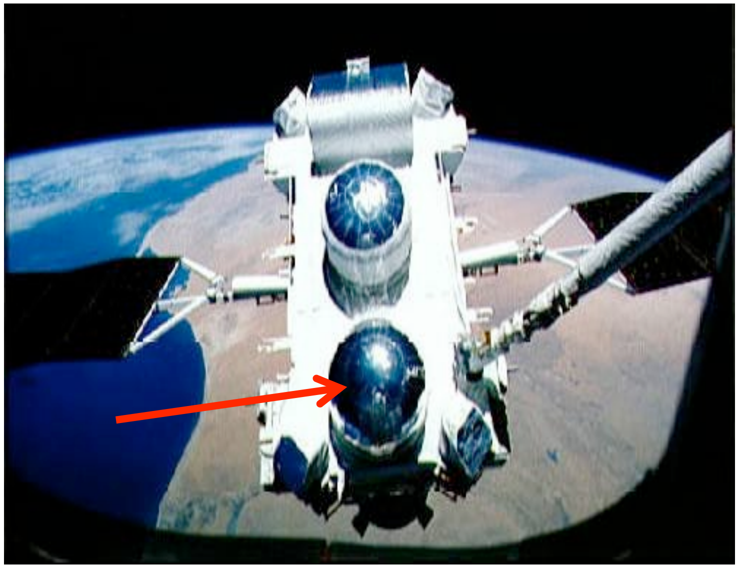
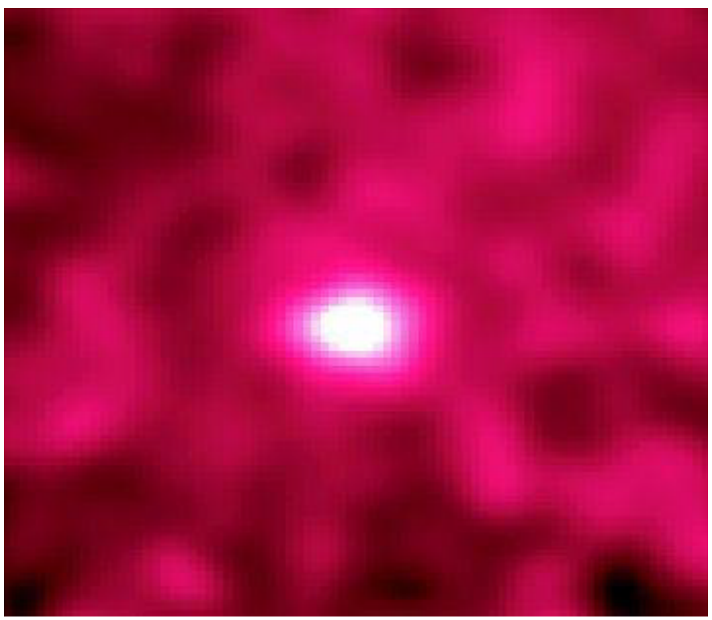
The Galactic center as a dark matter gamma-ray source

Cesarini et al.

Astroparticle Physics 21 (2004) 267-285





EGRET AND GLAST

- EGRET, the Energetic Gamma-Ray Experiment Telescope on CGRO (Compton gamma ray observatory):

  - > Detected gamma rays in the 20 MeV-30 GeV range.

  - > The angular resolution was strongly energy dependent, with a 67% confinement angle of 5.5° at 100 MeV, falling to 0.5° at 5 GeV on axis

