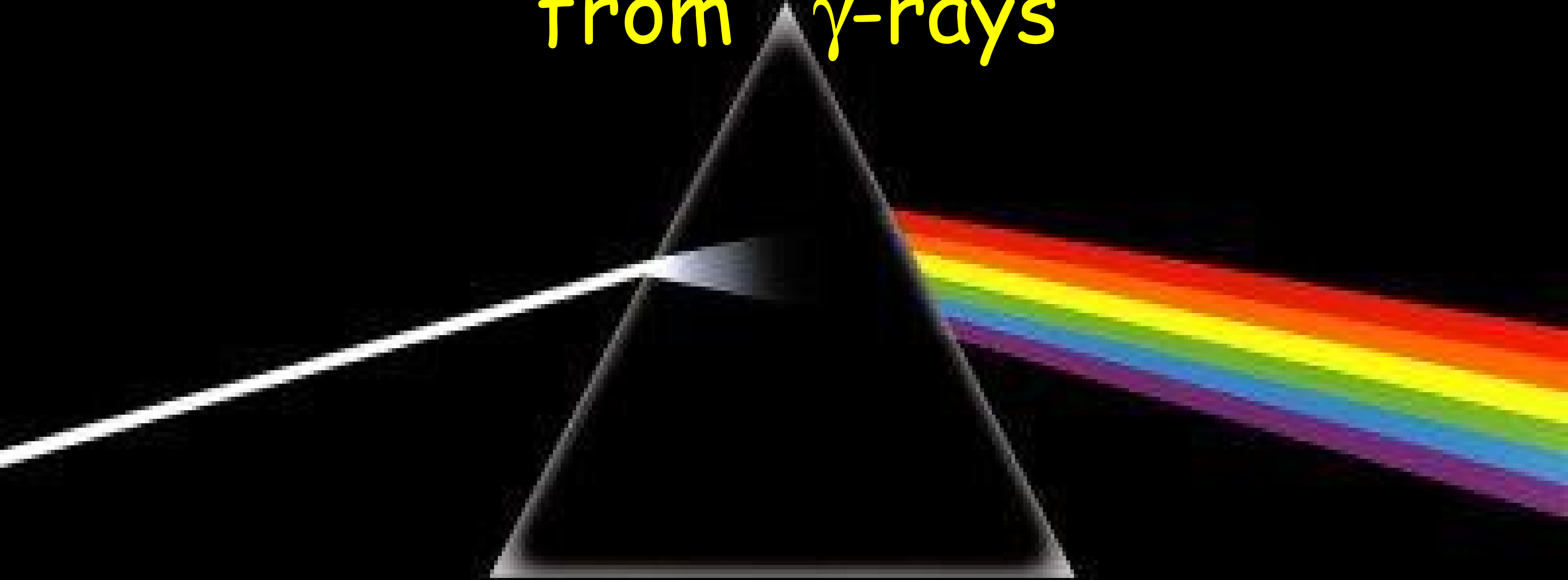
Supersymmetry and constraints from γ-rays



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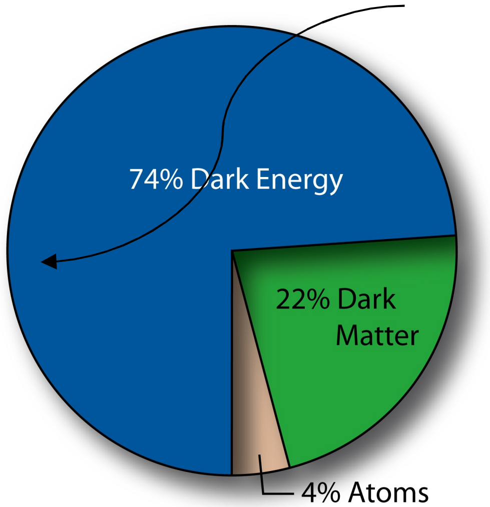
LPNHE, Paris 13.03.2009

Neutralino as the CDM candidate

$$\chi = a_1 \widetilde{B}_0 + a_2 \widetilde{W}_0^3 + a_3 \widetilde{H}_0^1 + a_4 \widetilde{H}_0^2$$



- **Stable** (if R-parity is conserved)
- **Mass**: $m_\chi \sim$ 10-1000 GeV
- Non-relativistic at decoupling $\Rightarrow$ **CDM**
- **Neutral** & **colourless**
- **Weakly** interacting (WIMP)
- Good relic density $\boldsymbol{\Omega_\chi h^2}$

$\Omega_m h^2 = 0.136$ $\Omega_b h^2 = 0.0227$ (WMAP05-Komatsu et al. ApJS2008)

$\Omega_m \sim 0.228$ $\Omega_\Lambda \sim 0.726$ (WMAP05&BAO&SNIa)

Which Supersymmetric Model?

- Theoretical and experimental constraints are too faint to outline a model
- Minimal Supersymmetric extension of the Standard Model **(MSSM)** depends on the SYMMETRY BREAKING mechanism:
  - **Gravity** mediated → **neutralino** DM
  - Gauge mediated → gravitino DM
  - Anomaly mediated → neutralino, stau sneutrino
- The nature and phenomenology of LSP depends on susy breaking and regions of the susy parameter space

Gravity mediated SUSY schemes

Supergravity inspired models (**SUGRA**)

- Unification conditions occur at the GUT scale (M_{GUT}~10^{16} GeV)

$$M_i(M_{GUT}) = m_{1/2} \qquad (gaugino\ masses)$$

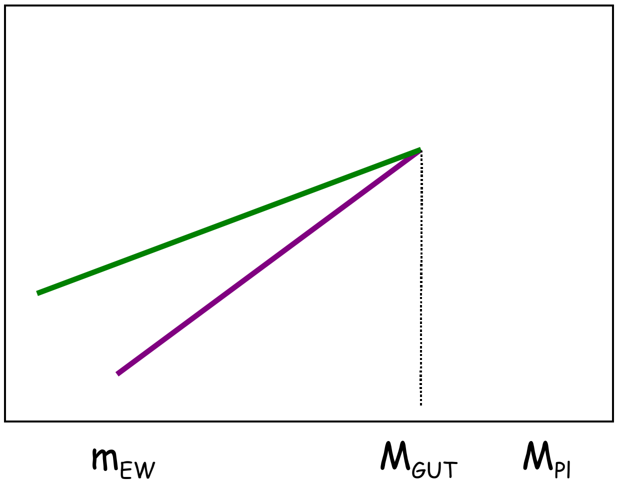
$$m_i(M_{GUT}) = m_0 \qquad (scalar\ masses)$$

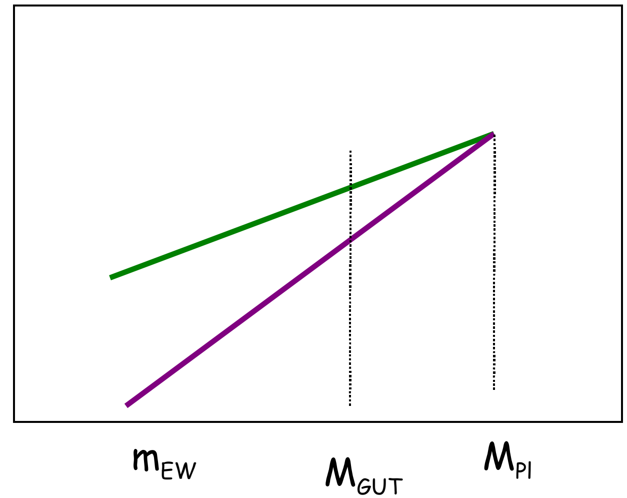
$$A^{u(d,l)}(M_{GUT}) = A_0 m_0 \qquad (trilinear\ terms)$$

- Free parameters of the model: $m_{1/2},\ m_0,\ A_0,\ sign(\mu),\ \tan\beta$

- RGE evolution down to EW scale & radiative EW symmetry breaking

SUGRA is severely constrained by unfication assumptions at M_{GUT}.





