Why the EGRET Excess of Diffuse Galactic Gamma Rays Points towards Heavy Scalars

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Recently it was shown that the excess of diffuse Galactic gamma rays above 1 GeV traces the Dark Matter halo, as proven by reconstructing the peculiar shape of the rotation curve of our Galaxy from the gamma ray excess. This can be interpreted as a Dark Matter annihilation signal. In this paper we investigate if this interpretation is consistent with Supersymmetry. It is found that the EGRET excess combined with all electroweak constraints is fully consistent with the minimal mSUGRA model for scalars in the TeV range and gauginos below 500 GeV.

1 Introduction

Cold Dark Matter (CDM) makes up 23% of the energy of the universe, as deduced from the temperature anisotropies in the Cosmic Microwave Background (CMB) in combination with data on the Hubble expansion and the density fluctuations in the universe [1]. One of the most popular CDM candidates is the neutralino, a stable neutral particle predicted by Supersymmetry [2, 3]. The neutralinos are spin 1/2 Majorana particles, which can annihilate into pairs of Standard Model (SM) particles. A large fraction of the annihilations is expected to go into quark-antiquark pairs. Since the DM particles are strongly non-relativistic, the initial energy is simply given by two times the neutralino mass, which is converted into energy of the quarks, which are then mono-energetic. In a recent paper we showed that the observed excess of diffuse Galactic gamma rays has all the properties of the π^0 decays of such mono-energetic quarks originating from the annihilation of neutralinos with a mass around 60 GeV [4, 5]. For a better understanding of the following we shortly summarize these results.

Gamma rays from Dark Matter Annihilation (DMA) can be distinguished from the background (BG) by their completely different spectral shape: the background originates mainly from cosmic rays (CR) hitting the gas of the disc and producing abundantly π^0 mesons, which decay into two photons. The initial CR spectrum is a steep power law spectrum, which yields a much softer gamma ray spectrum than the fragmentation of the hard mono-energetic quarks from DMA. The spectral shape of the gamma rays from the background is well known from fixed target experiments given the known CR spectrum. The spectral shape of the gamma rays from DMA is well known from the fragmentation of mono-energetic quarks studied at electron-positron colliders, like LEP at CERN, which has been operating up to centre-of-mass energies of about 200 GeV, i.e. it corresponds to gamma spectra from neutralino masses up to 100 GeV. The different quark flavours all yield similar gamma spectra at high energies. In addition to these two main components with a shape well known from accelerator experiments, there are contributions from inverse Compton scattering and Bremsstrahlung. In the gamma ray energy range of interest (above 0.1 GeV) these contributions are small, but their shape is well known too.

Experimentally, the spectral shape of the diffuse Galactic gamma rays has been measured with the EGRET satellite in the range 0.1 to 10 GeV. The EGRET data are publicly available as high resolution (0.5°) sky maps from the NASA archive[1], which allows an independent analysis in many different sky directions[4]. Comparing the BG with the EGRET data shows that above 1 GeV there is a large deficit of gamma rays, which reaches more than a factor of two towards the Galactic centre. However, fitting two components, namely BG and DMA, yields a perfect fit in all sky directions for a DM particle mass around 60 GeV. From the normalization factors for the BG and DMA components in 180 independent sky directions the distribution of DM has been obtained. Combining this with the known distribution of the visible matter yields the complete mass distribution, which in turn can be used to reconstruct the rotation curve of our Galaxy. The surprise was, that the gamma rays indeed explain the peculiar structure of this rotation curve, which was found to originate from substructure in the DM halo.

So the famous EGRET excess of diffuse Galactic gamma rays, discussed already in 1997 [6], was found to possess all the expected properties from DMA: it is observable in all sky directions and has everywhere the shape expected for the annihilation of DM particles with a mass around 60 GeV. In addition, the reconstruction of the rotation curve from the EGRET excess proves that the latter traces the DM in our Galaxy [4]. Note that the evidence for DMA is not so much the amount of excess, but how it is distributed in the sky and that it has the same spectral shape in all sky directions. Any unknown systematic errors in the EGRET data are expected to be independent of the sky direction, so the evidence for DMA does not depend on "unknown unknowns".

It is the purpose of the present paper to see if this intriguing hint of DMA is compatible with Supersymmetry. Here we will concentrate on the Minimal Supersymmetric Model with supergravity

[1]NASA archive: `http://cossc.gsfc.nasa.gov/archive/`.

inspired symmetry breaking (mSUGRA model)[7]. We assume that the EGRET excess originates from the annihilation of the stable, neutral lightest supersymmetric particles, the neutralinos. Their mass is then constrained to be between 50 and 100 GeV from the EGRET data, which strongly constrains the masses from all other SUSY particles, if mass unification at the GUT scale is assumed. It will be shown that combining the EGRET data with other constraints, like the electroweak precision data, Higgs mass limits, chargino limits, radiative electroweak symmetry breaking and relic density leads to a very constrained SUSY mass spectrum with light gauginos and heavy squarks and sleptons.

