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SEARCH FOR A DARK MATTER ANNIHILATION SIGNAL FROM THE GALACTIC CENTER WITH H.E.S.S.

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Abstract. The annihilations of WIMPs that may compose Dark Matter in the Galaxy would produce high energy gamma-rays in the final state. It is shown that the spectrum of the source HESS J1745-290 in the Galactic Center region is unlikely to be interpreted by such a signal. Constraints will be derived on a possible component due to Dark Matter annihilation. Future observations of dwarf spheroidal galaxies are also promising for detecting a possible gamma-ray signal from Dark Matter. The predictions for Sagittarius dwarf spheroidal galaxy in the framework of the supersymmetric and Kaluza-Klein models are also discussed.

1 Introduction

Latest results from high accuracy astrophysical and observational cosmology experiments provide convincing evidence that most of the matter in the Universe is composed of yet undicovered non-baryonic Dark Matter (DM) particles. The recent measurements on the cosmic microwave background fluctuations with WMAP (Spergel et al., 2003) constraints the Cold Dark Matter density to be in the range $0.095 < \Omega_{\mathrm{CDM}}\mathrm{h}^2 < 0.129$ at the 2σ level. At the galactic scale, evidence for DM comes from rotation curves which require a DM halo to reproduce the observed orbital velocities.
Among the best motivated candidates is a weakly interacting massive particle (WIMP). In R-parity conserved supersymmetric extensions of the Standard Model of particle physics, the lightest neutralino $\tilde{\chi}$, being the lightest supersymmetric particles (LSP) in various scenarii, is a suitable candidate intended to compose non-baryonic Dark Matter (Jungman et al., 1996). Another plausible candidate is provided by universal extra dimension theories. In the four-dimensionnal effective theory, all the particles are accompagnied by a tower of increasingly more massive Kaluza-Klein (KK) states. If the KK parity is conserved, the lightest Kaluza-Klein particle (LKP) is stable (Servant & Tait, 2003). Being neutral and non-baryonic, it is a viable candidate, the best-motivated being the first KK mode of the hypercharge gauge boson, $\tilde{B}^{(1)}$.
Besides collider experiments and direct searches in dedicated underground sites, the indirect searches via γ-rays produced by self annihilation of DM particles in deep gravitational wells has been suggested. High density regions such as the Galactic Center (GC) could produce detectable very high energy γ-ray flux (Bergström 2000). Other targets such as dwarf spheroidal galaxies may produce a strong signals in γ-rays. In this paper, the results from the observations of the Galactic Center with the H.E.S.S. array of imaging atmospheric Cherenkov telescopes (Bernlöhr et al., 2003) are discussed in terms of a DM annihilation signal. Prospects of indirect detection in the close-by dark matter dominated Sagittarius dwarf galaxy are investigated in MSSM and Kaluza-Klein scenarii.

2 γ-rays from Dark Matter annihilation

The annihilation of DM particles can produce γ-rays in several ways. For MSSM scenarii, the annihilation of neutralinos can result first in a continuum of gamma-rays from the hadronization and decay of π^0's generated in the cascading of annihilation products. γ-rays may also result from loop induced annihilation processes such as $\tilde{\chi}\tilde{\chi} \rightarrow \gamma\gamma$ or $\chi\chi \rightarrow Z\gamma$ leading to very distinct monoenergetic signals of $\mathrm{E}_\gamma = \mathrm{M}_{\tilde{\chi}}$ and $\mathrm{E}_\gamma = \mathrm{M}_{\tilde{\chi}}/(1-\mathrm{m}_{\mathrm{Z}}^2/4\mathrm{M}_{\tilde{\chi}}^2)$ respectively. However, the line-producing processes yield smaller fluxes than continuum emission. In the case of Kaluza-Klein scenarii, $\tilde{B}^{(1)}$ pairs annihilate preferentially into charged lepton pairs. Cascading decays of $\mathrm{q}\bar{\mathrm{q}}$

