APOEMA

Dark matter searches with a ground-based water Cherenkov observatory (SWGO)

High-energy astrophysics in the multi-messenger era

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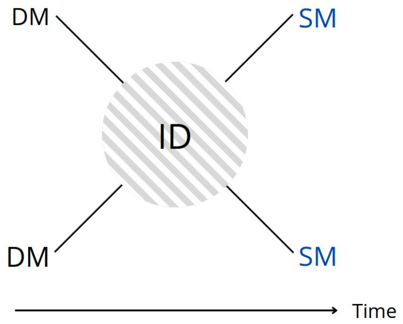
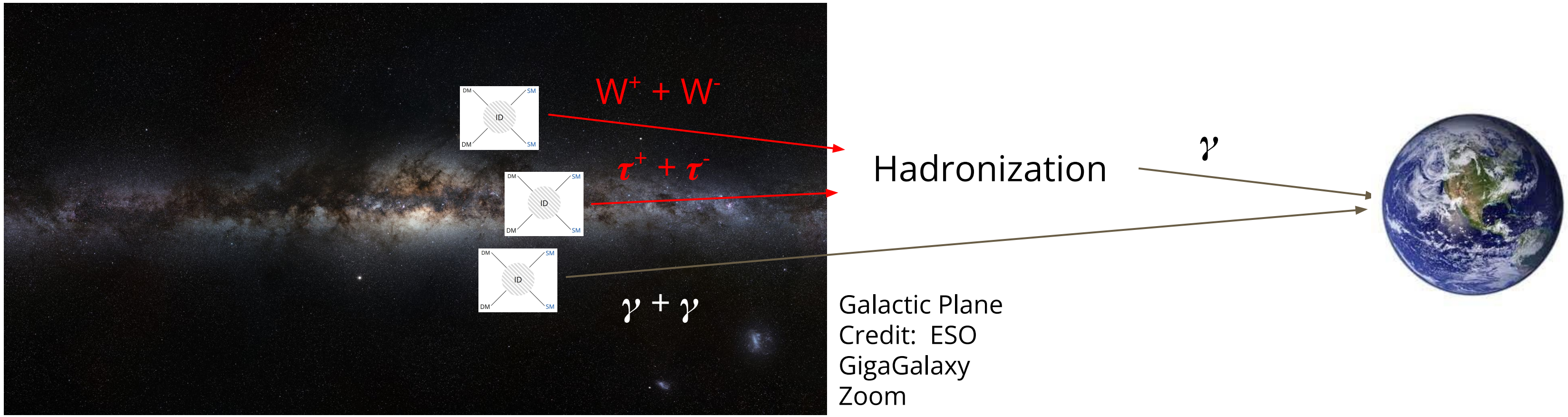
Dark matter indirect searches

So how do we detect dark matter indirectly?



Feynman diagram showing the principle behind Indirect detection.

Where are does this type of process happen with enough rate to generate a significant signal?



Galactic Plane
Credit: ESO GigaGalaxy Zoom

Dark matter indirect searches

The search for excess SM particles from Dark Matter annihilation or decay.

The flux of photons from dark matter annihilation is given by →

$$\text{Gamma-ray flux} = \overbrace{\frac{\langle\sigma v\rangle}{8\pi m_{DM}^2}\frac{dN}{dE}}^{\text{particle physics}} \underbrace{\int ds \int d\Omega\ \rho_{DM}^2}_{\text{astrophysics}}$$

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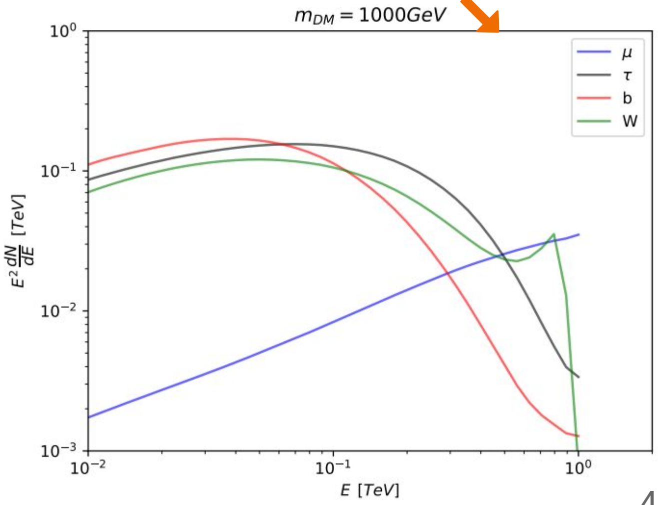
Spectrum from PPPC 4 DM ID, arXiv:1012.4515.

100% branching ratio (model independence).



Annihilation spectrum for a Dark Matter mass of 1000 GeV

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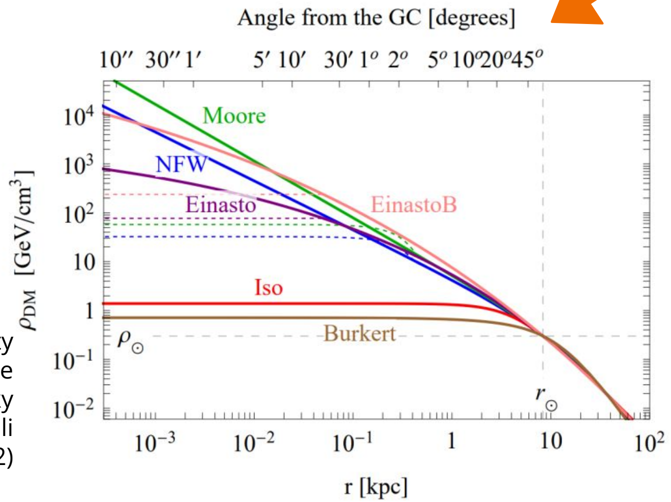
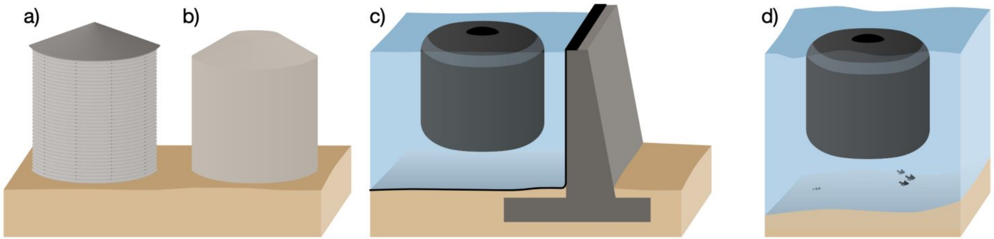
The astrophysical factors are given by these density profiles integrated over the a solid angle and line of sight.



