DM & IMBHs with Fermi-LAT

In prep.

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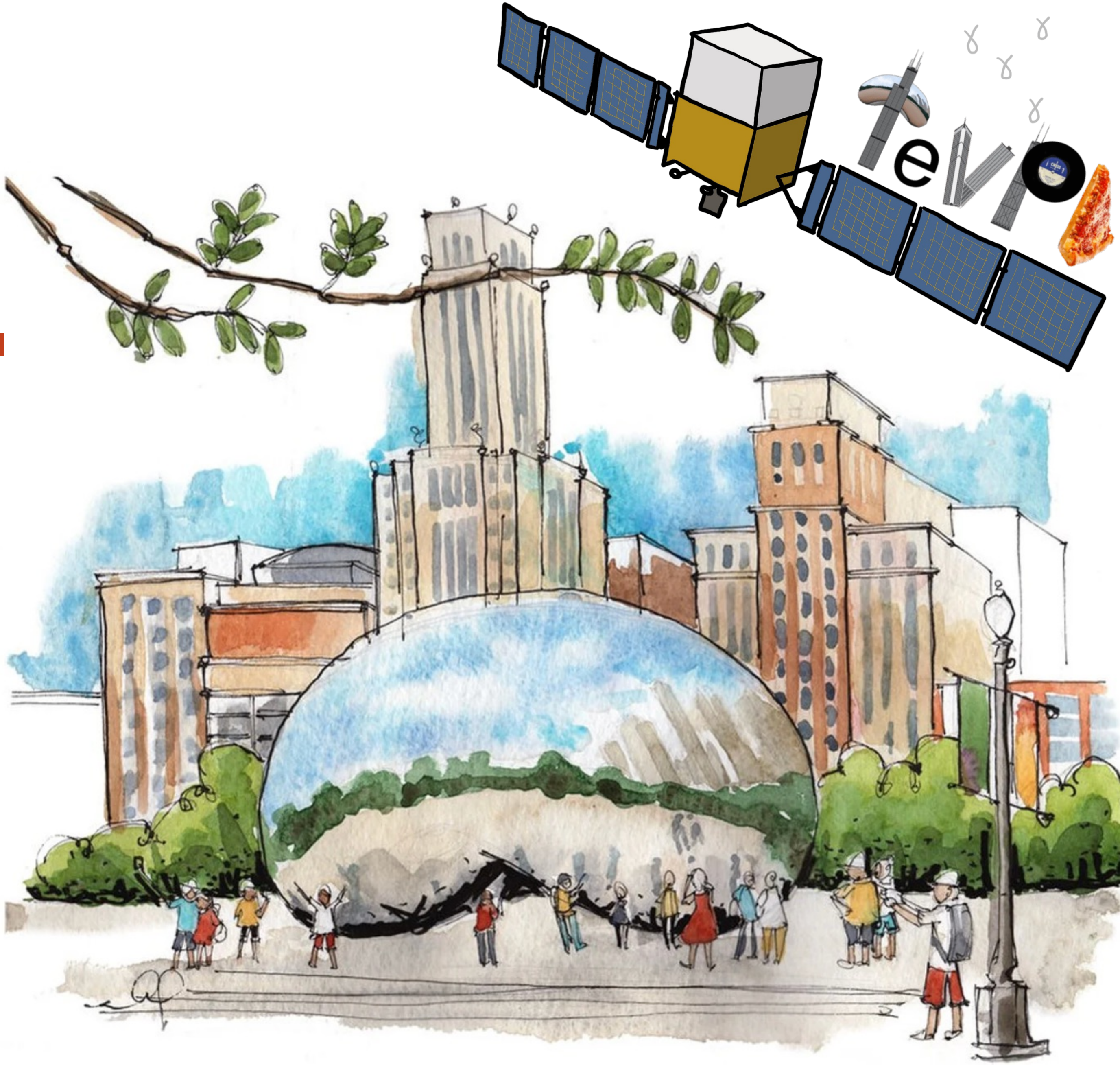

Image Credit: Stephanie Fowler, @designbystlight

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Dark Matter (DM) spikes

(cold, particle)

Astrophysical Processes

adiabatic growth of a black hole embedded within a dark matter halo

(see, e.g., Gondolo & Silk 1999)

