

Search for Dark matter in the sky in the Fermi era

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DOI: http://dx.doi.org/10.3204/DESY-PROC-2009-05/morselli_aldo

The Fermi Large Area Telescope is providing the measurement of the high energy (20 GeV to 1 TeV) cosmic ray electrons and positrons spectrum with unprecedented accuracy. This measurement represents a unique probe for studying the origin and diffusive propagation of cosmic rays as well as for looking for possible evidences of Dark Matter. In this framework, we discuss possible interpretations of Fermi results in relation with other recent experimental data on energetic electrons and positrons and in the searches of gamma-ray fluxes coming from WIMP pair annihilations in the sky.

1 Electron and positron flux

Recently the experimental information available on the Cosmic Ray Electron (CRE) spectrum has been dramatically expanded as the Fermi-LAT Collaboration [1, 2] has reported a high precision measurement of the electron spectrum from 20 GeV to 1 TeV performed with its Large Area Telescope (LAT) [3]. The spectrum shows no prominent spectral features and it is significantly harder than that inferred from several previous experiments. These data together with the PAMELA data on the rise above 10 GeV of the positron fraction[4] are quite difficult to explain with just secondary production [5],[6], [7]. The temptation to claim the discovery of dark matter is strong but there are competing astrophysical sources, such as pulsars, that can give strong flux of primary positrons and electrons (see [8], [9], [10], [11] and references therein). At energies between 100 GeV and 1 TeV the electron flux reaching the Earth may be the sum of an almost homogeneous and isotropic component produced by Galactic supernova remnants and the local contribution of a few pulsars with the latter expected to contribute more and more significantly as the energy increases.

Two pulsars, Monogem, at a distance of $d=290$ pc and Geminga, at a distance of $d=160$ pc, can give a significant contribution to the high energy electron and positron flux reaching the Earth and with a set of reasonable parameters of the model of electron production we can have a nice fit of the PAMELA positron fraction[4] and Fermi data (see figures 1 and 2) , but it is true that we have a lot of freedom in the choice of these parameters because we still do not know much about these processes, so further study on high energy emission from pulsars are needed in order to confirm or reject the pulsar hypothesis.

Nevertheless a dark matter interpretation of the Fermi-LAT and of the PAMELA data is still an open possibility. In Figure 3 is shown the parameter space of particle dark matter mass versus pair-annihilation rate, for models where dark matter annihilates into monochromatic e^\pm [11]. The preferred range for the dark matter mass lies between 400 GeV and 1-2 TeV, with

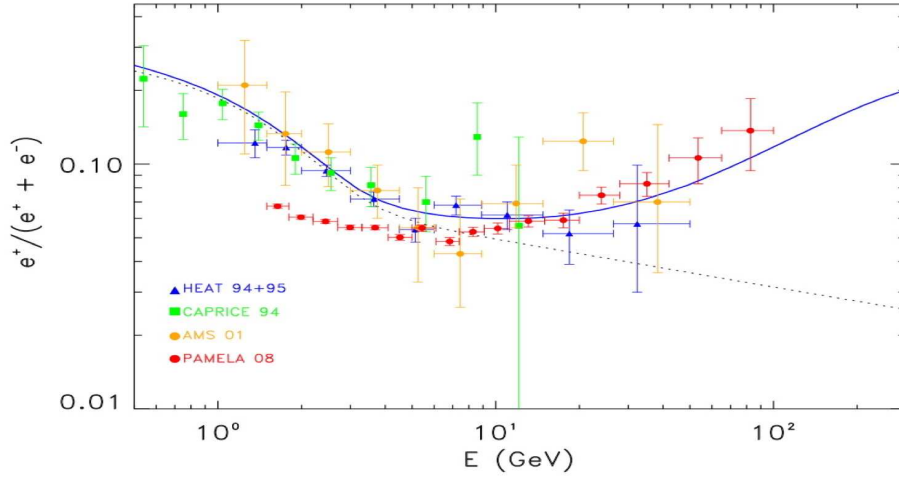


Figure 1: PAMELA data and a possible contribution from Monogem and Geminga pulsars [11]. Black-dotted line shows the background from secondary positrons in cosmic rays from GALPROP

