Sensitivity of the Cherenkov Telescope Array to dark subhalos

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cherenkov telescope array

ABSTRACT

We study the potential of the Cherenkov Telescope Array (CTA) for the detection of Galactic dark matter (DM) subhalos. We focus on low-mass subhalos that do not host any baryonic content and therefore lack any multiwavelength counterpart. If the DM is made of weakly interacting massive particles (WIMPs), these dark subhalos may thus appear in the gamma-ray sky as unidentified sources. A detailed characterization of the instrumental response of CTA to dark subhalos is performed, for which we use the ctools analysis software and simulate CTA observations under different array configurations and pointing strategies, such as the scheduled extragalactic survey. In the absence of detection, for each observation strategy we set competitive limits to the annihilation cross section as a function of the DM particle mass, that are at the level of $\langle\sigma v\rangle \sim 7 \cdot 10^{-25}$ cm^{3}s^{-1} for the $\tau^+\tau^-$ annihilation channel in the best-case scenario. The latter is reached with no dedicated observations, but just accumulating exposure time from all scheduled CTA programs and pointings over the first 10 years of operation. This way CTA will offer the most constraining limits from subhalo searches in the intermediate range between ~1-3 TeV, complementing previous results with Fermi-LAT and HAWC at lower and higher energies, respectively

Introduction

Dark subhalos annihilating into gamma rays may appear in the sky as unidentified sources (unIDs), with no association or multiwavelength counterparts. CTA [1], the future of the ground-based gamma-ray astronomy, will have several programs in which dark subhalos may be observed. Namely, we distinguish three scenarios:

- **Extragalactic Survey (EGAL): A Key Science Project (KSP) aiming to observe a 25% of the extragalactic sky with 3h individual pointings (total 1000h).**
- **Deep-field exposure (DEEP): Observation of a small (~100 deg^2), clean patch of the sky with long exposure (~100h).**
- **Overall Exposure (EXPO): Accumulating exposure from several observations, a dark subhalo may be serendipitously detected in the field of view.**

Dark subhalo detectability

To compute the sensitivity of CTA to dark subhalos, we simulate the instrumental response varying the WIMP mass and annihilation channel, as well as the search strategy. This can be computed with *ctools* by repeating the simulation 100 times to ensure proper statistics, and is codified in the minimum flux to reach a 5σ detection.