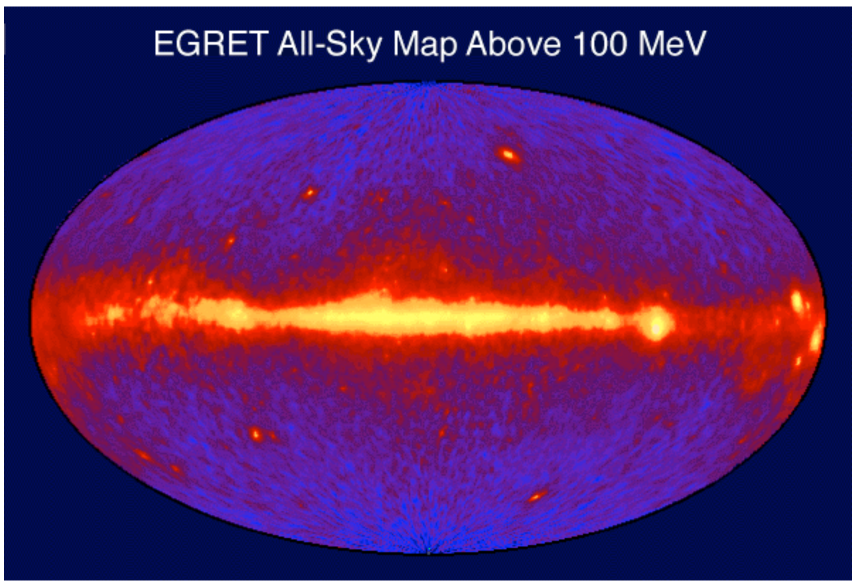
  - > Bright gamma-ray sources can be localized with approximately 10' accuracy.
- Gamma-ray Large Area Space Telescope (GLAST) is scheduled for May 16, 2008

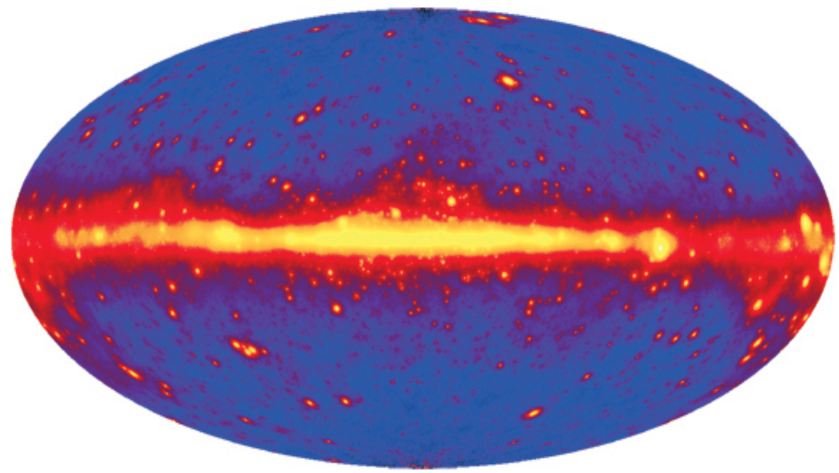
  - > Observe at energies from 8keV to 300 GeV

  - > Optical field of view over 2 steredians.

  - > Measure locations of bright sources within 1' accuracy.

EGRET ALL SKY MAP VS. SIMULATED GLAST ALL SKY MAP





Motivation

- The EGRET telescope has mapped the γ-ray sky up to an energy of about 20 GeV over a period of 5 yrs.
- The detected flux largely exceeds the diffuse γ-ray component expected in the GC direction within 1.5° of the GC (l = b = 0°)
- Compare with a standard modeling of the interaction of primary cosmic rays with the interstellar medium
- EGRET GeV excess shows, as basic features, the kind of distortion of the diffuse γ-ray spectrum one would expect from a WIMP-induced component, assuming that the dark matter halo profile is peaked toward the GC.

