PROSPECTS FOR THE SEARCH OF SUPERSYMETRIC DARK MATTER WITH HESS

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The H.E.S.S. sensitivity is presented for the first telescope already operating in Namibia and for the four telescopes of phase 1 that will take data in 2004. Located in the southern hemisphere at a latitude of 22 degrees, HESS can look at the galactic centre and many galactic sources. Its sensitivity to a point source at Zenith is 10^{-11} cm^2.s^{-1} for an integrated spectrum above a threshold of 150 GeV for the first telescope and 2×10^{-11} cm^2.s^{-1} above 80 GeV for four telescopes. We discuss the potential of HESS to detect γ-ray emission from neutralino annihilation at the galactic centre for several halos models and for the globular cluster Omega Centauri using a semi-analytical dynamical model. We scan supersymetric models in the CMSSM framework with the help of SUSPECT and DARKSUSY.

1. H.E.S.S. experiment

H.E.S.S. [1], High Energy Stereoscopic System, is situated in the Khomas Highlands in Namibia. In phase I, the array is comprised of four imaging Cerenkov telescopes forming a 120 meter square.

A γ-ray in the energy range 100 GeV to 1 TeV entering the atmosphere produces an electromagnetic shower reaching its maximum development at an altitude of about 10 km . Few secondary charged particles hit the ground but they produce Cerenkov light detectable within a typical radius of 150 m from the shower impact point. The light collected by the mirror forms a image of elongated shape in the focal plane. This shape permits the rejection of cosmic ray nuclei induced showers and estimation of the primary γ-ray energy by comparison with Monte Carlo simulations. In the stereoscopic mode, the orientation of images allows for a geometrical identification of the shower direction and impact position which increases background rejection. A trigger condition with several telescopes suppresses single muon events which account for more than 50% of single telescope triggers.

The reflector of each telescope is composed of 382 mirrors giving a point spread function of 1 mrad after alignment for a total area of 107 m^2. The focal plane is equipped with a camera of 960 photomultiplier tubes (PMT) of diameter 0.16° giving a 5° field of view. The trigger is obtained by adding the output comparator signal of 64 PMTs in 38 overlapping sectors. During trigger processing, the signal is buffered in analogue ring memories which sample the signal is 128 cells of one nanosecond. Two parallel high/low gain channels are used for each PMT to give a large dynamic range along with a precise measurement of single photoelectrons [2]. The structures of the four telescopes are installed are equipped with drive systems. The mirrors of all telescopes are produced. The first telescope is completely equipped and taking data since June 2002. A LED panel is placed on the camera lid for PMT calibration, CCD cameras on the dish are used for pointing corrections, and a radiometer allows clouds in the field of view to be detected. In addition, a laser placed at the centre of the dish permits to measure the light collection and conversion efficiencies of Winston cones and PMTs. More than 100 hours of observation of sources have been already acquired. Phase I is planned to be completed by 2004.

The performance of HESS was evaluated with Monte Carlo simulations before the first telescope installation. The collection area for single telescope is 4×10^4 m^2 at 80 GeV and 0.3 km^2 at 1 TeV for vertical showers. The sensitivity in 50 hours for the detection at 5σ of an unresolved source at Zenith is $F(E_{\rm GeV} > 150) > 10^{-11}{\rm cm}^{-2}{\rm s}^{-1}$ for single telescope and $F(E_{\rm GeV} > 80) > 2 \times 10^{-11}{\rm cm}^{-2}{\rm s}^{-1}$ for at least two telescopes triggered out of four. The angular resolution is about 0.15° for a single telescope and 0.1° in stereoscopic mode.

2. Dark Matter sources for HESS

HESS can contribute to the search for Dark Matter in the form of neutralinos (χ) (see [3] for a comprehensive introduction) by searching for the γ-ray flux from neutralino annihilation in dense Dark Matter regions. As emphasized in [4], the most important annihilation channels for γ-rays are $\chi\chi \to WW, ZZ$ at high energies and $\chi\chi \to b\bar{b}, t\bar{t}, u\bar{u}$ with a softer spectrum. The γ-ray flux can be factorized into two parts, one depending on the χ mass, annihilation cross-section and branching ratios, and one on the dark matter density distribution for the considered source. Following the notation in [4], the integrated flux over a threshold energy $E_{\rm th}$, can be written in the form

