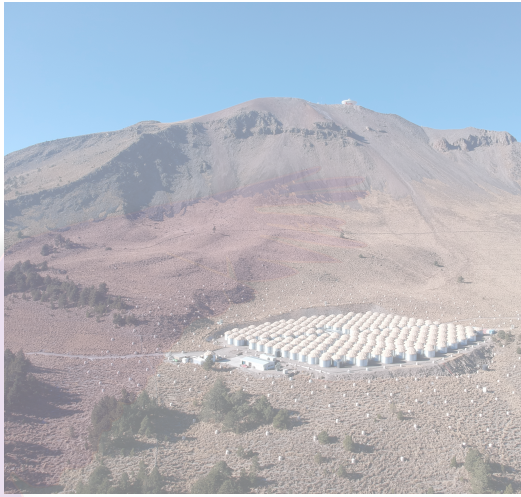
Ten years of Indirect Dark Matter searches at TeV scales with HAWC.

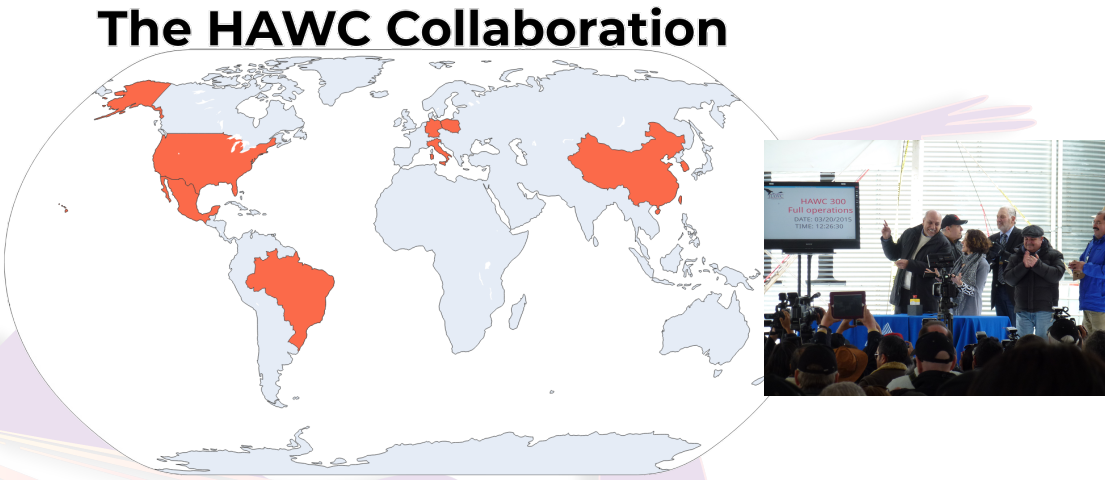
TeVPA 2025; Valencia, Spain

Sergio Hernández Cadena
(on behalf of the HAWC Collaboration)

TDLI-SJTU

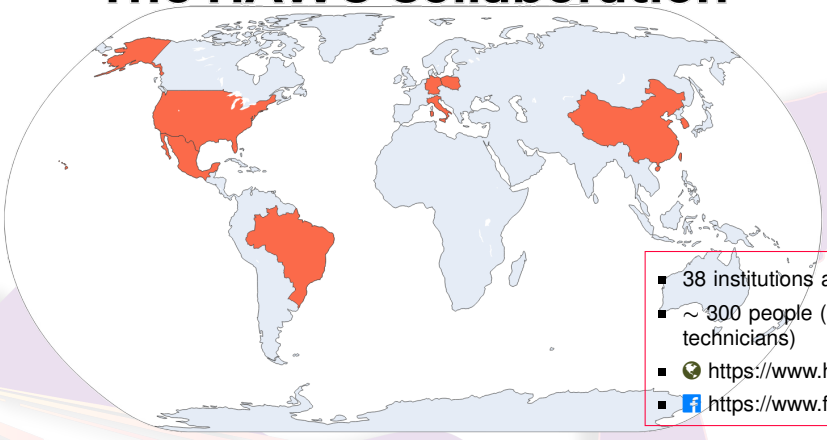
Contents




The HAWC Collaboration
HAWC 300
Full operations
DATE: 03/20/2015
TIME: 12:26:30

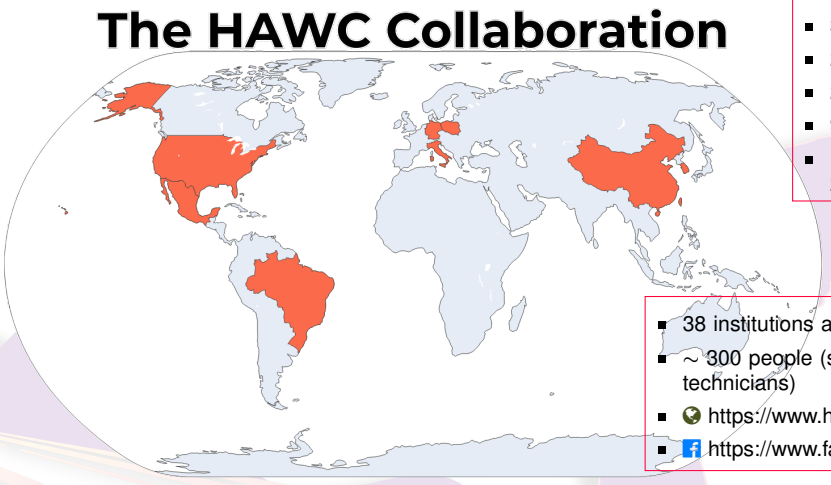
上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

The HAWC Collaboration



- 38 institutions around the world
- ∼ 300 people (students, researchers, technicians)
- https://www.hawc-observatory.org/
- https://www.facebook.com/hawcobservatory

The HAWC Collaboration



- 87 publications
- 26 ATELs
- 39 PhD thesis
- 27 MSc thesis
- 21 BSc thesis
- 9 editions of ICRC
- Participation on more than 250 conferences

- 38 institutions around the world
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HAWC

- **4,100 m a.s.l**
- **Tiltépetl (Sierra Negra), Puebla; Mexico**
- **300 Water Cherenkov Detectors (+ 300 outriggers)**
- **Full array (WCD) inaugurated on March 2015**
- **95 % duty cycle $\rightarrow$ Long term monitoring**
- **~ 2 sr instant coverage**

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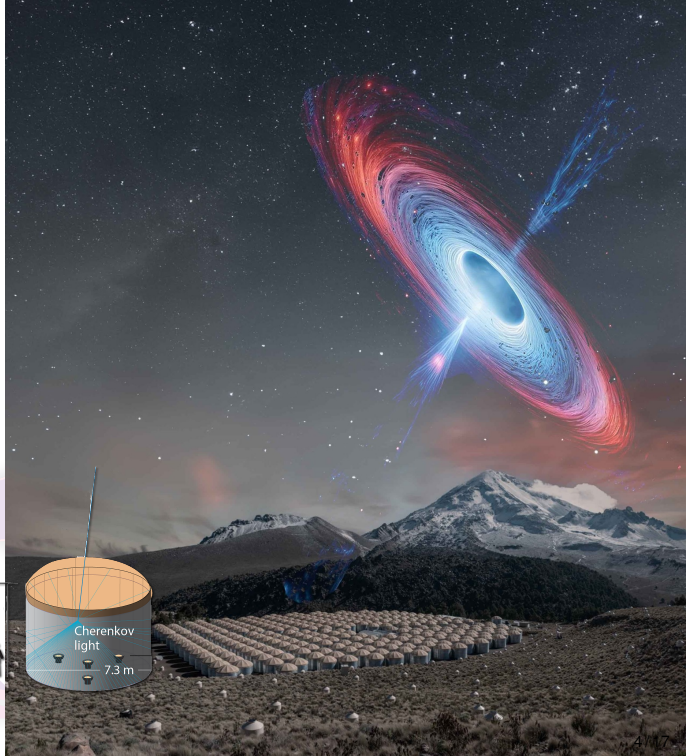
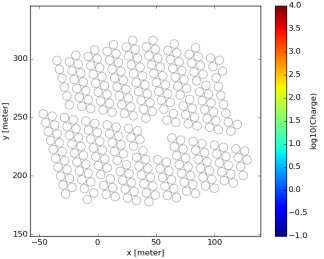