2 Comparison with mSUGRA

The mSUGRA model, i.e. the Minimal Supersymmetric Standard Model (MSSM) with supergravity inspired breaking terms, is characterised by only 5 parameters: m_0, $m_{1/2}$, $\tan\beta$, sign(μ), A_0 [7]. Here m_0 and $m_{1/2}$ are the common masses for the gauginos and scalars at the GUT scale. The latter is determined by the unification of the gauge couplings. Gauge unification is still possible with the precisely measured couplings at LEP [8]. The ratio of the vacuum expectation values of the neutral components of the two Higgs doublets in Supersymmetry is called $\tan\beta$ and A_0 is the trilinear coupling at the GUT scale. We only consider the dominant trilinear couplings of the third generation of quarks and leptons and assume also A_0 to be unified at the GUT scale. Electroweak symmetry breaking fixes the scale of μ [7], so only its sign is a free parameter. We use the positive sign, as suggested by the small deviation of the muon anomalous moment from the Standard Model (SM) [8].

The dominant annihilation diagrams of the lightest supersymmetric particle (LSP) neutralino are shown in figure 1. The cross sections are proportional to the final state fermion mass, which originates either from the Yukawa couplings for the Higgs exchange diagram or from the helicity suppression at the low energies involved in cold DMA [9]. Therefore heavy fermion final states, i.e. third generation quarks and leptons, are expected to be dominant. The Higgs exchange diagram is in addition proportional to $\tan\beta$ for down type quarks and $1/\tan\beta$ for up type quarks, indicating that top quark final states are suppressed for large $\tan\beta$. The W- and Z-final states from t-channel chargino and neutralino exchange have usually a much smaller cross section due to the weak couplings involved and are in addition kinematically suppressed for the 60 GeV neutralino mass preferred by the EGRET data.

The annihilation rate, which is proportional to the cross section multiplied by the relative neutralino velocities, is practically independent of the centre of mass energy for the pseudoscalar Higgs and sfermion exchange diagrams, but strongly dependent on energy for the other diagrams, as was calculated with the CalcHEP package [10] and shown in Fig. 2. This implies that for the present temperature of the universe close to absolute zero the neutralino annihilation is dominated by either sfermion exchange or pseudoscalar Higgs exchange. The sfermion exchange is suppressed for the following reason. The Born mass of the lightest Higgs is below the Z^0 mass, but radiative corrections can boost it up to 130 GeV in the minimal mSUGRA model[7]. These corrections depend on the heavy particles coupling to the lightest Higgs, like the top and stop quarks. These scalars have to be sufficiently heavy in order to reach a Higgs mass above 114 GeV, which is the present lower limit from the direct searches at LEP [11]. The Higgs mass was calculated with the FeynHiggs program [12]. Note that this Higgs limit from LEP is the limit on the Standard Model Higgs particle, but for heavy scalars the lightest SUSY Higgs particle has very much the properties of the SM Higgs, so the above limit is also valid in our case, as will be shown below.

For light neutralinos, i.e. small $m_{1/2}$, the Higgs mass limit requires m_0 to be in the TeV range, as indicated in the left hand panel of Fig. 3 by the almost vertical line, labeled m_h. The EGRET data requires $m_{1/2}$ to be below the almost horizontal line at $m_{1/2} = 230$ GeV. The low value of $m_{1/2}$ implies that the gluino QCD corrections to the stop quarks are rather small, so the “bare” quark mass m_0 has to be large to obey the Higgs limit, which requires heavy stops. In addition, the excluded regions from $b \to X_s\gamma$ and the anomalous magnetic moment of the muon have been indicated (left from the corresponding lines). These latter values were calculated with the publicly available web-based program from Ref. [13], which uses `micrOMEGAs 1.4` [14] for the relic density calculation and we opted for the SUSY mass spectrum from the `Suspect 2.3.4` program [15]. For the exclusion limits the following inputs were used: a) $Br(B \to X_s\gamma) = (3.43 \pm 0.36) \cdot 10^{-4}$, which is the average from BaBar, CLEO and BELLE [16] and b) the deviation of the anomalous magnetic moment of the muon a_μ from the expected value in the Standard Model was taken to be [17]: $\Delta a_\mu = a_\mu^{\rm exp} - a_\mu^{\rm theo} = (27 \pm 10) \cdot 10^{-10}$.

The lower limits on m_0 discussed above are practically independent of A_0 due to a coincidence from the constraints from the $b \to X_s\gamma$ rate and the lower limit on the Higgs mass of 114 GeV [8]. The absolute value of the Higgs mixing parameter μ is determined by electroweak symmetry breaking, while its sign is taken to be positive, as preferred by the anomalous magnetic moment of the muon. The region of large m_0, for which no electroweak symmetry breaking (EWSB) is possible, has been indicated in Fig. 3 as well as the region of small m_0, where the stau would be the lightest SUSY particle, which is excluded, since the DM candidate has to be neutral.

