On the detectability of gamma-rays from Dark Matter annihilation in the Local Group with ground-based experiments

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Abstract

Recent studies have suggested the possibility that the lightest supersymmetric particle is a suitable dark matter candidate. In this theoretical framework, annihilations in high density environments like the center of dark matter haloes may produce an intense flux of gamma-rays. In this paper we discuss the possibility of detecting the signatures of neutralino annihilation in nearby galaxies with next generation ground-based detectors.

1. Introduction

Revealing the nature of the Dark Matter (DM) is one of the most challenging problems, from both a theoretical and experimental viewpoint, facing particle physics and cosmology today. The concordance model [8] requires that non-baryonic DM should contribute to $\sim 26\%$ of the universe content. Moreover, according to the Cold Dark Matter (CDM) paradigm, the bulk of DM is required to be non-relativistic at the time of decoupling. A popular candidate for CDM is the Lightest Supersymmetric Particle (LSP). In most supersymmetry (SUSY) breaking scenarios this is the neutralino χ. Assuming gaugino-universality, its mass is constrained by accelerator searches and by theoretical considerations of thermal freeze-out to lie in the range $50\ GeV \lesssim m_\chi \lesssim 10\ TeV$ [4,5]. If R-parity is conserved, the LSP can change its cosmological abundance only through annihilation.

The Galactic Centre (GC) is the nearest high density region and thus represents the most obvious site where to look for DM annihilation signals. However, there are practical constraints: the GC is not visible at small zenith angles from sites in the Northern hemisphere, where most of the experiments are located; on the other hand, satellite instruments have small effective detection areas for high energy photons, and can investigate only up to $\sim 300\ GeV$. In this paper we study the sensitivity of ground-based experiments to γ-photon signals coming from the galaxies of the Local Group (LG).

2. Signal and sources

Expected photon fluxes from neutralino annihilation are given by

$$\frac{d\Phi_\gamma(E_\gamma)}{dE_\gamma} = \left[N_{\gamma\gamma} b_{\gamma\gamma} \delta(E_\gamma - m_\chi) + N_{Z\gamma} b_{Z\gamma} \delta\left(E_\gamma - m_\chi(1 - \frac{m_Z^2}{4m_\chi^2})\right) + \right.$$
$$\left. \sum_F \frac{dN_\gamma^F}{dE_\gamma} b_F \right] \frac{\langle\sigma v\rangle_a}{m_\chi^2} \frac{1}{4\pi D^2} \int_0^{r_{max}} \rho_\chi^2(r) 4\pi r^2 dr. \tag{1}$$