$$\begin{aligned}\Phi_\gamma(E_{\rm th}) &= 5.6\times 10^{-10}\ {\rm cm}^{-2}\ {\rm s}^{-1}\times \sum_i \int_{E_{\rm th}}^{m_\chi} {\rm d}E \frac{{\rm d}N_\gamma^i}{dE}\left(\frac{\sigma_i v}{{\rm pb}\ c}\right)\left(\frac{100\ {\rm GeV}}{m_\chi}\right)^2 \\ &\quad \times \bar{J}(\Delta\Omega)\Delta\Omega \\ \bar{J}(\Delta\Omega) &= 4.3\times 10^{-22}\ {\rm GeV}^{-2}\ {\rm cm}^5 \times \frac{1}{\Delta\Omega}\int_{\Delta\Omega}\int_{l=0}^{\infty}\rho^2\ {\rm d}l\ {\rm d}\Omega\end{aligned}$$

When trying to select sources for HESS, one should straightforwardly choose those that maximize $\bar{J}\Delta\Omega$ and that are visible from HESS with a Zenith angle $\lesssim 30°$. The Galactic Centre is an obvious candidate (see section 2.1) but one can also consider external galaxies such as M87 [5], M31 [6], dwarf galaxies Ursa Minor, Sextans, Draco, Carina [5,7]. One prediction of cold dark matter is the existence of numerous dark matter clumps in the Milky Way halo [8] which could lead to a high γ-ray flux if nearby [9]. Other promising candidates are globular clusters as discussed in section 2.2.

2.1. *Galactic Centre*

Many authors have studied the γ-ray signal from neutralino annihilation at the Galactic Centre. The predicted flux vary of many orders of magnitude with the halo density profile assumption. For instance [10] consider several halo models which result in $\bar{J}_{0.15}(\Delta\Omega = 2\times 10^{-5}\ {\rm sr}) = 29$ for a modified isothermal sphere, 9.6×10^3 for Navarro, Frenk and White model (NFW) and 8.3×10^6 for Moore's profile. The use of micro-lensing optical depth from the Galactic Centre tends to constrain severely the dark halo [11], leading to a maximum value of $\bar{J}_{0.15} = 62$. However the central black hole can dramatically modify the central distribution of Dark Matter. In the case where this black hole grows adiabatically at the halo centre [12], the γ-ray flux can reach the level of the EGRET source observed at the Galactic Centre [13] (but see also [14]), in which case HESS has the sensitivity to see the spectrum above 100 GeV.

2.2. *Globular Clusters*

We already mentioned that CDM predicts numerous sub-galactic clumps. Even though less massive, their proximity could lead to high $\bar{J}(\Delta\Omega)$. For instance, Peebles [15], followed by [16], proposes that some of the galactic globular clusters (GC) may be formed in the first virialized CDM halos. GC dynamics could be explained without dark matter, however distributions of stars in the GC cores are weakly sensitive to the dark halos when the central dark matter density is about 10% of the stars (see for instance a study based on multi-mass King models [17] for baryonic dark matter). Nevertheless, the extent and mass of the dark halo can be constrained from the observation of stars being tidally removed from the GC [18].

3. Omega Centauri

Let us focus on ω Centauri. With $M = 2.9 \times 10^6$ $\mathrm{M}_\odot$, $M/L = 3.6$, its retrograde orbit and metallicity suggest that ω Centauri is likely to be a dwarf spheroidal captured by the Milky Way [19,20]. Carraro et Lia [21] have simulated the evolution of a CDM halo with $\rho \propto 1/r$ of 10^8 $\mathrm{M}_\odot$ with 10% hydrogen with a N-body/hydrodynamical code. Including hydrogen cooling and star formation (with a rate $\sim 20\%$), they obtain a GC comparable to ω Centauri with a central density $\rho_0^{\rm stars} = 2660$ $\mathrm{M}_\odot.\mathrm{pc}^{-3}$ and a core radius r_c=3.2 arc-min, the dark halo extends to about one degree. Another point is that there is an EGRET upper limit [23] on the flux for 100 MeV $< \mathrm{E}_\gamma <$ 30 GeV which is $F_{\rm EGRET} < 1.78 \times 10^{-7}$ photons cm^{-2} s^{-1}.

