Supersymmetric Dark Matter with GLAST

MORIOND WORKSHOP ON

Exploring the Universe

La Thuile, Italy

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astro-ph/0305075 (accepted by Astroparticle Physics)

Dark Matter Evidence

We are now able to determine several fundamental cosmological parameters to a remarkable level of precision from CMB anisotropies measurements:
Boomerang, Maxima, Dasi, WMAP [a],...
In particular the contribution to the critical density of non-relativistic matter is:

$$\Omega_m h^2 \sim 0.3$$

where $h \sim 0.7$ is the Hubble constant in units of 100 km s^{-1} Mpc^{-1}:

$\Omega_m h^2$ much larger than the baryonic term $\Omega_b h^2 = 0.0224 \pm 0.0009$

$$\Downarrow$$

$$\Omega_m = \Omega_b + \Omega_\chi$$

[a] D.N. Spergel et al., Astrophys. J. Suppl. **148**, 175 (2003) (astro-ph/0302209)

Dark Matter Candidates

Strong indications that the dominant component is **non baryonic**

Two main possibilities (depending on the velocities at the decoupling):

- Warm Dark Matter
  Light neutrino, . . .
- Cold Dark Matter
  axions and WIMPs (Weak Interacting Massive Particles)

One of the best motivated candidate $\Rightarrow$ WIMP

WIMPs are stable particles that appears in extension of the SM of particle physics

Supersymmetric Dark Matter

Possible extension of the SM $\Rightarrow$ Supersymmetry

Minimal supersymmetric extension of the SM

$\Downarrow$

MSSM

The MSSM, with exact R-parity conservation, is the natural framework where to find WIMP candidates for dark matter

$\Downarrow$

Neutralino

The Neutralino

Linear combination of gaugino and higgsino fields appearing in MSSM lagrangian:

$$\psi^0 = (\tilde{B}, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0)$$

$$L \supset -\frac{1}{2}(\psi^0)^T \mathbf{M_{\tilde{N}}} \psi^{\mathbf{0}} + \mathbf{c.c.}$$

$$\mathbf{M_{\tilde{N}}} = \begin{pmatrix} M_1 & 0 & -c_\beta s_W m_Z & s_\beta s_W m_Z \\ 0 & M_2 & c_\beta c_W m_Z & -s_\beta c_W m_Z \\ -c_\beta s_W m_Z & c_\beta c_W m_Z & 0 & -\mu \\ s_\beta s_W m_Z & -s_\beta c_W m_Z & -\mu & 0 \end{pmatrix}$$

The Neutralino

The mass eigenstates can be obtained diagonalizing the mass matrix:

$$\mathbf{M}_{\tilde{\mathbf{N}}}^{\mathbf{diag}} = \begin{pmatrix} m_{\tilde{N}_1} & 0 & 0 & 0 \\ 0 & m_{\tilde{N}_2} & 0 & 0 \\ 0 & 0 & m_{\tilde{N}_3} & 0 \\ 0 & 0 & 0 & m_{\tilde{N}_4} \end{pmatrix}$$

$$m_{\tilde{N}_1} < m_{\tilde{N}_2} < m_{\tilde{N}_3} < m_{\tilde{N}_4}$$

$\tilde{N}_i = N_{ij}\psi_j^0 \rightarrow$ **neutralinos**, $\quad \tilde{N}_1 \rightarrow$ **"the Neutralino"**

In a wide class of supersymmetric models (exact R-parity conservation), the neutralino ($\tilde{N}_1$) is the LSP and is the best motivated CDM candidate.

γ-rays from Neutralino Annihilations

assumption: neutralino as the dominant component of the dark matter halo

Due to R-parity conservation the neutralino is stable so the dominant process is pair-annihilation

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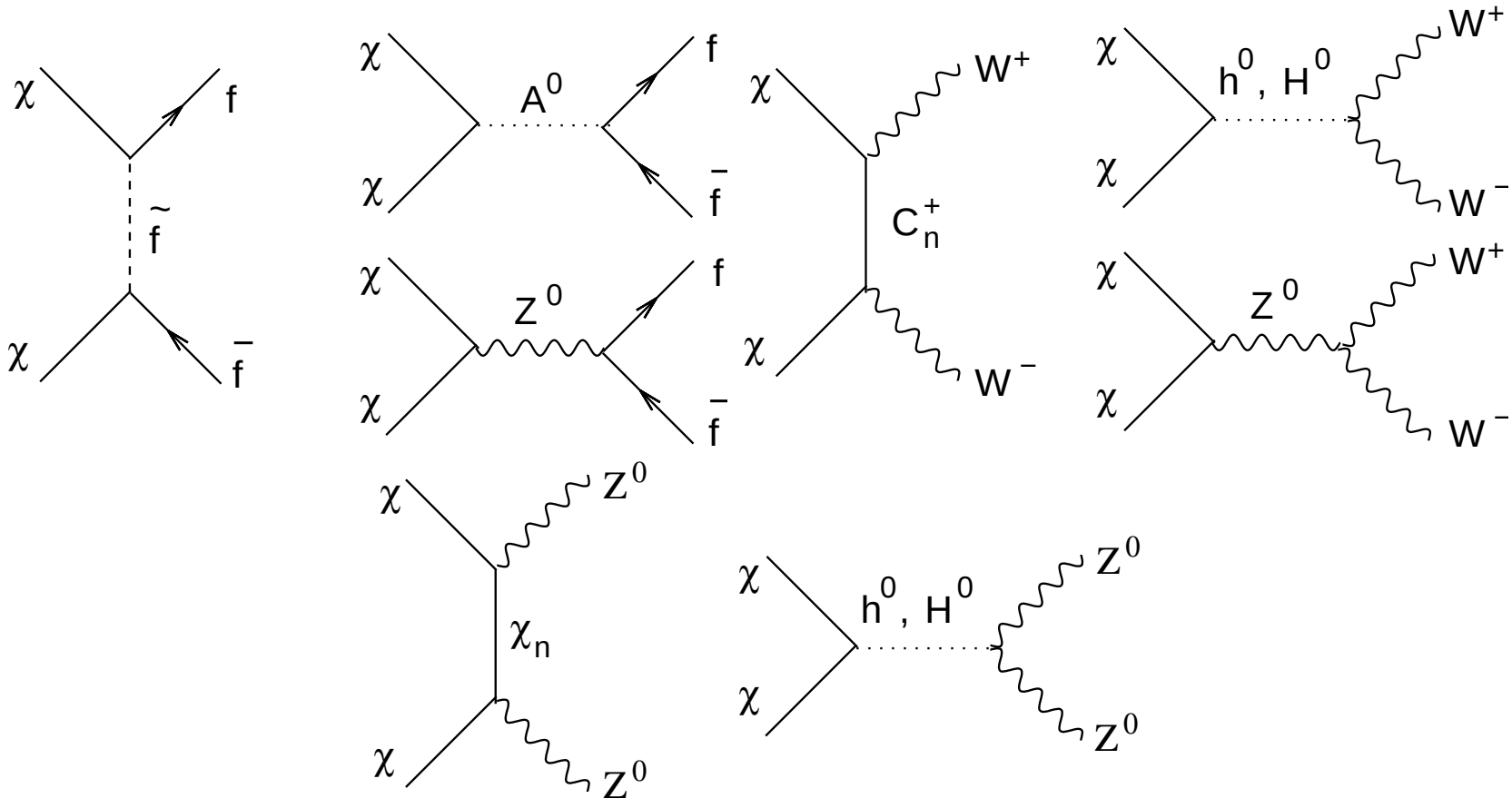
Let us focus on the continuum γ-ray flux production:

$$\chi\chi \to \left\{ \begin{array}{l} b\bar{b} \\ c\bar{c} \\ t\bar{t} \\ W^+W^- \\ Z^0Z^0 \\ \text{(light quarks)} \\ \text{(Higgs)} \end{array} \right\} \to \ldots \to \pi^0 \to 2\gamma \Rightarrow \phi_\gamma^{\chi\chi}(E_\gamma)$$

