Analysis methods for Milky Way dark matter satellite detection

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***Abstract**:*

The LAT Dark Matter and New Physics Working group has been developing approaches for the indirect detection of dark matter satellites in the Milky Way. 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 (>1GeV) that can be well measured in the GLAST LAT. 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.

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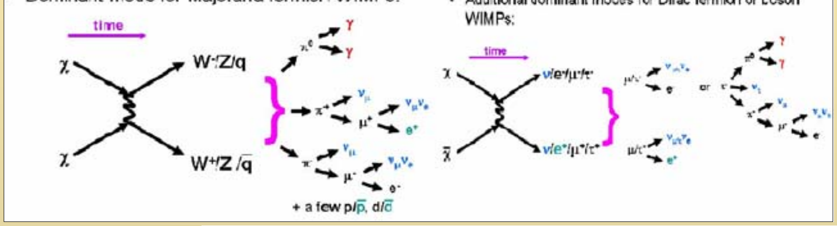
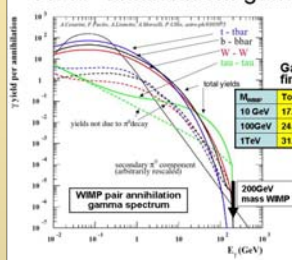
WIMP annihilation: continuum spectrum

- Dominant mode for Majorana fermion WIMPs:
- Additional dominant modes for Dirac fermion or boson WIMPs:



WIMP annihilation: gamma ray yield

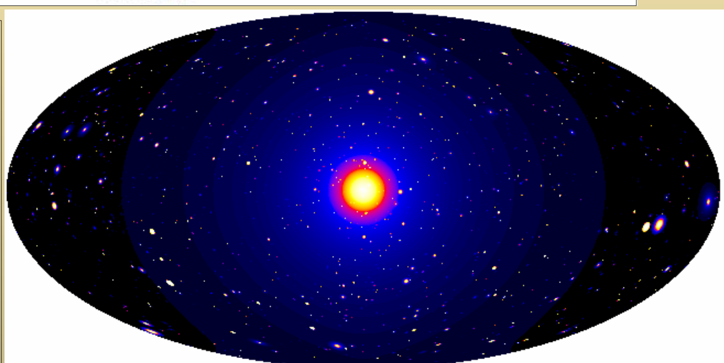


Gamma ray yield per final state $b\bar{b}$

M_{wimp}	Total# γ	>100MeV	>1GeV	>10GeV
10 GeV	17.3	12.6	1.0	0
100GeV	24.5	22.5	12.4	1.0
1TeV	31.0	29.3	22.4	12.3

Dark Matter Skymap

The image to the right is a simulated sky map 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 $10^6 M_{Sun}$. 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.



WIMP annihilation cross section at freeze-out versus the current time

- WIMP annihilation cross section can be written as $\sigma v = a + bv^2 + \ldots$

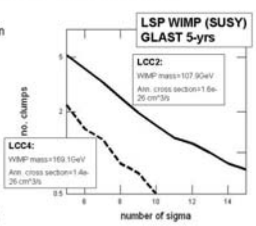
1. σv is independent of v
   Boltzmann equation => $\Omega_\chi h^2 = \frac{3\times10^{-27} cm^3 s^{-1}}{<\sigma v>} \approx 0.1$ from W-Map
   After freeze-out, the WIMP annihilation cross section remains constant,
   $<\sigma v>_0 = <\sigma v>_f = \frac{3\times10^{-27} cm^3 s^{-1}}{(\Omega_\chi h^2)_f} \approx 2.3\times10^{-26} cm^3 s^{-1}$
   where the subscript f denotes the value at freeze-out and the subscript 0 denotes the value today.
2. σv is weakly dependent on v, like LCC2 * and LCC4 *
   $<\sigma v>_0 \sim <\sigma v>_f \sim 10^{-26} cm^3 s^{-1}$
   In this case, WIMP annihilation signal can be observed by GLAST LAT.
3. σv is strongly dependent on v, like LCC1 *
   $<\sigma v>_0 << <\sigma v>_f$ since $v_0(\sim 0.001c) << v_f(\sim 0.5c)$
   In this case, WIMP annihilation signal is not detectable by GLAST LAT.