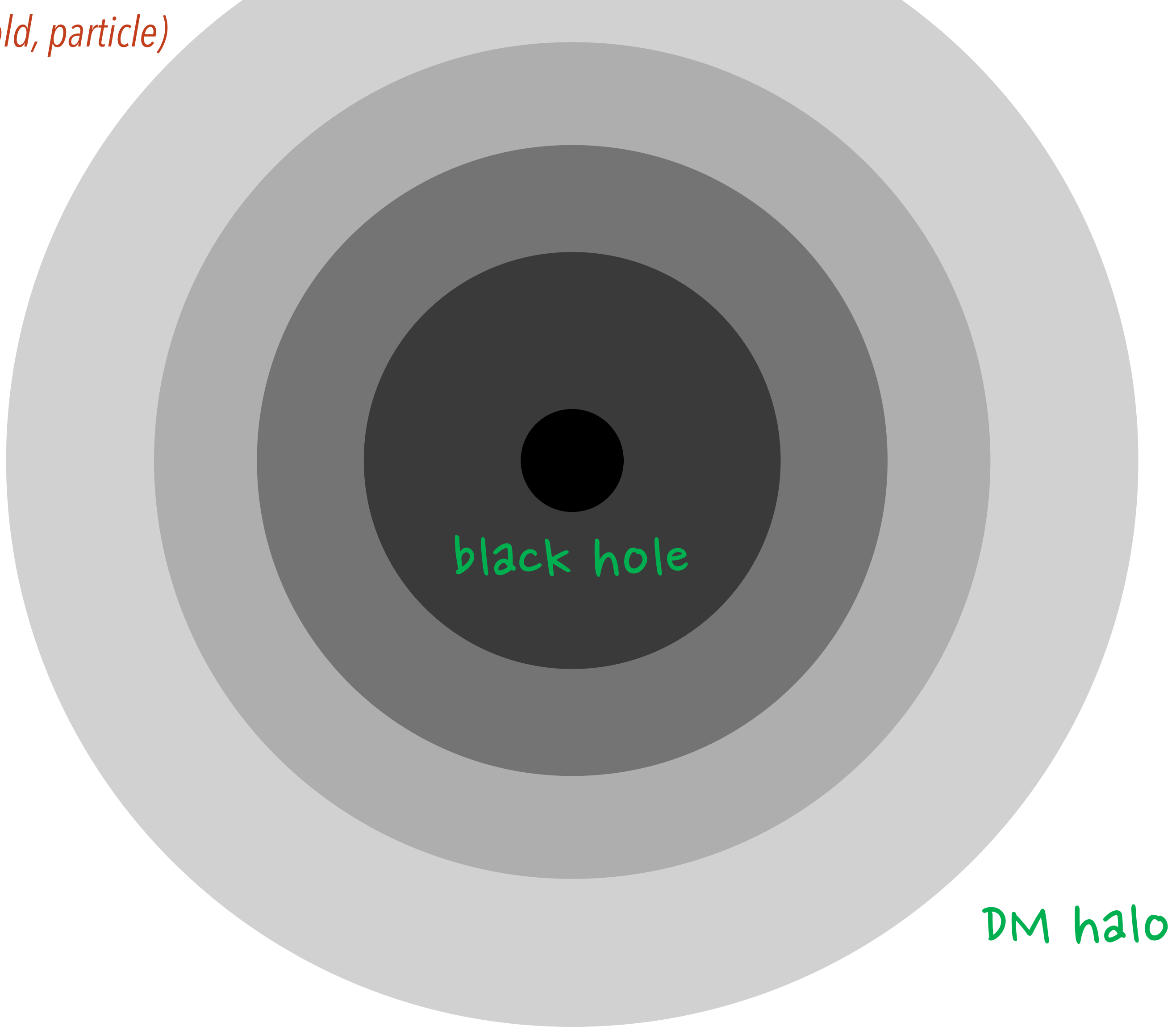
High Density Fluctuations

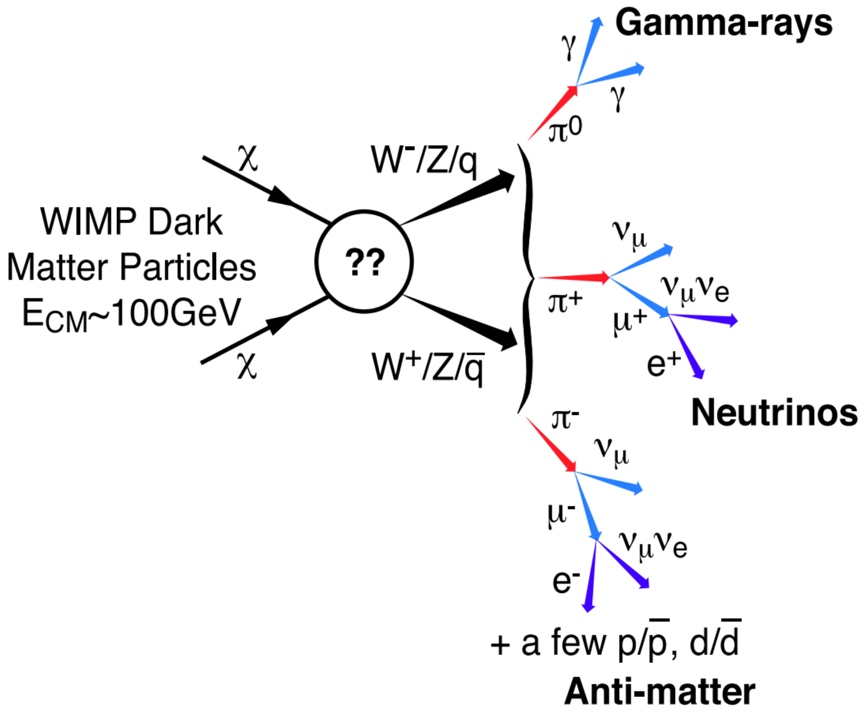
such as (primordial) black holes formed in the early Universe

(see, e.g., Bertschinger 1985)

Dark Matter (DM) spikes

(cold, particle)





self-annihilation may reduce the spike density but still results in γs and νs
(see, e.g., Bertone et al. 2005, Freese et al. 2022)

Intermediate-Mass Black Holes (IMBHs)

What? black holes, $M_{IMBH} = 10^2 - 10^6 M_{\odot}$

Why? missing link between stellar-mass and supermassive BHs

Where? globular clusters, nuclei of low-mass galaxies, outskirts of large galaxies

How? dynamical measurements, X-ray observations of accretion, gravitational lensing, gravitational wave emission, optical lines (BPT), radio emission from AGN, Fe coronal lines...
~ 100 candidates

(see, e.g., Greene & Ho 2005, Reines et al. 2013 & 2019, Birchall et al. 2020, Sacchi et al. 2024)

This work

Search for DM annihilation signals from highly concentrated DM regions, i.e., spikes, surrounding IMBHs using *Fermi-LAT* data

Why?

Less Crowded Environments

IMBHs are typically in less dense regions compared to SMBHs, reducing background contamination

Simpler Accretion Dynamics

IMBHs have less complex accretion processes, making it easier to distinguish DM-related emissions.

How?

Cross-Correlation Analysis

Utilizing the unresolved gamma-ray background (UGRB) and a mock catalog of IMBHs to identify spatial correlations indicative of DM annihilation

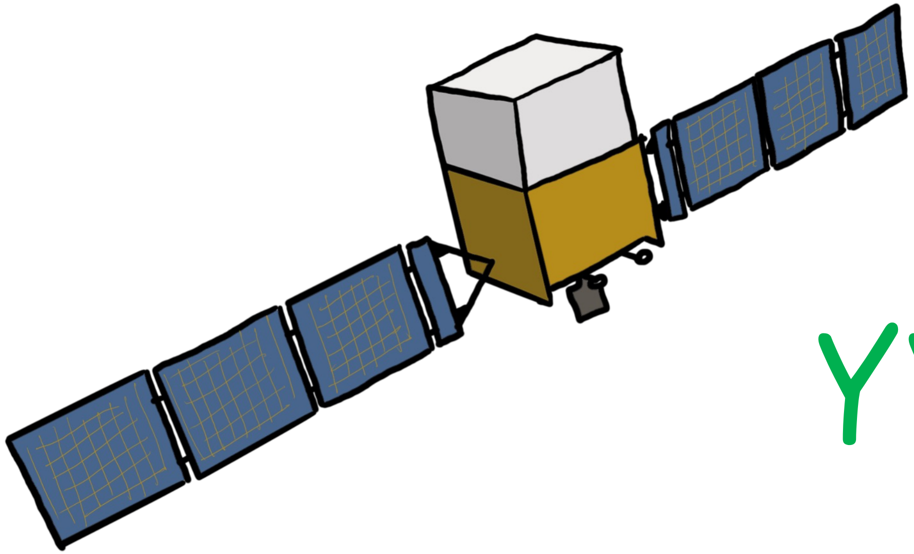
Individual/Stacking Analysis

Potential to detect gamma-ray emission that is individually below Fermi-LAT's sensitivity threshold

XX tsp DM

YY tsp IMBHs

...a recipe for disaster???