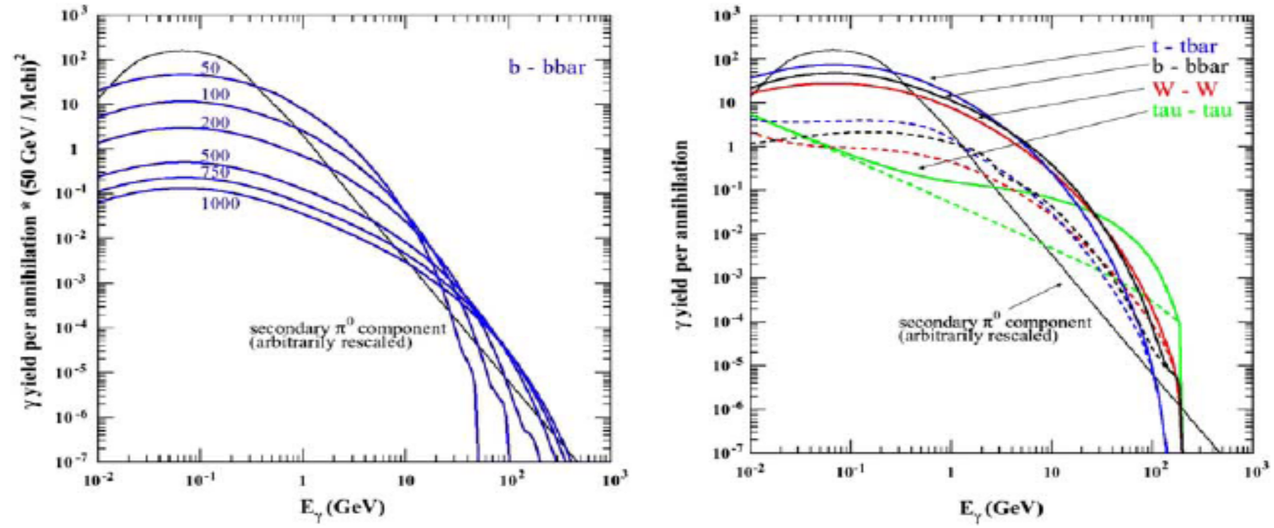


Fig. 1. In the left panel: differential γ-ray yield per annihilation (see Eq. (4)) for a fixed annihilation channel ($b\bar{b}$) and for a few sample values of WIMP masses. For comparison we also show the emissivity, with an arbitrarily rescaled normalization, from the interaction of primaries with the interstellar medium. In the right panel: differential yield per annihilation for a few sample annihilation channels and a fixed WIMP mass (200 GeV). The solid lines are the total yields, while the dashed lines are components not due to π^0 decays.

WHY IS WIMP ANNIHILATION IMPORTANT

•It has long been argued that if a SMBH exists at the galactic center, the process of adiabatic accretion of dark matter on it would produce a “spike” in the dark matter density profile.

•Dominant neutralino annihilation channels include annihilation to fermions, gauge bosons, higgs bosons, and also to photons.

•Fragmentation or decay of tree-level annihilation states give rise to photons.

Table 1
Estimated values for the Galactic diffuse γ-ray component (second column) and EGRET data from a region of 1.5° around the GC (third column), extracted from [12]

Energy bin (GeV)	Expected diffuse γ-ray flux ($cm^{-2}\,s^{-1}\,GeV^{-1}\,sr^{-1}$)	Total γ-ray flux ($cm^{-2}\,s^{-1}\,GeV^{-1}\,sr^{-1}$)
0.03–0.05	3.7×10^{-3}	$(5.0\pm0.8)\times10^{-2}$
0.05–0.07	1.8×10^{-3}	$(1.3\pm0.2)\times10^{-2}$
0.07–0.1	1.1×10^{-3}	$(6.1\pm0.5)\times10^{-3}$
0.1–0.15	6.2×10^{-4}	$(4.4\pm0.2)\times10^{-3}$
0.15–0.3	2.6×10^{-4}	$(2.03\pm0.06)\times10^{-3}$
0.3–0.5	1.0×10^{-4}	$(9.5\pm0.2)\times10^{-4}$
0.5–1	3.5×10^{-5}	$(3.9\pm0.1)\times10^{-4}$
1–2	9.1×10^{-6}	$(1.52\pm0.03)\times10^{-4}$
2–4	2.0×10^{-6}	$(3.2\pm0.1)\times10^{-5}$
4–10	2.3×10^{-7}	$(3.1\pm0.2)\times10^{-6}$

