PROCEEDINGS OF SCIENCE

The high energy view of the galactic center

Aldo Morselli[*] **INFN Roma Tor Vergata**

E-mail: `aldo.morselli@roma2.infn.it`

The inner region of the Milky Way Galaxy is one of the most interesting and complicated regions of the gamma ray sky because of the many point sources and potential confusion, the uncertainties associated with the diffuse gamma-ray emission, together with the potential for dark matter detection. Successfully launched in June 2008, the Fermi Gamma-ray Space Telescope, formerly named GLAST, has been observing the high-energy gamma-ray sky with unprecedented sensitivity in the 20 MeV - 300 GeV energy range. Here we report the status of the analysis of the galactic center region with the *Fermi* γ-ray Space Telescope.

The Extreme and Variable High Energy Sky - extremesky2011,
September 19-23, 2011
Chia Laguna (Cagliari), Italy

---

[*] Speaker.

PoS(Extremesky 2011)042

1. The Large Area Telescope on-board of *Fermi*

The *Fermi* γ-ray Space Telescope (*Fermi*) was launched on June 11, 2008 and began operations on August 11, 2008. The observatory carries two instruments for the study of γ-ray emission from astrophysical sources: the Large Area Telescope (LAT) and the γ-ray Burst Monitor (GBM). LAT is the primary instrument and is a pair-conversion telescope. It is composed of a 4×4 array of equal modules (towers) and surrounded by a segmented anti-coincidence detector (ACD). Each tower is made of a precision silicon-strip tracker (36 layers arranged in 18 X-Y pairs alternating with W converter layers and a calorimeter. The calorimeter is a hodoscopic configuration of 8.6 radiation lengths (X_0) of CsI crystals that allows imaging of the shower development in the calorimeter and thereby corrections of the energy estimate for the shower leakage fluctuations out of the calorimeter. The total thickness of the tracker and calorimeter is approximately 10 X_0 (1.5 X_0 for the tracker and 8.6X_0 for the calorimeter) at normal incidence. The ACD covers the tracker array, and a programmable trigger and data acquisition system uses prompt signals available from the tracker, calorimeter and ACD to form a trigger that initiates readout of these three subsystems. The on-board trigger is optimized for rejecting events triggered by cosmic-ray background particles while maximizing the number of events triggered by γ-rays, which are transmitted to the ground for further processing. The second instrument is the γ-ray Burst Monitor (GBM), which is a detector covering the 8 keV-40 MeV energy range, devoted to the study of the γ-ray Bursts. GBM complements the LAT for observations of high-energy transients. The GBM consists of two sets of six low-energy (8 keV to 1 MeV) NaI(Tl) detectors and a high-energy (0.2 to 40 MeV) BGO detector. Detailed descriptions of the *Fermi* observatory can be found in [1] and the LAT on-orbit calibration is reported in [2].

Over the first three years of mission the LAT collaboration has put a considerable effort toward a better understanding of the instrument and of the environment in which it operates. In addition to that a continuous effort was made to in order to make the advances public as soon as possible. In August 2011 the first new event classification (Pass 7) since launch was released, along with the corresponding Instrument Response Functions. Compared with the pre-launch (Pass 6) classification, it features a greater and more uniform exposure, with a significance enhancement in acceptance below 100 MeV.

The Second Fermi-LAT catalog (2FGL) [4] is the deepest catalog ever produced in the energy band between 100 MeV and 100 GeV. Compared to the First Fermi-LAT (1FGL) [3] , it features several significant improvements: it is based on data from 24 (vs. 11) months of observation and makes use of the new Pass 7 event selection. The energy flux map is shown in figure 1. In the catalog 127 sources of the 1873 sources are firmly identified, based either on periodic variability (e.g. pulsars) or on spatial morphology or on correlated variability. In addition to that 1170 are reliably associated with sources known at other wavelengths, while 576 (i.e. 31% of the total number of entries in the catalog) are still unassociated.

