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Analysis Methods for Milky Way Dark Matter Satellite Detection

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Abstract: The Gamma Ray Large Area Space Telescope (GLAST) Large Area Telescope (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) in the 100GeV mass range. The annihilation of two WIMPs results in the production of a large number of high energy gamma rays (>1GeV) that can be well measured by the GLAST LAT. The cold dark matter model implies a significant number of as yet unobserved dark matter satellites in our galaxy. The spectra of these galactic satellites are considerably harder than most, if not all, astrophysical sources, have an endpoint at the mass of the WIMP, and are not power laws. We describe a preliminary feasibility study for the indirect detection of dark matter satellites in the Milky Way using the GLAST LAT.

Key words: GLAST; WIMP; dark matter; indirect detection
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It is well established that the majority of matter in the universe is neutral weakly interacting non-baryonic matter or so called dark matter (DM). A very good candidate for cold DM (CDM) is weakly interacting massive particles (WIMPs) with a mass of the order of 100 GeV; in the theory of supersymmetry (SUSY), the Lightest Supersymetirc Particle (LSP) is one possible model for WIMP. WIMPs can annihilate at a very low rate, and produce a large number of high energy gamma rays; about half of the produced gamma rays are at the energy larger than one-hundredth of the WIMP mass. These high energy gamma rays can be detected by the GLAST LAT, due to its wide angular acceptance, large energy band, and very good energy and angular resolution. This indirect detection depends upon the density (squared) of WIMPs in regions of the galaxy or beyond, and also upon WIMPs being either Majorana particles or a mixture of WIMPs and anti-WIMPs.

The CDM model shows a hierarchical structure on galactic scales, which implies the dark halos of galaxies like the Milky Way contain large numbers of sub-halos, called DM satellites. Using the truncated NFW satellite structure [1], the satellite distribution simulated by Taylor & Babul [2], and the LSP WIMP for LCC2 and LCC4 benchmark points as defined in Baltz, et al [3], we estimate the number of Milky Way DM satellites with $>10^6$ solar masses observable by GLAST LAT. The DM satellite distribution is roughly spherically symmetric about the galactic center and extends well beyond the solar orbit; thus the observable satellites are located mostly at high galactic latitudes. The background was estimated using the EGRET point source subtracted sky map above 1GeV from Cillis & Hartman [4]. The significance of the DM signal was then estimated to be the calculated number of signal events within the satellite tidal radius (or the PSF 68% containment radius, whichever was bigger) divided by the square root of the number of background events within the same radius. The cumulative number of DM satellites with significance of at least 5 sigma is shown in Figure 1. For these benchmark SUSY points, we would expect to observe a few such DM satellites with 5 years of GLAST data. Based on having 40k ~1 degree bins on the sky, one would expect to see about 0.01 5 sigma fluctuation coming from background. This fluctuation can be further removed by using the measured photon spectrum as explained below.

We also calculated the GLAST LAT error ellipses for detection of DM satellites versus WIMP mass for a generic WIMP model, in which the WIMP mass is 100 GeV, WIMP annihilation cross section is $2.3\times10^{-26}\,cm^3 s^{-1}$, and WIMPs annihilate only to $b\bar{b}$ quarks. We used the likelihood ratio test statistic and profile likelihood to extract the 99%, 90% and 68.3% error contours on WIMP mass and annihilation cross section jointly as shown in Figure 2, for that generic WIMP satellite with the significance of 10 sigma for 1 year of GLAST data (> 1 GeV), where the unit of the vertical axis is given by

$$\frac{<\sigma v>}{2.3\times10^{-26}\,cm^{3}s^{-1}}\times\left(\frac{8.9\,kpc}{d}\right)^{2}\times\left(\frac{M_{satellite}}{2.7\times10^{7}\,M_{Sun}}\right)^{2}\times\left(\frac{0.2\,kpc}{r_{tidal}}\right)^{6}.$$

In order to identify DM satellites, we need, firstly, to find possible candidates for DM satellites; secondly, to make sure these candidates are not fluctuations of the background emission; and finally, to distinguish these real candidates from other typical astrophysical sources, such as pulsars or molecular clouds. The typical extent of the observable DM satellites is of the order of 1 degree. For those bright enough sources, GLAST LAT should be able to resolve them using the WIMP annihilation photons above 1 GeV, for which the PSF is approximately 0.5 degree. We use SExtractor, a free