But:

- universality might occur at higher scales (M_{plank}) leading to deviations from universality at M_{GUT}
- the starting point for RGE could begin at a lower scale, between M_{GUT} and M_{EW}

→ <u>non-universal SUGRA</u>

Supersymmetric Models

- effMSSM – Effective Minimal Supersymmetric Standard Model at the EW scale
- effMSSM with non-universal gaugino masses (low-mass neutralinos)
- Minimal SUGRA
- SUGRA with non-universal scalar masses in Higgs sector

with the inclusion of:

- Experimental Limits on susy particles
- Experimental Limits on Higgs masses
- $a_\mu=(g_\mu-2)/2$
- B rare decays

Effective MSSM scheme (effMSSM)

(Model parameters defined at the EW scale)

Independent parameters:

- M_1 U(1) gaugino soft breaking term
- M_2 SU(2) gaugino soft breaking term
- μ Higgs mixing mass parameter
- $\tan\beta$ ratio of two Higgs v.e.v.'s
- m_A mass of CP odd neutral Higgs boson
- m_q soft mass common to all squarks
- m_l soft mass common to all sleptons
- A trilinear parameter
- $R \equiv M_1/M_2$ (=0.5 in GUT)

- Experimental Bounds
- Requirements that neutralino is the LSP
- No a priori on the relic density $\Omega_\chi h^2$

Subdominant neutralinos, if detectable, could be very interesting for particle physics (new physics) and cosmology (mixture of candidates)

Experimental constraints

- EXPERIMENTAL BOUNDS:

  - Accelerator (LEP & Tevatron) data on Higgs and supersymmetric particle (negative) searches

  - $b \to s\gamma$

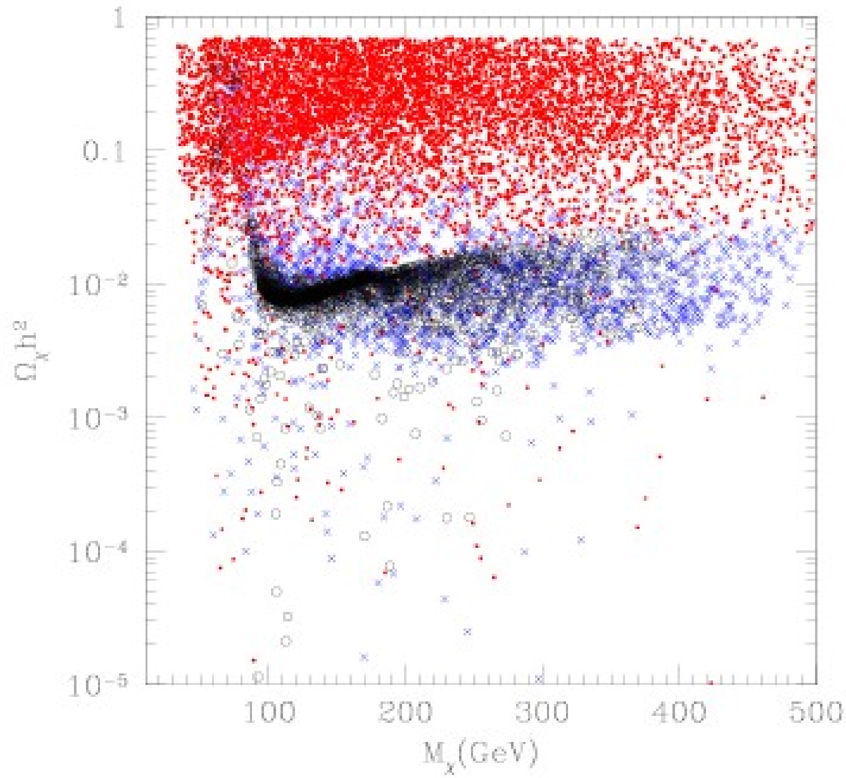
  - $B_S \to \mu^+ \mu^-$ (BR($B_S \to \mu^+ \mu^-$) $\leq 9.5 \times 10^{-7}$)

  - $a_m \equiv (g_m - 2)/2$ ($-142 \leq \Delta a_m \cdot 10^{11} \leq 474$)

- Requirements that neutralino is the LSP
- No a priori on the relic density $\Omega_\chi h^2$

Subdominant neutralinos, if detectable, could be very interesting for particle physics (new physics) and cosmology (mixture of candidates)

Neutralino relic abundance



effMSSM Bottino et al. 2001

The Neutralino can be THE DM candidate ($\Omega_\chi h^2$ ~ 0.1), able to explain the whole non-baryonic DM or a subdominant relic Particle

Red: gaugino
Blue: mixed
Black: higgsino

SIGNALS from RELIC WIMPs

For a review, see i.e. Bergstrom hep-ph/0002126

Direct searches: elastic scattering of a WIMP off detector nuclei
Measure of the recoil energy

Indirect detection: in CRs

- signals due to annihilation of accumulated $\chi\chi$ in the centre of celestial bodies (Earth and Sun)
  $\rightarrow$ **neutrino flux**

- signals due to $\chi\chi$ annihilation in the galactic halo
  $\rightarrow$ **neutrinos**
  $\rightarrow$ **gamma-rays**
  $\rightarrow$ **antiprotons, positrons, antideuterons**

N.B. New particles are searched at **colliders**
But we cannot say anything about **DM** candidates!

γ-rays From Relic Neutralinos

$\chi\chi \rightarrow (\ldots\pi\ldots) \rightarrow \gamma$ *DIFFUSE*

$\chi\chi \rightarrow (\text{1-loop}) \rightarrow 2\gamma$ *LINE*

$$\Phi_\gamma^{susy} = \frac{1}{4\pi} \frac{<\sigma_{ann} v>_0}{2m_\chi^2} \frac{dN_\gamma}{dE_\gamma} I(\Psi)$$

$\frac{dN_\gamma}{dE_\gamma}$ Source spectrum from $\chi\chi$ annihilation
Mostly from $\pi^0 \rightarrow 2\gamma$ calculated *i.e.* by Pythia MC

$$I(\Psi) = \int_{l.o.s.} \rho^2(r(\lambda,\psi))d\lambda$$

Integral along the line-of-sight and ρ is the DM density distribution

$$r = \sqrt{\lambda^2 + r_\oplus^2 - 2\lambda r_\oplus \cos\psi}, \quad \cos\psi = \cos l \cos b$$

r = galactocentric distance
l, b = longitude, latitude

Dark matter distribution

- Cored DM density:

$$\rho(r) = \rho_0 \frac{R_C^2}{r^2 + R_C^2}$$

Persic, Salucci, Stel 1996;
Burkert 1995; ...

- Singular profiles (N-body simulations):

Navarro, Frenk, White (NFW) 1996;
Navarro et al., 2004; Volker et al 2008;
Khulen et al 2007; Diemand et al. 2008; ETC

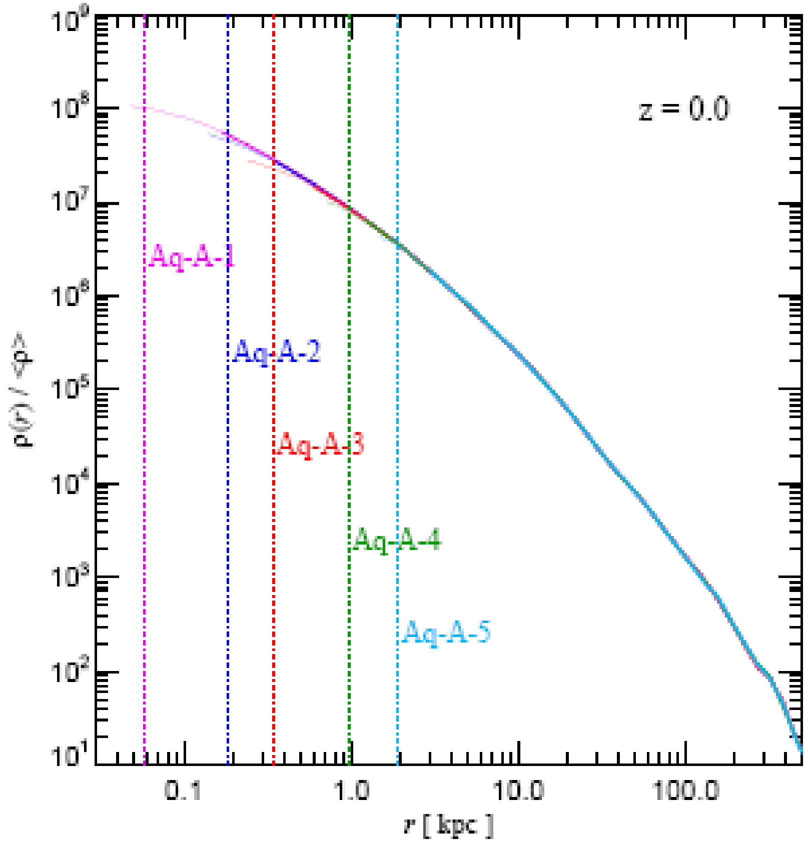
$$\rho_{NFW}(r) = \rho_0 \frac{\rho_S}{(r/r_S)(1 + r/r_S)^2}$$