Performance

S. Yun-Cárcamo+, 2024



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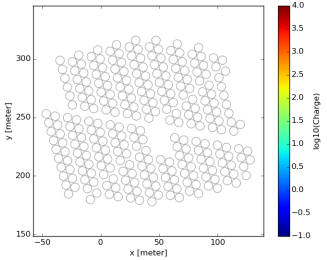

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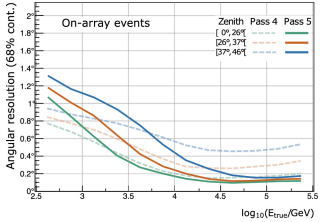
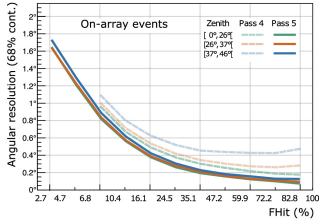


(a) Energy



(b) FHit

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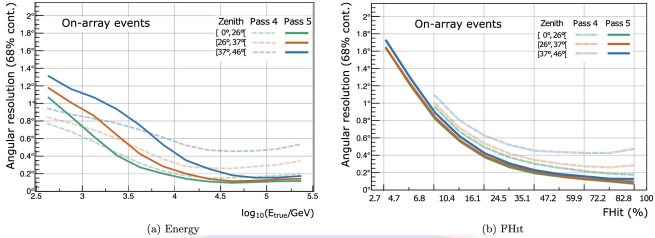
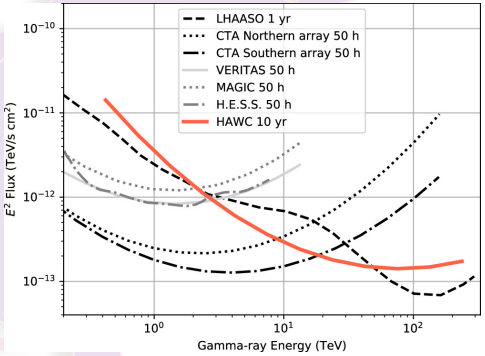


(a) Energy (b) FHit



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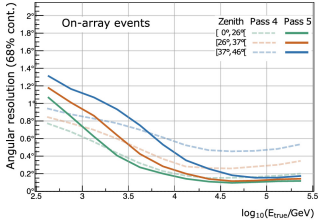

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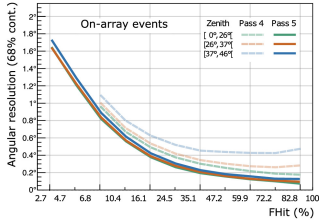


(b) FHit

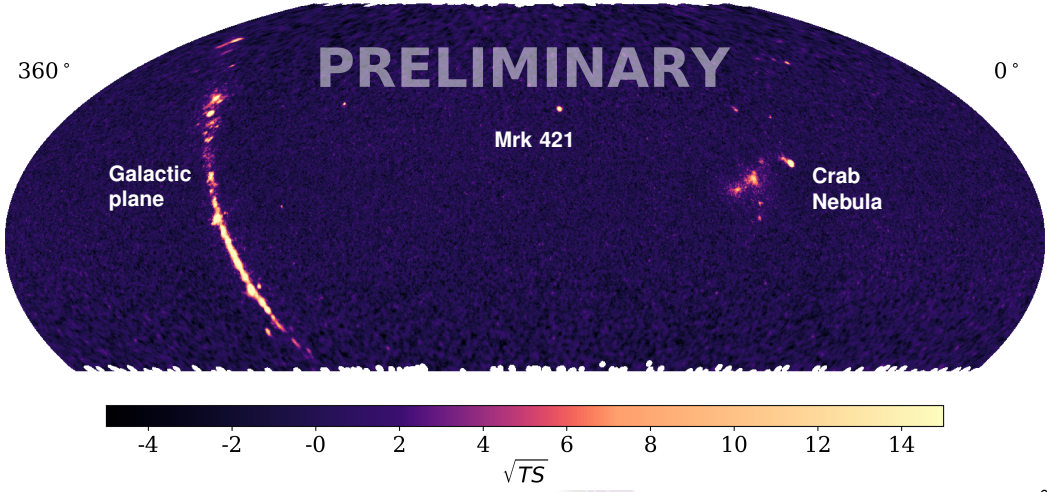
Pass 1	Pass 2	Pass 3	Pass 4	Pass 5
HAWC-111	HAWC-250	Full array	-	-
1.1σ	2.5σ	3.1σ	4.47σ	5.6σ

σ_{daily}@Crab Nebula

The TeV Gamma-ray Sky observed by HAWC

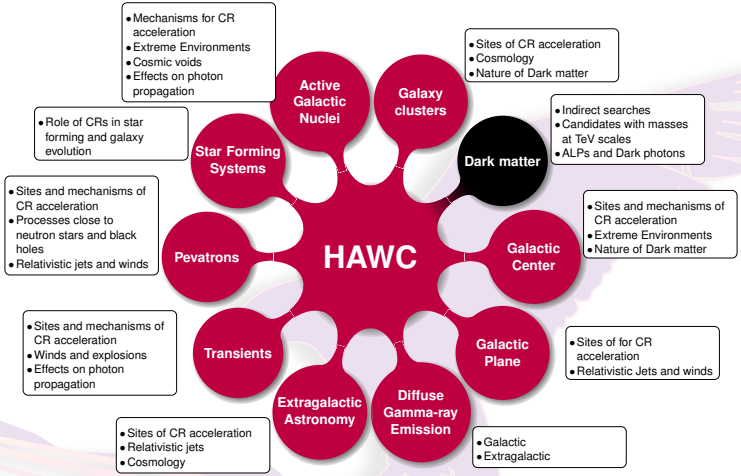
S. Groetsch

~ 2800 days, 80 sources [4HWC catalog].
Detection of galactic sources above 200 TeV



Scientific goals

Complementary with other observatories



Dark Matter

See talks by Marco Taoso [03/11/2025], David Cerdeño [04/11/2025], and Laura Lopez-Honorez [05/11/2025]

Materia oscura

- $\sim 27\,\%$ content of the Universe

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- Particle Physics Hypothesis

The True Dark Matter

Materia oscura

- $\sim 27\,\%$ content of the Universe
- (Gravitational) Evidence at all scales
- Particle Physics Hypothesis
- Cold Dark Matter (CDM)

