CTA sensitivity to branon dark matter models

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cherenkov telescope array

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ABSTRACT

In the absence of a clear hint of dark matter (DM) signals in the GeV regime so far, TeV DM candidates are gradually earning more attention within the community. Among others, extra-dimensional *brane-world* models may produce thermal DM candidates with masses up to 100 TeV, which could be detected with the next generation of very-high-energy gamma-ray observatories such as the Cherenkov Telescope Array (CTA). In this work, we study the sensitivity of CTA to branon DM via the observation of representative astrophysical DM targets, namely dwarf spheroidal galaxies. In particular, we focus on Draco and Sculptor, two well-known dwarfs visible from the Northern and Southern Hemisphere, respectively. For each of these targets, we simulated 300 h of CTA observations and studied the sensitivity of both CTA-North and CTA-South to branon annihilations using the latest publicly available instrument response functions and most recent analysis tools. We computed annihilation cross section values needed to reach a 5σ detection as a function of the branon mass. Additionally, in the absence of a predicted DM signal, we obtained 2σ upper limits on the annihilation cross section. These limits lie 1.5-2 orders of magnitude above the thermal relic cross section value, depending on the considered branon mass. Yet, CTA will allow to exclude a significant portion of the brane tension-mass parameter space in the 0.1-60 TeV branon mass range, and up to tensions of ~10 TeV. More importantly, CTA will significantly enlarge the region already excluded by AMS and CMS, and will provide valuable complementary information to future SKA radio observations. We conclude that CTA will possess potential to constrain brane-world models and, more in general, TeV DM candidates.

Branons

A particular class of WIMPs are branons [1], i.e. DM candidates that annihilate in several SM channels at once, depending on their mass. More specifically, they are WIMPs that annihilate into e.g. a pair of quarks, of leptons, of gauge bosons, or even of photons, but the ratio for the latter to occur is extremely low. The branching ratio of annihilation into each channel depends on two parameters, the mass of the particle and the tension of the brane. If branons were thermal relics, the tension would be a function of the branon mass, and we are thus left with only one free parameter; see Fig. 1.

