Constraining branon dark matter with MAGIC

from observations of the Segue 1 dwarf spheroidal galaxy

Tjark Miener (tmiener@ucm.es), Daniel Nieto, Viviana Gammaldi, Daniel Kerszberg, Javier Rico

17th MultiDark Consolider Workshop (27/01/2021)

Outline

Constraining branon dark matter
- Introduction
- Branon dark matter
- gLike tool
- Results

Introduction

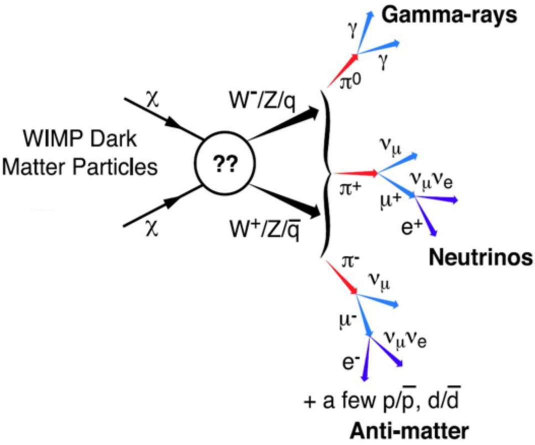
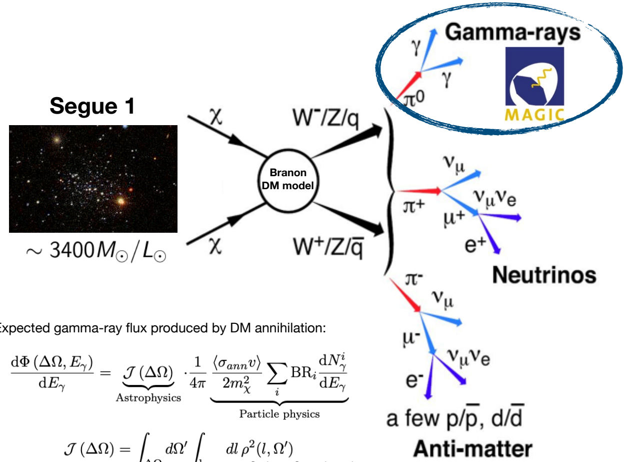


Figure: Dark matter (DM) self-annihilation.

Introduction



Expected gamma-ray flux produced by DM annihilation:

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

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

Geringer-Sameth et al.

Figure: Dark matter (DM) self-annihilation.

MAGIC telescope & Segue 1 observations

- Imaging atmospheric Cherenkov telescope located at the Roque de los Muchachos Observatory on La Palma at about 2200m above sea level
- Two telescopes with 17m diameter mirror dishes placed at a distance of 85m
- Sensitive to VHE gamma-rays (between ~ 50 GeV and ~ 50 TeV) arXiv1601.06590
- Segue 1 data set is almost 160 hours of good-quality data and was taken under four different experimental conditions

Dark matter particle zoo

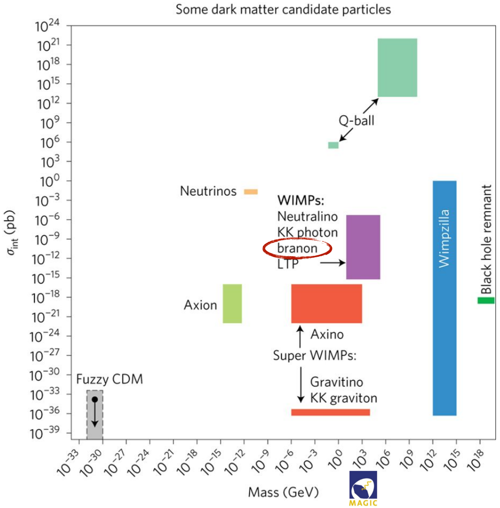


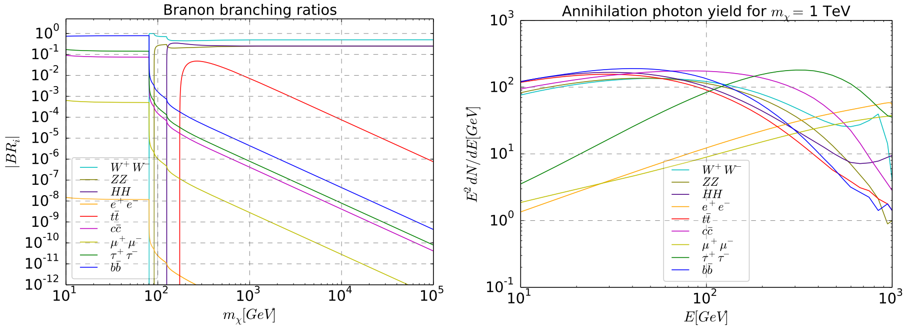
Figure: Summary of the DM particle zoo candidates. arXiv1705.11165