- Collisionless
- No electric or strong charge
- Relic density in agreement with observations
- Compatible with current upper limits
- Compatible with Big Bang Nucleo-synthesis
- Unmodified stellar evolution
- Experimental tests

[Taoso+,2008]

Materia oscura

- $\sim 27\,\%$ content of the Universe
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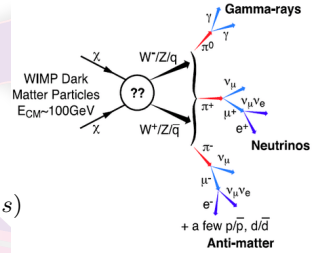
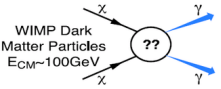
- Particle Physics Hypothesis
- Cold Dark Matter (CDM)
  - Weakly Interactive Massive Particles (WIMP)

- m_{WIMP} from 5 GeV to ~ 100 TeV
- Decoupling from other particles
- SUSY
- Annihilation/Decay into SM particles with photon final states



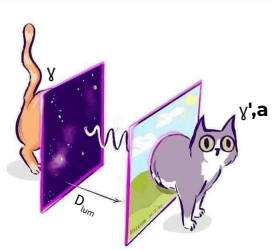


$$\frac{d\Phi_\gamma}{dE}(\Delta\Omega, l.o.s, E) = \frac{d\phi_\gamma}{dE}(E) \times \; J(\Delta\Omega, l.o.s)$$

Materia oscura

- $\sim 27\,\%$ content of the Universe
- (Gravitational) Evidence at all scales
- Particle Physics Hypothesis
- Cold Dark Matter (CDM)
  - Weakly Interactive Massive Particles (WIMP)
  - Axion Like Particles

- Generalization to Axion
- No needed to solve CP problem
- m_{a} from 10^{-22} eV to $\sim$ eV
- Coupling to EM
- Induce effect on the propagation of photons



$$P_{\gamma\to a} = \left(1+\frac{E_{\mathrm{c}}^2}{E_\gamma^2}\right)^{-1} \times \sin^2\left(\frac{g_{a\gamma}B_{\mathrm{T}}L}{2}\sqrt{1+\frac{E_{\mathrm{c}}^2}{E_\gamma^2}}\right)$$

Arlette Melo+, ICRC 2025

How do we do?

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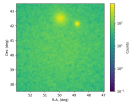
Analysis and ULs calculation

Observations



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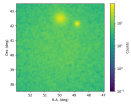
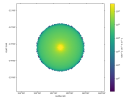


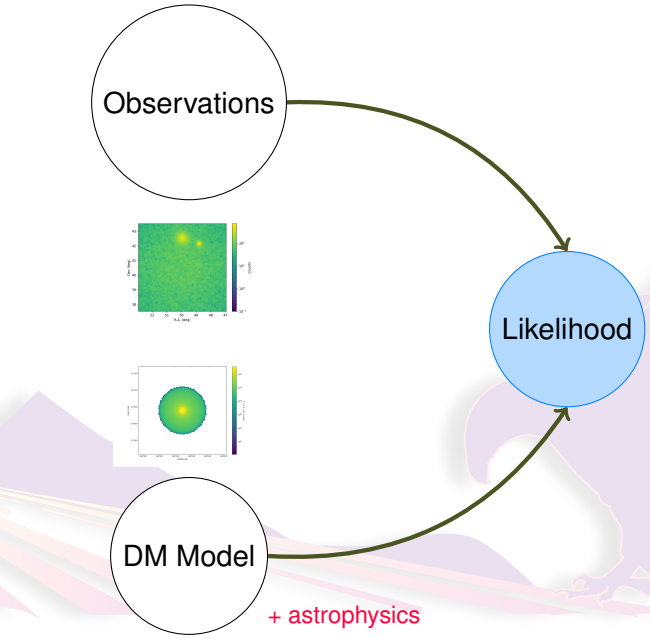


DM Model

+ astrophysics

How do we do?

Analysis and ULs calculation



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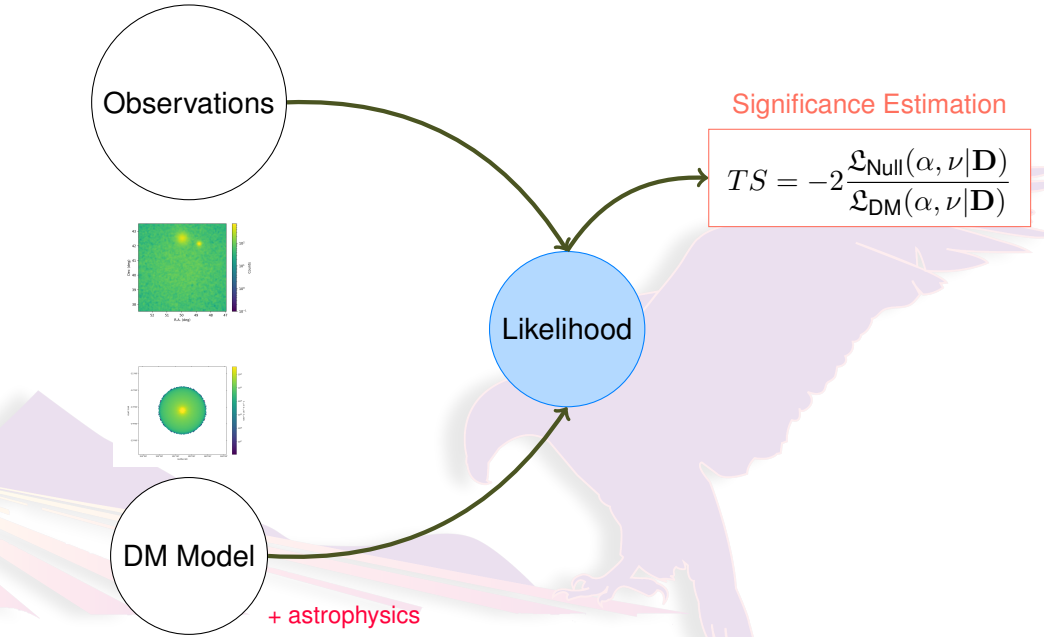

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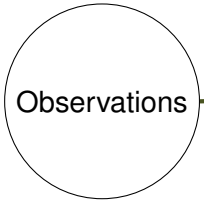
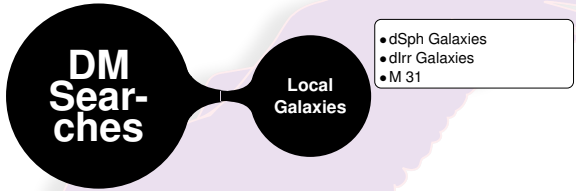


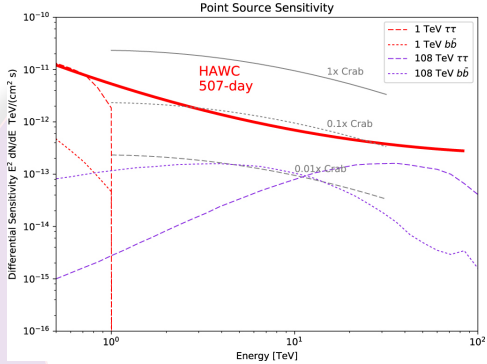
Results


DM Sear-ches
Local Galaxies
• dSph Galaxies
• dIrr Galaxies
• M 31

dwarf Spheroidal Galaxies

T. Yapici+,2018; A. Albert+,2020

- Search for continuum gamma-ray emission using 507 days for 15 dSphs (including Triangulum II)



