INVESTIGATING NEUTRALINO DARK MATTER : ADAGIOS AND PRESTOS

The Dark Side of the Universe 2006

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Contents

- *Where do we stand with neutralino dark matter ?*
- *Hints for relic neutralinos in present results from direct/indirect searches ?*
- *The role of astrophysical uncertainties*
- *Perspectives*

Combining data of WMAP (3 years data) with

- ★ *small-scale CMB data*
- ★ *large-scale structure surveys*
- ★ *weak gravitational lensing*
- ★ *high-redshift Supernovae*

(D.N. Spergel et al., astro-ph/0603449)

one can obtain

$$\boxed{0.08 \leq \Omega_{CDM} h^2 \leq 0.12}$$

Within supersymmetric theories with R-parity conservation, the neutralino provides one of the most interesting realizations of a cold dark matter particle (WIMP) with

- *appropriate relic abundance* $\Omega_\chi \approx \Omega_{CDM}$

- *sizeable rates for direct and indirect measurements*

A convenient susy scheme is an effective –Minimal Supersymmetric extension of the Standard Model at the electroweak scale - what we mainly consider in this talk

effective -MSSM

⋆ **Minimal Supersymmetric extension of the Standard Model at the electroweak scale (M_Z) in terms of the following parameters:**

$$\tan\beta = \frac{<\mathrm{H_2}>}{<\mathrm{H_1}>} \equiv \frac{\mathrm{v_2}}{\mathrm{v_1}} \qquad [{v_1}^2 + {v_2}^2 = v^2]$$

$\mathbf{M_2}$ **SU(2) gaugino mass**

$\mathbf{M_1}$ **U(1) gaugino mass** $\Longrightarrow R \equiv \frac{M_1}{M_2}$

μ **Higgs mixing parameter**

$\mathbf{m_A}$ **CP-odd neutral Higgs boson**

$\mathbf{m_{0\tilde{q}}, m_{0\tilde{l}}}$ **squark, slepton masses**

A **trilinear coupling**

Notice that no gaugino-mass unification is assumed

Neutralino relic abundance

Relic Abundance for Cold Candidates (WIMPs)

$$\Omega_\chi h^2 \approx \frac{3\times 10^{-39}\ \mathrm{cm}^2}{<\sigma_{\mathrm{ann}}\mathrm{v}>_{\mathrm{int}}}$$

$<\sigma_{\mathrm{ann}}\mathrm{v}>_{\mathrm{int}} \equiv$ *thermal average of* $\sigma_{\mathrm{ann}}\mathrm{v}$

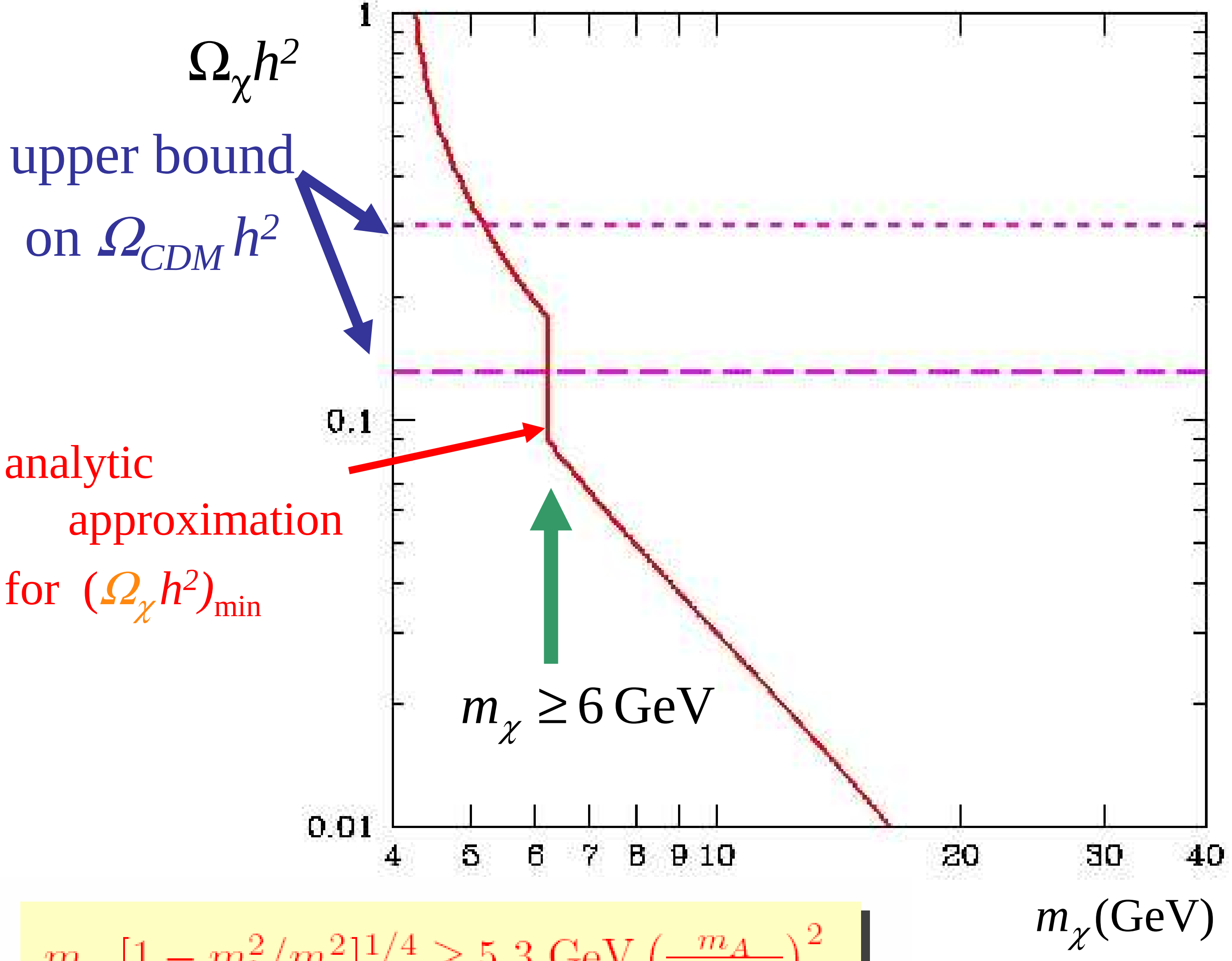
integrated from the decoupling time to the present epoch.

Cosmological bound:

$$\Omega_\chi h^2 \leq (\Omega_{\mathrm{CDM}} h^2)_{\max} \approx 0.13$$

$$\Rightarrow <\sigma_{\mathrm{ann}}\mathrm{v}>_{\mathrm{int}} \geq 2.3\times 10^{-38}\mathrm{cm}^2$$

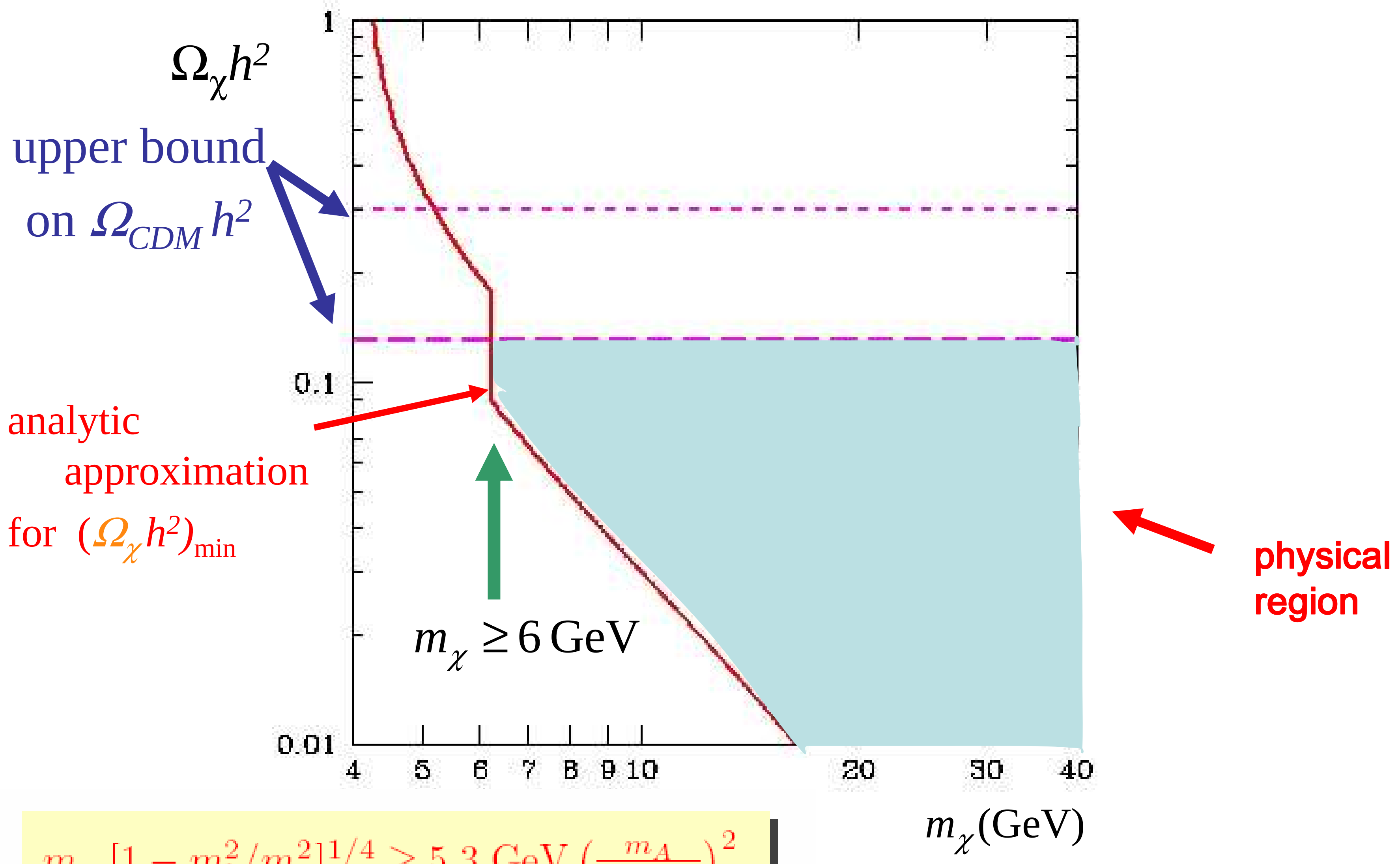
Cosmological bound on m_χ



$$m_\chi \, [1 - m_b^2/m_\chi^2]^{1/4} \gtrsim 5.3 \text{ GeV} \left(\frac{m_A}{90 \text{ GeV}}\right)^2$$