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final states lead to secondary γ-rays (Bergström et al., 2005).
For a Dark Matter particle of mass m_{DM} accumulating in a spherical halo of mass density profile ρ, the γ-ray flux $d\Phi(\Delta\Omega, E)/dE$, is proportional to the line-of-sight-integrated squared density profile, multiplied by the velocity-weighted annihilation cross-section $\langle\sigma v\rangle$, and the number of photons dN_γ/dE. The calculation of the γ-ray flux leads to the formula :

$$\frac{d\Phi(\Delta\Omega, E)}{dE} = F_0 \frac{dN_\gamma}{dE} \frac{\langle\sigma v\rangle}{\langle\sigma v\rangle_{ref}} \left(\frac{1TeV}{m_{DM}}\right)^2 \bar{J}(\Delta\Omega)\,\Delta\Omega \tag{2.1}$$

with $F_0 = 2.8 \times 10^{-12} \mathrm{cm}^{-2}\mathrm{s}^{-1}$. $\bar{J}$ corresponds to the average of J over the solid angle $\Delta\Omega$ usually matching the angular resolution of the instrument, normalized to the local DM density of 0.3 GeV cm^{-3} :

$$J = \frac{1}{8.5\,kpc} \left(\frac{1}{0.3\,GeV cm^{-3}}\right)^2 \int_{l=0}^{\infty} \rho^2(l)dl \tag{2.2}$$

3 Dark Matter interpretation of the Galactic Centre VHE γ-ray signals seen by H.E.S.S.

Data from 2003 Galactic Centre observations reveal a strong source of TeV γ-rays, HESS J1745-290, from the direction of the Galactic Centre (Aharonian et al., 2003). The GC region has been re-observed in 2004 and the initial discovery has been confirmed with a significance of about 38σ. Observations from 2003 and 2004 shows no indication for variability. The source position assuming a point-like source derived from 2004 dataset lies 5" $\pm$ 10"$_{\mathrm{stat}}$ $\pm$ 20"$_{\mathrm{syst}}$ from the supermassive central black hole Sgr A*. However, even the good pointing accuracy of the instrument of 20", the SNR Sgr A East and the recently discovered PSR G359.95-0.04 can not be ruled out as sources of the observed TeV γ-ray flux. The energy spectrum of the excess is presented on Fig. 2. The photon index is $\Gamma = 2.29 \pm 0.05_{\mathrm{stat}} \pm 0.15_{\mathrm{syst}}$ (Rolland & Hinton 2005). 90 cm images from radio data are overlaid (La Rosa et al., 2000).

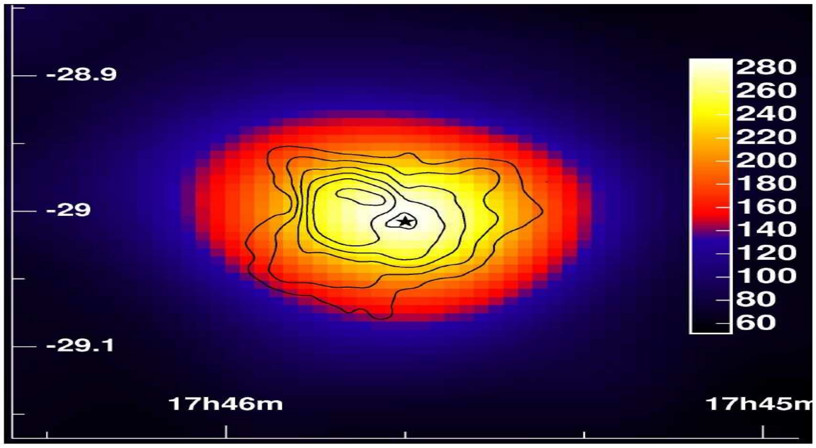

Fig. 1. VHE γ-ray images of the Galactic Center region (Aharonian et al., 2006). The smoothed count map for 2004 H.E.S.S. data shows a strong excess of VHE γ-rays from HESS J1745-290 close to the location of the Sgr $A^\star$ marked with a black star. The best localisation of HESS J1745-290 is within 1' of Sgr $A^\star$. Black contours show 90 cm images from radio data (La Rosa et al., 2000).