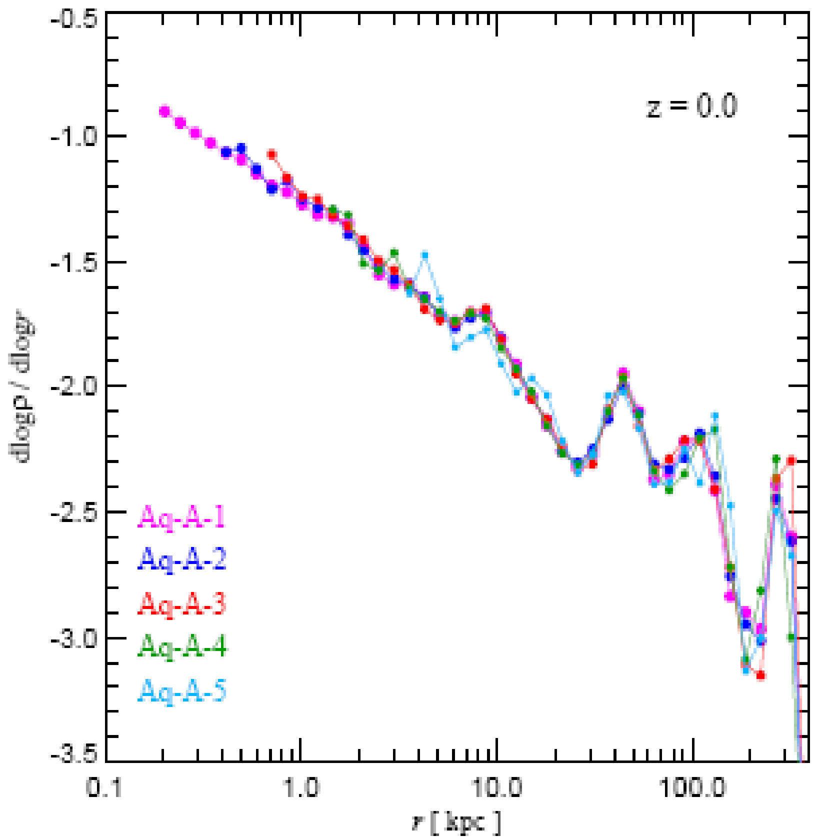
$$\rho_{NFW}(r) \xrightarrow{r \to 0} r^{-1}$$

Resolution of simulated galactic-sized haloes is r~1 kpc

Below 1 kpc it is an ARBITRARY extrapolation

Resolution and shape at small radii



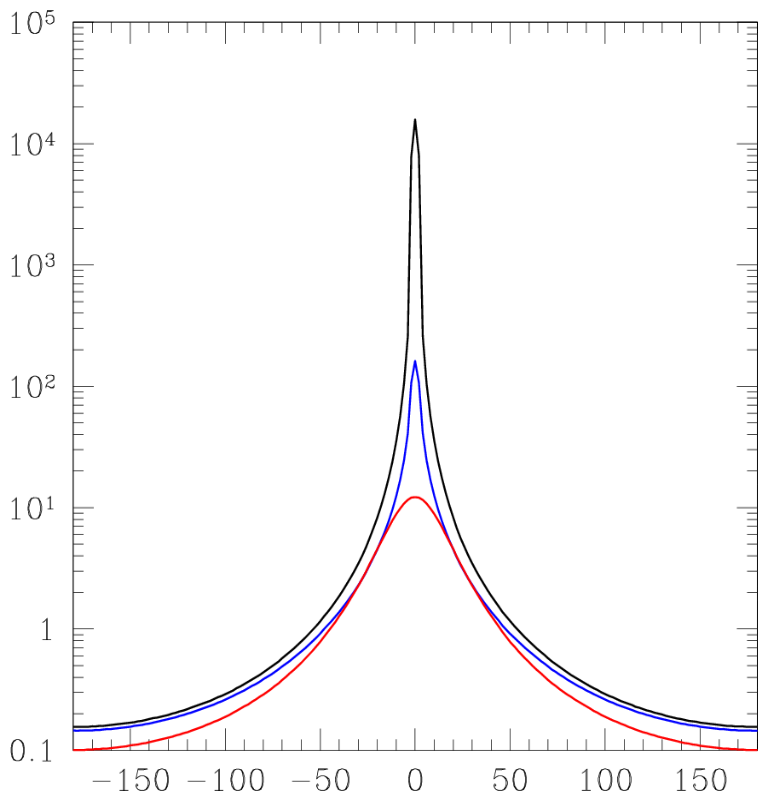


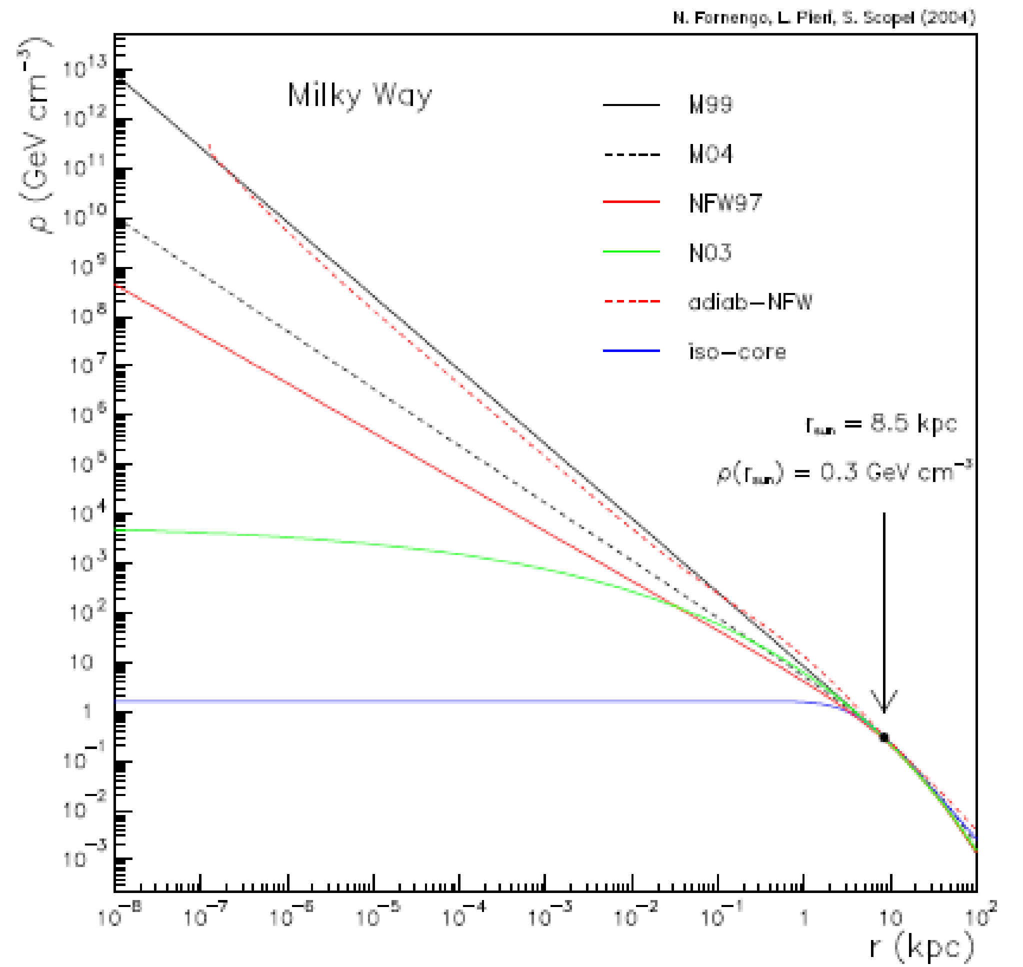
Volker et al. 2008 (Aquarius)

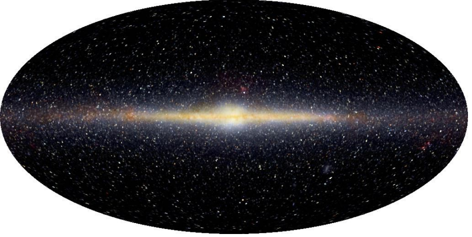
DM along l.o.s.

$$I_{\Delta\Psi} = \frac{1}{\Delta\Psi}\int_{\Delta\Psi} I(\Psi)\Delta\Psi$$

GC angle	Isoth. 3.5	NFW	Moore	Log-slope
HESS	18.9	6892	$7.7\ 10^6$	10229
EGRET	18.5	184.2	10866	600







EGRET and the Milky Way GC

The GC is a very peculiar site .... !