Spectrum from Pythia

$$\frac{d\Phi_\gamma}{dE}(\Delta\Omega, l.o.s, E) = \frac{\langle\sigma_\chi v\rangle}{8\pi m_\chi^2}\frac{dN_\gamma}{dE}(E) \times \; J(\Delta\Omega, l.o.s)$$

J-factor computed with Clumpy

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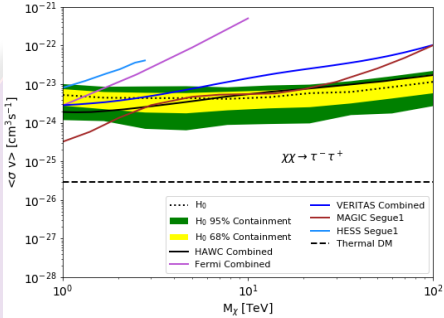

https://arxiv.org/abs/1706.01277

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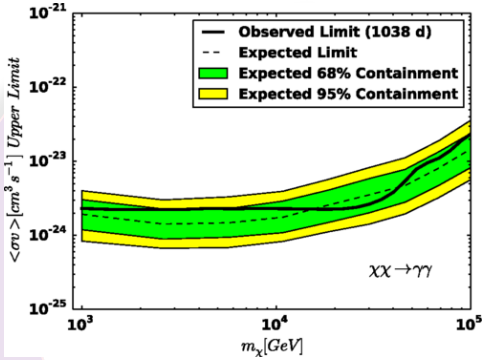

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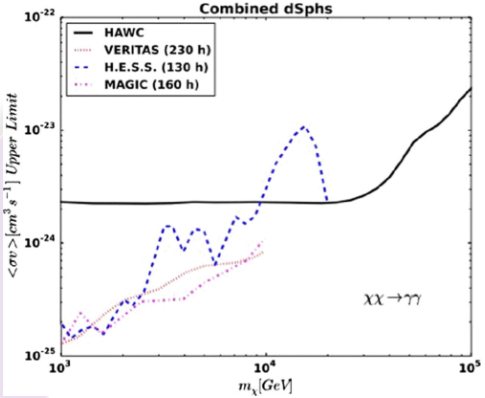

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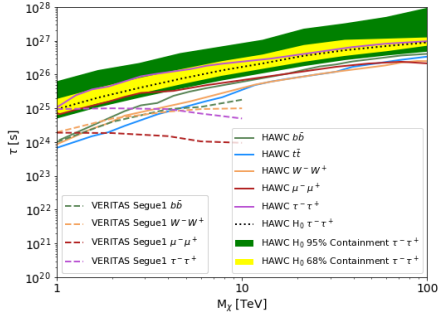

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V. Gammaldi, S. Hernández+; 2023

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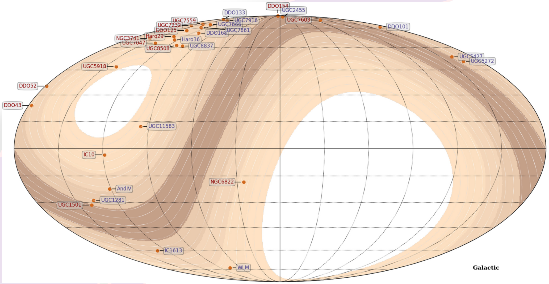

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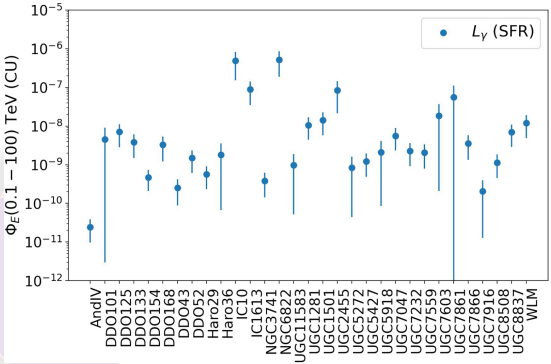

McGaugh+ 2017, Martin 2014

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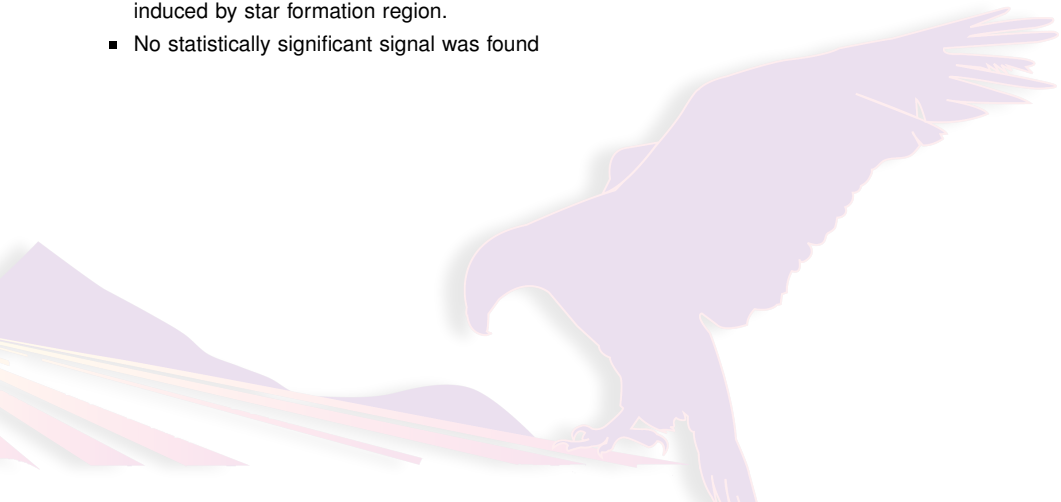

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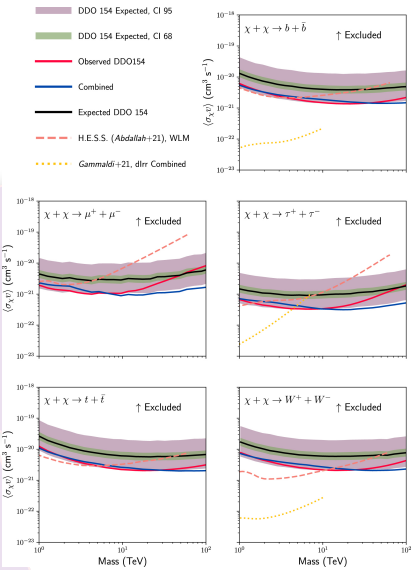

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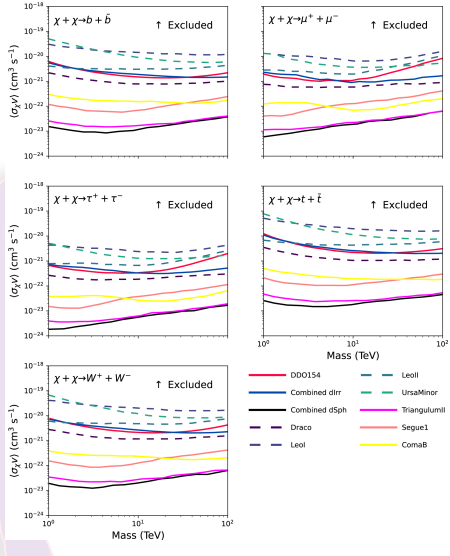

