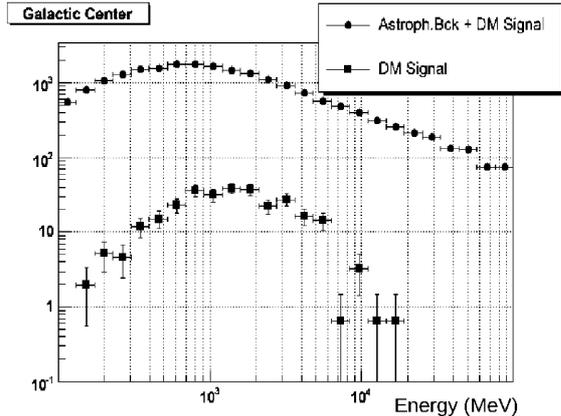


Fig. 1. Counts versus Energy, for a realizations of a Dark Matter source in the Galactic Center. Dark Matter particles with mass of 50GeV and a NFW spatial distribution are simulated. Plots from [22].

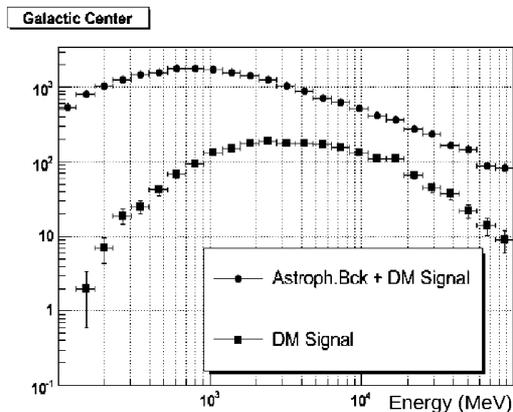


Fig. 2. Counts versus Energy, for a realizations of a Dark Matter source in the Galactic Center. Dark Matter particles with mass 500GeV and an adiabatically contracted NFW distribution are simulated. Plots from [22].

sources were then detected, for example DM50NFW was detected above 5σ in 30Ms, while DM500ADB at 9σ in 6Ms. These relatively realistic simulations demonstrate: (1) the likelihood analysis is well suited for the GC γ -ray study; (2) for a couple of DM benchmarks the detection is feasible within one year.

C. Bright Gamma-Ray Sources near the Galactic Center

With the Large Area Telescope the majority of the charged particles background is rejected at the level of the data reduction.

Then one is left with:

- γ rays coming from the source under study, i.e. the signal;
- γ rays coming from other sources, both diffuse emissions and resolved sources close to the one under study, i.e. a *astrophysical γ -ray background*.

In the Galactic Center region the γ -ray background, for the Dark matter study, is produced by many bright sources. The most relevant sources in the 100MeV-100GeV range and in the band above 100GeV (studied

with the ground based Imaging Atmospheric Cherenkov Telescopes, IACTs) are:

- the Galactic Diffuse emission. This is the main emission in the gamma-ray sky. It is originated in the interactions of energetic Cosmic Rays, mainly protons and electrons, with the interstellar gas and radiation field. The Galactic diffuse emission is the most important background for the study of gamma-ray sources in the Galactic Center region. The EGRET measurements of the Galactic Diffuse emission are in [36].
- 3 sources of the Fermi Bright Sources List [8], which have $-5^\circ < l < 5^\circ$ and $-5^\circ < b < 5^\circ$ and were detected with a statistical significance higher than 10σ with the data collected with the LAT in 3 months. They are listed in table 2.
- 0FGL J1746.0-2900 is likely associated to 3EG J1746-2851, an unidentified EGRET source, close to SgrA*, see [23] and [24], with a flux $F(E>100 \text{ MeV})=(118.6\pm 73)\times 10^{-8}\text{cm}^{-2}\text{s}^{-1}$. The source was also consider a possible Dark Matter gamma-ray emission in [25];
- the TeV source in the Galactic Center (HESS J1745-290), a bright source above the 100 GeV, detected by many IACTs, most recently by HESS [26] and MAGIC [27]. The source has a steady flux with a power-law spectrum, with photon index $\Gamma=2.25\pm 0.04$. HESS data disfavour an interpretation of this source as a Dark Matter gamma-ray emission, if Dark Matter particles with mass above 10TeV are not considered [35]. The identification of this source is still pending, although the source is located in the same region of the Milky Way central black hole. The association with the SgrA East complex seems excluded [32], while a the pulsar wind nebula PWN G359.95-0.04 has been recently discovered [33].
- HESS J1747-281, associated with the supernova remnant G0.9-0.1, detected with HESS [34], the source has photon index $\Gamma=2.39\pm 0.07$.
- the TeV Diffuse Emission, discovered with HESS [28], possibly associated with dense molecular clouds, in the Galactic Center region.

IV. DISCUSSION

The Galactic Center hosts the main DM density enhancement of the Milky Way and a relatively large γ -ray signal from annihilating DM is expected. The main issue for the detection of a annihilating DM γ -ray signal, from the Galactic Center, with LAT, is the large γ -ray background. The likelihood analysis is able to detect sub-dominant sources, but requires a detailed background model. Then one of the main aspect of the Galactic Center observations analysis is the galactic diffuse emission modeling, both for the spectrum and for the spatial distribution. The galactic diffuse emission map, with the best possible resolution, will be needed, in order to check the possible extension of the γ -ray

TABLE II

SOURCES OF THE FERMI BRIGHT SOURCES LIST [8], WITH $5^\circ < L < 5^\circ$ AND $-5^\circ < B < 5^\circ$. THE SOURCE IDENTIFIER, THE LONGITUDE, THE LATITUDE, THE 95% CONTAINMENT RADIUS AND THE INTEGRAL FLUX BETWEEN 1 AND 100 GeV, ARE REPORTED.

Source	l ($^\circ$)	b ($^\circ$)	θ_{95} ($^\circ$)	Int.Flux($1 < E < 100$ GeV) $\text{cm}^{-2}\text{s}^{-1} 10^{-8}$
0FGL J1732.8-3135	356.287	0.920	0.087	3.890 ± 0.33
0FGL J1741.4-3046	357.959	-0.189	0.197	2.00 ± 0.31
0FGL J1746.0-2900	359.988	-0.111	0.068	7.92 ± 0.47

emission from the Galactic Center (for example for 0FGL J1746.0-2900). Furthermore a study of the possible diffuse emission structures, might be important.

Also correct modeling of the resolved γ -ray sources is important. Then the search for the DM γ -ray signal will exploit two main features:

- the annihilating DM γ -ray spectrum is quite distinctive, and does not resemble the power-law form observed from typically astrophysical sources;
- the DM particles distribution is not producing a point-like γ source, nor a diffuse source which traces the Galactic Ridge.

An update of the Galactic Center observation analysis, and of the search for indirect γ -ray emission from annihilating DM will be presented at the 31st International Cosmic Ray Conference.

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