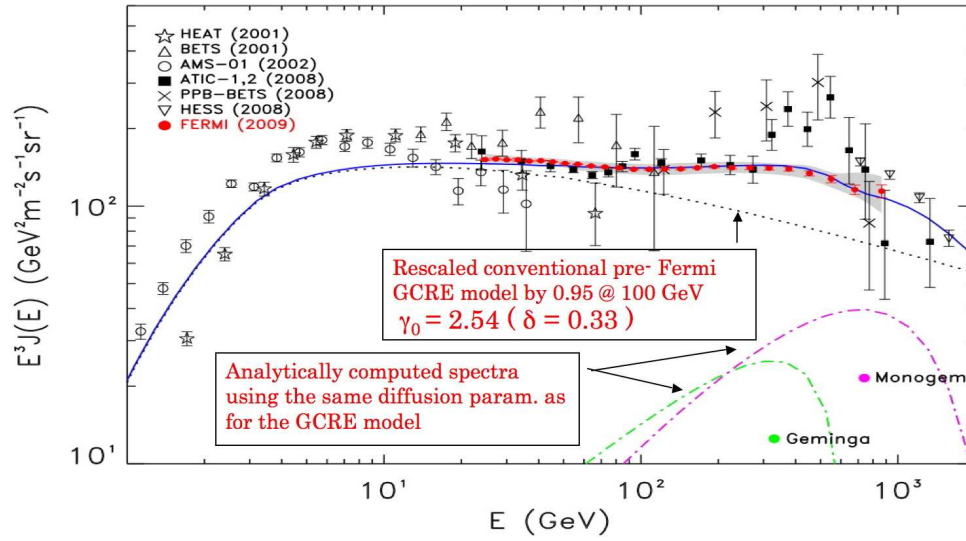


Figure 2: Electron-plus-positron spectrum (blue continuous line) for the same scenario as in figure 1. The gray band represents systematic errors on the Fermi-LAT data [3]

larger masses increasingly constrained by the H.E.S.S. results. The required annihilation rates, when employing the dark matter density profile imply typical boost factors ranging between 20 and 100, when compared to the value $\langle\sigma v\rangle \sim 3 \times 10^{-26} \text{ cm}^3/\text{sec}$ expected for a thermally produced dark matter particle relic.

How can one distinguish between the contributions of pulsars and dark matter annihilations?