γ-rays from Neutralino Annihilations

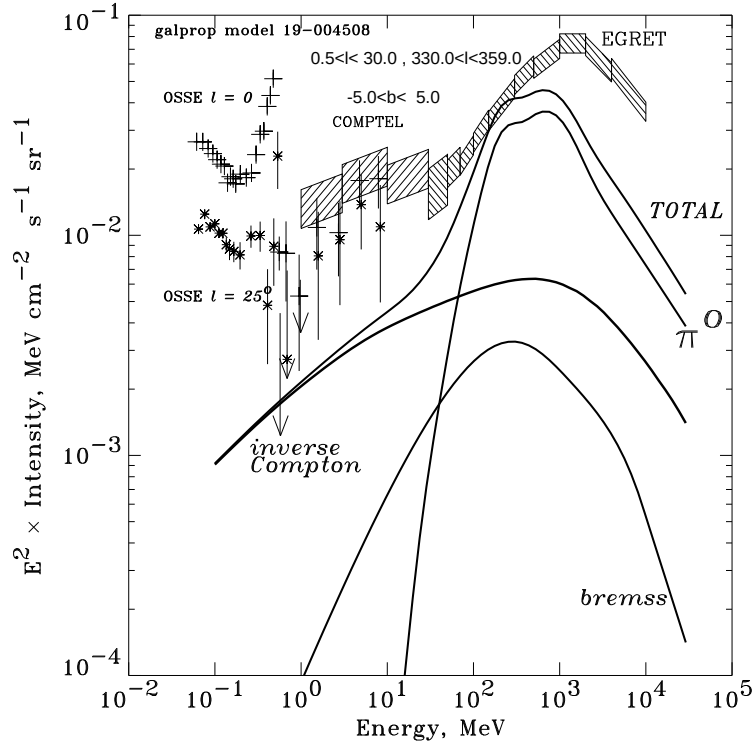
Tree level Feynman diagrams for the relevant annihilation channels:



Indirect detection with cosmic γ-rays

Cosmic γ ray from the galactic center (GC)

problem: excess with respect to the “standard model” production



From Strong, Moskalenko, astro-ph/9811296, fi g. 7

EGRET data from the GC

Region of 10^{-3} sr around the GC

Energy Bin (GeV)	Expected Diffuse $\gamma-$Ray Flux $\left(\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{GeV}^{-1}\mathrm{sr}^{-1}\right)$	Total $\gamma-$Ray Flux $\left(\mathrm{cm}^{-2}\mathrm{s}^{-1}\mathrm{GeV}^{-1}\mathrm{sr}^{-1}\right)$
$0.03-0.05$	$3.7\cdot10^{-3}$	$(5.0\pm0.8)\cdot10^{-2}$
$0.05-0.07$	$1.8\cdot10^{-3}$	$(1.3\pm0.2)\cdot10^{-2}$
$0.07-0.1$	$1.1\cdot10^{-3}$	$(6.1\pm0.5)\cdot10^{-3}$
$0.1-0.15$	$6.2\cdot10^{-4}$	$(4.4\pm0.2)\cdot10^{-3}$
$0.15-0.3$	$2.6\cdot10^{-4}$	$(2.03\pm0.06)\cdot10^{-3}$
$0.3-0.5$	$1.0\cdot10^{-4}$	$(9.5\pm0.2)\cdot10^{-4}$
$0.5-1$	$3.5\cdot10^{-5}$	$(3.9\pm0.1)\cdot10^{-4}$
$1-2$	$9.1\cdot10^{-6}$	$(1.52\pm0.03)\cdot10^{-4}$
$2-4$	$2.0\cdot10^{-6}$	$(3.2\pm0.1)\cdot10^{-5}$
$4-10$	$2.3\cdot10^{-7}$	$(3.1\pm0.2)\cdot10^{-6}$

Mayer-Hasselwander *et al.* Astron. AstroPhys. 335, 161

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$$p + X \rightarrow .. \rightarrow \pi^0 \rightarrow 2\gamma, \qquad He + X \rightarrow .. \rightarrow \pi^0 \rightarrow 2\gamma$$

p and He are primary protons and heliums,
X can be interstellar hydrogen ($\sim 93\%$) or helium ($\sim 7\%$)

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$$\Downarrow$$

$\phi_\gamma^{BKG}(E_\gamma)$ (considering only the π^0 component)

Indirect Detection with Cosmic γ Rays

$$\boxed{\phi_\gamma^{TOT} = \phi_\gamma^{BKG} + \phi_\gamma^{\chi\chi} = N_b S_b + N_\chi \phi_\chi}$$

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$$S_b(E_\gamma) = \frac{1}{(1\,cm^2 sr)} \cdot Em(E_\gamma),\; N_b = \frac{1}{(1\ \mathrm{cm}^{-2}\mathrm{sr}^{-1})} \cdot \int_{l.o.s.} dl \frac{n_H(l)}{4\pi} \frac{\phi_p^{prim}(l)}{\phi_p^{prim}(l=0)}$$

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$$\phi_\chi(E_\gamma) = 3.74 \cdot 10^{-10} \left(\frac{\sigma_{ann}\, v}{10^{-26}\ \mathrm{cm}^3\mathrm{s}^{-1}} \right) \left(\frac{50\ \mathrm{GeV}}{m_\chi} \right)^2 \sum_f \frac{dN_f}{dE} B_f$$

$$N_\chi = \langle J(\psi) \rangle = \frac{1}{\Delta\Omega} \int_{\Delta\Omega} d\Omega' J(\psi')$$

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Constraints on the variation of N_b and N_χ:

$$\phi_{dif} \leq N_b S_b + N_\chi \phi_\chi$$

ϕ_{dif} is the large scale γ ray diffuse emission from EGRET

Mayer-Hasselwander *et al.* Astron. AstroPhys. 335, 161

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$$\rho(r) = \rho_0 \left(\frac{r_0}{r}\right)^\gamma \left[\frac{1+(r_0/a)^\alpha}{1+(r/a)^\alpha}\right]^{(\beta-\gamma)/\alpha}$$

ρ_0 is the local WIMP density and r_0 is the galactocentric distance.

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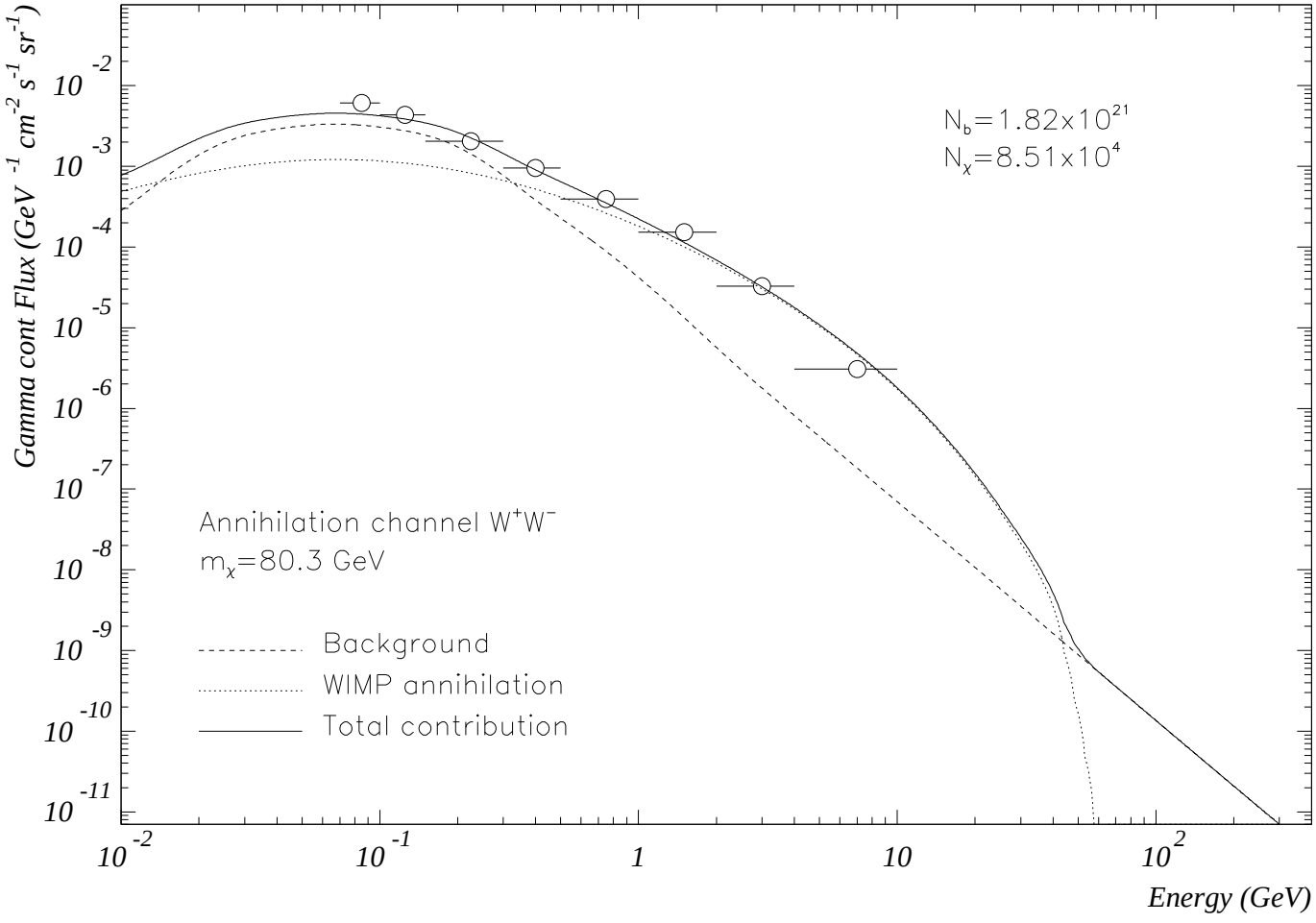
Values of $\langle J(0)\rangle_{\Delta\Omega}$ for two different $\Delta\Omega$'s and for three different density profi les

