Combined search in dwarf spheroidal galaxies for branon dark matter annihilation signatures with the MAGIC Telescopes

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Grupo de Altas Energías - UCM

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- Brane World Theory

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- Constraints from the observations of Segue 1 with MAGIC
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Introduction

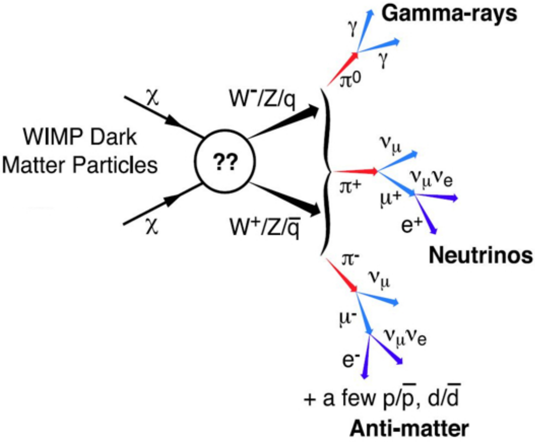
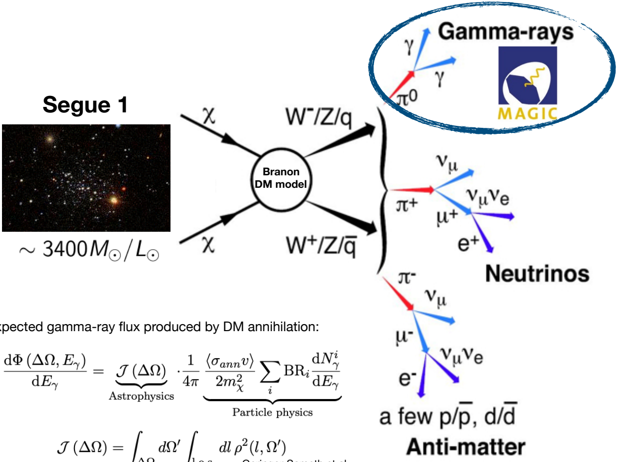


Figure: Dark matter (DM) self-annihilation.

Introduction



Expected gamma-ray flux produced by DM annihilation:

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

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

Geringer-Sameth et al.

Figure: Dark matter (DM) self-annihilation.

MAGIC telescopes & dwarf observations

- Imaging atmospheric Cherenkov telescopes located at the Roque de los Muchachos Observatory on La Palma at about 2200m above sea level
- Two telescopes with 17m diameter reflecting surfaces placed at a distance of 85m
- Sensitive to VHE gamma-rays [$\sim$ 50 GeV, $\sim$ 50 TeV]
- MAGIC recently published in [arXiv:2111.15009] a combined DM search in the dwarf spheroidal galaxies Segue 1 (158 h), Ursa Major II (95 h), Draco (52 h), and Coma Berenices (49 h) with a total exposure of 354 h.

Dark matter particle zoo

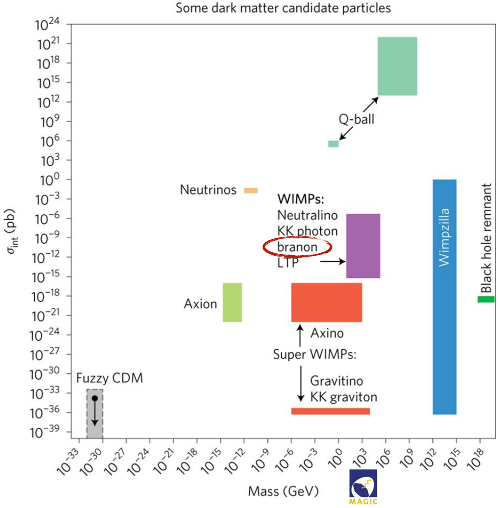


Figure: Summary of the DM particle zoo candidates.

Brane World Theory

- DM cannot be exclusively made of any of the known particles of the Standard Model (SM).
- Our work focuses on Brane World Theory as a prospective framework for DM candidates.
- Branons are new degrees of freedom that appear in flexible brane-world models corresponding to brane fluctuations.

