Impact of A_0 on the mSUGRA parameter space & Consequences for Cold Dark Matter Searches

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In minimal Supergravity (mSUGRA) models the lightest supersymmetric (SUSY) particle (assumed to be the lightest neutralino χ_1^0) provides an excellent cold dark matter (CDM) candidate. The supersymmetric parameter space is significantly reduced, if the limits on the CDM relic density $\Omega_{CDM}h^2$, obtained from WMAP data, are used. Assuming a vanishing trilinear scalar coupling A_0 and fixed values of $\tan\beta$, these limits result in narrow lines of allowed regions in the $m_0 - m_{1/2}$ plane, the so called WMAP strips. In this analysis the trilinear coupling A_0 has been varied within ± 4 TeV resulting in largely extended areas in the $m_0 - m_{1/2}$ plane which are no longer excluded.

This trilinear scalar coupling also influences the predicted $\gamma-$ray flux expected from neutralino-pair annihilation and thus impacts on the possible detection of CDM using Cherenkov telescopes.

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1. Introduction

In the mSUGRA framework the lightest neutralino lends itself as an excellent CDM candidate, thus providing a connection between particle physics and astrophysics. The inclusion of cosmological experimental data allows to significantly reduce the mSUGRA parameter space. The satellite born detector WMAP measured the abundance of CDM in the universe to be $0.094 < \Omega_{CDM} h^2 < 0.129$ (at 2σ C.L.) [1].

The SUSY parameter space in mSUGRA scenarios is usually studied in terms of the common scalar mass m_0, the common gaugino mass $m_{1/2}$, the ratio of the Higgs expectation values $\tan\beta$ and the sign of the Higgsino mass parameter μ. However, the fifth free parameter, the common trilinear scalar coupling A_0 was usually set to zero. In recent studies, the impact of non-zero A_0 values on the mSUGRA parameter space was recognised [2].

The soft SUSY breaking part of the Lagrangian provides additional contributions to the couplings of Higgs bosons to sfermions. However, as they are proportional to the mass of the corresponding SM fermion, they are only relevant for the third generation. These new couplings affect the masses of the sparticles through renormalisation group evolutions and through mixing effects. The relic density of the CDM particles, $\Omega_{CDM}h^2$, is connected to their annihilation cross sections by the Lee-Weinberg equation. A variation of A_0 affects the effective cross section and therefore also the relic density through the dependence of the SUSY particle masses on these trilinear scalar couplings at the EW scale.

## 2. The mSUGRA Parameter Space
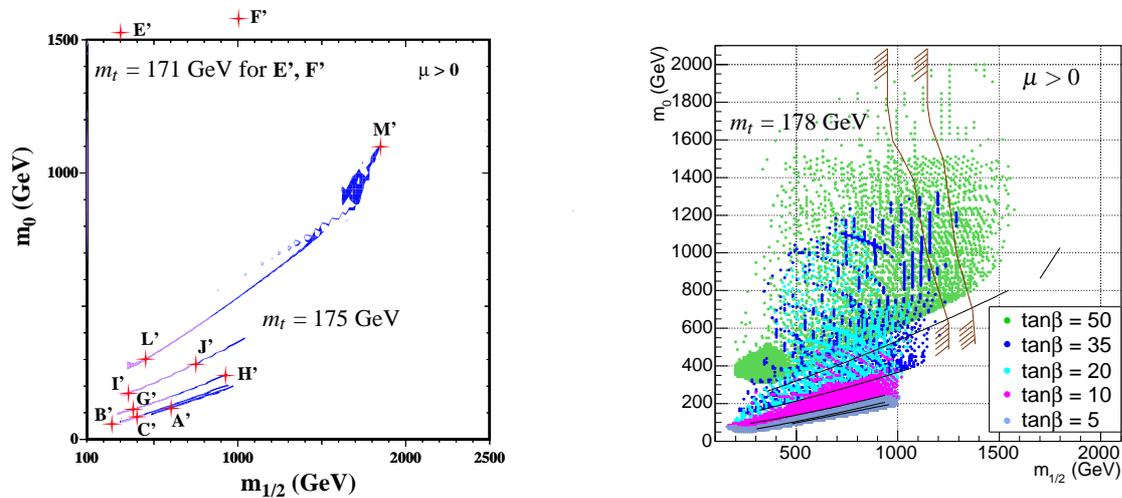
Figure 1: *Allowed models for m_0, $m_{1/2} \leq 2$ TeV, $\tan\beta$ between 5 and 50, $\mu > 0$ after imposing the WMAP constraints on $\Omega_\chi h^2$. For the WMAP strips [3] in the left plot a vanishing trilinear scalar coupling was assumed, while A_0 was left free within ± 4 TeV in the right one. The brown lines indicate the LHC discovery reach for an integrated luminosity of $100\,fb^{-1}$ and $300\,fb^{-1}$.*