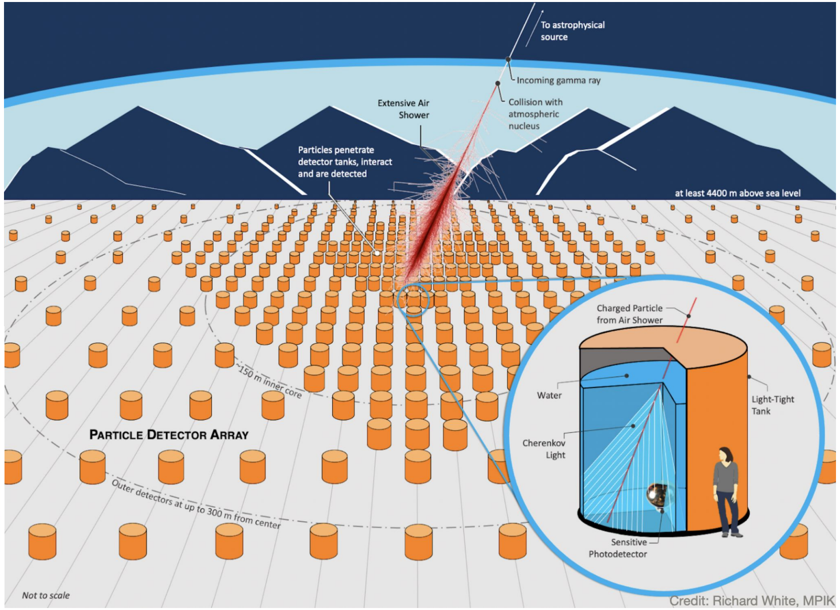
Dark matter density as a function of the distance for the Milky Way center by Cirelli et al. (2012)

The Southern Wide-field Gamma-ray Observatory (SWGO)

- SWGO is a gamma-ray observatory based on ground-level particle detection, currently in a research and development phase.
- Located in South America at a latitude between 10 and 30 degrees south.
- Access to the Galactic Centre and complementary with CTA-South



Detector concepts under study from Hinton, J. (2021)



Dwarf galaxies in the context of dark matter

Dominated by dark matter

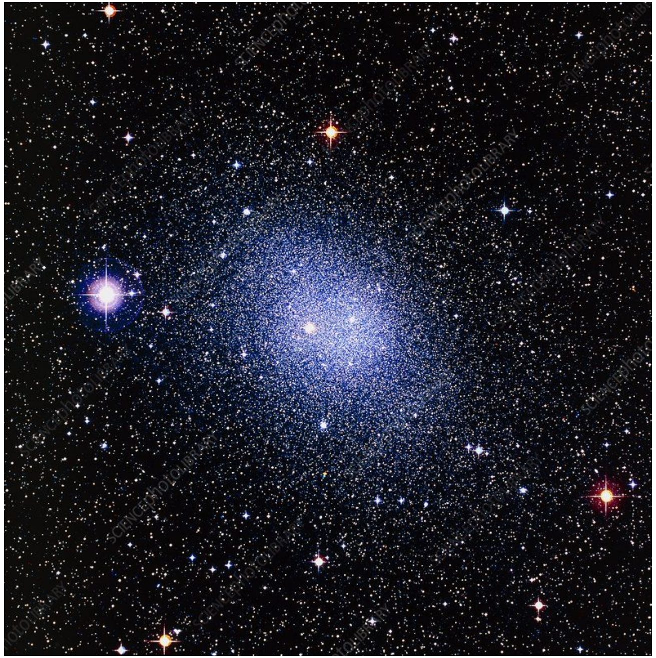
Distance

- ❖ Close to Earth
- ❖ Affects Astrophysical factors

(Ultra-Faint) Dwarf Spheroidal Galaxies (dSphs)

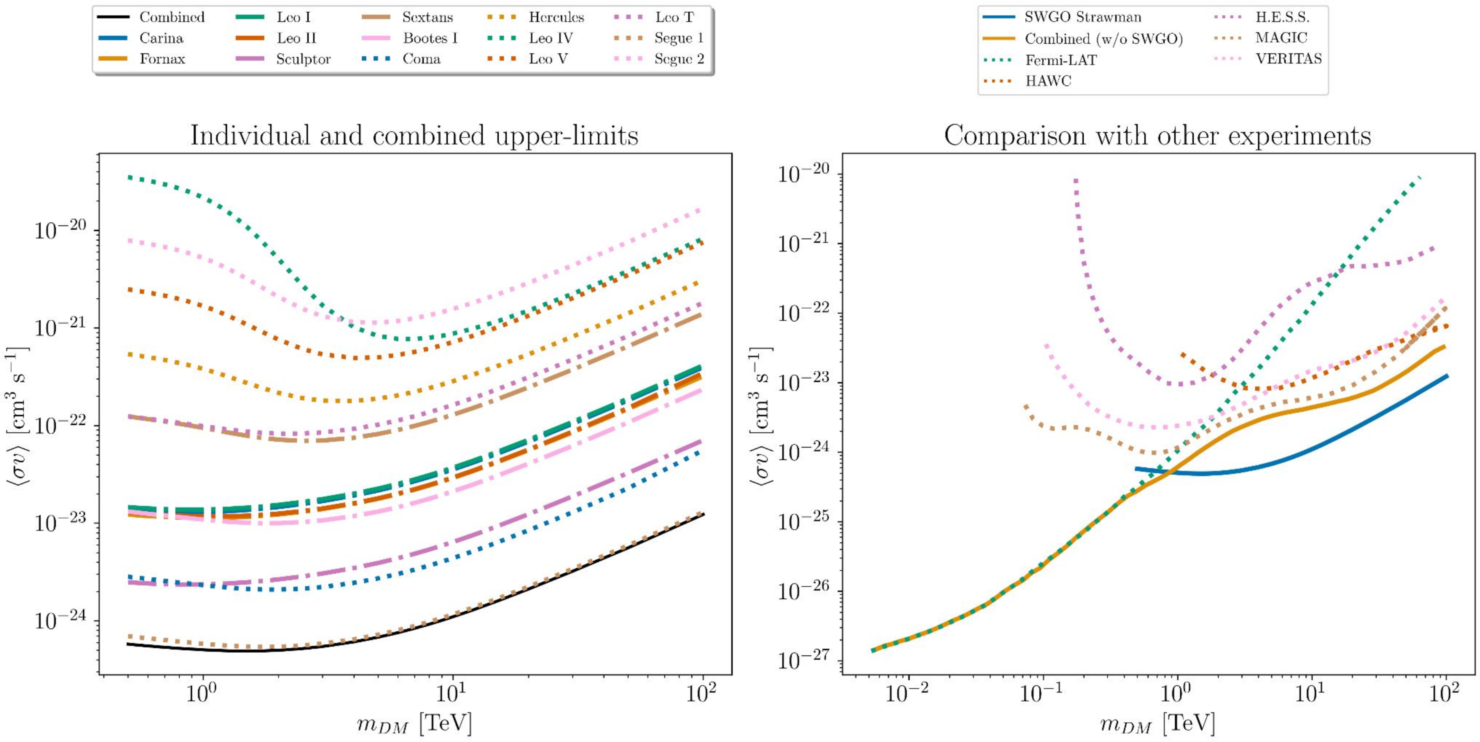
- ❖ Older stellar population
- ❖ No gamma-ray emission outside of (potentially) dark matter

