Constraining the Dark Matter annihilation cross section

with a combined analysis of dwarf spheroidal galaxy observations from Fermi-LAT, HAWC, H.E.S.S., MAGIC, and VERITAS

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H.E.S.S. MAGIC VERITAS Fermi Gamma-ray Space Telescope HAWC High Altitude Water Cherenkov Gamma-Ray Observatory

GLORY DUCK

Abstract

The nature of Dark Matter (DM) is still an open question for modern Physics. In the particle DM paradigm, this elusive kind of matter cannot be made of any of the known particles of the Standard Model (SM) of particle physics. Many efforts have been made in order to model the nature of the DM. Among others, weakly interacting massive particles (WIMPs) are one of the most favored candidates for DM. Ground-based and space-based gamma-ray telescopes could potentially detect DM indirectly, by observing secondary products of its annihilation into SM particles. In the past years, limits on the DM self-annihilation cross section have been produced independently by the Fermi-LAT, HAWC, H.E.S.S., MAGIC, and VERITAS collaborations from a variety of DM targets. In this contribution, we will focus on the combination of observations from these five experiments in order to maximize the sensitivity of DM searches in dwarf spheroidal galaxies (dSphs), using a joint maximum likelihood approach. dSphs are one of the most promising targets for indirect DM searches, due to their proximity and their negligible contamination by astrophysical background. The obtained limits to the DM self-annihilation cross section are presented as a function of the DM particle mass, ranging from 10 GeV to 100 TeV.

Dark Matter evidence and targets

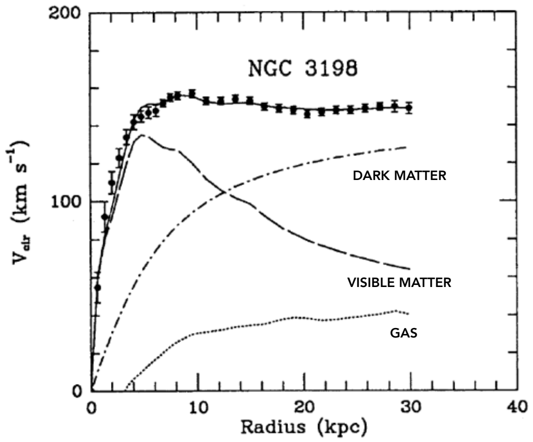
Dynamics of galaxies and gal. clusters

In 1933, Zwicky found a deficit of ~90% in mass in Coma cluster.

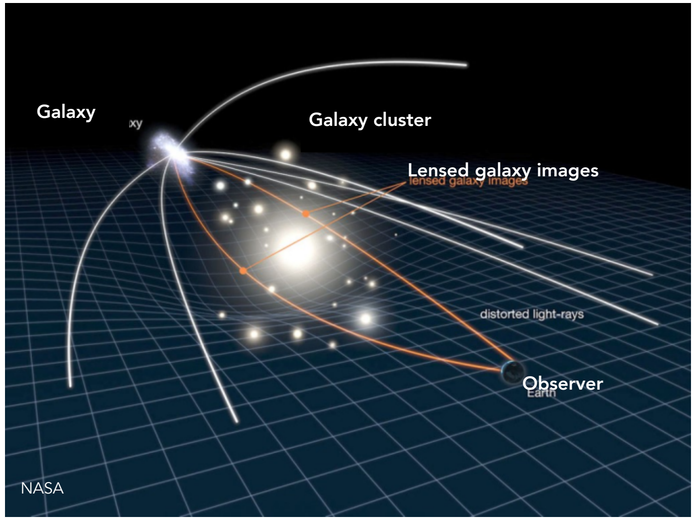
If Newtonian dynamics apply:

Inner system: $M(r) \propto r^3 \Rightarrow v \propto r$

Outer system: $M(r) \approx const \Rightarrow v \propto \frac{1}{r}$



Gravitational lensing



Expected gamma-ray flux produced by DM annihilation:

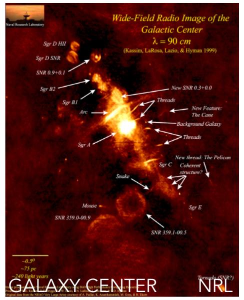
$$\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = \underbrace{\mathcal{J}(\Delta\Omega)}_{\text{Astrophysics}} \cdot \frac{1}{4\pi} \underbrace{\frac{\langle\sigma_{ann} v\rangle}{2m_\chi^2} \sum_i \mathrm{BR}_i \frac{dN_\gamma^i}{dE_\gamma}}_{\text{Particle physics}}$$

$$\mathcal{J}(\Delta\Omega) = \int_{\Delta\Omega} d\Omega' \int_{\text{l.o.s.}} dl\, \rho^2(l, \Omega')$$

Key concepts: ρ, distance, background

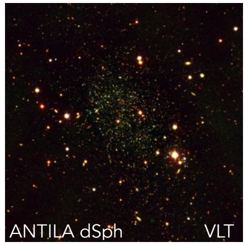
Galactic Center & Halo

- High flux
- Background Issues



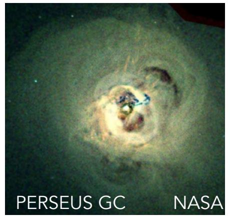
Dwarf Galaxies

- Large M/L
- Less background
- Low flux



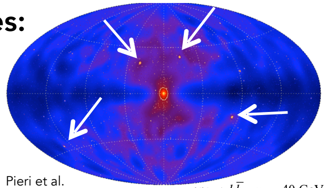
Galaxy Clusters

- Huge DM content
- Large distance
- High background



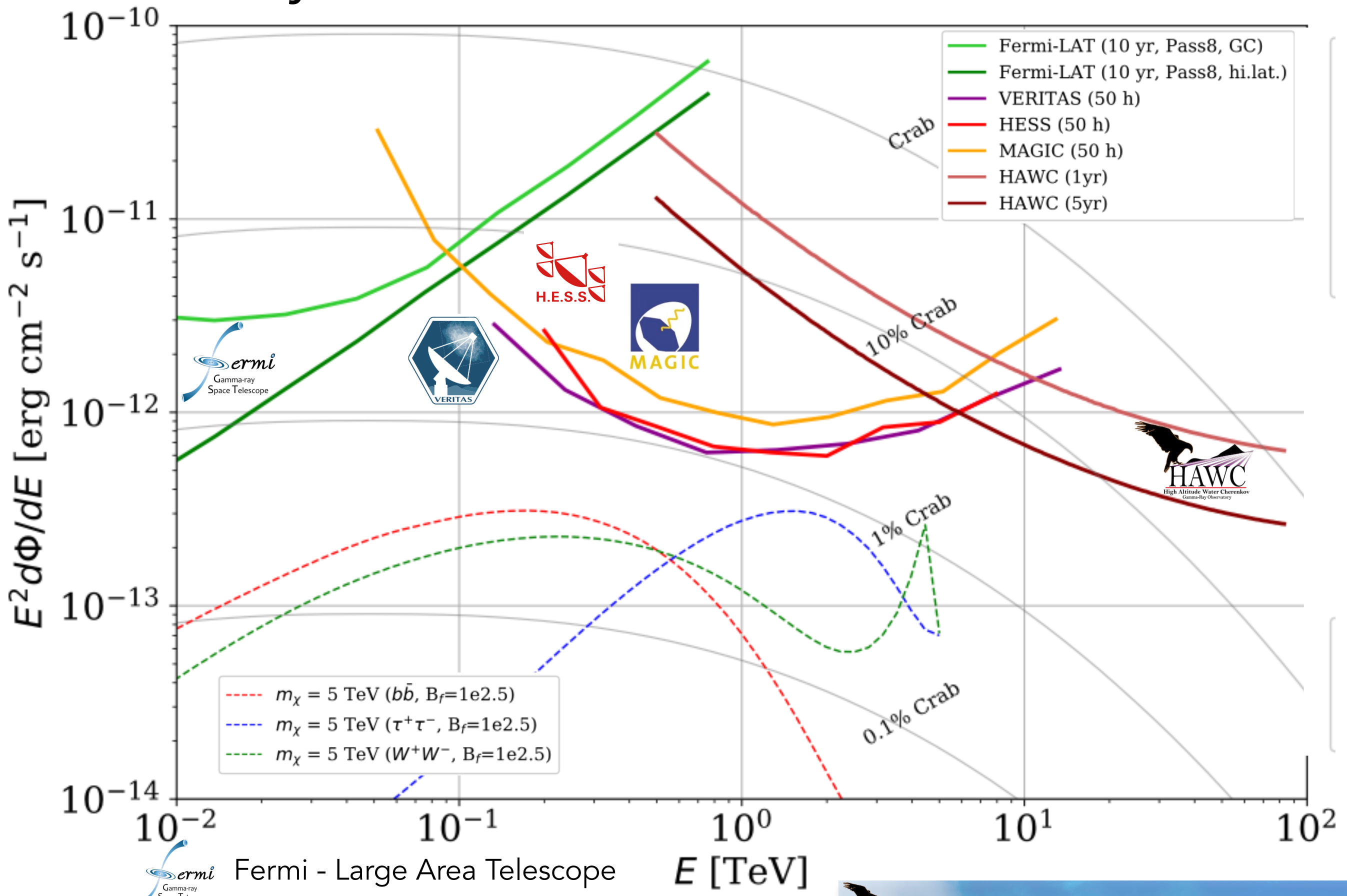
Unassociated HE Sources:

- DM Subhalos?

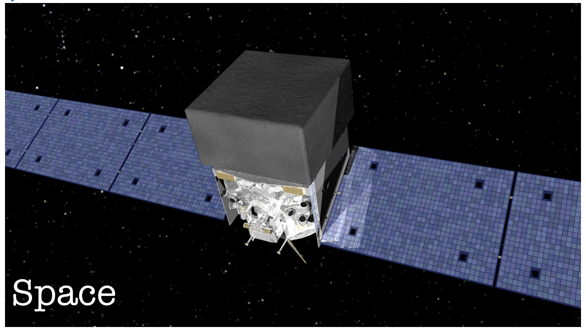


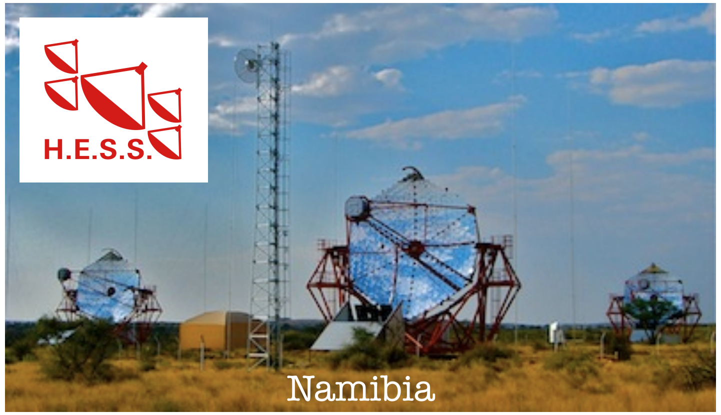
Pieri et al.
PRD 83:0235, 2008
$\chi\chi \rightarrow b\bar{b}$, m_χ = 40 GeV

