Indirect Dark Matter search with H.E.S.S.

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Dark Matter (DM) accounts for 25% of the mass-energy budget of the Universe but its nature is still to be discovered. The hypothesis that DM is made of Weakly Interacting Massive Particles (WIMPs) is explored by the latest generation of Astroparticle experiments. The indirect DM search methods are sensitive to self-annihilating/decay DM candidates leading also to the production of GeV-TeV gamma-rays in the final state. In particular these photons may be detected by Imaging Atmospheric Cherenkov Telescopes (IACT) like H.E.S.S.. Searches for WIMP-annihilation signatures from various candidate regions with enhanced DM density and related observations performed with H.E.S.S. are reviewed.

1 Introduction

The existence of DM assumed in the Standard Cosmological Model is supported by a series of observations such as rotation curves in spiral galaxies and velocity dispersion in elliptical galaxies, gravitational lensing and large scale distribution of galaxies. However, the nature of the DM remains unknown. Among many theoretical candidates for the DM particle, WIMPs predicted in theories beyond the Standard Model (SM) of particle physics such as the neutralinos introduced in Supersymmetry, are among the best motivated. A pair of WIMPs can annihilate and produce SM particles including photons. Unfortunately, potential direct annihilations into $\gamma\gamma$ or $Z\gamma$ producing a sharp line photon spectrum with a photon energy depending on the neutralino mass, are very rare because loop-suppressed. However DM can also annihilate to pairs of leptons or quarks, leading in subsequent processes to π^0 decays, resulting in a continuous photon spectrum.

2 The H.E.S.S. observations towards potential targets

The High Energy Stereoscopic System (H.E.S.S) located in Namibia is an array composed of four IACTs of large collection surface (107 m^2 per telescope) and fine pixelated cameras (960 PMTs). It is designed for high sensitivity measurements in the energy range from 100 GeV to 10 TeV (e.g. 1% of the Crab Nebula flux is detected after ∼25 h observation [1]). H.E.S.S. has started its observations in 2003; since then it has deeply explored a large fraction of the galactic sky accessible from the southern hemisphere and it has investigated, among other targets, the potential TeV γ-ray emission of exotic origin bringing a potential signature of WIMPs annihilations. Such a signal would depend on: 1) the intrinsic DM density distribution in the observed source; 2) the particle physics coupling of the WIMP; 3) the field of view $\Delta\Omega$ within which the signal is integrated. The resulting γ-ray flux is then usually factorized in two terms: $\Phi_{pp}(E_\gamma)\times J(\Omega)\Delta\Omega$. The first factor accounts for the particle physics, while the second factor is about the nature of the DM density distribution. In particular $\Phi_{pp}(E_\gamma) = 1/8\pi\langle\sigma v\rangle/m_\chi^2\times dN_\gamma/dE_\gamma$, where $\langle\sigma v\rangle$ is the velocity averaged annihilation cross section, m_χ is the WIMP particle mass, and dN_γ/dE_γ is the differential γ-ray spectrum summed over the whole final states with their corresponding branching ratios. In the astrophysical factor $J(\Omega)\Delta\Omega$, the integral along the line-of-sight (l.o.s.) of the squared density of the DM distribution in the object is averaged over the instrument solid angle of the integration region. Therefore the best places to look for DM will be those with the highest DM concentrations. Distance is also very important, since candidate DM-dominated systems that are located too far from us will yield too low WIMPs annihilation fluxes at Earth. For those reasons H.E.S.S. searches have focused on the Galactic Center and dwarf galaxy satellites of the Milky Way. Nearby Globular Clusters have been considered more recently as very suitable targets, since they may also yield similar γ-ray fluxes despite their distance. No signals have been found in the H.E.S.S. DM searches and upper limits on the $\langle\sigma v\rangle$ value as a function of m_χ and under specific assumptions on the DM density profile (e.g. $J(\Omega)$) are derived.

