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Search for point-like Dark Matter sources with the GLAST Large Area Telescope

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Abstract: The space satellite GLAST is expected to play a crucial role in indirect Dark Matter (DM) searches, thanks both to its ability to perform observations at energy scales comparable to the mass of common DM candidates and to its potential of making deep full-sky maps in gamma-rays, thanks to its large (~ 2.4 sr) field-of-view. Here we will describe the prospects for detecting gamma-rays from point sources of Dark Matter annihilation.

Introduction

The GLAST Large Area Telescope (LAT) design and science prospects will be illustrated in [1]. Here we would like to point out that the GLAST-LAT collaboration pursues complementary searches for Dark Matter, each presenting its own challenges and advantages. The center of our own galaxy is a formidable astrophysical target to search for a Dark Matter signal, the reason being that simulations of Dark Matter halos predict high densities at the center of the galaxy and since the WIMP annihilation rate is proportional to the density squared, significant fluxes can be expected. On the other hand, establishing a signal requires identification of the high energy gamma-ray sources which are close (or near) the center and also an adequate modeling of the galactic diffuse emission due to cosmic rays colliding with the interstellar medium. The latter is even more crucial for establishing a WIMP annihilation signal from the galactic halo. The LAT capability to detect a gamma-ray flux coming from WIMP pair annihilations in diffuse astrophysical sources and from extragalactic diffuse gamma-ray radiation and line searches from annihilation into gamma-gamma and/or gamma-Z final states will be discussed in [2].

We focus now on a theoretically particularly well-motivated type of Weakly Interacting Massive Particle (WIMP) dark matter candidate, the neutralino (see [3] for a classic review) that appears in most supersymmetric extensions to the Standard Model as the lightest supersymmetric particle (LSP) and is given by a linear combination of the superpartners of the gauge and Higgs fields. The most restrictive supersymmetric extension of the Standard Model is the minimal supergravity (mSUGRA) framework that has five input parameters: $m_{1/2},\ \ m_0,\ \ sign(\mu),\ \ A_0\ \ \mathrm{and}\ \ \tan\beta$, where m_0 is the common scalar mass, $m_{1/2}$ is the common gaugino mass and A_0 is the proportionality factor between the supersymmetry breaking trilinear couplings and the Yukawa couplings. $\tan\beta$ denotes the ratio of the vacuum expectation values of the two neutral components of the SU(2) Higgs doublet, while the Higgs mixing μ is determined (up to a sign) by imposing the Electro-Weak Symmetry Breaking (EWSB) conditions at the weak scale. The parameters at the weak energy scale are determined by the evolution of those at the unification scale, according to the renormalization group equations (RGEs). For this purpose, we have made use of the ISASUGRA RGE package in the ISAJET 7.64 software [4]. After fixing the five mSUGRA parameters at the unification scale, we extract from the ISASUGRA output the weak-scale supersymmetric mass spectrum and the relative mixings. Cases in which the lightest neutralino is not the lightest supersymmetric particle or there is no radiative EWSB are disregarded. The ISASUGRA output is then used as an input in the DarkSUSY package . The latter is exploited to: a) reject models which violate lim-

