Legacy Analysis of Dark Matter Annihilation from the Milky Way Dwarf Spheroidal Galaxies with 14 Years of *Fermi*-LAT Data

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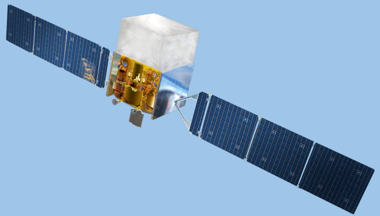
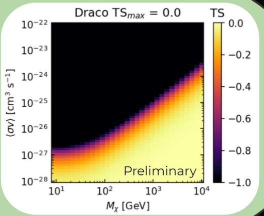
Project Overview

Milky Way dwarfs are excellent DM targets, *Fermi*-LAT studies of dSphs provide some of the best constraints on WIMP DM.

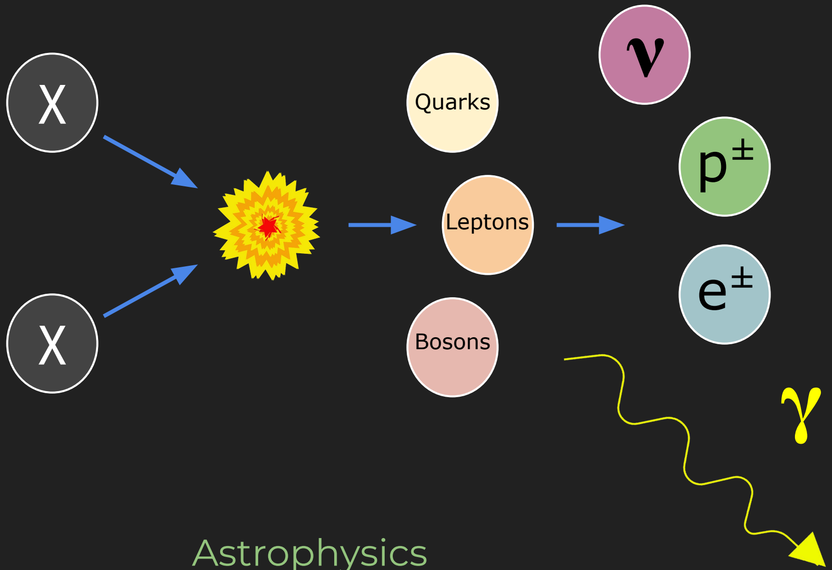


Our analysis follows previous *Fermi* dSph analyses, but includes a longer *Fermi* exposure, new dSphs and new J-factor measurements, and updated *Fermi* catalogs

In addition to reporting the updated results, we will provide several data products available to the community (e.g., limits, SEDs, DM likelihood profiles)



Dark Matter: WIMP Annihilation



Astrophysics
"J-factor"

Gamma-ray Flux: $$\frac{d\Phi}{dE} \propto \int_{\Delta\Omega}\int_{los}\rho_\chi^2 \times \frac{\langle\sigma v\rangle}{2M_\chi^2}\sum B_i\frac{dN_\gamma}{dE}$$

