PROCEEDINGS OF SCIENCE

Indirect searches for dark matter with HESS

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The H.E.S.S. experiment is an array of four identical imaging atmospheric Cherenkov telescopes in the Southern hemisphere, designed to observe very high energy gamma-rays (E $>$ 100 GeV). The annihilation of dark matter particles in dense astrophysical objects could produce detectable very high energy gamma-rays. The HESS collaboration has searched for a dark matter annihilation signal towards several potential targets: the Galactic Centre, dwarf spheroidal galaxies, globular clusters and speculative Intermediate Mass Black Holes. In this paper, the H.E.S.S observations towards the Carina and Sculptor dwarf galaxies and the M15 globular cluster will be described. In the absence of clear signals, constraints on the Dark Matter particle annihilation cross-section in several particle physics scenarios are derived.

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1. Introduction

The HESS (High Energy Stereoscopic System) array is composed of four Imaging Atmospheric Cherenkov telescopes with $\sim$107 m^2 reflectors, located in the Khomas highlands of Namibia at an altitude of 1800 m above sea level. It detects Cherenkov light emitted by charged particles in atmospheric showers and is sensitive to very high energy (VHE) gamma-rays ($E_\gamma \geq 100$ GeV). The stereoscopic technique allows for an accurate reconstruction of the energy and arrival direction of gamma-rays, as well as an efficient hadronic background rejection in the 100 GeV - 100 TeV energy range [9]. The HESS instrument achieves an angular resolution of 5' and a point-like source sensitivity at the level of $2 \times 10^{-13}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ above 1 TeV at a 20° observation zenith angle for a 5σ detection in 25 hours [2]. In the context of WIMP models, WIMP particles annihilate by pairs, producing standard model particles. High energy gamma rays are produced, either directly or through the hadronization of the annihilation products. The gamma-ray flux expected from these annihilations can be decomposed in an astrophysical term and a particle physics term as [3]:

$$\frac{d\Phi(\Delta\Omega, E_\gamma)}{dE_\gamma} = \frac{1}{8\pi} \underbrace{\frac{\langle\sigma v\rangle}{m_{\mathrm{DM}}^2} \frac{dN_\gamma}{dE_\gamma}}_{Particle\,Physics} \times \underbrace{\bar{J}(\Delta\Omega)\Delta\Omega}_{Astrophysics}. \tag{1.1}$$

For the HESS experiment $\Delta\Omega \simeq 5\ 10^{-6} - 10^{-5}$ sr, depending on the analysis cut. The particle physics part contains the DM particle mass, m_{DM}, the velocity-weighted annihilation cross section, $< \sigma v >$, and the differential gamma ray spectrum from all final states weighted by their corresponding branching ratios, dN_γ/dE_γ. The last term is estimated by the parametrization given by Bergström et al [5], based on the annihilation of WIMPs into W pairs. The astrophysical term $\bar{J}$ is the integral of the square density over the line of sight.

The HESS collaboration has searched for annihilation signals towards several dark matter annihilation targets. This paper focuses on H.E.S.S searches towards the Sculptor and Carina dwarf spheroidal galaxies and the M15 globular cluster.

2. HESS dark matter searches towards the Sculptor and Carina dwarf galaxies

The Sculptor and Carina dwarf galaxies are among the most luminous dwarf spheroidal galaxies in the Local Group. They are located respectively at 79 kpc and 101 kpc from the sun. The observations of the Sculptor and Carina dSphs were conducted between January 2008 and December 2009. The amount of good quality data taken was 11.8 hours towards Sculptor and 14.8 hours towards Carina. No significant signal was seen at the position of either dwarf, resulting in 95% C.L. on the number of detected photons of 32.4 and 8.6. Equation 1.1 is used to calculate the corresponding exclusion limits on the DM annihilation cross-section. targets has to be modelled to obtain the astrophysical $\bar{J}$ factor. The dark halo of Sculptor is studied in details in Battaglia et al [4]. The NFW profile of Carina was taken from Walker et al [13] and the pseudo-isothermal model from Gilmore et al. [10]. The 95% exclusion limits on $< \sigma v >$ as a function of m_{DM} obtained with the HESS observation of the Sculptor dwarf galaxy are shown on the left panel of figure 1. The Sculptor galaxy has also been observed by the Fermi-LAT instrument on-board the Fermi satellite. The limits obtained by the Fermi collaboration[1] are also shown on the left panel of figure 1. The

