Search for Dark Matter Satellites of the Milky Way with the *Fermi*-LAT

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Fermi Gamma-ray Space Telescope

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Abstract

We present a search for dark matter satellites of the Milky Way using the Large-Area Space Telescope (LAT) onboard the *Fermi* Gamma-ray Space Telescope (*Fermi*). Current N-body simulations based on ΛCDM cosmology predict a large number of yet unobserved dark matter satellites in our galaxy. These satellites could potential produce gamma-rays through dark matter self-annihilation. The unprecedented angular resolution and sensitivity of the LAT makes it an excellent instrument for detecting new gamma-ray sources. We search for potential dark matter satellites in the unassociated LAT sources by testing for spatial extension and spectral shape consistent with dark matter annihilation. We find no candidate dark matter satellites in 1 year of LAT data and begin to examine how this can be interpreted in the context of current N-body simulations.

Introduction

Current N-body simulations suggest that the Milky Way halo is populated by copious amounts of dark matter substructure [1]. Large substructure hosts dwarf spheroidal galaxies, while lower mass dark matter satellites are more numerous (though lack visible tracers). We search for these satellites through the gamma-ray signal that could be produced from self-annihilation of the dark matter itself [2].

A popular candidate for dark matter is a Weakly Interacting Massive Particle (WIMP), which could continue to annihilate into Standard Model particles in regions of high dark matter density today. WIMP annihilations can produce both line and continuum gamma-rays emission which could be detected by the *Fermi*-LAT.

We expect the gamma-ray emission from dark matter satellites to be unassociated with known sources in other wavelengths, spatially extended, and non-power law in spectral shape [2]. We design tests to distinguish spatial extension and non-power-law spectra with 99% purity and apply them to unassociated sources in 1 year of LAT data. We find no viable dark matter satellite candidates according to these criteria.

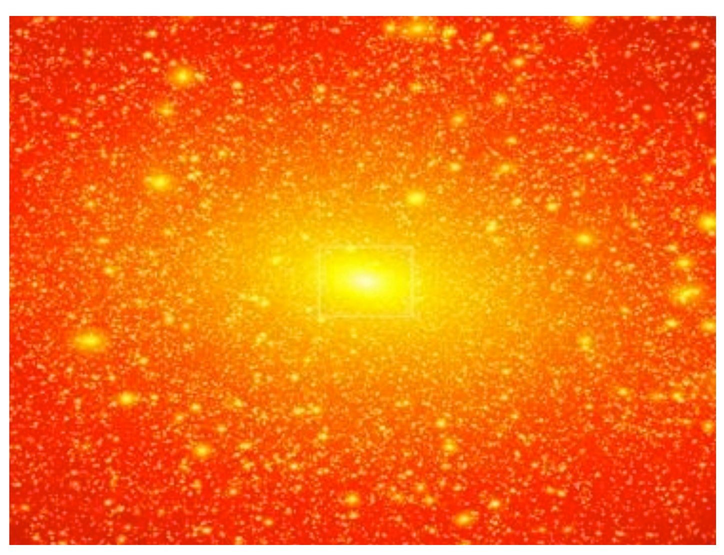

Figure 1: Dark matter substructure in the Via Lactea II N-body simulation [1].

Search for Dark Matter Satellites

Using 1 year of LAT data, we select high-latitude (|b|>20°), unassociated sources (Fig. 2) from both:

- The 1FGL catalog [3]
- An independent source search with fewer spectral assumptions. This search is performed with the internal collaboration tool, Sourcelike.

We design cuts with 99% purity to test for:

- Spatial extension that is inconsistent with the LAT point-spread function.
- A spectral shape that is inconsistent with a conventional power law.

Applying these tests has the following result:

- Two 1FGL sources pass our spatial extension test, but an internal 2 year catalog finds both to be coincident with a weak neighboring source.
- One of these 1FGL sources also passes our spectral test, but is subsequently found to be a millisecond pulsar. Possible contamination from pulsars is examined in more detail below.

