Prospects for dark matter searches with CTA

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Dark matter particle annihilations are expected to occur in dense regions of the universe. Among the final annihilation products are very high energy gamma rays. The future array of Imaging Atmospheric Cherenkov Telescopes (IACTs), *i.e.* the Cherenkov Telescope Array (CTA), is a well-suited instrument to look further for particle dark matter annihilations in the 10 GeV - 100 TeV range. Here, I present CTA prospective studies for targeted and wide-field survey searches.

1 Dark matter annihilations searches with IACTs

In the context of gamma-ray astronomy, the gamma-ray flux from self-annihilations of dark matter (DM) particles of mass m towards a given astronomical target can be written as:

$$\frac{\mathrm{d}\Phi_\gamma(\Delta\Omega, E_\gamma)}{\mathrm{d}E_\gamma} = \frac{1}{8\pi} \underbrace{\frac{\langle\sigma v\rangle}{m^2} \sum_i BR_i \frac{\mathrm{d}N^i_\gamma}{\mathrm{d}E_\gamma}}_{Particle\ Physics} \times \underbrace{\int_{\Delta\Omega}\int_{LOS} \rho(r[s])^2 ds\, d\Omega}_{Astrophysics}\,, \tag{1}$$

where $\langle\sigma v\rangle$ is the velocity-weighted annihilation cross section of the DM particle and $\mathrm{d}N_\gamma/\mathrm{d}E_\gamma = \sum_i BR_i \mathrm{d}N^i_\gamma/\mathrm{d}E_\gamma$ is the annihilation spectrum summed over all the possible annihilation channels i with branching ratios BR_i. The astrophysical factor corresponds to the integration of the square of the density ρ over the line of sight (LOS) and the solid angle $\Delta\Omega$. In the absence of a clear gamma-ray signal, the DM constraints are expressed in terms of the remaining particle physics parameters $\langle\sigma v\rangle$ and m for given annihilation spectrum and DM halo profile.
The DM searches with very high energy (VHE) gamma rays focus on regions with expectedly high DM density. Among them are the dwarf spheroidal galaxy (DSG) satellites of the Milky Way, and DM subhalos populating the Milky Way halo. Current IACTs, *i.e.* HESS, MAGIC and VERITAS, are actively searching for DM signals towards a variety of astronomical targets. Even though competitive limits are obtained, the present generation does not have the required sensitivity to probe natural value of $\langle\sigma v\rangle$ for thermally-produced DM. The next generation of IACTs, *i.e* the Cherenkov Telescope Array [1], will consist of a large array with improved overall performances over present IACTs: i) The extended energy range from a few tens of GeV to several tens of TeV will allow to connect with the Fermi-LAT instrument at low energies, and for an improved sensitivity for DM masses above 100 GeV. ii) The probability of detection will be evidently increased by the improved sensitivity over the whole energy range. iii) The increased field of view will allow to efficiently search for extended DM emissions. iv) The better energy resolution should make easier the detection of possible spectral features in the DM-induced gamma-ray spectrum.