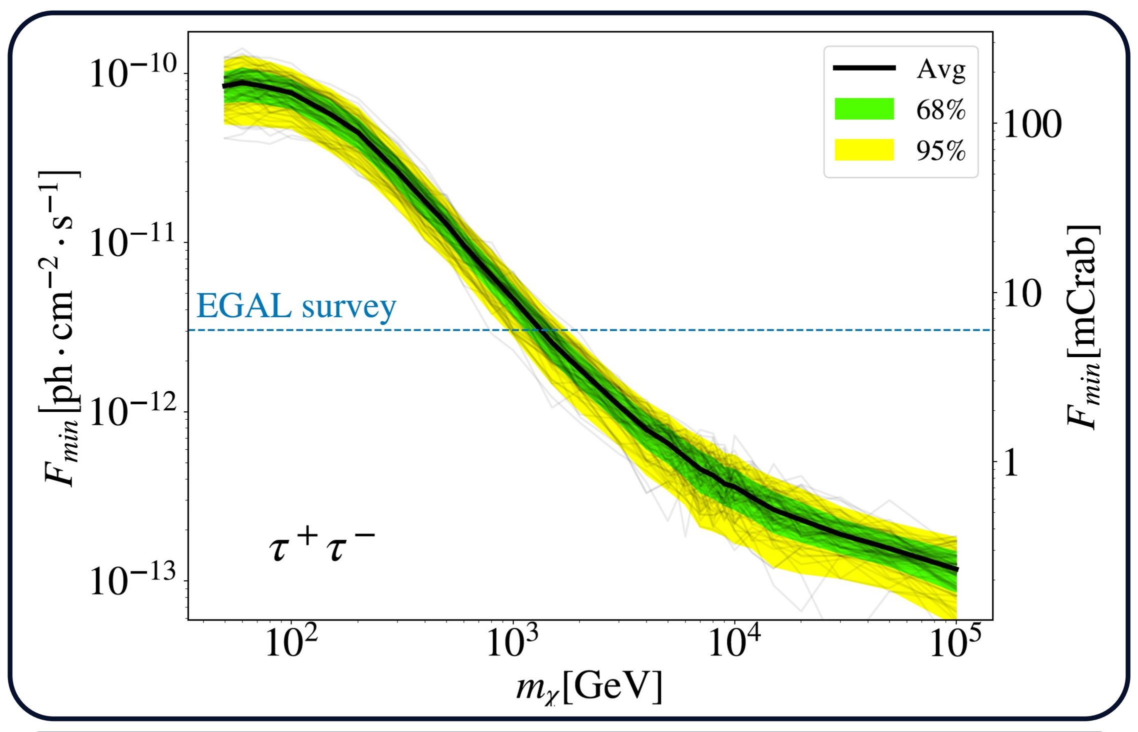

Fig. 1: Sensitivity of CTA to dark subhalos, for the $\tau^+\tau^-$ annihilation channel. Figure shows the minimum integrated flux to have a 5σ detection in. Horizontal line marks the EGAL sensitivity

Characterizing the sky fraction observed by CTA in 10 years of operation

To estimate the sensitivity of the EXPO scenario, it is necessary to compute the expected sky fraction observed by CTA and the exposure time distribution. To do so, we extrapolate the observations of the MAGIC IACT [2] (located where CTA-North) in 6.5 years to 10 years of CTA operations with both arrays. This results in ~45% of the sky observed with a median ~40h pointing.

This extrapolation takes into account the overlaps between pointings, and to simulate the double array layout the declination of half of the pointings is inverted, as CTA-South (Atacama desert) latitude is practically the opposite of CTA-North (Canary Islands). The result is shown in Fig. 2 as a skymap and time distribution.

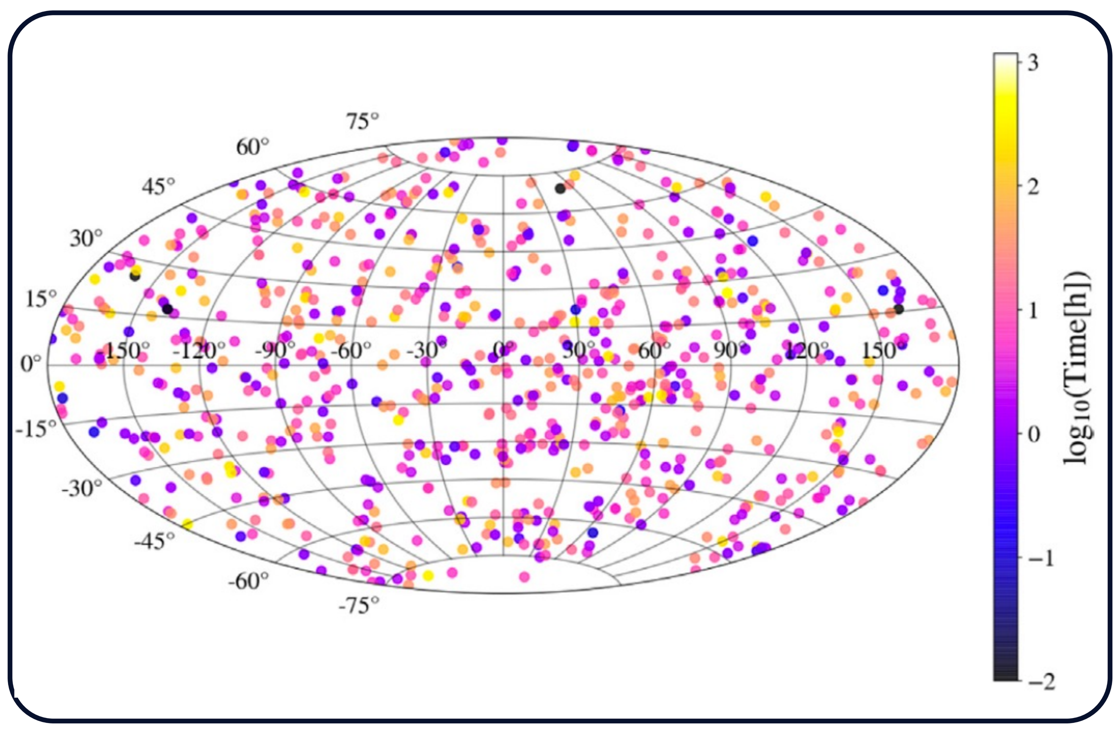

Fig. 2: Results of the extrapolation for the EXPO scenario, shown as a skymap of the 10-year individual pointings with a color time distribution

