# MADderHAT: Weighting the Model-Agnostic Dark Halo Analysis Tool

By Zack Carter

Image by Gary - cloudynights.com/topic/708862-the-draco-dwarf-galaxy-ugc-10822/

# Collaborators

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# Outline

1. What is MADHAT?
2. Why weight?
3. What's next?

# MADHAT 1.0: Overview

- Model-Agnostic Dark Halo Analysis Tool
- Processes data taken from *Fermi Gamma-ray Space Telescope* observations of dwarf galaxies[1]
  - Dwarf appeal: high DM concentration, few baryonic sources of high-energy photons
- Can ultimately produce bounds on dark matter properties[1]
  - I.e. annihilation cross-section and decay rate
- Structure of analysis is model-independent[1]

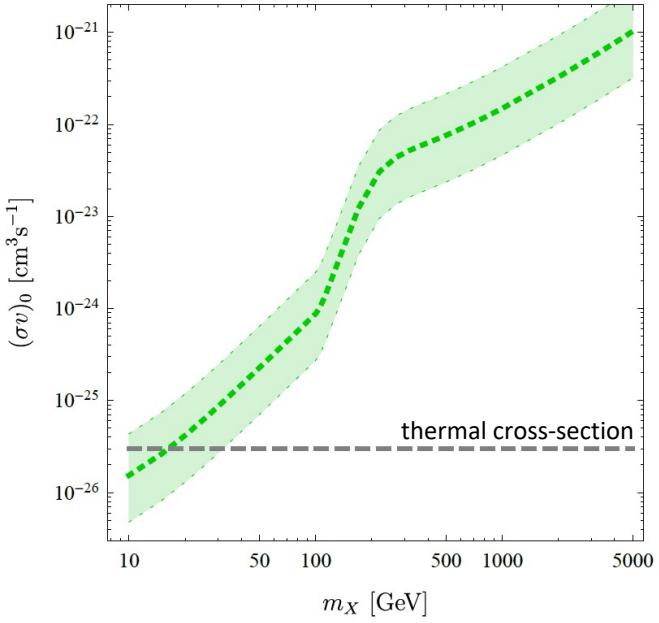


Figure 1: 95% confidence level bounds of $(\sigma v)_0$ versus $m_X$ assuming internal bremsstrahlung annihilation[1]

1. Boddy, Kumar, Marfatia, and Sandick 2018; Boddy, Hill, Kumar, Sandick, Shams Es Haghi 2021

# MADHAT 1.0: Calculations

- Background distribution from data

(Not a literal sum)

- Signal distribution is Poisson centered around expected number of anomalous photons

- Upper bound on expected number of anomalous photons, $N_{\mathrm{bound}}(\beta)$

$$\overline{N}_{\mathrm{DM}} = \Phi_{\mathrm{PP}} \times J(\Delta\Omega) \times (T_{\mathrm{obs}} \bar{A}_{\mathrm{eff}})$$

