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PROSPECTS FOR DARK MATTER SEARCHES WITH CTA

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Abstract. CTA is the next generation of ground-based Cherenkov telescopes, it will allow a deeper look into the gamma-ray sky in the 10 GeV-100 TeV range. Beside the conventional physics program, the CTA instrument will be adapted to search further for particle dark matter. Under the assumption that dark matter is made of new particles, their annihilations are required to reproduce the correct dark matter abundance in the Universe. This process is expected to occur in dense regions of our Galaxy such as the Galactic center, dwarf galaxies and other types of sub-haloes. High-energy gamma-rays are produced in dark matter particle collisions and could be detected by CTA. Here we recall the pros and cons of the Cherenkov telescope technique and illustrate the different strategies that are foreseen.

Keywords: CTA, gamma-ray astronomy, dark matter

1 Particle dark matter and the γ-ray sky

The cosmological standard model stipulates that 84% of the matter in the Universe is non-baryonic. This is motivated by different probes on various scales (Spergel et al. (2007)). In an independent way, models beyond the standard model of particle physics predict the existence of new massive stable particles that have the required properties to make up the cosmological non-baryonic matter, dubbed dark matter (DM) in the following. In this scenario, the current cosmological DM density is set by their annihilation rate in the early Universe. This provides a natural value for the annihilation cross section of $\langle\sigma v\rangle \sim 3 \times 10^{-26}$ cm^{3}s^{-1}, where $\langle\sigma v\rangle$ is the velocity-weighted annihilation cross-section. In the standard picture, the stars of our Galaxy lie in a thin disk of ~ 20 kpc radius, which is dipped into a spherical DM halo of scale a factor of ~ 10 larger. Some of the DM particles happen to collide within the halo, producing standard model particles. This exotic production of standard model particles is associated with the emission of γ-rays with energies of the order of the DM particle mass. The considered weakly interacting massive particle (WIMP) being related to electroweak physics, its mass is expected to range between 100 GeV and a few TeV. In this paper, we focus on two widely studied targets where DM annihilations could occur in an efficient way: dwarf galaxies and DM clumps in the Galactic halo.

2 Cherenkov telescopes now and then

The basic idea of running ground based telescopes to observe cosmic γ-rays is to use the atmosphere as a calorimeter. When a high energy particle hits the top of the atmosphere, it induces a cascade of secondary particles. At TeV energies, that cascade is fully contained in the atmosphere, and it produces a flash of Cherenkov photons. Hadronic and electromagnetic particles produce different types of cascades. While hadrons induce irregular particle showers, electrons, positrons and γ-rays produce a more even shower. The projection of Cherenkov flash cone on the ground is a disk of order 250 m diameter. From any place inside this disk, the atmospheric shower is observable, should one use a sensitive enough instrument. Ground-based γ-ray observatories use this principle to measure γ-ray induced Cherenkov light, as sketched on the left panel of Fig. 1. Large dishes are used to collect enough photons, those are focused on very sensitive cameras equipped with photomultipliers. To gain in angular resolution, energy resolution and background subtraction, several telescopes are used simultaneously to observe the event, thus getting a stereoscopic view of the particle cascade. The cameras are

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able to integrate the signal very quickly and to resolve the image of the atmospheric showers, in order to fight against different types of backgrounds: night sky background, hadronic cosmic ray induced showers, electrons and positrons induced showers, and diffuse gamma-rays. The different methods for background rejection allow an efficient reconstruction of gamma-ray sources, as long as its extension is smaller than the $\sim 5°$ field of view of the telescope arrays (see Brun (2011) and references therein).