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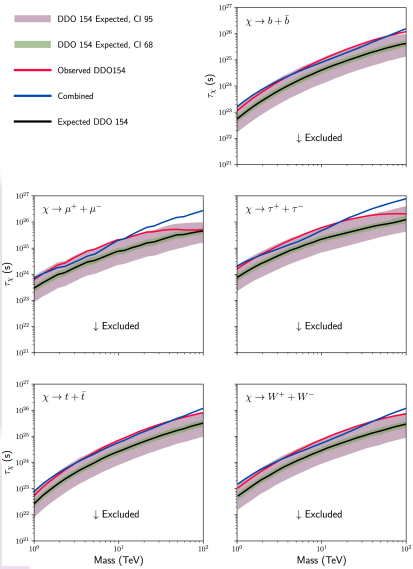
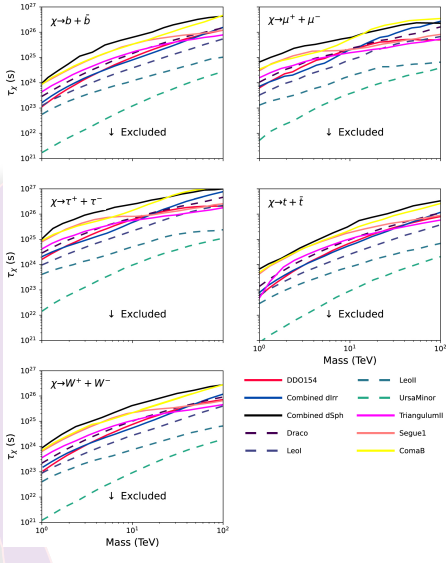


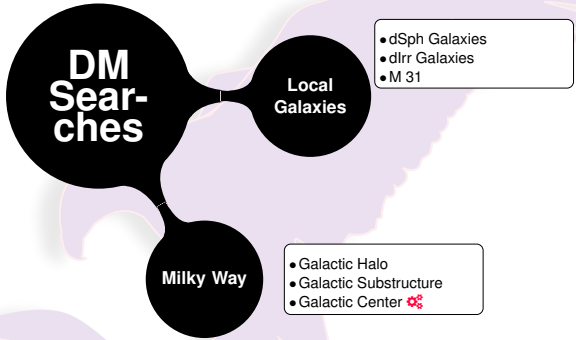
dwarf Irregular Galaxies

V. Gammaldi, S. Hernández+; 2023

- Search for continuum gamma-ray emission using 1017 days for 31 dIrr galaxies (PS and no substructure)
- Estimation of the gamma-ray background induced by star formation region.
- No statistically significant signal was found
- Individual and Combined Upper Limits (95 % C.L.) on $\langle \sigma_\chi v \rangle$
- Individual and Combined Lower Limits (95 % C.L.) on τ_χ (only continuum emission)



https://arxiv.org/pdf/2302.07929


DM Sear-ches
Local Galaxies
• dSph Galaxies
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• Galactic Substructure
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Galactic Halo

J. Lundeen, P. Harding +; 2023

- Search for continuum gamma-ray emission using 803 days.

EW Corrections

$$\frac{d\Phi_\gamma}{dE}(\Delta\Omega, l.o.s, E) = \frac{\langle\sigma_\chi v\rangle}{8\pi m_\chi^2}\frac{dN_\gamma}{dE}(E) \times \ J(\Delta\Omega, l.o.s)$$

J-factor computed with Clumpy

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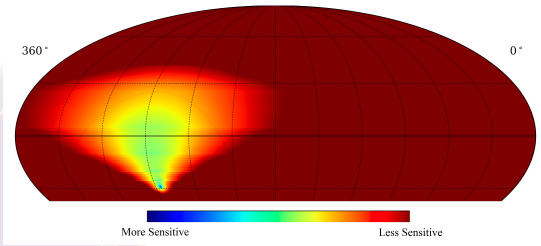

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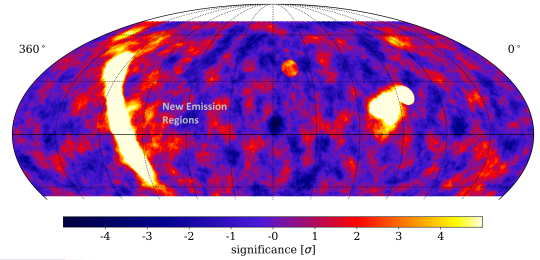

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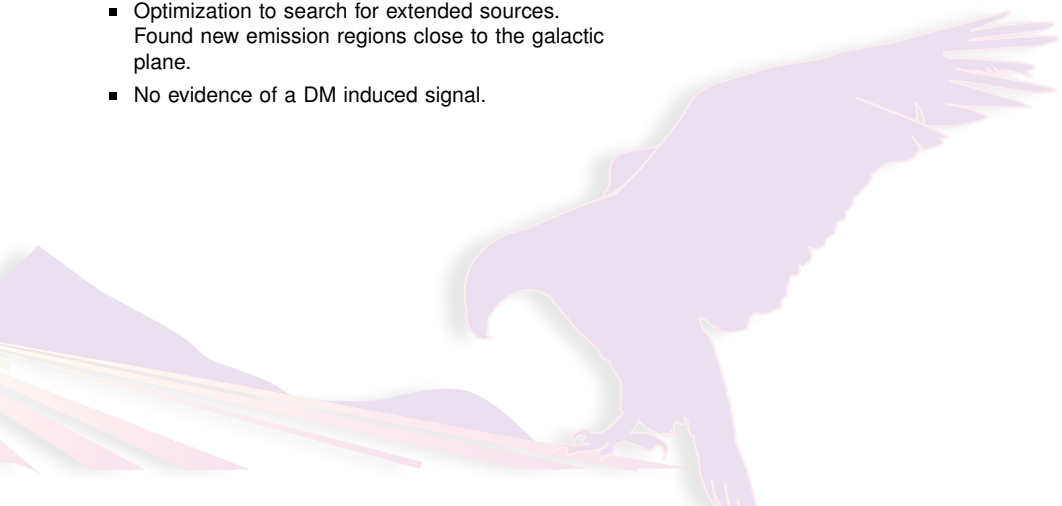

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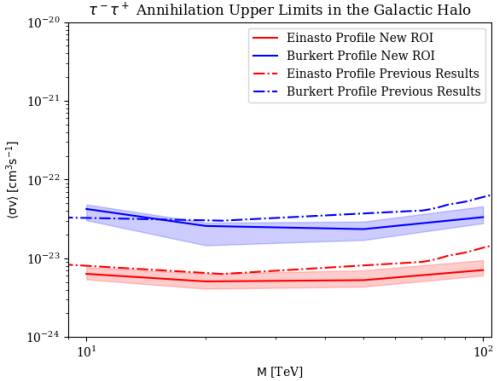

https://arxiv.org/pdf/2305.09861

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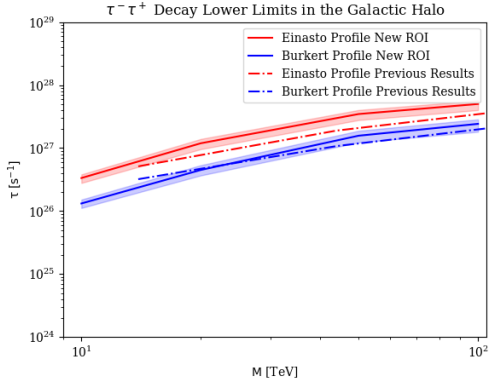