The high-energy gamma-ray sky is dominated by diffuse emission: more than 70% of the photons detected by the LAT are produced in the interstellar space of our Galaxy by interactions of high-energy cosmic rays with matter and low-energy radiation fields. An additional diffuse component with an almost-isotropic distribution (and therefore thought to be extragalactic in origin) accounts for another significant fraction of the LAT photon sample. The rest consists of vari-

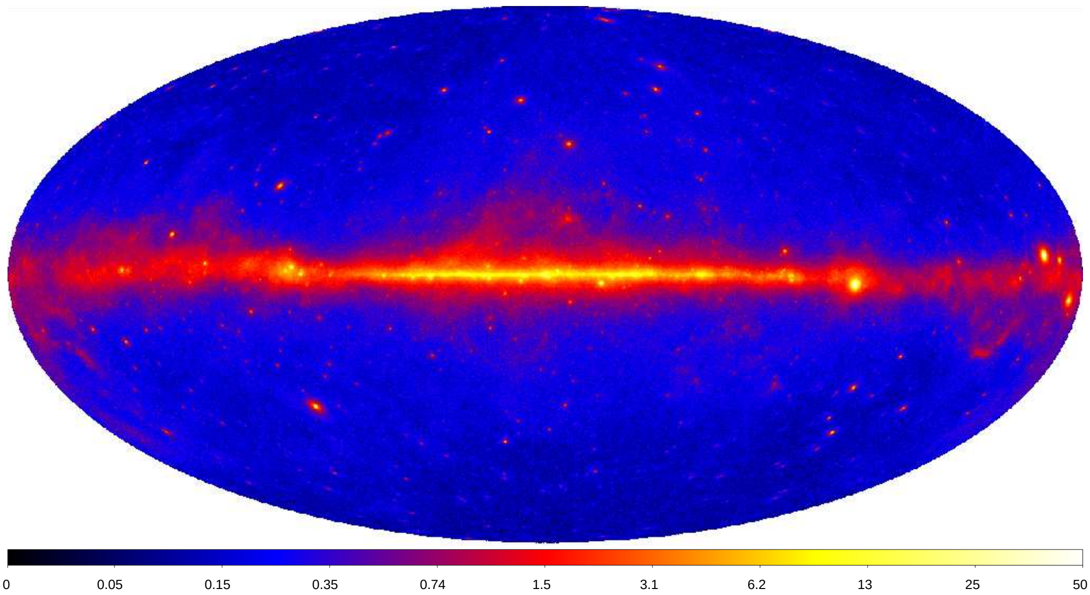

Figure 1: Sky map of the energy flux derived from 24 months of observation. The image shows γ-ray energy flux for energies between 100 MeV and 10 GeV, in units of 10^{-7} erg cm^{-2} s^{-1} sr^{-1}.

ous different types of point-like or extended sources: Active Galactic Nuclei (AGN) and normal galaxies, pulsars and their relativistic wind nebulae, globular clusters, binary systems, shock-waves remaining from supernova explosions and nearby solar-system bodies like the Sun and the Moon.

2. The Indirect Search for DM with High Energy γ rays

One of the major scientific objectives of the LAT is the indirect search for dark matter (DM), by means of the production of secondary γ-rays after the annihilation (or decay) of the DM particle candidates. The search strategy, which was assessed with a detailed study [5], comprises the study of targets with an expected relatively large γ-ray signal (such as the Galactic Center, which was previously studied with EGRET data [6]), or with a very low foreseen conventional γ-ray emission [7], [8], the search for annihilation lines [9] and also the search of possible anisotropies generated by the DM halo substructures [10]. The indirect DM searches with γ rays are complemented with those performed with the detection of cosmic-ray electrons by the LAT [11], [12]. In models in which DM is characterized by weak-scale interaction cross-sections (WIMP DM), DM particles can produce a gamma-ray signal by pair annihilation.