Total flux as superposition of two contributions

- Component due to interaction of primary cosmic rays with interstellar medium (background contribution with spectral shape defined by S_b (E_γ) (background contribution)
- Component due to WIMP annihilation in the dark matter halo, whose energy spectrum is defined by S_χ (E_γ)
- N_b and N_χ are dimensionless normalization parameters.

$$\phi_\gamma = \phi_b + \phi_\chi = N_b S_b + N_\chi S_\chi$$

Background component

- Production and decay of Π^os, inverse Compton scattering and bremsstrahlung
- For $E_\gamma > 1$ GeV, the dominant background source is given by Π^o decays.

$$S_b(E_\gamma) = \frac{1}{(1\ \mathrm{cm}^2\,\mathrm{sr})} \cdot Em(E_\gamma)$$

and

$$N_b = \frac{1}{(1\ \mathrm{cm}^{-2}\,\mathrm{sr}^{-1})} \cdot \int_{\mathrm{l.o.s.}} \mathrm{d}l \, \frac{n_\mathrm{H}(l)}{4\pi} \, \frac{\phi_p^{\mathrm{prim}}(l)}{\phi_p^{\mathrm{prim}}(l=0)}$$

Signal Component

$$\phi_\chi(E,\psi) = 3.74 \times 10^{-10} \left(\frac{\sigma v}{10^{-26}\ \mathrm{cm^3\,s^{-1}}} \right) \left(\frac{50\ \mathrm{GeV}}{M_\chi} \right)^2 \times \sum_f \frac{\mathrm{d}N_f}{\mathrm{d}E} B_f \cdot J(\psi)\ \mathrm{cm^{-2}\,s^{-1}\,GeV^{-1}\,sr^{-1}}$$

$$J(\psi) = \frac{1}{8.5\ \mathrm{kpc}} \left(\frac{1}{0.3\ \mathrm{GeV\,cm^{-3}}} \right) \int \rho^2(l)\,\mathrm{d}l(\psi)$$

$$\langle J(\psi) \rangle_{\Delta\Omega} = \frac{1}{\Delta\Omega} \int J(\psi)\,\mathrm{d}\Omega$$

$$N_\chi \equiv \langle J(\psi) \rangle_{\Delta\Omega} \qquad S_\chi \equiv \phi_\chi / N_\chi$$