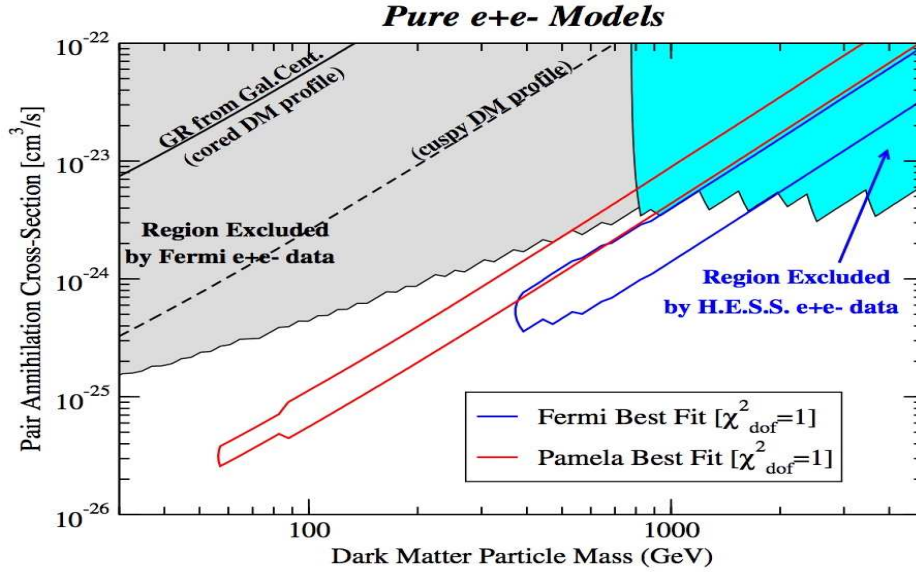


Figure 3: The parameter space of particle dark matter mass versus pair-annihilation rate, for models where dark matter annihilates into monochromatic e^\pm . Models inside the regions shaded in gray and cyan over-produce e^\pm from dark matter annihilation with respect to the Fermi-LAT and H.E.S.S. measurements, at the $2\text{-}\sigma$ level. The red and blue contours outline the regions where the χ^2 per degree of freedom for fits to the PAMELA and Fermi-LAT data is at or below 1.

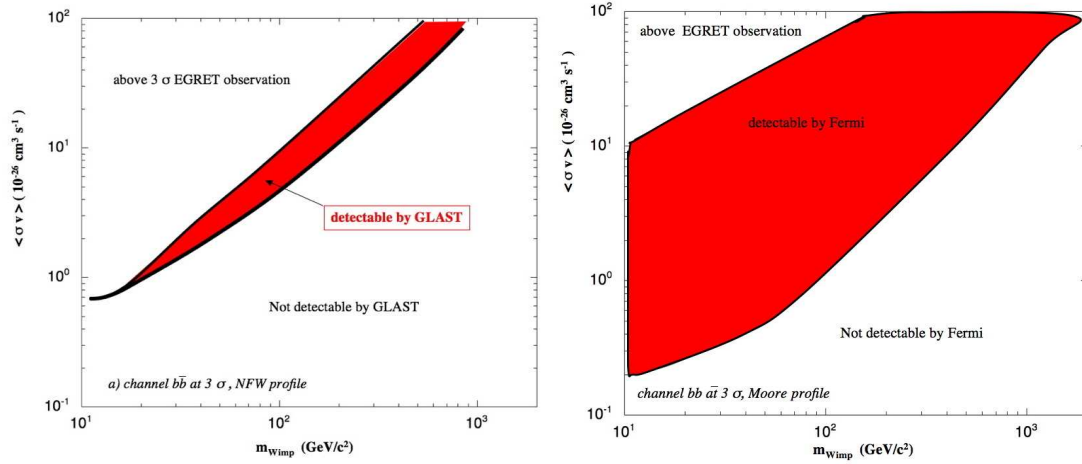


Figure 4: *Left*: Cross Section times WIMP velocity versus the WIMP mass for the $b\bar{b}$ annihilation channel. The red region is allowed by EGRET data and detectable by GLAST for 3σ significance and 5 years of Fermi operation. *Right*: Same as figure on the left but for Sagittarius Dwarf assuming a Moore profile as described in [12]

Most likely, a confirmation of the dark matter signal will require a consistency between different