Besides plausible astrophysical origins, is the alternative of annihilation of DM in the central cusp of our Galaxy. On the spectrum presented on Fig. 2, no indication for γ-ray lines was found. The observed γ-ray flux may result from DM annihilation only. In the representation given in Fig. 2, $E^2 d\Phi/dE$ as a function of the γ-ray energy E, the neutralino annihilation is characterized by a plateau for γ-ray energies E_γ much lower than the neutralino mass m_χ. A rapid decrease is observed when the $E_\gamma \sim m_\chi$. We observe that the spectrum extended up to masses about 10 TeV requires too large neutralino masses which are unnatural in phenomenological MSSM scenarii. The Kaluza-Klein models provide harder spectrum but significatively deviate from the measured one. Non minimal version of the MSSM may yield flatter spectrum with mixed 70% b $\bar{\mathrm{b}}$ and 30% $\tau^+\tau^-$ final states.

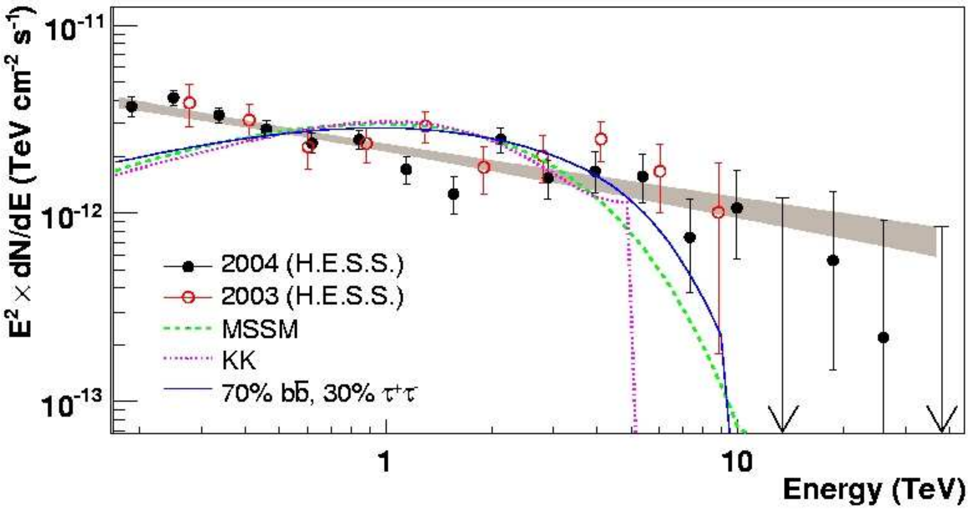

Fig. 2. Spectral energy density $E^2 \times dN/dE$ of γ-rays from HESS J1745-290 for 2003 (red empty circles) and 2004 (black filled circles) dataset from the H.E.S.S. observation of the Galactic Centre. The shaded area shows the best power law fit curve to the 2004 data points. The best-fit curves for a 14 TeV neutralino annihilation spectrum in a phenomenological MSSM (dashed green line), a 5 TeV KK DM particle (dotted pink line) and a 10 TeV DM particle annihilating into 70% b $\bar{b}$ and 30% $\tau^+\tau^-$ in final state (solid blue line). The hypothesis from Dark Matter annihilation only is highly disfavoured from the H.E.S.S. measured spectrum.

Even this scenario does not fit to the measured spectrum. The hypothesis that the spectrum measured by H.E.S.S. results from DM particle annihilation only is highly disfavoured.

On the other hand, the observed signal may result from the superposition of a DM annihilation signal on a power-law spectrum astrophysical background. In this case, using a NFW profile, only a constraint on the velocity-weighted annihilation cross-section $\langle \sigma v \rangle$ can be derived (Ripken et al., 2005). Fig. 3 shows 99% C.L. limits on $\langle \sigma v \rangle$ from H.E.S.S. data in the case of pMSSM and KK DM models. Predictions from pMSSM models