Numerical cosmological simulations have proven to be a fundamental tool in the study of DM. Being weakly interacting, DM can be very well approximated by a collisionless fluid, its dynamics being driven only by the gravitational interaction. However, high non-linearity makes it impossible to study analytically its dynamics and the evolution of its distribution, and numerical simulations become essential. These have shown that large amounts of DM accumulate in the center of galactic halos. The center of our Galaxy is therefore the closest and brightest source of gamma-rays coming from annihilating DM and a very promising target for DM searches. Over the

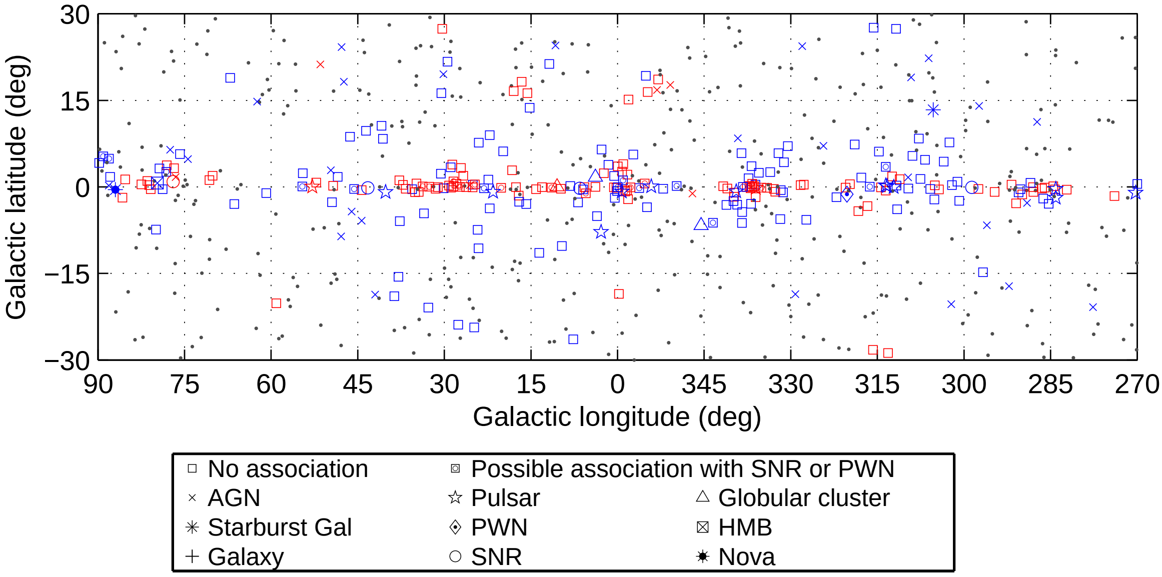

Figure 2: Map of the Inner Galactic region in the 100 MeV to 100 GeV energy range showing sources by source class. Identified sources are shown with a red symbol, associated sources in blue. Sources with no flag set are shown as small dots.

last years, the development of new numerical algorithms and simulation codes together with the rapid progress in computer technology have permitted to increase the resolution of cosmological simulations by several orders of magnitude and to produce some of the current state-of-the-art cosmological simulations, such as Via Lactea [13], GHALO [14] or Aquarius [15]. These confirm that the inner density profiles of halos are well fitted by functions which are steeper and cuspier than the traditionally used Navarro Frenk and White profile [16]. However, moving yet further towards the center of the halos, predictions on the dark matter and total mass distribution require a realistic treatment of the baryons and their dynamical interactions with the DM. Indeed, the presence of baryons and the physical processes in which they are involved, dramatically affect the distribution of DM in galaxies. In particular, the DM density profiles can steepen through the adiabatic contraction due to dissipating baryons. This adiabatic contraction can be implemented analytically within halo models obtained in collisionless DM simulations, or one can attempt to include baryons in numerical simulations, as done, e.g. within the CLUES project [17]. However, there is still a large uncertainty on how baryons affect the distribution of DM in the center of our Galaxy, which needs to be taken into account when trying to disentangle a DM signal from the galactic center.