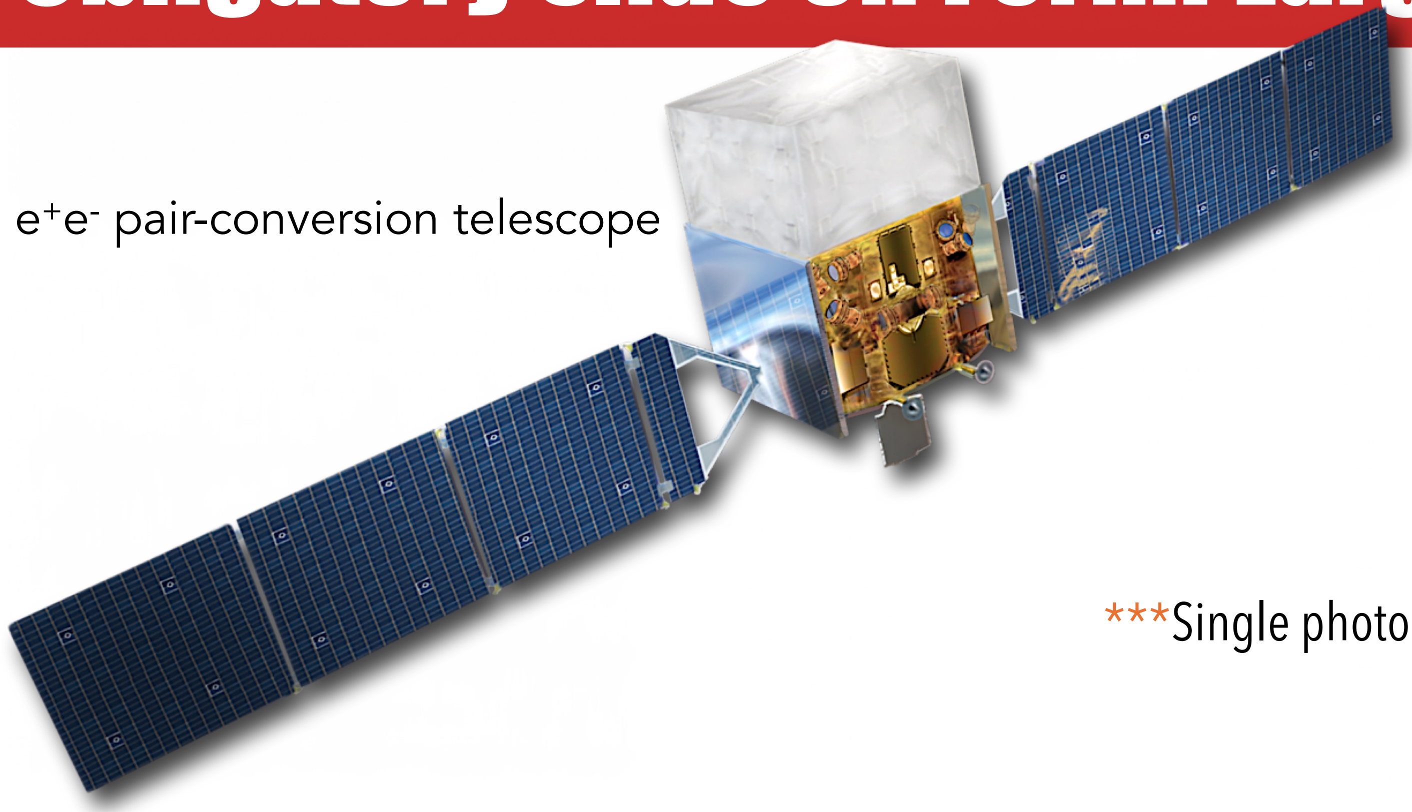


XX tsp DM

YY tsp IMBHs

…a recipe for γ-rays!

Obligatory slide on Fermi Large Area Telescope



e^+e^- pair-conversion telescope

*Energy range	20 MeV to > 300 GeV
**Field of View	2.4 sr (~1/5 of the whole sky)
***Single photon angular resolution	< 1 deg at 1 GeV
Timing accuracy	1 microsecond

**ideally suited for WIMP searches*
***whole sky every ~3 hours*
****point-source localization <0.5 arcmin*

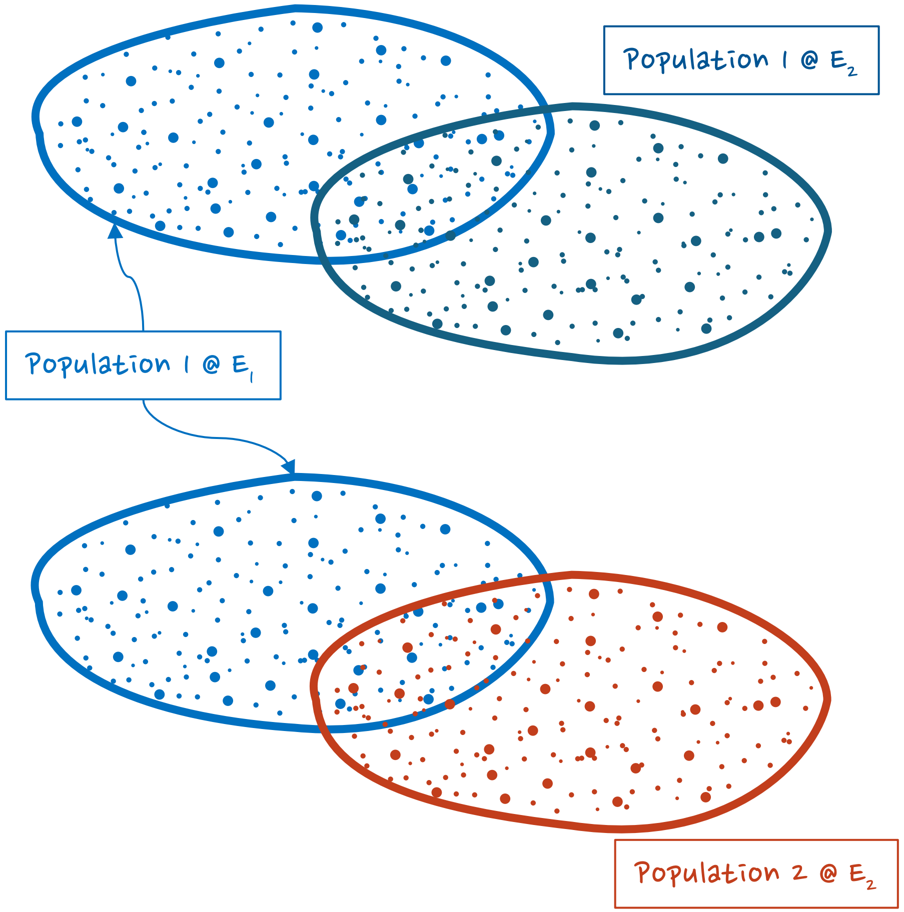
individual γ rays convert into e^+e^- pairs
→ tracks (localization) & deposited energy

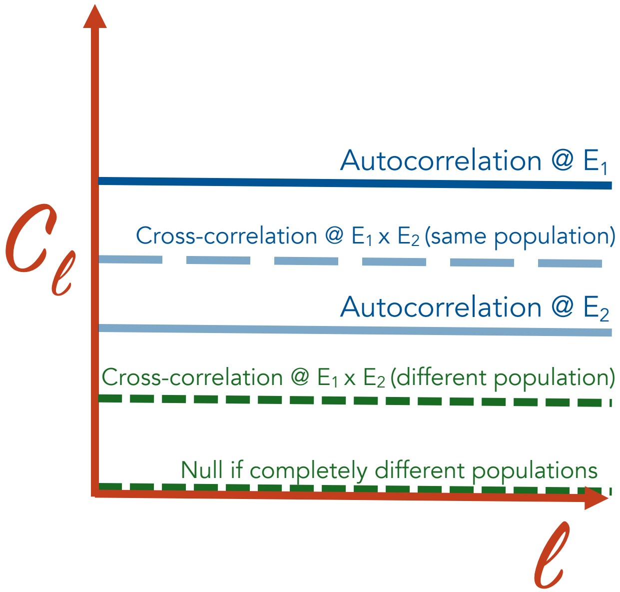
…it also detects electrons.

1st approach: Cross-correlation

Cross-correlation Analysis: Intro Slide

well-known technique used to characterize the sub-threshold gamma-ray sky.