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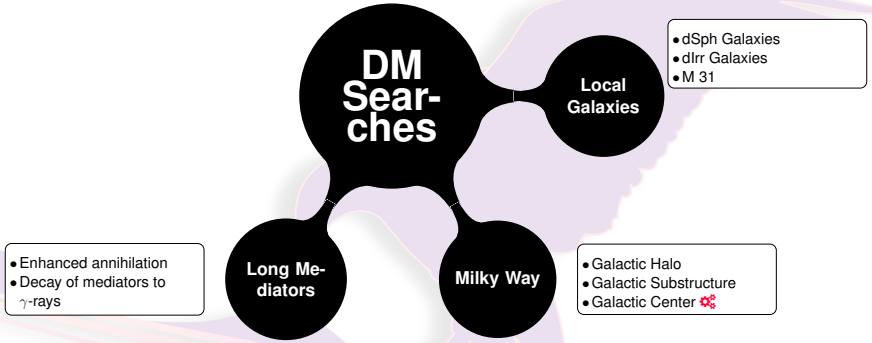
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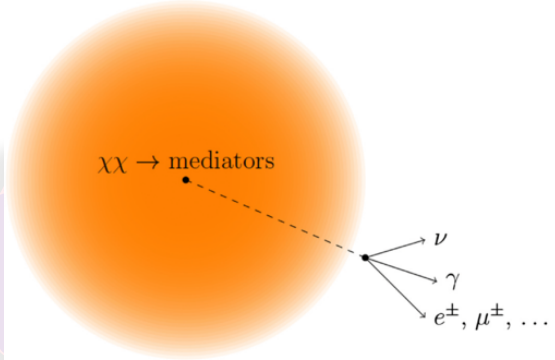
SD DM scattering with long-lived mediators

M. Un Nisa, S. BenZvi+; 2018

- Capture of DM by elastic interactions with solar nuclei followed by annihilation into long-lived mediators can produce a gamma-ray signal



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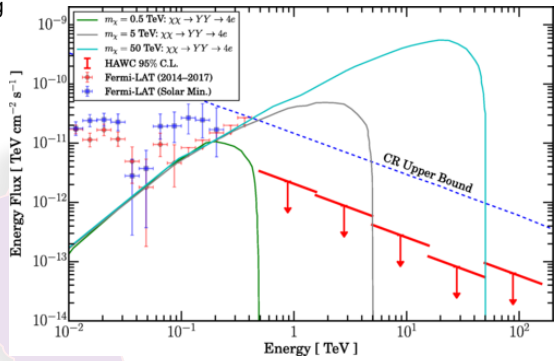

$$E^2 \frac{d\Phi_\gamma}{dE} = \frac{\Gamma_{\rm ann}}{4\pi D^2} R_i E^2 \frac{dN_\gamma}{dE}(E) \left(e^{-R_\odot/L} - e^{-D/L} \right)$$

SD DM scattering with long-lived mediators

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上海交通大學 SHANGHAI JIAO TONG UNIVERSITY

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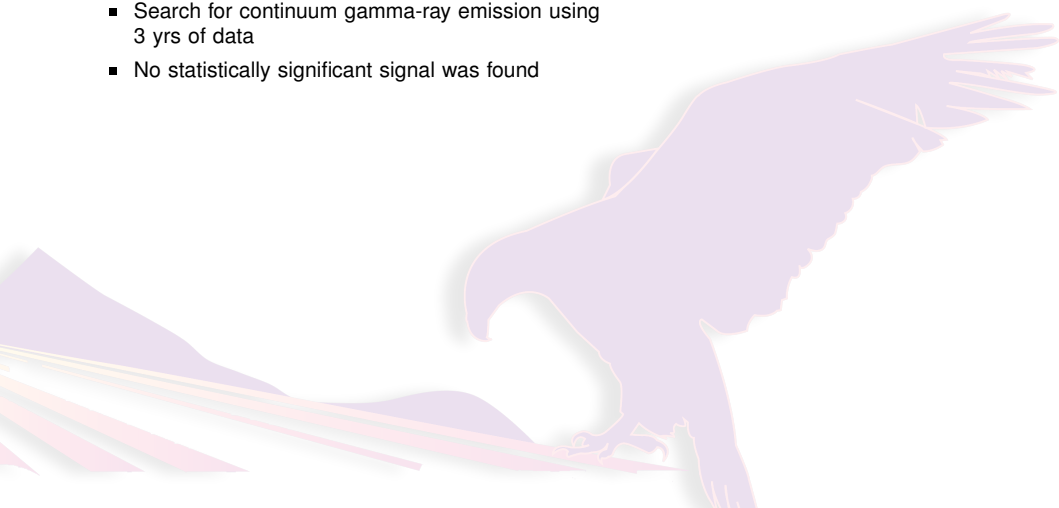

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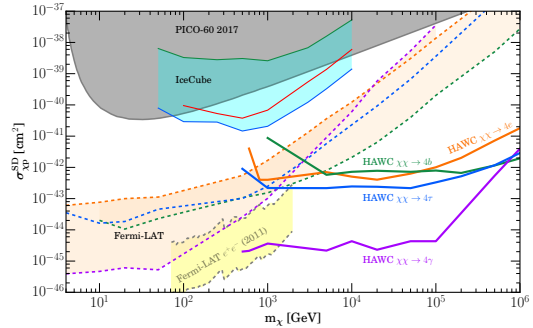
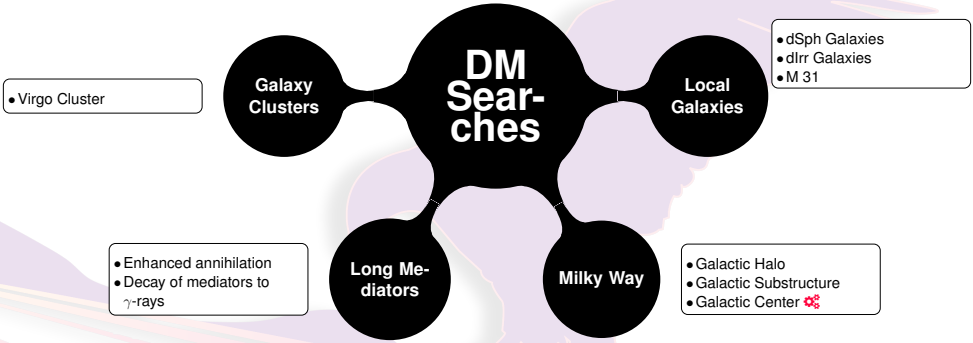
- Search for continuum gamma-ray emission using 3 yrs of data
- No statistically significant signal was found
- ULs (95 % C.L.) complement the results obtained by Fermi-LAT and other experiments dedicated to direct DM searches



https://arxiv.org/abs/1808.05620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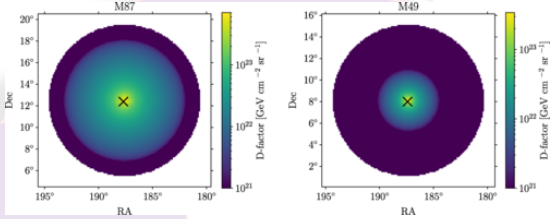
Virgo Cluster

M. Un Nisa, P. Harding +; 2024

- Search for continuum gamma-ray emission using 2141 days from the Virgo Cluster considering M 87 and M 49 subhalos.