- Coannihilation
  – Like LCC3 *, at freeze-out, in coannihilation with stau particle, total cross section $\sim 2.3\times10^{-26} cm^3 s^{-1}$. As the universe further cooled, staus decayed away as they are not stable, and only the WIMP were left, and the WIMP has a much smaller annihilation cross section.

* SUSY model LCC# definitions from Baltz, et al, 2006

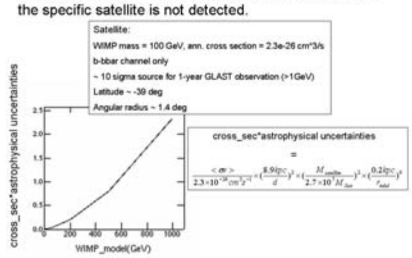
Observable satellites in the Milky Way (estimate)

- Simulation of Milky Way dark matter satellites from Taylor & Babul, 2004, 2005
- SUSY model definitions from Baltz, et al, 2006
- Background estimate using EGRET above 1GeV (point-source subtracted) from Cillis & Hartman 2005
- Signal, background flux inside the tidal radius
- LCC2 and LCC4 are favorable to GLAST than LCC1 and LCC3



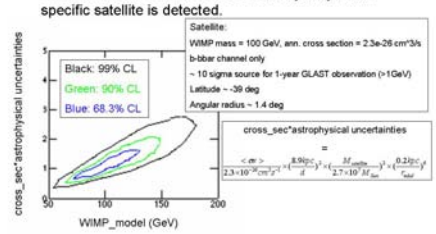
Confidence level on ann. cross section

- Calculate 95% confidence level on ann. cross section if the specific satellite is not detected.

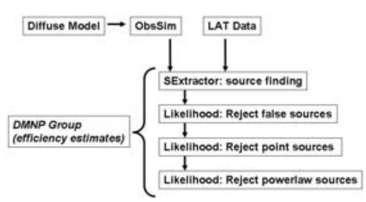


Confidence intervals on WIMP mass and ann. cross section

- Calculate the 99%, 90% and 68.3% confidence regions on WIMP mass and ann. cross section jointly if this specific satellite is detected.

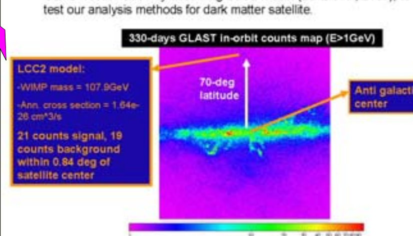


Analysis flow for dark matter satellites



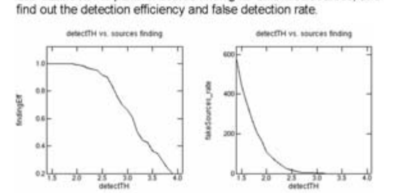
Simulation example satellite

- We choose one typical WIMP satellite with 5 sigma for 1-year GLAST observation by assuming LCC2 model (Baltz et al, 2006), to test our analysis methods for dark matter satellite.



SExtractor: source finding

- We generate 120 "330-day GLAST experiments" for the example satellite, by fixing latitude, but shifting in longitude by 3 degrees; use SExtractor to perform source finding for extended sources, and find out the detection efficiency and false detection rate.



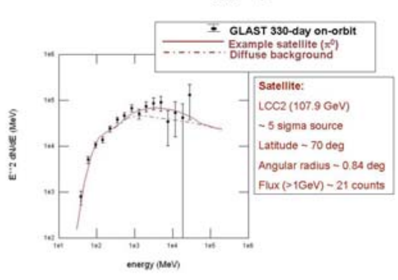
Summary:

We estimated the significance of dark matter satellites in the Milky Way, by modeling the satellites using the semi-analytic method of Taylor & Babul and the SUSY LCC# benchmark of Baltz, et al.

We used test statistics and profile likelihoods to extract the GLAST sensitivity versus WIMP mass.

We selected one example satellite to demonstrate statistical methods for distinguishing between satellite and diffuse background. In the future, we can use the same methods to distinguish satellite from other astrophysical sources.

Likelihood: energy spectrum



Likelihood: null hypothesis testing

•120 "330-day GLAST experiments"

•Compute max likelihood difference between bkgd only and bkgd+signal, a.k.a. "TS" (test statistic)