Dark matter searches with H.E.S.S.: nearby dwarf galaxies and IMBH mini-spikes

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Abstract. WIMP pair annihilations produce high energy gamma-rays in the final state, which can be detected by Imaging Atmospheric Cherenkov Telescopes such as the H.E.S.S. array. We focus in this contribution on searches towards dwarf galaxies and mini-spikes around intermediate mass black holes (IMBHs) in the Galactic halo. H.E.S.S. observations towards the nearby dwarf galaxies Sagittarius and Canis Major are presented. Using realistic modellings for the dark matter (DM) density profiles, constraints on the velocity-weighted annihilation cross section σv of DM particles are derived in the framework of Supersymmetric and Kaluza-Klein models. A search for DM mini-spikes around IMBHs is described as well as constraints on the particle physics parameters.

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INTRODUCTION

A substantial body of cosmological and astrophysical measurements suggests that ~22% of the Universe is composed of non-baryonic DM, e.g. [1], commonly assumed to be in the form of Weakly Interacting Massive Particles (WIMPs) arising in extensions of the Standard Model of Particle Physics. The lightest neutralino in supersymmetric (SUSY) extensions of the Standard Model [2] and the first excitation of the Kaluza-Klein bosons (LKP) in universal extra dimension theories [3, 4] are amongst the most widely discussed DM candidates.

The annihilation of WIMP pairs can produce in the final state a continuum of gamma-rays whose flux extends up to the DM particle mass, from the hadronization and decay of the cascading annihilation products. In SUSY, the gamma-ray spectrum from neutralino annihilation is not uniquely determined and the branching ratios (BRs) of the open annihilation channels are not determined since the DM particle field content is not known *a priori*. In Kaluza-Klein scenarios, the BRs of the annihilation channels can be computed given that the field content of the DM particle is known. The annihilation rate being proportional to the square of the DM density integrated along the line of sight, regions with enhanced DM density are primary targets for indirect searches. Among them are the Galactic Center, nearby external galaxies and substructures in galactic haloes.

We report here on the H.E.S.S. results concerning nearby dwarf galaxies and DM mini-spikes around IMBHs.

NEARBY DWARF GALAXIES

Nearby dwarf galaxies are known to be amongst the best targets to search for DM signals, being considered as the most extreme DM-dominated environments. Unlike the Galactic Center, those galaxies are expected to have reduced astrophysical backgrounds.

Sagittarius

The Sagittarius (Sgr) dwarf galaxy located at 24 kpc from the Sun is one of the nearest Galaxy satellites of the Local Group. Sgr has been observed by H.E.S.S. since 2006. 11 hours of high quality data are presented here. The target position is chosen at the location of the Sgr luminous cusp, coincident with the center of