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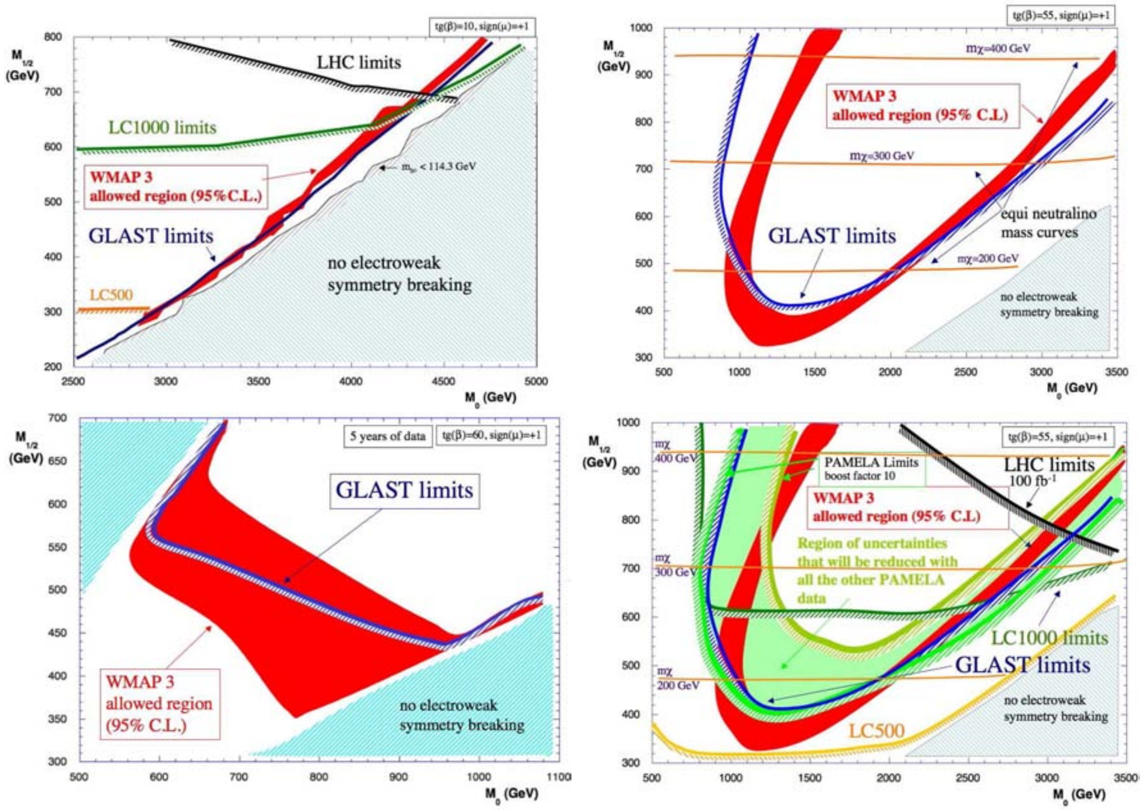

Figure 1: GLAST sensitivity to a dark matter signal via the observation of WIMP annihilation photons (continuum spectrum) in the $m_{1/2}$ and m_0 mSUGRA parameter plane for $\tan\beta = 10$, 55 and 60. GLAST 3σ sensitivity is shown at the blue line and below. The lower right plot shows the comparison for $\tan\beta = 55$ with LHC, LC and the antimatter experiment PAMELA. The stripped regions correspond to models that are excluded either by incorrect ElectroWeak Symmetry Breaking (EWSB), LEP bounds violations or because the neutralino is not the Lightest Supersymmetric Particle (LSP).

its recommended by the Particle Data Group 2002 (PDG) b) compute the neutralino relic abundance, with full numerical solution of the density evolution equation including resonances, threshold effects and all possible coannihilation processes [5] c) compute the neutralino annihilation rate at zero temperature in all kinematically allowed tree-level final states (including fermions, gauge bosons and Higgs bosons); d) estimate the induced gamma-ray yield by linking to the results of the simulations performed with the Lund Monte Carlo program Pythia as implemented in the DarkSUSY package. Figure 1 shows our estimates of GLAST sensitivity to a dark matter signal via the observation of WIMP annihilation photons (continuum spectrum) in the $m_{1/2}$ and m_0 mSUGRA parameter plane for $\tan\beta = 10$, 55 and 60. These figures have been obtained performing a detailed scan in the mSUGRA parameter space, computing for each model the neutralino induced γ-ray flux and the relic density. The lower right plot shows the comparison for $\tan\beta = 55$ with the exclusion limits from LHC, LC [6] and the antimatter experiment PAMELA [7]. The values of the neutralino mass is also shown in both figures on the right. For the region in red, the cosmologically allowed WIMP region, the signal above the blue line ($M_{WIMP} \sim 200GeV$) is not observable by GLAST due the higher WIMP mass as one moves to higher $m_{1/2}$. The dark matter halo used for