A.B., Donato, Fornengo, Scopel
hep-ph/0304080

Cosmological bound on m_χ



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A.B., Donato, Fornengo, Scopel
hep-ph/0304080

Much lighter neutralinos are allowed in Next-to-Minimal Supersymmetric extensions of the Standard Model :

R. Flores, K.A. Olive and D. Thomas, Phys. Lett. B263 (1991) 425

S.A. Abel, S. Sarkar and I.B. Whittingham, hep-ph/9209292

D.G. Cerdeno, C. Hugonie, D.E. Lopez-Fogliani, C. Munoz and A.M. Teixera hep-ph/0408102

J. Gunion, D. Hooper, and B. McElrath, hep-ph/0509024

MSSM is extended by adding a new gauge singlet chiral supermultiplet

- special features:

a very light CP-odd Higgs boson

a 5-components neutralino (the usual 4 components + a singlino)

$$\chi = a_1\tilde{B} + a_2\tilde{W}^{(3)} + a_3\tilde{H}_0^{(1)} + a_4\tilde{H}_0^{(2)} + a_5\tilde{S}$$

Also direct detection rates for relic neutralinos are sizeably enhanced

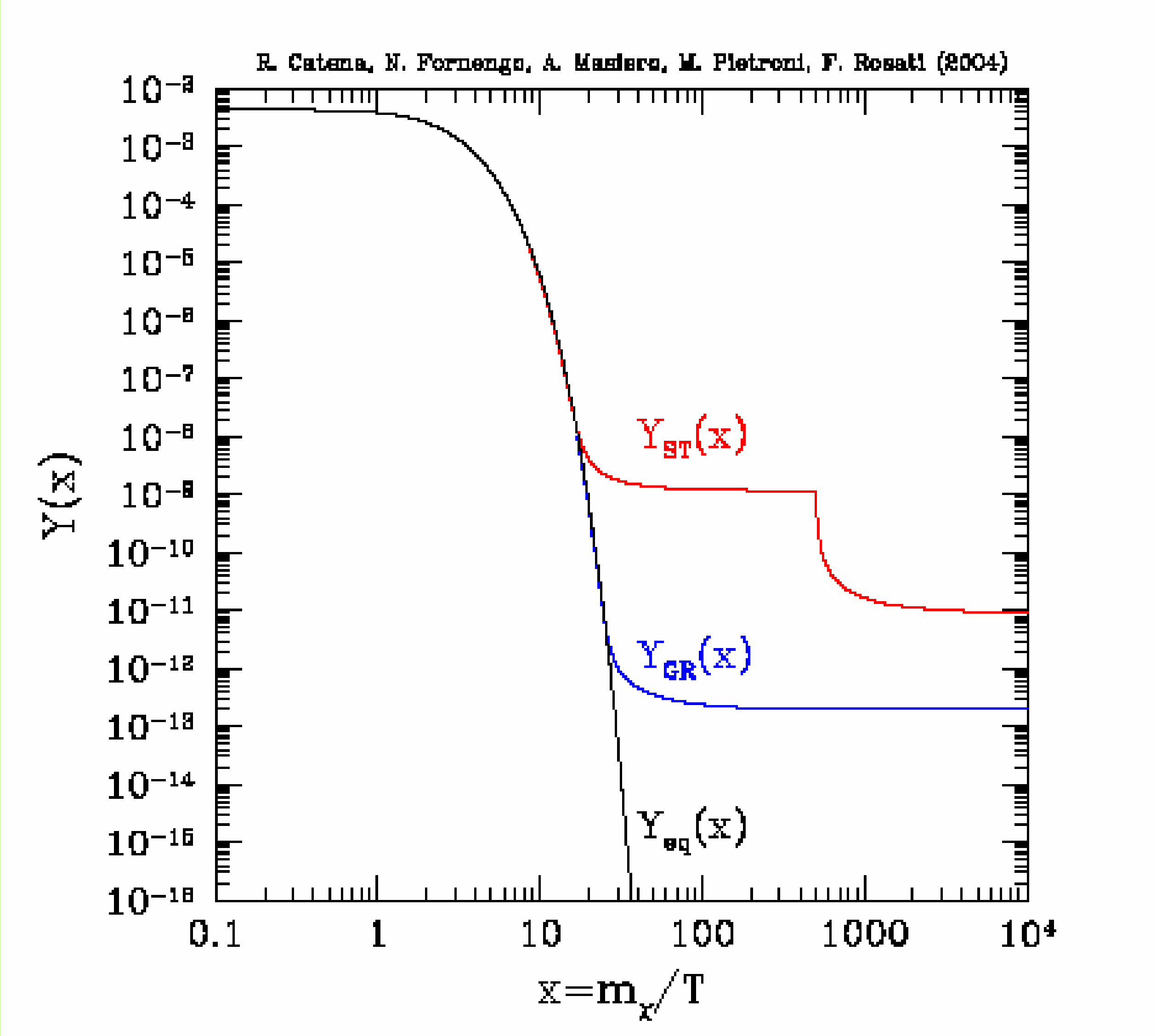
Notice: the WIMP relic density might be much higher than the standard one in cosmological models which imply an enhancement in the expansion rate of the Universe at the WIMP decoupling time

This is the case for:

- Cosmological models with a kination phase
  (Salati, astro-ph/0207396; Rosati, hep-ph/0309124)
- Dark-energy models based on scalar-tensor gravity
  (Catena, Fornengo, Masiero, Pietroni and Rosati, astro-ph/0403614)
- Randall-Sundrum D-brane model
  (Randall and Sundrum, PRL 83 (4690) 1999)

For constraints using cosmic antiprotons, see Schelke, Catena, Fornengo, Masiero and Pietroni, hep-ph/0605287

$$Y = nR^3$$

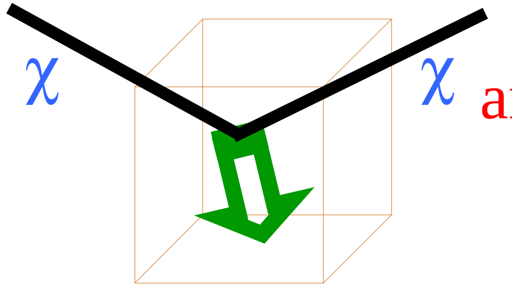


enhancement of the relic abundance in a scalar-tensor gravity model

Catena, Fornengo, Masiero, Pietroni and Rosati: astro–ph/0403614

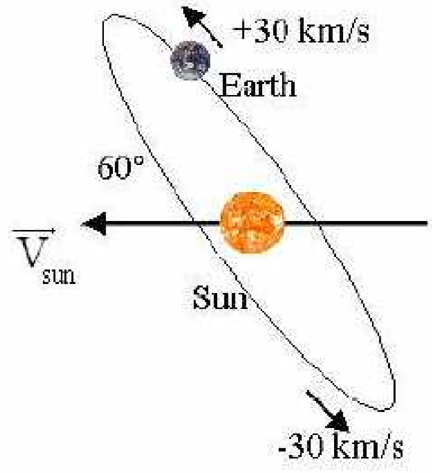
Detection of relic particles

WIMP direct measurements

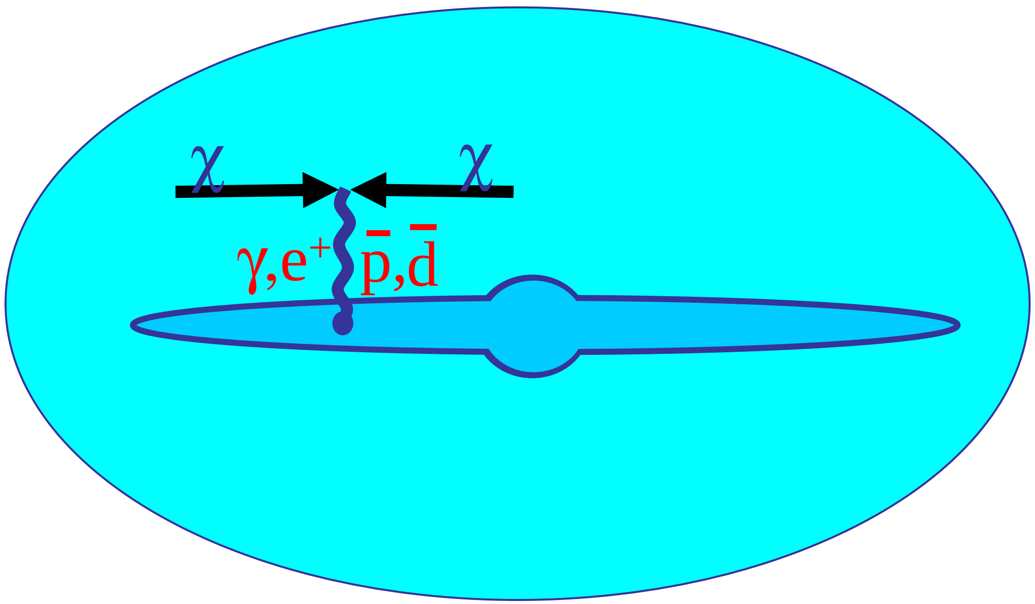


nuclear-recoil measurement

annual-modulation effect



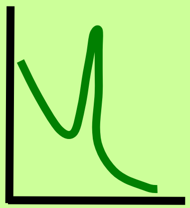
Pair annihilation in the halo



Annihilations taking place in the Halo

$\chi + \chi \rightarrow$

$\nu, \bar{\nu}$



γ (continuum)

γ line ($Z\gamma$)

keep directionality

e^+

$\bar{p}$

$\bar{D}$

searches for rare
components in cosmic rays

$$\text{detection rates} \propto (\text{Wimp density})^2$$

if halo is clumpy,
strong enhancement in signal

Bengtsson, Salati, Silk
Silk, Stebbins
Berezinsky, A.B., Mignola

Detection rates depend sensitively on the following properties:

☆ ***phase-space distribution function for the WIMPs in the galactic halo***

-- deviations of the smooth component from the isothermal sphere

-- possible existence of streams and clumps

☆ ***for signals due to*** $e^+, \overline{p}, \overline{d}$ ***produced by WIMP self-annihilations in the galactic halo***

-- propagation and diffusion of the charged particles in the halo

-- evaluation of the secondary productions (background)

Neutralino – nucleon cross section

Color code from now on:

- $\Omega_\chi h^2 < 0.095$

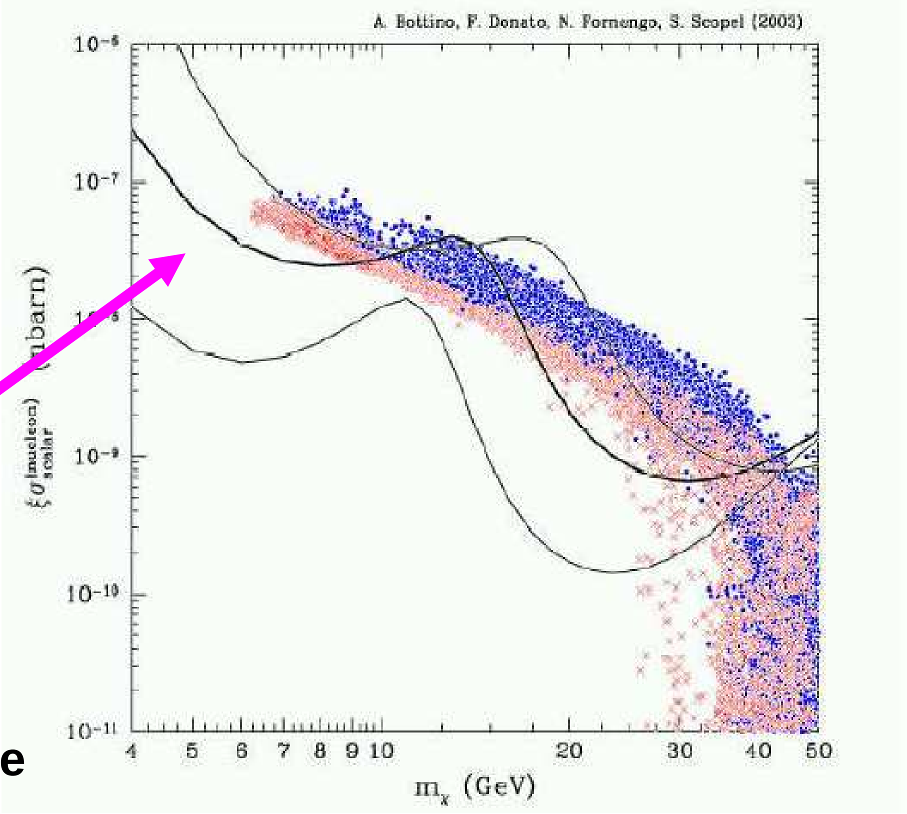
× $\Omega_\chi h^2 > 0.095$

$$\Omega_\chi h^2 \leq (\Omega_{CDM} h^2)_{max}$$

$$\sigma^{(\text{nucleon})}_{\text{scalar}} \gtrsim \frac{10^{-40} cm^2}{(\Omega_{CDM} h^2)_{max}} \frac{\text{GeV}^2}{m_\chi^2 \, [1 - m_b^2/m_\chi^2]^{1/2}}$$ for $m_\chi \lesssim 20$ GeV

The elastic cross section is bounded
- from below by the cosmological upper limit
- from above by the susy model

This generates a “funnel” at low mass



Sensitivity lines for a NaI detector with a low energy threshold and a large exposure for various WIMP distribution functions In the galactic halo

AB, Donato, Fornengo and Scopel, hep-ph/0304080

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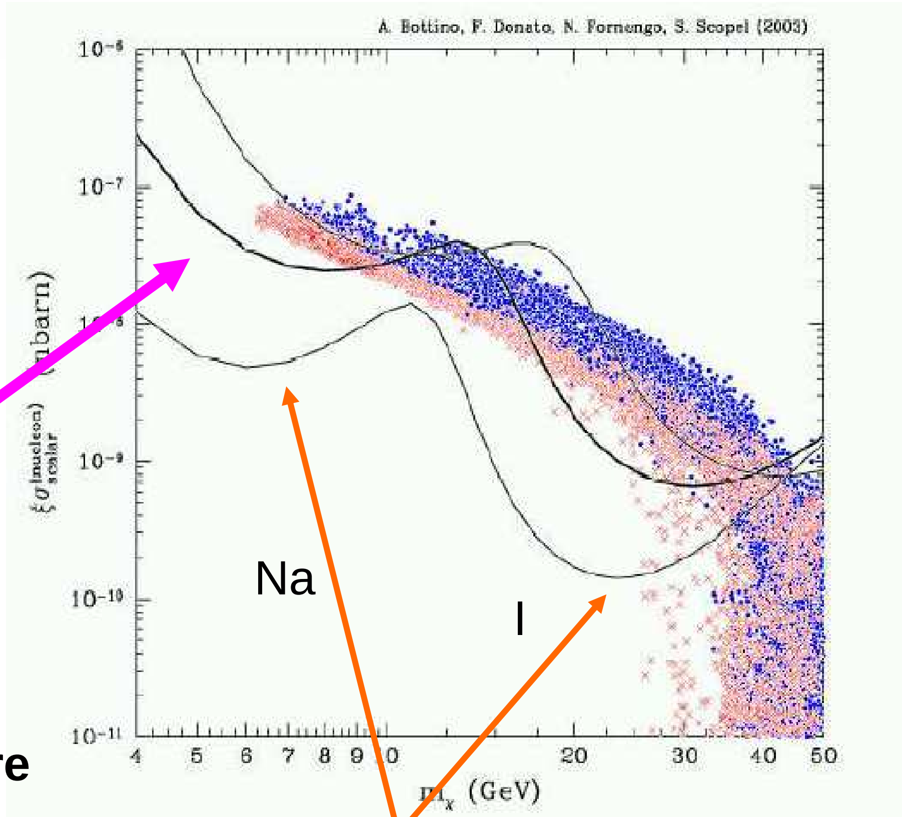


Sensitivity lines for a NaI detector with a low energy threshold and a large exposure for various WIMP distribution functions In the galactic halo

Neutralino-nucleus mass matching

AB, Donato, Fornengo and Scopel, hep-ph/0304080

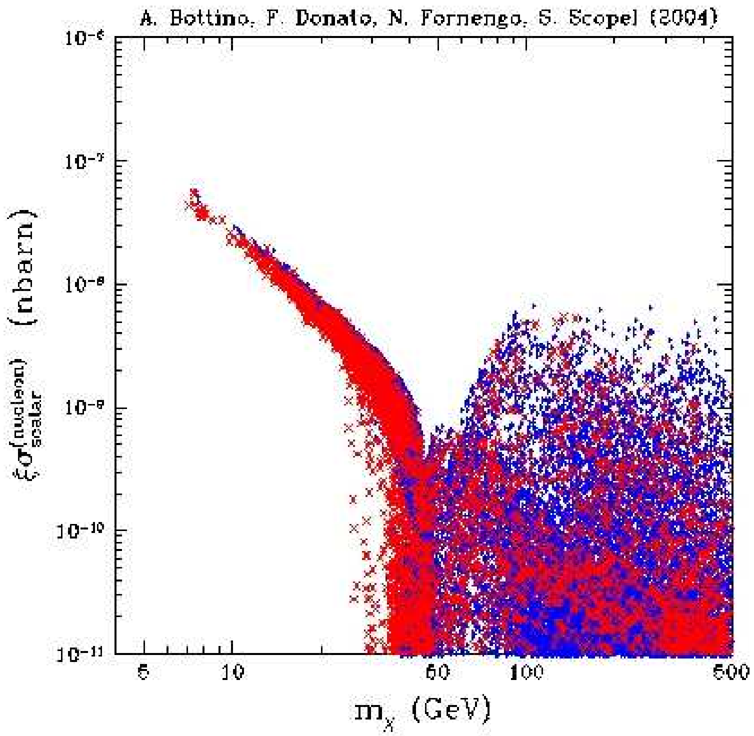
Neutralino – nucleon cross section

Color code:

● $\Omega_\chi h^2 < 0.095$

× $\Omega_\chi h^2 > 0.095$

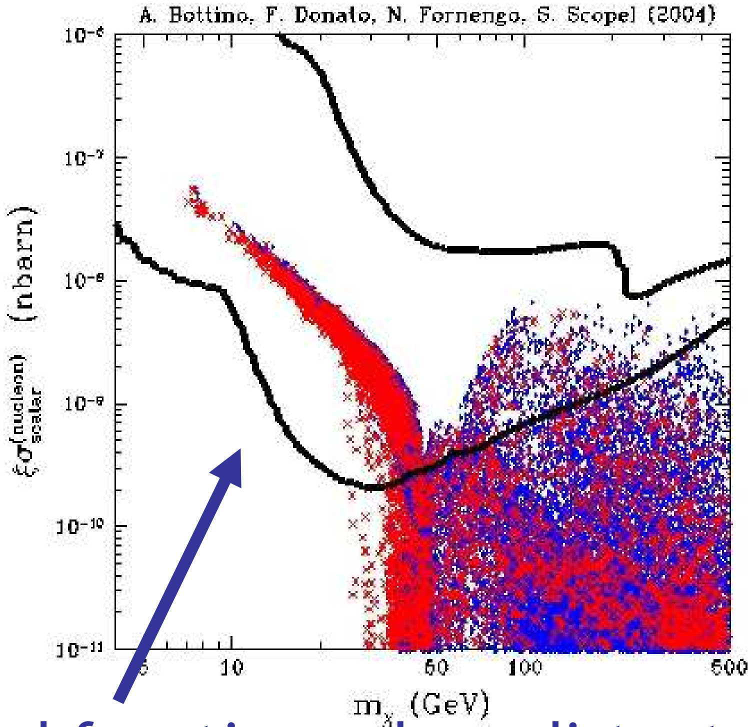
Extending the scatter plot to higher neutralino masses