Table 1. Summary of the positions and integrated gamma-ray fluxes (above 0.1, 1 and 5 GeV) from the gamma-ray sources in an angular region of 4 degrees around the Galactic center. Units for the photon fluxes are 10^{-8} photons per cm^2 per s.

	l	b	0.1 GeV	1 GeV	5 GeV
3EG J1736-2908	358.9	1.4	31.5	1.6	8×10^{-4}
3EG J1744-3011	358.7	-0.64	64.0	4.3	0.64
HESS J1747-281	0.87	0.077	1.10	0.34	0.09
3EG J1746-2851	0.19	-0.08	212	46	1.95
HESS J1745-290	359.9	0.03	0.42	0.10	0.03
Sgr A* - Sc.2	359.9	0.03	189	51	0.87

Jeltema & Profumo 2008

Sources

in addition to diffuse radiation

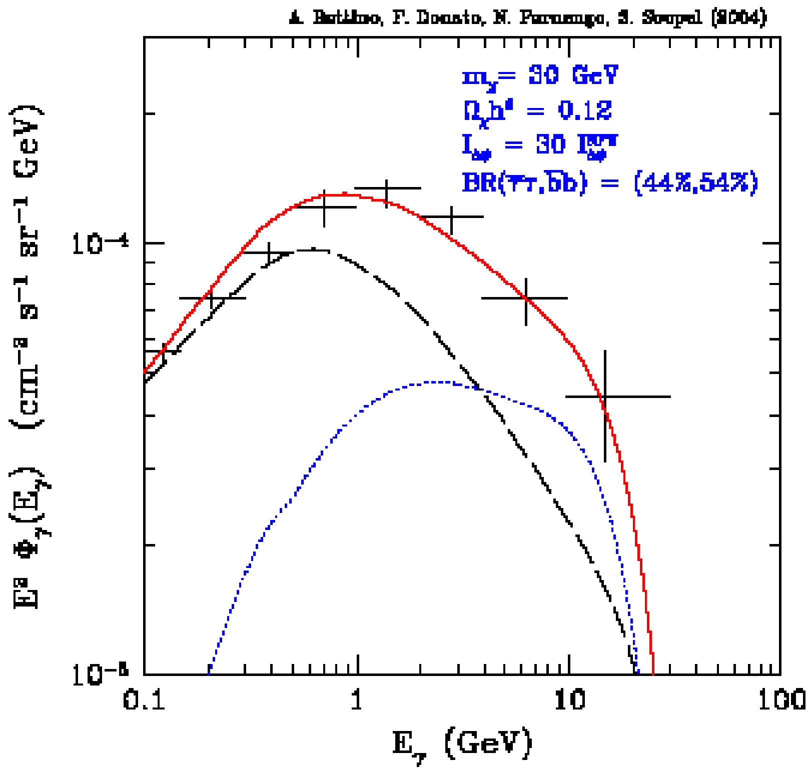
Great uncertainty in the background evaluation

Hunter et al. ApJ 1997, Mori ApJ 1997, Strong et al. ApJ 2000,

Aharonian & Atonyan A&A 2000, Busching et al. A&A 2001, Erlykin & Wolfendale JPG 2002, ……

Difficult interpretation of EGRET measured flux

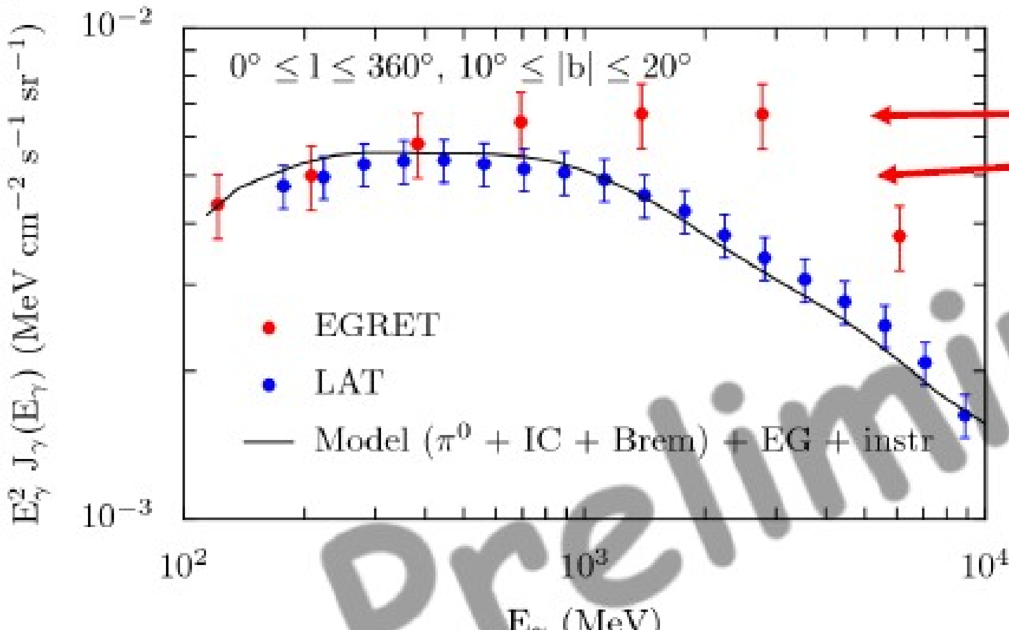
Egret measurements at the GC

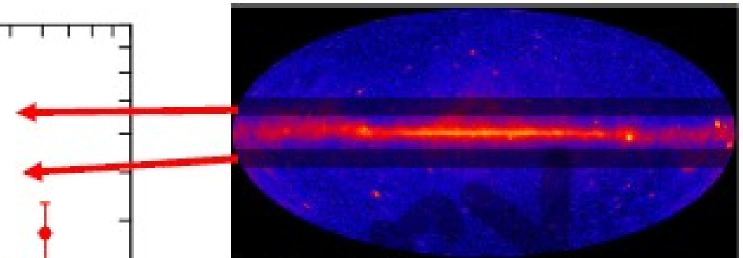


Dotted: neutralino

Dashed: backgrouns (MS)