Profi le	$\langle J(0)\rangle_{\Delta\Omega}$ ($\Delta\Omega = 10^{-3}$ sr)	$\langle J(0)\rangle_{\Delta\Omega}$ ($\Delta\Omega = 10^{-5}$ sr)
Navarro, Frenk, White	$1.21 \cdot 10^3$	$1.26 \cdot 10^4$
Moore *et al.*	$1.05 \cdot 10^5$	$9.46 \cdot 10^6$
Modifi ed isothermal	$3.03 \cdot 10^1$	$3.03 \cdot 10^1$

Fit of EGRET data

The fit is better for small WIMP mass.



GLAST expectation

The possibility of indirect detection can be improved by GLAST [a]

GLAST is scheduled for launch in 2006

With respect to EGRET, GLAST will have:

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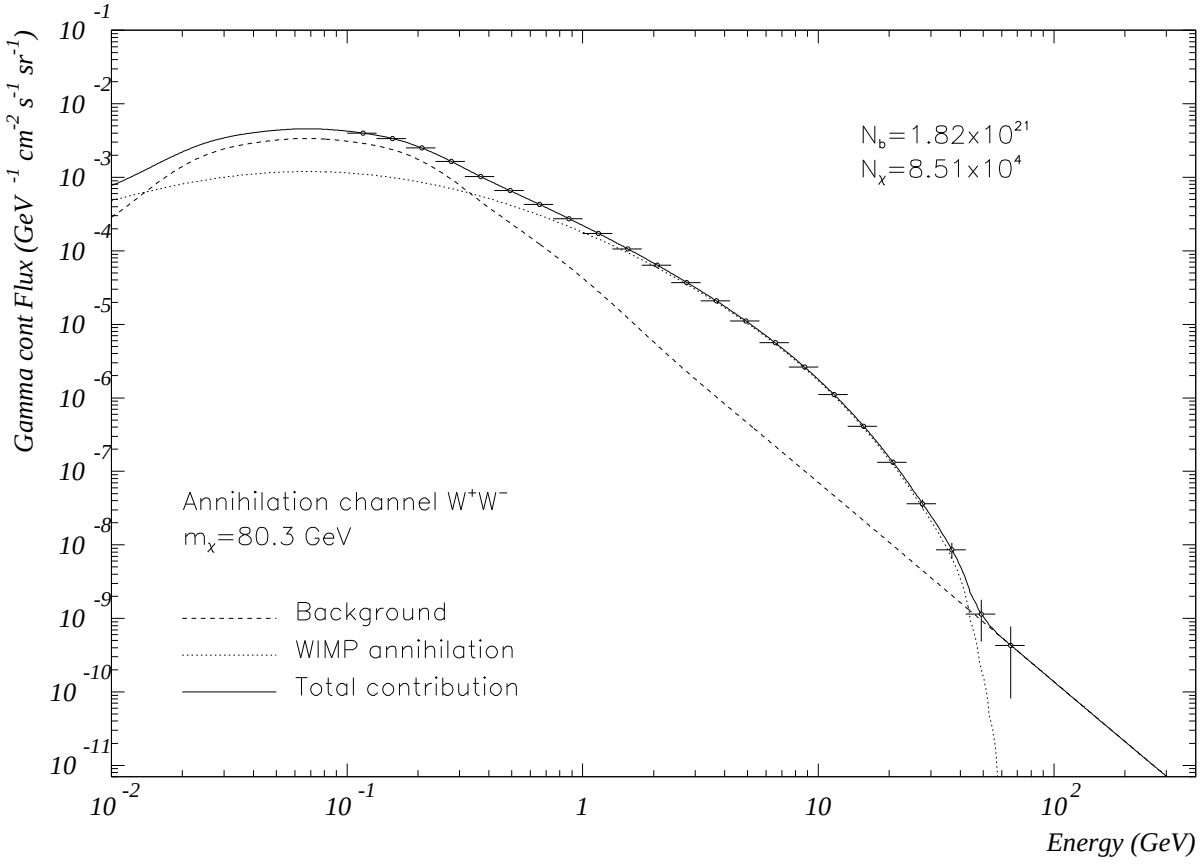
With respect to EGRET, GLAST will have:

- A larger effective area $\sim 10^4$ cm^2
- A better angular resolution $\sim 10^5$ sr
- A better energy resolution 10%
- And it will cover a much wider energy range

GLAST proposal to NASA, SLAC-R-522 (1998)

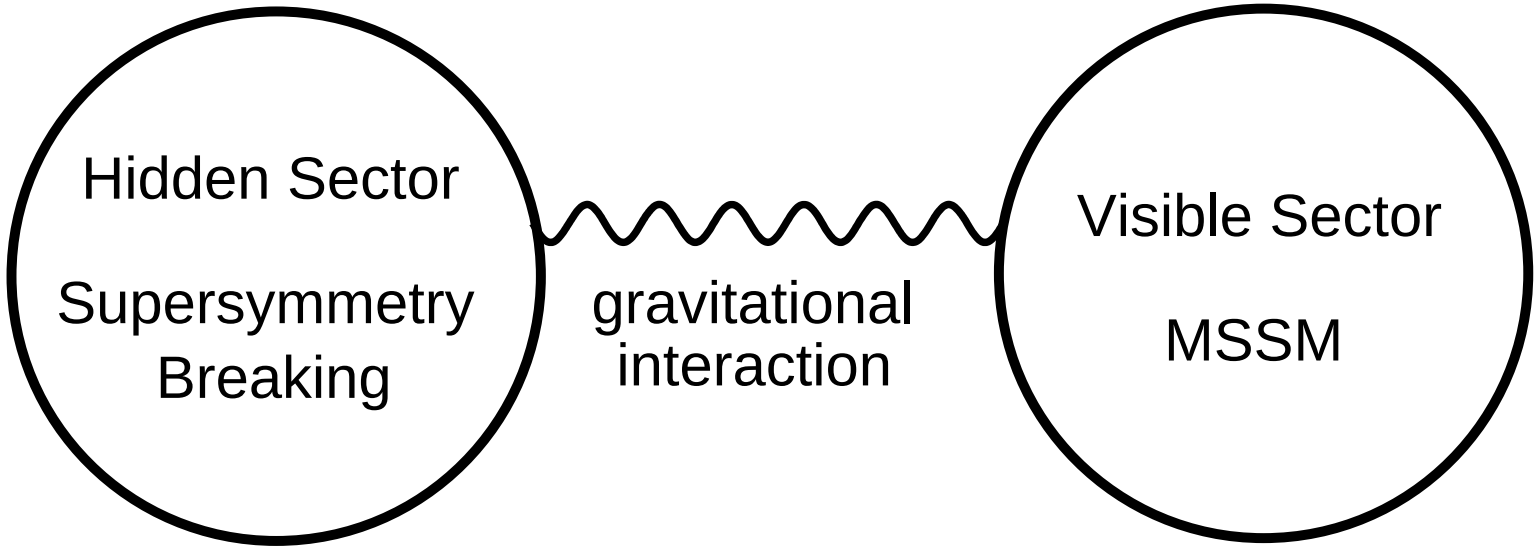
GLAST expectation

Computation of the data set which will be obtained with GLAST in 2 years, in case the EGRET GC excess is due to the WIMP-induced flux ($\Delta\Omega = 10^{-3}$ sr)