Two-point cross-correlation function (CCF)

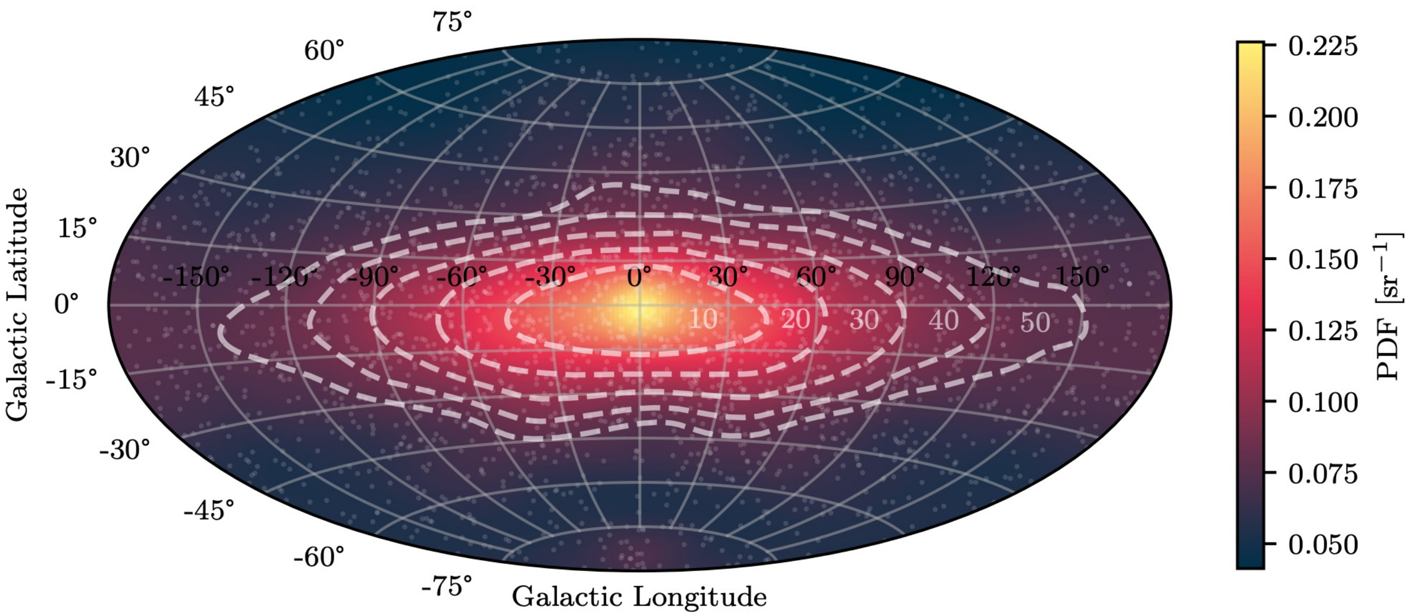
$$CCF(\theta) = \langle \delta\Phi_\nu(\bar{n})\delta\Phi_\gamma(\bar{n}') \rangle$$

measures the excess probability, above the expectation from a random distribution, of finding an object in a volume dV_A at a separation r from an object (or overdensity) in a volume dV_B.

Cross-correlation angle power spectrum (CAPS)

$$\sum_l \frac{2l+1}{4\pi} C_l^{(\gamma\nu)} P_l[\cos(\theta)]$$

Gamma-ray DM Spikes from EAGLE simulations

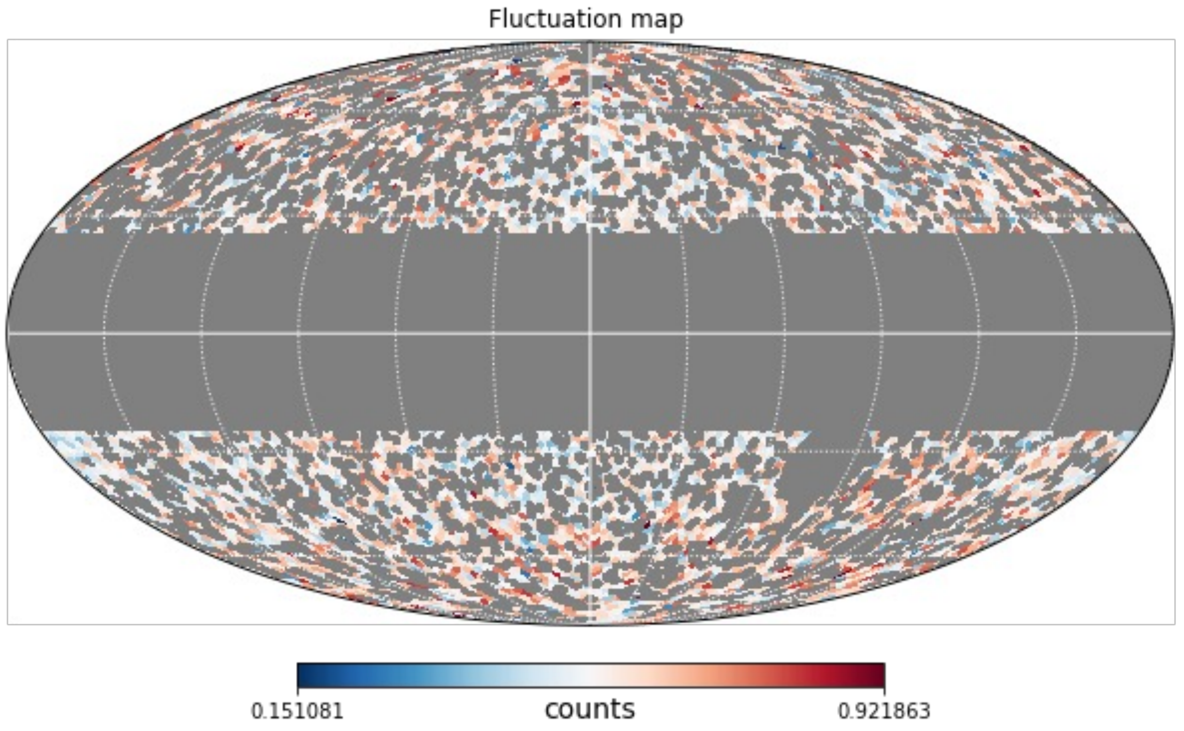


- coordinates and DM spike parameters for ~2500 IMBHs in ~150 Milky Way-like galaxies.
- Assumes adiabatic processes for IMBH formation and distribution (astrophysical processes)
- DM Spike profile: NFW