The Fermi LAT View

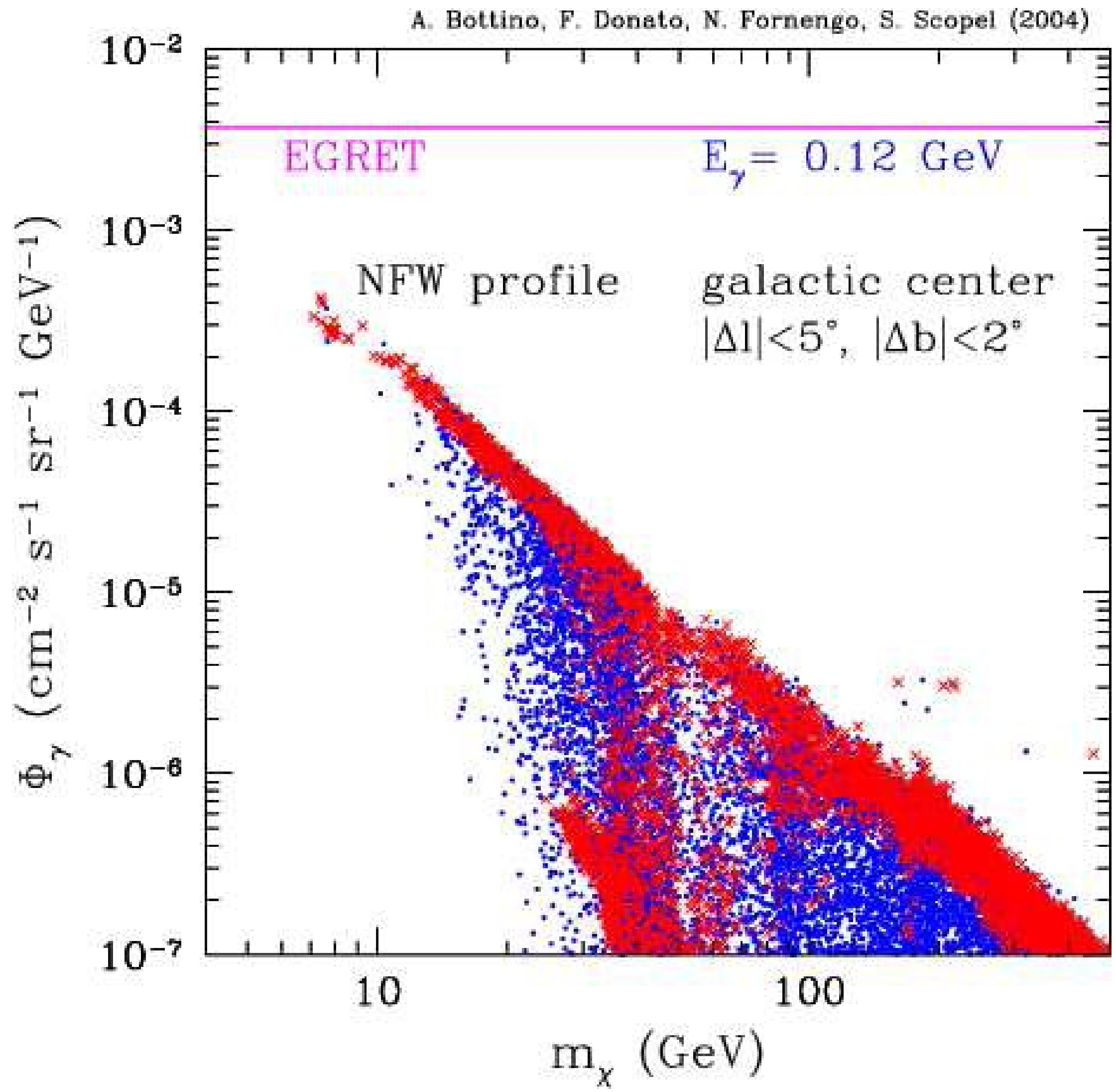




- Spectra shown for mid-latitude range -> GeV excess in this region is not confirmed.
- LAT errors are dominated by systematic uncertainties and are currently estimated to be ~10% - this is preliminary.
- EGRET data is prepared as in Strong, et al. 2004 with a 15% systematic error assumed to dominate (Esposito, et al. 1996).

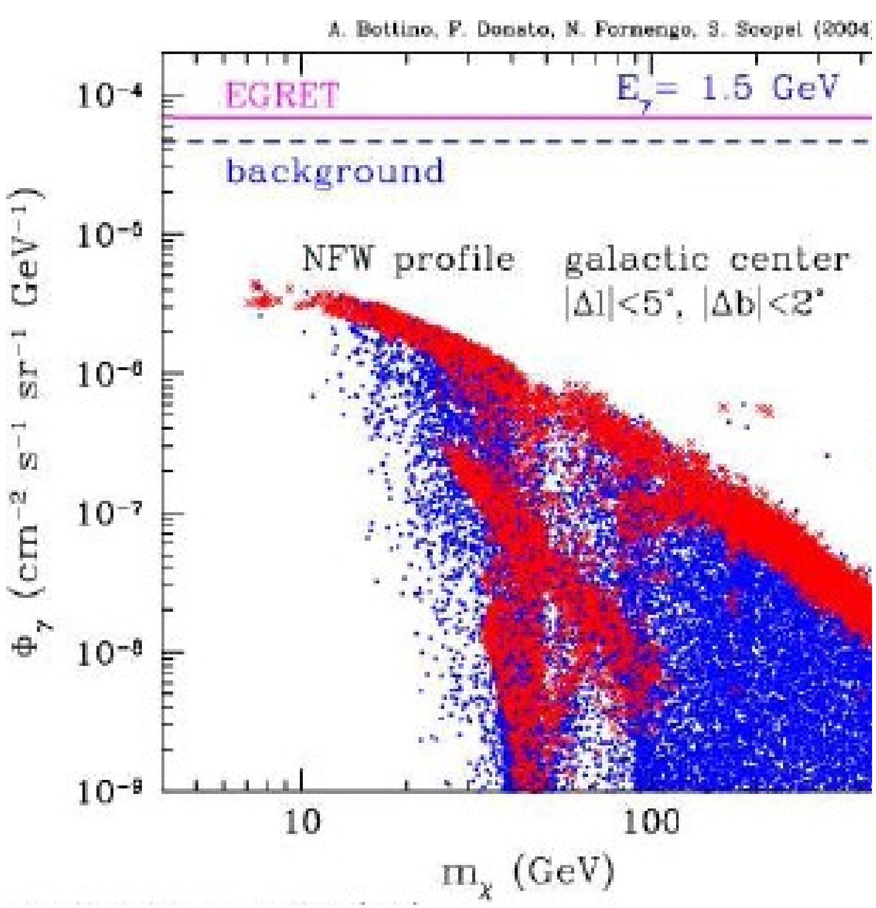
Is the galactic center the best place to look for DM signals?