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program available on the web that builds a catalogue of objects from an astronomical image, to search for possible candidates for DM satellites; and use likelihood analysis to reject false sources and other typical classes of sources. In Figure 3 we plot the counts spectra for a LCC2 WIMP satellite, high latitude (b = 70 deg), "5 sigma source" for 1 year of GLAST data (this significance is estimated using the back of the envelop method described in Figure 1), plus diffuse background. The diffuse background model consists of the optimized background model from Strong, Moskalenko, Reimer [5] and the isotropic diffuse background described in Sreekumar et. al [6]. By using a null hypothesis test, we can distinguish this example satellite from the background fluctuation. We generated 120 simulated GLAST experiments for background only and also for the example satellite. Then we computed the maximum likelihood difference between background only and background plus signal, a.k.a. a "TS" (test statistic). In Figure 4 we show a two dimensional plot, TS for background only (filled triangles) and for background plus signal (filled squares) versus best fit signal strength, which is the fitting normalization of the satellite flux and the unit is the simulated flux of the satellite. We find that this "5 sigma signal" is separable from the background. Using the unique WIMP pair annihilation spectrum, which is extremely hard, non-power law and has an end point at the mass of WIMP, we will use the same hypothesis testing method to distinguish DM satellites from other astrophysical sources.

REFERENCES

1. E. Hayashi et al., Astrophys. J. **584**, 541 (2003)
2. J. E. Taylor and A. Babul, Mon. Not. R. Astron. Soc. **348**, 811 (2004); Mon. Not. R. Astron. Soc. **364**, 515 (2005); Mon. Not. R. Astron. Soc. **364**, 535 (2005)
3. E. A. Baltz el al., hep-ph/0602187
4. A. N. Cillis and R. C. Hartman, Astrophys. J. 621, 291 (2005)
5. A. W. Strong, I. V. Moskalenko and O. Reimer, Astrophys. J. **613**, 962 (2004); A. W. Strong and I. V. Moskalenko, Astrophys. J. **509**, 212 (1998)
6. P. Sreekumar et al., Astrophys. J. **494**, 523 (1998)
7. L. Wai, astro-ph/0701885

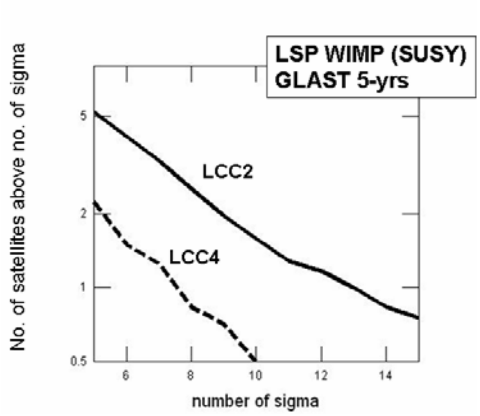

FIGURE 1. Estimation of the number of observable DM satellites for the GLAST LAT in the Milky Way

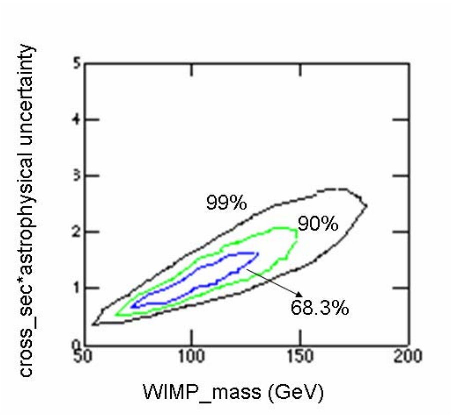

FIGURE 2. GLAST LAT error ellipses for a simulated 10 sigma DM satellite with 100 GeV mass WIMP

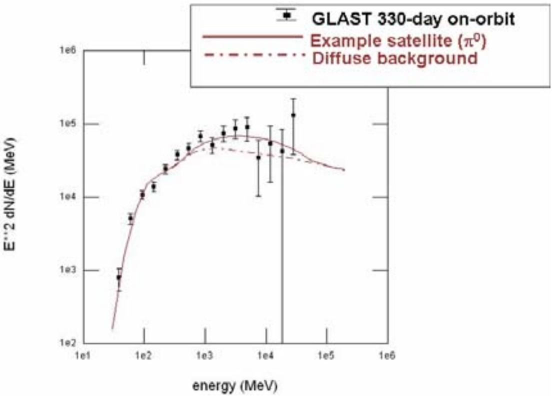

FIGURE 3. Counts spectra for a LCC2 WIMP satellite

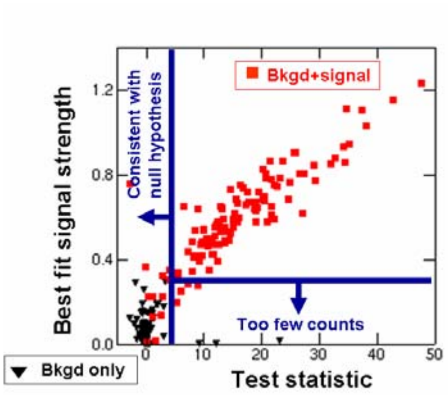

FIGURE 4. Null hypothesis test to exclude background fluctuation