Brane World Theory

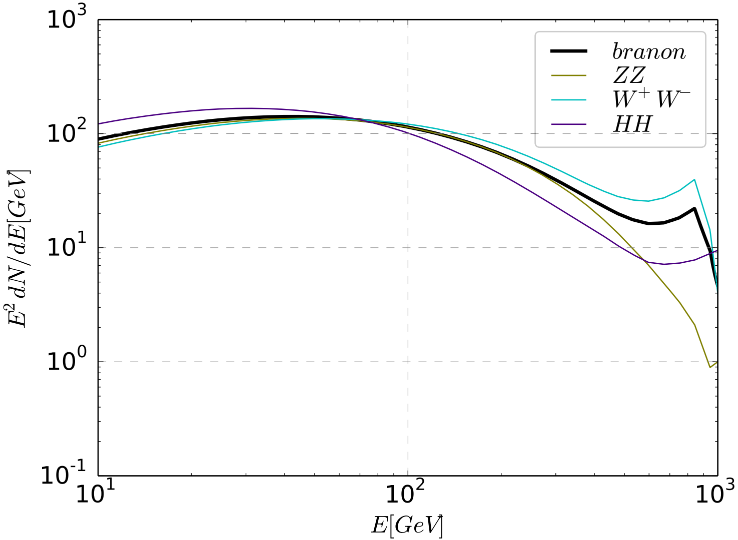
- Dark matter cannot be made of any of the known particles of the Standard Model (SM).
- Our work focuses on Brane World Theory as a prospective framework for DM candidates.
- Branons are new degrees of freedom that appear in flexible brane-world models corresponding to brane fluctuations.
- Branons behave as Weakly Interacting Massive Particles (WIMPs), that are one of the most favored candidates for DM.

Branon dark matter

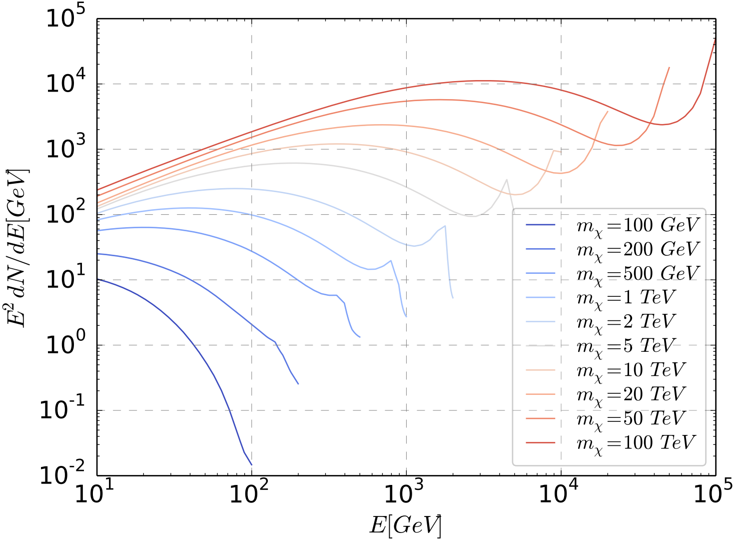
$$\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = \underbrace{\mathcal{J}(\Delta\Omega)}_{\text{Astrophysics}} \cdot \frac{1}{4\pi} \underbrace{\frac{\langle \sigma_{ann} v \rangle}{2m_\chi^2} \sum_i \text{BR}_i \frac{dN_\gamma^i}{dE_\gamma}}_{\text{Particle physics}}$$