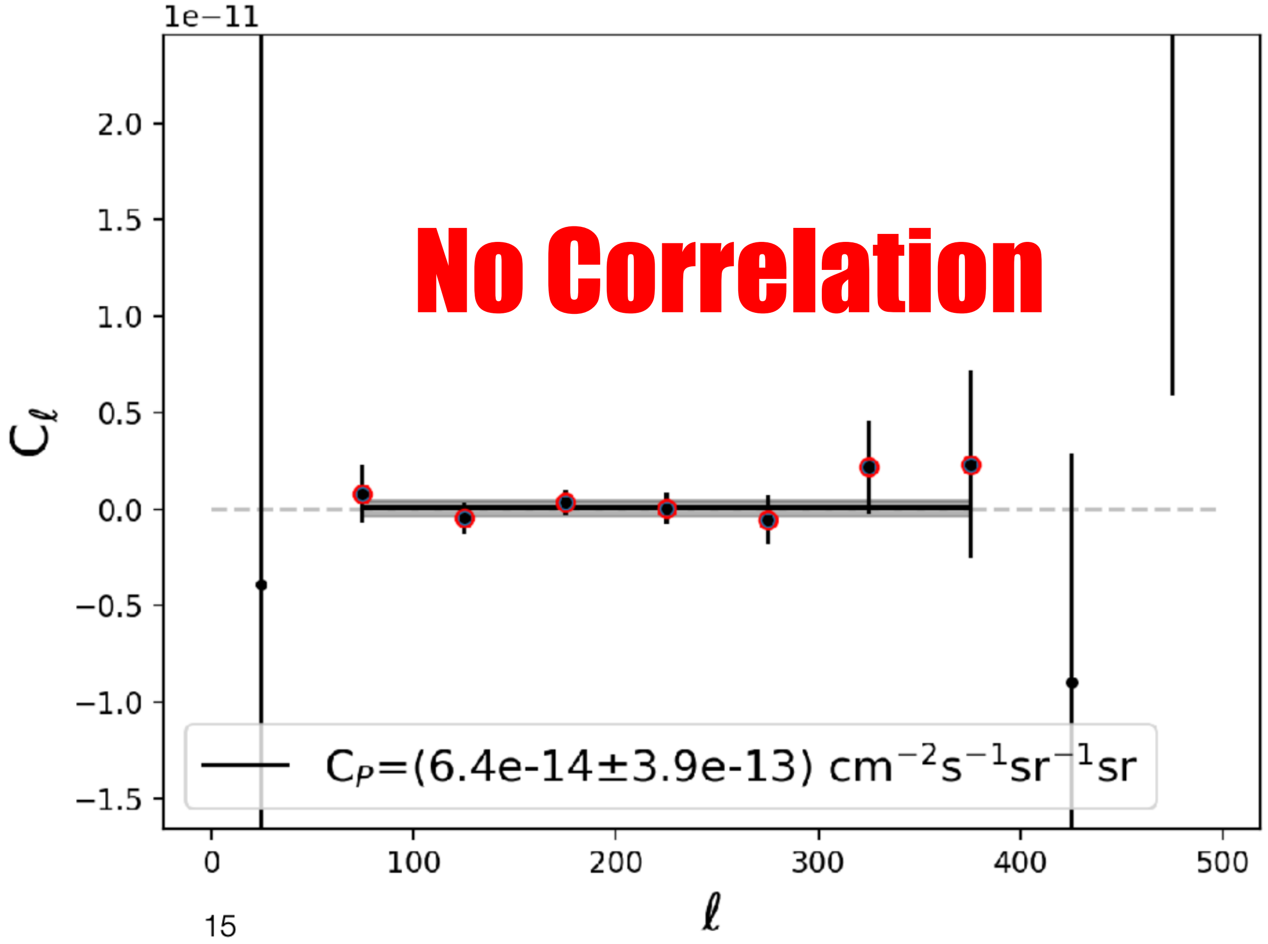
(Aschersleben et al. 2024)

Fermi data

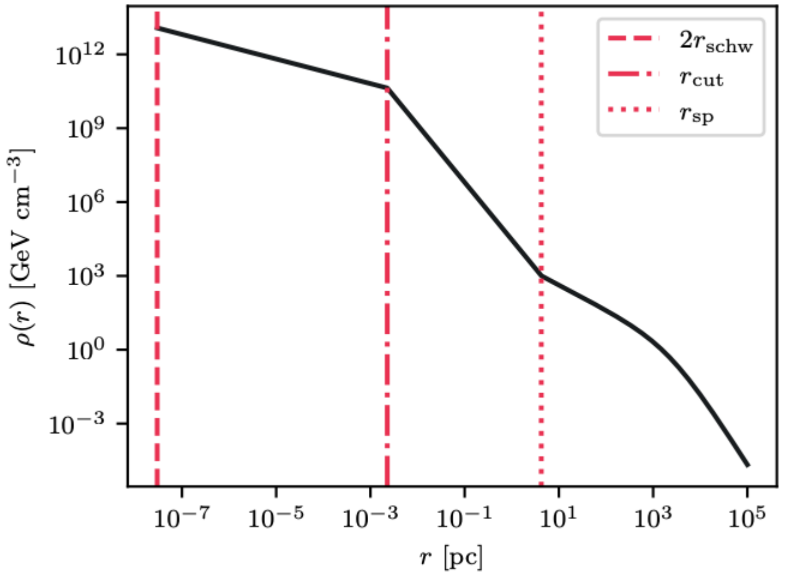
- Fermi all-sky
- Excluding 4FGL-DR4, Roma BZCAT, CRATES, WIBRaLS2, Galactic Plane
- 15 years of *Fermi* data
- PSF 1+2+3
- `SOURCEVETO`
- 500 MeV to 500 GeV
- Standard *Fermi* analysis



EAGLE x Fermi



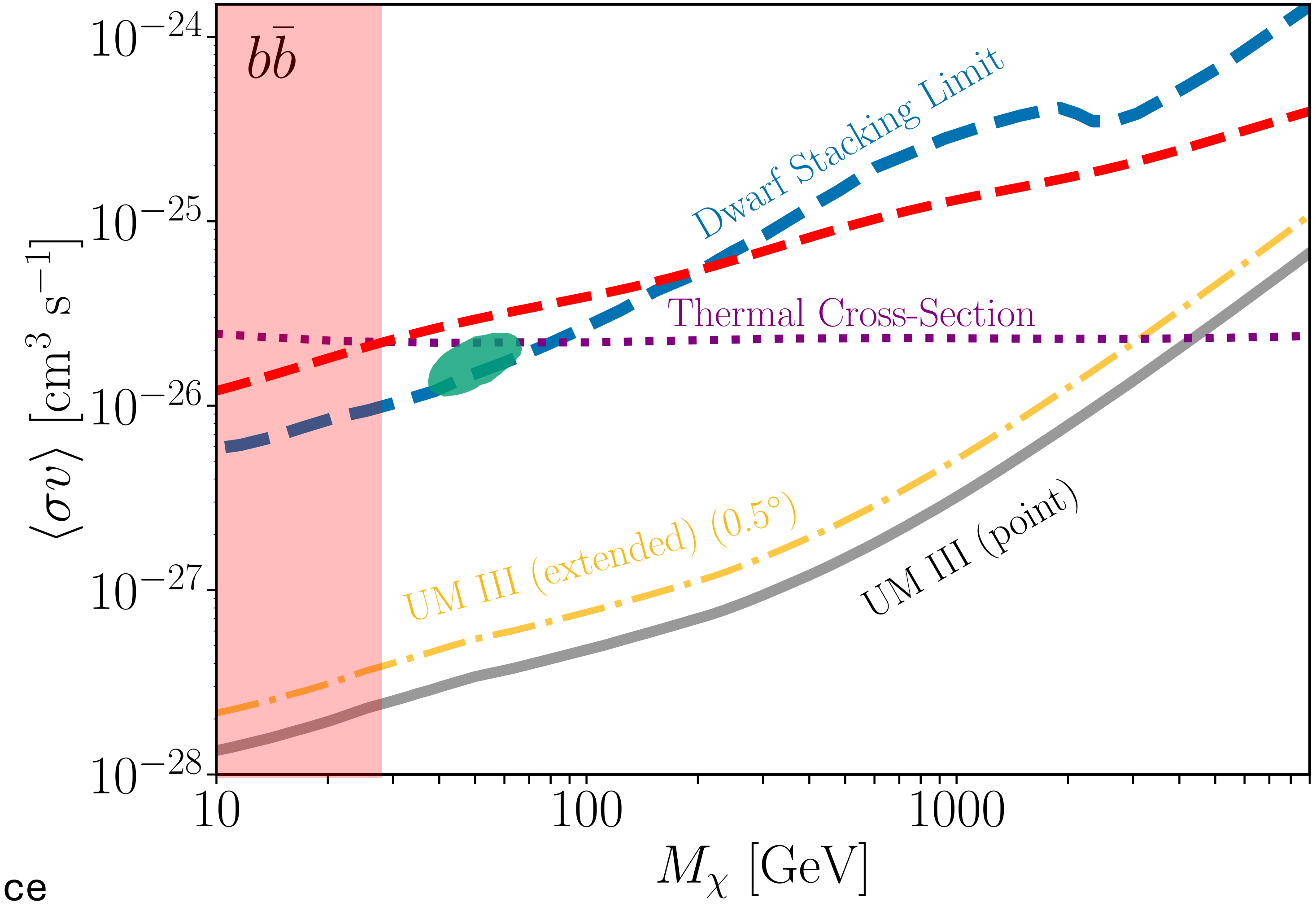
$$\Phi(E,D) = \frac{1}{2}\frac{\langle\sigma v\rangle}{m_\chi^2}\frac{1}{D^2}\frac{\mathrm{d}N}{\mathrm{d}E}\int_{2r_{\rm schw}}^{r_{\rm sp}}\rho^2(r)r^2dr$$
$$\approx \frac{\mathrm{d}N}{\mathrm{d}E}\frac{\langle\sigma v\rangle}{m_\chi^2 D^2}\rho(r_{\rm sp})^2 r_{\rm sp}^3 \frac{2\gamma_{\rm sp}-1}{8\gamma_{\rm sp}-12}\left(\frac{r_{\rm cut}}{r_{\rm sp}}\right)^{3-2\gamma_{\rm sp}}$$