Supersymmetry breaking

In the so called gravity mediated scenario:



Different schemes

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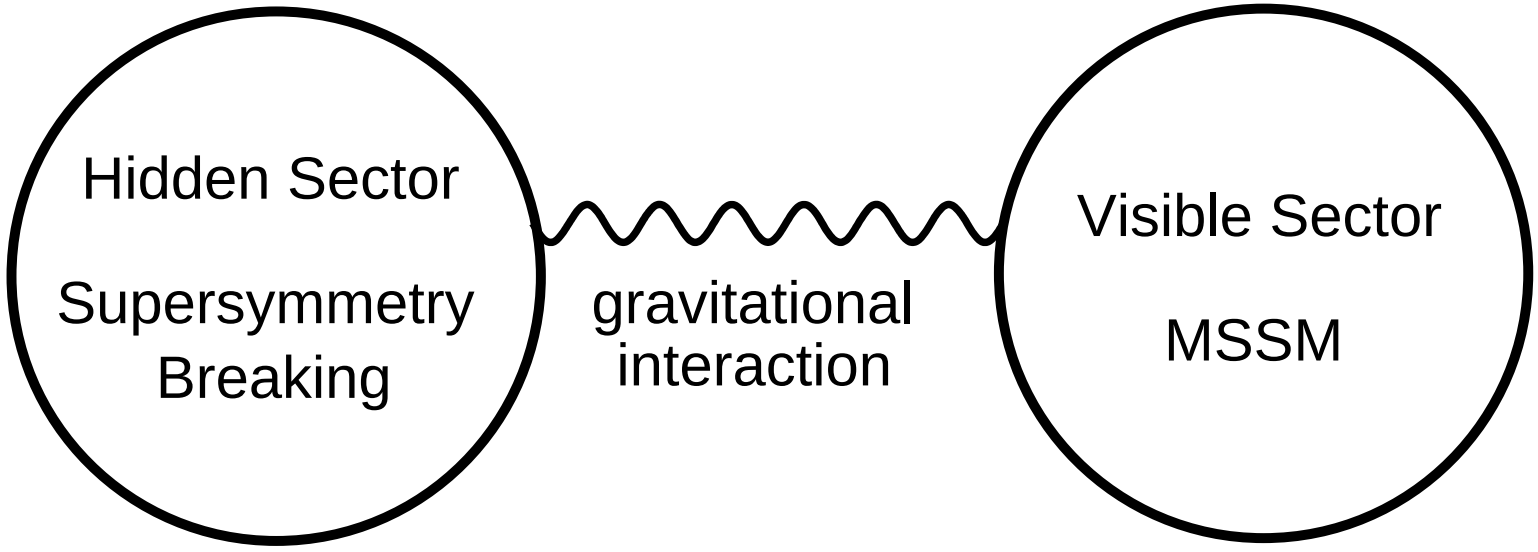

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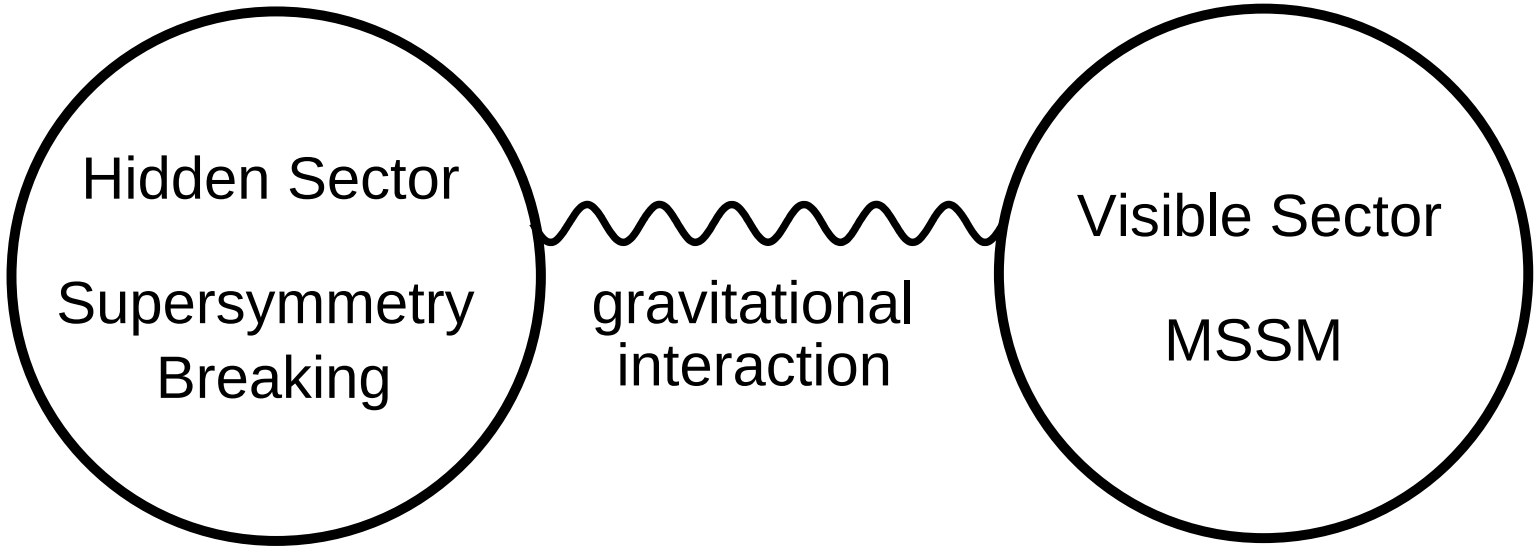

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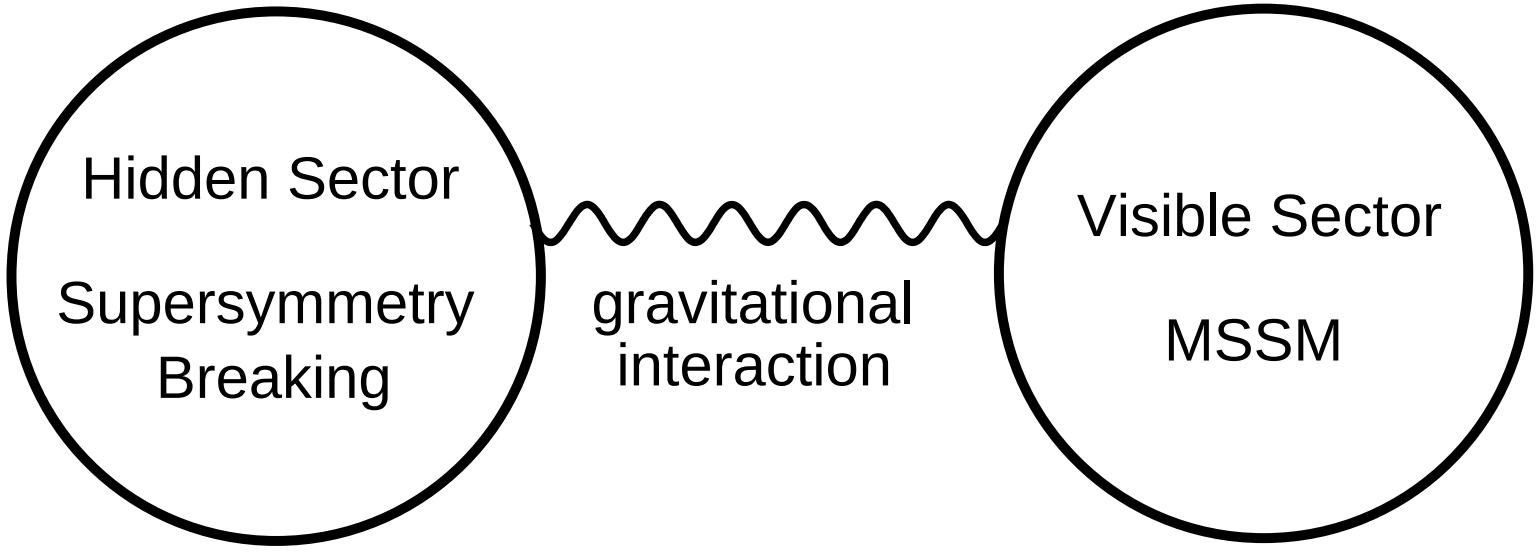

