# Indirect Search for Dark Matter with H.E.S.S.

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The Universe is filled with non-baryonic Dark Matter which prevails the known form of matter (leptons and baryons). Indirect Dark Matter search methods are sensitive to self-annihilating Dark Matter candidates: among the spray of particles released in the self-annihilation process, gamma-rays and to some extent neutrinos can be used to trace regions with high overdensities of Dark Matter. The energy of these photons reaches up to the mass of the annihilating particles. For Dark Matter particles more massive than 100 GeV, atmospheric Cherenkov telescopes become sensitive to these radiation energies while for less massive particles, space-based detection techniques are favorable (e.g. with the recently commissioned Fermi mission). Here, we present a summary of results obtained with the H.E.S.S. experiment located in Namibia using four 100 $m^2$ optical telescopes to detect and image air Cherenkov light from extensive air showers. The experiment has been used to search for annihilation radiation from various candidate regions with enhanced Dark Matter density including the Galactic center, Sagittarius dwarf, M87, and clumps in the Galactic halo.

## 1 Introduction

A particularly interesting class of dark matter (DM) candidates are “weakly interacting massive particles” (WIMPs) which naturally arise in various extensions (or completions) of the standard model of elementary particle physics as e.g. the class of supersymmetric models or theories invoking extra dimensions. The simplest representative of the latter class of models is the widely studied Kaluza-Klein (KK) theory (see [7]). Some of these DM candidates are Majorana particles. In these specific cases, indirect search methods for DM are feasible. Self-annihilation could lead to an observable excess of $\gamma$-ray photons, neutrinos, and antimatter in cosmic-rays. Indirect search methods are complementary to direct search methods as well as to accelerator based methods. We are currently witnessing a rapid progress in the sensitivities reached in all domains including the commissioning/planning of new instruments for ground based gamma-ray astronomy (CTA), space-based gamma-ray satellites (Fermi, formerly known as GLAST, PAMELA), accelerator based experiments (LHC, ILC) and direct search methods (ZEPELIN, etc.).

Here, we present recently obtained results with the H.E.S.S. experiment. In the interpretation of the results we mainly focus on supersymmetric extensions of the standard model with the Neutralino as the lightest supersymmetric particle (LSP) as well as KK models, where the lowest excited state $B^{(1)}$ is the WIMP candidate.

There are two ways for the investigated WIMP candidates to produce $\gamma$-ray photons. In principle annihilation into monoenergetic photons is possible, but because of loop suppression unlikely and therefore not considered here. Most of the photons are produced in secondary reactions of the annihilation products following a continuous energy spectrum, which is challenging to distinguish from gamma-ray emission from more conventional sources (SNR, etc.).

We are considering a DM density profile with an inner slope $\varrho(r) \propto r^{-\gamma}$ (special cases: $\gamma = 1$ for an NFW-profile [12] and $\gamma = 1.5$ for a Moore-profile [10]), and a DM candidate with a mass $m_{\mathrm{WIMP}}$. With an averaged velocity weighted annihilation cross section $\langle\sigma v\rangle$ (in the following text this parameter is only called "cross section") producing a photon spectrum $dN_\gamma/dE$ per annihilation, the observed flux is $\Phi \propto \langle\sigma v\rangle \cdot dN_\gamma/dE \cdot \bar{J}(\Delta\Omega)\Delta\Omega$ with $\bar{J}(\Delta\Omega)\Delta\Omega \propto \int_{\Delta\Omega} d\Omega \int_{los} ds\, \varrho^2$.

Since the emissivity increases with $\varrho^2$, it is suggestive to search for this radiation from regions with a large density of DM.