Gamma-Ray Observatories



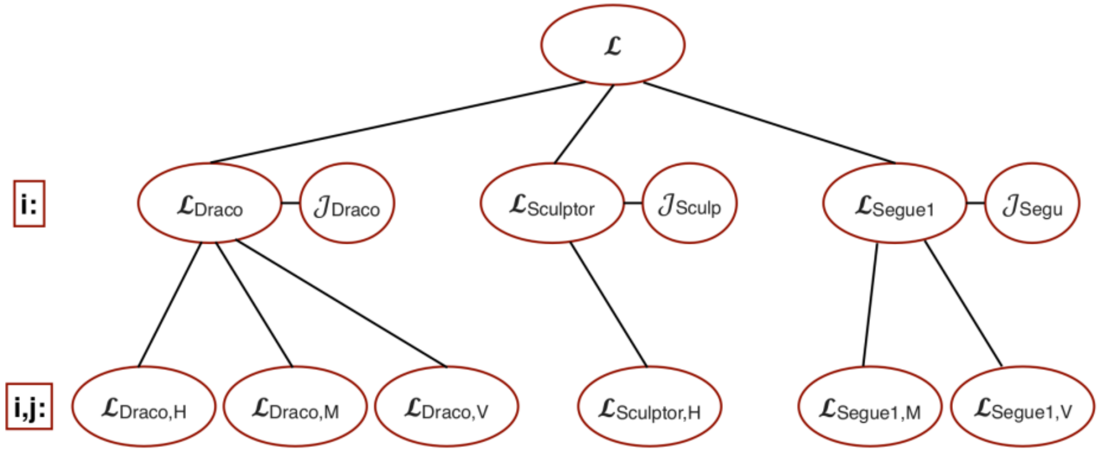
Fermi - Large Area Telescope





Combining likelihoods

Likelihood formula: $$\mathcal{L}(\alpha;\boldsymbol{\nu}|\boldsymbol{\mathcal{D}}) = \prod_{l=1}^{N_{\mathrm{dSph}}} \mathcal{L}_\gamma(\alpha\bar{J}_l;\boldsymbol{\mu}_l|\boldsymbol{\mathcal{D}}_{\gamma l}) \cdot \mathcal{L}_J(\bar{J}_l|\boldsymbol{\mathcal{D}}_{J_l})$$



J. Rico

Analysis frameworks:

gLike: Code framework for the numerical maximization of joint likelihood functions
https://github.com/javierrico/gLike

LikelihoodCombiner: Python package to cross-check the results from gLike
https://github.com/TjarkMiener/likelihood_combiner