Assuming CDM to consist exclusively of the lightest neutralino, the cosmological bounds on the neutralino relic density $\Omega_\chi h^2$ imply constraints on the mSUGRA parameter space, which however also depend on A_0, as illustrated in Fig.1. Under the assumption of $A_0 = 0$ TeV and fixed

$\tan\beta$ values, only narrow lines in the $m_0 - m_{1/2}$ plane (left plot in Fig.1) are left over as allowed regions after including WMAP data [3]. The right plot of Fig.1 illustrates the effect of varying A_0 within $\pm$ 4TeV [4]. In contrast to the left plot, where only a line survived the WMAP constraints for each chosen $\tan\beta$ value, extended regions in the mSUGRA parameter space are allowed for the same $\tan\beta$ value, if A_0 is varied.

3. $\gamma-$**Ray Flux from CDM annihilation**

In the following only the upper bound on the CDM relic density provided by WMAP is respected, as the total amount of CDM may not consist exclusively of neutralinos. The expected $\gamma-$ray flux is a function of the SUSY parameters and the halo properties of the observed target. The factor derived from particle physics is called fSUSY and includes the information about the number of photons produced per annihilation N_γ, the thermal average of the annihilation cross section times the velocity $\langle\sigma v\rangle$ and the neutralino mass M_χ. The cosmological characteristics of the source enter in the calculation of the so called J(ψ) factor, which is the integral over the line of sight (los) of the CDM density distribution squared. ψ is the angle between the direction of the target and that of observation.
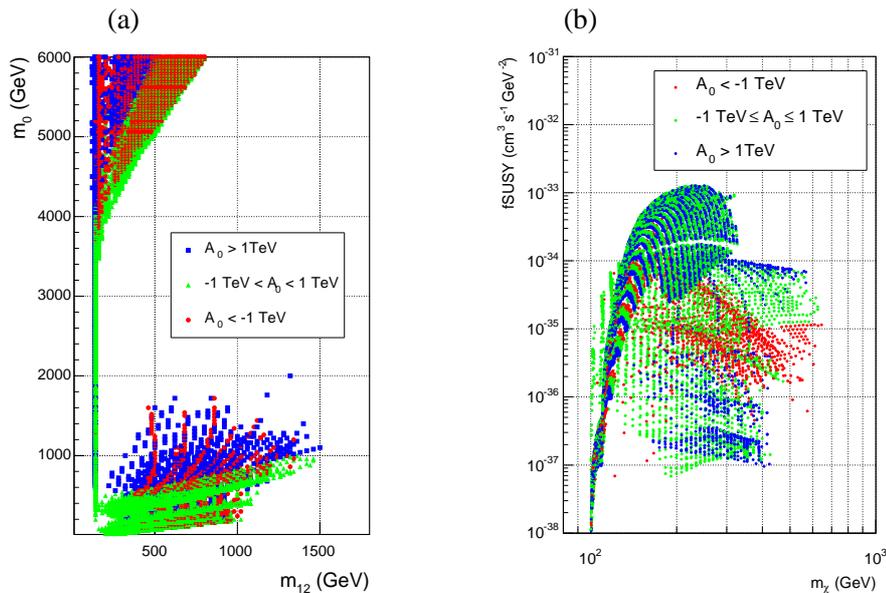