Annihilation photon yield for $m_\chi = 1$ TeV



Branon annihilation photon yields



Profile likelihood

- We are interested in the parameter $g = (g_1, \ldots, g_k)$. (For DM searches g is $\langle \sigma v \rangle$)
- The model describing our data depends on g and additional nuisance parameters $h = (h_1, \ldots, h_l)$.
- The full likelihood function is given by

$$\mathcal{L}\left(g; h|X\right) = \prod_{i=1}^{n} \mathrm{f}\left(X_i|g; h\right),$$

where $X = (X_1, \ldots, X_n)$ are n independent observations and $\mathrm{f}\left(X|g; h\right)$ is the probability density function PDF.

gLike

- gLike is a code framework for the numerical maximization of joint likelihood functions.
- gLike can estimate the dark matter annihilation cross-section combining observations of dark matter targets by different ground-based gamma-ray telescopes, satellite gamma-ray detectors, neutrino telescopes, ...
- Open source on GitHub: https://github.com/javierrico/gLike

Observational 95% CL upper limits to branon dark matter

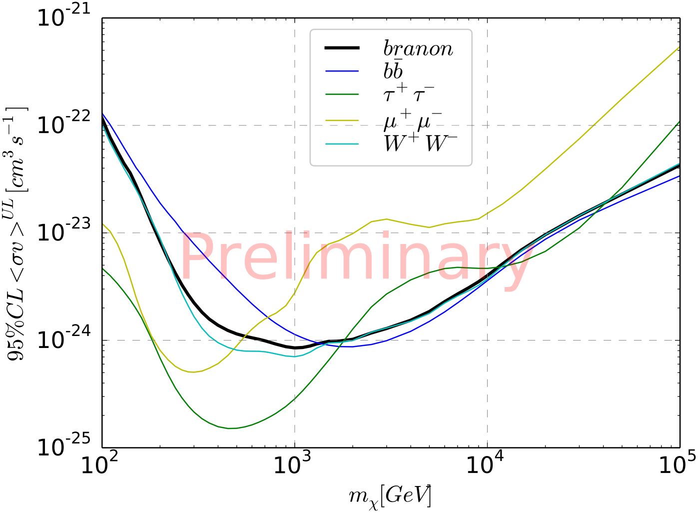


Figure: 95% CL upper limits to branon dark matter annihilation cross-section from MAGIC observations of Segue 1.

Summary & Outlook

- We analyzed the MAGIC Segue 1 high-level data set, which is the deepest IACT observational campaign on any dwarf galaxy.
- We performed a full joint likelihood analysis from four different instrument conditions.
- We modified the gLike code to include the branon dark matter model in our analysis.
- We would like to combine more observations from other dark matter targets from different instruments to improve our branon limits.

Gracias por su atención!

Back up

Segue1 observational campaign with MAGIC

	Sample A	Sample B1	Sample B2	Sample C
Readout	DRS2	DRS4	DRS4	DRS4
MAGIC-I camera	old	old	old	new
Obs. period	Jan–May 2011	Jan–Feb 2012	Mar–May 2012	Nov 2012–Feb 2013
Obs. time [h]	64	24.28	59.77	55.05
Zd range [deg]	13–33.7	13–32.5	13–35.7	13–37
Az range [deg]	104.8–250.2	120.2–252.0	115.4–257.2	103.8–259.4
Wobble around	dummy	dummy	dummy	Segue 1
Wobble offset [deg]	0.29	0.29	0.29	0.40
W1 t_{eff} [h]	22.66	6.07	25.02	23.71
W2 t_{eff} [h]	24.35	6.20	26.11	23.80
t_{eff} [h]	47.00	12.26	51.13	47.51
Total t_{eff} [h]				**157.9**

Table 1: Basic details of the Segue 1 observational campaign with MAGIC. Refer to the main text for additional explanations.

Figure: arXiv1312.1535

Joint likelihood

- Combining likelihood functions for different targets:

$$\mathcal{L}\left(\langle\sigma v\rangle;\nu|X\right)=\prod_{i=1}^{N_{target}}\mathcal{L}_i\left(\langle\sigma v\rangle;J_i,\mu_i|X_i\right)\cdot\mathcal{J}\left(J_i|J_{obs,i},\sigma_i\right)$$

- Combining likelihood functions (of a particular target) for different experiments:

$$\mathcal{L}_i\left(\langle\sigma v\rangle;J_i,\mu_i|X_i\right)=\prod_{j=1}^{N_{instrument}}\mathcal{L}_{ij}\left(\langle\sigma v\rangle;J_i,\mu_{ij}|X_{ij}\right)$$