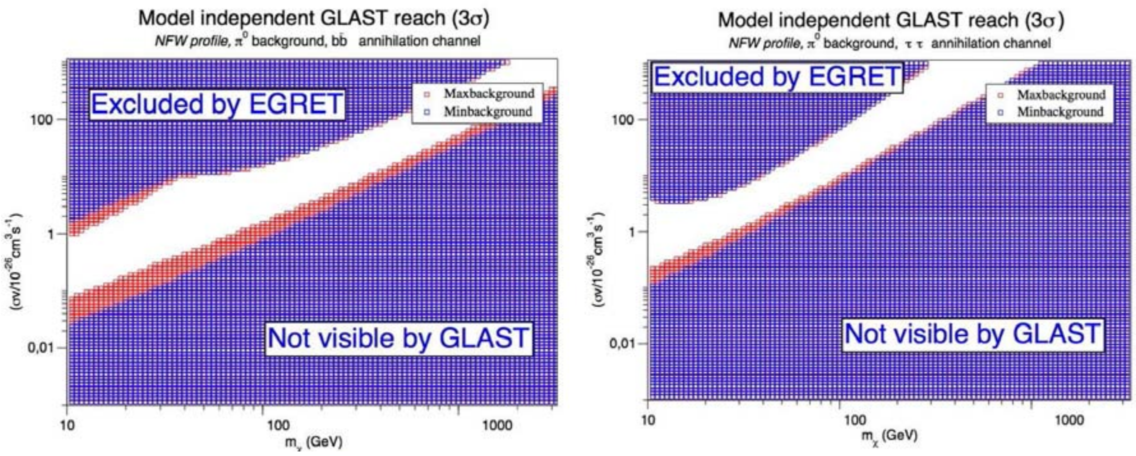

Figure 2: Cross Section times WIMP velocity versus the WIMP mass. The white region is allowed by EGRET data and detectable by GLAST

the GLAST indirect search sensitivity estimate is a truncated Navarro Frank and White (NFW) halo profile as used in [8]. For steeper halo profiles (like the Moore profile) the GLAST limits move up, covering a wider WMAP [9] allowed region, while for less steep profile (like the isothermal profile) the GLAST limits move down, covering less WMAP allowed region.

Model Independent GLAST Reach

The expression of the γ-ray continuum flux for a generic WIMP at a given photon energy E is given by

$$\phi_{\rm wimp}(E) = \frac{\sigma v}{4\pi} \sum_f \frac{dN_f}{dE} B_f \int_{l.o.s} dl \frac{1}{2} \frac{\rho(l)^2}{m_{\rm wimp}^2} \tag{1}$$

This flux depends from the WIMP mass $m_{\rm wimp}$, the total annihilation cross section times WIMP velocity σv and through the sum of all the photon yield dN_f/dE per each annihilation channel weighted by the corresponding branching ratio B_f. The flux (1) also depends from the WIMP density in the galactic halo $\rho(l)$. The integral has to be performed along the line of sight (l.o.s.). As pointed out in [8], apart from the $\tau\bar{\tau}$ channel, the photon yields are quite similar. So fixing the halo density profile (for example a NFW profile), a dominant annihilation channel (that is $b\bar{b}$, $t\bar{t}$, W^+W^-, ...) and the corresponding yield, it is possible to perform a scan in the plane ($m_{\rm wimp}$, σv) in order to determine the GLAST reach and the regions that are already excluded by the EGRET data in the 2 degrees region around the galactic center [8], [10], i.e. the flux predicted by the susy+background model must not exceed the total flux predicted from EGRET data. The result of the scan is given in figure 2. For every couple of values ($m_{\rm wimp}$, σv) we compute the expected flux (1) and we performed a standard χ^2 statistical analysis to see if GLAST is able to disentangle the WIMP contribution among the standard astrophysical π^0 background as used in [8] . The result is given at a 3σ confidence level. The background uncertanties are reflected in the red regions. We assumed a total exposure of $3.7 \times 10^{10}\,{\rm cm}^2\,s$, for a period of 4 years of data taking and an angular resolution (at 10 GeV) of $\sim 3 \times 10^{-5}$ sr as it can be derived from the GLAST LAT performance [11].