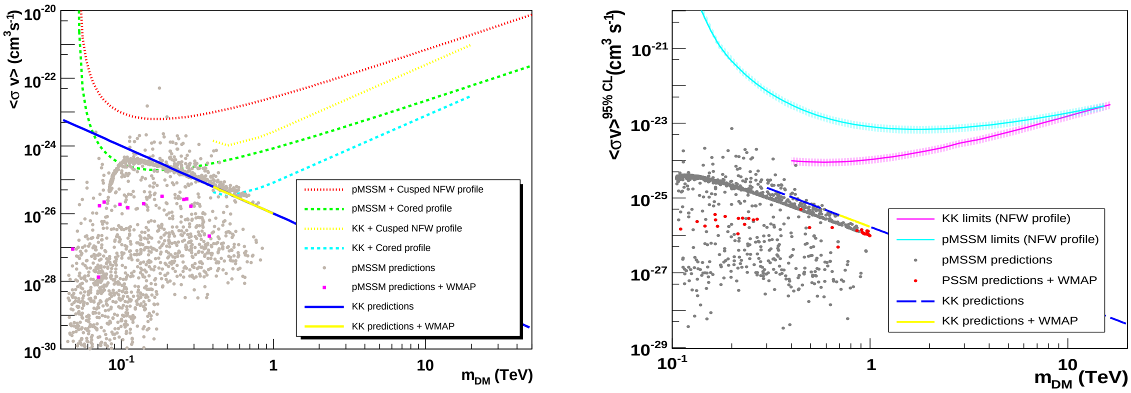

FIGURE 1. Left : Upper limits at 95% C.L. on σv versus the DM particle mass in the case of a cusped NFW and cored DM halo profile for the Sgr dwarf galaxy. The predictions in pMSSM and KK models are also plotted with in addition those satisfying in addition the WMAP constraints on the cold DM density. Figure extracted from [5]. Right : Upper limits at 95% C.L. on σv as a function of the DM particle mass in the case of a NFW profile and an assumed CMa total mass of 3×10^8 $M_\odot$. The shaded area correspond to the 1σ error bars on σv for pMSSM and KK DM particles. pMSSM and KK models are also plotted with those satisfying the WMAP+SDSS constraints on the cold DM density. Figure extracted from [6].

the globular cluster M54. The annihilation signal from Sgr is expected to come from a region of 1.5 pc, thus much smaller than the H.E.S.S. point spread function so that a point-like signal has been searched for. No significant gamma-ray excess is detected at the nominal target position. A 95% C.L. upper limit on the gamma-ray flux is derived : $\Phi_\gamma(E_\gamma > 250\ \mathrm{GeV}) < 3.6\times10^{-12}$ $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ assuming a power-law spectrum of spectral index 2.2 [7].

A modelling of the Sgr DM halo has been carried out. Two models of the mass distribution of the DM halo have been studied: a cusped NFW profile used as a reference model, and a cored isothermal profile. For the NFW profile, the structure parameters are extracted from [8]. In case of the cored model, the velocity dispersion is assumed to be independent of the position and equal to the central velocity dispersion of 8.2 ± 0.3 kms^{-1}. The velocity dispersion tensor is taken isotropic as in [8]. The mass density profile of stars is extracted from [9]. The cored profile has a small core radius due to a cusp in the luminous profile. The value of the line-of-sight-integrated-squared density is then found to be larger for the cored profile than for the NFW profile (see [7] for more details).

Fig. 1 presents the constraints on σv in the case of a cusped NFW and cored profiles in the solid angle integration region $\Delta\Omega = 2\times10^{-5}$ sr, for neutralino and KK DM. Predictions for SUSY and KK models are also displayed. For a cusped NFW profile, H.E.S.S. does not set severe constraints on σv. For a cored profile, due to a higher central density, stronger constraints are derived and some pMSSM models can be excluded in the upper part of the scanned region. In the case of a cored profile, some models providing a LKP relic density compatible with WMAP contraints lying in the mass range 300 - 500 GeV can be excluded.

Canis Major

Since the discovery of Canis Major (CMa) in 2004, its nature is still debated on whether it is a Galactic warp or a dwarf galaxy. In [10], CMa corresponds to the warp and flare of the outer disk since kinematics of the CMa stars do not present peculiar motion as compared to those of the Galactic disk. Another scenario represents CMa as the remnant of a disrupted dwarf galaxy that could have given birth to the Monoceros ring [11]. Despite the controversial nature of CMa, the scenario in which it is presented as a dwarf galaxy makes it a potentially interesting target for DM searches.

CMa is located at $\sim$8 kpc from the Sun in the Galactic anti-center direction. Observations towards CMa with H.E.S.S. have been carried out in 2006. After standard quality criteria, the CMa dataset amounts to 9.6 hours [6]. The DM mass content of dwarf galaxies can be derived using velocity dispersion measurements of their stellar population as well as their luminosity profile as in [7]. In the case of CMa, the lack of available observational data prevents the modelling of its density profile. A cusped NFW halo is assumed to model the CMa mass distribution. The parameters of the NFW profile are determined by solving a three-equation system in a Λ-CDM cosmology with the following unknown quantities: the virial mass, the scale radius and the density profile normalisation (see [6] for details on the procedure). In order

