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Estimate for GLAST LAT Milky Way Dark Matter WIMP Line Sensitivity

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Abstract. The LAT Dark Matter and New Physics Working group has been developing approaches for the indirect astrophysical detection of annihilation of dark matter. Our work has assumed that a significant component of dark matter is a new type of Weakly Interacting Massive Particle (WIMP). The annihilation of two WIMPs usually results in the production of many high energy gamma rays (>1 GeV) that can be well measured in the GLAST LAT if present. There is also the possibility to observe γ lines from annihilation into γγ and or γZ final states. In popular SUSY theories these line decays occur at the 10^{-4} to 10^{-2} branching fraction level. Estimates of LAT sensitivity (at 5σ above background) and upper limits (upper limit at the 95% confidence level) to these WIMP lines will be presented. These sensitivities are given in photons/cm^2/sec/sr and so do not depend on the WIMP models. However, they do depend on the diffuse background model. The latter is derived from GALPROP[1] based on EGRET and other data in the EGRET energy range. We use extrapolations, provided by the GALPROP team to the higher energy range of 150 GeV explored in the preliminary line sensitivity study presented here. Comparison with theory depends upon the WIMP model (e.g., line energy and 1 or 2 lines), the DM halo model, and other astrophysics backgrounds. Thus estimates of the ability of the LAT to actually observe WIMP lines can vary over orders of magnitude depending upon which models are chosen.

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This analysis used diffuse model data [1] from the galactic centered annulus(r ε [25º, 35º]), excluding the region within 10º from the galactic plane to estimate the photon background for WIMP annihilation into narrow lines. This annulus could give a signal to noise ratio as much as 12 times greater than at the galactic center [2].

LAT line energy sensitivities were calculated at 5σ and for the 95% upper limit confidence level (ULCL). This was done in the case when the line energy is known (e.g. supplied by discovery at the LHC), and also for the case when it is unknown. The latter gives somewhat poorer limits as further statistical treatment is needed to account for the number of energy bins searched over the range of interest. We used the Observation Simulator (ObsSim) to generate LAT resolved annihilation lines[3]. ObsSim was run for 55 days (uniform all-sky coverage for the LAT in scanning mode) for a high latitude ($l = -76º$, $b = 26º$) point source with a narrow Gaussian energy distribution ($\sigma/E_0 = 10^{-3}$). Instrument response functions (IRFs) from Data Challenge-2 (DC-2)[4] were used. For calculating known line energy sensitivities, LAT resolved lines were generated for 25, 50, 75, 100, 125 and 150 GeV (the current version of the LAT IRFs cut-off at 200 GeV). The ObsSim results for the all-sky scan were well fit by a double Gaussian distribution, ϕ_1:

$$\phi_1(E; E_0, N_T, r, \sigma_1, \sigma_2) = N_T \big/ \sqrt{2\pi} \left[(1-r)\big/\sigma_1 \, e^{-(E-E_0)^2/2\sigma_1^2} + r\big/\sigma_2 \, e^{-(E-E_0)^2/2\sigma_2^2} \right] \quad (1)$$

where $N_T = N_1 + N_2$, and $r = N_2/N_T$. Linear fits for E_0, σ_1, and σ_2 as a function of E modeled the effects of ObsSim reasonably well.

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A 5 year all-sky diffuse background was generated using Galprop and DC-2 IRFs. The region of interest, the galactic annulus excluding the area closest to the galactic plane, was fit with an exponential background, ϕ_2:

$$\phi_2(E;a,b) = a \times e^{-E/b}, \text{ for } E \; \varepsilon \; [40,200] \text{ GeV} \tag{2}$$