2.1 The Galactic Center region

One of the closest in distance and the most dense region of our Galaxy is its center, located at 8.5 kpc from the Earth, and potentially populated by an over-density of relic annihilating WIMPs. H.E.S.S. dedicated more than 100 hrs of observation to the Galactic center, and it is a target from which a γ-ray emission has actually been measured (i.e. source HESS J1745-290) coincident with the position of the supermassive black hole Sgr A* [2]. Although its temporal stability is consistent with a WIMP annihilation signal and the morphology is not excluding a potential consistency with the DM halo shapes predicted by some structure formation simulations, the detected emission shows an energy spectrum which extends beyond 10 TeV (requiring WIMP masses which are uncomfortably large) and a shape more consistent with an astrophysical origin. One should note also that several astrophysical objects are indeed present in the same field of view and that the galactic γ-ray diffuse emission is also contributing to the general picture. Assuming a NFW dark matter halo profile, 99% CL upper limits on the velocity-weighted annihilation cross section $\langle\sigma v\rangle$ are of the order of 10^{-24} - 10^{-23} cm^{3}s^{-1}. These limits can vary by plus or minus three orders of magnitude if one assumes other DM halo shapes. In particular large differences among different parametrisation occur if they are extrapolated down to the very center of the halo (e.g. where the NFW profile is more strongly peaked). At distances >10 pc, however, these differences are less pronounced, allowing one to put limits on $\langle\sigma v\rangle$ which do not depend strongly on the

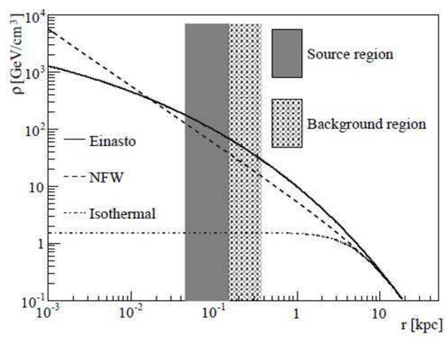

Figure 1: Galactic halo analysis: the source region and the region used for background estimation are indicated. NFW, Einasto and an isothermal profiles are shown for comparison.

shapes. In H.E.S.S. this fact was exploited by searching for a VHE γ-ray signal from DM annihilation in a region with a projected galactocentric distance of 45 pc - 150 pc excluding the Galactic plane [3]. The target region (observed for 112 h) corresponds to a circular source region of radius 1.0° centered at the Galactic Center. Contamination of the DM signal by local astrophysical γ-ray sources is excluded by restricting the analysis to Galactic latitudes $|b| > 0.3°$, effectively cutting the source region into two segments above and below the Galactic plane. For the data analysis, background regions are located further away from the Galactic Center than the source region. This is an important aspect, since, unavoidably, a certain amount of DM annihilation events would be recorded in the background regions, too, reducing a potential excess signal obtained in the source region. For the two studied halo profiles, NFW and Einasto, the expected DM annihilation flux is thus smaller in the background regions than in the source region (see Figure 1), making the measurement of a residual annihilation flux possible. Both source and background analysed spectra agree well within the errors, resulting in a null measurement for a potential DM annihilation signal, from which upper limits on $\langle\sigma v\rangle$ can be determined. These are among the best reported so far for the energy range 300 GeV - 10 TeV. In particular, for the DM particle mass of $\sim$ 1 TeV, values for $\langle\sigma v\rangle$ above 3 $\times 10^{-25}$ cm^3 s^{-1} are excluded for the Einasto density profile (see Figure 2 - left).