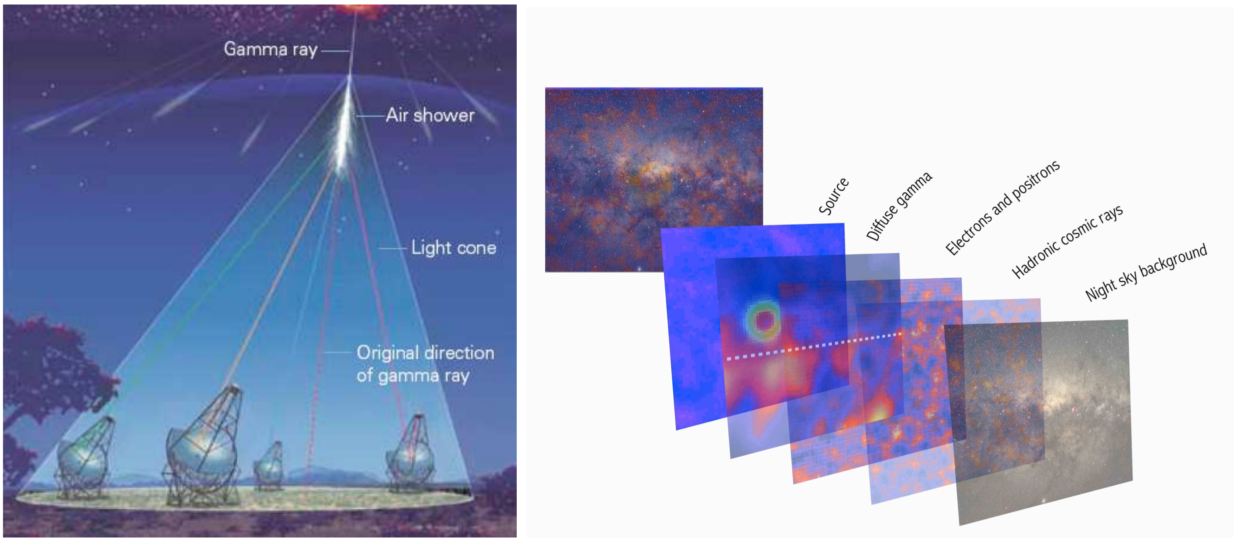

Fig. 1. Left: Principle of the Cherenkov telescopes, several telescopes measure the Cherenkov flash induced by the initial γ-ray (image from Völk & Bernlöhr (2009)). **Right**: Schematic representation of the different layers of background that Cherenkov astronomers have to suppress to obtain a image of the TeV sources (image from Brun (2011)).

There are now three main telescope arrays running in the world, MAGIC and VERITAS in the northern hemisphere, and HESS in the southern hemisphere. All of those performed observation of potential DM targets such as dwarf galaxies or globular clusters. Next generation of Cherenkov observatories will involve tens of telescopes. For instance, the CTA project intends to built up two arrays –one in each hemisphere– made of more than 50 telescopes each (CTA-consortium (2010)). The gain in sensitivity with respect to current generation instruments is of order an order of magnitude and the angular resolution will be better by a factor 2 to 3. CTA will allow observing more deeply the sources, and also to perform surveys of the sky in a more efficient way than it is done today, with sub-arrays pointing in distinct regions of the sky simultaneously.

3 Current observations of dwarf galaxies and limits on dark matter parameters

At the moment, Cherenkov observatories have performed observation of selected targets. Some of those are listed on the skymap of Fig. 2. For each of the selected targets, the DM density has been inferred from stellar dynamics within the object. Once the DM content of the target is modeled, the annihilation rate is determined by the mass and the annihilation cross-section of the WIMP. The absence of detection of any signal gives constraints on these two parameters. Fig. 3 displays some limits from Magic, Veritas, Whipple and HESS, as well as a comparison with a limit from Fermi. Some of these results account for the uncertainty on the DM profile of the target and present a band instead of a single line. In the best case, current limits on the annihilation cross section reach 10^{-22} cm^3/s around $m = 1$ TeV, still 4 orders of magnitude above the value of 10^{-26} cm^3/s corresponding to thermally produced WIMPs.

4 Prospects for CTA with the observation of Sagittarius dwarf galaxy

The Sagittarius dwarf galaxy has been observed by HESS to derive constraints on the DM particle properties. The results are presented in Aharonian et al. (2008a), they correspond to XX h of observation. In Viana et al. (2011), these results have been extrapolated to 50 h of observations and the expected sensitivity of the CTA array has been used to compute future constraints. These two results are displayed in Fid. 4. Different halo modeling and observation times have been used to drive the CTA constraints, that is why the predictions spread

