The Search for Dark Matter and New Physics using the Gamma Ray Large Area Space Telescope (GLAST) Large Area Telescope (LAT)

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Abstract

The LAT Dark Matter and New Physics Working group has been developing approaches for the indirect detection of in situ 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 results in the production of a large number of high energy gamma rays (> 1 GeV) that can be well measured in the GLAST LAT. These searches involve strategies for observation of the galactic center, galactic halo (optimized diffuse all sky analysis), galactic satellites (almost point, high latitude, sources), and cosmological signals in the extra-galactic diffuse. The spectra of these potential signals are considerably harder than most, if not all, astrophysical sources, have an endpoint at the mass of the WIMP, and are not power laws. In addition, there is the possibility to observe lines from annihilation into γ-γ and/or γ-Z final states. The estimates of LAT sensitivity depends upon the WIMP model, the DM halo model and other astrophysics backgrounds. Thus estimates of LAT sensitivity can vary over orders of magnitude depending on which models are chosen. Preparations for these searches and other type of new physics searches will be presented.

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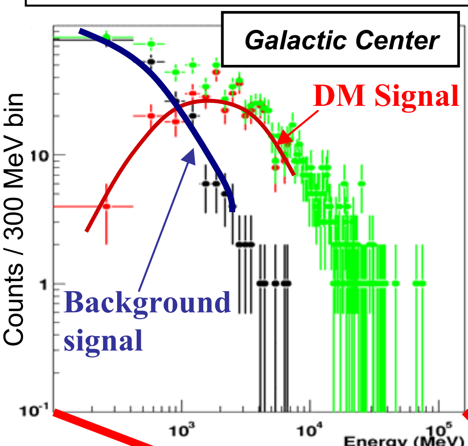
Physics Overview

The existence of dark matter has been well established for many years based on astronomical measurements of Galactic rotation curves, Galactic cluster dynamics, precision WMAP measurements of the CMB [D. N. Spergel, et al.2006], and a number of other measurements. The best estimates indicate that ~20% of the energy density of the universe is dark matter. However, we currently don't know what the dark matter is. From the viewpoint of particle physics the possibilities range in mass and character from axions (micro to milli eV) to WIMPS ($10 - 10^4$ GeV/c^2), to primordial black holes (mass 10^{-5} $M_\odot$). What seems clear is that understanding what constitutes the dark matter will require a broad range of experiments.

To uncover the dark matter, to connect what is astrophysically observed to what may be seen as new particles produced in accelerators, we need new measurements. It is plausible that the Large Hadron Collider (LHC) at CERN will have either discovered putative dark matter related candidates or it will have set important new limits soon after the start of full operations in 2008. If the former, the astronomy and physics community will be intensely searching for any additional information about this new particle sector as well as clues to the relevance of the new particle(s) to the dark matter. Information about both can be obtained using GLAST, by indirect detection of dark matter, *i.e.*, the detection of the gamma ray signatures of dark matter particle annihilations that are ubiquitously expected in the annihilation of WIMPs essentially independent of theory. This search is well suited to the GLAST LAT due to its energy resolution for gamma rays of < 10% over much of its energy range (~100 MeV – 300 GeV) and acceptance, its large effective area, and solid angle on the sky.

GLAST will search for these gamma ray signatures of dark matter from a number of perspectives. We will search for WIMP continuum and line annihilations from the galactic center, galactic inner halo, galactic satellites, extragalactic, and the more exotic possibilities that continually arise. Below we discuss a few examples referring for context to the all sky map in galactic coordinates of the simulated dark matter sky. Note that there is no gamma radiation from normal matter shown in this all sky map, only gamma radiation from dark matter WIMP annihilations.

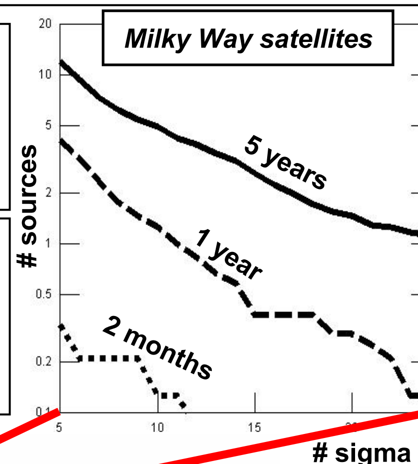


Galactic Center.

An unusual EGRET source was found at or near the Galactic Center; the spectrum is extremely hard and non-power law, and the source is possibly extended (Mayer-Hasselwander, *et.al.* 1998). Several hypotheses for the origin of this source have been proposed. The dark matter hypothesis is not yet ruled out. We performed a 1 year GLAST simulation for a NFW profile with a $m_{neutralino}$=175 GeV mSUGRA point. For E>100 MeV we find ~ 3×10^{-7} cm^{-2} s^{-1} in a 30° x 30° map using Dark Susy. The simulated dark matter counts map was compared with the expected background as computed using GALPROP. The figure on the left shows the resulting differential spectra and background simulations for a 0.1° radius region centered on the Galactic Center. Detailed modeling of Galactic Center region gamma ray sources in combination with the high statistics of the GLAST measurement should allow us to confirm or rule out the dark matter particle hypothesis for the EGRET Galactic Center source.