Neutralino – nucleon cross section

Color code:
- $\Omega_\chi h^2 < 0.095$
- × $\Omega_\chi h^2 > 0.095$

Extending the scatter plot to higher neutralino masses

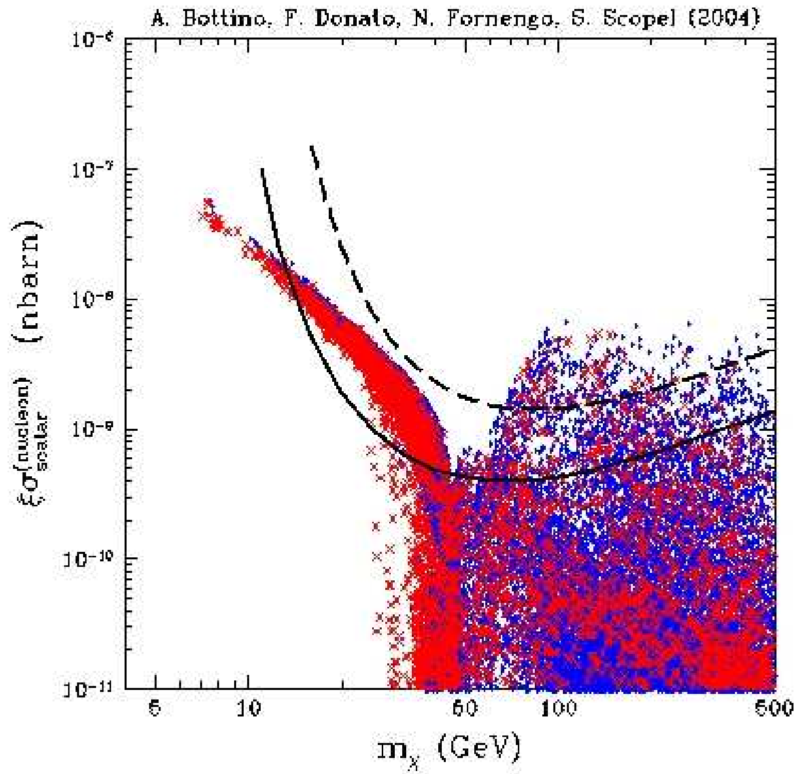


DAMA modulation region, likelyhood function values distant more than 4 σ from the null result (absence on modulation) hypothesis, Riv. N. Cim. 26 n. 1 (2003) 1-73, astro-ph/0307403
Exposure: about 108.000 kg day

Neutralino – nucleon cross section

Upper limits from direct searches

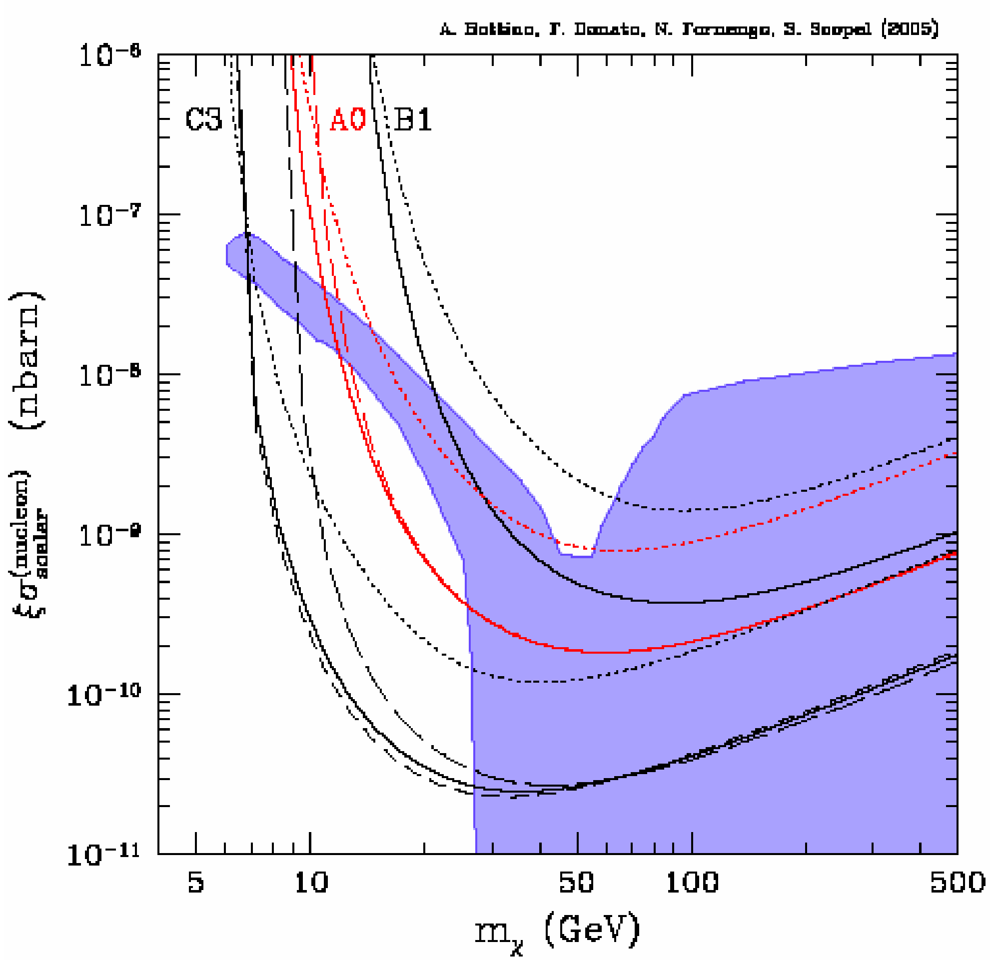
assumptions:
isothermal sphere,
v_0=220 km/sec,
ρ_0=0.3 GeV/cm^3



— — — EDELWEISS
A. Benoit *et al.*,
Phys. Lett. B 545, 43 (2002)

——— CDMS
D. S. Akerib *et al.*, astro-ph/0405033
(in astro-ph/0509259 the upper limit is improved by a factor of 2.5)

Dependence of the upper bounds on the WIMP galactic distribution function



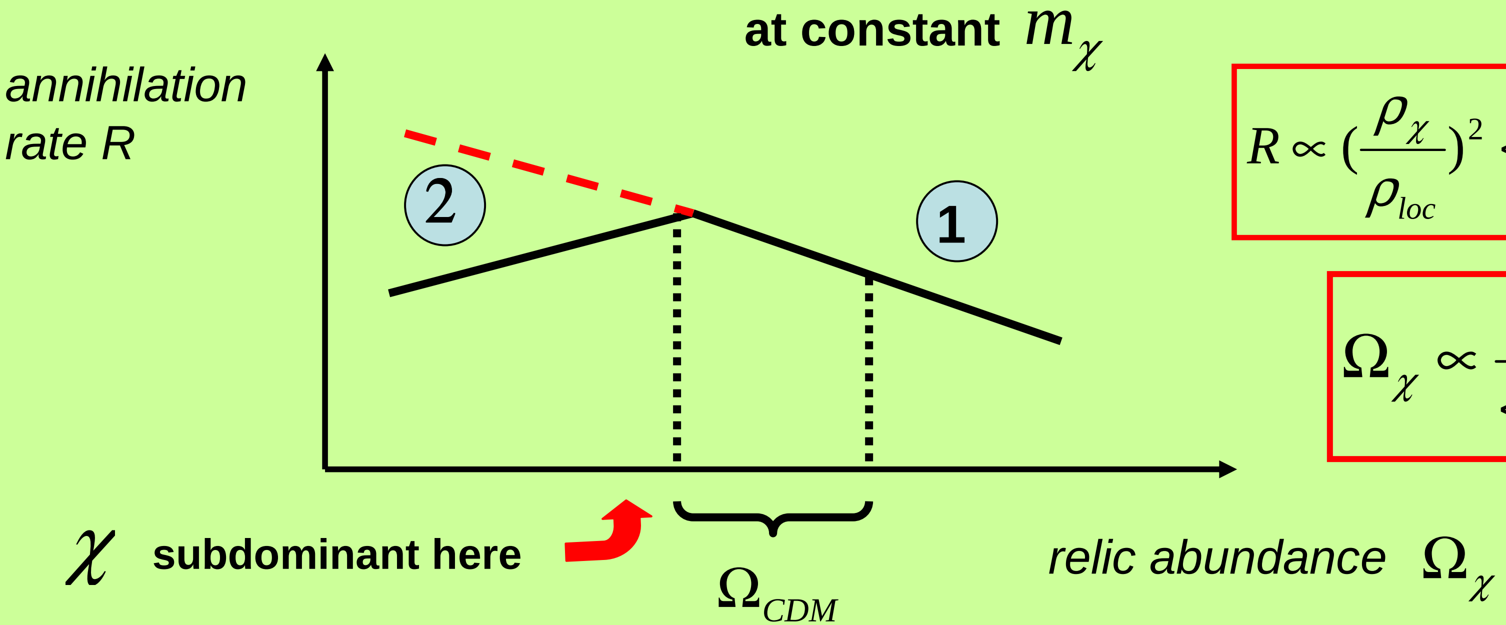
B1 = non-isotropic velocity dispersion

A0 = isothermal sphere

C3 = axisymmetric spatial distribution

Experimental data from
Akerib et al., astro-ph/0509259

Signals due to WIMP self-annihilation in the halo



$$\boxed{R \propto \left(\frac{\rho_\chi}{\rho_{loc}}\right)^2 < \sigma_{ann} v >_0 \frac{1}{m_\chi^2}}$$