Toy model

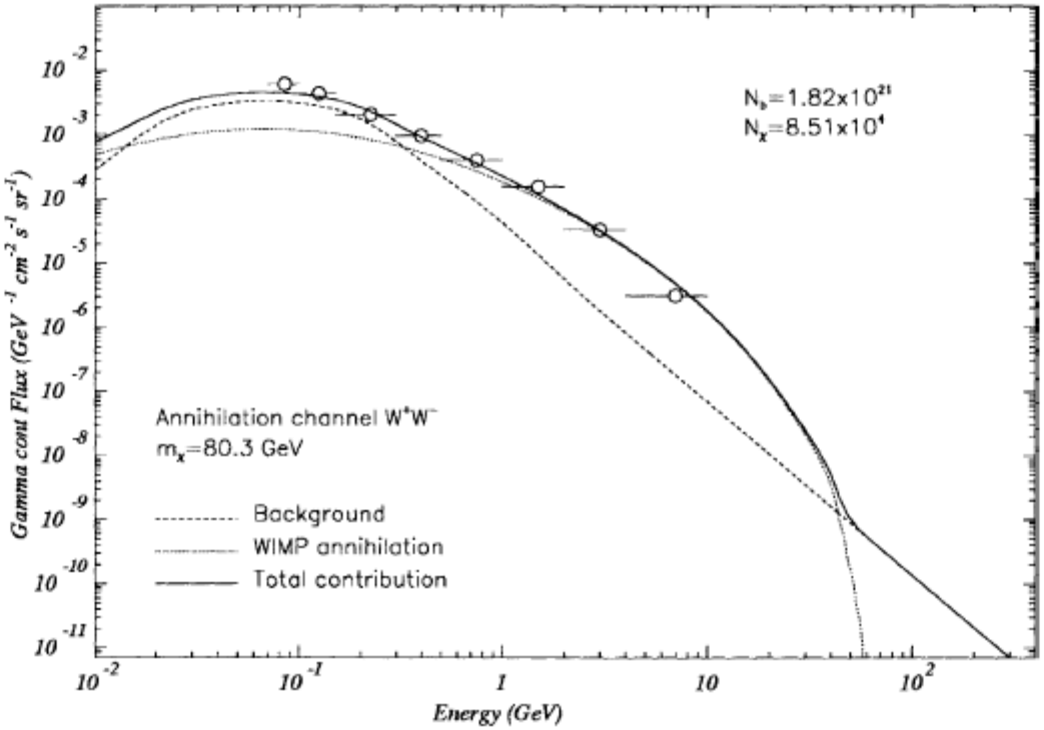


Fig. 2. Fit of the EGRET GC γ-ray data for two sample WIMP models. We fix the WIMP mass ($M_\chi = 50$ GeV in the upper panel, $M_\chi = 80.3$ GeV in the lower panel) and select a single annihilation channel in each of the two cases ($b\bar{b}$ in the upper panel, W^-W^+ in the lower one). Signal and background components are indicated separately, while their sum is shown with a solid line. For both models the value of the reduced statistical χ^2 variable obtained from the fit is around 5.

Simulation from GLAST

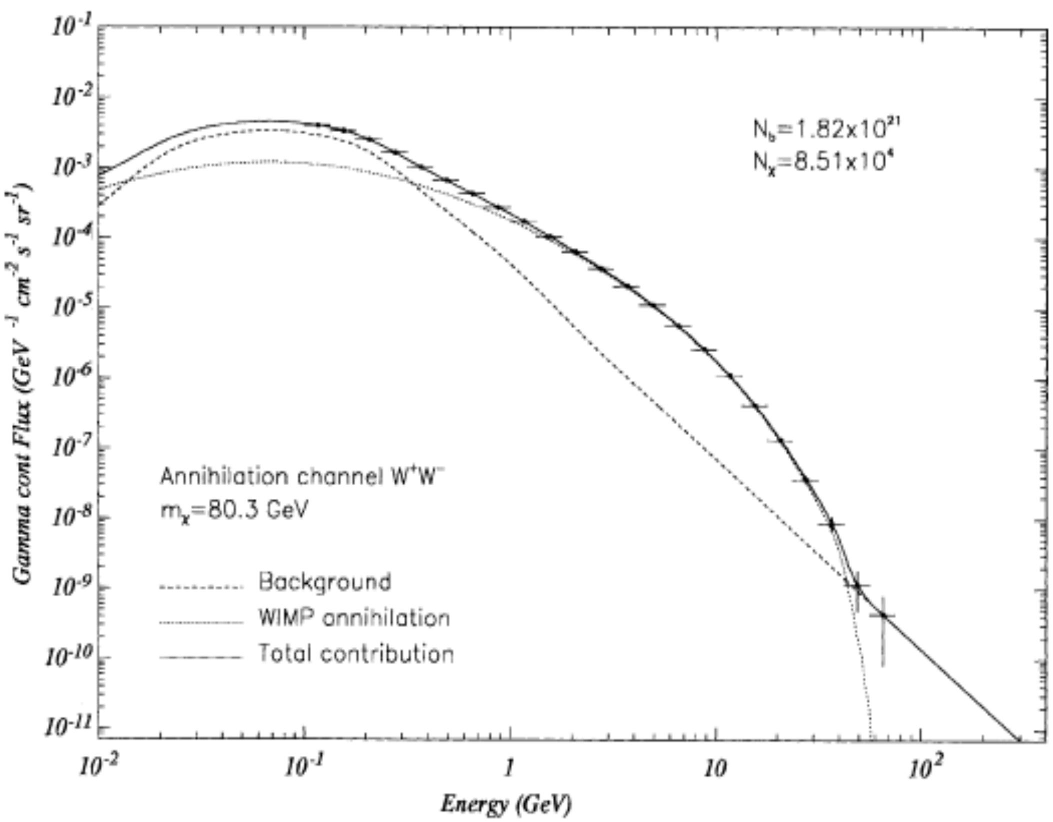


Fig. 5. Simulation of the data set which will be obtained with GLAST in 2 years, in case the EGRET GC excess is due to the WIMP-induced flux shown in one of the sample fits in Fig. 2 (lower panel). The error bars refer to statistical errors for the chosen energy binning and for the angular acceptance $\Delta\Omega = 10^{-3}$ sr.