Figure 2: *(a) Allowed mSUGRA models in the m_0-$m_{1/2}$ plane for different A_0 regions (all other parameters like in Fig.1) (b) The corresponding fSUSY factor for the generated models.*

The properties of the SUSY model determine the fSUSY factor. Four different parameter regions in the $m_0 - m_{1/2}$ plane exist (Fig.2a): The bulk region at low m_0 , $m_{1/2}$ values, the coannihilation region with small m_0, the focus point region at low $m_{1/2}$ values and the region for very high m_0 values. mSUGRA models with m_0 values in the multi TeV region correspond to large fSUSY factors (Fig.2b). These models provide the highest $\gamma-$ray fluxes. However they only exist under the assumption that a small fraction of the total amount of CDM consists of neutralino.
Since the energy dependence of the neutralino CDM flux does not depend on the cosmological

J(ψ) factor, the shape of the annihilation spectra is already defined by the fSUSY factor (Fig.3). The spectra of models with a small neutralino mass show a strong A_0 dependence for small values of $\tan\beta$.
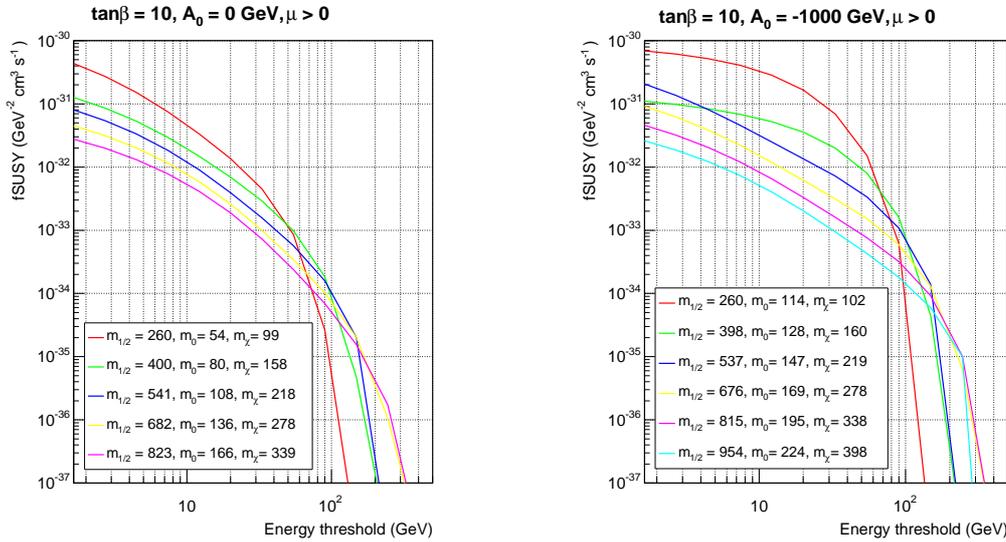
Figure 3: *Annihilation spectra for mSUGRA models with $A_0 = 0$ TeV, -1 TeV and $\tan\beta = 10$.*

4. Conclusion

The lightest neutralino in the MSSM is an excellent CDM candidate. Within the mSUGRA framework neutralino annihilation cross sections can be calculated. However, the predicted number of photons produced per annihilation as well as their energy spectrum depends strongly on the chosen parameters. Particular care must be taken to also include a possible non-zero trilinear scalar coupling A_0, resulting in an extended area of the allowed SUSY parameter space, after taking WMAP constraints into account. This also influences the discovery potential for CDM using space-born or ground-based instruments for photon detection.

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