3. Results on Indirect Search from the Galactic Center

The map of the Inner Galactic region in the 100 MeV to 100 GeV energy range is shown in figure 2 [4]. A preliminary spectral analysis of first 11 months of *Fermi* LAT observations (August 2008 - July 2009) is shown in figures 3 and 4. The binned likelihood analysis was performed with the analysis software developed by the *Fermi* LAT collaboration (gtlike, from the *Fermi* analysis

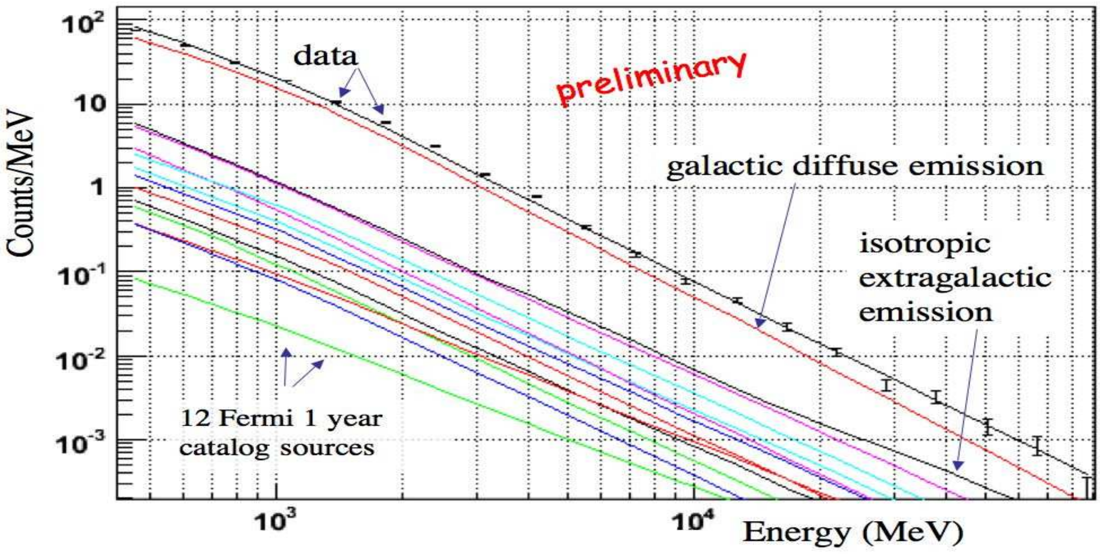

Figure 3: Spectra from the likelihood analysis of the *Fermi* LAT data (number of counts vs reconstructed energy) in a 7°×7° region around the Galactic Center (number of counts vs reconstructed energy)

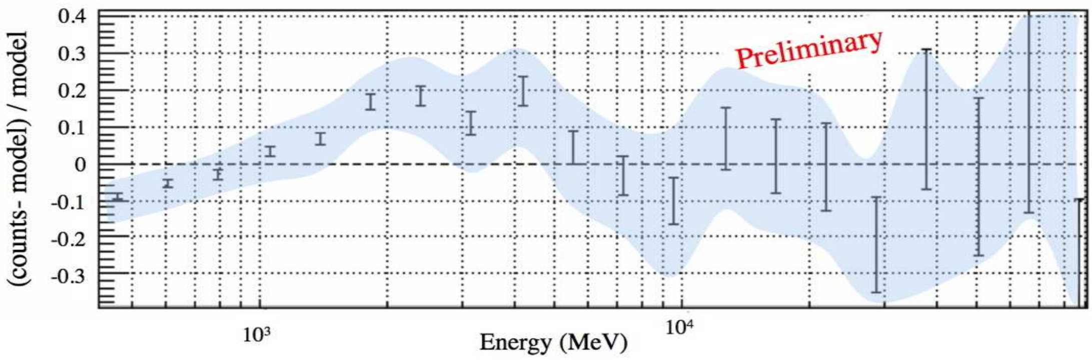

Figure 4: Residuals ((exp.data - model)/model) of the above likelihood analysis. The blue area shows the systematic errors on the effective area.

tools [18]). For this analysis a region of interest (RoI) of 7°×7° was considered in order to minimize the diffuse backgrounds contributions. The RoI was centered at the Galactic Center position at RA = 266.46°, Dec=-28.97°. The events were selected to have an energy between 400 MeV and 100 GeV, to be of the "diffuse" class (high purity sample) and to have converted in the *front* part of the tracker. The selection conditions provided us with events with very well reconstructed incoming direction (for further details see [19], [20]).