Spectrum from Pythia

$$\frac{d\Phi_\gamma}{dE}(\Delta\Omega, l.o.s, E) = \frac{\langle\sigma_\chi v\rangle}{8\pi m_\chi^2}\frac{dN_\gamma}{dE}(E) \times \ D(\Delta\Omega, l.o.s)$$

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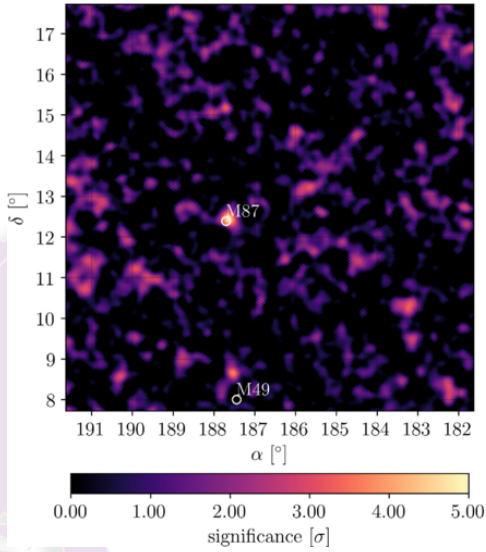

McGaugh+ 2017, Martin 2014

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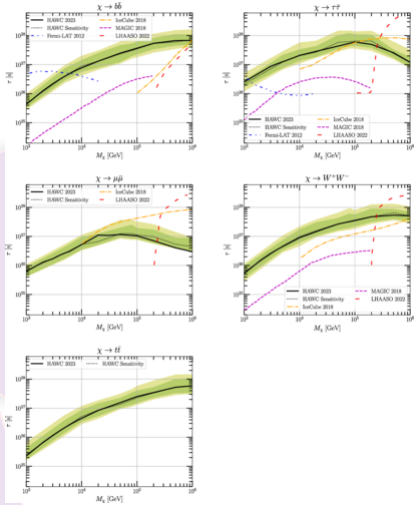
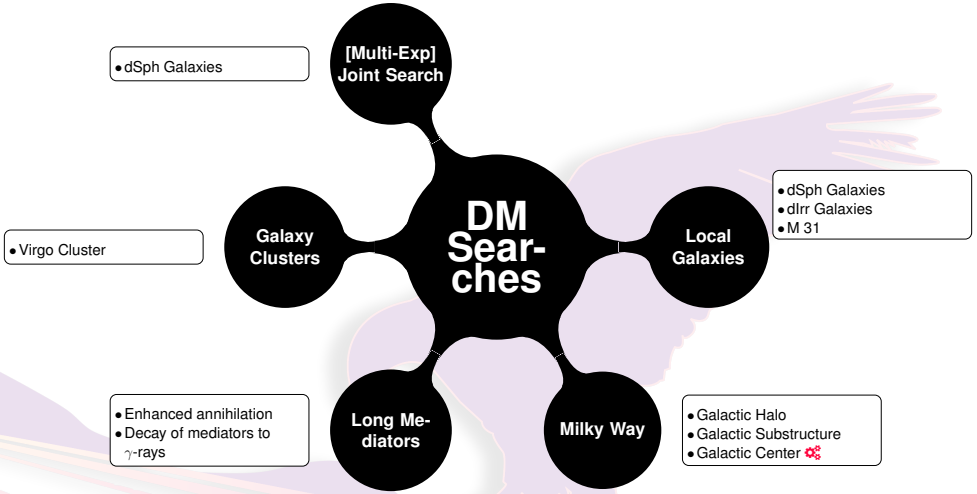


https://arxiv.org/abs/2309.03973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Joint Experiment Limits for dSph

D. Salazar-Gallegos, P. Harding, K. Tollefson+; coming soon

- Search for continuum gamma-ray emission using data from Fermi-LAT, HAWC, H.E.S.S., MAGIC, and VERITAS.

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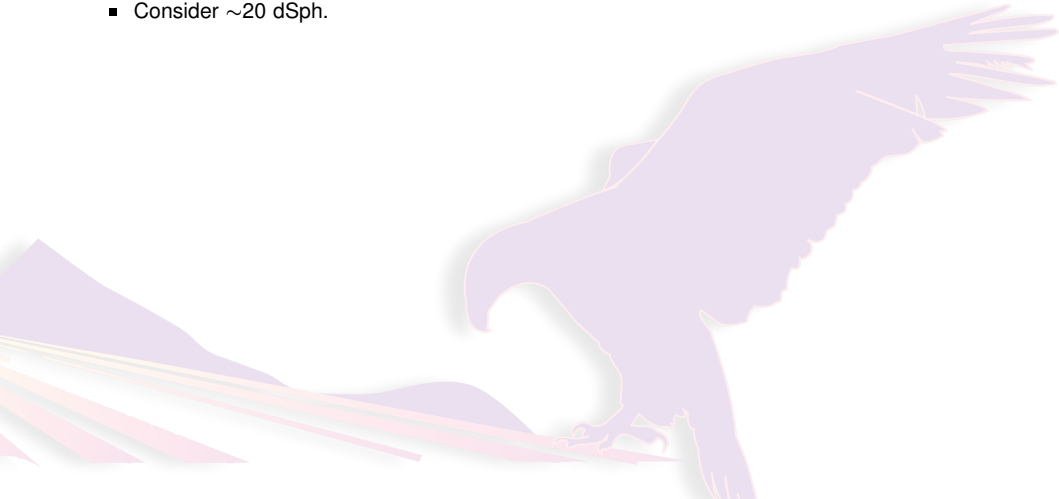
- Consider $\sim$20 dSph.



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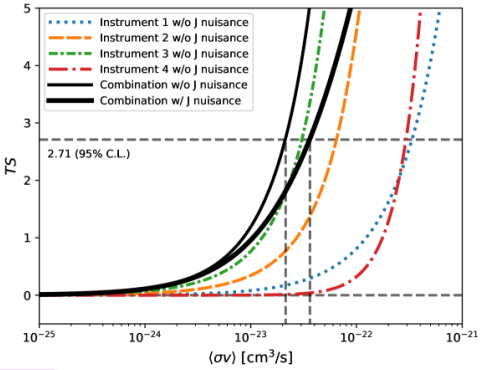
- Search for continuum gamma-ray emission using data from Fermi-LAT, HAWC, H.E.S.S., MAGIC, and VERITAS.
- Consider ∼20 dSph.
- Joint Likelihood

$$\mathcal{L}(\langle\sigma v\rangle;\nu|\{D\}_{\text{dSph}}) = \prod_{i}^{n_{\text{dSph}}} \mathcal{L}_i(\langle\sigma v\rangle;\nu|D_i) \times \mathcal{J}_i(J|J_{\text{obs}},\sigma_{\log J})$$