GLAST simulations according to NFW and Moore et al. models

- Is flux coming from point source located at GC or from a diffuse source?
- NFW and Moore et al. predict an enhancement in dark matter distribution towards GC.
- r_0= 8.5 kpc, ρ_0=0.3Gev/cm^3, γ=1.54
- r_{min}= 10^{-5}kpc

$$\rho(r) = \begin{cases} \rho_0\left(\frac{r}{r_0}\right)^{-\gamma}, & r > r_{\min} \\ \rho_0\left(\frac{r_{\min}}{r_0}\right)^{-\gamma}, & r \leqslant r_{\min} \end{cases}$$

ANGULAR SIGNATURE OF WIMP FROM GLAST SIMULATION

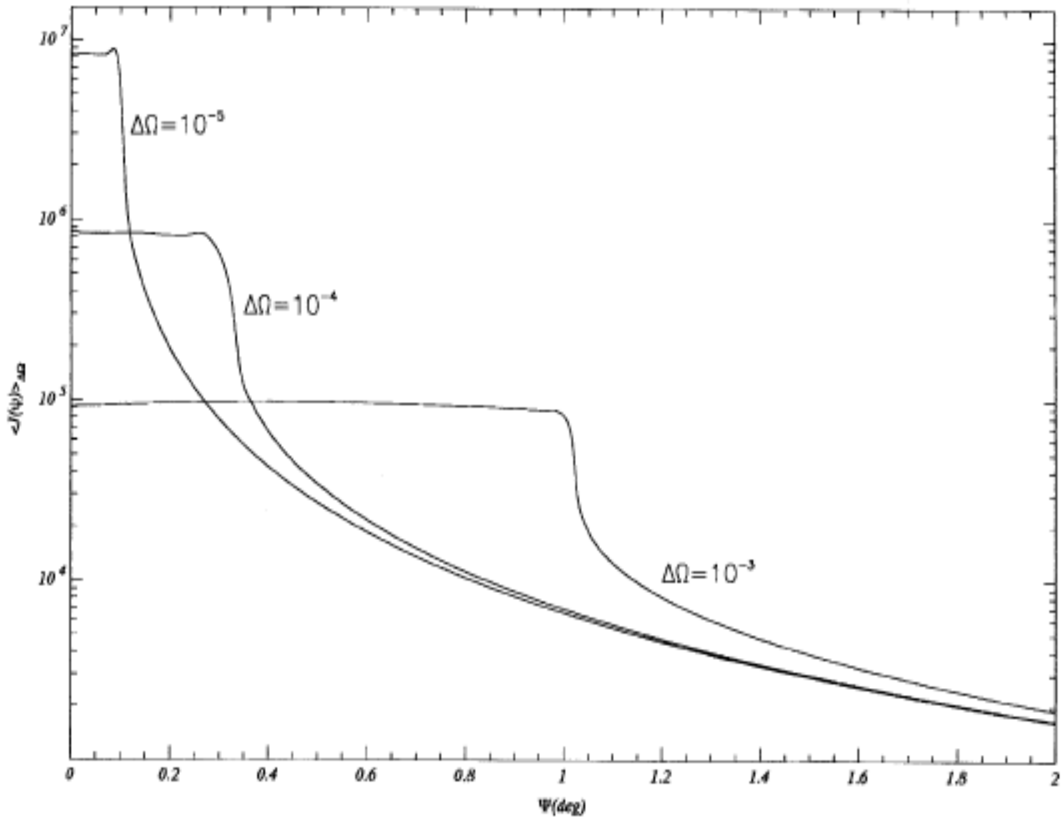


Fig. 6. Angular dependence for the WIMP signal displayed in the lower panel of Figs. 2 and 5 in the case in which the dark matter density profile $\rho(r)$ has the power law form introduced in Eq. (9). ψ is the angle between the direction of observation and that of the GC. $\langle J(\psi)\rangle_{\Delta\Omega}$ coincides with N_χ for the toy-model we introduced. Three sample angular acceptances $\Delta\Omega$ are considered.