## 2 Observations with H.E.S.S.

The H.E.S.S. experiment located in Namibia is an experiment investigating VHE $\gamma$-radiation. It consists of four imaging atmospheric Cherenkov telescopes observing stereoscopically the air showers initiated by energetic particles ($E > 100\,\mathrm{GeV}$) impinging on Earth's atmosphere. The shower images are used to distinguish between photon induced air showers and the much more abundant hadronic ones. The technique is sufficiently advanced to reconstruct the direction of the primary photon with an accuracy of 0.08° (per event), and to estimate the primary energy with a relative accuracy of around 15%. With this observatory it is possible to search for sources of VHE $\gamma$-ray photons with an energy $100\,\mathrm{GeV} < E < 100\,\mathrm{TeV}$ (the upper bound is limited by the collection area of the experiment of $\approx 10^5\,\mathrm{m}^2$: typically, non-thermal energy-spectra follow a power-law shape with $I(> E) \propto E^{-2\cdots-3}$). A considerable share of the observation time of the H.E.S.S. telescopes has been used to observe potential sites of detectable DM annihilation.

**The Galactic center:** The center of our Galaxy is an obvious target to search for $\gamma$-radiation from DM annihilation: the assumed Galactic density profile of the DM has there its maximum. H.E.S.S. has observed the super-massive black hole Sgr A$^\star$ at the Galactic center for a total of 64 h. A steady, point-like VHE $\gamma$-ray source has been found, co-located within the astrometric uncertainties of the H.E.S.S. telescopes of $\approx 10$ arcsec with the position of Sgr A*.

We consider an exclusive origin of the observed $\gamma$-rays from WIMP annihilation unlikely, because the required $m_{\mathrm{WIMP}} > 20\,\mathrm{TeV}$ and large cross section are difficult to reconcile with common WIMP models [9].

On the other hand only a part of the observed radiation could originate from DM annihilation, since there are several other possible sources of VHE $\gamma$-radiation in the observed region. In the following we derive an upper limit on the admixture of gamma-rays from DM annihilation and gamma-rays from astrophysical backgrounds. The measured spectrum is fitted with the sum $\Phi(E) = \Phi_{\mathrm{bg}}(E) + \Phi_{\mathrm{DM}}(E)$: $\Phi_{\mathrm{DM}}(E)$ describes the annihilation radiation, while $\Phi_{\mathrm{bg}}(E) \propto E^{-\Gamma}$ represents a background from other sources. In order to derive an upper limit, $\Phi_{\mathrm{DM}}$ is increased until the minimal $\chi^2$ of the fit of $\Phi(E)$ to the data reaches its 99% confidence limit. With these results an upper limit on $\bar{J}(\Delta\Omega)\Delta\Omega \cdot \langle\sigma v\rangle$ can be calculated. Assuming a density profile, limits on the annihilation cross section (see table 1) can be derived and vice versa. For these topics see also references [3, 13, 14]. More data have been taken in the meantime (under preparation).

**The Sagittarius dwarf galaxy:** The Sagittarius dwarf galaxy is a recently found dwarf galaxy in the halo of our galaxy at a heliocentric distance of 24 kpc. Since dwarf galaxies are dominated by DM, a realistic model of the density profile exists with less uncertainties than for the Galactic center (where baryonic matter dominates the stellar and gas dynamics). H.E.S.S. has observed this target. No indication for $\gamma$-radiation from Sgr Dwarf has been found so far. Upper limits on the annihilation cross section as function of the WIMP mass can be calculated.

For a cored density profile the limits on the cross section for neutralino annihilation have their minimum at $m_\chi \approx 200\,\text{GeV}$ with $\langle\sigma v\rangle_{\text{limit}} \approx 2\cdot 10^{-25}\,\text{cm}^3\text{s}^{-1}$ not reaching into the area of WMAP compatible parameter sets. For $B^{(1)}$ annihilation the limits have their minimum at $m_{B^{(1)}} \approx 500\,\text{GeV}$ with $\langle\sigma v\rangle_{\text{limit}} \approx 4\cdot 10^{-26}\,\text{cm}^3\text{s}^{-1}$. For this density profile a $B^{(1)}$ annihilation can be excluded for particle masses $m_{B^{(1)}} < 500\,\text{GeV}$ (see reference [4]).

**The unidentified source HESS J1303-631:** The source of VHE $\gamma$-rays HESS J1303-631 was serendipitously found in the same field of view during observations of the pulsar binary system PSR B1259-63/SS 2883. HESS J1303-631 is a spatially extended source with no detected flux variability and no known counterpart at other wavelengths. This behavior is consistent with the expectations from DM accumulations. Therefore, the question was investigated whether this source could be a DM clump in the halo [11].

