DARK MATTER DETECTION IN GAMMA ASTROPARTICLE EXPERIMENTS

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Abstract

The content of matter in the Universe is estimated to be the 27% of its critical density. It is almost universally accepted that most of this matter is non-baryonic. Constraints from primordial nucleosynthesis and cosmic background radiation measurements impose that the baryonic content of the Universe cannot exceed the 4% of the critical density, so the nature of the remaining 23% has yet to be identified. In this sense, one of the most promising candidates is represented by supersymmetric neutralinos. If they exist, they give rise to relic densities in the required range, and are very well motivated in the framework of theoretical extensions of the Standard Model of particle physics. In addition to direct neutralino searches and collider experiments, neutralino annihilation into gamma rays, neutrinos and synchrotron emission from the charged products represents a reliable way of detecting these intriguing particles. The strongest signals are expected to come from the Galactic Center and from the nearest dwarf spheroidals. Clumps of dark matter in galactic haloes are well predicted by high resolution cold dark matter numerical simulations. In this work we present our studies on the gamma-ray emission from the Galactic Center and from the Draco dwarf spheroidal. We investigate the effect of clumpiness on the detection of signals from neutralinos for different mass density profiles. One of the scientific goals of the MAGIC telescope are just searches for the stable lightest supersymmetric particle in the different physical scenarios in which they are produced. Assuming MAGIC specifications, we draw some conclusions about the potentialities of this telescope in such a kind of investigation.
1 Introduction

One of the most promising candidates for halo dark matter are weakly interacting massive particles (WIMPs), although it is not excluded that particles of other kinds, not yet predicted by particle physics models, might represent the solution of this issue. These particles give a relic density which is of the right order of magnitude to explain the dark matter on all scales. Neutralino is the lightest stable supersymmetric particle in most models, so we focus on detection prospects of such a candidate, working either in the MSSM or in the mSUGRA frameworks.

High resolution numerical simulations of dark haloes formation suggest that the strongest signals are likely to come from the Galactic Center and from the nearest dwarf spheroidals. The persistence of substructures in these simulations induces to argue that at least a fraction of the dark matter in haloes is clustered in clumps.

Taking a phenomenological approach, we here discuss the implications of clumpiness on neutralino dark matter searches.

2 Particle physics models

Minimal supersymmetric model has many free parameters, but with some assumptions we are left with seven parameters in the MSSM model and with five parameters in the mSUGRA setup, namely the supersymmetric extension of the Standard Model defined in a supergravity inspired framework. For details about the parameters which fully define the action of MSSM and mSUGRA see Ref. [6, 7].

Table 1 shows the range of parameter values used in our scan of the MSSM space. Choosing the cosmologically interesting relic density range $0.094 < \Omega \chi h^{2} < 0.129$, we generate in this framework 500000 models and impose that they are not excluded by accelerators constraints.

We sample the 5-dimensional mSUGRA parameter space choosing a few values of $t g \beta$ and $A_{0}$, and slices along the $m_{1/2}, m_{0}$ plane for both $\text{sign} \mu$. We consider both the slepton and the stop coannihilation regions and calculate the relic density with all coannihilations. Visited benchmark points are indicates at the upper left of Fig. (3).

Table 1. Scans of the MSSM space.

| Parameter | Unit | $\mu$ | $M_{2}$ | $m_{1/2}$ | $m_{0}$ | $A_{0}$/|$m_{0}$ | $A_{t}$/|$m_{0}$ |
|-----------|------|-------|--------|-----------|--------|-----------|-----------|
| Min       | GeV  | 10    | 10     | 1         | 10     | -3        | -3        |
| Max       | GeV  | 10000 | 10000  | 60        | 1000   | 3         | 3         |
3 Dark matter distribution models

We focus on indirect searches of neutralinos in the Milky Way and in the Draco dwarf spheroidal. We model haloes of these galaxies using the following dark matter profiles:

- **Navarro–Frenk–White cuspy model** [4]:
  \[ \rho_{cusp}(r) = \rho_0 \left( \frac{r}{r_s} \right)^{\gamma} \left( 1 + \left( \frac{r}{r_s} \right) \right)^{3-\gamma}, \]
  \( \gamma = 1; \)

- **Moore & al. cuspy model** [3]: the same as above with \( \gamma = 1.5; \)

- **a milder cuspy profile** [2]: the same as above with \( \gamma = 0.5; \)