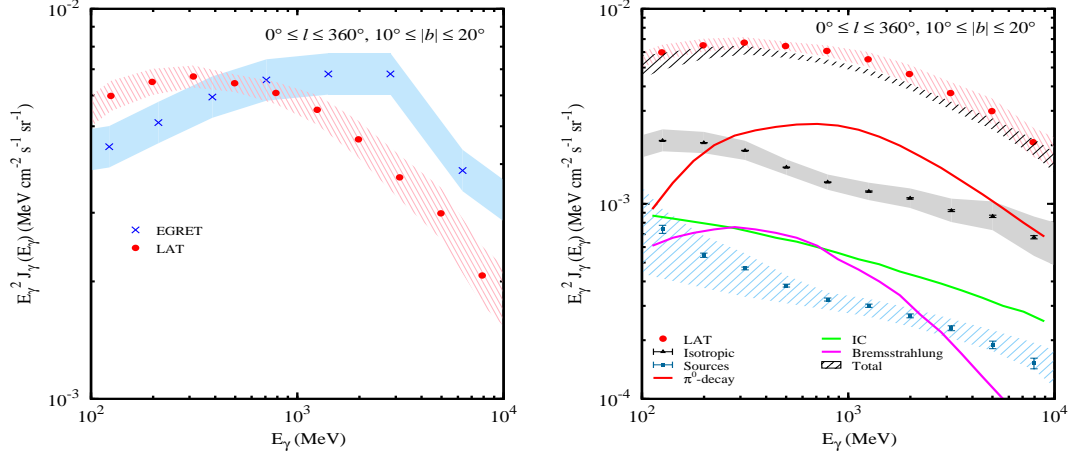


Figure 5: *Left:* Preliminary diffuse emission intensity averaged over all Galactic longitudes for latitude range $10^\circ \leq |b| \leq 20^\circ$. Data points: Fermi LAT, red dots; EGRET, blue crosses. Systematic uncertainties: Fermi LAT, red; EGRET, blue. *Right:* Preliminary Fermi LAT data with model, source, and isotropic components for same sky region.

experiments and new measurements of the reported excesses with large statistics. The observed excess in the positron fraction should be consistent with corresponding signals in absolute positron and electron fluxes in the PAMELA data and all lepton data collected by Fermi. Fermi has a large effective area and long projected lifetime, 5 years nominal with a goal 10 years mission, which makes it an excellent detector of cosmic-ray electrons up to ~ 1 TeV. Future Fermi measurements of the total lepton flux with large statistics will be able to distinguish a gradual change in slope with a sharp cutoff with high confidence [12]. The latter, can be an indication in favor of the dark matter hypothesis. A strong leptonic signal should be accompanied by a boost in the γ -ray yield providing a distinct spectral signature detectable by Fermi.

The Galactic center (GC) is expected to be the strongest source of γ - rays from DM annihilation, due to its coincidence with the cusped part of the DM halo density profile [13, 14].

An excess in gamma-ray should also be seen in the Galactic diffuse spectrum. Figure 5 (left) shows the LAT data averaged over all Galactic longitudes and the latitude range $10^\circ \leq |b| \leq 20^\circ$. The hatched band surrounding the LAT data indicates the systematic uncertainty in the measurement due to the uncertainty in the effective area described above. Also shown on the right are the EGRET data for the same region of sky where one can see that the LAT-measured spectrum is significantly softer than the EGRET measurement [15]. Figure 5 (right) compares the LAT spectrum with the spectra of an *a priori* diffuse Galactic emission (DGE) model. While the LAT spectral shape is consistent with the DGE model used in this paper, the overall model emission is too low thus giving rise to a $\sim 10 - 15\%$ excess over the energy range 100 MeV to 10 GeV. However, the DGE model is based on pre Fermi data and knowledge of the DGE. The difference between the model and data is of the same order as the uncertainty in the measured CR nuclei spectra at the relevant energies. Overall, the agreement between the LAT-measured spectrum and the model shows that the fundamental processes are consistent with our data, thus providing a solid basis for future work understanding the DGE.