(Aschersleben et al. 2024)

using code developed in [Negro, MC, et al. (2023)], relying on PolSpice https://www2.iap.fr/users/hivon/software/PolSpice/

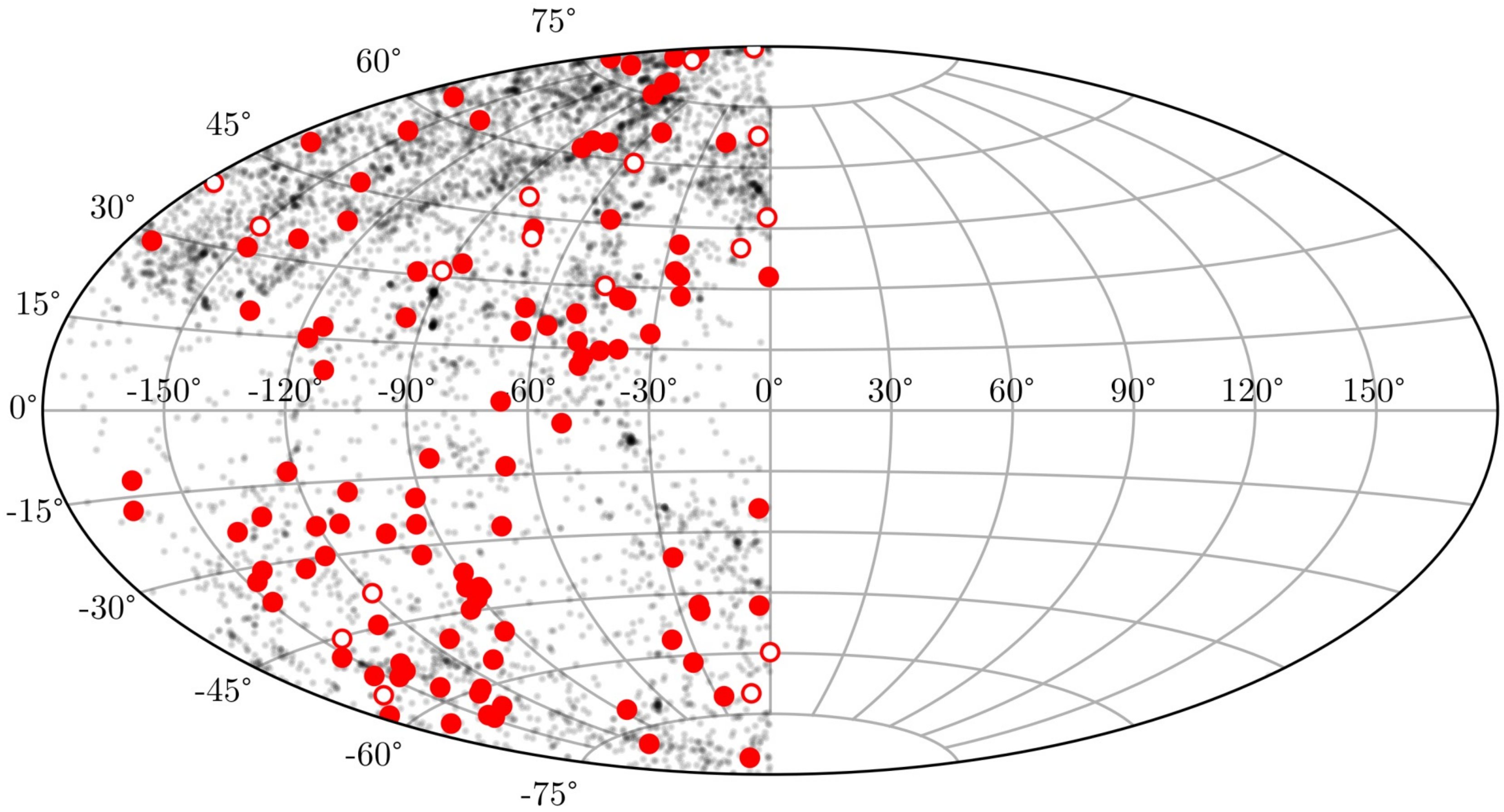
EAGLE x Fermi



Not accounting distance
Conservative mask

2nd approach: Stacking dwarf AGNs

eROSITA data



(Sacchi et al. 2024)

- West hemisphere with eROSITA
- Identified 74 AGN-IMBH pairs within 200 Mpc
- About 50% of the sample are off-nuclear

