The Search for Dark Matter Galactic Satellites with Fermi - LAT

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on behalf of the Fermi Large Area Telescope Collaboration

Summary: 10 months of Fermi LAT all sky data is used to perform a search for undiscovered dark matter galactic satellites. At this time, none have been found and this result is preliminary. Comparison with theories are made.

Abstract

The launch of Fermi by NASA on June 11, 2008 has ushered in a new era in indirect searches for dark matter. The unprecedented sensitivity of Fermi has opened up new discovery space in formally exotic channels of exploration. One of these is the search for dark matter galactic satellites that have not been observed in other wavelengths (optical). Discovery of one or more of these satellites in Fermi LAT γ-rays would be a distinctive signal for dark matter distinguishable from astrophysical sources that might quickly be confirmed by optical telescopes after the coordinates of our candidate(s) was made public. The Fermi LAT 10 month data set and analysis are described here. Preliminary estimates of numbers of satellites expected in a few theories are discussed. Recent theories trying to explain the Pamela e^+/e^- ratio and the Fermi $e^- + e^+$ measurement are more vulnerable to falsification. Our preliminary result is that no satellites are observed by Fermi using the 10 month data sample with this analysis that focuses on extended sources.

1. OUTLINE

- Overview of galactic dwarfs.
- The sources of gamma rays from dark matter.
- Description of the data set.
- Criteria for DM satellite candidate selection.
- Preliminary results for 10 month LAT data set.
- Fermi LAT sensitivity to Dark Matter satellites.

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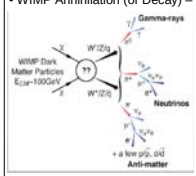
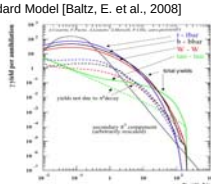
2. Overview of Galactic Dwarfs

- Currently only 25 galactic dwarfs are known, and they have been discovered by optical telescopes. 14 of these are ultra faint [SDSS, 2005, 2007] . There should be many more according to CDM simulations [e.g., Via Lactea II, 2009]. Current theoretical models predict we could observe a factor of ~10 more [Tollerud, et al., 2008].
- The most recently discovered galactic dwarfs have very few stars, e.g., Segue 1 might have 65 stars associated with it [Geha, 2009]. They also have M/L ratios ~>1000 (compared with ~10 for the Milky Way galaxy). Thus they appear to contain dark matter and little else.
- Such dwarf galaxies are good dark matter source candidates for Fermi LAT as any γ-ray emission in the Fermi range would likely come from dark matter annihilation or decay. (Interesting limits from the known dwarfs for some dark matter models are reported at this conference [Farnier, C., et. al., 2009].)
- In this work we are searching for galactic dwarfs that have no counterparts at this time. We are trying to discover new galactic dwarfs via a γ-ray signal that would be a distinctive signature for the nature of dark matter distinguishable from a purely astrophysical source.

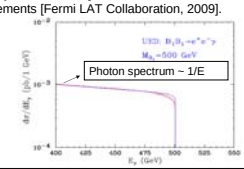
3. The sources of γ-rays from Dark Matter

- WIMP Annihilation (or Decay) – Standard Model [Baltz, E. et al., 2008]





Final State Radiation Models [for example see; Arkani-Hamed, N., et al., 2009] Stimulated by Pamela e^+/e^- [Pamela Collaboration, 2009], and Fermi LAT ($e^- + e^+$) measurements [Fermi LAT Collaboration, 2009].



4. Description of the Data Set

- 10 months of Fermi LAT data; All-sky scanning mode, 8/8/2008-6/720/09
- Exclude the SAA and non-standard data modes (e.g., calibration, problem runs).
- Earth Albedo Cuts
  - photon angle to the Zenith < 105º.
  - LAT z-axis angle to the Zenith < 47º (52º after about 9/1/09) – LAT rocking angle cut
- Pass 6 Version 3, public data release; diffuse class
- 100 MeV < E_γ < 300 GeV.

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5. Criteria for DM Satellite Candidate Selection

- Source has spatial extension (can be resolved by the LAT ~> 1º on the sky).
- Source energy spectrum is non-power-law (if WIMP annihilation) or 1/E power-law (if FSR).
- Source is not variable.
- Source has no counterparts at other wavelengths.

6. Analysis Method to Search for Extended DM Satellites with the Fermi LAT

- Blind search strategy
  - Optimize the analysis method using 3 months of LAT data.
  - Fix the analysis method and analyze 10 months of LAT data.
- Analysis method Fixed with 3 Months of Data.
  - Search for 4 sigma detections with |b|>10º (cut away galactic plane), which are not identified sources in Fermi LAT catalog using source-like, a Fermi Collaboration code to establish extended sources.