GLAST performance for a weaker source

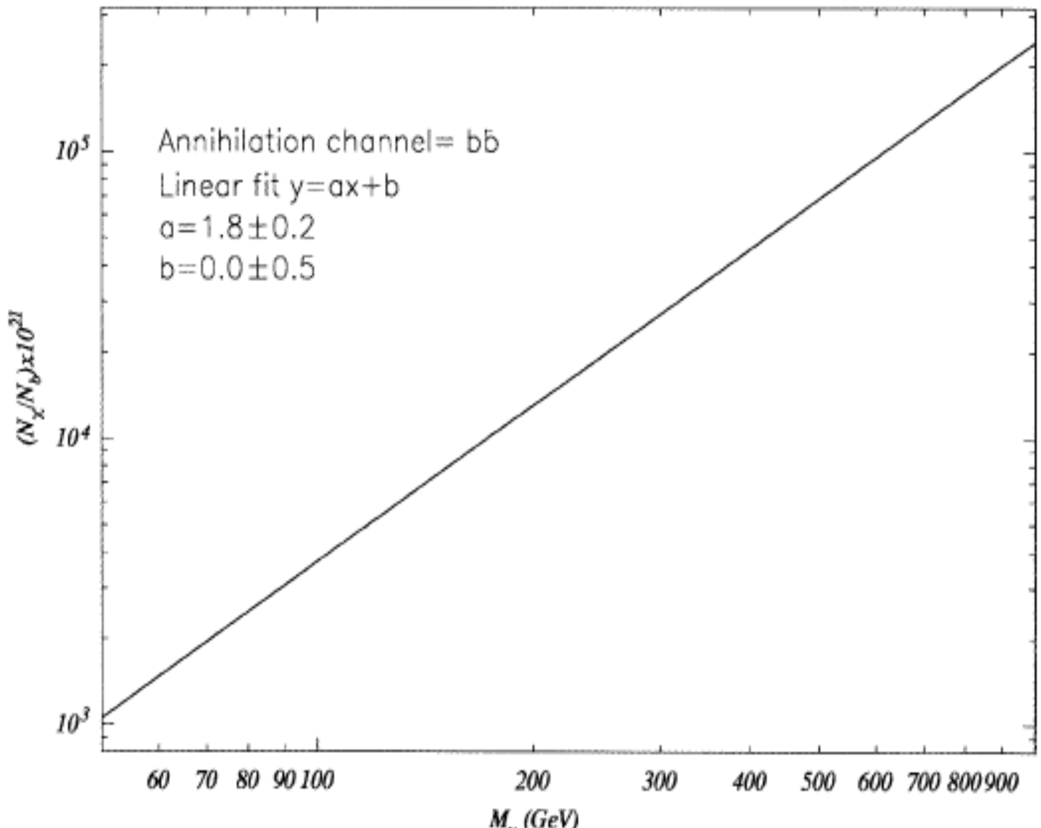


Fig. 8. Minimum ratio between the normalization of the WIMP signal N_χ and the background normalization N_b such that the WIMP induced signal would be singled out of the background with GLAST. We are referring to a toy-model with a single annihilation channel allowed, i.e. $b\bar{b}$ in the case displayed. In the linear regression fit marked in the figure $y = \log_{10}\left(\frac{N_\chi}{N_b}\right)$ and $x = \log_{10} M_\chi$.