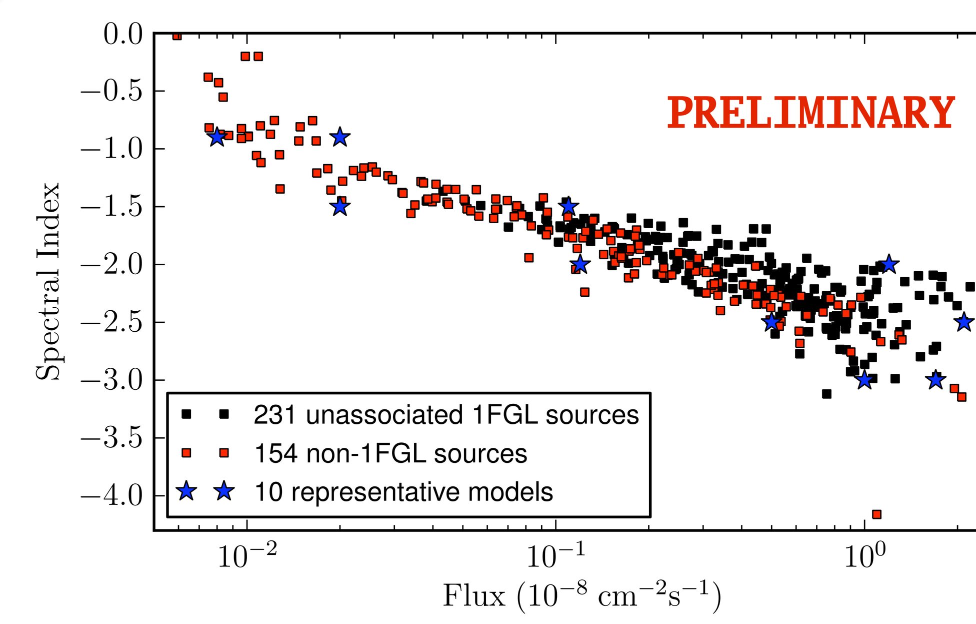

Figure 2: The flux and spectral index of the 385 unassociated sources tested. Simulations of 10 representative models were used to assign a significance to the spatial extension and spectrum tests as a function of source flux and spectral index.

Distribution of Low-Mass Dark Matter Satellites

Low-mass dark matter satellites:

- Theoretical arguments suggest that dark matter satellites could extend down to masses of ~10^{-6} $M_\odot$.
- However, current N-body simulations are resolution limited at a mass of ~10^5 $M_\odot$.
- To account for some of these low-mass satellites, we use the Via Lactea II simulation [1] to extrapolate the relations between the tidal mass (M_{tidal}) and both the maximum circular velocity (v_{max}) and the radius at which the maximum circular velocity occur (r_{vmax}).
- Assuming a NFW [4] dark matter density profile for all satellites, we are able to extend the dark matter satellite population to low mass using the following relations [5]:

$$r_s = \frac{R_{V_{max}}}{2.163}, \quad \rho_s = \frac{4.625}{4\pi G}\left(\frac{V_{max}}{r_s}\right)^2$$

Detection potential for low-mass satellites:

- Approximating the astrophysical contribution to the gamma-ray flux with a toy model yields the relationship:

$$J \approx \frac{1}{D^2}\int_V \rho(r)^2 dV \propto \frac{r_s^3\rho_s^2}{D^2} \propto \frac{M^{0.81}}{D^2}$$

- We find that the majority of the original and extended mass Via Lactea II satellites have smaller detection potential than the known dwarf spheroidal Draco.
- Of course, this does not preclude fortuitous positioning of a low-mass satellite close to Earth.