3.1. *Model*

The assembly of stars is described via its phase-space distribution function [24].

$$f(v, L_z) = C \left\{ \exp\left[-\frac{v^2}{2\sigma^2} - \frac{\phi - \phi_t}{2\sigma^2} \right] - 1 \right\} \exp\left(\frac{\Omega L_z}{\sigma^2} \right) \tag{1}$$

where C is a normalization constant, σ is a dispersion velocity parameter, ϕ_t is the tidal potential (*i.e.*, the potential difference between the centre and the physical boundary of the cluster), Ω is the angular rotation parameter and L_z the angular momentum. We adopt the same functional form (1) for the phase space density of Dark Matter (DM). The interaction between these two components drives the distributions toward thermalization for which $m_{\rm DM}\sigma^2_{\rm DM} \sim m_{stars}\sigma^2_{\rm stars}$. Since the dark matter particles are much lighter than stars, we consider the limit $\sigma_{\rm DM} \to \infty$.

3.2. *Comparison with observations*

We assume a central density of the Dark Matter $\rho^0_{\rm DM}$ labeled by its ratio to the density of stars $\alpha = \rho^0_{\rm DM}/\rho^0_{\rm stars}$. The model is first fitted on the observed surface brightness profile (table 1 in [25]). Then the velocity dispersion is fitted using the maximum likelihood method of Gunn & Griffin [26]. We use for this purpose the measured radial velocities of 471 giant stars in Ω Centauri [27]. The central star density is then scaled in order to match the core radius obtained from the surface brightness fit. We obtain good agreement with data for $\alpha \lesssim 1.5$ (see Fig. 1 for $\alpha = 1$).

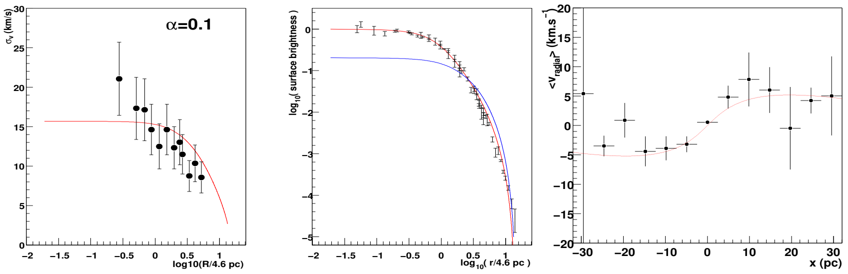

Figure 1. Left: Velocity dispersion of stars; Centre: Normalized Surface Brightness profile; Right: Radial velocities as a function of projected distance to the rotation axis. The curves correspond the model. The lower curve in the central panel is the normalized surface density of Dark Matter.

4. HESS Potential

We scan CMSSM parameter space with the help of SUSPECT and DARKSUSY for the calculation of branching ratios, γ-ray spectrum from secondary particle hadronization, and for the relic density calculation. For these models, we consider $A_0 = 0$, $m_0 < 3$ TeV, $m_{1/2} < 1$ TeV, $0.04 < \Omega_{\rm DM} h^2 < 0.25$ and take into account accelerator constraints from the Particle Data Group (2000). Figure 2 shows the γ-ray flux for Omega Centauri are obtained considering $\alpha = 0.125$ which gives $\bar{J}(\Delta\Omega = 2 \times 10^{-5}\ \mathrm{sr}) = 3 \times 10^5$.

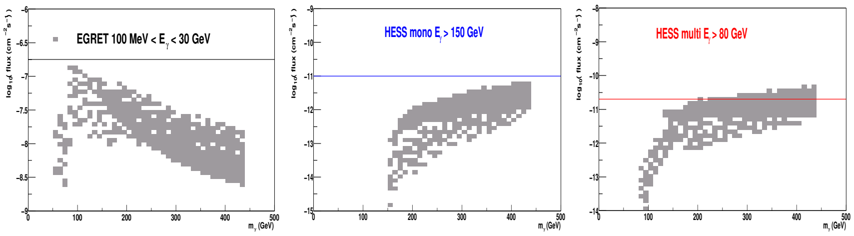

Figure 2. γ-ray flux from Omega Centauri with $\alpha = 0.125$ as a function of neutralino mass for a set of CMSSM models. Left: between 100 MeV and 30 GeV with EGRET limit; Centre: above 150 GeV with H.E.S.S. sensitivity with one single telescope; Right: above 80 GeV with H.E.S.S. sensitivity with four telescopes.

5. Conclusion

H.E.S.S. will observe the Galactic Centre and therefore should provide constraints to the model of Bertone, Silg and Silk [12]. However other sources such as globular clusters are interesting for γ-ray detectors. We have shown that for Omega Centauri, a density fraction of 10% of Dark Matter is theoretically well motivated and not observationnaly constrained and can lead to γ-ray fluxes within the sensitivity limit of H.E.S.S. in stereoscopic mode.

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