The m_0 values in the TeV range between the Higgs mass limit and EWSB limit are allowed by all constraints considered sofar. It should be noted that these boundaries are quite sensitive to the gauge and Yukawa couplings, which determine the radiative corrections to the Higgs mass and the radiative corrections to the Higgs potential needed for EWSB. E.g. increasing the top mass from 175 to 178 GeV increases the lightest Higgs mass by about 1 GeV, which can be compensated by lowering m_0 by 200 GeV. Thus the error on the curve labeled m_h is around 200 GeV in the horizontal direction in the range below the EGRET line. The uncertainty on the EWSB region is even larger at large values of $\tan\beta$. Increasing the top mass from 175 to 178 GeV moves the EWSB boundary by approximately 1 TeV to the right. This sensitivity can be understood as follows. Electroweak symmetry breaking is triggered if the following condition is fulfilled:

$$\frac{M_Z^2}{2} = \frac{m_1^2 - m_2^2 \tan^2\beta}{\tan^2\beta - 1} \approx -m_2^2. \tag{1}$$

Here m_1 and m_2 are the mass parameters in the Higgs potential with two Higgs doublets[7]. The last term is valid for large $\tan\beta$, implying m_2 becoming negative for a positive value of M_Z^2 and large $\tan\beta$ is required by the relic density, as will be discussed below. EWSB is then possible for large values of the top Yukawa coupling, which drives m_2 negative, as shown on the right hand side of Fig. 3, where the running masses corresponding to a set of GUT scale parameters compatible with all constraints are shown. The starting value of m_2 at the GUT scale is $\sqrt{m_0^2 + \mu^2}$. The running of m_2 over 14 orders of magnitude between the GUT scale and the electroweak scale implies that a small increase in the top Yukawa coupling, thus increasing the slope of the running, requires a large increase in m_0.

In summary: increasing the top mass by 3 GeV widens the allowed region in Fig. 3: 200 GeV to lower values of m_0 and around 1 TeV to larger values of m_0, but from the running of the masses in Fig. 3 it is clear that the low energy masses for squarks and sleptons are in the TeV range or above and the gauginos below 500 GeV. The spectrum and the corresponding values of the relic density Ωh^2, $b \to X_s\gamma$ and Δa_μ have been tabulated in Table 1 for a typical set of parameters compatible with all constraints.

As discussed above the uncertainty in m_0 is large, but the 95% C.L. upper limit on the lightest neutralino is around 70 GeV, as can be deduced from the χ^2 fit to the EGRET energy spectrum of the diffuse gamma rays. This χ^2 distribution is shown in Fig. 4 together with the probabilities. Above 70 GeV the fit probability is below 5%, implying $m_{1/2} < 175$ GeV. However, for background models, which try to maximize the background by assuming that the local cosmic ray spectrum is not representative for our galaxy, neutralino values up to 100 GeV can be obtained [4, 5], as indicated in Fig. 3 by the "EGRET" line. A lower limit of 50 GeV on the neutralino mass avoids the dominance of the Z^0 cross section in the annihilation, since if the neutralino mass is close to half of the Z^0 mass the annihilation signal at the present temperature of the universe would be practically zero, as demonstrated in Fig. 2 in disagreement with the EGRET excess (unless one allows unrealistically large clumping of the

DM, which increases the annihilation rate). The lightest neutralino is a mixture of all spin 1/2 neutral particles: $|\chi_o\rangle = N_1|B_0\rangle + N_2|W_0^3\rangle + N_3|H_1\rangle + N_4|H_2\rangle$ with $(N_1, N_2, N_3, N_4) = (0.95, -0.10, 0.27, -0.09)$ for the values of Table 1 meaning that the lightest neutralino is an almost pure bino for the allowed region of Fig. 3.

The correct value of the relic density is obtained for large $\tan\beta$, as shown on the right hand side of Fig. 4 for a given set of SUSY mass parameters and different values of the SM parameters α_s, m_t and m_b. The relic density was calculated with `micrOMEGAs 1.4` [14]. Scanning over the allowed region of Fig. 3 *and* requiring an LSP mass above 50 GeV requires $\tan\beta$ to be in the range of 50 to 55. Note that the EGRET data itself is only sensitive to the masses, not to $\tan\beta$. But for practically any set of masses the correct relic density can be obtained by a suitable value of $\tan\beta$ and A_0 [5]. The strong dependence of the relic density on $\tan\beta$ for large values of $\tan\beta$ originates from the strong dependence of the pseudoscalar Higgs mass on $\tan\beta$, which in mSUGRA is given by:

$$m_A^2 = m_1^2 + m_2^2 = m_{H_1}^2 + m_{H_2}^2 + 2\mu^2, \tag{2}$$

where m_{H_i} are the Higgs mass terms. However, at large $\tan\beta$ m_1^2 is also driven negative, since then the bottom Yukawa coupling becomes of the same order as magnitude as the top Yukawa coupling. This can be seen as follows: the top and bottom masses are given by:

$$\begin{aligned} m_t^2 &= h_t^2 \cdot |H_2|^2 = h_t^2 \cdot v_2^2 = h_t^2 \cdot |v|^2 \sin^2\beta \\ m_b^2 &= h_b^2 \cdot |H_1|^2 = h_b^2 \cdot v_1^2 = h_b^2 \cdot |v|^2 \cos^2\beta, \end{aligned} \tag{3}$$

so if the ratio $\tan\beta \approx 50 \approx m_t/m_b$ then the Yukawa couplings h_t and h_b must be of the same order of magnitude. If both m_1 and m_2 are driven negative, the pseudoscalar Higgs mass can only become positive by large radiative corrections from stop and sbottom quarks, which works if the latter are heavy. But large radiative corrections lead to a large variation in the pseudoscalar Higgs mass and a correspondingly large variation in the relic density, as shown in Fig. 4. Note that it is interesting that the EGRET scenario combined with the relic density from WMAP requires $\tan\beta$ to be in the range, where the Yukawa couplings of top, bottom and tau can be unified[18], as expected e.g. in SO(10), which allows simultaneously for massive neutrinos[7].

For large values of $\tan\beta$ the annihilation via pseudoscalar Higgs exchange, being proportional to $(\tan\beta)^2$, becomes dominant. The annihilation cross section for a correct relic density requires relatively light pseudoscalar Higgs masses, typically below or around 500 GeV, which is consistent with the values given in Table 1. It should be noted that the annihilation is still in the so-called bulk region, i.e. the regions not dominated by co-annihilation or resonances, since the neutralino mass is far away from the pseudoscalar Higgs mass resonance for the mSUGRA spectrum and not close to any of the other sparticles, like stau or chargino, as shown in Table 1. If these latter Next-to Lightest Supersymmetric Particles (NLSP) are almost degenerate with the LSP, their number density, given by the Boltzmann factor, would be high enough to cause a fast annihilation in the early universe into taus and charged W-bosons. The total annihilation rate, which is the sum of the self-annihilation and co-annihilation rate, is fixed by the observed relic density. Therefore a large co-annihilation rate automatically implies a negligible self-annihilation rate. Since in the present universe the NLSPs have decayed, only the self-annihilation is operative now and would be practically zero in case of strong co-annihilation. So it is fortunate for indirect DM detection that the combination of EGRET data with the Higgs mass limit results in a spectrum, for which the co-annihilation is negligible.

An independent check that the scalars should be heavy comes directly from the EGRET data: if the scalars are light, the stau is usually the lightest scalar, in which case the stau exchange in the t-channel (left diagram of Fig. 1) would be dominant, thus leading to tau final states. The low decay multiplicity of tau leptons leads to a much harder gamma ray spectrum from the hadronic decays, which is excluded by the EGRET data, as shown in Fig. 5. This plot has been made for a neutralino mass of about 100 GeV in order to obey the Higgs limit with the low value of m_0 required for the stau exchange to be dominant. A neutralino of 50 GeV would still yield a maximum in the spectrum around 20 GeV in disagreement with the EGRET data, which shows a maximum excess around 2 GeV.

The SUSY spectrum of Table 1 yields excellent gauge unification, as shown in Fig. 6. The used value of $\alpha_s = 0.122$ was taken from the ratio R_l of the hadronic and leptonic width of the Z^0 boson was taken, since the averaged LEP value of 0.118 is the average of 0.115 from the hadronic cross section σ_h at LEP and 0.122 from R_l. However, the value of 0.115 becomes 0.122 as well, if the luminosity at LEP is normalized such that the number of neutrino generations is moved from 2.98 to 3 [8]. Note that in contrast to the earlier evidence for gauge unification, where the SUSY mass scale had to be taken as a free parameter [19], there are now *no* free parameters anymore since the initial starting points of the running coupling constants are given by the electroweak precision data from LEP and the change in the running from the SM to the MSSM value is determined by the allowed masses in Fig. 3 or Table 1. So one either gets unification or one does not get it. Using the EGRET data and Higgs constraints one *gets* unification in mSUGRA.

3 Conclusion

In our previous paper [4] the observed excess of diffuse Galactic gamma rays was shown to exhibit all features of Dark Matter Annihilation, especially the spatial distribution of the excess was shown to trace the DM distribution, as proven by the fact that one could reconstruct the peculiar shape of the rotation curve of our Galaxy from the gamma ray excess. In this paper the DM interpretation of the EGRET excess is compared with Supersymmetry and it is shown that the minimal supersymmetric model with the popular supergravity inspired symmetry breaking, gauge unification and radiative electroweak symmetry breaking is in perfect agreement with the EGRET excess. The mass spectrum of the gauginos is governed by the neutralino mass corresponding to $m_{1/2}$ between 125 and 175 GeV, if the conventional background model is chosen. In case of a model maximizing the background (optimized model, see Ref. [4]) values of $m_{1/2}$ up to 230 GeV are allowed. For the low values of $m_{1/2}$ the scalar masses are constrained by the Higgs mass and/or $b \to X_s\gamma$ to have m_0 above 1 TeV. The allowed mass spectrum is observable at the LHC. If confirmed, especially a neutralino mass around 60 GeV, then this would prove that DM can indeed be considered to be the supersymmetric partner of the Cosmic Microwave Background, since the neutralino is almost a pure bino in this case.