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The mSUGRA (cMSSM) model

Gravity directly couples the hidden sector (where susy is broken) to the MSSM

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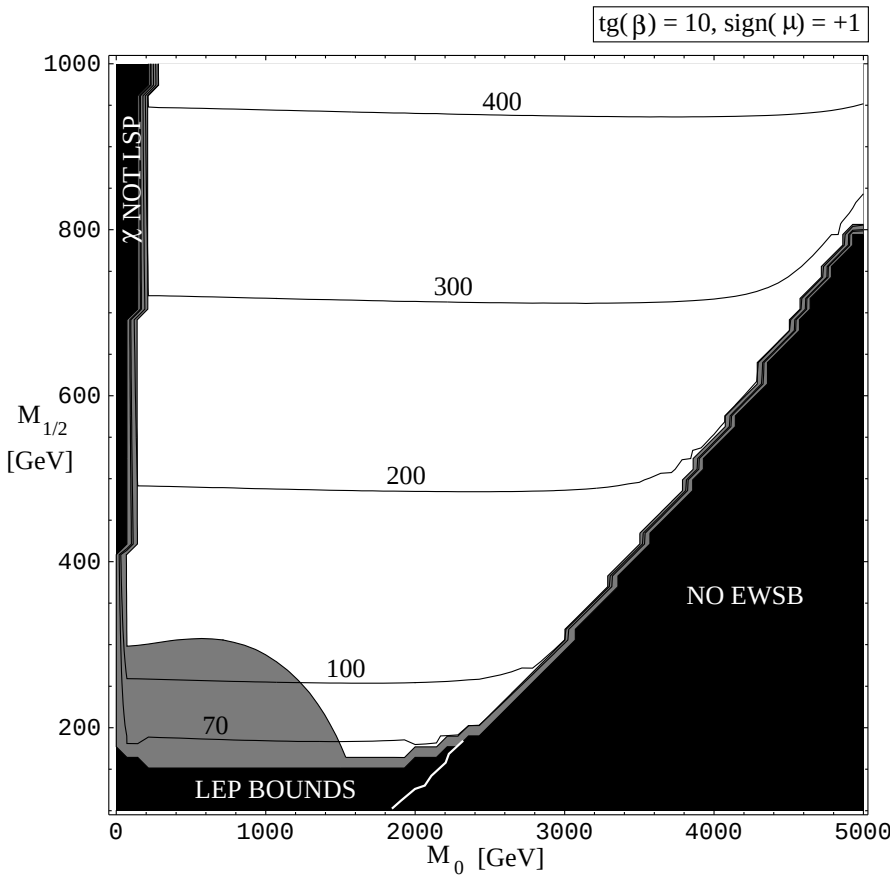
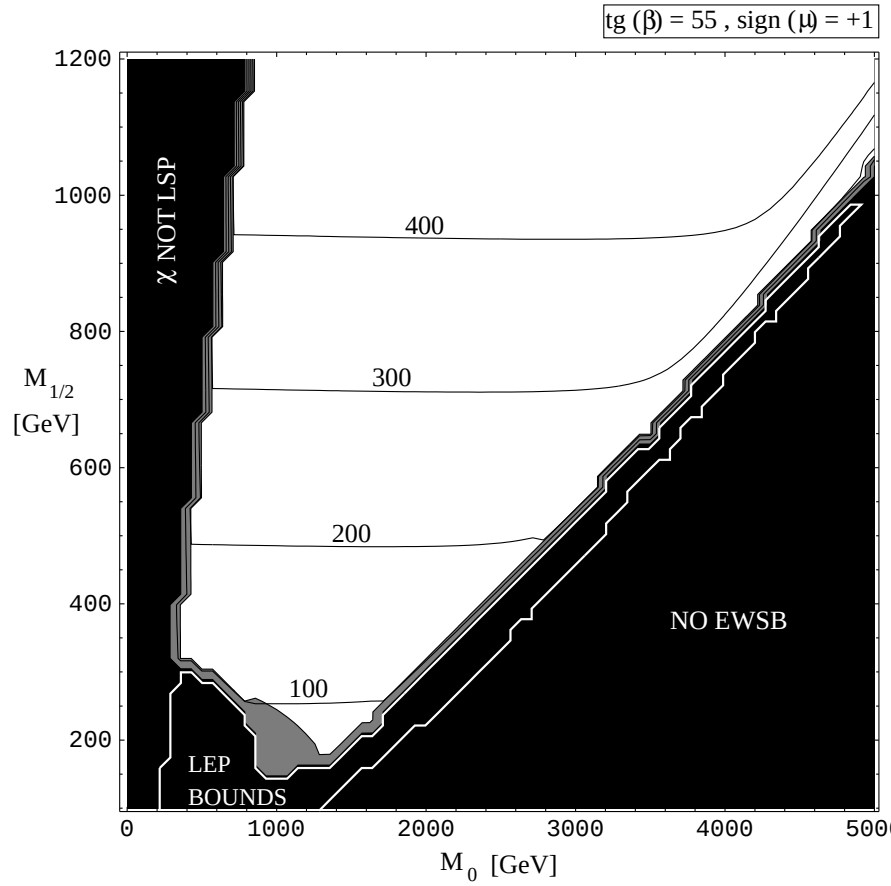
The mSUGRA model is specified by 5 parameters (at GUT scale):

- m_0 universal scalar mass
- $m_{1/2}$ universal scalar mass
- A_0 universal trilinear coupling
- $tan\,(\beta) = v_u/v_d$
- $sgn\,(\mu)$