$$\boxed{\Omega_\chi \propto \frac{1}{< \sigma_{ann} v >_{\rm int}}}$$

1 $R \propto < \sigma_{ann} v >_0 \dfrac{1}{m_\chi^2}$

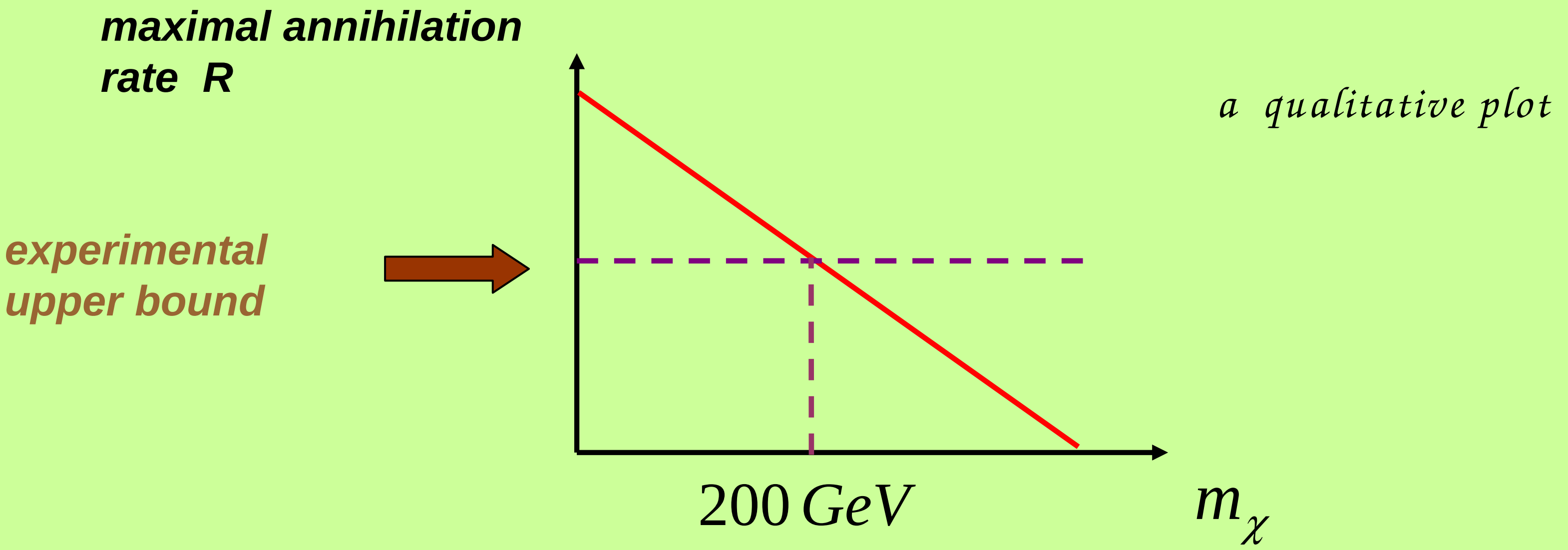
2 $R \propto \left(\dfrac{\rho_\chi}{\rho_{loc}}\right)^2 < \sigma_{ann} v >_0 \dfrac{1}{m_\chi^2} \propto \dfrac{< \sigma_{ann} v >_0^2}{< \sigma_{ann} v >_{\rm int}^2} \dfrac{1}{m_\chi^2}$

Thus the quantity $\left(\dfrac{\rho_\chi}{\rho_{loc}}\right)^2 < \sigma_{ann} v >_0$ **is maximal at** $\Omega_\chi = (\Omega_{CDM})_{\rm min} \cong 0.1$

$$\boxed{\left[\left(\frac{\rho_\chi}{\rho_{loc}}\right)^2 < \sigma_{ann} v >_0\right]_{\max} \cong 10^{-36} cm^2}$$

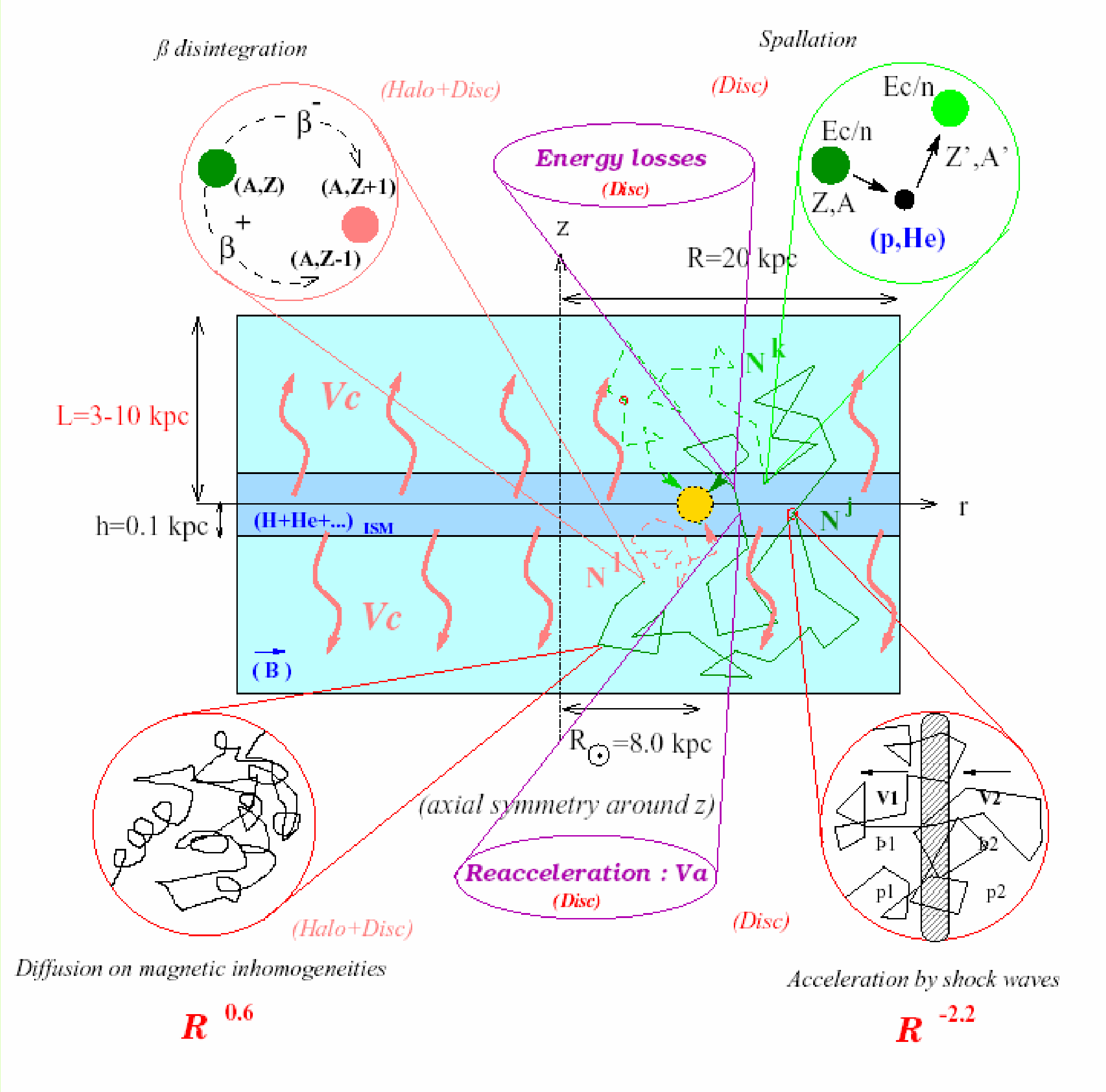
Antiprotons

Among the signals due to WIMP self-annihilation in the halo, those of antiprotons are the most constraining ones for relic neutralinos with masses in the range $10\,GeV \leq m_\chi \leq 200\,GeV$



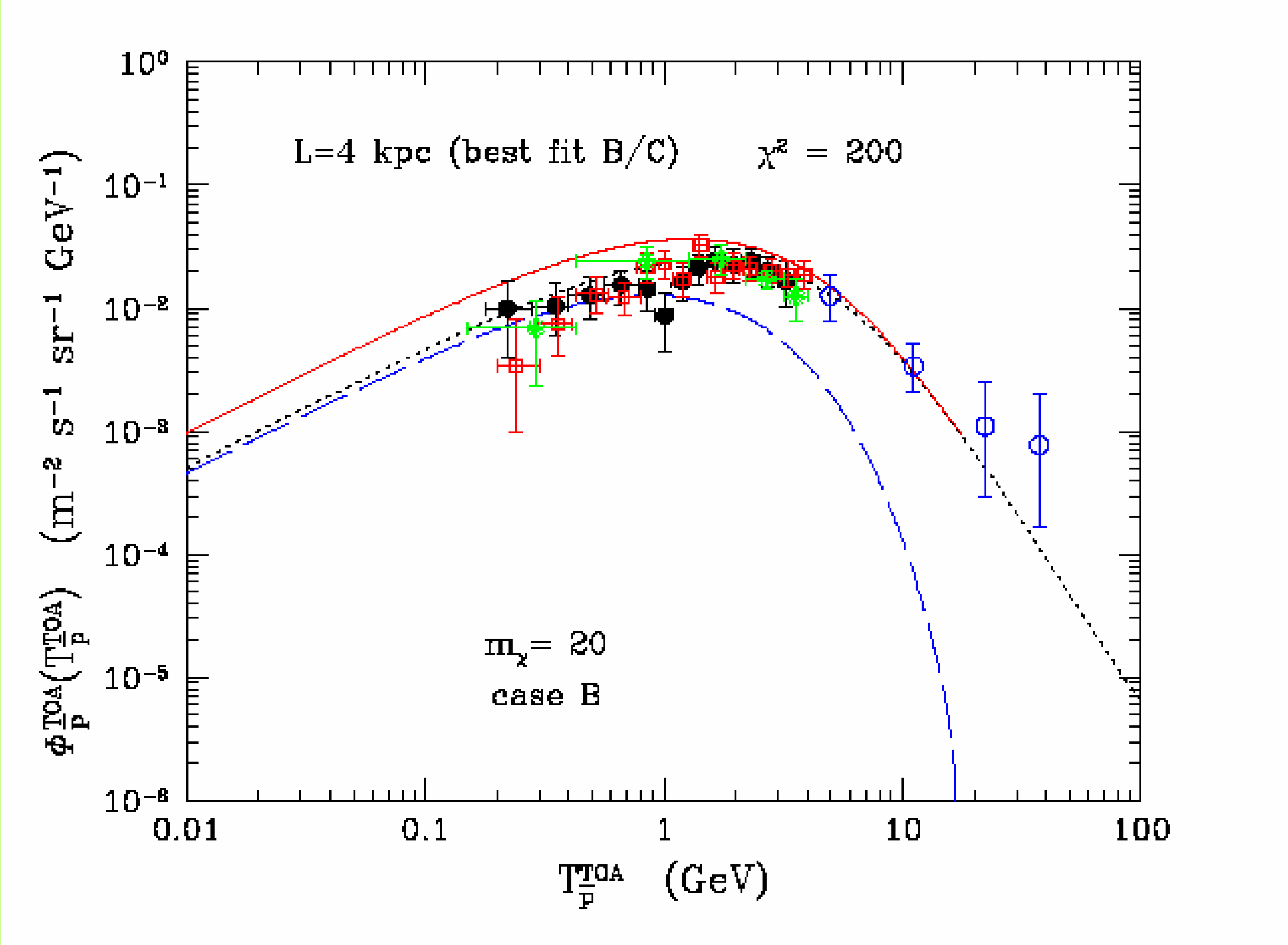
above $m_\chi \approx 200\,GeV$ ***antiprotons from neutralino self annihilation are irrelevant (e.g. are dominated by secondary production) unless the halo is substantially clumpy***