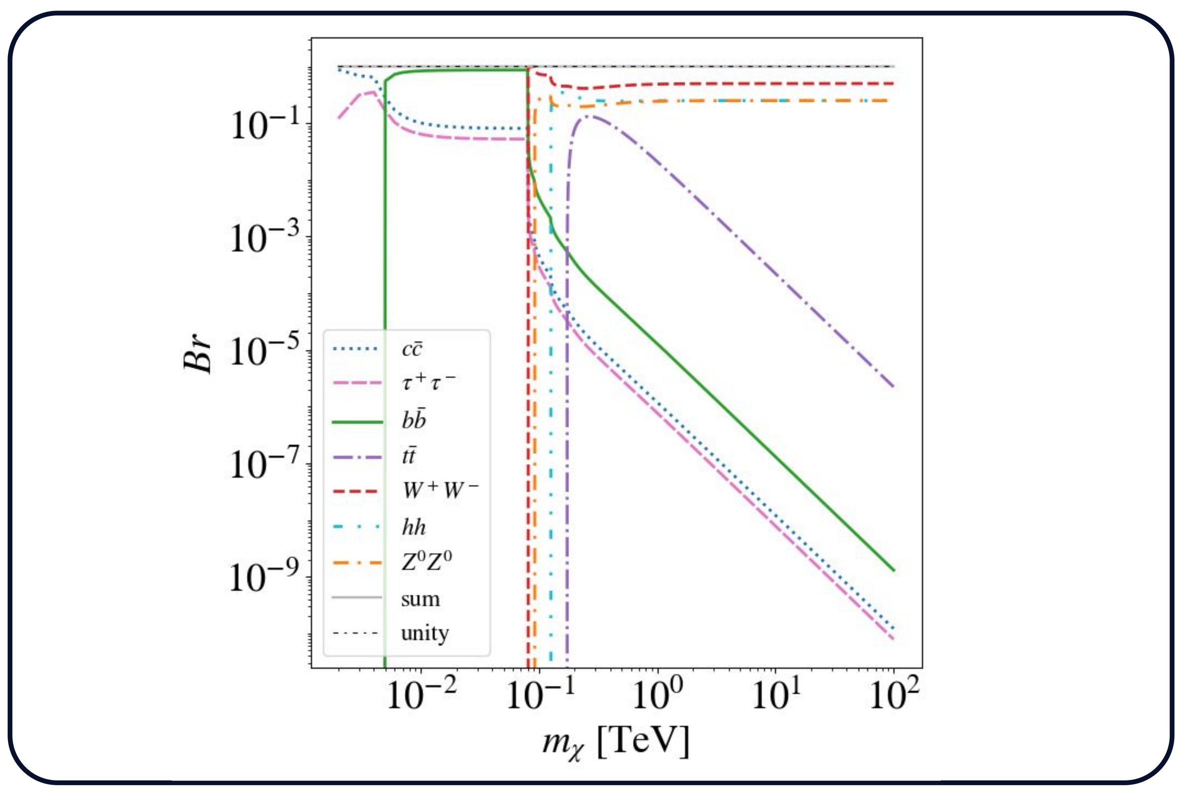

Fig. 1: Branching ratios of branons

The differential annihilation flux yielded by branons will be

$$\frac{dN}{dE} = \int_{l.o.s.} \rho_A^2(r)\, dr \frac{\langle\sigma v\rangle_{\chi\chi}}{2\pi m_\chi^2} \sum B_r^i \frac{dN_i}{dE}\ [\mathrm{ph\ cm^{-2}\ s^{-1}}] \qquad (1)$$

Here, $\langle\sigma v\rangle_{\chi\chi}$ is the averaged annihilation cross section of the DM particle times the velocity, m_χ is the branon mass, ρ_A the DM density profile, B_r^i are the branching ratios of Fig. 1 and $l.o.s.$ is the line of sight. In Fig. 2, the annihilation spectra for different branon masses are shown. The photon yield is shown on the left panel and the annihilation flux on the right panel.

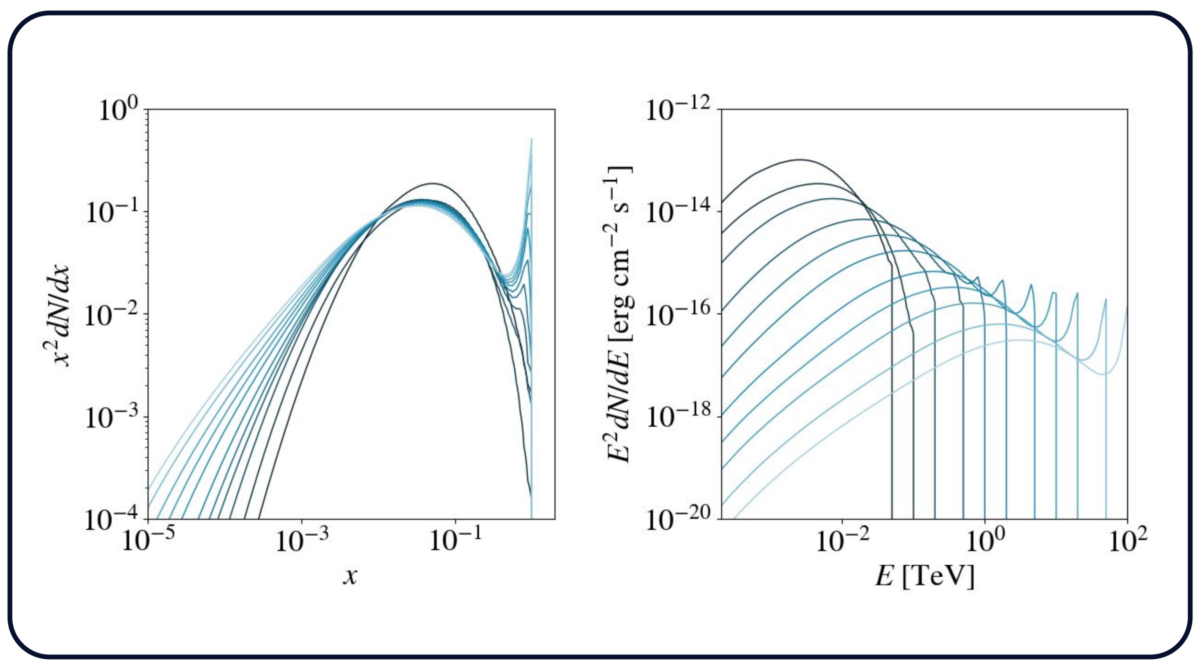

Fig. 2: Branon annihilation spectra

Cherenkov Telescope Array (CTA)

CTA [3] is an international project whose main goal is to build a new generation of ground-based gamma-ray telescopes. The energy range will cover from dozens of GeV up to 300 TeV. CTA will actually consist of two arrays. One of them will be located in the Northern Hemisphere, namely La Palma (Canary Islands, Spain), and the Southern array will be situated in the Atacama desert (Chile).