Density profile measured



Fornax Dwarf Spheroidal
Credit: UK Schmidt Telescope

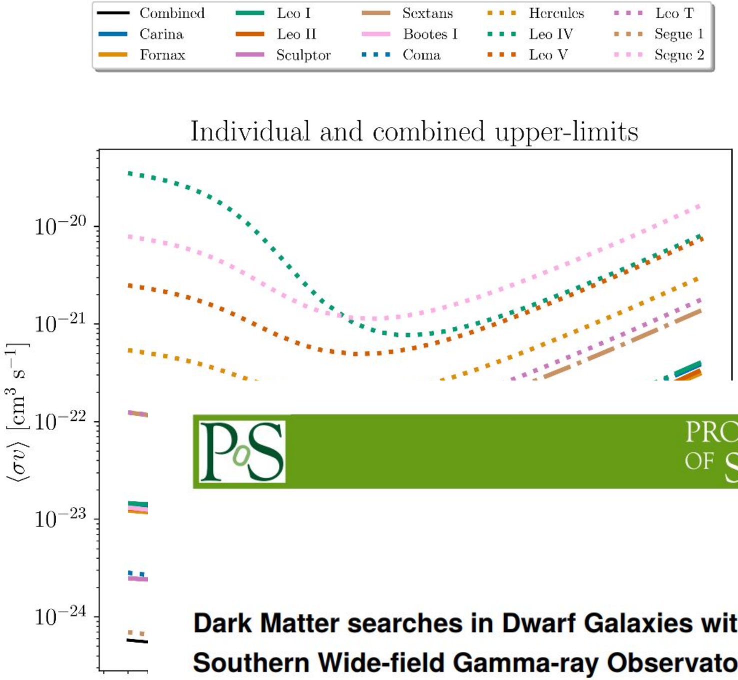
Dwarf galaxies in the context of dark matter

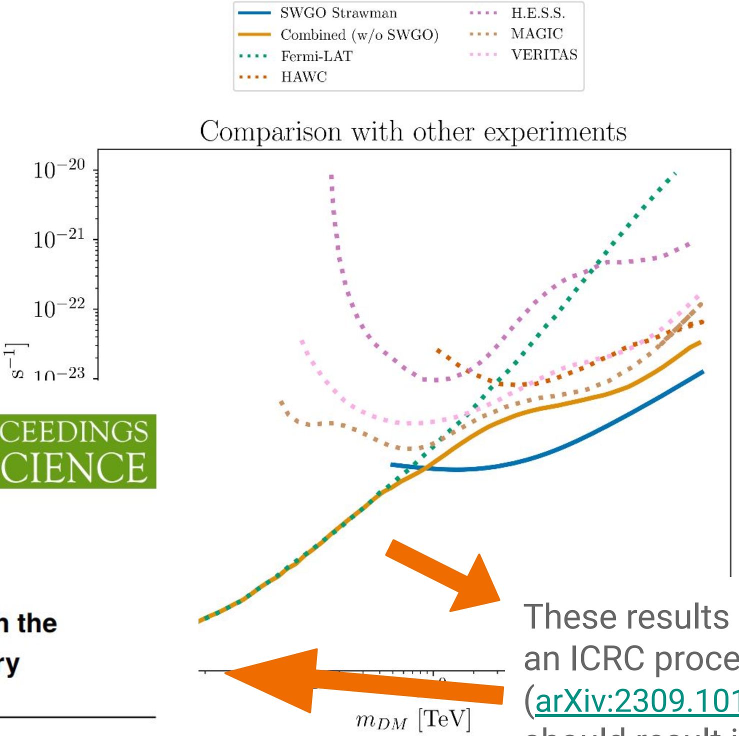


Individual and combined sensitivity curves for the channel $\tau^+\tau^-$

Strawman design IRFs

Dwarf galaxies in the context of dark matter





r the channel $\tau^+\tau^-$

PoS PROCEEDINGS OF SCIENCE

Dark Matter searches in Dwarf Galaxies with the Southern Wide-field Gamma-ray Observatory

Micael Andrade[a,*] and Aion Viana[a] for the SWGO collaboration[†]

[a] *Instituto de Física de São Carlos, Universidade de São Paulo Av. Trabalhador São Carlense 400, São Carlos, Brazil*

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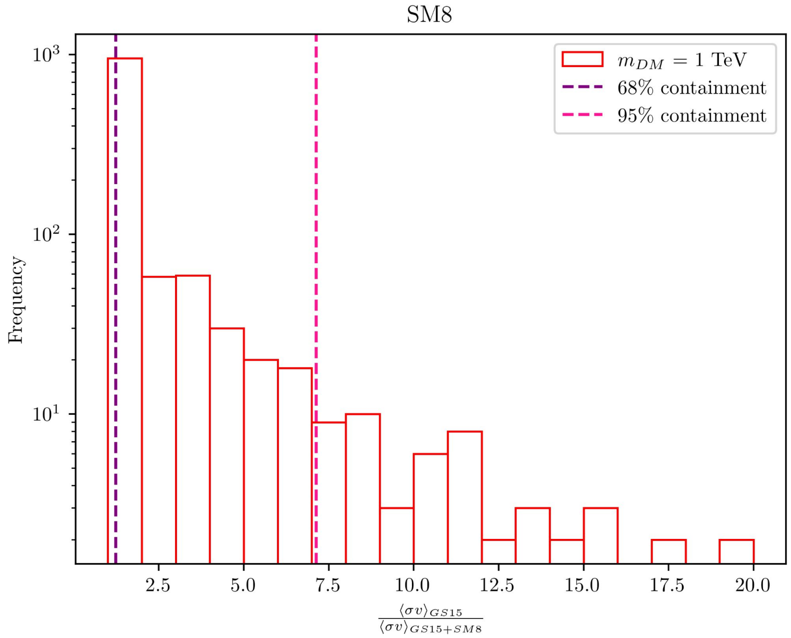
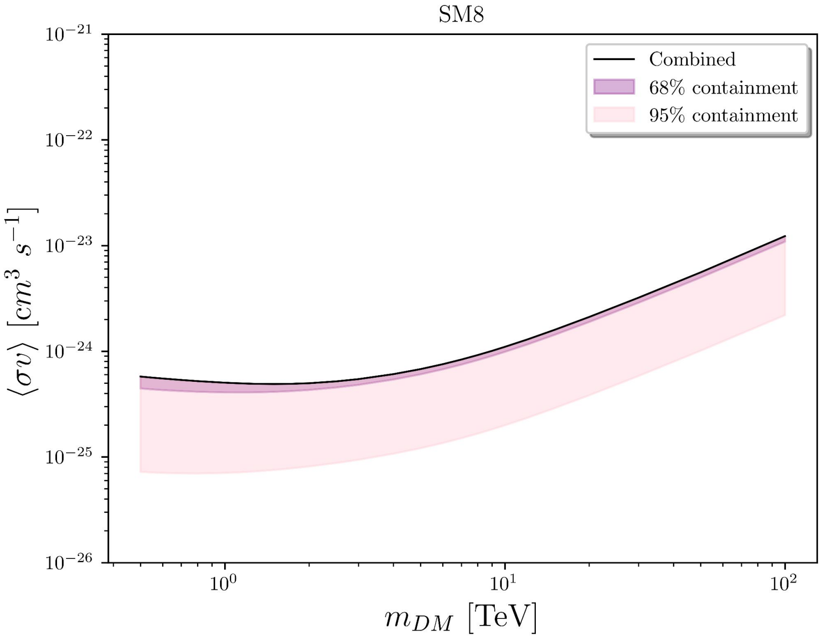
Strawman design IRF