Brane World Theory

- Branons behave as Weakly Interacting Massive Particles (WIMPs), that are one of the most favored candidates for DM.
- The branching ratios as a function of the DM mass m_χ are computed with the leading term in the thermally averaged cross section of annihilation into the Dirac fermions ψ, massive gauge fields (W or Z) and (complex) scalar field Φ by

$$\langle \sigma_\psi v \rangle = \frac{m_\chi^2 m_\psi^2}{16\pi^2 f^8} \left(m_\chi^2 - m_\psi^2 \right) \sqrt{1 - \frac{m_\psi^2}{m_\chi^2}},$$

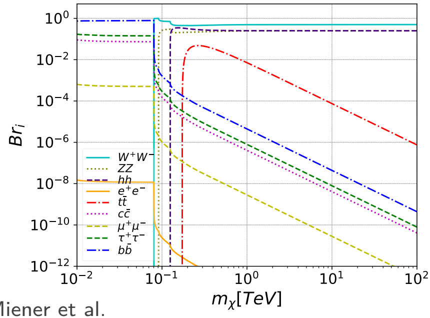
$$\langle \sigma_{W,Z} v \rangle = \frac{m_\chi^2}{64\pi^2 f^8} \left(4m_\chi^4 - 4m_\chi^2 m_{W,Z}^2 + 3m_{W,Z}^4 \right) \sqrt{1 - \frac{m_{W,Z}^2}{m_\chi^2}}$$

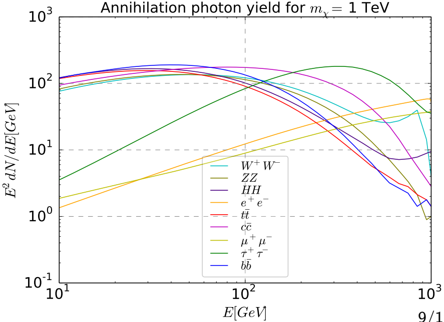
$$\langle \sigma_\Phi v \rangle = \frac{m_\chi^2}{32\pi^2 f^8} \left(2m_\chi^2 + m_\Phi^2 \right)^2 \sqrt{1 - \frac{m_\Phi^2}{m_\chi^2}}$$

Branon dark matter

$$\mathrm{BR}_i\left(m_\chi\right) = \frac{\langle\sigma_i v\rangle}{\langle\sigma v\rangle}, \text{ with } \langle\sigma v\rangle = \sum_j \langle\sigma_j v\rangle.$$

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





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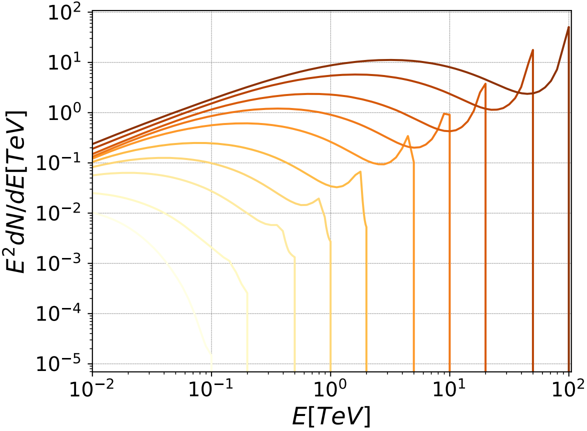
Branon annihilation photon yields



We are using the following ingredients in our analysis:

- The J-Factor and statistical uncertainty are taken from A. Geringer-Sameth et al., Astrophys.J. 801, no.2, 74, 2015
- DM spectra and DM mass spacing are taken from M. Cirelli et al, JCAP 1103:051, 2011
- Analysis technique:
  - Binned likelihood [arXiv:1712.03095]
  - Take spatial extension of the dwarfs into account
  - Use $\langle \sigma v \rangle > 0$ prescription
  - J-factor as nuisance parameter