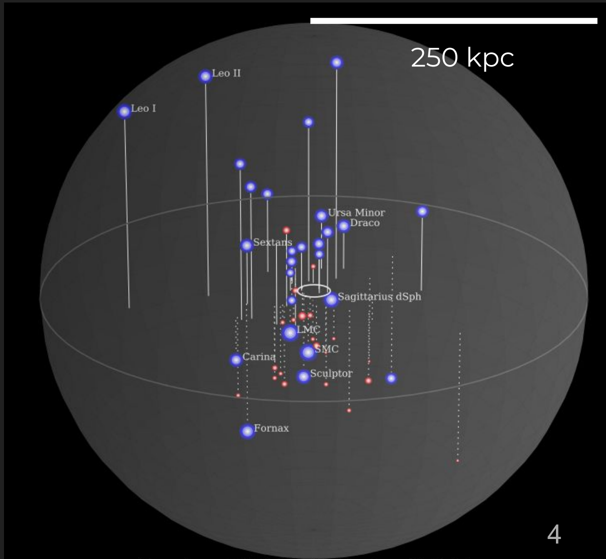
Particle Physics

dSphs as targets of DM searches

Nearby, $\lesssim$ a few hundred kpc

Low astrophysical backgrounds

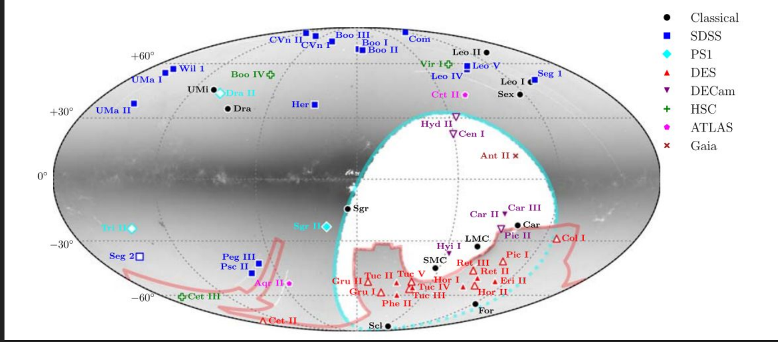
High dark matter concentration



Pawlowski/Bullock/Boylan-Kolchin

dSph Sample

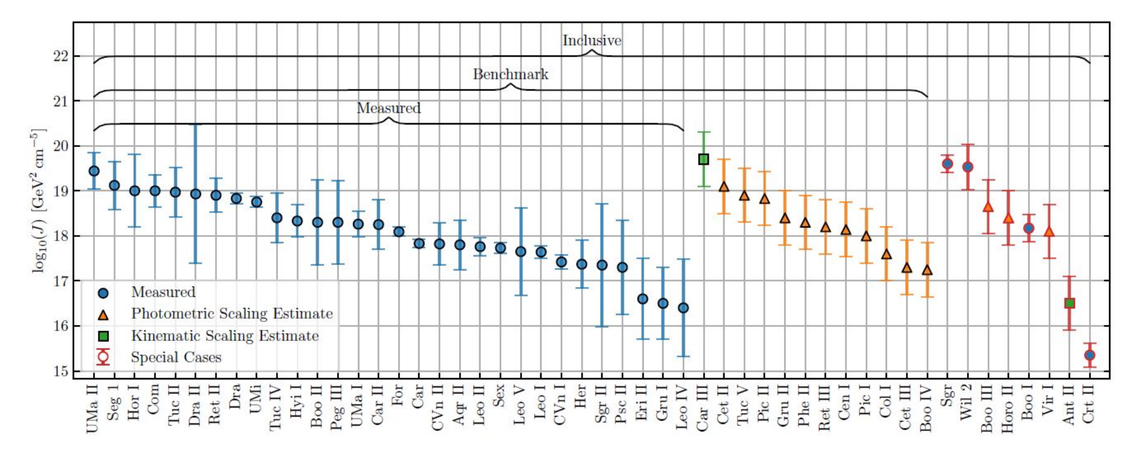
Census of known dSphs collected in [Drlica-Wagner+2020]
Discovered in optical surveys, e.g. SDSS, DES, PanSTARRs, DECam, Gaia, …



~75 % sky coverage

<u>Sample subsets:</u>

1. Inclusive: All dSphs, including special cases (50)
2. <u>**Benchmark**: All dSphs, Excluding Special cases (42)</u>
3. Measured: dSphs with measured J-factors, Excluding Special cases (30)



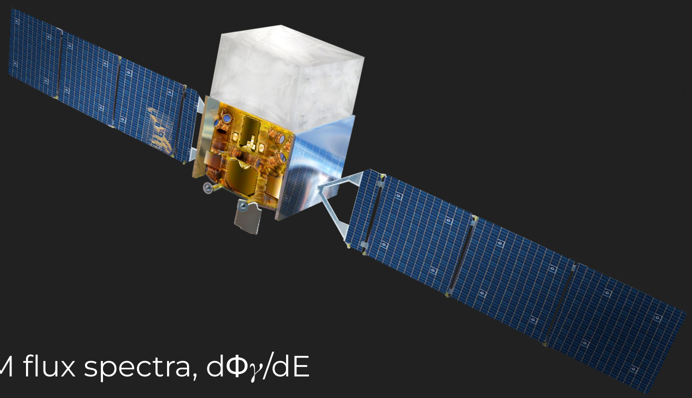
*Special cases:

i) Tidally disrupted systems

ii) dSphs background undetected blazars or blazar candidates

Fermi γ-ray Analysis

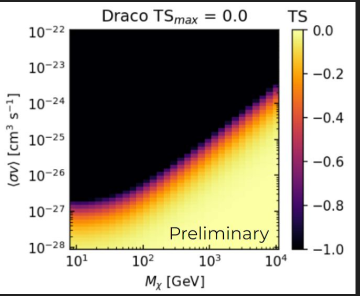
- 14 years of Fermi-LAT exposure
- 500 MeV - 1 TeV
- 4FGL - DR3 Source Catalog
- New dSphs, updated J-factors (e.g., June 2023 most recent)



Individual dSph Analysis:

Analyze the gamma-ray data, construct TS profiles in terms of $\langle\sigma v\rangle$ - M_χ from DM flux spectra, $d\Phi\gamma/dE$

TS ≤ 0 ⇒ No gamma-rays



$$TS = 2\log\left(\frac{\mathcal{L}_{\mathrm{DM}}}{\mathcal{L}_{\mathrm{null}}}\right)$$

*L_{DM} function of $\langle\sigma v\rangle$, M_χ and includes J-factor likelihood term:

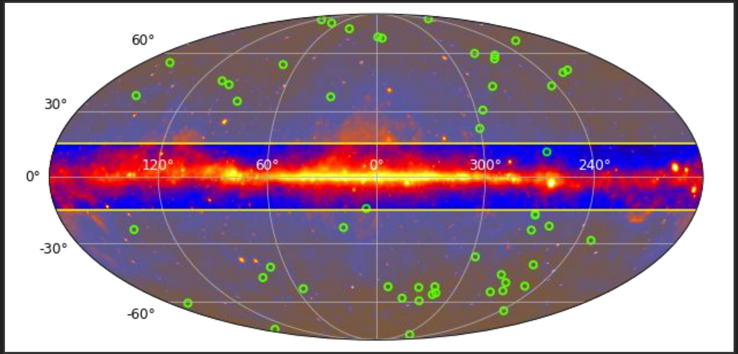
$$\mathcal{L}_J(J) \propto \exp\left[-\left(\frac{\log(J)-\log(J_{obs})}{\sqrt{2}\sigma_J}\right)^2\right]$$

Combined analysis of dSphs ("Stacking" method) used to improve sensitivity. Takes advantage of the additive nature of the TS.

Combined results come from summation of the Individual dSph results

Blank-field Analysis

- Allows us to quantify significance accounting for backgrounds, deviations from Poissonian statistics
- "Blank" -> no Fermi sources, or multiwavelength blazars/blazar candidates
- Procedure is nearly identical to dSph analysis and uses the dSph J factors of the sample



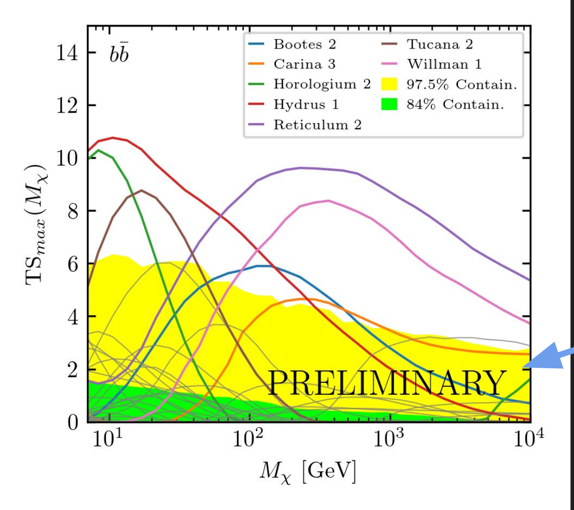
Sample ~1000 high latitude (|b|>15 deg) regions consistent with the dSphs (shaded region)

Results

dSph Analysis Results - TS vs M

Individual dSphs:

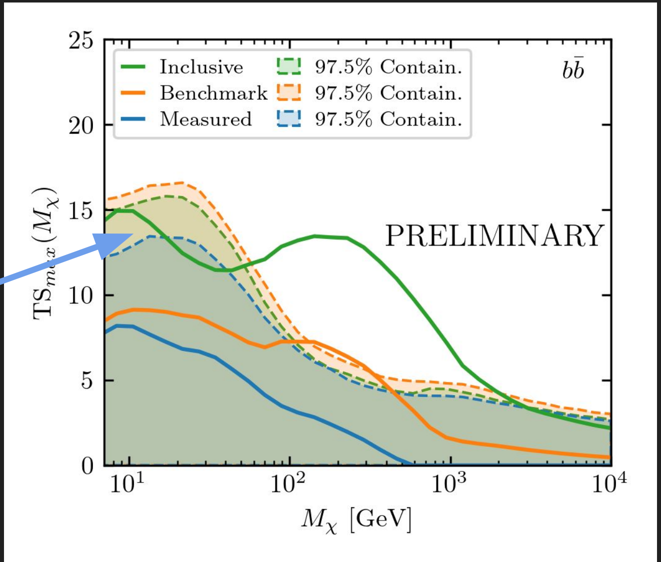
7 with local significance > 2σ in tested channels channels.



Consistent in the case of previously marginally detected dSphs, as well as finding more

Combined Analysis:

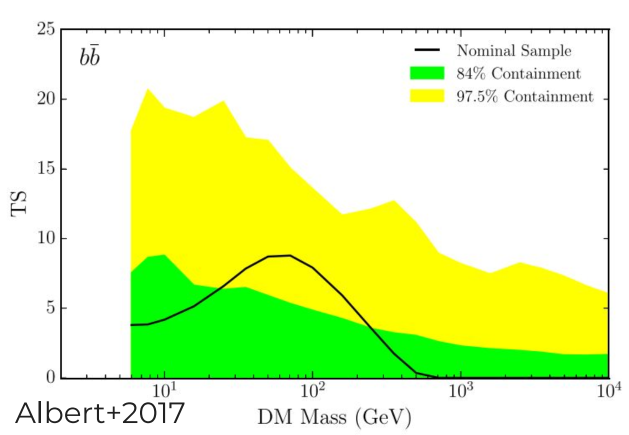
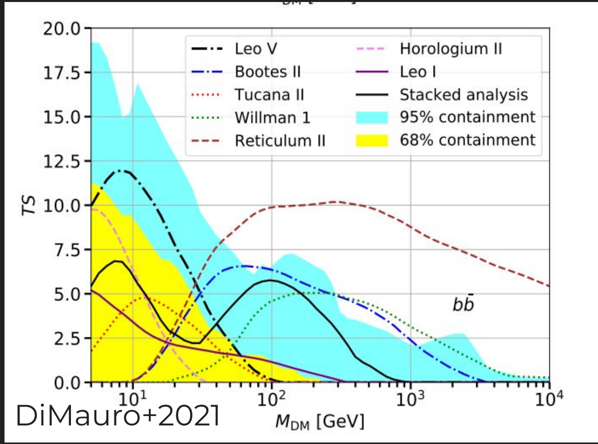
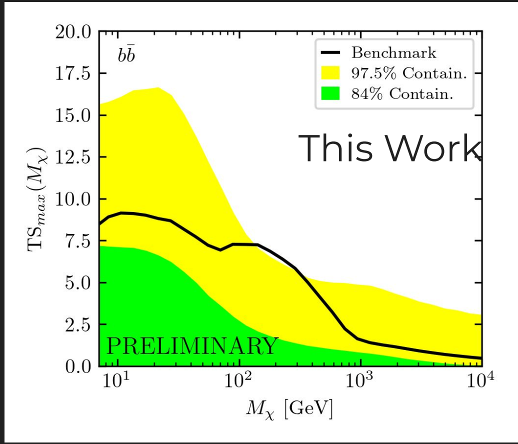
Benchmark: 150-300 GeV ~2σ (~30-50 GeV for tau)