These results were in an ICRC proceeding (arXiv:2309.10102) and should result in a full article when the final IRFs are available.

Dwarf galaxies in the context of dark matter

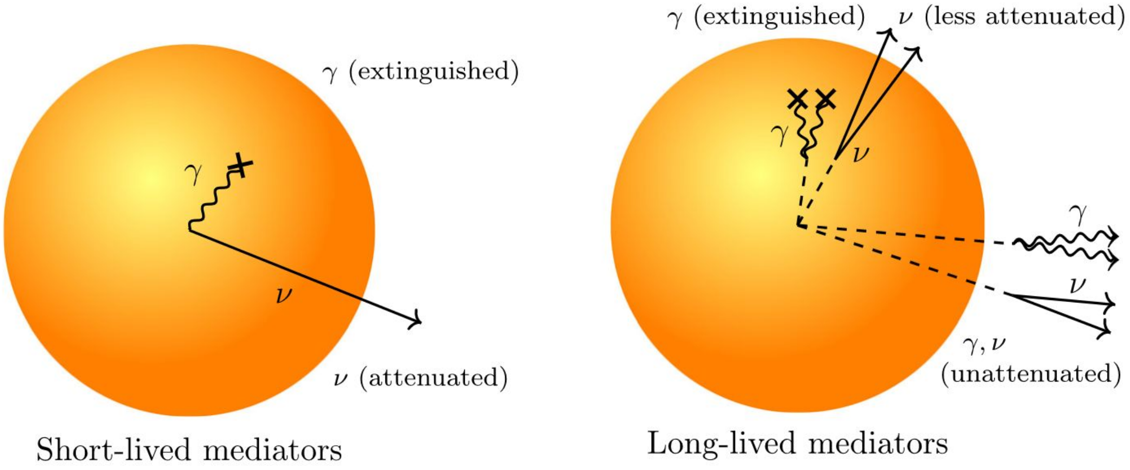
Use clumpy simulations of the milky way to simulate “to be found” dwarfs and extrapolate limits





Dark matter annihilation in the Sun

Long-lived mediators between the dark sector and the standard model can lead to gamma-rays from DM annihilation in the Sun



Explanation to gamma-ray signals from DM annihilation detectable in Earth. Credit: arXiv:1703.04629

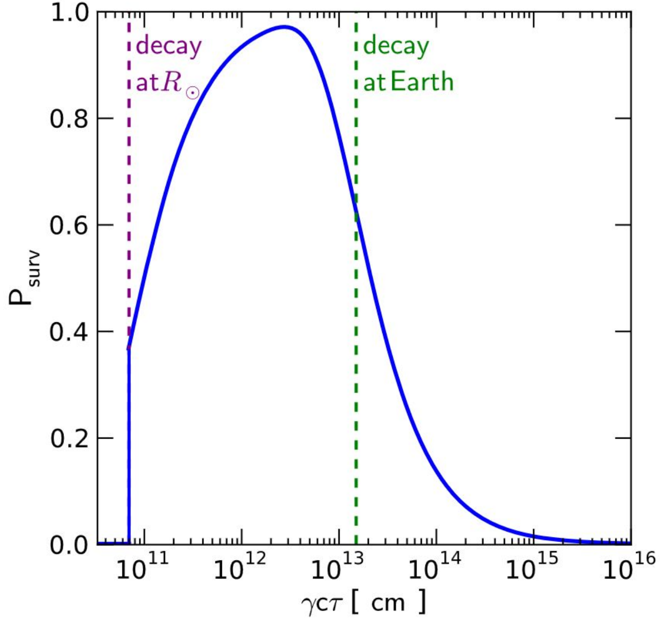
Dark matter annihilation in the Sun

The gamma-ray flux is given by:

$$\frac{d\Phi_\gamma}{dE} = \frac{\Gamma_C}{8\pi D_{sun}^2} \sum_i B_i \frac{dN_i}{dE} P_{SE}$$

With $P_S = e^{-R_\odot/L} - e^{-D_{sun}/L}$

Besides that the equation is almost the usual DM indirect detection equation.



Probability of gamma rays from the mediator surviving and reaching a detector at Earth. Credit: arXiv:1703.04629