Neutralino in mSUGRA framework

Neutralino mass in the mSUGRA framework for different parameter choices

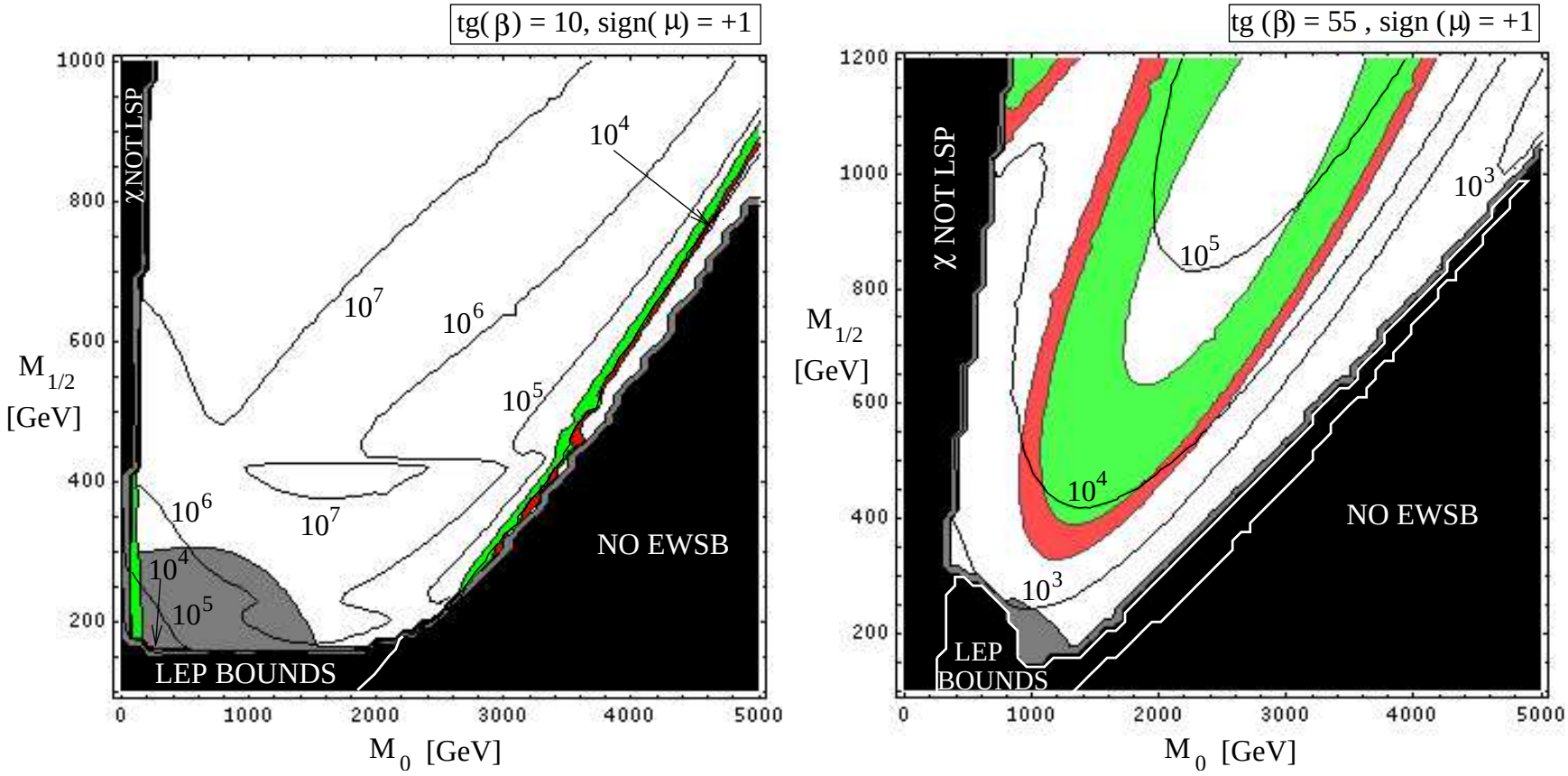




dark shaded region: $m_{h_0} < 114.3$

mSUGRA framework with GLAST

Contour plots in the mSUGRA $(m_0, m_{1/2})$ plane, for the normalization factor N_χ, that allows the detection (3σ level) of the neutralino γ ray signal, with GLAST.

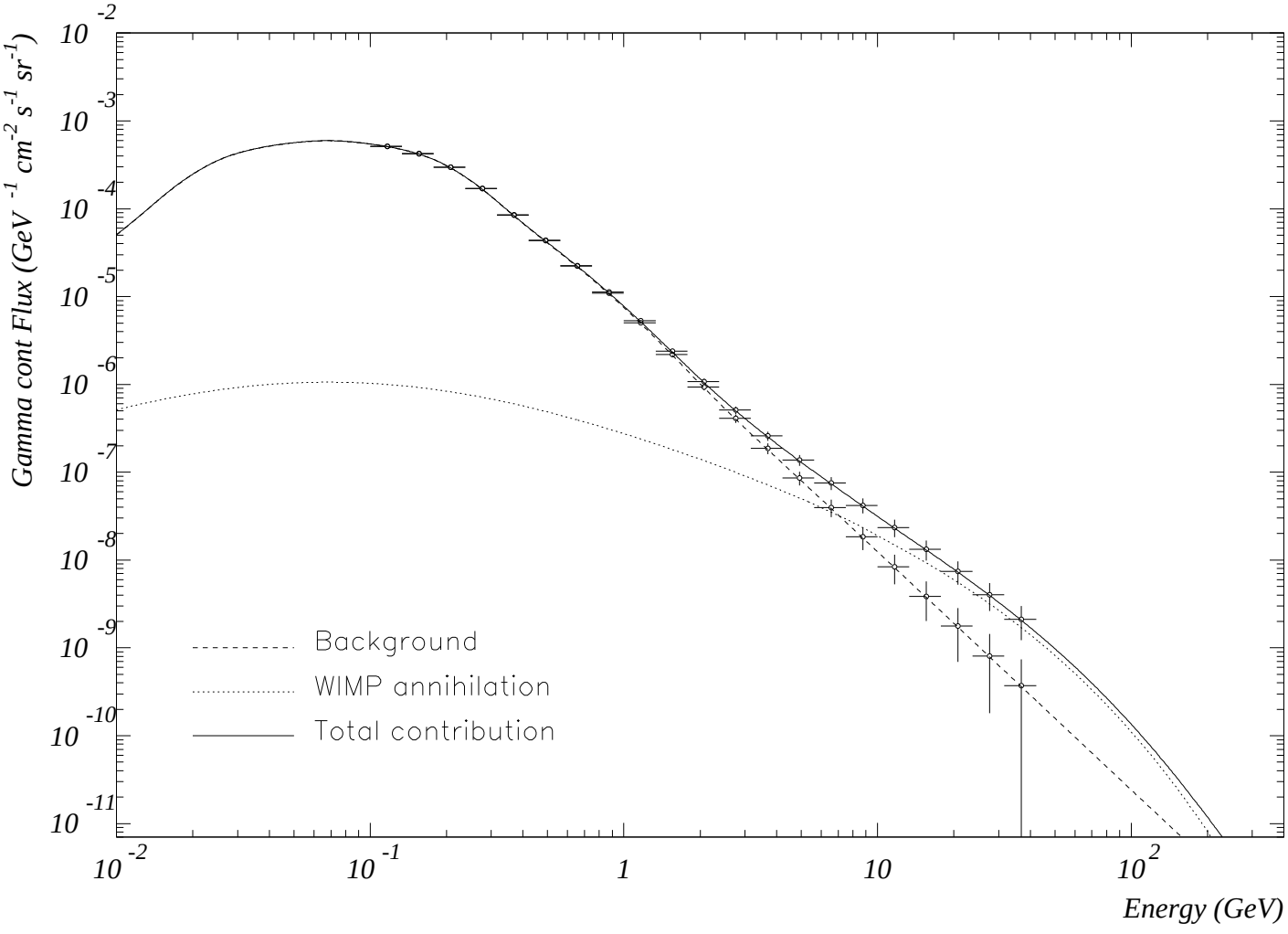


green region: $0.13 \leq \Omega_\chi h^2 \leq 0.3$, red region: $0.09 \leq \Omega_\chi h^2 \leq 0.13$

dark shaded region: $m_{h_0} < 114.3$

mSUGRA framework with GLAST

Detectable γ-ray flux in the mSUGRA framework at 3σ level



Mixed Supersymmetry Breaking

It is possible to consider different supersymmetry breaking scenarios. We built a model that is able to eliminate some unwanted features of the anomaly mediated models.