2 Dwarf spheroidal galaxies

DSGs have concentrated a lot of interest to search for DM with VHE gamma rays: i) Stellar dynamic measurements show that DSGs are among the most DM-dominated systems in the universe. Stellar dynamics also allow to control the astrophysical factor. ii) They show favorably low astrophysical background gamma-ray environments. These galaxies are expected to harbor no strong astrophysical VHE gamma-ray emitters due to the lack of recent star formation history (supernova remnants, pulsar wind nebula,...) and little or no gas acting as target material for cosmic rays. iii) Baryon-DM interaction is not expected to play an important role in the DM distribution. iv) Many of them lie in the 100 kpc from the Sun.
The nearest objects are in principle the best targets. They may however experience tidal effects from the Milky Way. It has been shown recently that one could take advantage of this effect to trace back the evolution history of the object [2]. During the orbital motion of a DSG, multiple crossings of the dwarf galaxy through the galactic disc of the Milky Way give rise to the formation of tidal streams. Their careful study allows to infer its gravitational potential. In the case of the Sagittarius Dwarf galaxy (SgrDw), the tidal streams have been detected with multiple tracer populations and used to derive the DM halo potential. Furthermore, measurements of stars within SgrDw and the luminosity of its core and surrounding debris, allows the estimate of the DM content prior to tidal disruption [3, 4]. Other peculiar features of SgrDw include the presence of the globular cluster M 54 coincident in position with its gravity centre, and hints for the presence of a central Intermediate Mass Black Hole (IMBH) [5]. Figure 1 (left) shows 95% C.L. sensitivity towards SgrDw for a CTA-like instrument for NFW and isothermal (ISO) DM halo profiles[1]. For 200 h observation time, the sensitivity reaches a few 10^{-25} cm^{3}s^{-1} for TeV DM masses [6]. Assuming that the DM velocity dispersion is close to that of stars, the *Sommerfeld* effect can substantially boost the annihilation cross section in DSGs (see, for instance, Ref. [7]), since it is particularly effective in the low velocity regime. The value of the DM velocity dispersion in SgrDw is fixed at 11 kms^{-1}. Figure 1 (right) presents the 95% C.L. sensitivity assuming the *Sommerfeld* enhancement for the ISO DM profile and 200 h observation time [6]. The values of $\langle\sigma v\rangle$ corresponding to thermally-produced DM can be probed for specic wino masses in the resonance regions of the *Sommerfeld* effect. Outside the resonances the sensitivity reaches the level of 10^{-26} cm^{3}s^{-1} for TeV DM masses.
The issue of possible standard astrophysical gamma-ray background in the search for DM annihilation signal towards DSGs has been first addressed in the case of SgrDw. Even though DSGs are believed to harbor little standard astrophysical emitters at VHE, some gamma-ray emission may still be expected, in particular from pulsars, and black hole accretion and/or jet emission processes[2]. Conservative models for the collective VHE emission from millisecond pulsars in M 54 would give a signal with a significance of about 4σ in 200 h observation time. With long-enough observation times, gamma-ray background from millisecond pulsars in M 54 may limit the sensitivity to DM annihilations (see Ref. [6] for more details). SgrDw may also host a 10^4 M$_\odot$ IMBH. The modeled gamma-ray emission based on relativistic jets associated with active galactic nuclei has been done in [6] assuming that the IMBH is active and has a jet inclined towards the line of sight. The emission from *pp* interactions is dominant in the CTA energy range. For a reasonable set of parameters, the emission is too faint to be detected by CTA. However, under favorable circumstances (active black hole and jet aligned towards the

[1]The sensitivity is computed here with more realistic DM halo profiles than used in Ref. [8]

[2]The collective emission of high energy gamma rays by millisecond pulsars in Galactic globular clusters has been detected by Fermi-LAT [9] and recently by HESS from Terzan 5 [10].

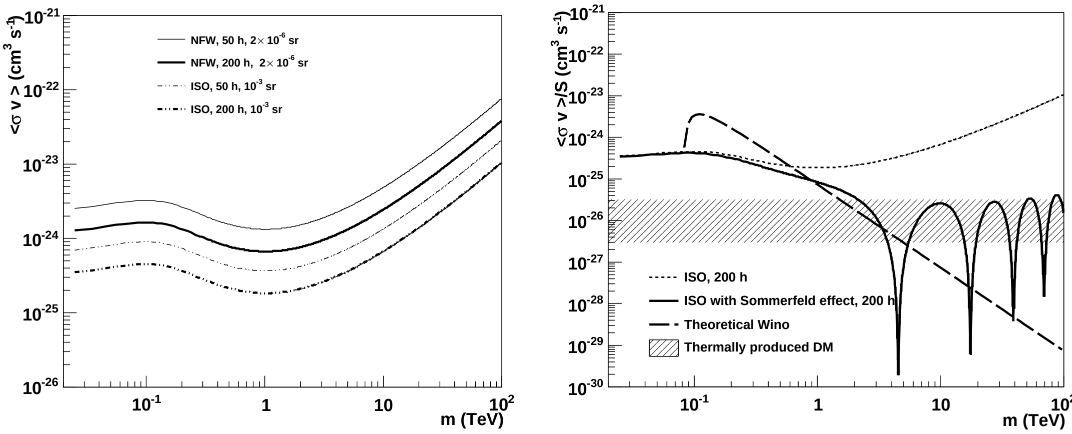

Figure 1: Left: 95% C.L sensitivity on $\langle \sigma v \rangle$ towards SgrDw for a CTA-like instrument for an NFW (solid line) and an Isothermal (ISO) (dashed line) DM halo profiles, respectively. The sensitivity is shown for 50 and 200 h observation times. The solid angle of observation is taken as $\Delta\Omega = 2 \times 10^{-6}$ sr for the NFW profile and $\Delta\Omega = 10^{-3}$ sr for the ISO profile. Right: 95% C.L. sensitivity on $\langle \sigma v \rangle / S$ enhanced by the Sommerfelf effect for the ISO profile (solid line). Figures extracted from Ref. [6].

line of sight), it might nevertheless be detectable in observations of SgrDw.