2.2 The Dwarf galaxies

Dwarf galaxies are considered DM-dominated objects, having a reduced astrophysical background since they have little or no recent star formation activity. Nearby dwarf galaxies in the Local Group have been observed with H.E.S.S.. The *Sagittarius Dwarf* (Sgr dSph) was observed in the 2006-2010 period for 45 h. No significant γ-ray excess was found above the estimated background at the nominal target position (RA $=18^h55^m59.9^s$, Dec = $-30°28'59.9''$, J2000.0). A 95% confidence level upper limit on the total observed numbers of γ-rays is computed. For that two different modelling of the dark matter halo of Sgr dSph have been considered: the NFW and an isothermal profile taking into account also disruptions by tidal winds by imposing a truncation in the dark matter density profiles [4]; both result in similar values for the J-factor yielding two exclusion limits of the same order $\sim 10^{-22}$ cm^3 s^{-1} (Figure 2). The *Sculptor* and *Carina* Dwarf spheroidal galaxies were observed between 2008 and 2009 for 11.8 and 14.8 hours respectively. No gamma-ray signal was detected at the nominal positions of these galaxies. 95% CL constraints on the velocity weighted WIMP annihilation cross section for both Sculptor and Carina range from $\langle\sigma v\rangle \sim 10^{-21}$ cm^3 s^{-1} down to $\langle\sigma v\rangle \sim 10^{-22}$ cm^3 s^{-1} depending on the dark matter halo model used. Possible enhancements of the γ-ray flux are studied: the Sommerfeld effect, which is found to exclude some dark matter particle masses, the internal Bremsstrahlung and clumps in the dark-matter halo distributions [5]. The *Canis Major* (CMa) overdensity has been observed by H.E.S.S. as a potential target for indirect DM search. The nature of CMa is still controversial and one scenario represents it as a dwarf galaxy. A total of 9.6 h of data were collected and no evidence for a very high energy γ-ray signal is found. Constraints on $\langle\sigma v\rangle$ are calculated using a NFW DM-halo model: assuming a total halo mass of $3\times10^8 M_\odot$, 95% CL exclusion limits of the order of $\sim 5\times10^{-24}$ cm^3 s^{-1} are reached in the 500 GeV - 10 TeV WIMP particle mass interval [6]. Although these are competitive limits on DM annihilation cross sections (as summarised in Figure 2) the present IACT instruments like H.E.S.S. do not have yet the required sensitivity to probe thermally-produced DM limit (of the order of $\sim 3\times10^{-26}$ cm^3 s^{-1}).

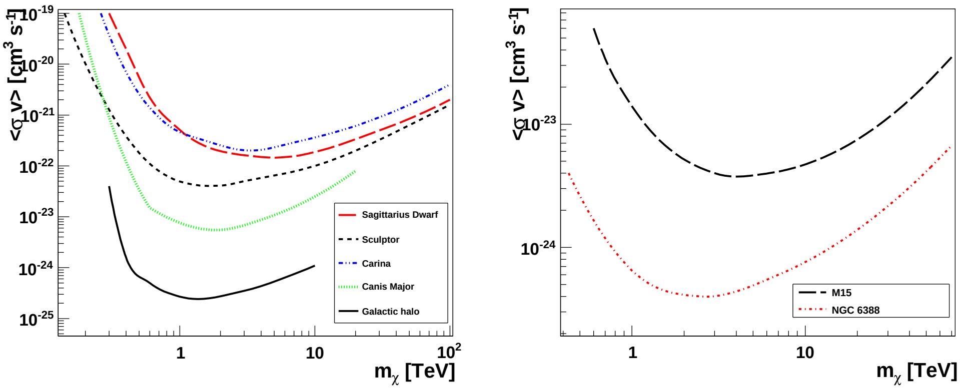

Figure 2: Left) Compilation of H.E.S.S. constraints in the DM search: 95% CL upper limits on $\langle \sigma v \rangle$ as a function of the WIMP mass. Right) 95% CL limits for M15 and NGC 6388 in the final state and starting with an initial NFW dark matter density profile.

2.3 Globular Clusters

Globular Clusters (GCs) are dense stellar systems found in halos of galaxies, with typical masses similar to dwarf galaxies but much more compact and dominated by a baryonic environment. However GCs are suggested as potential targets for indirect DM searches since in the primordial formation scenario they could have been formed in DM minihalos, before or during the reionization, before formation of galaxies and WIMPs could still be present in their environment. Under such hypothesis H.E.S.S. has observed M 15 which is a metal-poor GC (therefore of cosmological origin), and NGC 6388, which although metal-rich might host a $>10^3 M_\odot$ black hole suggested to be of primordial origin. The DM content of the globular clusters NGC 6388 and M 15 (observed for 27.2 and 15.2 hours respectively) is modelled taking into account the astrophysical processes that can be expected to influence the WIMPs distribution during the evolution of the globular cluster: the DM adiabatic contraction by baryons, the adiabatic growth of a black hole in the DM halo and the kinetic heating of DM by stars. The 95% confidence level exclusion limits on $\langle \sigma v \rangle$ are derived at the level of 10^{-25} cm^3 s^{-1} and few 10^{-24} cm^3 s^{-1} for NGC 6388 and M 15 respectively [7] (Figure 2). The upgrading of the H.E.S.S. system with a fifth telescope of larger size will provide observations at energies as low as 30 GeV addressing DM search at lower values of the candidate WIMP mass. First results are expected in 2012.

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