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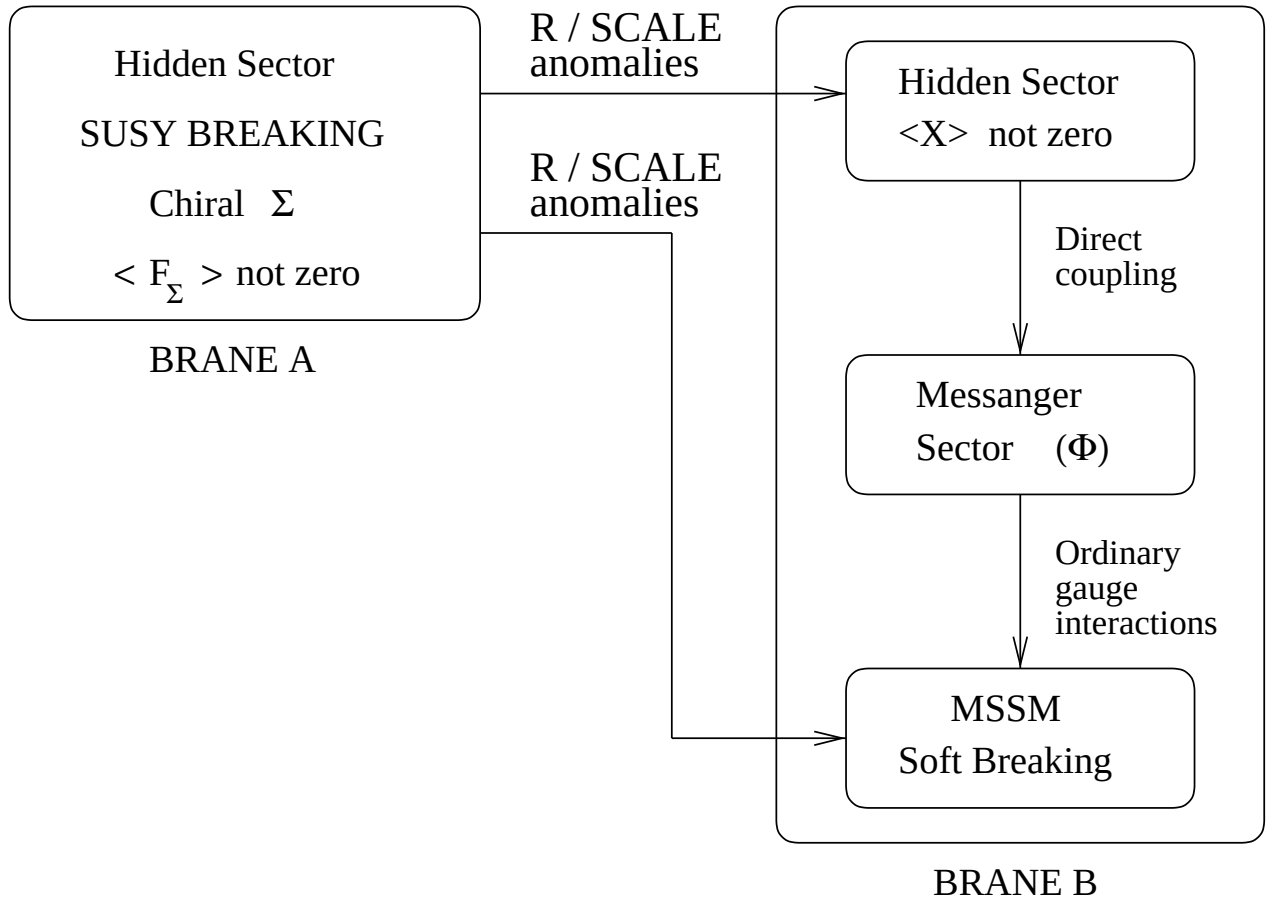

Phenomenology

Soft terms boundary conditions given at the messengers renormalization scale $m = \xi F_\varphi$.

Low energy M_Z prediction are obtained using the appropriate renormalization group equations at two loop level.

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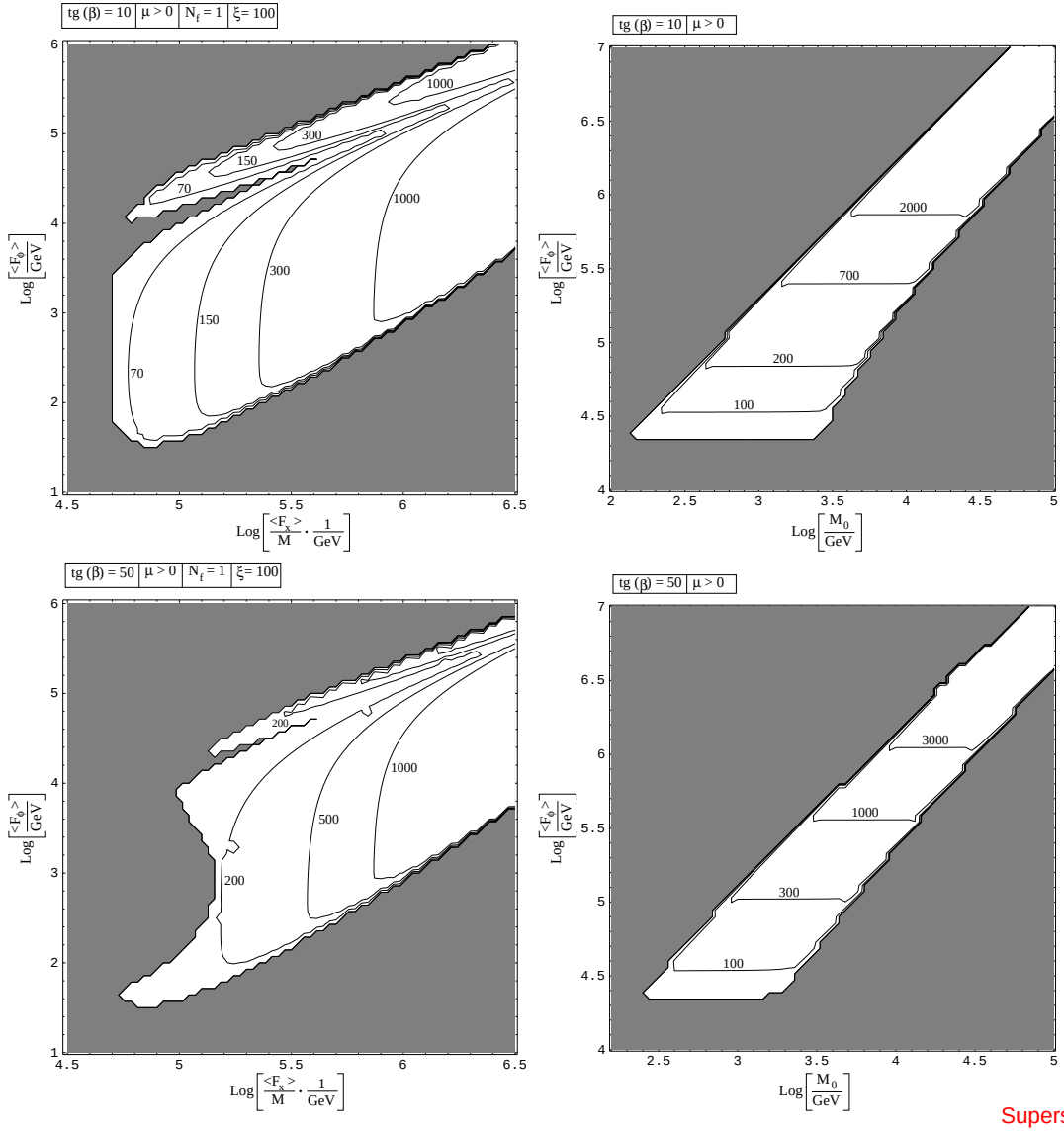
- N_f number of messengers