The first two terms in square brackets represent the γ-lines with branching ratios of $\sim 10^{-3}$. The photon flux is dominated by the continuum emission given by the sum running over all the F final states. At the tree-level neutralinos annihilate into fermions, gauge bosons, Higgs particles, gluons. Branching ratios depend on the assumed SUSY model. Decay and/or hadronization in π^0 give a continuum spectrum of γ-photons emerging from the π^0 decay [2]. $\langle\sigma v\rangle_a$ is the thermally-averaged annihilation cross-section. The DM is assumed to be concentrated in a single, spherical DM halo of radius r_{max} and density profile $\rho_\chi(r)$ located at distance D from the observer. The halo density profiles are poorly constrained by observations. In this work we adopted the Moore profile, which is supported by numerical experiments [6]: $\rho_\chi = \rho_s(\frac{r}{r_s})^{-1.5}(1 + (\frac{r}{r_s})^{1.5})^{-1}$, where ρ_s and r_s are scale quantities; it was truncated at the radius r_{min} where the self-annihilation rate equals the dynamical time [1]. We imposed $\rho_\chi(< r_{min}) = \rho_\chi(r_{min})$.
Since we are interested in nearby sources, we have considered the nearest 45 LG galaxies, shown in the left panel of Fig. 1. The size of each circle is proportional to the expected γ-ray flux within 1 squared degree, with a Moore density profile and a cutoff radius r_{min}. Zenithal visibility from different sites on the earth of M31 and the GC is shown on the right panel.
 Hierarchical clustering in the CDM scenario predicts the presence of sub-haloes that accrete into larger systems. DM haloes should host a population of sub-haloes with a distribution function giving the probability of finding a sub-halo of mass m at a distance r from the halo center: $n_{sh}(r, m) = A(m/m_H)^{-1.9}(1 + \tilde{r}^2)^{-1.5}$, $\tilde{r} = r/r_c^{sh}$ where r_c^{sh} is the core radius of the sub-haloes distribution, m_H is the mass of the parent halo and A is a normalization constant [3]. Mass stripping and tidal heating modify both the size and the shape of sub-haloes. If we define the sub-halo tidal radius, r_{tid}, as the distance from the sub-halo center where the tidal forces of the parent halo potential equal the self-gravity of the sub-halo. One can assume that all the mass beyond r_{tid} is lost in a single orbit without affecting its central density profile. In [7] the effect on the expected fluxes has been studied varying the mass clumped in sub-haloes, m_{cl}, the value of r_c^{sh}, the minimum mass for sub-haloes, m_{min}, and the sub-haloes shape. Shallower density distributions and the presence of a black hole at the centre of the parent haloes have been taken into account as well. It is found that the fluxes from the Small
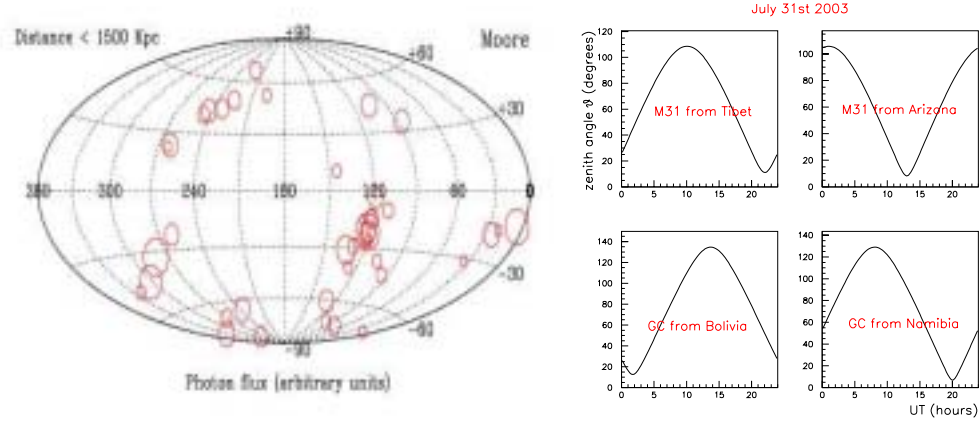
Fig. 1. Left: Aitoff projection of the 45 nearest LG galaxy distribution in Galactic coordinates. The size of each circle is scaled to the γ-photons flux emitted within 1 squared degree from the halo center. Right: zenith angle under which M31 and the GC are seen from sites of various ground-based experiments.

and Large Magellanic Clouds (SMC, LMC) and M31 are well above the Galactic level for any choice of these parameters. In some cases, like M33 and Sagittarius, extragalactic and Galactic contributions are comparable. In the left panel of Fig. 2 is shown the contribution to γ fluxes from the MW smooth halo (dashed line) and LG galaxies above the Galactic background (starred symbols) as a function of the viewing angle ψ from the GC. The effect of including sub-haloes with tides calculated at the circular orbit is also shown, both for the MW (solid line) and for the LG galaxies (big dots). $m_{cl} = 10\% \ m_H$, $r_c^{sh} = 30\%$ of the virial radius of the parent halo, $m_{min} = 10^6 M_\odot$, $m_\chi = 1 \ TeV$ and $\langle \sigma v \rangle_a = 10^{-25} \ cm^3 \ s^{-1}$ were assumed to obtain this figure.