Next, the 5 year 5σ signal sensitivity was estimated at each line energy. For each line the input background was bootstrapped with a MC signal 1000 times and fit to $\phi_1 + \phi_2$, and ϕ_2. This series of 1000 bootstraps was rerun varying the average number of MC signal counts (constant across series) until $<\Delta\chi^2> = \chi^2_{\phi_2+\phi_1} - \chi^2_{\phi_2} \approx 25$ (5σ over background). The average number of signal counts needed at each energy was then converted to the known line energy sensitivity using average exposures integrated over the annulus (fig 1). The LAT detection sensitivity for a line of unknown energy (E ε [40,150] GeV) for a 5σ above background signal corresponds to a confidence level of $1\text{-}10^{-7}$. To calculate the number of counts needed at each energy in this case we used:

$$(1-P)^{1/\#ofEnergyBins} = 1\big/\sqrt{2\pi}\int_{-\infty}^{\#of\sigma s} e^{-x^2/2}dx, \tag{3}$$

where $P = 10^{-7}$ is the probability of detecting a signal greater than "#ofσs" in one or more bins. A bin width of $fwhm/E = 2\ln\left(2\sqrt{2}\right)\cdot 0.08$ was used, giving 8 bins over the energy range. The "#ofσs" needed for a 5σ detection over 8 bins was found to be 5.39. The unknown line energy sensitivity was estimated by scaling the known line energy sensitivity by $(5.39/5)^2$ (fig 1).

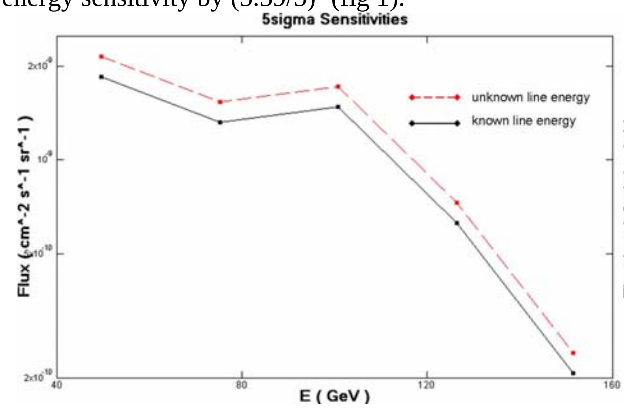

FIGURE 1. 5σ senstivities.

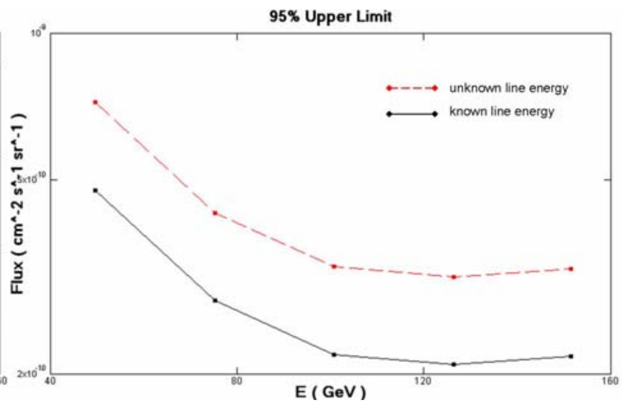

FIGURE 2. 95% Upper Limit.

The 5 year 95% CLUL sensitivity for known line energies was obtained similarly to the 5σ case by bootstrapping the ObsSim diffuse background and fitting $\phi_1 + \phi_2$ with no MC generated signal. After the calculation of $N_T \pm \sigma_{NT}$, the 95% CLUL was obtained from $1.64\sigma_{NT}$ and sensitivities calculated (fig 2). The case of unknown line energy (E ε [40,150] GeV) 95% CLUL was calculated as in the 5σ case with scale factor 2.49/1.64 (fig 2).

These results are preliminary as they depend on the DC-2 IRFs, require refined statistical methods (e.g. Poisson statistics), and lack the WIMP continuum contribution to ϕ_2. The current preliminary version of LAT IRFs cuts off at 200 GeV, a result of the optimization of event selection and analysis cuts for the 'core' energy range of the LAT. Work is underway in the LAT collaboration to extend the IRFs to much higher energies.

In summary, preliminary work on WIMP line sensitivity has been presented. A double Gaussian fits the ObsSim data well for a 55 day scan of a high latitude point source with a narrow Gaussian energy distribution. The flux needed for a 5σ signal of known energy on a 5 year diffuse galactic annulus background was estimated using a bootstrap corresponding to a $\Delta\chi^2$ distribution with $<\Delta\chi^2> = 25$. The 95% CLUL flux at known line energy was calculated as $1.64\sigma_{NT}$. Sensitivities for the case of unknown line energy (E ε [40,150] GeV) for a 5σ signal and a 95% CLUL were calculated taking into account the number of energy bins in the energy range.

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