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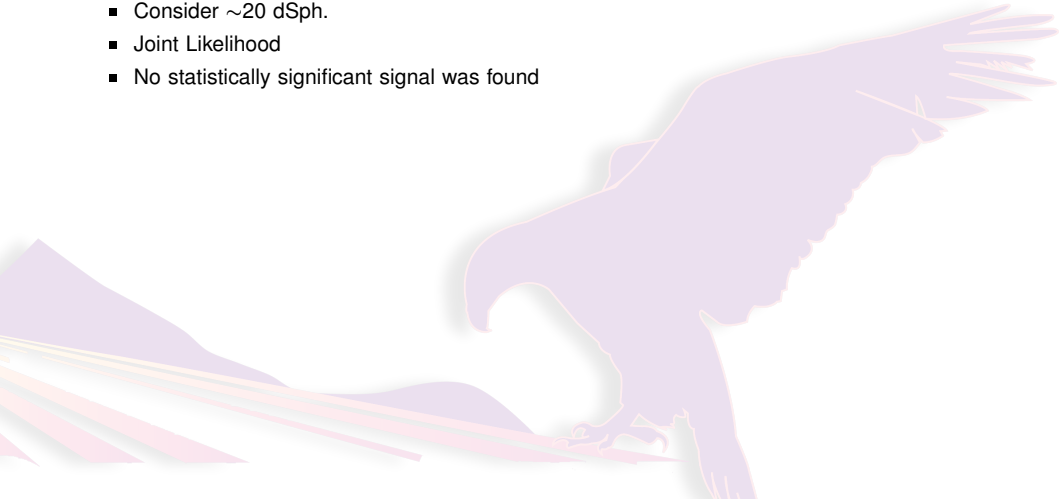

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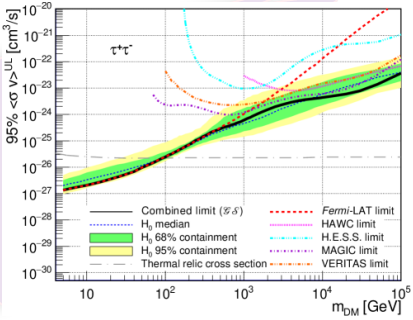
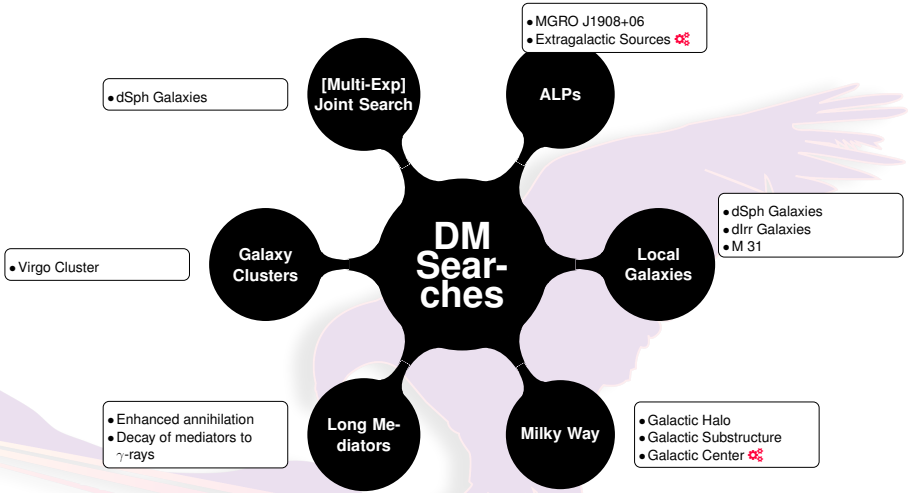
- Consider ∼20 dSph.
- Joint Likelihood
- No statistically significant signal was found
- Exclusion limits to annihilation cross-section to 5 different channels



https://arxiv.org/abs/2508.20229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Axion-Like Particles

A. Pratts, S. Hernández +; coming soon

- ALPs coupled to SM ($\mathcal{L}_{a\gamma\gamma} = a g_{a\gamma} \vec{E} \cdot \vec{B}$)

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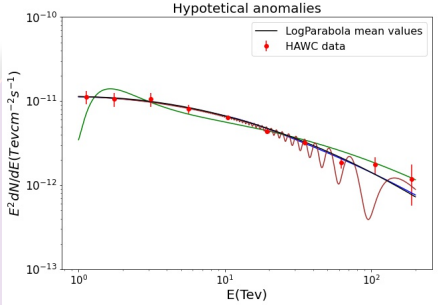
- ALPs coupled to SM ($\mathcal{L}_{a\gamma\gamma} = a g_{a\gamma} \vec{E} \cdot \vec{B}$)
- Induce irregularities (wiggles, overall attenuation) in the gamma-ray spectrum of all sources



$$\frac{d\Phi_\gamma}{dE} = (1 - P_{a\to\gamma}) \left.\frac{d\phi_\gamma}{dE}(E)\right|_{\text{Int}}$$

$$P_{\gamma\to a} = \left(1 + \frac{E_c^2}{E_\gamma^2}\right)^{-1} \times \sin^2\left(\frac{g_{a\gamma} B_T L}{2} \sqrt{1 + \frac{E_c^2}{E_\gamma^2}}\right)$$

Axion-Like Particles

A. Pratts, S. Hernández +; coming soon

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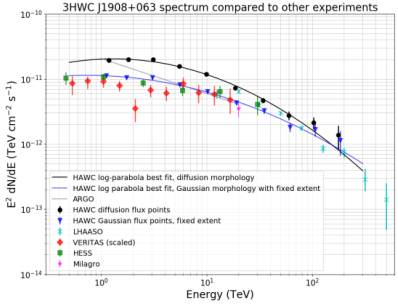
- Induce irregularities (wiggles, overall attenuation) in the gamma-ray spectrum of all sources
- MGRO J1908+06 is one of the brightest gamma-ray emitters. However, the mechanism behind the emission is still unclear

A composite scenario have been proposed to explain the gamma-ray emission from MGRO J1908+06: PSR J1907+0602 (2.3 kpc, 3.2 kpc) and the interaction of SNR G40.5-0.5 (between 3.4 to 8.3 kpc) [Duvidovich+, 2019]



2565 transits

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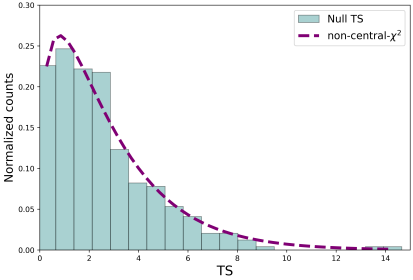

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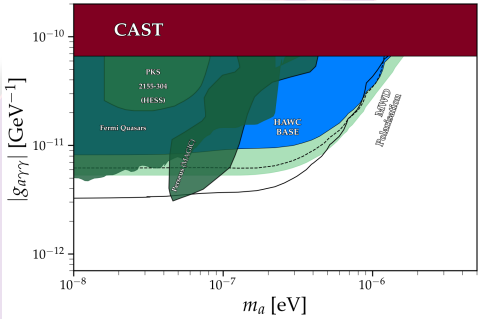
- Non-linearity of ALP hypothesis require to estimate new TS threshold to find exclusion limits at 95 % C.L.
- Strong dependence on the MW magnetic field and the true distance to the source
- Comparison with other experiments and searches



Summary

Summary

1. 9 papers related to particle DM.
2. 4 ongoing analysis (3 dedicated to ALPs).
3. Not in this talk: Evaporation of PBH and LIV.
4. Complementary limits to other experiments: Fermi-LAT, H.E.S.S., MAGIC, LHAASO, VERITAS.
5. Reducing the allowed parameter space to test for particle DM.
6. There is still much work to be done: Population studies, test heavier candidates, test other UL candidates, Joint Experiment analysis.
7. Future: SWGO and CTAO will help to improve our current limits about the nature of DM.

Thanks! c:

You survived!!!
Take this!