Propagation and diffusion of cosmic rays in the halo



Maurin, Taillet, Donato, Salati, Barrau, Boudoul, astro-ph/0212111

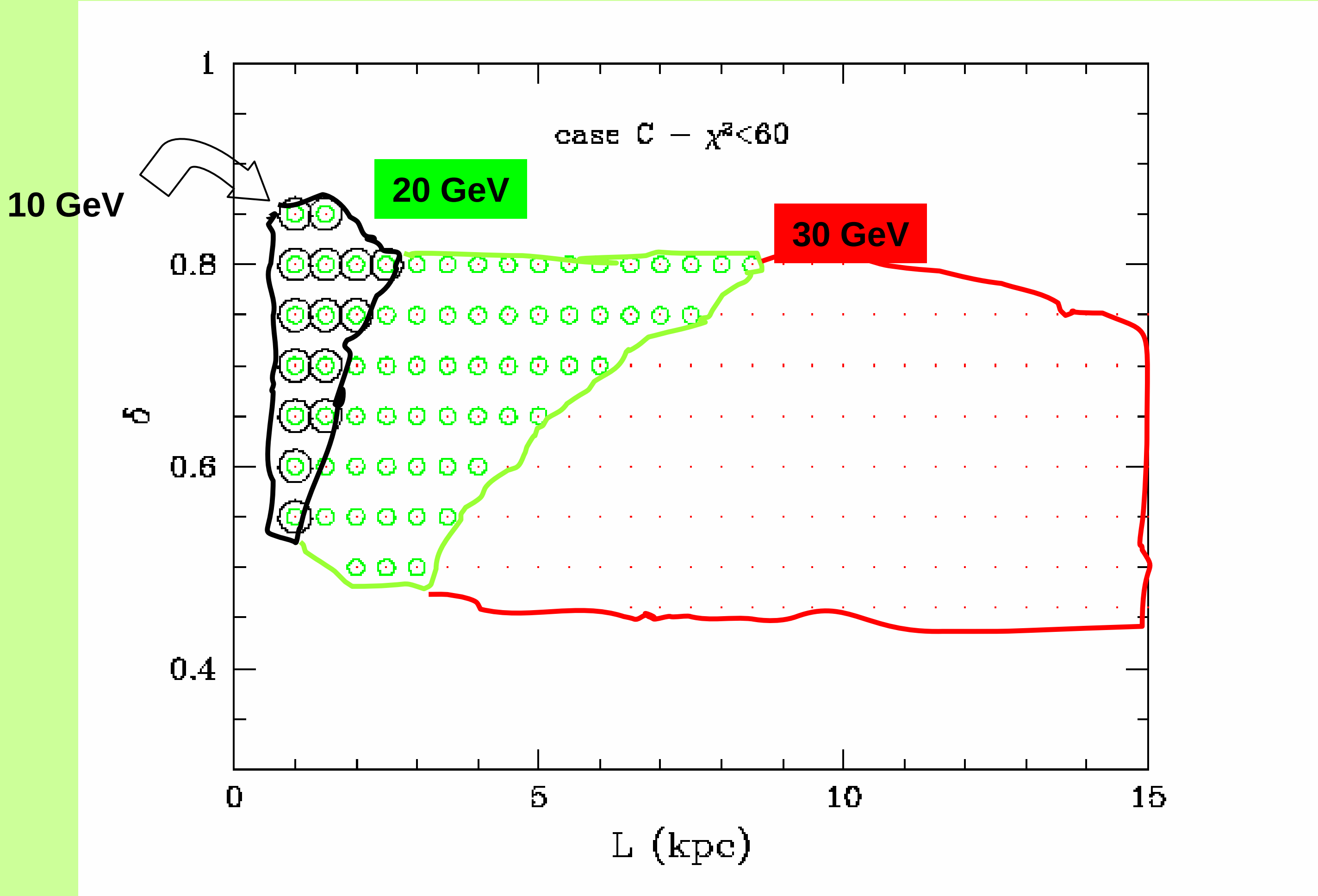
A.B., Donato, Fornengo and Salati: hep-ph/0507086



- *effects due to light neutralinos can be sizeable, but hardly distinguishable from background*
- *constraints relaxed by astrophysical uncertainties of primary fluxes*

Compatibility among the WIMP and the astrophysical parameters

A.B., Donato, Fornengo, Salati, hep-ph/0507086

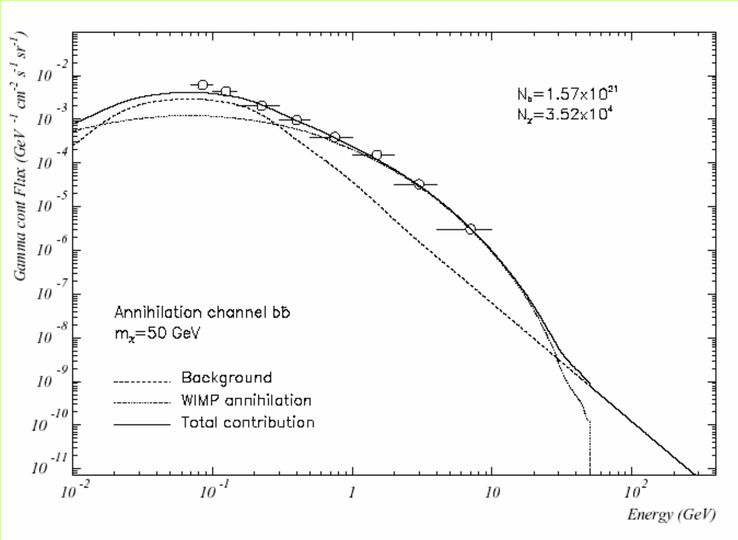


Diffusion in a two-zones halo:

- **energy-dependent coefficient** $K = K_0 \beta R^{\delta} (R = rigidity)$
- **L = halo thickness parameter**

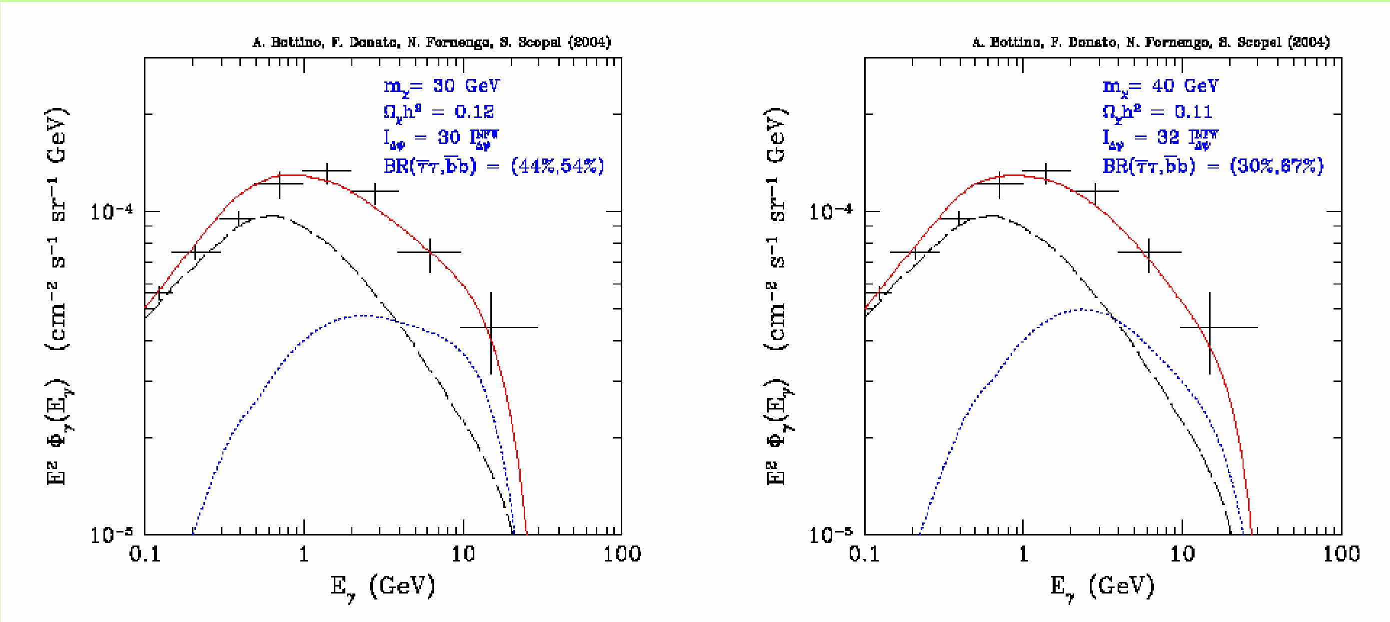
The Gamma-rays Saga

EGRET excess from the Galactic Center



Explanation in terms of neutralino self-annihilation possible, but not compelling (boost factor required)