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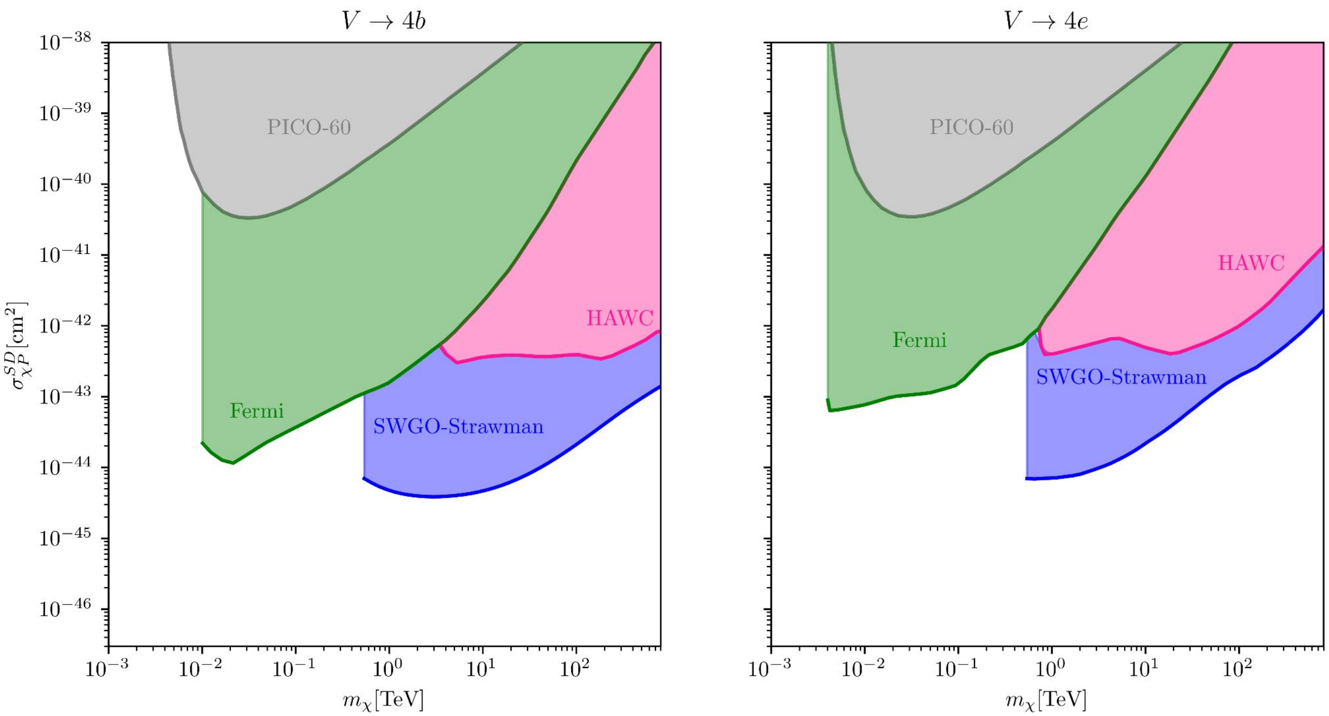
And the capture rate is given by:

$$\Gamma_C = 3.4 \times 10^{20}\,\mathrm{s}^{-1} \left(\frac{\rho_\chi^\odot}{0.3\,\mathrm{GeV/cm^3}}\right) \left(\frac{270\,\mathrm{km/s}}{\bar{v}_\chi}\right)^3 \left(\frac{\sigma_{\chi p}}{10^{-42}\,\mathrm{cm^2}}\right) \left(\frac{100\,\mathrm{GeV}}{m_\chi}\right)^2$$

Dark matter annihilation in the Sun

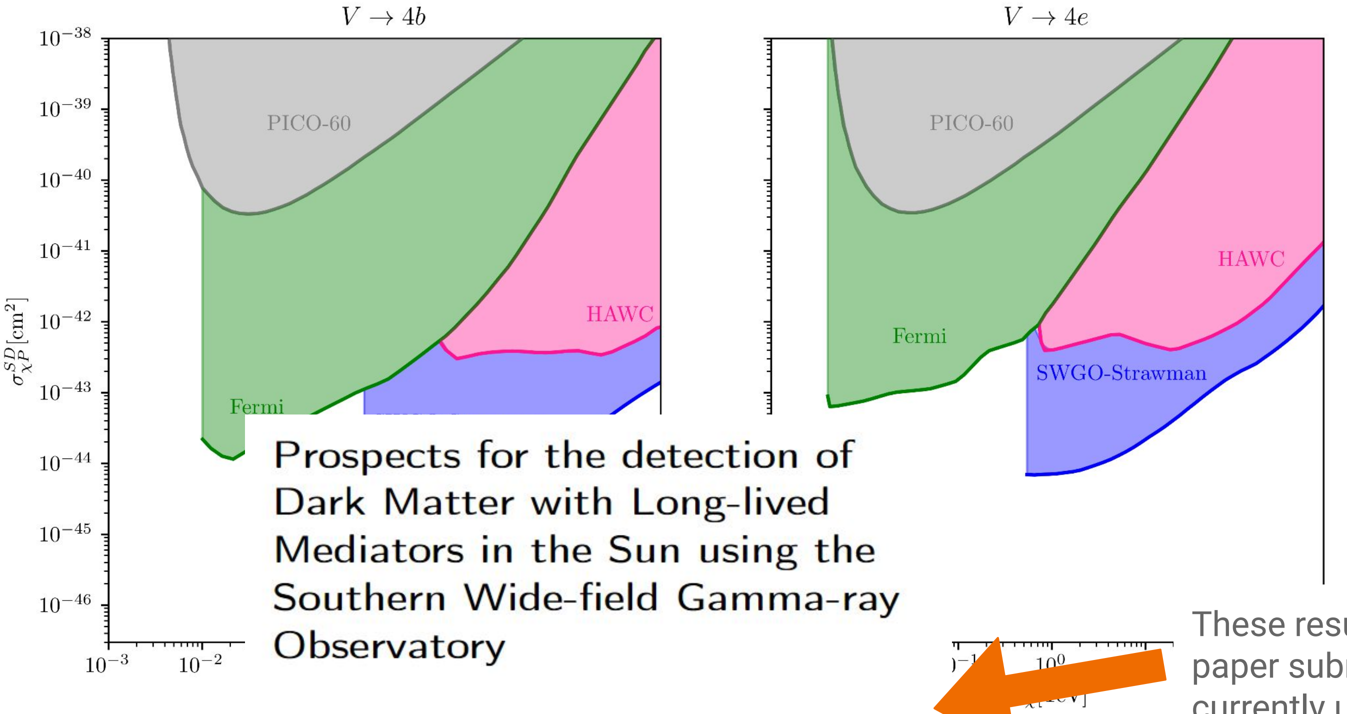


Sensitivity curves for dark matter–proton spin-dependent cross section the channels b and e.

Strawman design IRFs

Fermi and HAWC limits from arXiv:1808.05624; Pico 60 limits from arXiv:1702.07666

Dark matter annihilation in the Sun



Prospects for the detection of Dark Matter with Long-lived Mediators in the Sun using the Southern Wide-field Gamma-ray Observatory

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These results are a CAT 3 paper submission, currently under internal SWGO review.

Sensitivity curves for … section the cha…

… limits from arXiv:1702.07666

Strawman design IRFs

Galactic Halo dark matter benchmark for SWGO

As mentioned before, SWGO is in a research and development phase.

This means that the final detector and array configuration weren't decided -> no final IRFs yet.