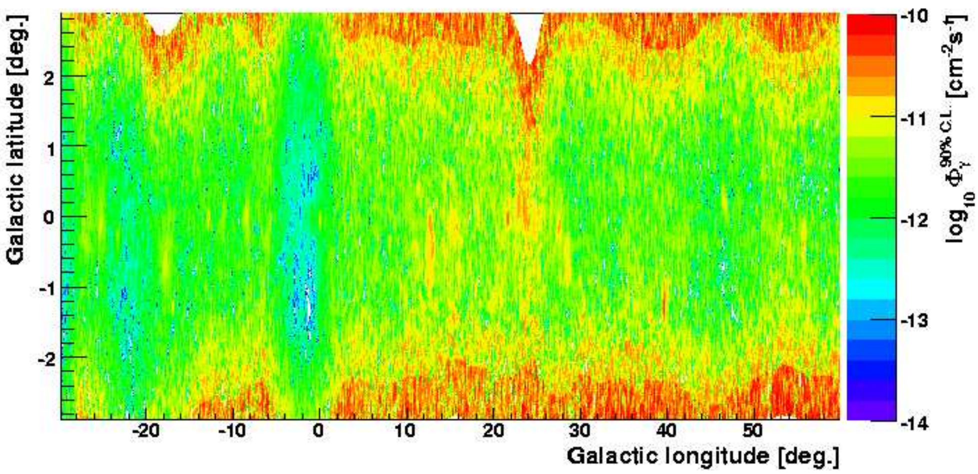

FIGURE 2. H.E.S.S. sensitivity map in Galactic coordinates, i.e. 90% C.L. limit on the integrated gamma-ray flux above 100 GeV, for a DM particle of mass m_χ = 500 GeV annihilating with a 100% branching ratio into the $b\bar{b}$ channel.

to account for the tidal disruption of CMa due to its proximity to the Galactic plane, the halo mass is estimated by computing the mass inside the tidal radius. The mass is then calculated using the Roche criterion and an iterative tidal stripping procedure, assuming that the inner part of the profile is not affected [6]. For a CMa mass of 10^8 $M_\odot$, the line-of-sight-integrated squared density is $\sim 10^{25}$ GeV^{2}cm^{-5}.

Halo independent constraints on the annihilation signal can be derived for various neutralino masses. In the center of the field of view, H.E.S.S. sensitivity reaches 10^2 GeV^{2}cm^{-2}s^{-1} for 1 TeV higgsino-like neutralino annihilating in W and Z pairs. The left hand side of Fig. 1 shows the constraints on σv. Using a NFW profile, 95% C.L. exclusion limits reach $\sim 5\times 10^{-24}$ cm^{3}s^{-1} in the 500 GeV - 10 TeV DM particle mass range assuming a total halo mass of 3×10^8 $M_\odot$ [6].

H.E.S.S. SENSITIVITY IN THE GALACTIC PLANE SURVEY

Data collected between 2004 and 2007 during the Galactic plane survey have allowed to accurately map the Galactic plane between $\pm 3^\circ$ in latitude and from -30° to 60° in longitude with respect to the Galactic Center position. The H.E.S.S. sensitivity map for DM annihilations has been calculated [12]. Fig. 2 shows the experimentally observed sensitivity map in the Galactic plane for a DM particle of 500 GeV mass annihilating into the $b\bar{b}$ channel. The sensitivity depends strongly on the exposure time and acceptance maps which are related to the choice of the pointing positions. The flux sensitivity varies along the latitude and longitude due to inhomogeneous coverage of the Galactic plane. In the band between -2° and 2° in Galactic latitude b, a DM annihilation flux sensitivity at the level of 10^{-12} cm^{-2}s^{-1} is achieved. Deeper observations towards the Galactic Center and at Galactic longitude of 20° allow a flux sensitivity of $\sim 5\times 10^{-13}$cm^{-2}s^{-1} for a 500 GeV DM particle annihilating entirely in the $b\bar{b}$ channel. For $|b|>2^\circ$, the sensitivity is deteriorated due to a weaker effective exposure. H.E.S.S. thus reaches the required sensitivity to be able to test DM annihilations from mini-spikes in the context of one relatively favorable scenario for IMBH formation and adiabatic growth of the DM halo around the black hole (see Fig.1 of [12]).