  - Test source extension with **hypothesis testing**: NFW model VS. point source model using source-like:
    * TS = 2 (ln(L1) – ln(L0)), L0 is the null hypothesis.
    * TS statistically follows a chi-square distribution if comparing two hierarchically nested models (one more parameter -> χ^2_{1dof}).
    * NFW source vs. point source (NFW dist. with very small extent).
    * TS_NFW: bkgd and a NFW source
    * TS_Point: bkgd and a "point" source
  - Fit counts map using source-like
    * ROI, centered on putative source, is energy dependent, a function of LAT PSF.
    * ΔTS_{extent} = (TS_NFW – TS_Point).
  - Fit includes Ring Diffuse Model (standard LAT galactic diffuse), isotropic term, known point sources from the year-1 catalog under development by the LAT team [Abdo, A., et al., in preparation].
    * 100 MeV < E_γ < 300 GeV.

  - On resulting extended candidates test for DM spectrum with gtlike (standard LAT science tool).
  - Fit includes Ring Diffuse Model (standard LAT galactic diffuse), isotropic term, known point sources from the year-1 catalog under development by the LAT team [Abdo, A., et al., in preparation].
    * Fixed 30º x 30º ROI with putative source at center for both hypotheses.
    * 200 MeV < E_γ < 300 GeV (Fits more stable with higher energy cut.)
    * Require TS_pwl and/or TS_DMFit > 25, and a good fit (χ^2 from fit residuals).
    * Spectral models are not nested.
    * Determine proper ΔTS cut from MC bootstrap: Make cut at p value of 10^{-3} .

7. Preliminary Results from 10 Months LAT Data

- 54 extended sources found over the entire sky using source-like. These are 4σ sources.
- After further analysis of each extended source with gtlike as describe on previous panel
  - 4 extended sources left with 5 sigma significance - TS_pwl>25 using gtlike.
- None of these sources prefer DM spectral fits.
- We have not found any new extended galactic dwarf galaxies with this data analysis in 10 months of data.
- One of the 4 extended sources found is also a known point source in the year-1 catalog under development by the LAT team [Abdo, A., et al., in preparation], and may be associated with a molecular cloud known from the CfA CO survey [Dame, T., 2007]

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8. Fermi LAT Sensitivity to Dark Matter Satellites

- Use gtobssim and Via Lactea II [Kuhlen, M., et al. 2008] CDM simulation to generate count maps of satellites that are closer than 25 kpc to the sun or mass > $5x10^7$ solar masses.
- Choose a number of realizations that rotate the simulation and place the sun origin at different locations on a sphere 8.0 kpc from the center of the galaxy.
- Each realization corresponds to 1 year of Fermi all-sky scanning operation.
- Consider 3 theoretical models:
  - Standard WIMP model, $<\sigma v> = 3 \times 10^{-26}$ cm^3/s, M_{WIMP} = 100 GeV, annihilation into b-bar.
  - FSR model, $<\sigma v> = 2 \times 10^{-23}$ cm^3/s, M_{WIMP} = 1000 GeV, annihilation into $\mu^+\mu^-$.
  - Wino LSP model [Kane, G., et al., 2009], $<\sigma v> = 2.5 \times 10^{-24}$ cm^3/s, M_{WIMP} = 180 GeV, annihilation into W^+W^-.
- Use gtobssim to simulate photons from model and with proper exposures. P6V3 diffuse class IRFs were used.
- Show photons with E > 200 MeV.

See next panel for preliminary results.

- **Future Plans**
  - Insert simulated photons into the 12 month data set and test ability to find subhalos using the analysis presented in this poster.
  - Extend the mass function to lower mass halos

9. Fermi LAT Sensitivity to Dark Matter Satellites

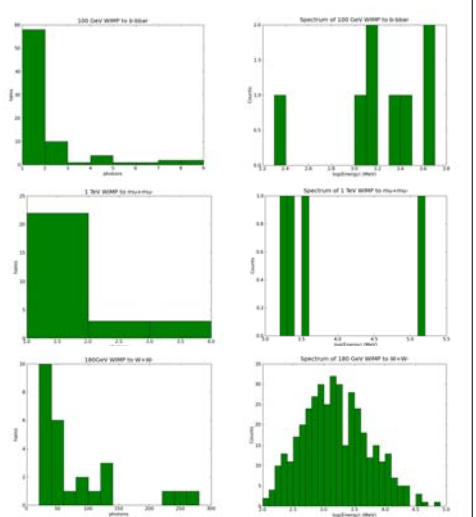

Figure Caption: Results from the 3 models presented in the previous panel. On the left is the number of photons vs. number of satellites (halos) producing photons in one realization of 1 year Fermi All-sky scanning mode for the 3 models as labeled on the figures. On the right are the energy spectra of the models taken from the satellite with the most counts (from the corresponding figures on the left). The bottom two figures show the results from the "Wino LSP" (Kane, G., et al. 2009).

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