THE LIGHTEST NEUTRALINO IN MSUGRA FRAMEWORK

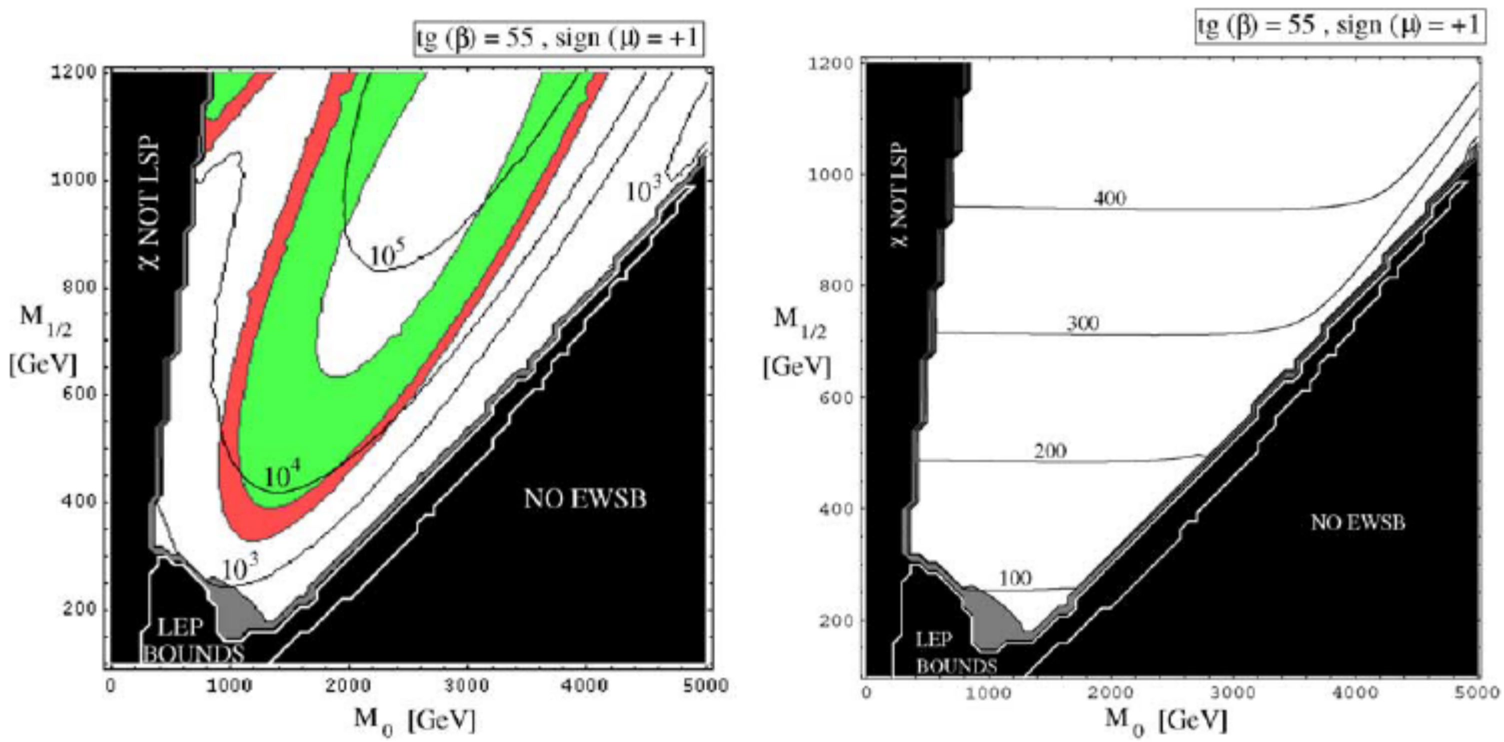


Fig. 10. Contour plots in the mSUGRA $(m_0, m_{1/2})$ plane for $\tan\beta = 55$. Left panel: values of the normalization factor N_χ, that allow the detection of the neutralino γ ray signal, with GLAST. Right panel: values of the neutralino mass. The excluded and colored regions are as in Fig. 9. (For interpretation of references to color in this figure legend, the reader is referred to the web version of this article.)