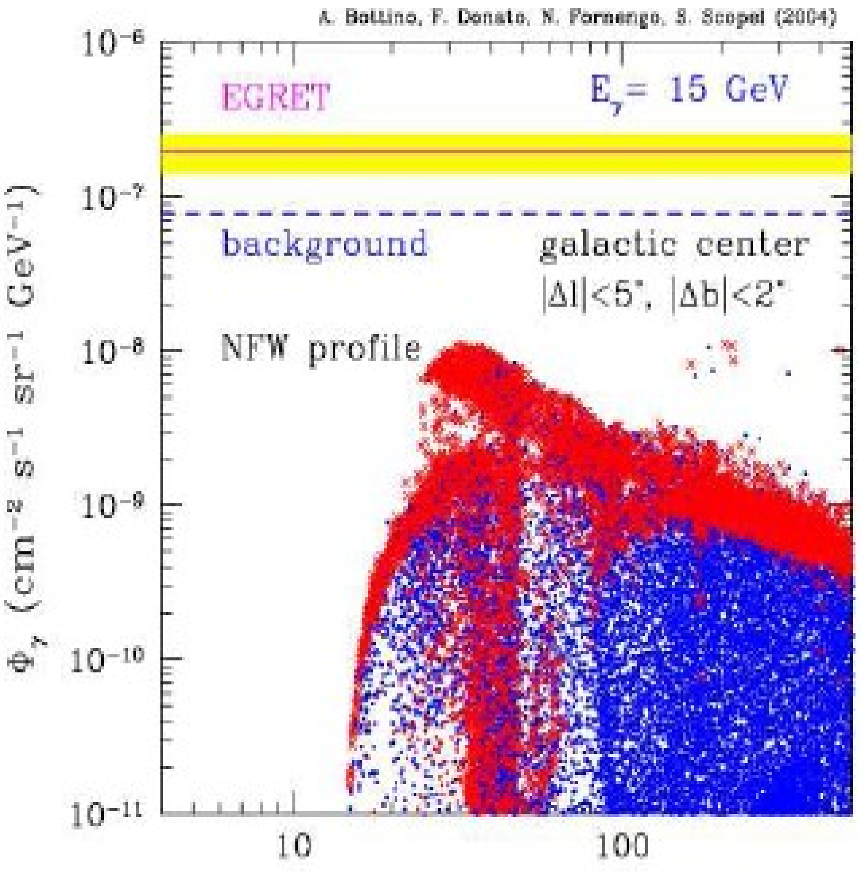
effMSSM



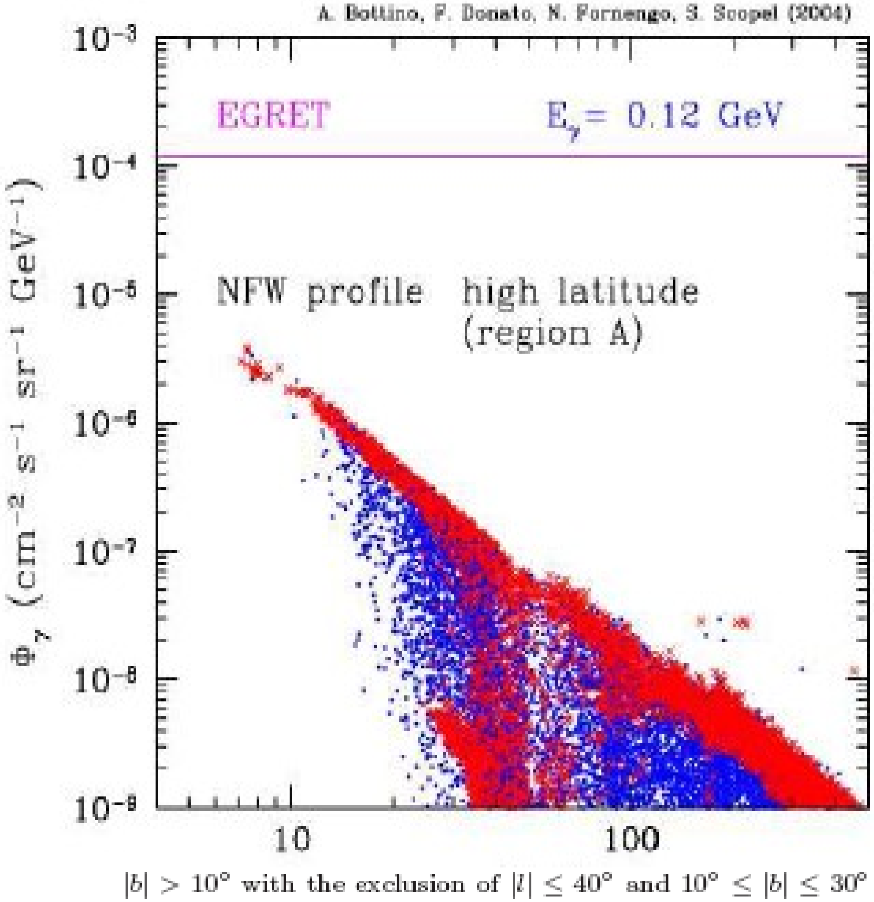
Bottino, FD, Fornengo, Scopel PRD 2004

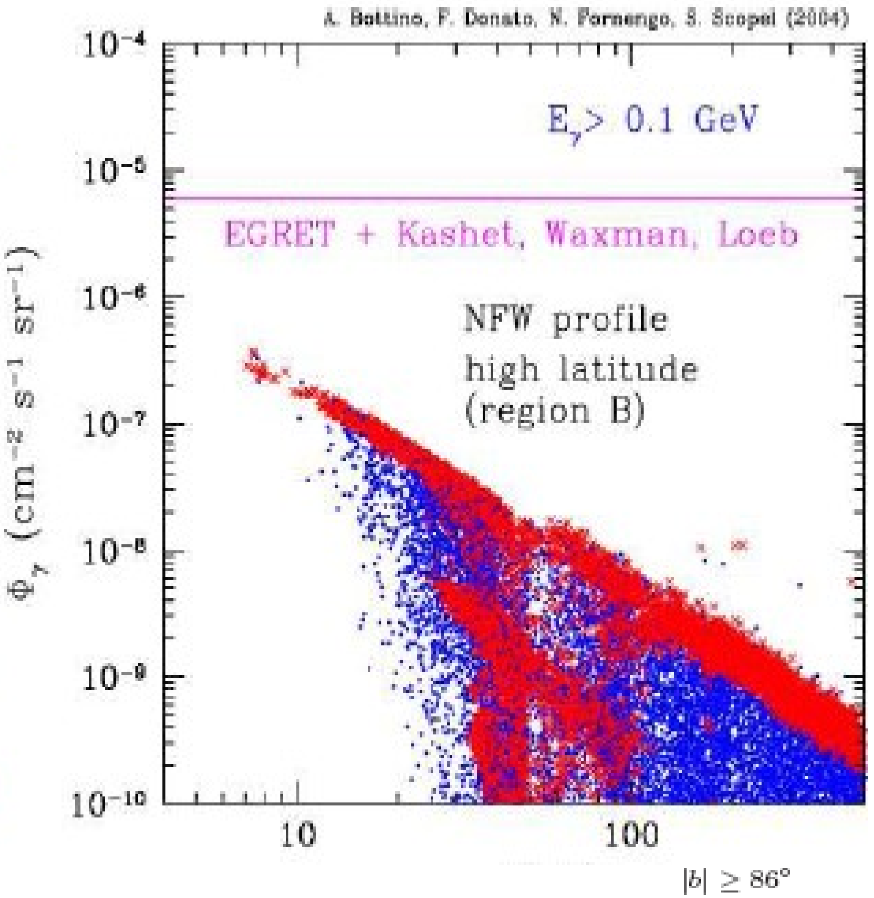
EffMSSM and gamma-ray fluxes





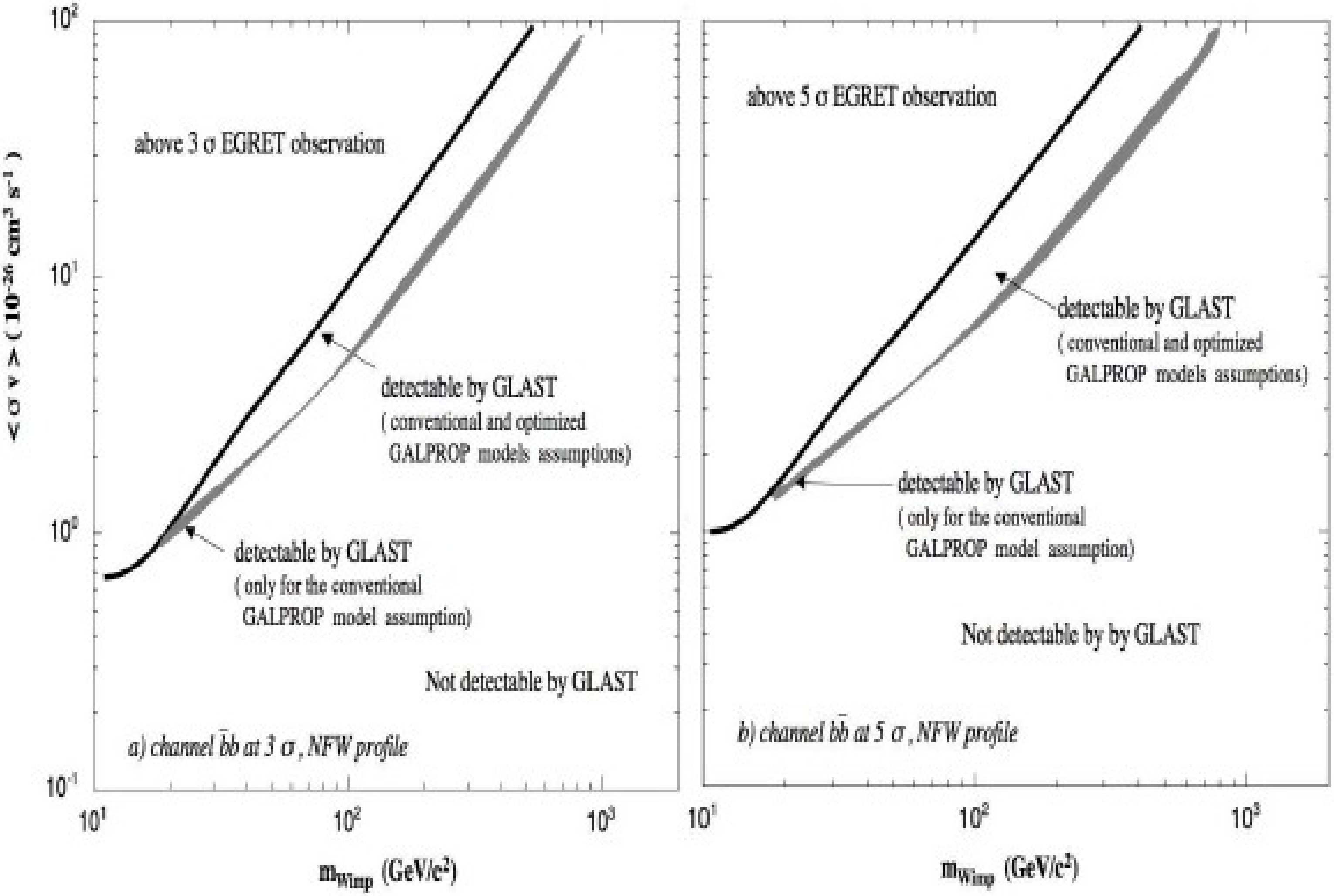
Polar regions





Sensitivity for FERMI/LAT