The considered energy spectra for annihilation radiation does not fit the measured spectrum well. In addition to this, we fit the measured luminosity profile with the line of sight integral of a given density profile ($\varrho \propto r^{-\gamma}$) convolved with the point spread function of the detector. The best fit is achieved with $\gamma = -0.8$. This would require a shell-like structure of the clump and is in contradiction with the expected NFW- ($\gamma = 1$) and the Moore-profile ($\gamma = 1.5$). Therefore, a DM nature of this source is very unlikely (see reference [15]).

**Intermediate mass black holes:** Intermediate mass black holes (IMBH) ($10 - 10^6 M_\odot$) in the Galactic halo can accumulate DM into so called mini-spikes [8]. This could lead to pointlike unidentified sources. H.E.S.S. has performed a systematic scan of the Galactic plane. No candidate of IMBH with a DM mini-spike was found. Depending on scenarios about the occurrence of IMBH and the mini-spike density profile, upper limits on the annihilation cross section can be derived. The upper limits rule out a massive WIMP with $m_{\text{WIMP}} > 1\ TeV$. (see reference [5]).

**The radio galaxy M87:** The radio galaxy M87 is located in the center of the Virgo galaxy cluster. It is a giant elliptical (cD type) galaxy at a distance of 16 Mpc. VHE $\gamma$-rays from this source were detected in 1998/99 with HEGRA [1]. The detection was later confirmed in 2004 and 2005 by H.E.S.S. with a fast flux variability [2]. The variability immediately rules out an exclusive DM origin of of the radiation. Even when considering the possible quiescent flux level, it is still by orders of magnitude larger than the expectations from DM annihilation. The upper limits on the annihilation cross section (analogous to the calculations about the galactic center) are highly above the model cross sections. No DM is detectable from this source so far. With observations at lower energies (GLAST/Fermi or low-energy threshold Cherenkov telescopes) this could in principle be achieved.

# 3 Summary and outlook

So far, the indirect search for Dark Matter with H.E.S.S. has not produced any convincing evidence for gamma-ray emission from self-annihilating Dark Matter (with the possible exception of the Galactic center). The limits (listed in table 1) are however starting to constrain some models.

Future experiments will improve the abilities in the search for WIMP DM (mainly by lower sensitivity and wider energy reach). The lower energy window will be covered by the

| | Galactic Center [1] | Sgr Dwarf [2] | M87 [3] | IMBH [4] |
|---|---|---|---|---|
| $\langle \sigma v \rangle_{\rm limit}(\chi\chi)$ [cm$^3$s$^{-1}$] | $10^{-24}$ | $2 \cdot 10^{-25}$ | $10^{-22}$ | $10^{-28}$ |
| $\langle \sigma v \rangle_{\rm limit}(B^{(1)}B^{(1)})$ [cm$^3$s$^{-1}$] | $10^{-24}$ | $4 \cdot 10^{-26}$ | $10^{-22}$ | $3 \cdot 10^{-29}$ |
| $T_{\rm obs}$ $[h]$ | 64 | 11 | 89 | $\sim 400$ |

Table 1: Limits on the annihilation cross section of neutralino and $B^{(1)}$ annihilation. Typical annihilation cross sections are $\langle \sigma v \rangle_{\chi\chi} = 2 \cdot 10^{-26}\,{\rm cm^3 s^{-1}}$ and $\langle \sigma v \rangle_{B^{(1)}B^{(1)}} = 1.7 \cdot 10^{-26}\,{\rm cm^3\,s^{-1}}/(m_{\rm WIMP}/1\,{\rm TeV})^2$.

GLAST/Fermi satellite. The H.E.S.S. experiment will be upgraded with a central large Cherenkov telescope (H.E.S.S. Phase II) reducing the threshold from 100 GeV to $\approx$ 20 GeV. The multi-pronged approach (accelerator, direct and indirect search) to identify Dark matter will hopefully help to solve the origin of Dark Matter within the next decade.

## References


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[1] Assuming an NFW-profile
[2] Assuming a cored profile
[3] Profile considered in [6]
[4] Limits constraining for $m_{\rm WIMP} > 1\,{\rm TeV}$