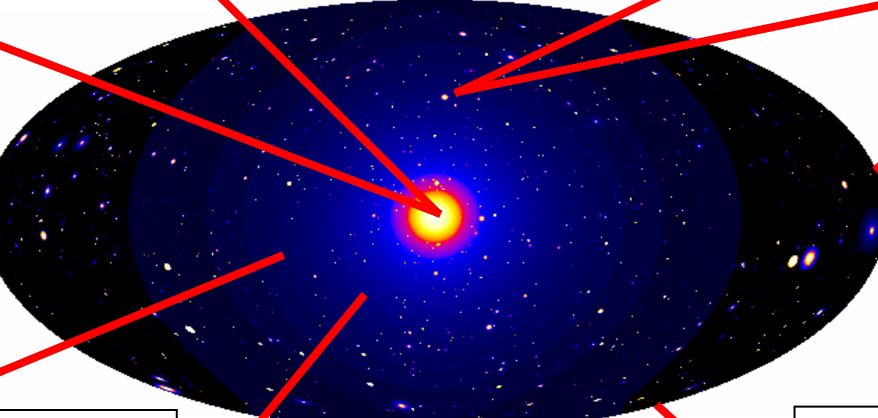
Milky Way satellites.

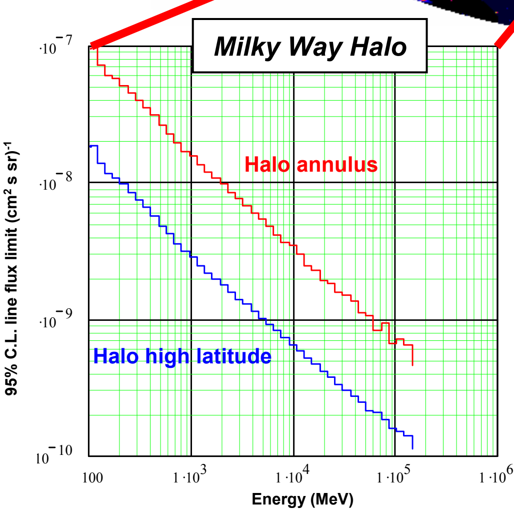
The standard model of cosmology relies on a hierarchical distribution of dark matter which on galactic scales implies a significant number of as yet unobserved dark matter satellites with masses less than approximately 10^7 $M_\odot$, the mass scale of the known dark matter dominated low surface brightness dwarf galaxies. We have estimated the number of Milky Way dark matter satellites observable by GLAST. The dark matter calculation was performed with the semi-analytic method of Taylor & Babul (2004, 2005). The dark matter satellite distribution is roughly spherically symmetric about the galactic center and extends well beyond the solar orbit; thus the dark matter satellites are located mostly at high galactic latitudes. We assumed a WIMP mass of 100 GeV and velocity averaged annihilation cross-section of 3×10^{-26}cm^{3}s^{-1}. The resulting number of dark matter satellites (# sources) with significance above # sigma is shown in the figure to the right. The lines correspond to 5 year, 1 year and 2 months of GLAST data. EGRET, which is equivalent to approximately 2 days of GLAST data, would not have had any significant signals.



Dark Matter Skymap.

The image to the right is a simulated skymap for dark matter annihilation radiation. Gamma rays from a hierarchical distribution of dark matter within our Galaxy is simulated with a minimum cutoff of the mass distribution function at 10^6 $M_\odot$. The overall normalization of the flux depends upon the pair annihilation cross-section. Note that there is no gamma radiation from normal matter shown in this all sky map, only gamma radiation from dark matter WIMP annihilations.





Milky Way Halo and Lines.

The Milky Way Halo comprises the single largest source of WIMP annihilation flux. However, systematic uncertainties in the astrophysical sources of galactic diffuse gamma rays makes it difficult to disentangle the WIMP signal. On the other hand, a gamma ray line would be a smoking gun for WIMPs. Due to the large flux of gamma rays from the Milky Way Halo, we may hope to discover diffuse gamma ray lines. The graph to the left shows the 95% confidence level limit to lines, based on 330 days of simulated in-orbit GLAST data. The simulation uses GALPROP (Strong, Moskalenko, Reimer 2004) and an extragalactic isotropic diffuse background (Sreekumar, et.al. 1998). The two regions viewed are an annulus within 25° to 35°of Galactic Center but excluding ±10° of the Galactic equator (red line), and latitude >20° but excluding the region within 35°of the Galactic Center (blue line).

Extragalactic.

The origin of the diffuse extragalactic background is a matter of on going research. One possible contribution could come from WIMP dark matter annihilating into photons inside galactic haloes. The gamma ray flux would receive contributions from galaxies at all redshifts and would end at the mass of the WIMP. The level of flux depends both on the specific particle physics model and of how dark matter cluster in the universe. Shown to the right are the EGRET data points (cyan stars). The black data points are the unresolved blazer model normalized to the EGRET data. Also shown are simulations of one year of GLAST data from two dark matter candidates (76 GeV and 171 GeV). The red points are what GLAST sees from the unresolved blazer model. The red, green, and blue curves are the theoretical inputs before being run through the GLAST simulation.