data | particle physics model | astrophysical model | detection details

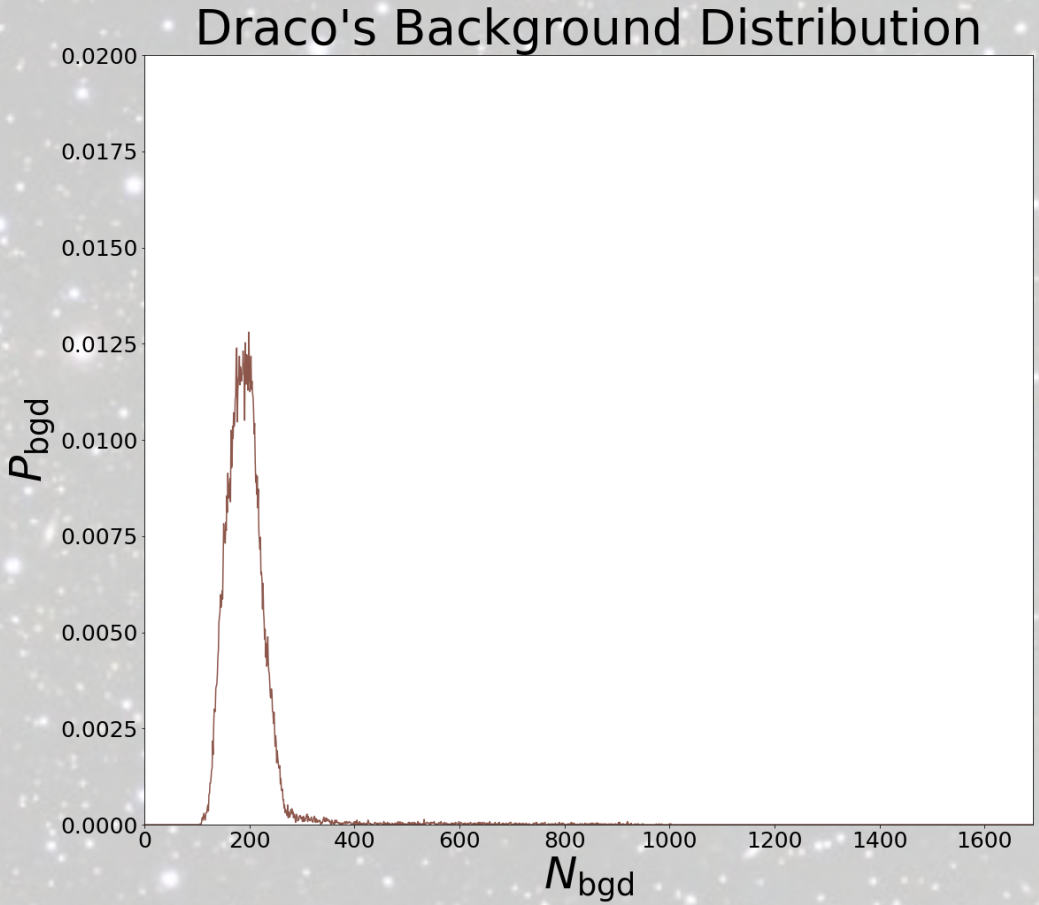


Figure 2: Background distribution of the dwarf Draco

# MADHAT 1.0 vs MADHAT 2.0: Abstract Overview

- We have
  - background count probabilities from off-axis counting
  - DM-produced count probabilities from $\Phi_{\mathrm{PP}}$ and $J$
- Thus, given any function $F$ of the photon counts, we can create a probability distribution for $F$
- A model is excluded at confidence level $\beta$ if there's a probability higher than $\beta$ of observing a value of $F$ higher than the value given by observed counts
- MADHAT 1.0's $F$ is the total count; MADHAT 2.0's is the *weighted* total

# MADHAT 2.0: Concrete Benefits

- Adding galaxy weighting functionality
  - I.e. weight galaxies based upon the odds of a given photon received from a given galaxy to be from dark matter versus some background process[2]
  - Improves bounds[2]