~2σ

Shaded bands from the blank-field analysis

Combined dSph Analysis - Previous Results

6 years	11 years	14 years
		
$<2\sigma$	$\lesssim 2\sigma$	$\gtrsim 2\sigma$

dSphs Upper Limits

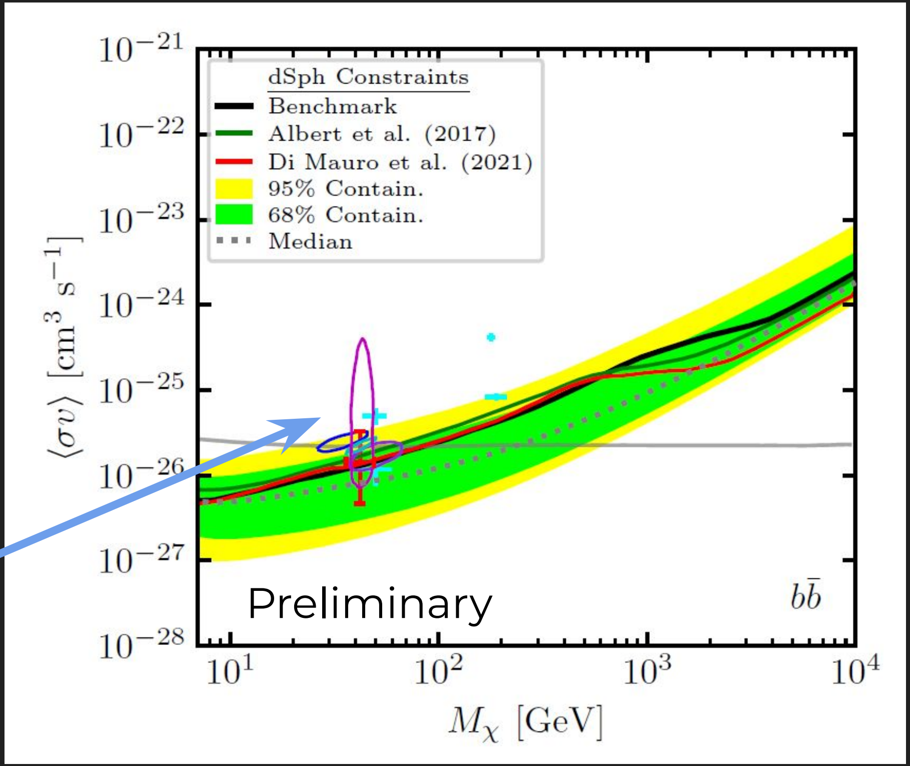
Trials factor penalty from testing different masses, annihilation channels reduces the significance ~0.5 σ

<u>Instead, place upper limits</u>

Generally consistent with previous limits.

Limits are in tension with GCE models, but cannot rule out DM given uncertainties in GC DM profile and diffuse model

Galactic Center Excess models



Sensitivity/Detection Projections

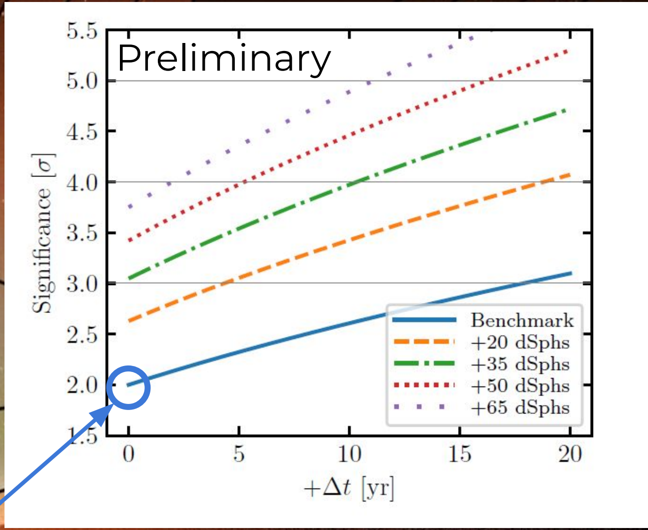
Erin O'Flynn/The Daily Beast/Getty Images and Rubin Obs/NSF/AURA