- **Burkert & al. profile** [5]:
  \[ \rho_{Burk}(r) = \rho_0 \left( 1 + \left( \frac{r}{r_s} \right) \right) \left( 1 + \left( \frac{r}{r_s} \right)^2 \right). \]

4 Gamma ray flux

Neutralino annihilation in the galactic halo produces both a gamma-ray flux with a continuum energy spectrum and monochromatic gamma-ray lines. Considering a detector with an angular acceptance \( \Delta \Omega \) pointing in a direction of galactic longitude and latitude \((l, b)\), the gamma-ray flux from neutralino annihilation at a given energy \( E \) is:

\[
\Phi_{\gamma}(E, \Delta \Omega, l, b) = \text{const.} \sum_F \frac{\langle \sigma v_F \rangle}{m_X^2} \frac{dN_F}{dE} < J(l, b) > (\Delta \Omega) \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1}
\]

for the continuum gamma. If we assume a spherical dark matter halo in the form of a perfectly smooth distribution of neutralinos, \( < J(l, b) > (\Delta \Omega) \) is equal to:

\[
< J(l, b) > (\Delta \Omega) = \text{const'} \frac{1}{\Delta \Omega} \int_{\Delta \Omega} d\Omega' \int_{\text{line of sight}} \rho(L, \psi')^2 dL,
\]

where \( L \) is the distance from the detector along the line of sight, \( \psi \) is the angle between the direction of observation and that of the center of the galaxy and the integration over \( d\Omega' \) is performed over the solid angle \( \Delta \Omega \) centered on \( \psi \).

4.1 EFFECT OF CLUMPINESS

To discuss the implications of clumpiness on neutralino dark matter searches, we follow the phenomenological approach of Bergström & al. (1999) [1]. This model is mainly focused on a many small clumps scenario, where substructures are light, with \( M_{cl} \) less than \( 10^4 - 10^6 M_\odot \). Postulating that a fraction \( f \) of the dark matter is concentrated in clumps, they find that the increase of the signal compared to a smooth halo is determined by the enhancement factor \( f \delta \), where \( \delta \) is the effective contrast between the dark matter density in clumps and the local halo density \( \rho_0 \).
Assuming that the clumps can be regarded as pointlike sources, authors derive the analogous of Eq. (2) in the clumpy scenario:

$$< J(l, b) > (\Delta \Omega) = \text{const} \int d\Omega' \int_{\text{line of sight}} \rho(L, \psi') dL.$$

5 Results and discussion

As the background follows a poissonian statistics, the minimum detectable flux of gamma rays from an ACT telescope is determined by the condition:

$$\frac{\Phi_{\gamma} A_{\text{eff}} t \Delta \Omega}{\sqrt{N_b}} \geq 5,$$

for a 5σ detection level. $N_b$ is the number of background counts, hadrons and electrons, which is obtained on the ground of Ref. [1]. We assume the following
Figure 2. The minimum detectable $< \sigma v >_{\text{cont}}$ versus $m_\chi$ for the NFW, Moore & al. and Burkert & al. profiles. Dots are points of the parameter space of MSSM, lines represent the 5$\sigma$ detection level for the MAGIC telescope. Only models corresponding to SUSY points above the curves yield a detectable signal.

MAGIC specifications: $E_{th} = 60$ GeV, $A_{eff} = 10^9$ cm$^2$, $t = 250$ h, $\Delta \Omega = 10^{-5}$ sr and an energy resolution of 25%. Plotting inequality (4) with the equality sign onto the SUSY parameter space, we divide it into the detectable (above the line) and undetectable (below the line) regions. Results for the Galactic Center are shown in Fig. (2) and Fig. (3), for the MSSM and mSUGRA scenarios respectively and for a clumpiness enhancement factor of 20. This factor is anyway uninformative in this case.

As we can see from Fig. (2—3) plots, detectability of SUSY particles is very sensitive to the choice of the dark matter profile. We find that the scenario which gives the best opportunities for the MAGIC telescope is the Navarro-Frenk-White. Anyway, our model doesn’t take into account distribution functions for substructures; an extension of our investigations at higher galactic latitudes does need this to be modeled in detail, so we will address our future interests in this direction.

References

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![Graph showing the minimum detectable $(\sigma v)_{\text{cont}}$ versus $m_\chi$ for the NFW, Moore & al. and Burkert & al. profiles. Dots are points of the parameter space of mSUGRA, lines represent the 5$\sigma$ detection level for the MAGIC telescope. Only models corresponding to SUSY points above the curves yield a detectable signal.]

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