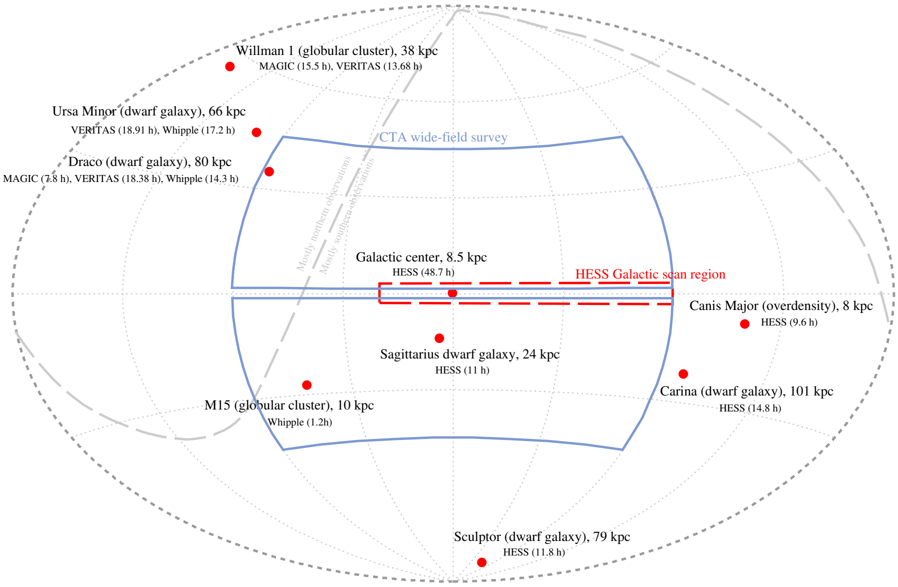

Fig. 2. Skymap with positions of some observed DM targets and scan regions both observed (red) and foreseen (blue).

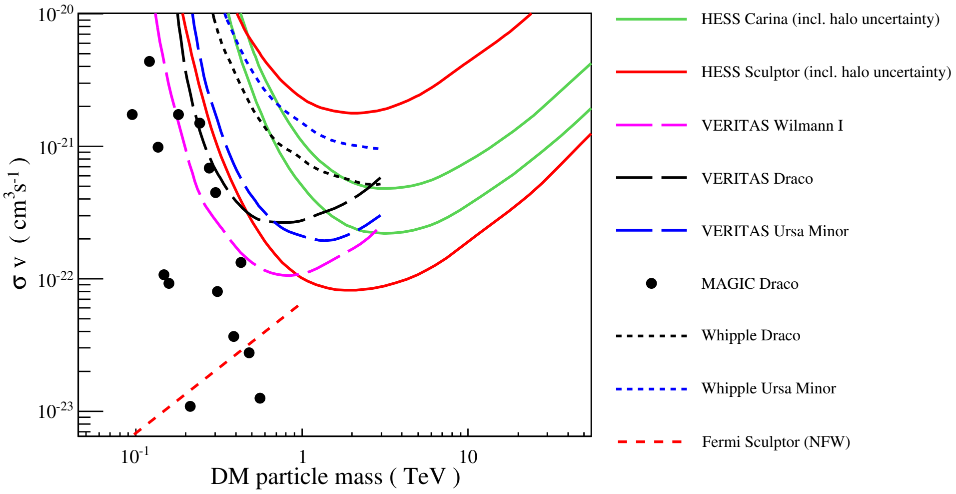

Fig. 3. Current constraints on DM particle from observations of selected targets

over an order of magnitude or so, reaching $\sim 10^{-24}$ cm^3/s at best. In Viana et al. (2011), we also considered possible conventional signal from Sagittarius dwarf galaxy: signal from a possible central intermediate mass black hole and collective emission from millisecond pulsars (MSP). Indeed the main limitation comes from MSPs, because the M54 globular cluster lies in the center of Sagittarius dwarf. The signal from MSPs should be observable with more sensitivity. As it would overcome an eventual DM signal, this defines a no-go line for the sensitivity to DM annihilations, at the level of 10^{-25} cm^3/s, one order of magnitude above the region of interest for thermal WIMPs. Therefore we conclude that Sagittarius dwarf galaxy might not be the best target for indirect detection.

5 Wide-field searches for clumps with HESS and CTA

One possibility to avoid possible conventional signal from the baryonic content of the targets is to search for the most primitive sub-haloes that our Galaxy harbors. N-body simulations such as *Via Lactea* (Diemand

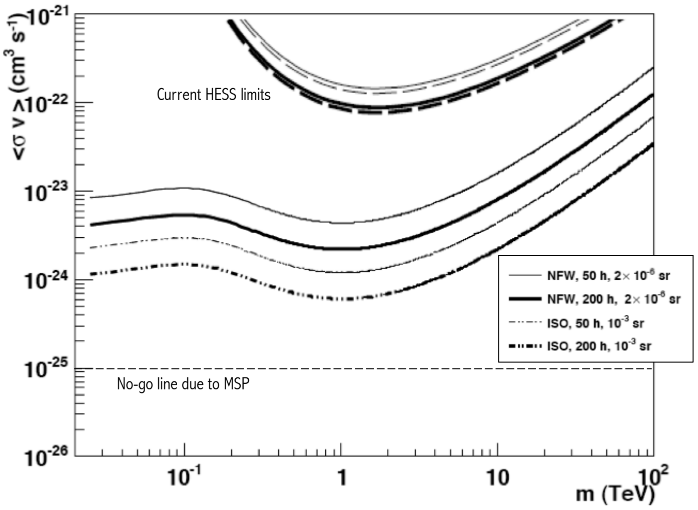

Fig. 4. Current and projected constraints on DM particle parameters from the observation of Sagittarius dwarf galaxy