Name	Distance (kpc)	*l*, *b* ($^\circ$)	$\log_{10} J$ ($\mathcal{GS}$set) $\log_{10}(\mathrm{GeV}^2\mathrm{cm}^{-5}\mathrm{sr})$	obs. time (*hours*)
Coma Berenices	44	241.89, 83.61	$19.02^{+0.37}_{-0.41}$	49
Draco	76	86.37, 34.72	$19.05^{+0.22}_{-0.21}$	52
Segue I	23	220.48, 50.43	$19.36^{+0.32}_{-0.35}$	158
Ursa Major II	32	152.46, 37.44	$19.42^{+0.44}_{-0.42}$	95

Analysis tools

- Detailed description in *Open-source Analysis Tools for Multi-instrument Dark Matter Searches* [arXiv:2112.01818]
- gLike (10.5281/zenodo.4597500) is a code framework for the numerical maximization of joint likelihood functions.
- gLike can estimate the DM annihilation cross-section combining observations of DM targets by different ground-based gamma-ray telescopes, satellite gamma-ray detectors, neutrino telescopes, ...
- LikelihoodCombiner (10.5281/zenodo.4597500) is a python-based tool combining likelihoods from different instruments to produce combined exclusion limits on the DM annihilation cross-section.
- Open source on GitHub: https://github.com/javierrico/gLike & https://github.com/TjarkMiener/likelihood_combiner

Results - Limits to branon dark matter (Segue 1)

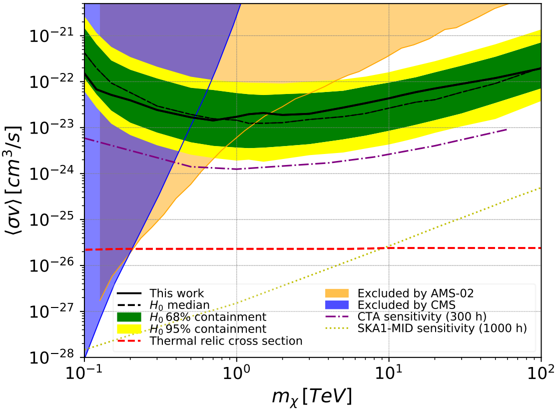


Figure: Limits to branon dark matter annihilation cross-section from MAGIC observations of Segue 1 [JCAP05(2022)005]

Results - Constraints to the branon tension f (Segue 1)

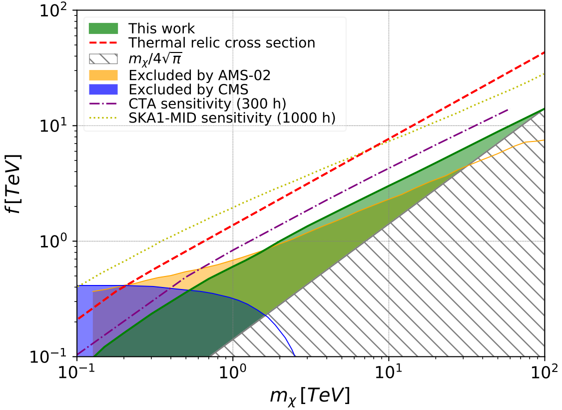


Figure: Translation the limits to branon tension space [JCAP05(2022)005]

Results - Branon DM limits from multi-dwarf observations

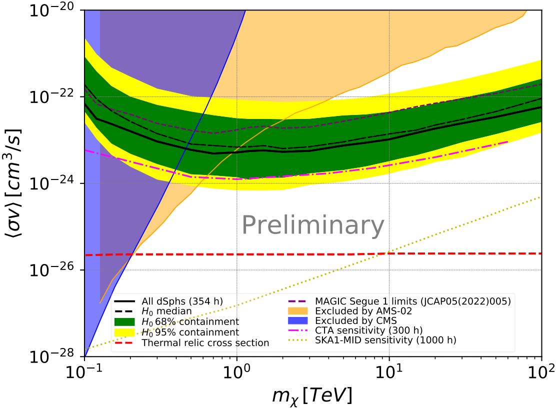


Figure: Limits to branon dark matter annihilation cross-section from multi-dwarf observations with the MAGIC Telescopes.