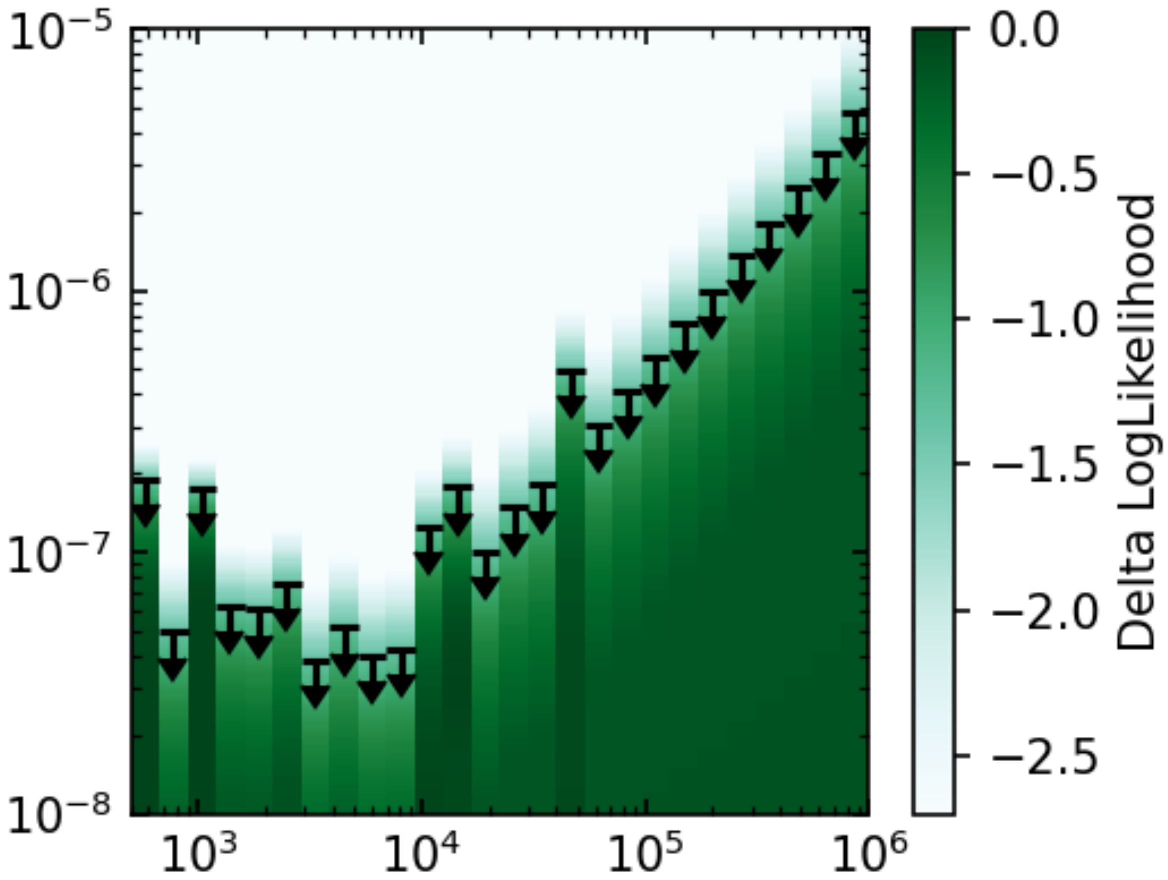
Gamma-rays from dwarf AGN

- [see the next talk by Rodrigo Nemmen]

Do we see them at all???