References

[1] C. L. Bennett *et al.*, Astrophys. J. Suppl. **148** (2003) 1 [arXiv:astro-ph/0302207].

[2] J. R. Ellis, J. S. Hagelin, D. V. Nanopoulos, K. A. Olive and M. Srednicki, Nucl. Phys. B **238** (1984) 453.

[3] G. Jungman, M. Kamionkowski and K. Griest, Phys. Rept. **267** (1996) 195 [arXiv:hep-ph/9506380].

[4] W. de Boer, C. Sander, V. Zhukov, A. V. Gladyshev and D. I. Kazakov, Astron. Astrophys. **444** (2005) L51 [arXiv:astro-ph/0508617];

[5] C. Sander, PhD Thesis, 2005 (University of Karlsruhe), http://www-ekp.physik.uni-karlsruhe.de/theses/phd/2005.html.

[6] S. D. Hunter *et al.*, Astrophys. J. **481** (1997) 205.

[7] Reviews and original references can be found in:
W. de Boer, Prog. Part. Nucl. Phys. **33** (1994) 201 [arXiv:hep-ph/9402266];
D. I. Kazakov, arXiv:hep-ph/0012288, arXiv:hep-ph/0411064;
P. Fayet and S. Ferrara, Phys. Rept. **32** (1977) 249;
H. P. Nilles, Phys. Rept. **110** (1984) 1;
H. E. Haber and G. L. Kane, Phys. Rept. **117** (1985) 75;
M. F. Sohnius, Phys. Rept. **128** (1985) 39;
A. B. Lahanas and D. V. Nanopoulos, Phys. Rept. **145** (1987) 1.

[8] W. de Boer and C. Sander, Phys. Lett. B **585** (2004) 276 [arXiv:hep-ph/0307049].

[9] H. Goldberg, Phys. Rev. Lett. **50** (1983) 1419.

[10] A. Pukhov, arXiv:hep-ph/0412191;
`http://www-zeuthen.desy.de/ pukhov/calchep.html`.

[11] R. Barate *et al.* [LEP Working Group for Higgs boson searches Collaboration], Phys. Lett. B **565** (2003) 61 [arXiv:hep-ex/0306033].

[12] S. Heinemeyer, W. Hollik and G. Weiglein, Comput. Phys. Commun. **124**, 76 (2000) [arXiv:hep-ph/9812320]; The program is available from http://www.feynhiggs.de.

[13] B. C. Allanach, S. Kraml and W. Porod, JHEP **0303** (2003) 016 [arXiv:hep-ph/0302102];
`http://cern.ch/kraml/comparison/`.

[14] G. Belanger, F. Boudjema, A. Pukhov and A. Semenov, arXiv:hep-ph/0405253;
G. Belanger, F. Boudjema, A. Pukhov and A. Semenov, Comput. Phys. Commun. **149** (2002) 103 [arXiv:hep-ph/0112278].

[15] A. Djouadi, J. L. Kneur and G. Moultaka, arXiv:hep-ph/0211331.

[16] K. Abe *et al.* [Belle Collaboration], Phys. Lett. B **511** (2001) 151 [arXiv:hep-ex/0103042];
S. Chen *et al.* [CLEO Collaboration], Phys. Rev. Lett. **87** (2001) 251807 [arXiv:hep-ex/0108032];
B. Aubert *et al.* [BaBar Collaboration], arXiv:hep-ex/0207076.

[17] G. W. Bennett *et al.* [Muon g-2 Collaboration], Phys. Rev. Lett. **92** (2004) 161802 [arXiv:hep-ex/0401008].

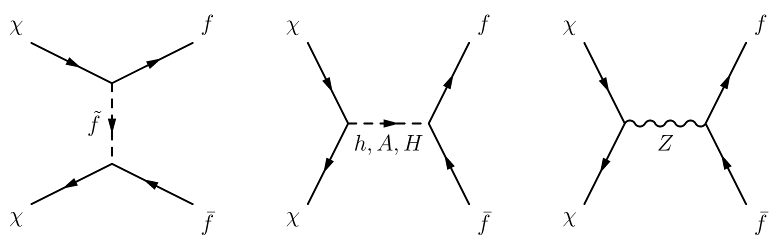
[18] W. de Boer, M. Huber, A. V. Gladyshev and D. I. Kazakov, Eur. Phys. J. C **20**, 689 (2001) [arXiv:hep-ph/0102163].

[19] U. Amaldi, W. de Boer and H. Fürstenau, Phys. Lett. B **260** (1991) 447.