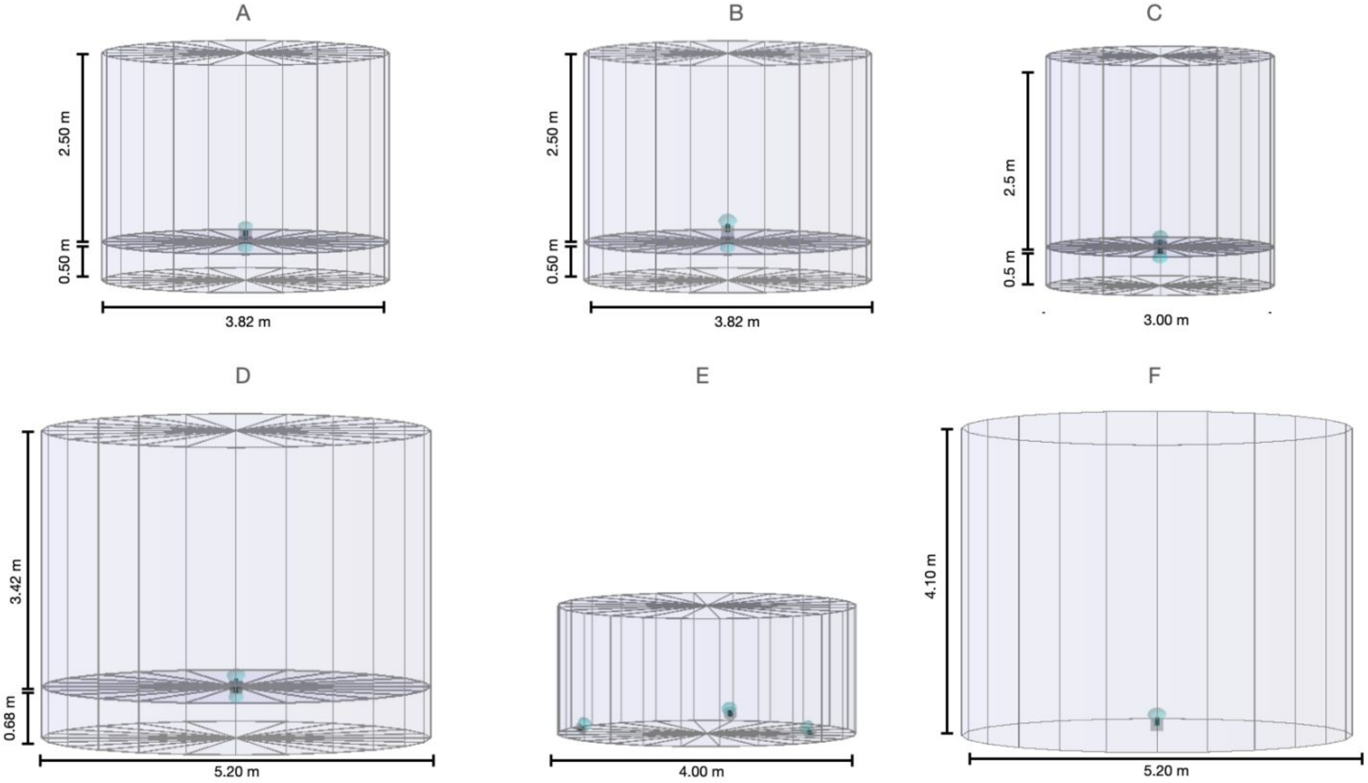
Some benchmarks were chosen internally that will be used to decided the final array configuration and detector unit. Example: Pevatrons, GRBs, etc;

One of these benchmarks involves annihilating dark matter in the galactic halo, so I'm also working on that.

	SWGO R&D Phase Milestones	
✓	**M1**	R&D Phase Plan Established
✓	**M2**	Science Benchmarks Defined
✓	**M3**	Reference Configuration & Options Defined
✓*	**M4**	Site Shortlist Complete
✓	**M5**	Candidate Configurations Defined
	M6	Performance of Candidate Configurations Evaluated
	M7	Preferred Site Identified
	M8	Design Finalised
	M9	Construction & Operation Proposal Complete

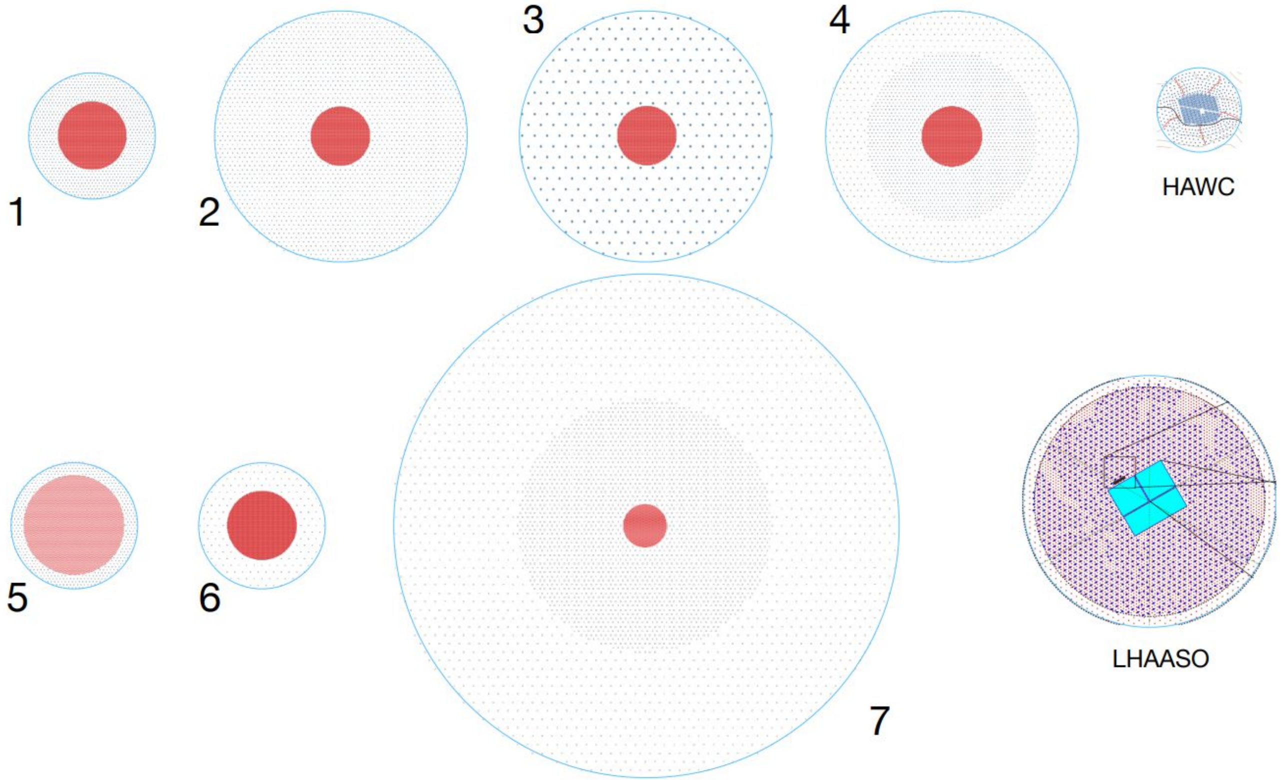
Galactic Halo dark matter benchmark for SWGO