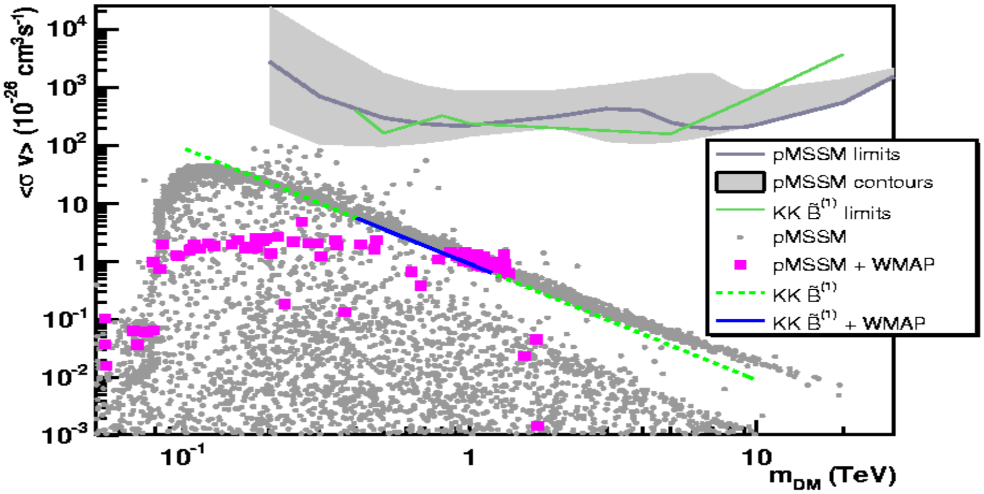

Fig. 3. Exclusion limits on $\langle \sigma v \rangle$ versus the DM particle mass for NFW DM halo. Limits derived from H.E.S.S. data for pMSSM (grey line and light grey contours) and KK DM models (green line) are shown. The grey points and dashed green lines correspond to pMSSM and KK models respectively, allowed by particle physics. Pink boxes and blue segment represent DM models allowed by cosmological constraints.

calculated with DarkSUSY4.1 (Gondolo et al., 2004) and KK models allowed by particle physics are shown as well as those satisfying cosmological constraints. The limits on $\langle\sigma v\rangle$ derived from H.E.S.S. data for both DM models are $\mathcal{O}(10^{-24})\mathrm{cm}^3\mathrm{s}^{-1}$. With a NFW profile, no $\langle\sigma v\rangle$ from SUSY nor KK DM models can be ruled out.

4 Detection prospects of H.E.S.S. from the Sagittarius dwarf spheroidal galaxy

Dwarf spheroidal galaxies such as Sagittarius, Canis Major or Draco, discovered recently in the Local Group, are amongst the most extreme DM dominated environnement. Closely dwarfs are ideal astrophysical systems to be used to probe the nature of DM as they usually consist of a stellar population with no hot or warm gas, no cosmic ray population and little dust. Sagittarius dwarf located at a distance of about 25 kpc with a size of $3^\circ \times 8^\circ$, presents a high M/L ratio and a cuspy luminous profile (Monaco et al., 2005) thus consists of a source of interest for indirect dark matter search.

From calculations in the framework of effective pMSSM and KK models, predicted γ-ray fluxes have been derived for Sagittarius dwarf galaxy. The number of γ and well as its significance has been calculated. Results are presented in Tab. 1.

Models	Exposure (hrs)	Nγ	Nσ
Best pMSSM	50	650	13
KK $\tilde{\mathrm{B}}^{(1)}$	50	39	0.8

Table 1. H.E.S.S. sensitivity to neutralino and KK $\tilde{\mathrm{B}}^{(1)}$ DM annihilation in the Sagittarius dwarf spheroidal galaxy. Values are derived assuming a NFW profile. Acceptance and rejection effeciency are taken from the GC analysis.

5 Conclusion

The TeV γ-ray energy spectrum measured by H.E.S.S. in the GC region is unlikely to be interpreted in terms of neutralino or KK $\tilde{\mathrm{B}}^{(1)}$ DM annihilation. In the case of a background component with a power-law spectrum, loose constraints on the velocity-weighted annihilation cross-section have been derived. Neither pMSSM nor KK models can be ruled out. Indirect DM searches with H.E.S.S. will follow with observations on the Sagittarius dwarf spheroidal galaxy.

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