DARK MATTER MINI-SPIKES IN IMBH SCENARIOS

Mini-spikes around IMBHs have been recently proposed as promising targets for indirect DM detection [13]. The growth of massive black holes inevitably affects the surrounding distribution of DM. The profile of the final DM overdensity, called mini-spike, depends on the initial distribution of matter, but also on astrophysical processes such as gravitational scattering of stars and mergers. Ignoring astrophysical effects, and assuming adiabatic growth of the black hole, if one starts from a NFW profile, a spike with a power-law index 7/3 is obtained, as relevant for the scenario B of [13] characterized by black hole masses of $\sim 10^5$ $M_\odot$.

Since astrophysical processes are unlikely to take place around IMBHs, mini-spikes that never experience

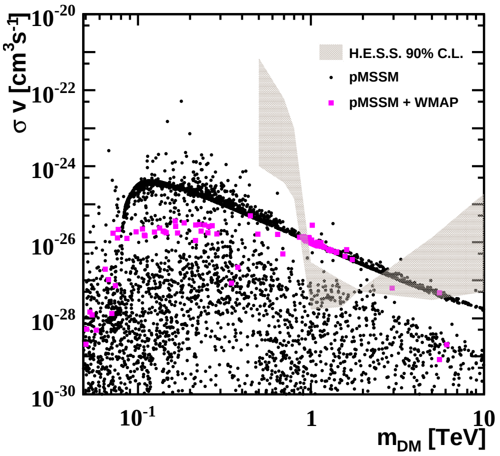

FIGURE 3. Constraints on the IMBH γ-ray production scenario for different neutralino parameters, shown as upper limits at 90% C.L. on σv as a function of the mass of the DM particle, in scenario B (grey shaded area). The DM particle is assumed to be a neutralino annihilating into $b\bar{b}$ or $\tau^+\tau^-$ pairs to encompass the softest and hardest annihilation spectra. The limit is derived from the H.E.S.S. flux sensitivity in the Galactic plane survey within the mini-spike scenario. SUSY models from the pMSSM (black points) are plotted together with those satisfying the WMAP constraints on the cold DM density (magenta points).

mergers are therefore expected to be stable structures over cosmological timescales, and they are thus promising targets for indirect detection. The gamma-ray flux from these targets can be calculated, once the DM profile has been determined. The scenario B [13] leads to gamma-ray fluxes accessible to H.E.S.S. For a 5 TeV neutralino mass, the mean integrated gamma-ray flux is $4.5\times10^{-11}\text{cm}^{-2}\text{s}^{-1}$ [12].

H.E.S.S. observations (2004-2006) of the Galactic plane allowed to discover more than 20 very high energy gamma-ray sources [14]. Some of them have been identified owing to their counterparts at other wavelengths, but almost half of the sources have no obvious counterpart and are still unidentified [15]. An accurate reconstruction of their energy spectra shows that all the spectra are consistent with a pure power-law, spanning up to two orders of magnitude in energy above the energy threshold. None of them exhibits an energy cut-off, characteristic of DM annihilation spectra, in the energy range from $\sim$100 GeV up to 10 TeV. Furthermore, the detailed study of their morphology [15] shows that all the sources have an intrinsic spatial extension greater than $\sim$5', while mini-spikes are expected to be point-like sources for H.E.S.S. H.E.S.S. has detected so far no IMBH candidate within the survey range.

Based on the absence of plausible IMBH candidates in the H.E.S.S. data, constraints are derived on the scenario B for neutralino or LKP annihilations, shown as upper limits on σv [12]. Fig. 3 shows the exclusion limit at the 90% C.L. on σv as a function of the neutralino mass. The neutralino is assumed to annihilate into $b\bar{b}$ and $\tau^+\tau^-$ with 100% BR, respectively. Predictions for SUSY models are also displayed. The limits on σv are at the level of 10^{-28} cm^{-3}s^{-1} for the $b\bar{b}$ channel for neutralino masses in the TeV energy range. Limits are obtained on one mini-spike scenario (scenario B) and constrain on the entire gamma-ray production scenario.

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