3 Blind searches for dark matter subhalos

Thanks to their very large collection area, IACTs are very well suited for deep observations of pointed DM sources associated with standard astrophysical counterparts. However, HESS has demonstrated the ability to accurately map large regions of the sky, as obtained from the Galactic Plane Survey (GPS) [11, 12]. The GPS have been used to perform for the first time a blind search for DM substructures (DM spikes around galactic IMBHs) using an IACT wide-field survey [13]. Constraints have been then derived from the HESS GPS on the conventional CDM subhalo distribution obtained by the cosmological N-body simulation Via Lactea II [14]. Values of $\langle \sigma v \rangle$ at the level of 10^{-23} cm^{3}s^{-1} can be tested [15]. A projected sensitivity map for a GPS for CTA have been computed. Figure 2 (left) shows that the 90% C.L. sensitivity reaches a few 10^{-25} cm^{3}s^{-1} in the TeV mass range [15]. However, the flux sensitivity along the Galactic plane is limited by the new population of sources that will be detected at a flux level of 10^{-12} cm^{-2}s^{-1}. The Galactic plane might also not be the best place to look for DM subhalos since they could have been tidally affected by the Galactic disk.
Larger scans of the sky will most likely be conducted by CTA. In particular, a more extended survey of the order of a quarter-sky size is foreseen. A large survey increases the probability to find bright DM subhalos in the field of view, which thus translates into better constraints. Such a survey should not include the Galactic plane where numerous standard astrophysical sources are expected to shine and therefore decrease the sensitivity to DM clumps. On the other hand, the central region of the Milky Way is attractive since the Via Lactea-II subhalo distribution is

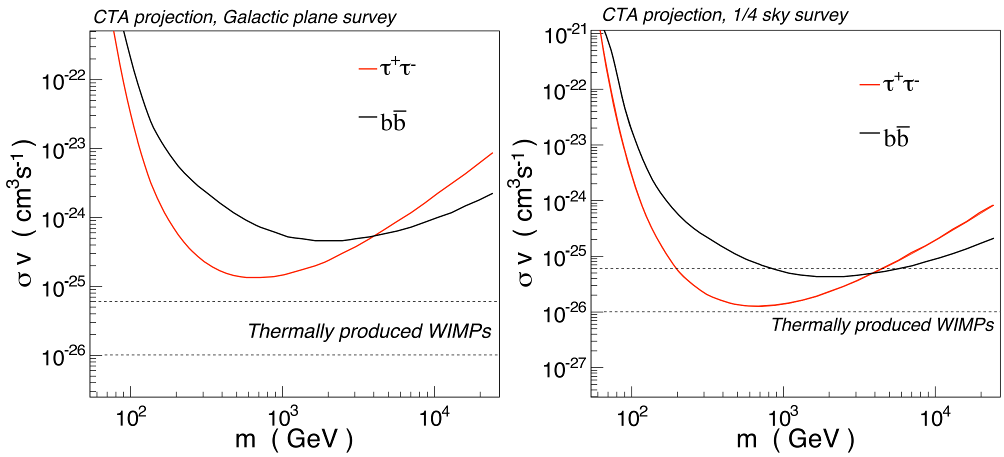

Figure 2: Sensitivity on σv versus the DM particle mass m for a CTA GPS (left) and for a CTA survey of a one-fourth of the sky (right). The sensitivity is calculated at 90% C.L. for the DM clumps provided by the VL-II simulation. The DM particle is assumed to annihilate into purely $b\bar{b}$ and $\tau^+\tau^-$ pairs, respectively. The region of natural values of σv for thermally produced WIMPS is also plotted. Figures extracted from Ref. [15].

peaked towards the centre. A prospective study has been conducted selecting the region from -90° to +90° in Galactic longitude and from -45° to +45° in Galactic latitude, excluding the Galactic plane between ±1.5° [15]. A constant flux sensitivity of about 5×10^{-13} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ is taken over the entire field of view. Figure 2 (right) shows the 90% C.L. sensitivity on σv as a function of the DM particle mass. It is shown that thermally-produced DM can be probed with an ambitious quarter-of-the-sky survey with CTA.

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