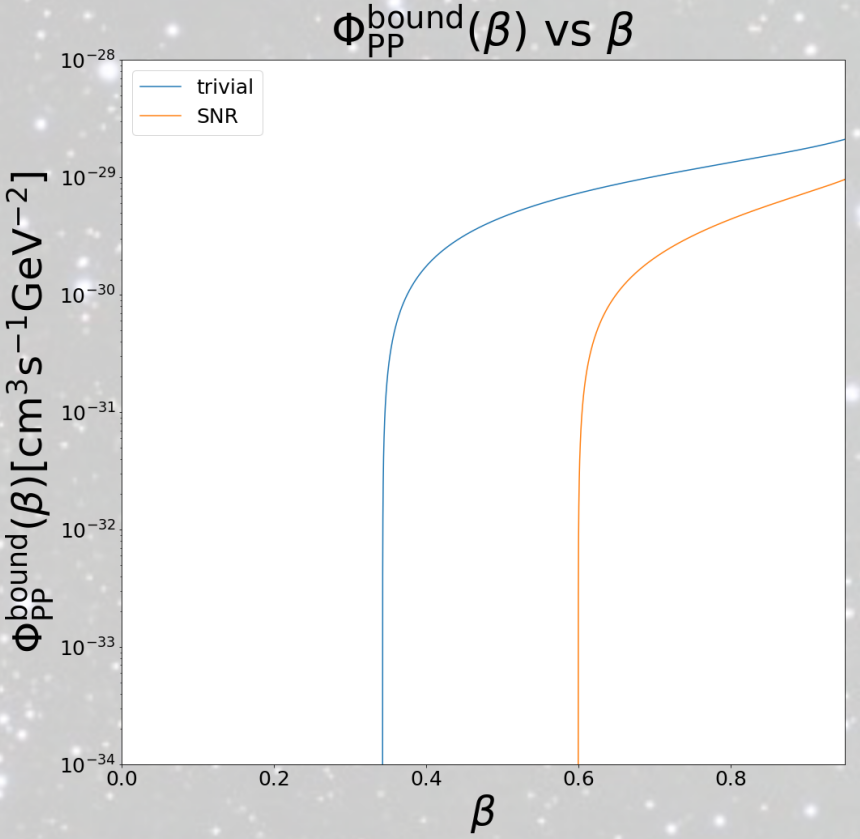


Figure 3: $\beta$ confidence level bounds of $\Phi_{PP}^{bound}$ versus $\beta$, trivial (equal) and SNR (Geringer-Sameth and Koushiappas's) weighting used

2. Geringer-Sameth and Koushiappas 2011

# MADHAT 2.0: Tradeoffs

- 1.0: One quantity, $N_{\mathrm{bound}}(\beta)$, that depends *entirely* on data
- 2.0: No single $N_{\mathrm{bound}}(\beta)$ and no clean separation between astrophysics model and data, but bounds are more optimal

# Future Work

- Add photon energy binning/weighting
  - Will be MADHAT's first time using spectral info
- Extend photon energy range into the keV, MeV, and TeV range and even incorporate neutrino data
- Incorporate into public likelihood calculators

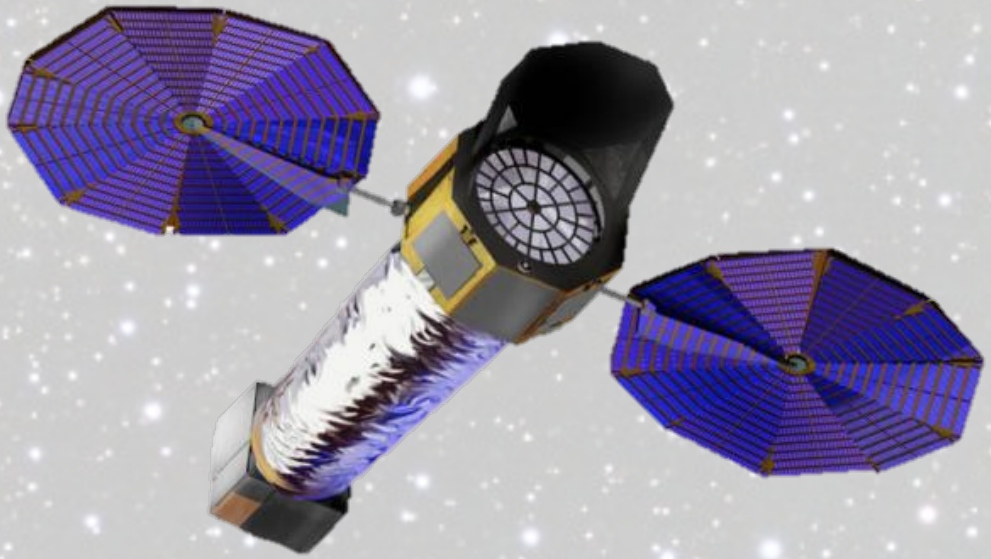

Image from Harvard - https://pweb.cfa.harvard.edu/facilities-technology/telescopes-instruments/lynx-x-ray-observatory

# Summary

1. MADHAT analyzes gamma-ray data to produce bounds on dark matter properties in an exceptionally flexible manner.
2. Weighting photons based on their source galaxies improves these bounds.
3. Photon-energy weighting, energy-range expansion, and likelihood calculator inclusion are coming soon.

- https://github.com/MADHATdm