Results - Constraints to the branon tension f from multi-dwarf observations

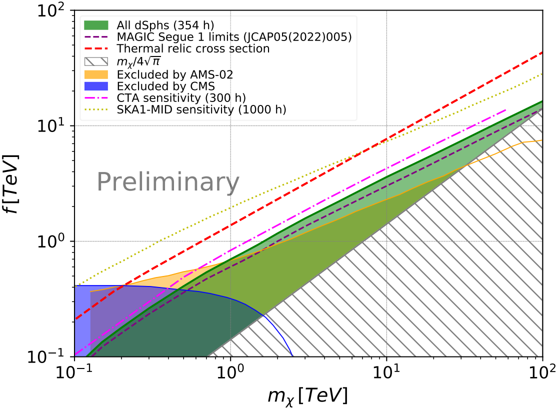
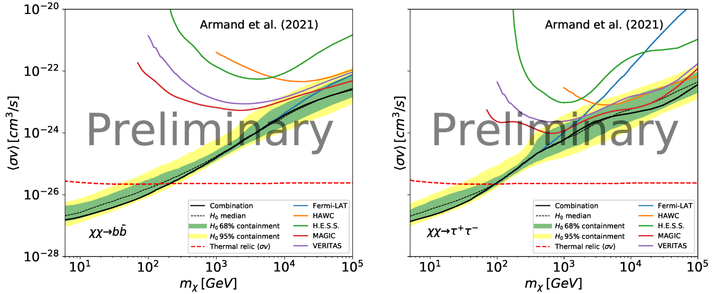


Figure: Translation the limits to branon tension space.

Future global branon DM search in the gamma-ray band

- Future global branon analysis inspired by *Combined dark matter searches towards dwarf spheroidal galaxies with Fermi-LAT, HAWC, H.E.S.S., MAGIC, and VERITAS* [arXiv:2201.03344]
- With the established multi-instrument analysis framework, we can set global constraints to branon DM search in the gamma-ray band and also with a multi-messenger effort in the future.



Summary

- We analyzed the high-level data sets of the MAGIC dSphs to set the tightest constraints in the multi-TeV DM mass regime.
- Efforts to expand the branon DM search with the datasets of the major gamma-ray telescopes are planned for the future. We also want to include other DM models like the heavy WIMP candidates Wino and Higgsino and secluded DM with Dark Photons.

Gracias por su atención!

Back up

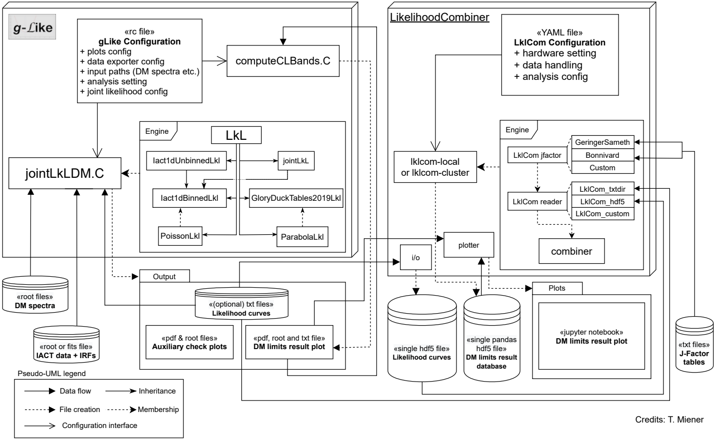
Lagrangian for branon DM

The lowest-order effective Lagrangian for branon DM reads

$$L_{\rm BDM} = \frac{1}{2} g^{\mu\nu}\partial_\mu\pi^\alpha\partial_\nu\pi^\alpha - \frac{1}{2} m_\chi^2 \pi^\alpha\pi^\alpha + \frac{1}{8f^4}\left(4\partial_\mu\pi^\alpha\partial_\nu\pi^\alpha - m_\chi^2\pi^\alpha\pi^\alpha g_{\mu\nu}\right) T^{\mu\nu}_{\rm SM},$$

where π denotes the branon field and α runs over the number of extra dimensions N, f and m_χ are the tension of the brane and the mass of the branon respectively, and $T^{\mu\nu}_{\rm SM}$ is the energy-momentum tensor of the SM fields.

Pseudo-UML workflow of gLike & LklCom



Credits: T. Miener