- *DM annihilation*

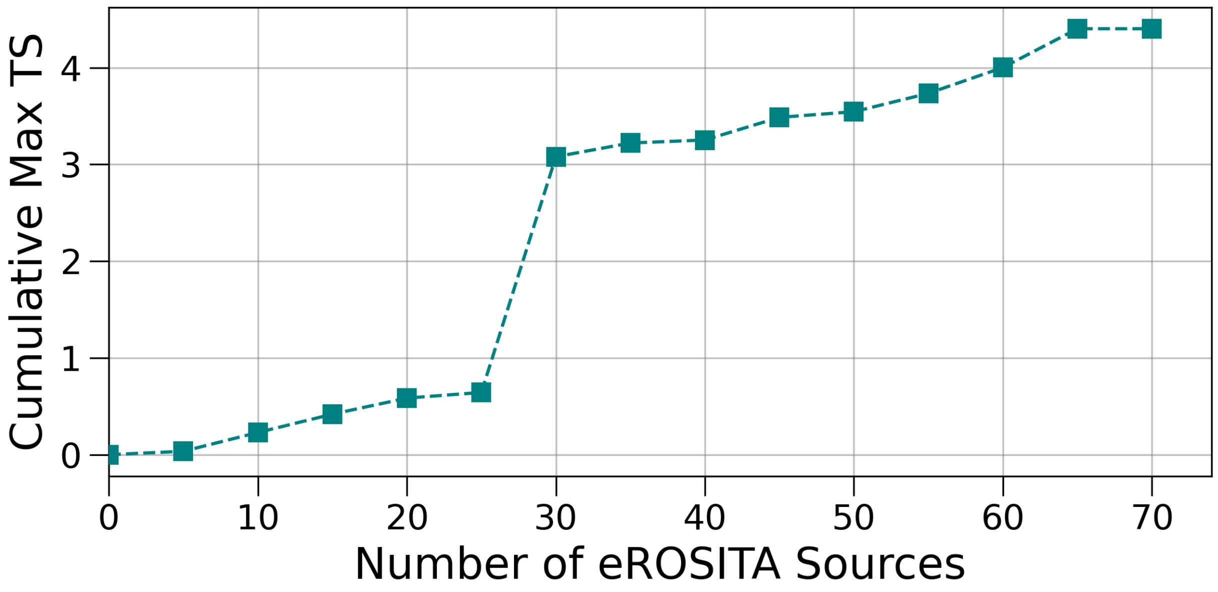
Fermi Analysis

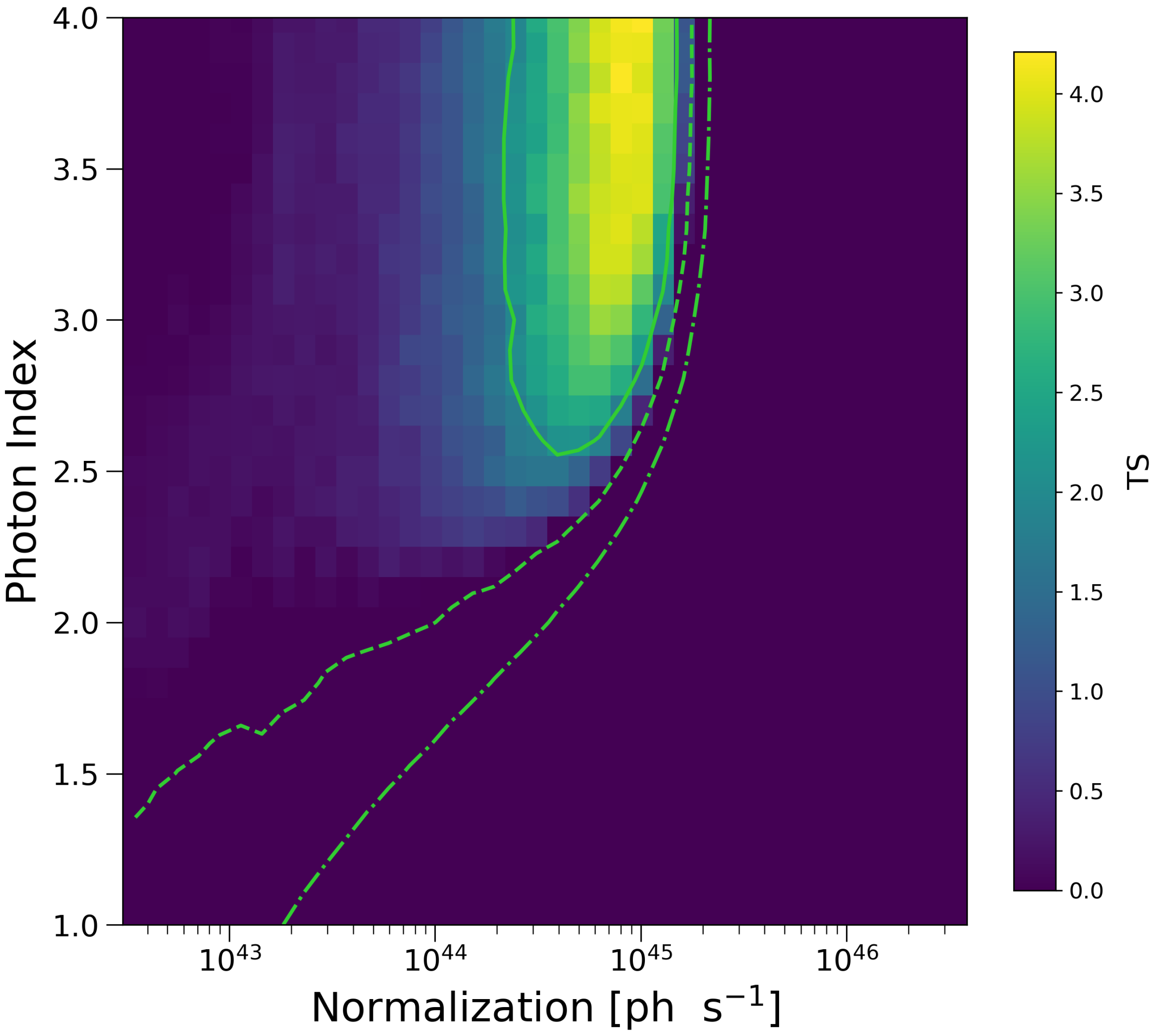


Example, PGC 2077238

- Standard *Fermi* analysis
- 15 years of *Fermi* data
- 500 MeV to 500 GeV
- 4FGL-DR4 Source catalog
- Construct TS profiles assuming power law
- No significant detection for any of the 74 sources

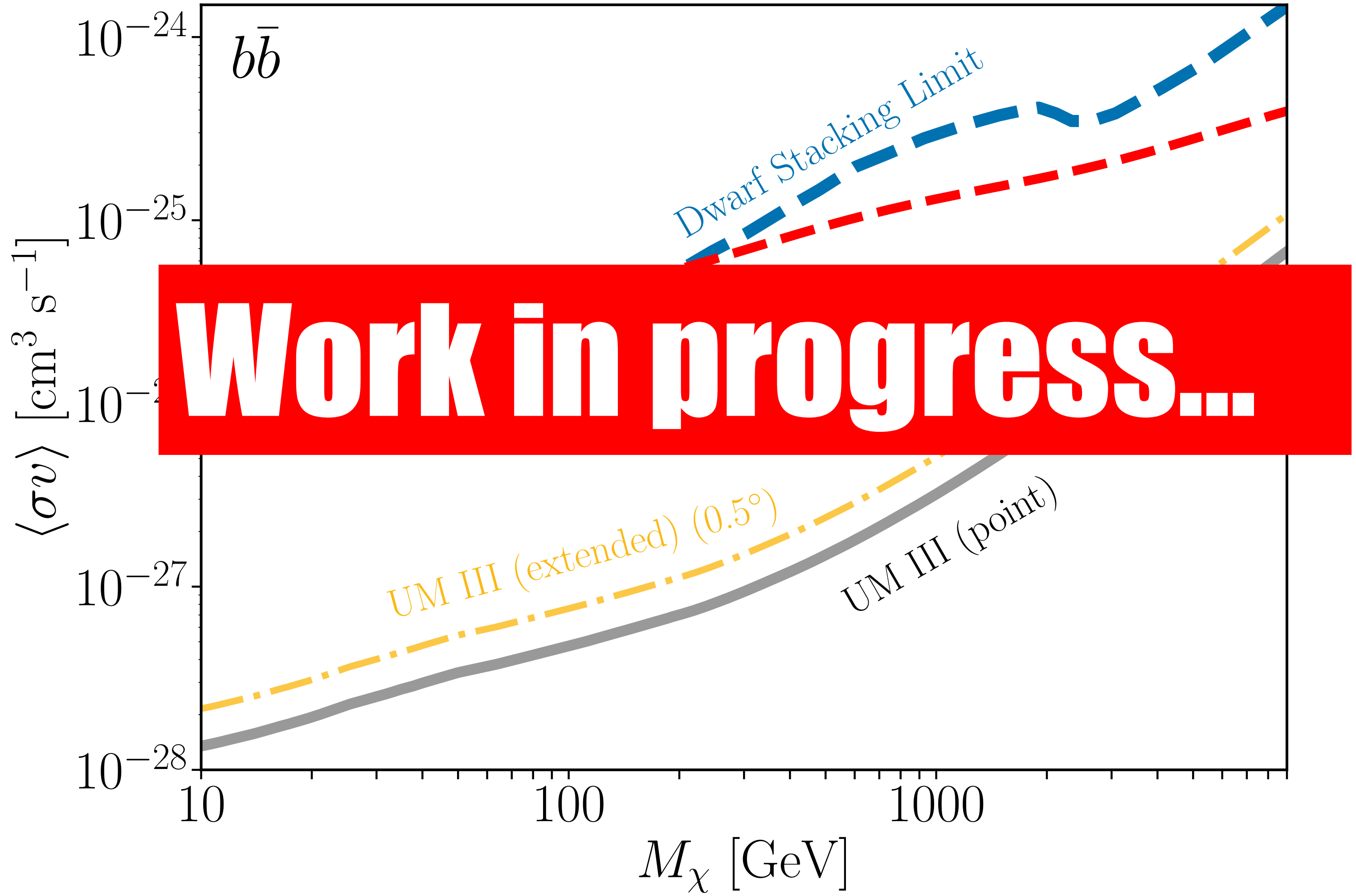
Stacking Analysis



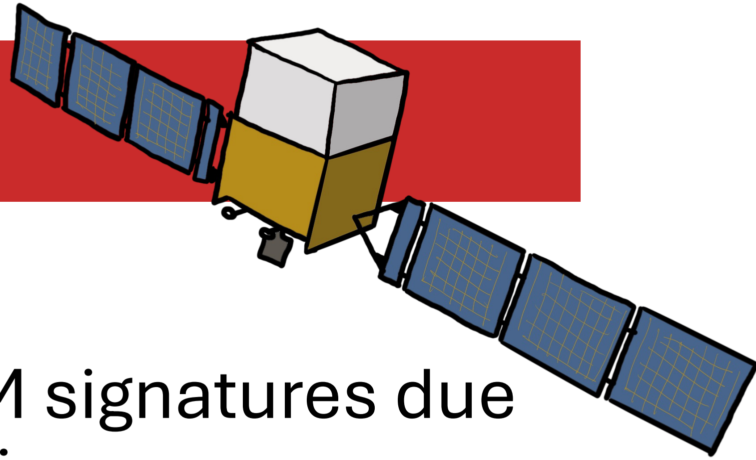


- ~ 2.1 σ joint-likelihood value (comparable to blank skies)
- PGC 2077238

DM constraints



Summary



- IMBHs are promising candidates for detecting DM signatures due to their unique environments and simpler dynamics.
- While the cross-correlation analysis did not yield significant detections, it provided constraints that will inform future searches
- Assumptions: luminosity function of IMBHs, IMBHs halo density profiles...
- AGN dwarfs: stacking of eROSITA likely IMBHs yields no detection
- Upper limit calculations in progress

Thank you!