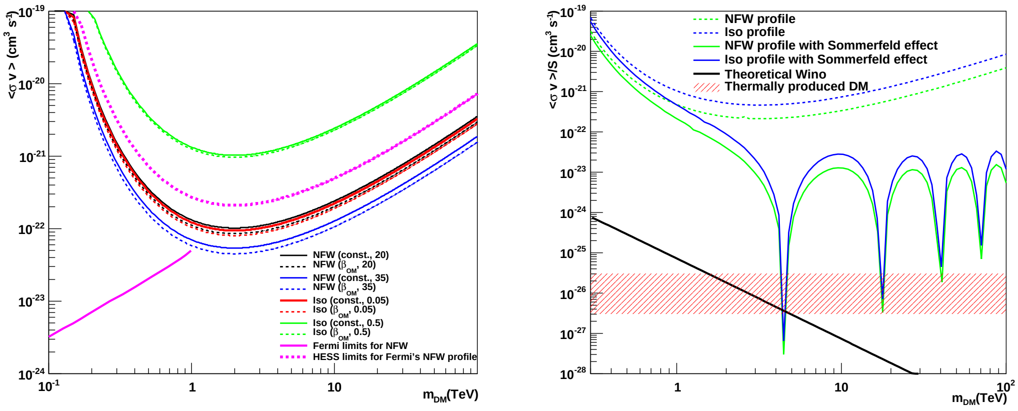

Figure 1: Left panel: 95 % C.L. upper limits on the velocity weighted WIMP annihilation cross-section $<\sigma v>$ as a function of the WIMP mass obtained with the Sculptor dwarf Galaxy. Several Galactic models are plotted. The purple solid line is the limit published by the Fermi-LAT instrument. Right panel: Same plot for the Carina dwarf Galaxy. The boost given by the Sommerfeld effect and the effect of Internal Brehmstrahlung are also shown. The red band gives the range of annihilation cross-sections compatible with the WMAP constraints on Ω_m.. The solid line is the theoretical wino $<\sigma v>$.

limits obtained by the HESS collaboration complement those of the Fermi collaboration at high energy. The flux from WIMP annihilations can be enhanced by several effects. The clumpiness of dark-matter gives an enhancement of just a few %. The largest boosts come from particle physics effects. The Sommerfeld effect [11] arises when the relative velocity of annihilating particles is small. It is thus especially important for dwarf galaxies and clumps which have velocity dispersions of the order of a few km/s. The right panel of figure 1 shows the 95% exclusion limits on $<\sigma v>$ as a function of m_{DM} obtained with the HESS observation of the Carina dwarf galaxy. The Sommerfeld effect, calculated in the case of a wino-like neutralino, is seen to lower the limits by several order of magnitudes. The annihilation flux can also be boosted in some particle models by internal bremstrahlung[7]. The effect of internal bremstrahlung on the annihilation into a W pair is also shown on figure 1. When this effect is taken into account, the limits are lowered by a factor 5 in the small m_{DM} regime.

Dwarf spheroidal galaxies are known to be embedded in a massive dark halo. The situation is more controversial for globular clusters (see Brodie & Strader 2006[8] for details). Some globular clusters of primordial origin could have formed in a dark halo. M15 belongs to this class of globular clusters.

3. M15 globular cluster

M15 (NGC 7078) is a well-studied Galactic GC, located at ∼10.1 kpc from the Sun. Its estimated mass is $\sim 5\times 10^5$ $M_\odot$. It has a very dense stellar core with radius $r_c \sim 0.2$ pc and a density of about 10^7 $M_\odot pc^{-3}$. The M15 globular cluster has been observed by the Whipple collaboration [14] in the context of dark matter searches. The dark halo model used by the Whipple collaboration is a NFW halo which was adiabatically compressed by the baryonic core collapse. This results in an increase of $\bar{J}$ of a factor of 2000. The 95 % C.L. limits on $<\sigma v>$ obtained are at the level of $10^{-23}\ cm^3/s$ for just 1.2 hour of observation.

The observations of M15 by HESS were carried out in 2006 and 2007. More than 15 hours of high quality data at a mean zenith angle of 37.0° were obtained. The core of M15 cannot be resolved given the angular resolution of HESS so that the signal would appear point-like. The data analysis reveals no significant gamma-ray signal at the nominal position. With $N_{observed}$ = 28, $N_{background}$ = 27, the 95% C.L. upper limit on the number of gamma-rays is $N_{\gamma}^{95\%C.L.}$ = 11.5

The dark halo modeling of M15 is performed in 2 steps. In the first step, the dark halo is adiabatically compressed during the collapse of the core of M15. The model used for the initial and final baryon and dark matter densities is described in Wood et al 2008[14]. The final baryon density is just the observed density. The dark matter is compressed in a time shorter than the dynamical time. At the same time, dark matter is heated up by stellar matter. This process is described by Merritt[12], and was neglected by Wood et al.[14]. Dark matter is scattered by stars in a time T_h inversely proportionnal to the stellar density. In the case of the center of M15, $T_h = 10^4$ years. The dark matter scattering is taken into account with the procedure described in Bertone & Fairban 2008[6] for the M4 globular cluster. The combined influence of adiabatic compression and dark matter scattering tend to cancel out and in the end, the preliminary 95 % C.L. exclusion limit for $<\sigma v>$ obtained by the HESS collaboration is at the level of 4 $10^{-23}\ cm^3/s$.

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