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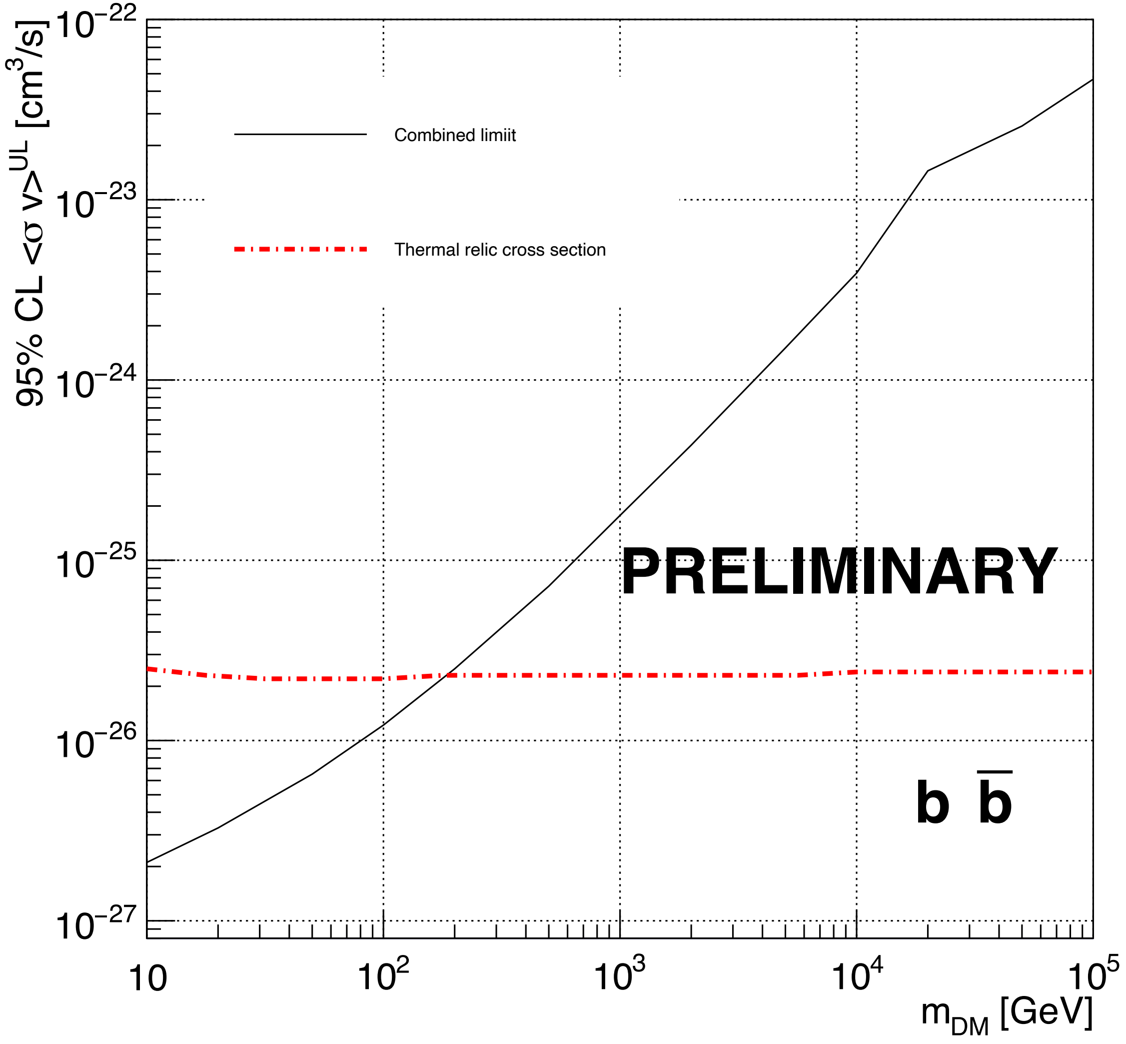
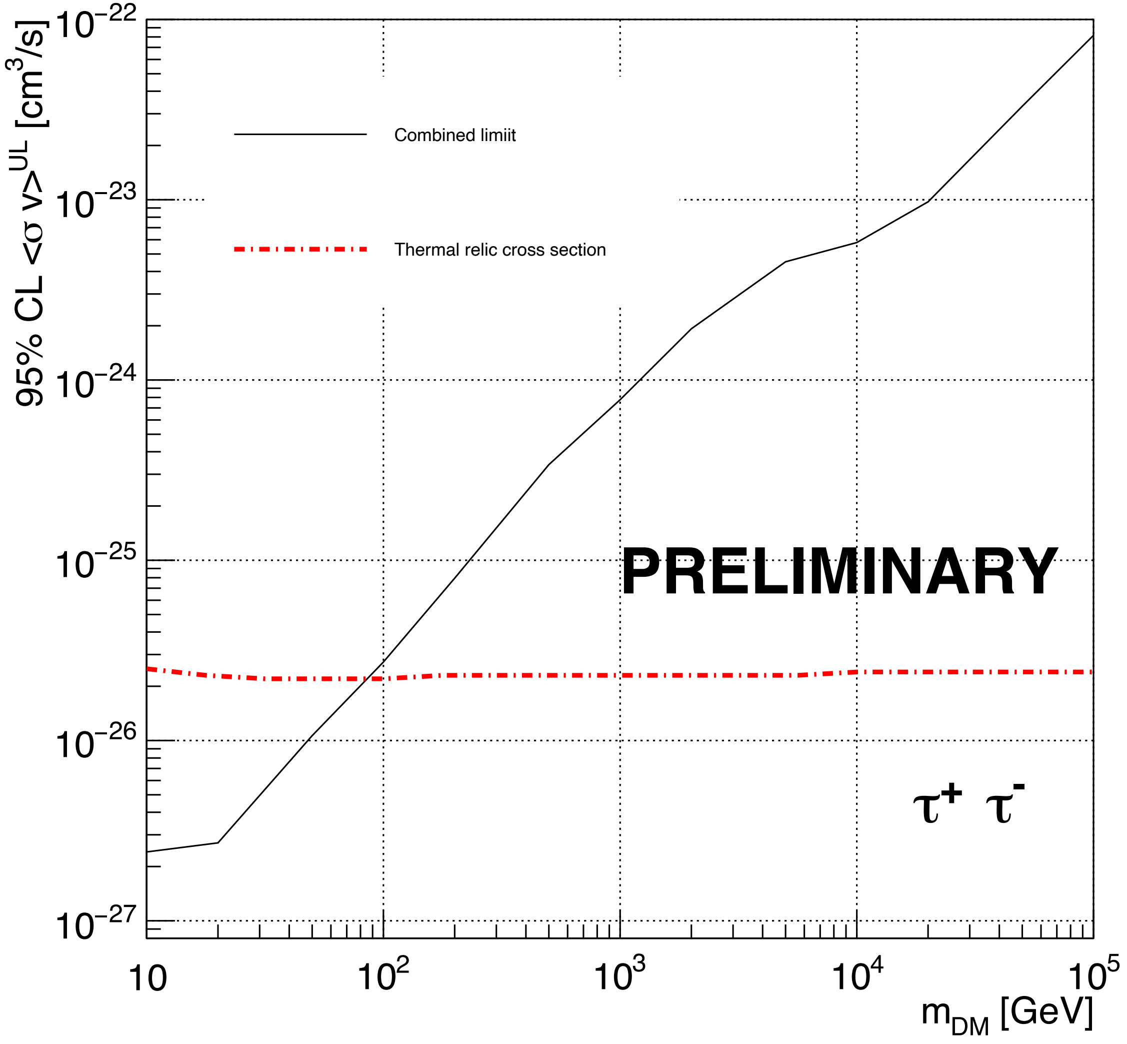
Dwarf spheroidal galaxies