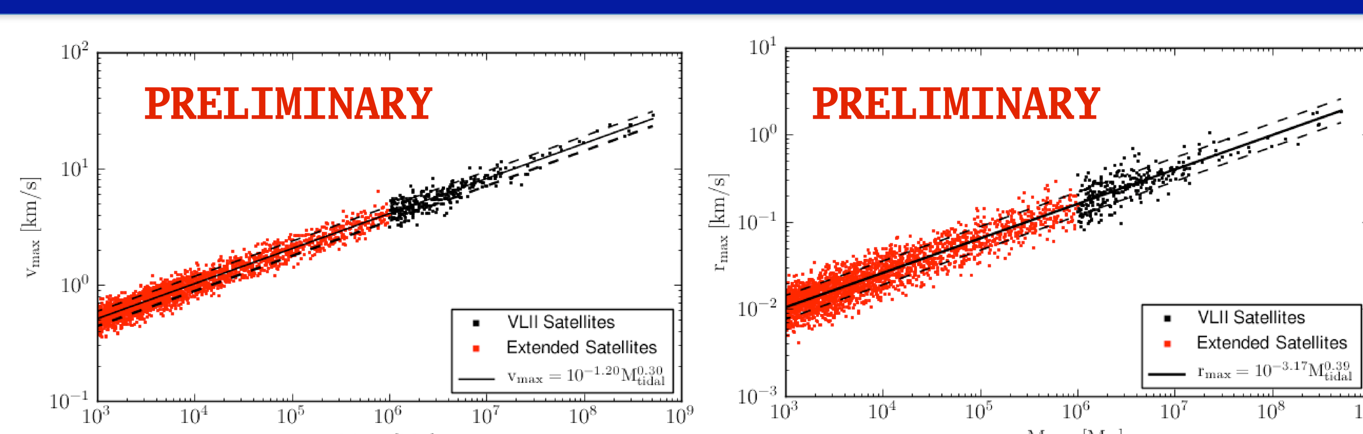

Figure 3: Relation of v_{max} and r_{vmax} with M_{tidal} for Via Lactea II satellites and their low mass extensions.