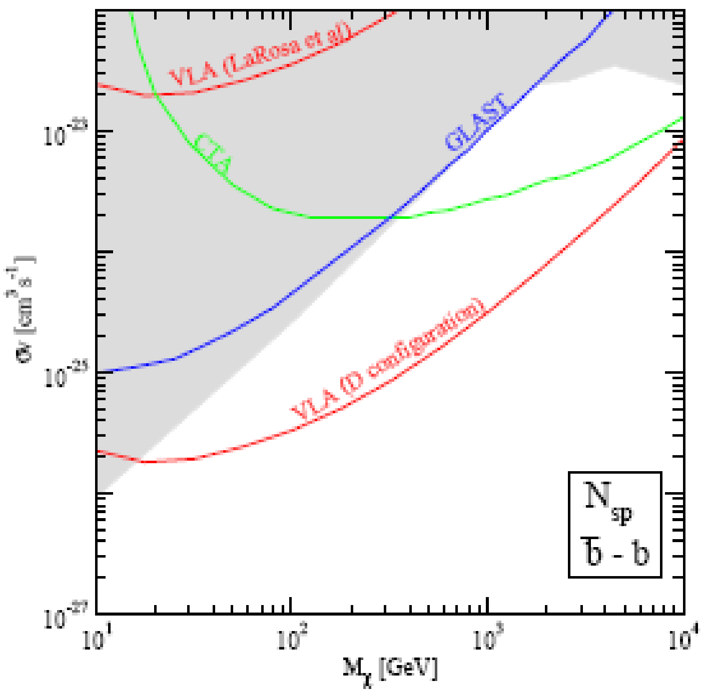
Baltz et al. 2008 (Glast Coll.)



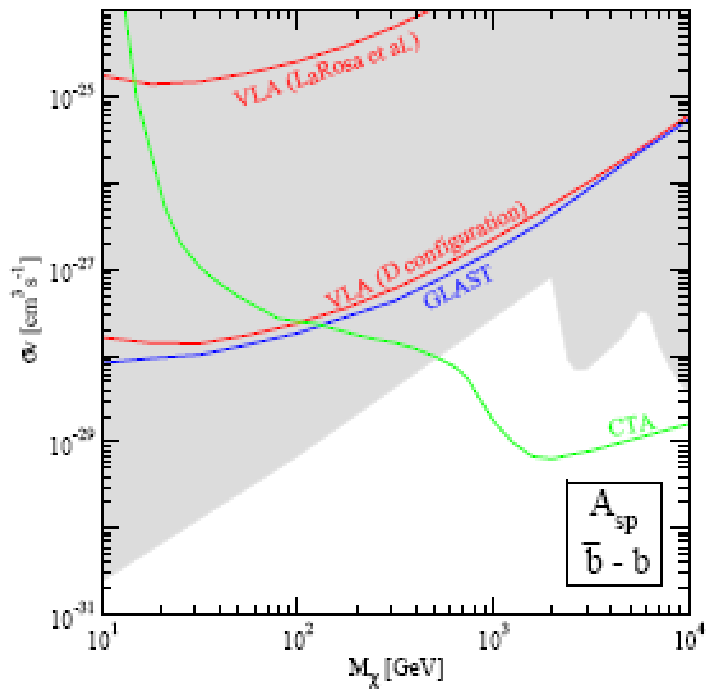
Substructures: see Lidia Pieri's talk

Projected exclusion limits

Regis & Ullio 2008



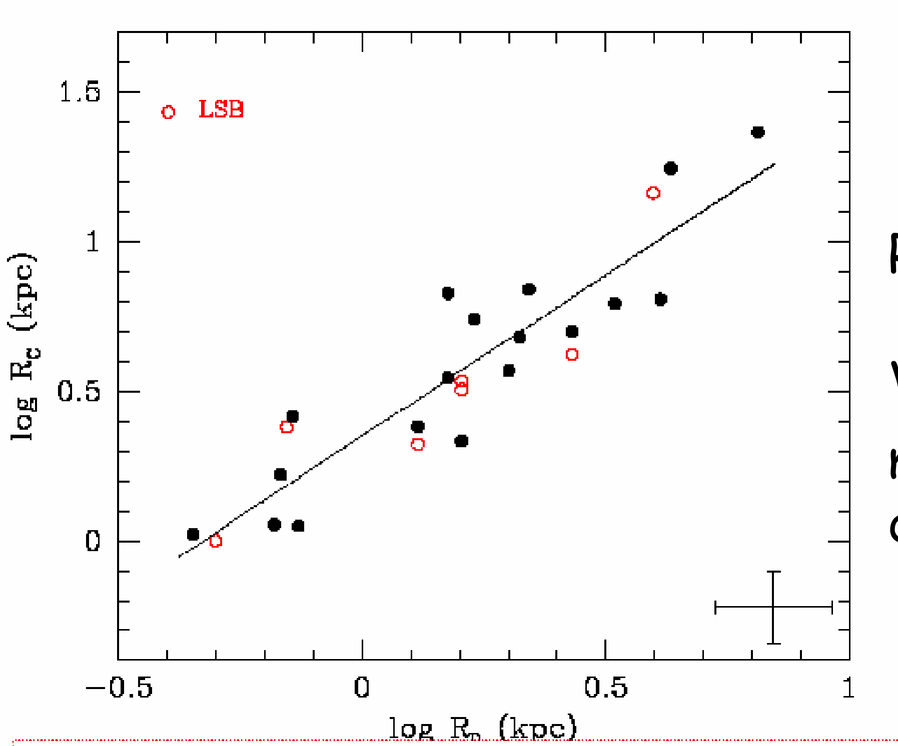
Density spike



Adiabatic contraction

DM distribution … Cored?
See Mark's talks !