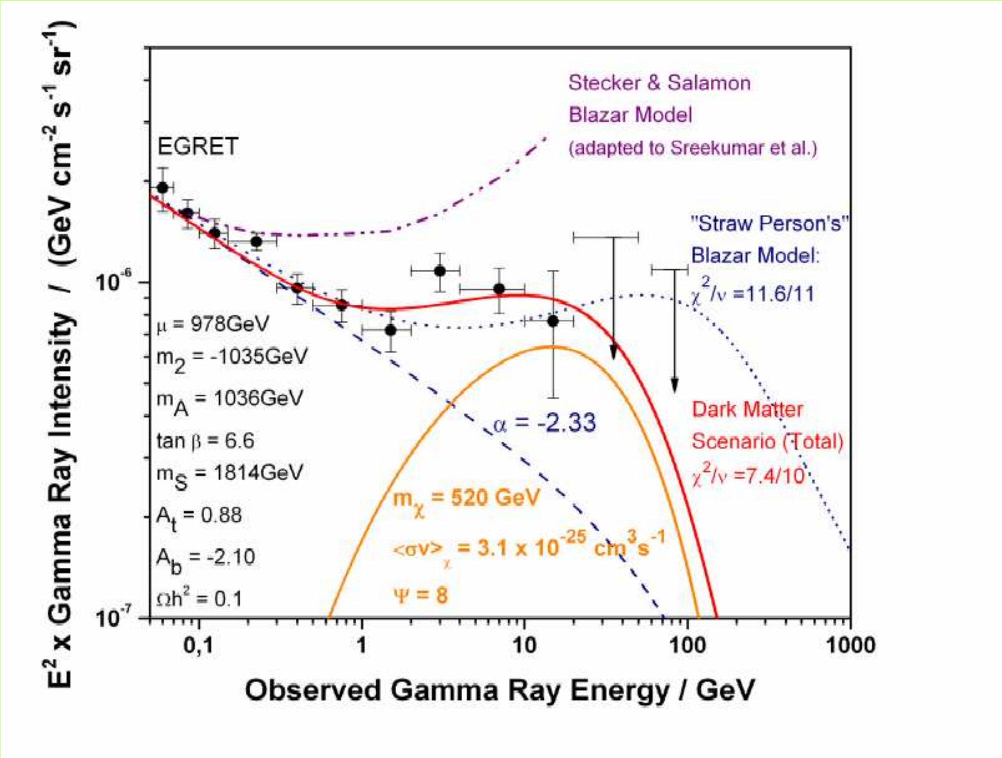
Cesarini, Fucito, Lionetto, Morselli, Ullio, astro-ph/0305075



A.B., Donato, Fornengo, Scopel, hep-ph/0401186

Extragalactic gamma-ray background

Elsasser and Mannheim: astro-ph/0405235



best fit: $m_\chi = 515^{+110}_{-75}\,GeV$

Important caveats:

- the background is affected by large uncertainties

- such a sizeable primary flux would imply violation of observational bounds on gamma-ray flux from the Galactic Center (S. Ando, astro-ph/0503006)

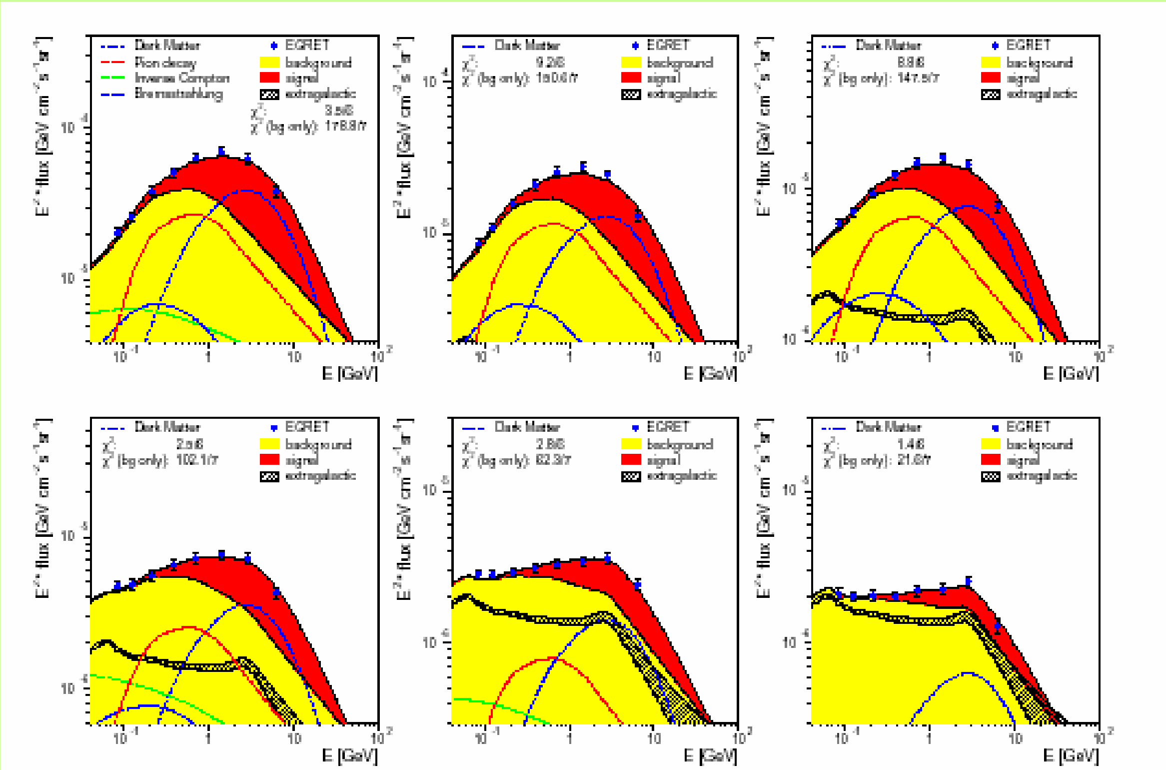
EGRET excess of diffuse galactic gamma-rays fluxes

Analysis by de Boer, Sander, Zhukov, Gladyshev and Kazakov of the EGRET data in 180 independent sky directions

Claims:

- the common spectral shape of the excess singles out a WIMP mass ~ 60 GeV

- the flux of the excess determines a halo dark matter distribution in good agreement with rotation curve

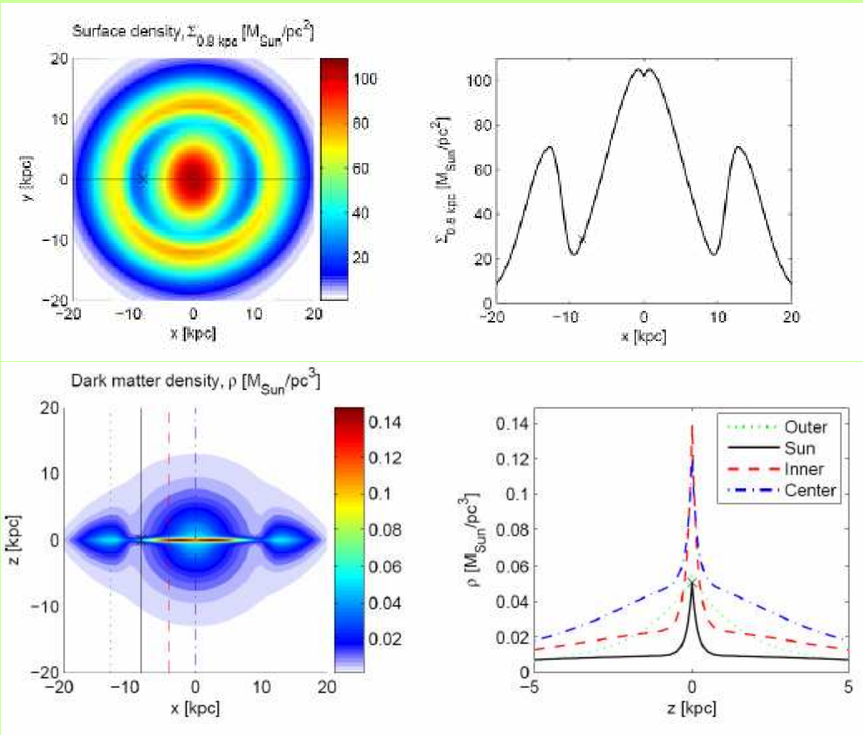


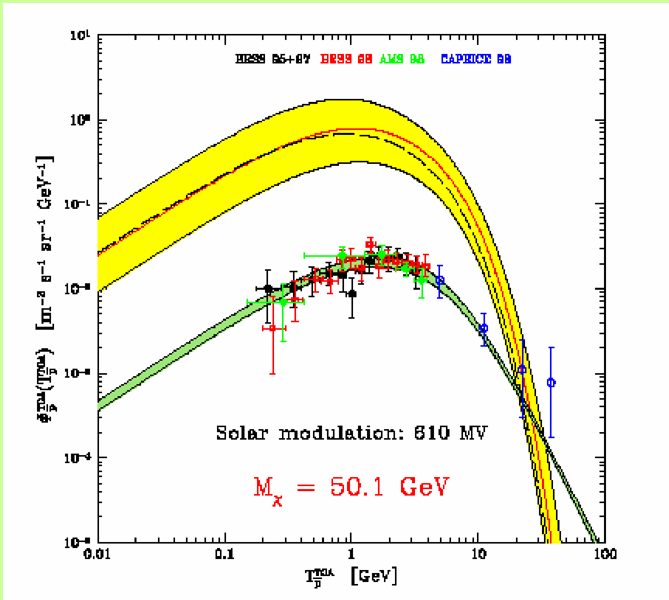
But ...