Fermi-LAT dSph sensitivity improves with greater exposure, larger sample size

Sensitivity projections were studied in depth in Charles+2016 for future dSph DM searches

With +35 (+65) new dSphs, we would be able to approach the 4σ (5σ) local significance level in ~10 years

Local Significance

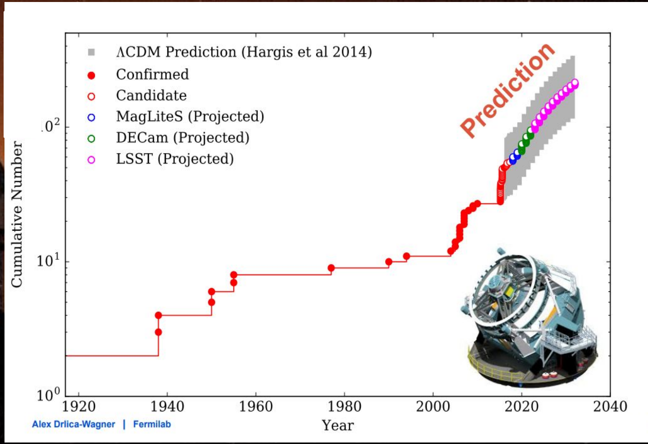


Additional Fermi Exposure

This result

Discovery potential

~100-200 New dSphs with *Rubin*/LSST



Summary

- We have performed an updated analysis of the Milky Way dSphs with
  - 14 years of Fermi Data
  - Updated Fermi Catalogs
  - New dSphs, updated J factor measurements and estimates

- No signal is found in individual dSphs or combined analysis.

- 7 dSphs show relative $>2\sigma$ local excess

- Combined analysis shows local excesses $\gtrsim 2\sigma$ in both channels, ($<1\sigma$ when accounting for trials)
  - 150-300 GeV $b\bar{b}$ (30-50 GeV $\tau^+\tau^-$)

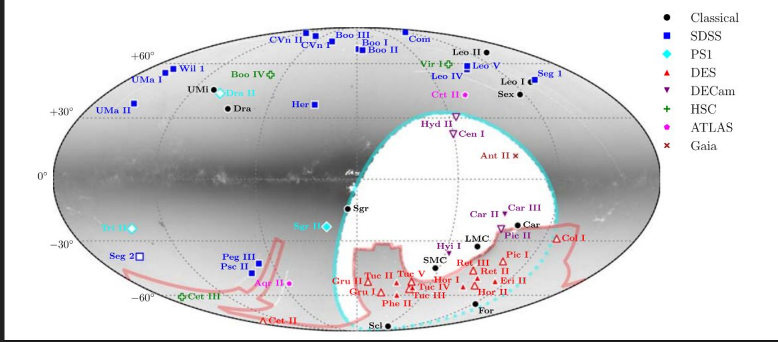
- Fermi sensitivity has largely tracked well with expectation. With additional exposure + newly discovered dwarfs we could approach a $\sim 4\sigma$ signal.

- With the release of the paper, data products will be available for community use (e.g. limits. likelihood profiles, SEDs).

Thank you!

dSph Sample

Census of known dSphs collected in Drlica-Wagner+2020
Discovered in optical surveys, e.g. SDSS, DES, PanSTARRs, DECam, Gaia, ...

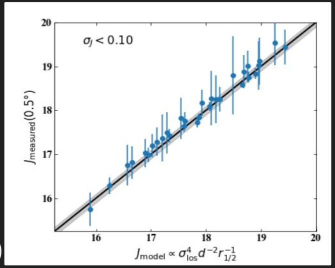


~75 % sky coverage

Some complicating factors to consider

Measured J factors vs Scaling relation estimates

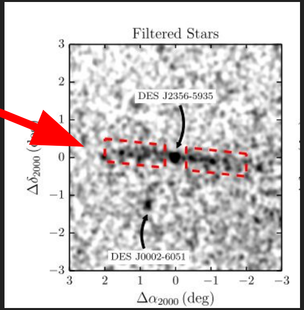
Pace & Strigari (2019)