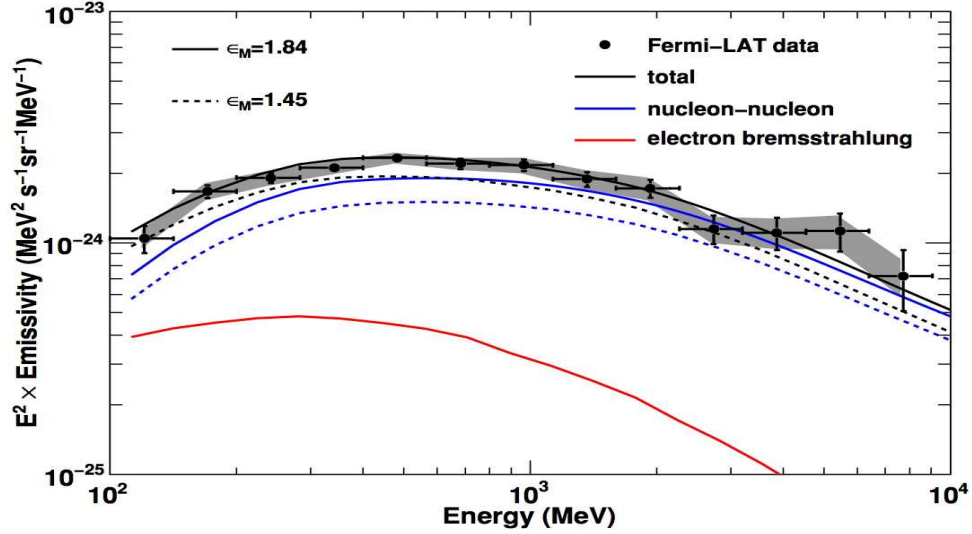


Figure 6: Differential γ -ray emissivity from the local atomic hydrogen gas compared with the calculated γ -ray production. The horizontal and vertical error bars indicate the energy ranges and 1σ statistical errors, respectively. Estimated systematic errors of the LAT data are indicated by the shaded area. A nucleus enhancement factor ϵ_M of 1.84 is assumed for the calculation of the γ -rays from nucleon-nucleon interactions. Dotted lines indicate the emissivities for the case of $\epsilon_M = 1.45$, the lowest values in the referenced literature.

Also at higher latitudes for the moment we did not observe any excess. Figure 6 shows the diffuse γ -rays in a mid-latitude region in the third quadrant (Galactic longitude l from 200° to 260° and latitude $|b|$ from 22° to 60°). The region contains no known large molecular cloud and most of the atomic hydrogen is within 1 kpc of the solar system. The contributions of γ -ray point sources and inverse Compton scattering are estimated and subtracted. The residual γ -ray intensity exhibits a linear correlation with the atomic gas column density in energy from 100 MeV to 10 GeV. The differential emissivity from 100 MeV to 10 GeV agrees with calculations based on cosmic ray spectra consistent with those directly measured, at the 10 % level. The results obtained indicate that cosmic ray nuclei spectra within 1 kpc from the solar system in regions studied are close to the local interstellar spectra inferred from direct measurements at the Earth within $\sim 10\%$ [16].

Finally a line at the WIMP mass, due to the 2γ production channel, could be observed as a feature in the astrophysical source spectrum [12]. Such an observation is a “smoking gun” for WIMP DM as it is difficult to explain by a process other than WIMP annihilation or decay and the presence of a feature due to annihilation into γZ in addition would be even more convincing.

2 Conclusion

Recent accurate measurements of cosmic-ray positrons and electrons by PAMELA, and Fermi have opened a new era in particle astrophysics. The CRE spectrum measured by Fermi-LAT

is significantly harder than previously thought on the basis of previous data. Adopting the presence of an extra e^\pm primary component with ~ 2.4 spectral index and $E_{cut} \sim 1TeV$ allow to consistently interpret Fermi-LAT CRE data (improving the fit), HESS and PAMELA. Such extra-component can be originated by pulsars for a reasonable choice of relevant parameters or by annihilating dark matter for model with $M_{DM} \sim 1TeV$. Improved analysis and complementary observations (CRE anisotropy, spectrum and angular distribution of diffuse γ , DM sources search in γ) are required to possibly discriminate the right scenario. Their exotic origin has to be confirmed by complimentary findings in γ -rays by Fermi and atmospheric Cherenkov telescopes, and by LHC in the debris of high-energy proton destructions. A positive answer will be a major breakthrough and will change our understanding of the universe forever. On the other hand, if it happens to be a conventional astrophysical source of cosmic rays, it will mean a direct detection of particles accelerated at an astronomical source, again a major breakthrough. In this case we will learn a whole lot about our local Galactic environment. However, independently on the origin of these excesses, exotic or conventional, we can expect very exciting several years ahead of us.

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