Parameter	Value
m_0	1500 GeV
$m_{1/2}$	170 GeV
A_0	$0 \cdot m_0$
$\tan\beta$	52.2
sign μ	$+$
$\alpha_s(M_Z)$	0.122
$\alpha_{em}(M_Z)$	0.0078153697
$1/\alpha_{em}$	127.953
$\sin^2(\theta_W)_{\overline{MS}}$	0.2314
m_t	175 GeV
m_b	4.214 GeV

Particle	Mass [GeV]
$\tilde{\chi}^0_{1,2,3,4}$	64, 113, 194, 229
$\tilde{\chi}^{\pm}_{1,2}, \tilde{g}$	110, 230, 516
$\tilde{u}_{1,2} = \tilde{c}_{1,2}$	1519, 1523
$\tilde{d}_{1,2} = \tilde{s}_{1,2}$	1522, 1524
$\tilde{t}_{1,2}$	906, 1046
$\tilde{b}_{1,2}$	1039, 1152
$\tilde{e}_{1,2} = \tilde{\mu}_{1,2}$	1497, 1499
$\tilde{\tau}_{1,2}$	1035, 1288
$\tilde{\nu}_e, \tilde{\nu}_\mu, \tilde{\nu}_\tau$	1495, 1495, 1286
$h, H, A, H^{\pm}$	115, 372, 372, 383
Observable	**Value**
$Br(b \to X_s\gamma)$	$3.02 \cdot 10^{-4}$
Δa_μ	$1.07 \cdot 10^{-9}$
Ωh^2	0.117

Table 1: Typical mSUGRA parameters from the EGRET analysis and electroweak constraints. The corresponding mass spectrum of the SUSY particles and observables is shown on the right.



$\propto \frac{\mathbf{m_\chi \cdot m_f}}{\mathbf{m^2_{\tilde{f}}}}$ $\quad \propto \frac{\tan\beta \cdot \mathbf{m_{f_d}}}{\mathbf{m_W}} \mathbf{N_1 N_{3(4)}}$ $\quad \propto \frac{\mathbf{m_f \cdot m_\chi}}{\mathbf{m^2_Z}} \mathbf{N^2_{3(4)}}$

$\tan\beta \cdot \mathbf{m_{f_d}} \leftrightarrow \frac{\mathbf{m_{f_u}}}{\tan\beta}$

Figure 1: The dominant annihilation diagrams for the lightest neutralino, which is a linear combination of the gaugino and Higgsino states: $|\chi_0\rangle = N_1|B_0\rangle + N_2|W^3_0\rangle + N_3|H_1\rangle + N_4|H_2\rangle$. The dependence of the amplitudes on masses and neutralino mixing parameter N_i has been indicated.

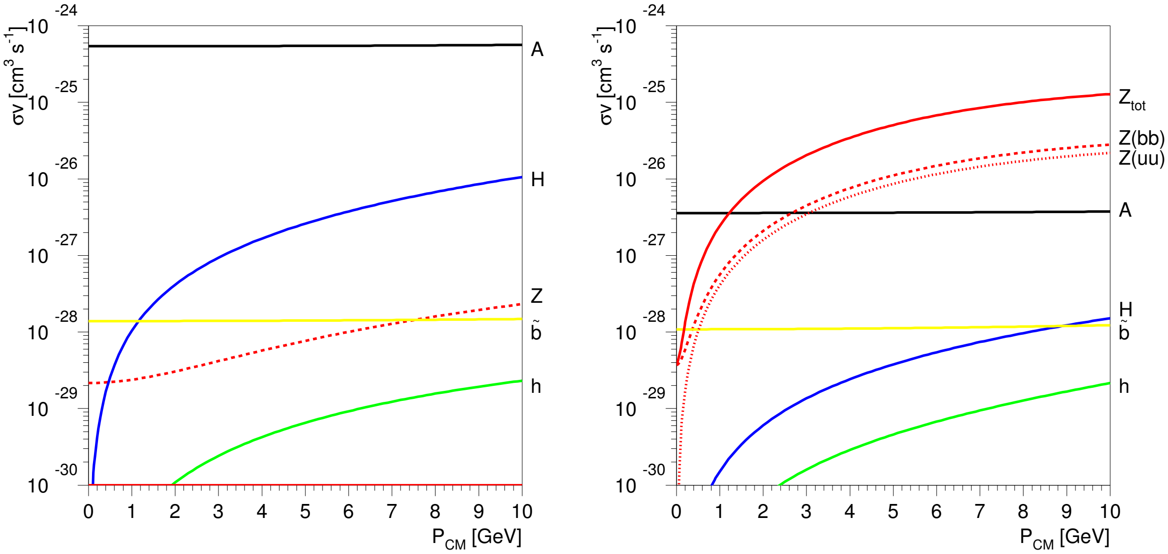


Figure 2: The neutralino annihilation cross section σ multiplied by the relative neutralino velocities (v) for the different diagrams of Fig. 1 (indicated by the exchanged particle) as function of the center of mass momentum for two different sets of parameters: left: the annihilation via the pseudoscalar Higgs A is dominant (heavy scalars, large $\tan\beta$); right: the dominant channel is through the Z-Boson ($m_\chi \sim m_Z/2$).