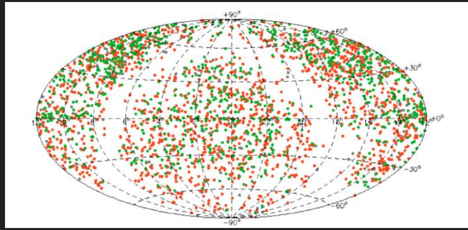
Flagged as "Special cases"

Non-equilibrium dynamics (e.g. tidal disruption)

Ex. Tidal tails in Tuc III indicate non equilibrium dynamics (Drlica-Wagner+2015)



Contamination from potential gamma-ray sources (e.g. unresolved blazars)

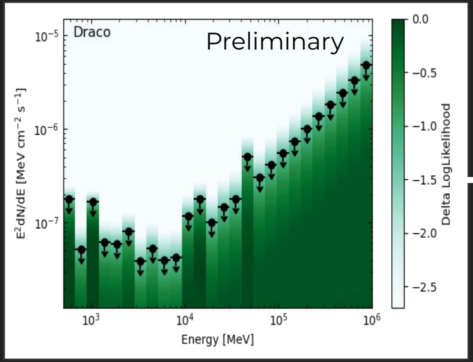


BZCat

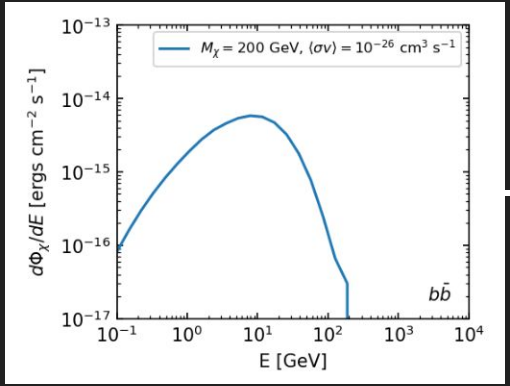
Flux-Energy -> <σ v>-M_{chi}

$$\mathcal{L}\left(\langle\sigma v\rangle, M_\chi\right) = \sum_{E_i} \mathcal{L}\left[\frac{d\Phi_\chi}{dE}\left(\langle\sigma v\rangle, M_\chi, E_i\right), E_i\right],$$

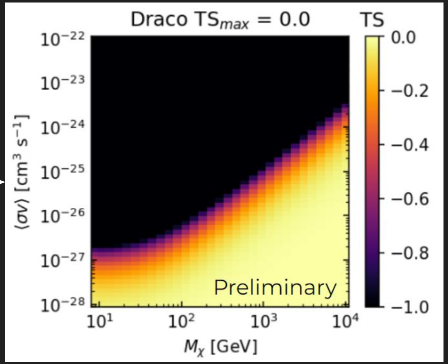
Flux-energy likelihood profile



DM Flux vs Energy



<σ v>-M_{chi} likelihood profile

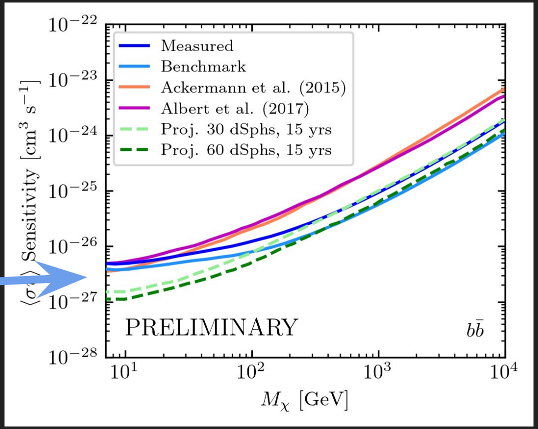


Fermi-LAT Sensitivity

Fermi-LAT dSph sensitivity improves with greater exposure, larger sample size

Sensitivity projections were made in Charles+2016 for future dSph DM searches with 15 years of data

Sensitivity lines from the blank field analysis



Above ~ 200 GeV, observed sensitivity is in excellent agreement with projections.

Solid lines show median of the blank-fields in Ackermann+2015, Albert +2017 compared to our results for the Measured (30 dSphs) and Benchmark (42 dSphs) samples. Also shown are the projections from Charles+2016 (dashed)