SWGO detectors



Galactic Halo dark matter benchmark for SWGO

SWGO array configurations



Galactic Halo dark matter benchmark for SWGO

Galactic Center and Halo

- ❖ Highest dark matter density in our proximities
- ❖ Background problems caused by the galactic plane (can be mitigated by masking out the galactic plane)
- ❖ Systematic uncertainties from modeling the density profile (because of the gravitational potential from the bulge)

The Milky Way Galaxy as seen from Earth. Credit: Encyclopædia Britannica

Galactic Halo dark matter benchmark for SWGO

Usual Galactic Halo dark matter analysis:

- 5 years of observation time of the SWGO (1825 transits)
- Galaxy halo analysis with a mask in the galactic plane (±0.3° band in latitude)
- Einasto Dark Matter profile characteristic values r_s = 20 kpc, α = 0.17, and ρ_s = 0.081 GeV/cm3
- Annihilation channel bb as it is the weakest annihilation channel (softest spectra).
- Statistical analysis: 2D binned-likelihood (N_{ON}, N_{OFF}, N_{sig}, N_{bck})
- The 95% C.L. upper-limit on the annihilation cross-section for m_{DM}=100 TeV is one of the benchmarks for the array/detector decision

The Milky Way Galaxy as seen from Earth. Credit: Encyclopædia Britannica

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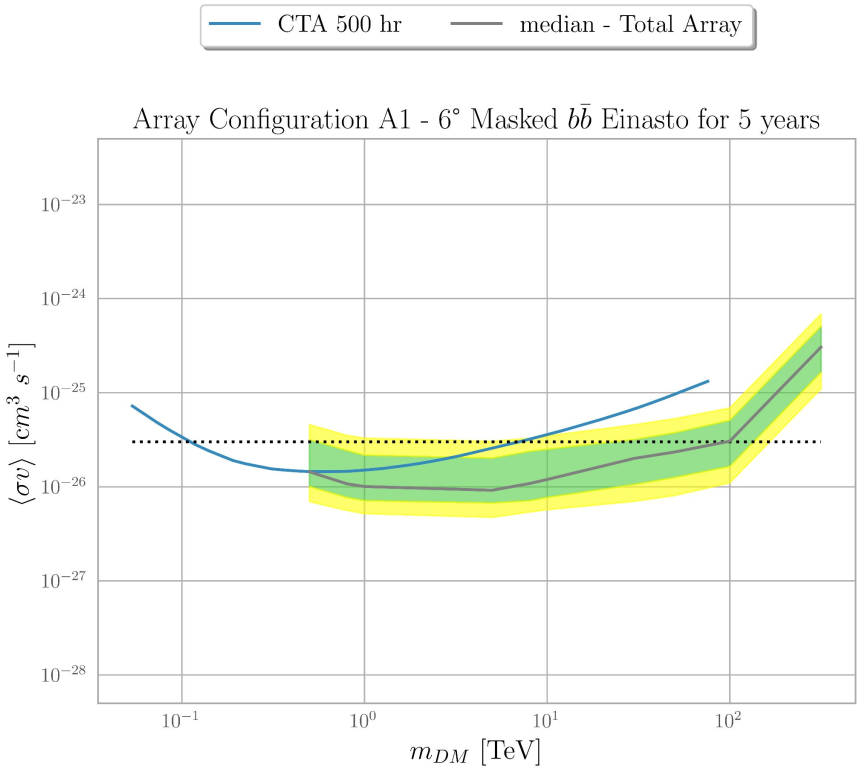
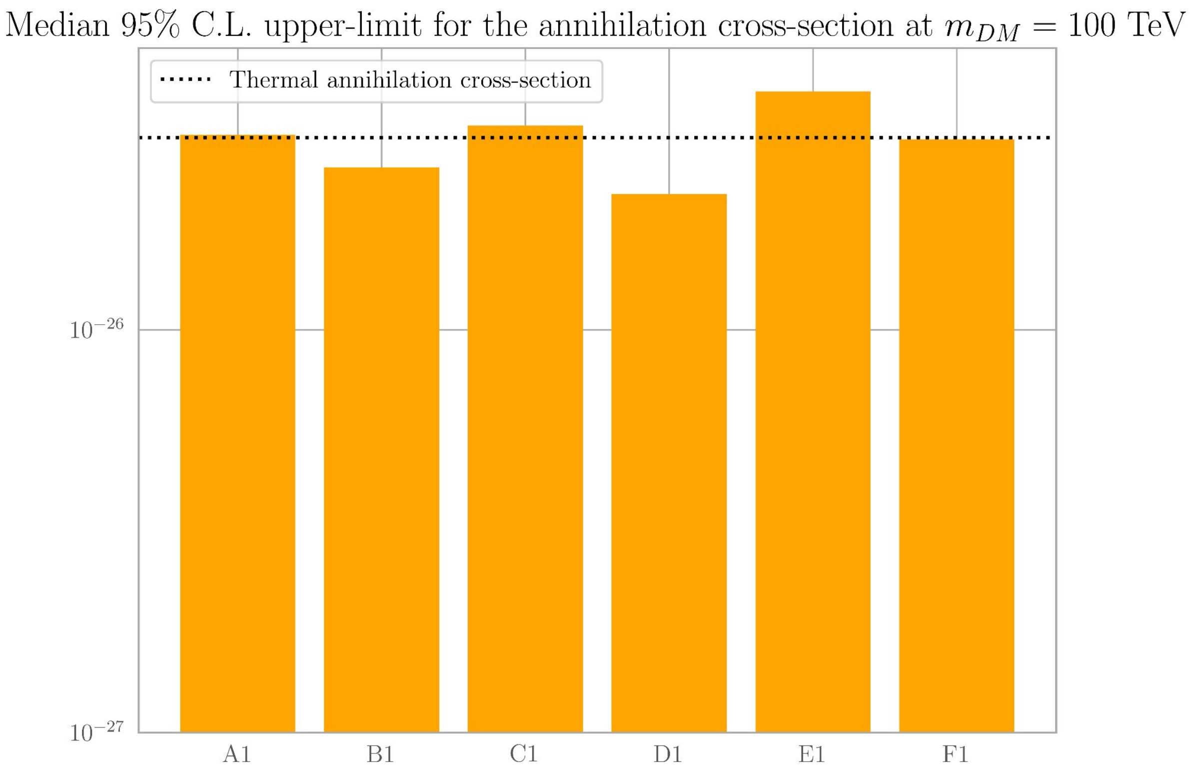


Galactic Halo dark matter benchmark for SWGO



This is better

Conclusions/Prospects

Seems like I work with dark matter!