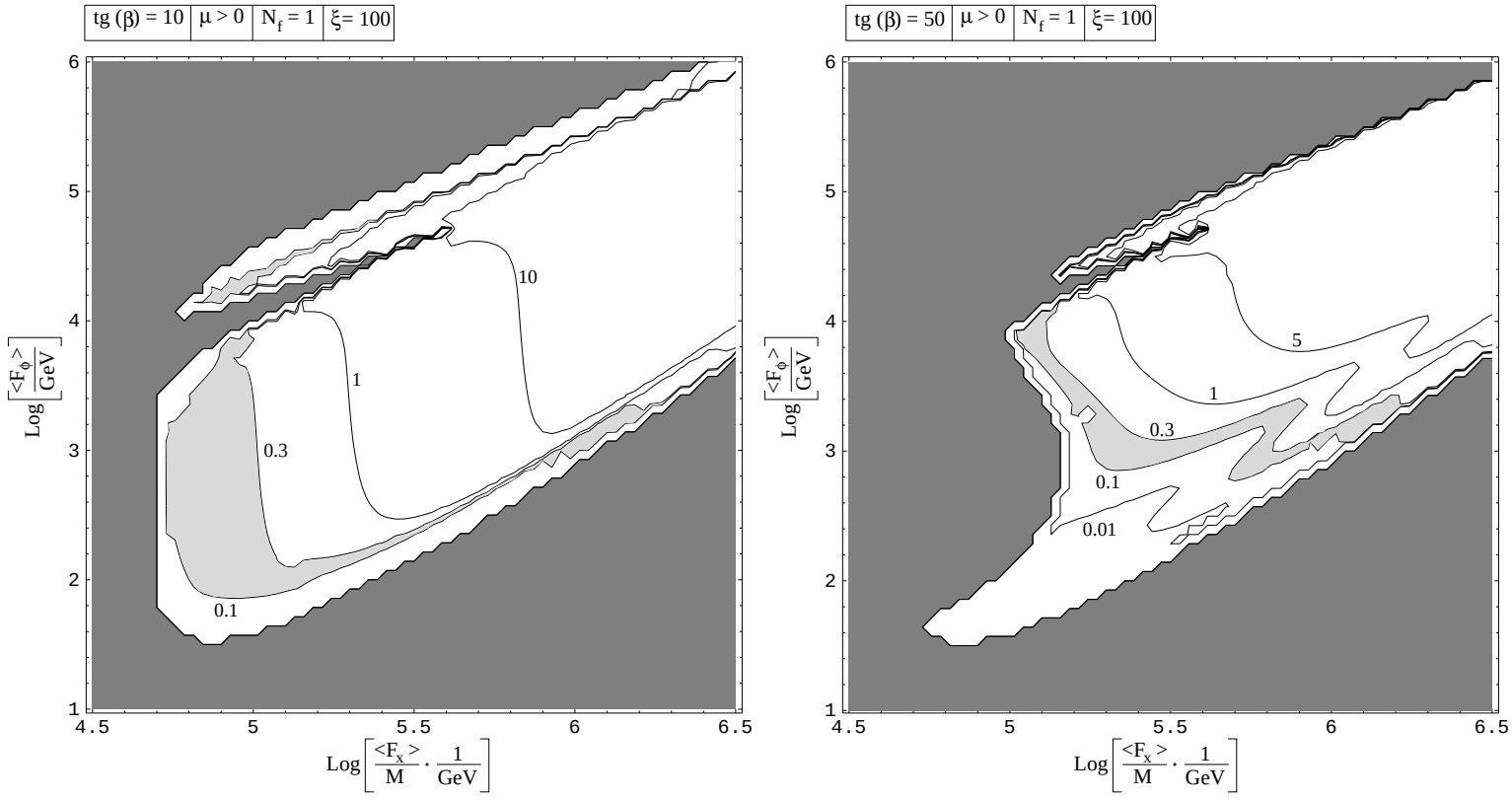
Phenomenology

Contour plots in the $(f/m, F_\varphi)$, fi xingξ, $\tan\beta$, sign(μ) and N_f.



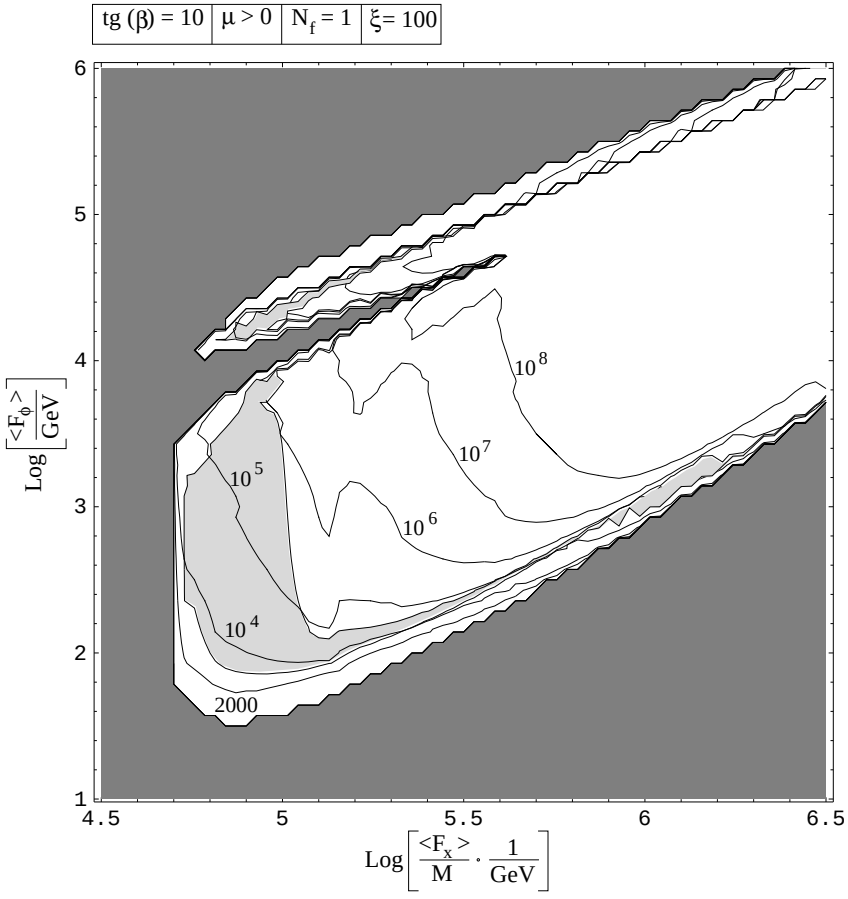
Relic density

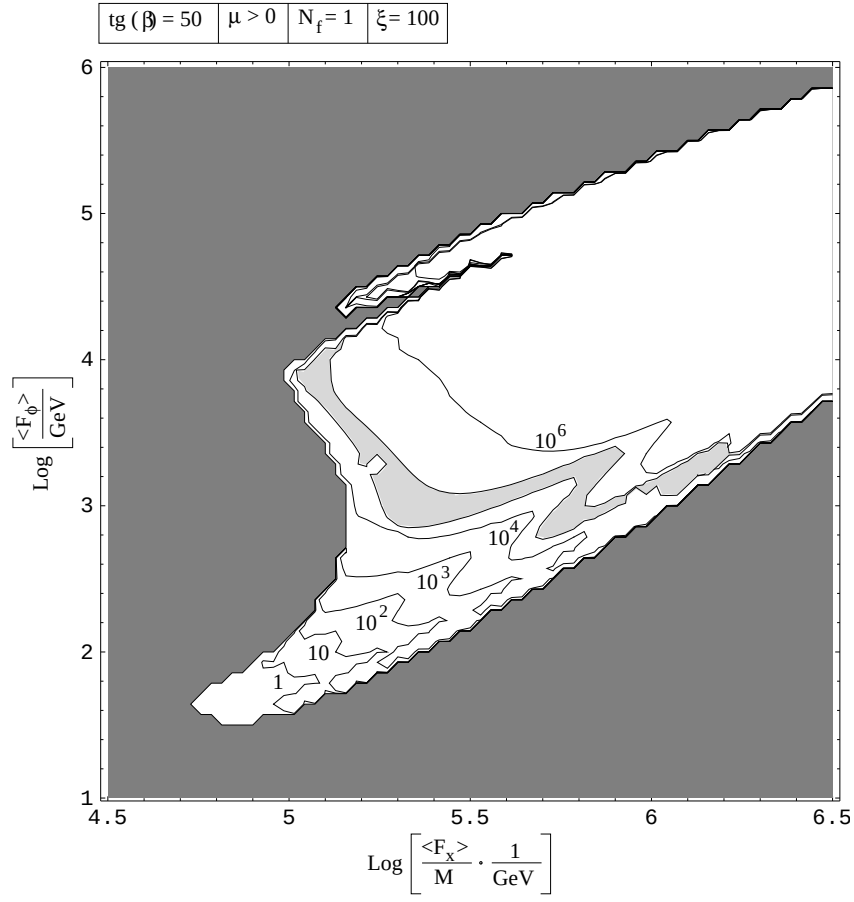
Lines of constant neutralino relic abundance for the mixed-model case. The light-shaded region highlights the portion of the $(f/m, F_\varphi)$ parameter space in which the neutralino relic abundance lies inside or near the interval $(0.1 \leq \Omega_\chi h^2 \leq 0.3)$.



Mixed Framework with GLAST

Isolevel lines for N_χ for the discrimination of ϕ_χ from ϕ_b
($N_\chi \sim$ DM halo density)





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- GLAST will allow to understand if the GC -source is due to “standard” processes or not
- In the case of the mSUGRA model, the GC SUSY source can be detected by GLAST for moderate DM halo profiles
- In the case of the Mixed model, the GC SUSY source can be detected by GLAST for very low DM halo profile

Developments

Possible extension (work in progress):

- monochromatic γ lines (smoking gun signal)
- other supersymmetric models (extra dimensions, brane world, . . .)