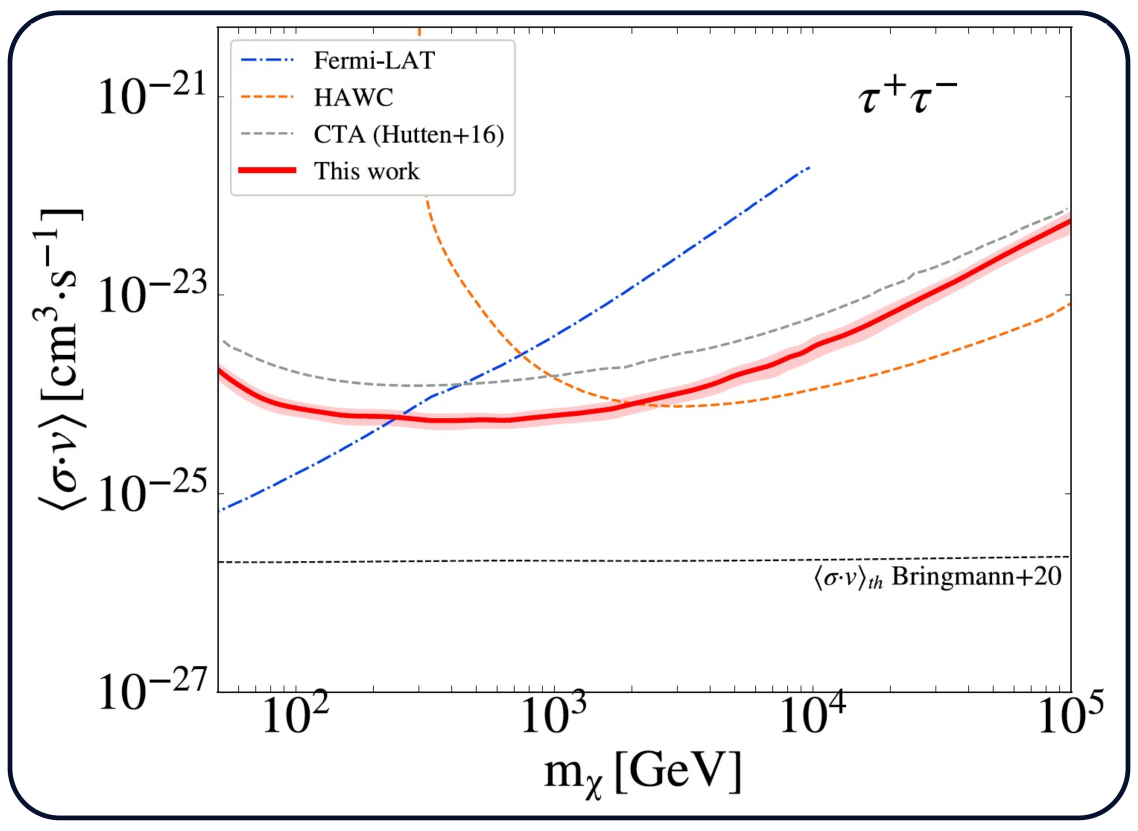

Fig. 3: 95% C.L. constraints for the $\tau^+\tau^-$ annihilation channel in the EXPO scenario. Different lines are the dark subhalo constraints obtained with Fermi-LAT [4] and HAWC [5]

Upper limits to the cross section

Assuming no unID is detected or compatible with a DM origin, upper limits to the cross section can be placed. These constraints are derived at 95% C.L. with [3],

$$\langle\sigma v\rangle_{95\%} = \frac{8\pi\, m_\chi^2\, F_{min}}{J_{95}\, N_\gamma}$$

Where J_{95} is the 95% C.L. J-factor, as derived from the N-body simulations, and N_γ is the integrated DM annihilation spectrum. The best results, shown in Fig. 3, are for the EXPO scenario, and are complementary to other probes and instruments.

CTA, with its angular and energy resolution, combined with the high sensitivity in the TeV range, proves to be a superb instrument for dark subhalo detection, via WIMP co-annihilation in gamma rays. A detailed characterization of the sensitivity is necessary to predict the expected number of subhalos detectable. If no DM-compatible unID is detected, stringent constraints to the mass/cross section parameter space can be placed, which complement previous works.

ACKNOWLEDGEMENTS

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www.cta-observatory.org/consortium_acknowledgments

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