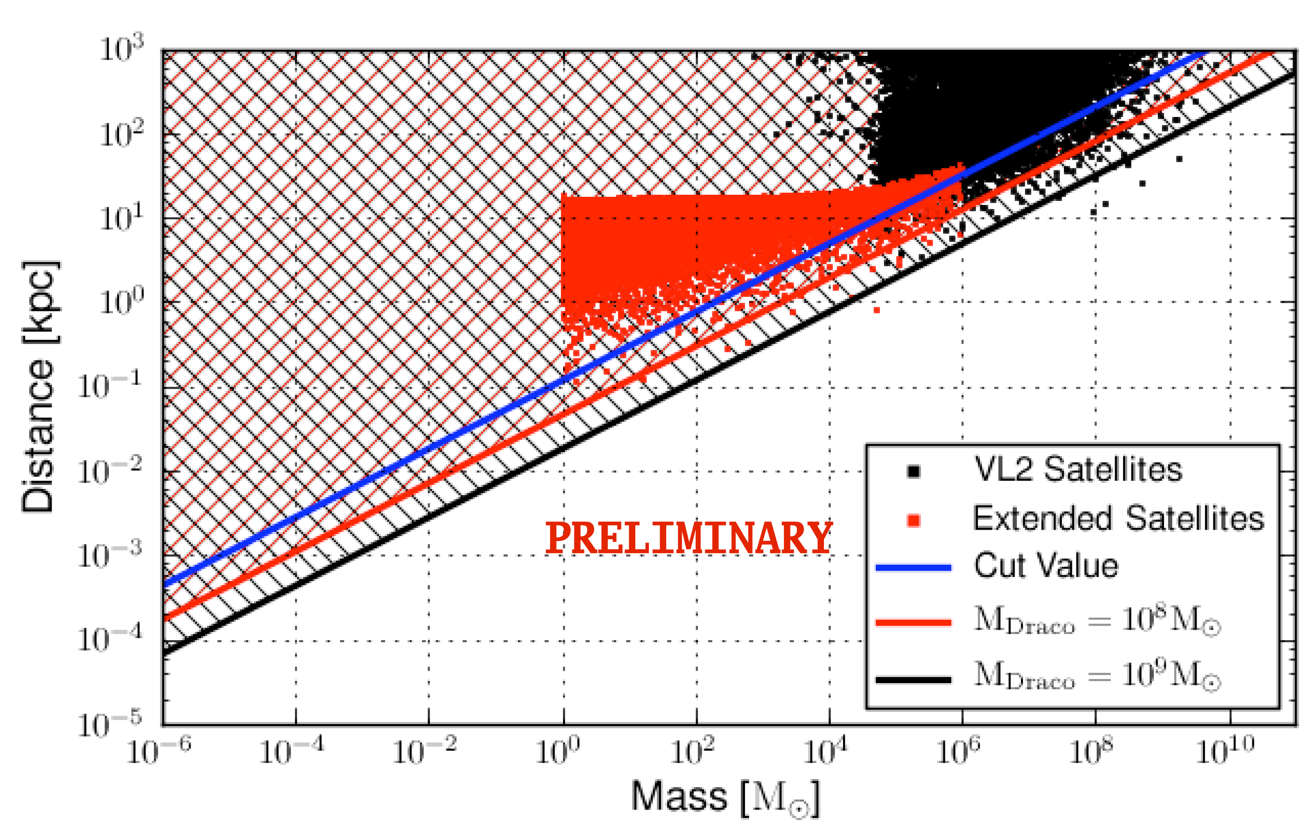

Figure 4: Relative astrophysical potential of Via Lactea II satellites compared to that of the Draco satellite. Contours parallel to the solid lines denote equivalent astrophysical contributions.

Contamination from Pulsars

- We find that nearly all (24 of 25) high-latitude LAT-detected pulsars pass our spectral test.
- Figure 5 shows the similarity between the exponentially cutoff power law commonly used to model pulsar spectra and a conventional low-mass WIMP annihilation spectrum.
- When fitting pulsars with WIMP annihilation spectra, they prefer WIMP masses around 25 GeV.
- This emphasizes the importance of testing for spatial extension to select against high-latitude pulsars (though weak neighboring sources or pulsar wind nebulae could cause confusion here as well).

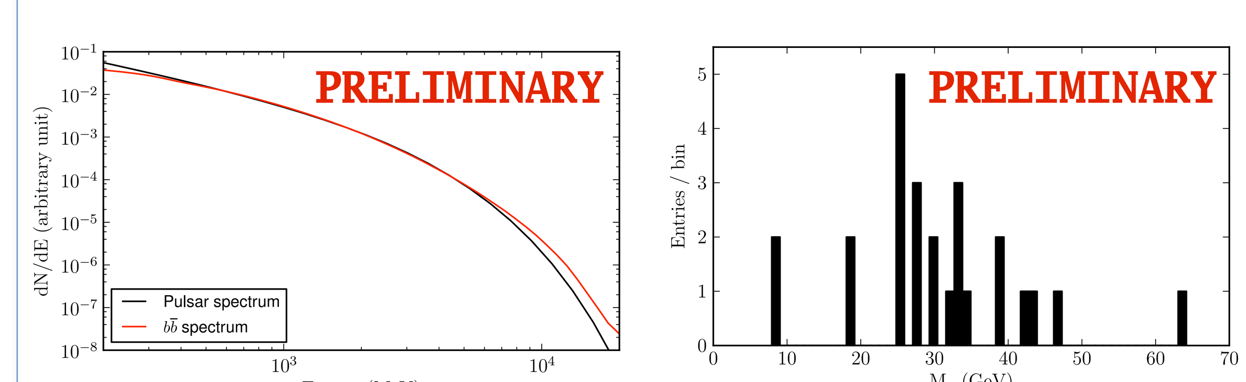

Figure 5: Comparison between a power law with exponential cutoff spectrum and a low mass WIMP annihilation spectrum (**left**). Best fit mass for for 25 high-latitude pulsars (**right**).

Conclusions

- No viable dark matter satellite candidates pass our cuts on spatial extension and spectral shape.
- We find that tests on spatial extension are required to remove contamination from high-latitude gamma-ray pulsars.
- We extrapolate the distribution of dark matter satellites below the resolution limit of current N-body simulations and find that a few of these low-mass satellites may have larger detection potential than the Draco dwarf spheroidal. Additionally, we cannot rule out the possibility that a low-mass dark matter satellite may be located fortuitously close to Earth.
- Efforts are on going to use the non-detection of dark matter satellites to set upper limits on the dark matter annihilation cross section in the context of current N-body simulations

Acknowledgements

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References

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