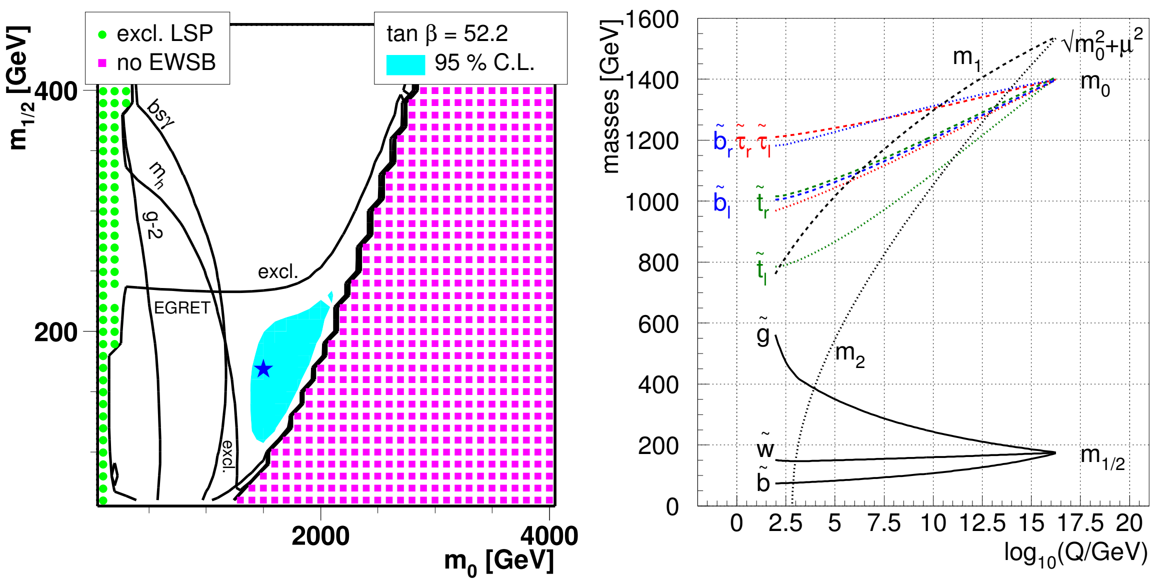


Figure 3: Left: the light shaded area (blue) indicates the 95% C.L. parameter range in the m_0-$m_{1/2}$-plane allowed by the EGRET data, if the constraints from electroweak data, a neutral LSP and electroweak symmetry breaking (EWSB) are imposed as well. The individual constraints have been indicated by the lines and dots. For the left hand panel the values of $A_0 = 0$ and $\tan\beta = 52.2$ were chosen and the choice of parameters of Table 1 has been indicated by a star. The right hand side shows the running SUSY masses for a set of allowed parameters.

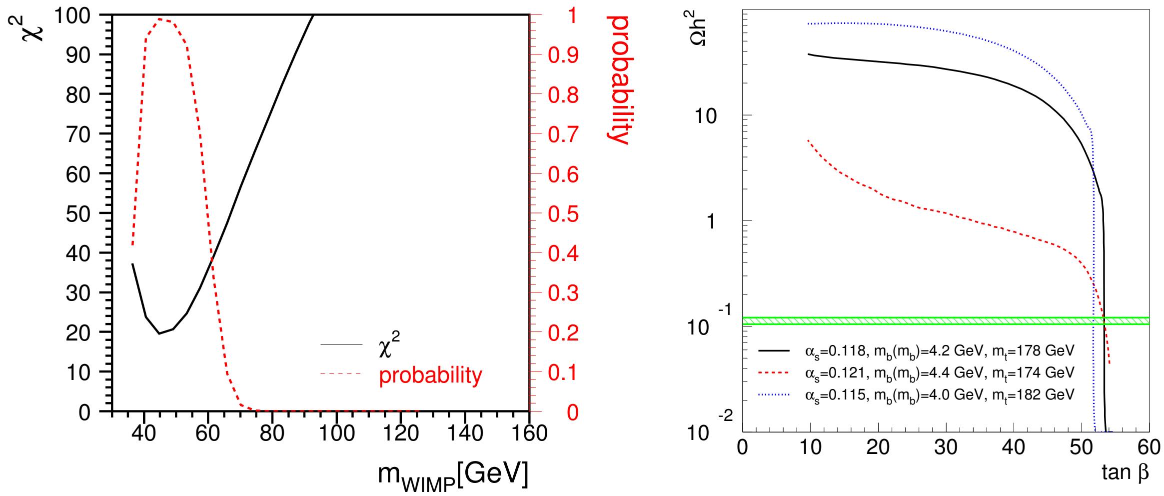


Figure 4: Left hand side: the χ^2 distribution and corresponding probability as function of the WIMP mass from a fit to the EGRET data on galactic gamma rays. The 95% CL upper limit on the WIMP mass is 70 GeV for the conventional background model. The limit can be stretched to 100 GeV for a model maximizing the background [5]. On the right hand side Ωh^2 as a function of $\tan\beta$ is plotted for $m_0 = 1500$ GeV, $m_{1/2} = 200$ GeV, $A_0 = 0$. The horizontal shaded band corresponds to the observed relic density.