Source name	Experiments
Boötes I	VERITAS (14h), HAWC, *Fermi*-LAT
Canes Venatici I	HAWC, *Fermi*-LAT
Canes Venatici II	*Fermi*-LAT
Carina	H.E.S.S. (23h), *Fermi*-LAT
Coma Berenices	H.E.S.S. (11h), HAWC, *Fermi*-LAT
Draco	HAWC, *Fermi*-LAT
Fornax	H.E.S.S. (6h), *Fermi*-LAT
Hercules	HAWC, *Fermi*-LAT
Leo I	HAWC, *Fermi*-LAT
Leo II	HAWC, *Fermi*-LAT
Leo IV	HAWC, *Fermi*-LAT
Leo T	*Fermi*-LAT
Leo V	*Fermi*-LAT
Sculptor	H.E.S.S. (12h), *Fermi*-LAT
Segue I	MAGIC (158h), VERITAS (92h), HAWC, *Fermi*-LAT
Segue II	*Fermi*-LAT
Sextans	HAWC, *Fermi*-LAT
Ursa Major I	HAWC, *Fermi*-LAT
Ursa Major II	MAGIC (95h), HAWC, *Fermi*-LAT
Ursa Minor	*Fermi*-LAT

Results





Presented at the ICRC 2019 https://arxiv.org/abs/1909.06310

Outlook

Next steps:

- Combination for more annihilation channels
- Compute the 68% and 95% confidence intervals of the limits using MC simulations
- Use a different set of J-Factors

Future prospects:

- Extension of the considered data sets by adding
  - new dwarf observations
  - other targets such as galaxy clusters
  - multi-messenger observations such as neutrino experiments

Goals:

- Publication under preparation (in final stage) to produce legacy results from the current generation of Gamma-Ray observatories for the search for annihilating DM in dwarf galaxies