Point Sources of Dark Matter Annihilation

There is the possibility that the annihilation signal originates from large Dark Matter overdensities around Intermediate Mass Black Holes. In Fig. 3 we show some illustrative examples of simulated sources. On the left there is an an example with a moderate diffuse background contribution and a source corresponding to EGRET's faintest

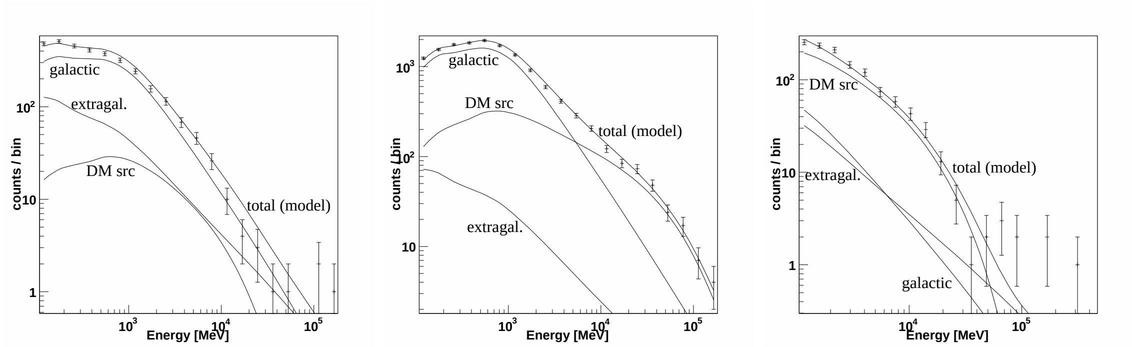

Figure 3: Examples of spectral fits of simulated DM point sources of intensity Φ, for different values of m_χ and different annihilation channels. On the left for $\Phi = 2 \times 10^{-3}$ ph m^{-2} s^{-1}, $m_\chi = 150$ GeV, $b\bar{b}$, (l, b)=$(0, 25)$; in the middle for $\Phi = 2 \times 10^{-2}$ ph m^{-2} s^{-1}, $m_\chi = 150$ GeV, $b\bar{b}$, (l, b)=$(50, 0)$ and on the right for $\Phi = 2 \times 10^{-2}$ ph m^{-2} s^{-1}, $m_\chi = 150$ GeV, 80 % $b\bar{b}$, 20 % e^+e^-, (l, b)=$(0, 50)$. Solid lines are fits obtained under the assumption of annihilation to $b\bar{b}$. For each model we also give the significance of the detection. Points with error bars are photon counts from the simulated observation.

detected source. For a more complete description of the figure see [12], [13]. If we apply this analysis to the mini-spikes scenario discussed in Ref. [14], consisting of a population of ~ 100 DM overdensities, dubbed mini-spikes, around Intermediate Mass Black Holes, we found that a large number of these objects can be detected and identified with GLAST, if they exist, while null searches would place extremely stringent constraints on the whole scenario.

Conclusions

We showed the GLAST ability to detect an exotic signal from WIMP's annihilation both in mSUGRA and in a model indipendent framework. GLAST will be able to probe a good portion of the parameter space. An interesting possibility will be the detection of point sources of DM annihilation in the mini-spikes scenario.

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