et al. (2008)) predict a large number of DM sub-haloes in Milky-Way sized haloes. Those clumps which never accreted no baryon are supposed to be very dense in their center and in principle cannot be detected directly other than via their DM annihilations. As the position of these objects are unknown, we rely on cosmological structure formation simulations to estimate the probability to have a given clump at a given position in the sky. Then, the probability to observe it with a Cherenkov telescope is the convolution of the sensitivity of the instrument and the size of the field of view that is used. It turns out that in the typical $5^\circ \times 5^\circ$ field of view of current Cherenkov telescopes, the probability to have a sufficiently bright clump is very low. In order to make this technique more sensitive, one has to use large surveys. The HESS array of Cherenkov telescopes performed a survey of the Galactic plane. Data from this survey has been used to build up a sensitivity map in a $\pm 3^\circ$ latitude and $-30^\circ/+90^\circ$ longitude window in Aharonian et al. (2008b) (red rectangle on Fig. 2). This sensitivity map has been compared to predictions from *Via Lactea* in Brun et al. (2011). The absence of clump candidates in the HESS survey leads to the exclusion curves that are presented in the left panel of Fig. 5. The sensitivity map for the Galactic scan has been extrapolated to CTA, the exclusion curves in the no detection hypothesis are shown in the right panel of Fig. 5 (dashed curves). The projected constraints for CTA in the case of a Galactic scan are still an order of magnitude above the region of interest. The only way of reaching this region is to take advantage of an ambitious quarter sky survey with CTA. Notice that such a survey may be performed independently of MD searches. The suggested survey appears as blue contours on Fig. 2. In the no detection hypothesis, the thermal WIMPs annihilation cross section is reached within 6 years.

6 Conclusions

Some results regarding DM searches towards known targets with Cherenkov telescopes are reviewed. In the case of the observation of Sagittarius dwarf galaxy with CTA, it is shown that conventional physics processes could curb searches for DM. Alternative methods are proposed, based on blind searches for DM clumps, it is shown that an ambitious survey of a quarter of the sky with CTA could give the required sensitivity to reach thermally produced WIMPs.

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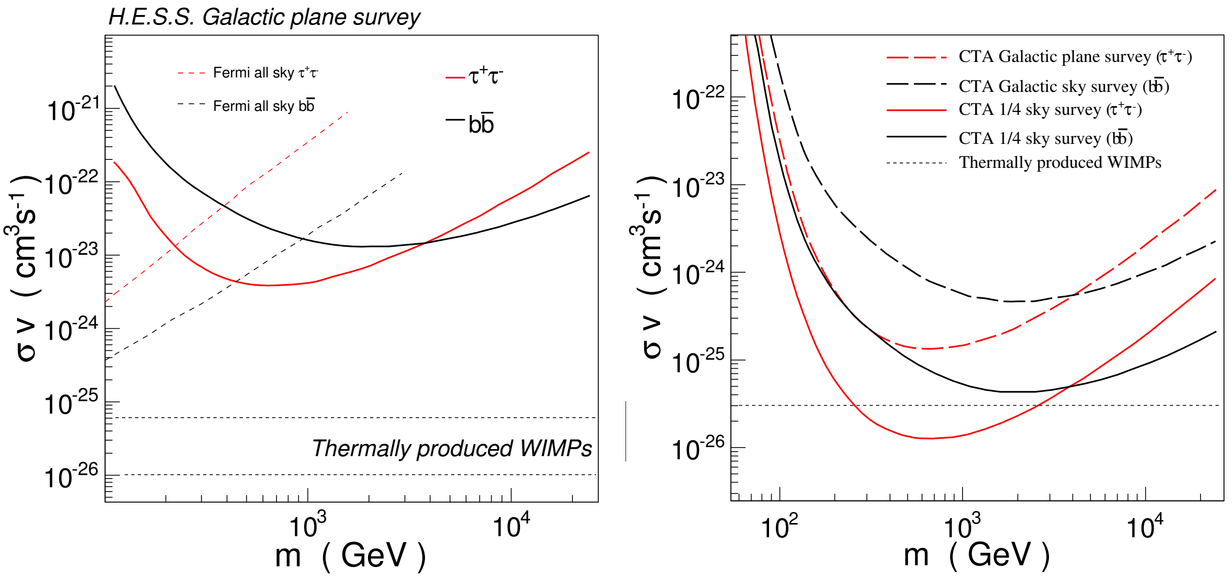

Fig. 5. Current constraints from the HESS Galactic scan (left) and CTA projection for a Galactic scan and a 1/4-sky survey (right).

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