Conclusions by de Boer at al. contradicted by Bergstrom, Edsjo, Gustafsson and Salati, astro-ph/0602632:

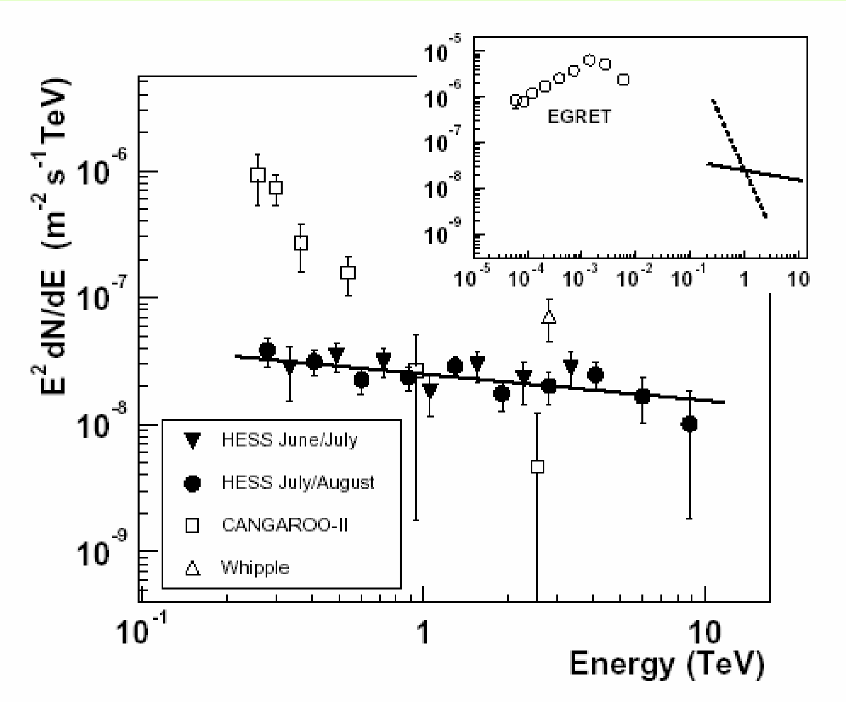
the peculiar features of the dark matter distribution used by de Boer et al. difficult to achieve with non-dissipative dark matter and may have problems with the disc surface mass density

the ensuing antiproton fluxes would overshoot the observational data





High energy gamma-flux from the Galactic Center

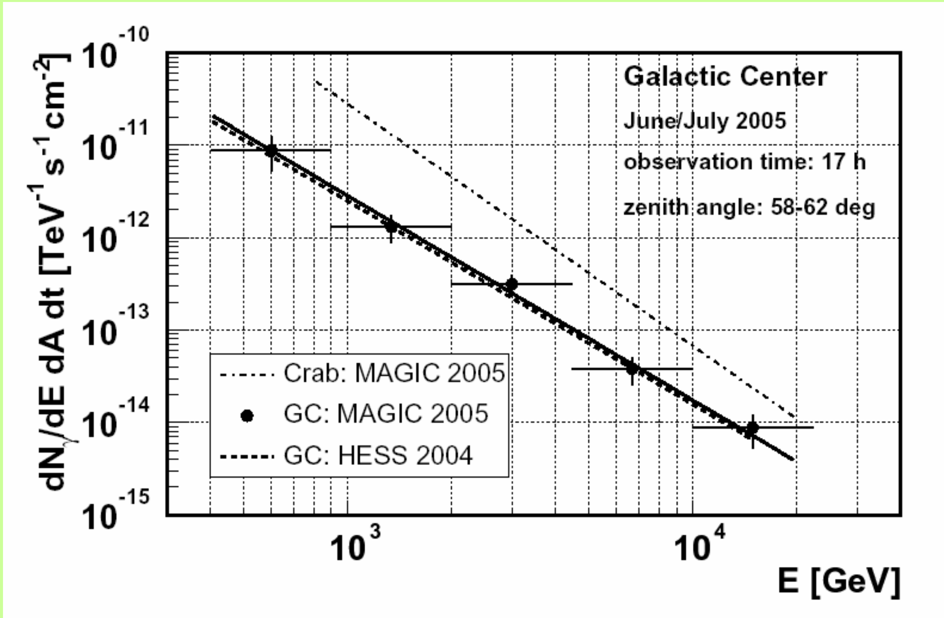


Aharonian et al (HESS Collaboration) astro-ph/0408145

Power-law spectrum with an index

$$\alpha = -2.2 \pm 0.09 \pm 0.15$$

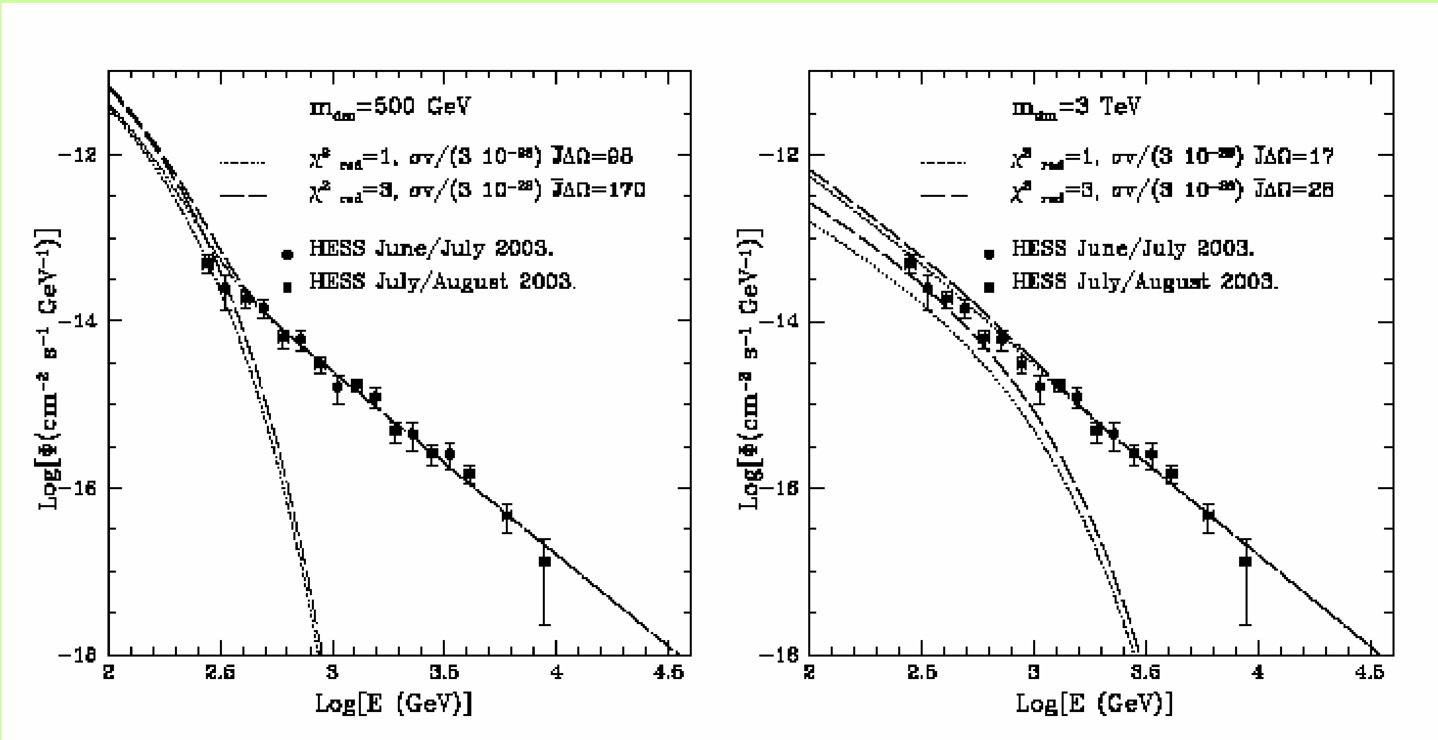
J. Albert et al (MAGIC Collaboration, astro-ph/0512469



The TeV radiation is well explained by astrophysical processes (Aharonian and Neronov, astro-ph/0503354)

Hard to disentangle a signal due to   WIMP self-annihilation

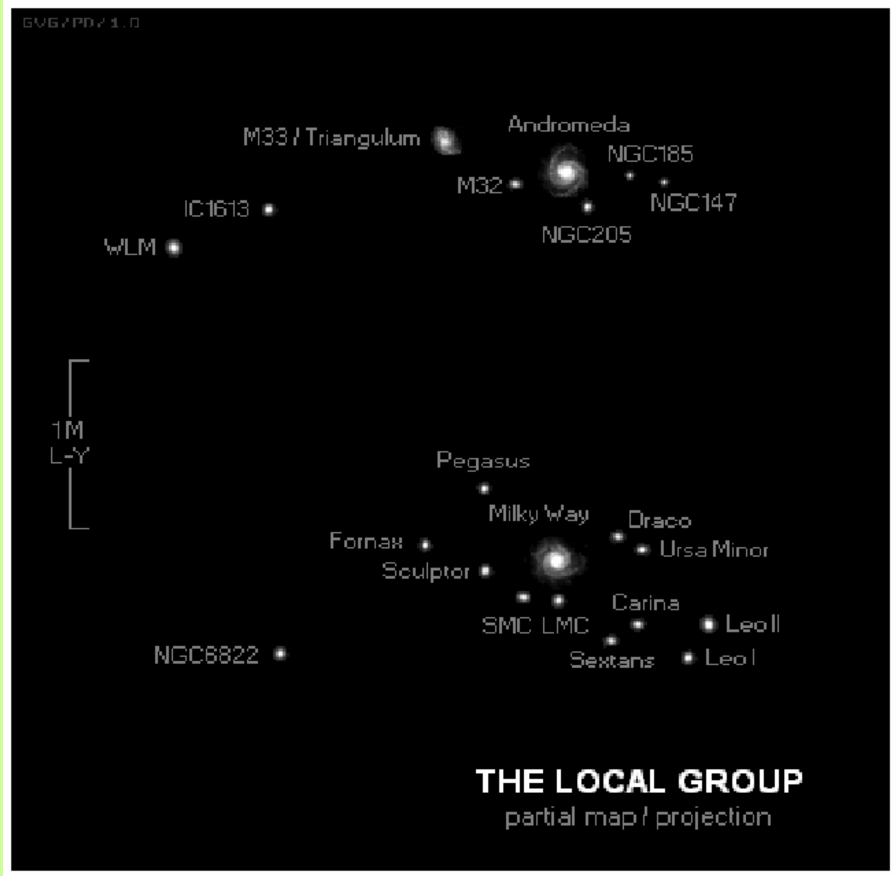
Zaharijas, Hooper, astro-ph/0603540



Signals from dwarf galaxies satellites of the Milky Way: the case of Draco - good prospects for GLAST and MAGIC in case of favorable neutralino schemes :

Bergstrom and Hooper, hep-ph/0512317

See also: Profumo and Kamionkowski, astro-ph/0601249



Conclusions

- ***The sensitivities of present direct and indirect WIMP searches*** ***already allow investigation of some interesting regions of the neutralino parameter space***
- ***Main challenge - to reduce some large uncertainties affecting the astrophysical aspects: WIMP distribution function, propagation and diffusion properties of CRs, …***
- ***In view of these uncertainties the interpretation of experimental data requires a conservative approach***
- ***Among the signals due to WIMP self-annihilation in the halo, the antiprotons are the most powerful signal for*** $m_\chi \leq 200\, GeV$
- ***Gamma-rays very intriguing – but great caution is needed before drawing strong conclusions***
- ***Independent information from accelerators is desperately needed***