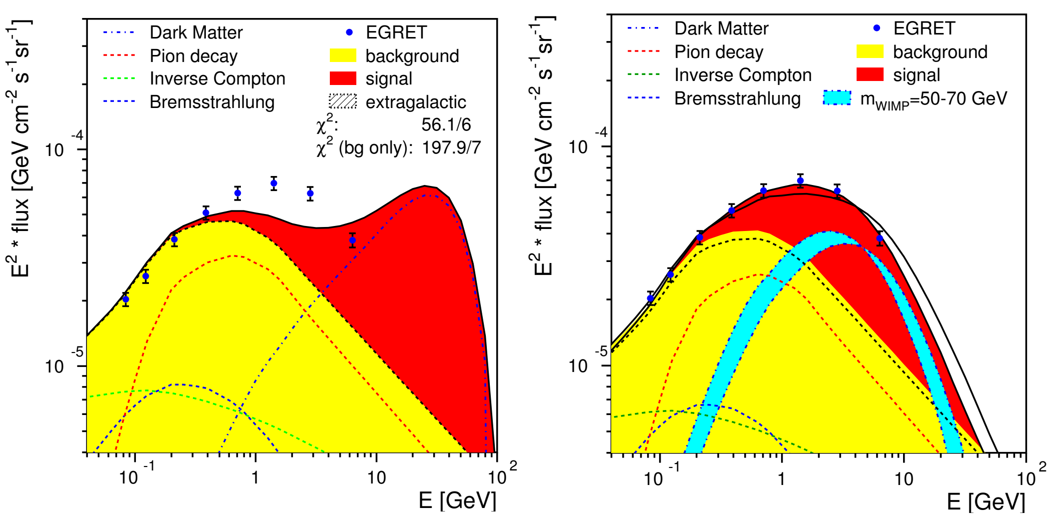


Figure 5: The EGRET gamma ray spectrum fitted with DM annihilation for ($m_0 = 70$ GeV, $m_{1/2} = 250$ GeV, $\tan\beta = 10$) (left) and ($m_0 = 1400$ GeV, $m_{1/2} = 175$ GeV, $\tan\beta = 51$) (right). In both cases the relic density corresponds to the WMAP value, but in the first case of low m_0 the annihilation into tau pairs dominates, while in the latter case the annihilation into b-quarks dominates. The first case is excluded by the EGRET data. On the right hand side the variation of the WIMP mass between 50 and 70 GeV ($m_{1/2}$ between 125 and 175 GeV) is shown as well (blue shaded area), which is the range allowed by the EGRET data with the conventional background (see Ref. [4]).

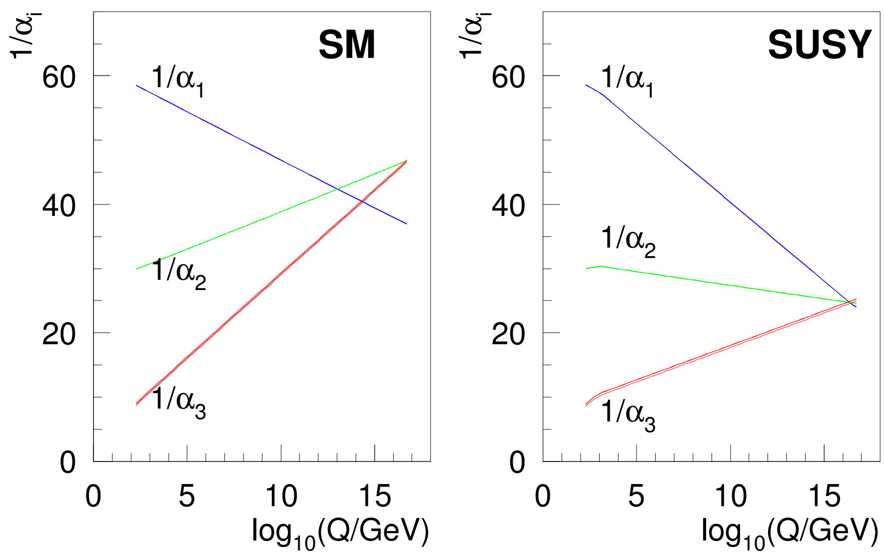


Figure 6: The running of the inverse of the gauge couplings in the SM (left) and in Supersymmetry with the SUSY mass spectrum from Table 1 (right).