SWGO has potential to be competitive in indirect dark matter detection and have great complementarity with CTA.

That potential goes from the the usual Dwarf and Galactic Halo Analysis to even more exotic situations like the Sun capture of Dark matter (something IACTs can't do) .

The DM benchmark evaluation should be ready to go whenever the final IRFs for SWGO are ready.

Thank you!

Acknowledgements

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2023/15494-0
2019/14893-3
2021/01089-1

CNPq

Grant 314955/2021-6

CAPES

IFSC USP

Backup: Analysis framework for Dwarf Galaxy Analysis

10 years of observations with the Strawman design of SWGO

2D binned joint-likelihood

$$L_{ij} = \frac{(B_{ij} + S_{ij})^{N_{ij}} e^{-(B_{ij}+S_{ij})}}{N_{ij}!}$$

Nuisance parameter (Uncertainties)

$$\mathcal{J}_j = \frac{1}{\sqrt{2\pi}\sigma_j log(10)\bar{J}} e^{-(log_{10}J - log_{10}\bar{J})^2/2\sigma_J^2}$$

Combined Lkl →

$$\mathcal{L} = \prod_i \prod_j \mathcal{L}_{ij} = \prod_i \prod_j L_{ij} \times \mathcal{J}_j$$

Test statistics (2.71 → 95% C.L.)

$$TS = -2ln(\mathcal{L}/\mathcal{L}_0)$$

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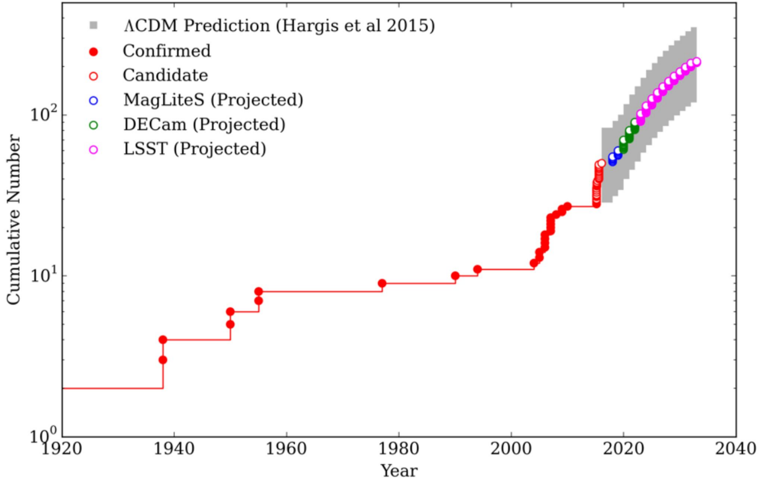
Backup: Vera Rubin

- Vera Rubin Observatory: Currently under construction in Chile
- Its main task will be carrying out a synoptic astronomical survey
- It is expected that many new dwarfs will be found



Credit: A. Drillica Wagner

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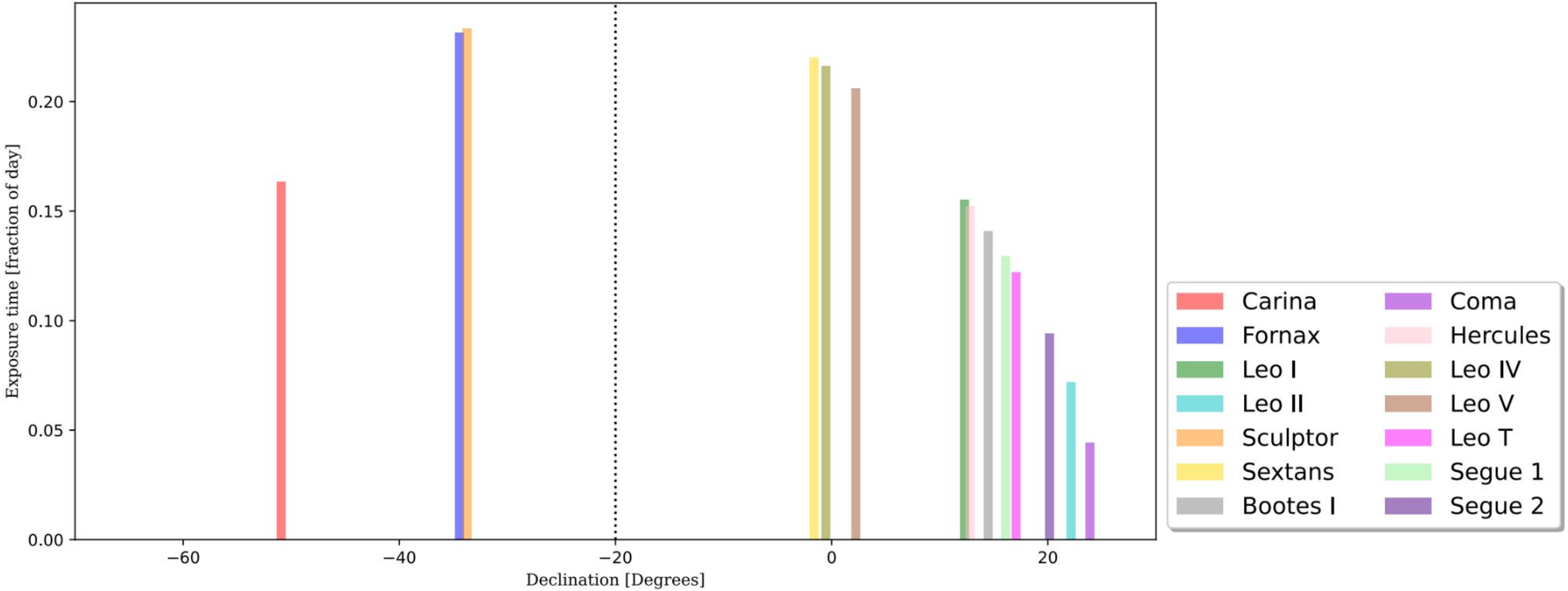
Backup: Target dwarfs



Target dwarfs in the range of the SWGO and their exposure time as a fraction of a day. SWGO is assumed to be positioned at -20º latitude and have a 45º maximum zenith angle of observation

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