Analysis pipeline

We have used the `ctools` software package [4] to simulate the CTA gamma-ray observations and make analyses. `ctools` operates with reconstructed event lists, supressing most of the background based on Cherenkov showers properties. We also have made use of the public CTA instrument response functions (IRFs).

- First, in our simulations we generate source events assuming a DM annihilation spectrum for the source.

- After that, a maximum likelihood analysis is applied to those data to look for a DM signal.

- In the absence of a signal, we compute 2σ upper limits to the annihilation cross section. We also compute the annihilation cross section values that are needed for detection.

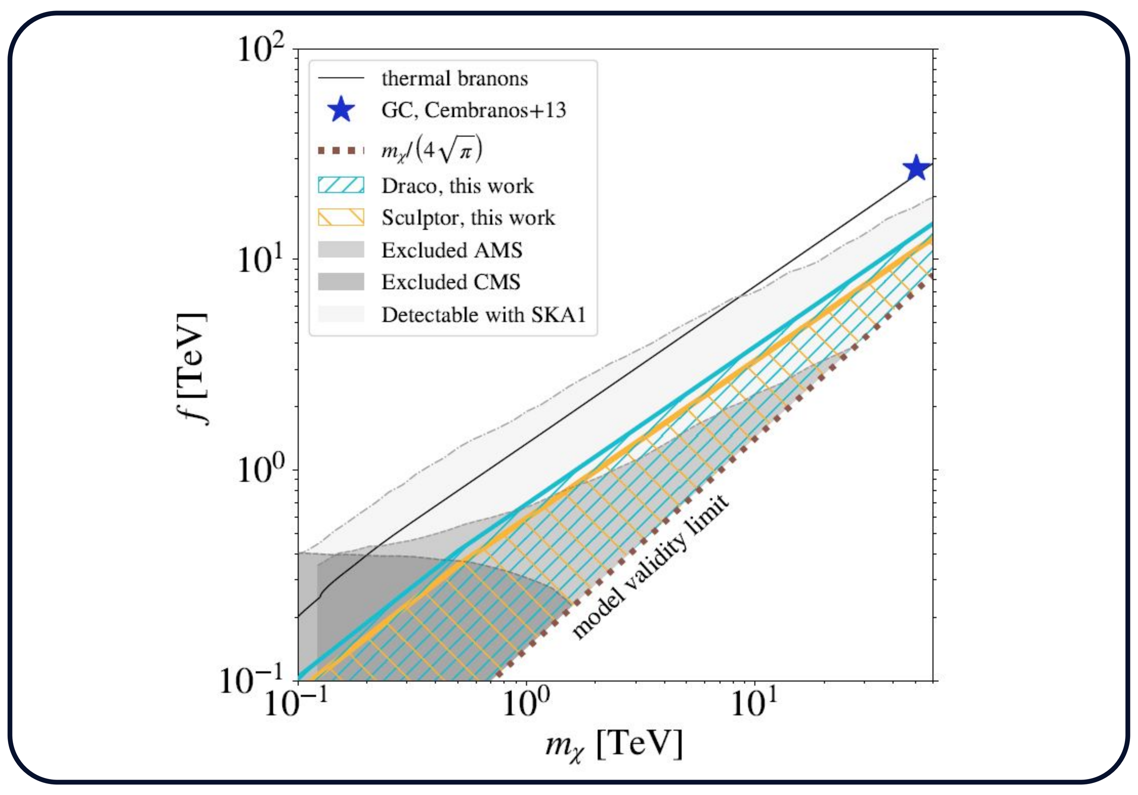

Fig. 4: Branon tension - branon mass parameter space and constraints

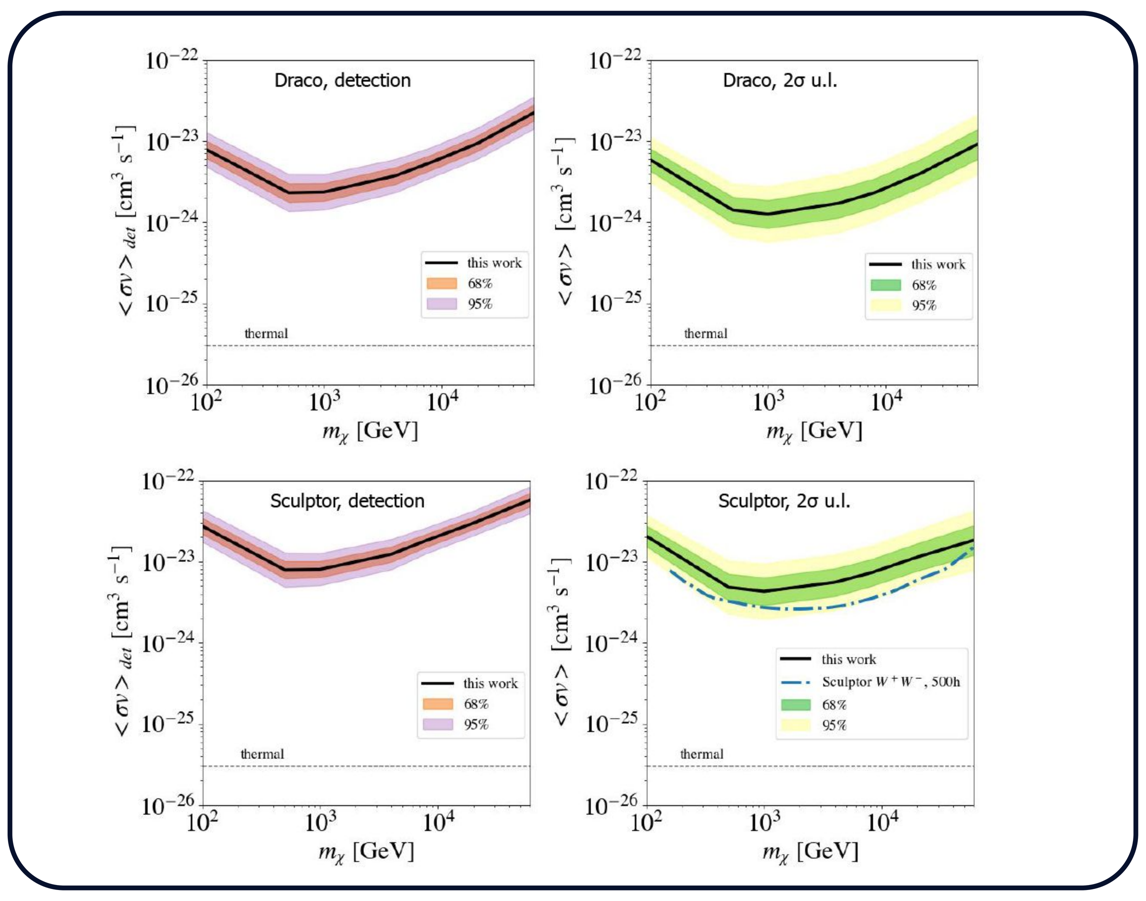

Fig. 3: detection and upper limit values of the cross section

Results

We have performed several realizations with 50 hours of observation time, using the full CTA energy range and reaching both TS~25 for detection and TS~2.71 for 95% confidence level upper limits. In the latter case, as seen in Fig. 3, our limits are around 1.5 orders of magnitude above the estimates of the thermal relic cross-section. We are assuming a NFW profile for the selected dwarfs, Draco and Sculptor, and the J-factors listed in Table 1 of our paper.

We have also set constraints in the mass-tension parameter space, our results expanding the excluded region for TeV masses with respect to the limits from current experiments such as AMS and CMS, as shown in Fig. 4.

Conclusions and future

In this work, we have studied the branon detection prospects for the future CTA. We chose two dSphs as DM targets, Draco and Sculptor. In the absence of a detection signal, we have computed expected 2σ exclusion limits for branon DM. Finally, we have set a large exclusion region in the tension-mass parameter space, enlarging the current one.

References

[1] J. A. R. Cembranos, A. Dobado, and A. L. Maroto. *Brane world dark matter.* Phys. Rev. Lett., 90:241301, 2003.
[2] J. A. R. Cembranos, A. Dobado, and A. L. Maroto. *Cosmological and astrophysical limits on brane fluctuations.* Phys. Rev., D68:103505, 2003.
[3] CTA Consortium. *Science with the Cherenkov Telescope Array.* 2019.
[4] J. Knödlseder, M. Mayer, C. Deil et al. *GammaLib and ctools. A software framework for the analysis of astronomical gamma-ray data.* 593:A1, Aug 2016.

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