As one can see from figures 3 and 4 the diffuse γ-ray backgrounds and discrete sources, as we know them today, can account for the large majority of the detected γ-ray emission from the Galactic Center. Nevertheless a residual emission is left, not accounted for by the above models. Improved modelling of the Galactic diffuse model as well as the potential contribution from other astrophysical sources (for instance unresolved point sources) could provide a better description of the data. Analyses are underway to investigate these possibilities.

Acknowledgments

The *Fermi* LAT Collaboration acknowledges support from a number of agencies and institutes for both development and the operation of the LAT as well as scientific data analysis. These include NASA and DOE in the United States, CEA/Irfu and IN2P3/CNRS in France, ASI and INFN in Italy, MEXT, KEK, and JAXA in Japan, and the K. A. Wallenberg Foundation, the Swedish Research Council and the National Space Board in Sweden. Additional support from INAF in Italy and CNES in France for science analysis during the operations phase is also gratefully acknowledged.

References

[1] W.B.Atwood *et al.* [Fermi Coll.] ApJ 697 No 2 (2009 June 1) 1071-1102 [arXiv:0902.1089]

[2] A.Abdo *et al.* [Fermi Coll.] Astroparticle Physics 32 (2009) 193-219 [arXiv:0904.2226]

[3] A.Abdo *et al.*[Fermi Coll.] Astrophys. J. Suppl. Series 188, 405 (2010) [arXiv:1002.2280]

[4] A.Abdo *et al.* [Fermi Coll.] submitted to Astrophys. J. Suppl. Series [arXiv:1108.1435]

[5] E. Baltz *et al.* , JCAP07 (2008) 013 [arXiv:0806.2911]

[6] A.Cesarini, F.Fucito, A.Lionetto, A.Morselli, P. Ullio, Astropart. Phys. 21 (2004) 267 [astro-ph/0305075]

[7] A.Abdo *et al.* [Fermi Coll.] ApJ 712 (2010) 147-158 [arXiv:1001.4531]

[8] M.Ackermann *et al.* [Fermi Coll.] 2011, PRL accepted [arXiv:1108.3546]

[9] A.Abdo *et al.* [Fermi Coll.], Phys.Rev.Lett.104, 091302-08 (2010) [arXiv:1001.4836]

[10] M.Ackermann *et al.* [Fermi Coll.], Physical Review D 82, 092003 (2010) [arXiv:1008.5119]

[11] A.A.Abdo *et al.* [Fermi Coll.], PRL 102, 181101 (2009) [arXiv:0905.0025]

[12] M.Ackermann *et al.* [Fermi Coll.], PRD 82, 092004 (2010) [arXiv:1008.3999]

[13] J.Diemand *et al.* Nature 454 2008 735 [arXiv:0805.1244]

[14] J.Stadel *et al.* (2008) [arXiv:0808.2981]

[15] V.Springel *et al.* Mon.Not.Roy.Astron.Soc.39120081685-1711 [arXiv:0809.0898]

[16] J.Navarro, J.Frenk, S.White Astrophys. J. 4621996 563 [arXiv:astro-ph/9508025]

[17] http://www.clues-project.org

[18] http://*Fermi*.gsfc.nasa.gov/ssc/data/analysis/ software/

[19] V.Vitale and A. Morselli for the Fermi/LAT Collaboration, 2009 Fermi Symposium [arXiv:0912.3828]

[20] A.Morselli, B.Cañadas, V.Vitale, Il Nuovo Cimento Vol. 34 C, N. 3 (2011) [arXiv:1012.2292]