3. Ground-based detectability of DM photons

The sensitivity of experimental apparates is computed by comparing the number of γ events expected from the source to the fluctuations of background events. Due to the low signal level, the electron and diffuse γ-ray backgrounds must be taken into account besides the usual hadron background:

$$\frac{n_\gamma}{\sqrt{n_{bkg}}} = \frac{\sqrt{T_\delta}\epsilon_{\Delta\Omega}\int\int\epsilon_\gamma A_\gamma^{eff}(E,\theta)\frac{d\phi_\gamma^{DM}}{dE}dEd\theta}{\sqrt{\Delta\Omega\int\int\left[(1-\epsilon_h)A_h^{eff}(E,\theta)\frac{d\phi_h}{dE} + \epsilon_\gamma A_\gamma^{eff}(E,\theta)\left(\frac{d\phi_e}{dE} + \frac{d\phi_\gamma^{diff}}{dE}\right)\right]dEd\theta}}.$$

(2)

T_δ is the time during which the source is seen with zenith angle $\theta \leq 30^o$, $\epsilon_{\Delta\Omega} = 0.7$ is the fraction of signal events within the optimal solid angle $\Delta\Omega$, $\epsilon_{\gamma,h}$ are the identification efficiencies of showers induced by photons or hadrons. Sensitivities
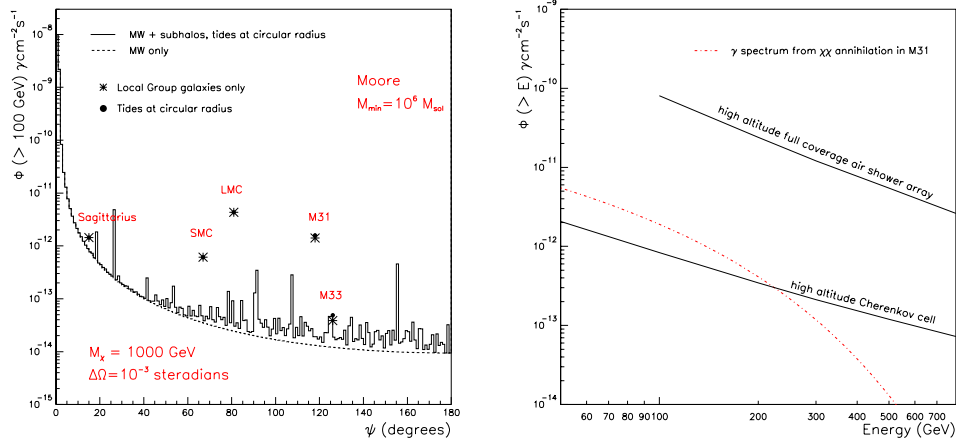
Fig. 2. Left: integrated γ-photon flux $> 100\ GeV$ from neutralino annihilation. Right: 5σ sensitivity of a high altitude full coverage air shower detector array (in 1 year of data taking, $\epsilon_{\gamma,h} = 75\%$, $\Delta\Omega = 10^{-3}\ sr$) and of a high altitude Cherenkov cell (in 20 days, $\epsilon_{\gamma,h} = 99\%$, $\Delta\Omega = 10^{-5}\ sr$) to γ-photons from $\chi\chi$ annihilation in M31.

for a $\sim 80 \times\ 80\ m^2$ high altitude full coverage array (effective areas $A_{\gamma,h}^{eff}$ were taken from [9]) and for a high altitude Cherenkov cell (an effective area of $10^4\ m^2$ has been assumed) have been computed. The resulting curves are plotted in the right panel of Fig. 2 (solid lines), where expected γ flux from $\chi\chi$ annihilation is also shown for comparison (dot-dashed curve).

In conclusion, we found that DM annihilation signatures in extragalactic dense objects could be revealed with a significance of $5\ \sigma$ with next generation ground-based detectors mainly based on the Cherenkov tecnique.

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