Donato, Gentile, Salucci MNRAS2004



$$\log R_C = (1.05 \pm 0.11)\ \log R_D + (0.33 \pm 0.04)$$

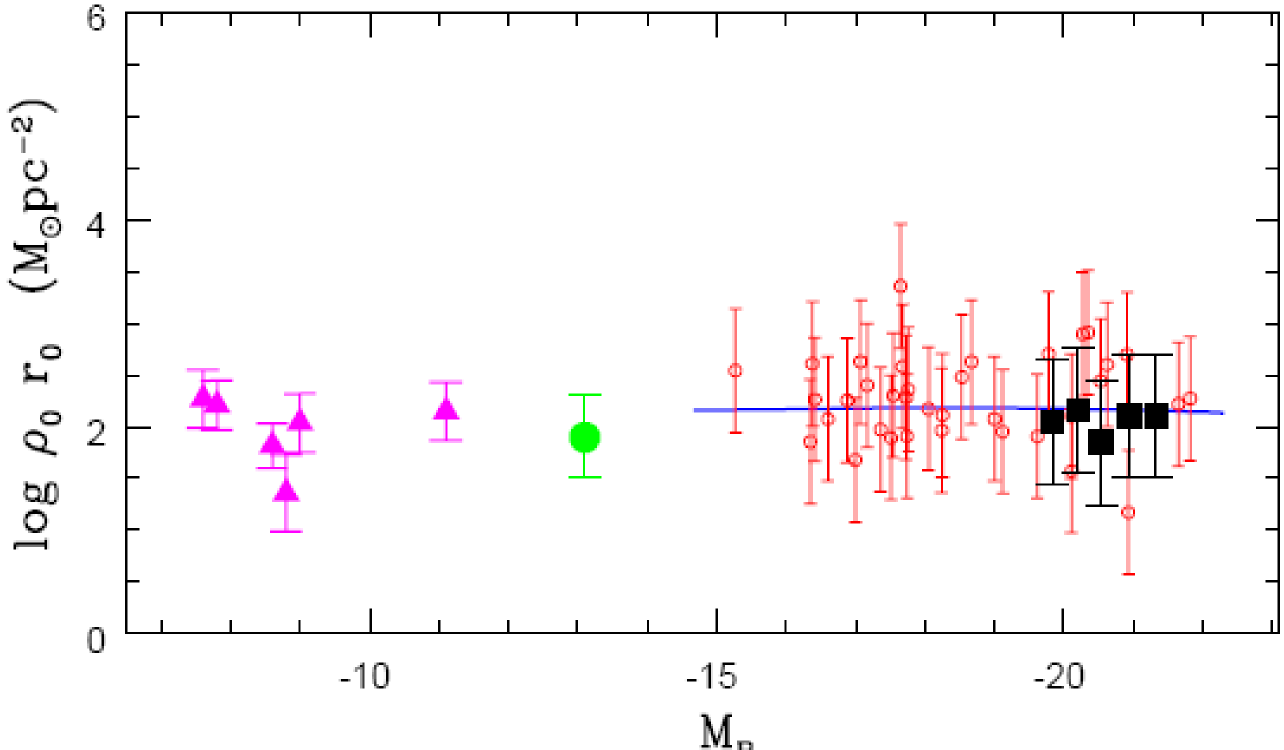
$$corr = 0.90, \quad r.m.s. = 0.16\ dex$$

Relationship Hubble-type free

We exclude R_c arises from wrong mass modelling, peculiar or biased dynamics, observational errors

Further hints toward a cored profile

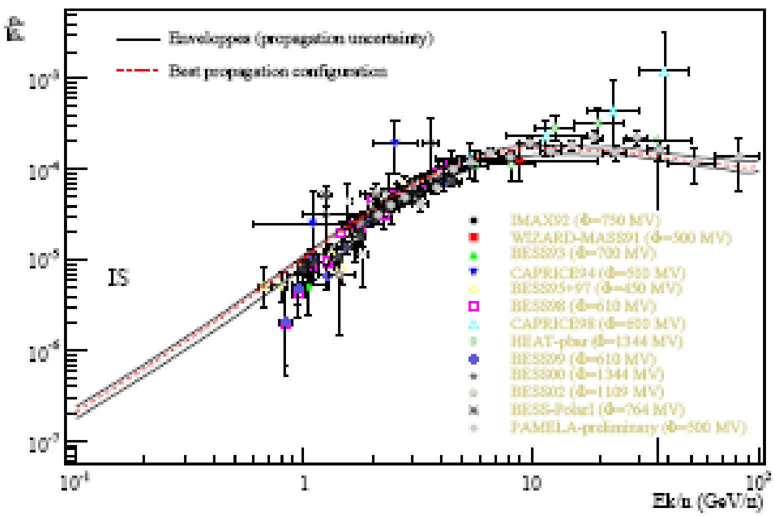
Donato et al. MNRAS submitted

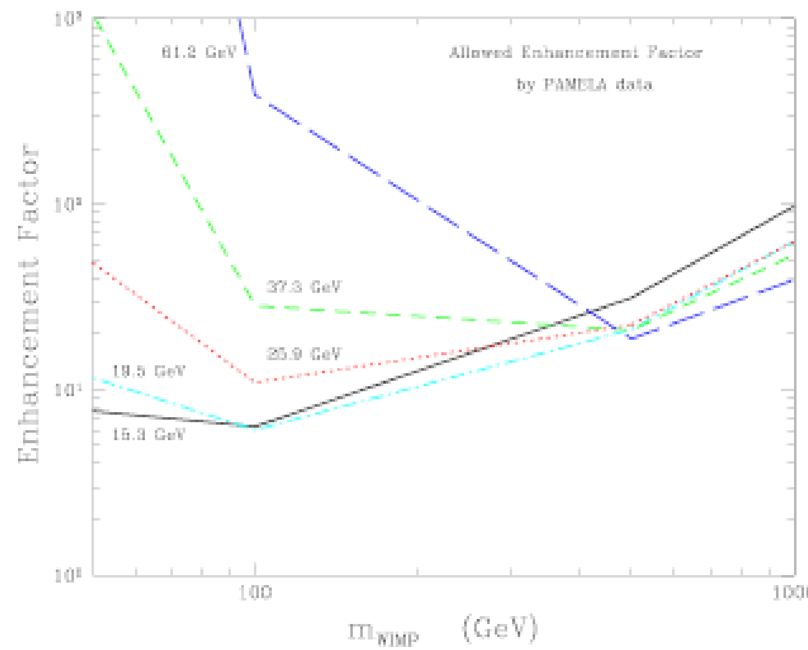


A constant surface mass density is arising, independent of Hubble type and luminosity: it may be an important PHYSICAL quantity

At Fermi energies, measurements of charged cosmic rays (antiprotons) are very competitive

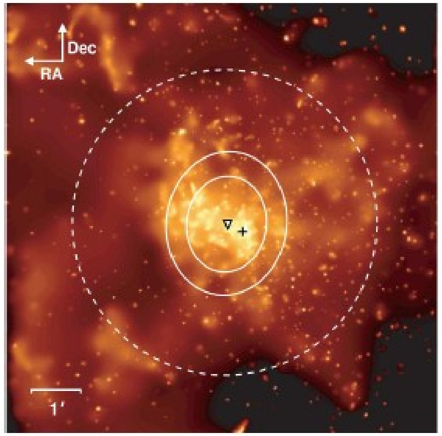
Donato, Maurin, Brun, Delahaye, Salati PRL 2009



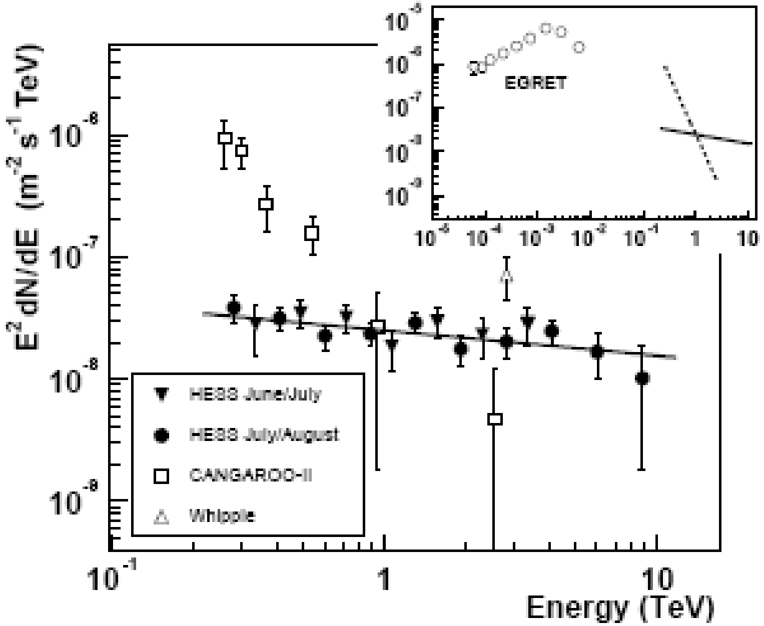


Antiproton data do not allow big boosts

Caveats: uncertanties in the primary (susy) flux
different astrophysics for different species



HESS view of the GC at TeV energies



- Data fit by hard spectrum $E^{-2.2}$ ($E^{-2.7}$ is the CR induced power law)

- Astrophysical background

  For TeV region: Aharonian & Neronov 2006

  For GeV region: Hunter et al. ApJ 1997, Mori ApJ 1997, Strong et al. ApJ 2000, Aharonian & Atonyan A&A 2000, Busching et al. A&A 2001, Erlykin & Wolfendale JPG 2002, ……

Few comments:

Looking for DM in gamma rays at different angles and external sources

Careful estimation of the backgrounds

If the DM has a cored profile, the task is even more difficult

Crossed-analysis with antimatter in Crs, direct detection and ... LHC!