Sneutrino cold dark matter: cosmological and detection properties[1]

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[1] based on: **C.Arina and N.Fornengo**, *Sneutrino cold dark matter, a new analysis: relic abundance and detection rates*, arXiv:0710.0553, accepted for publication in JHEP

Outline

1. **Supersymmetric Models**
   - Minimal Supersymmetric Standard Model (MSSM)
   - Models with a right–handed sneutrino field (LR models)
   - Models with a lepton–number violating term ($\not{L}$ models)
   - Models with a Majorana mass term (Maj models)
2. **Phenomenological relevant sneutrino configurations**
   - Relic abundance
   - Direct detection searches
   - Indirect detection rates
3. **Conclusions**

Standard Minimal Supersymmetric Model conserving R-parity $\Rightarrow \tilde{\nu}$ LSP by assumption

Scalar lepton sector

$(\tilde{\nu}, \tilde{e}^-)_L$	$(\nu, e^-)_L$
$\tilde{e}_R^-$	e_R^-

$$W_{\mathrm{MSSM}} = \epsilon_{ij}(\mu \hat{H}_i^1 \hat{H}_j^2 - Y_I^{IJ} \hat{H}_i^1 \hat{L}_j^I \hat{R}^J)$$

$$V_{\mathrm{soft}} = (M_L^2)^{IJ} \tilde{L}_i^{I*} \tilde{L}_i^J + [\epsilon_{ij}(\Lambda_I^{IJ} H_i^1 \tilde{L}_j^I \tilde{R}^J) + \mathrm{h.c.}]$$

$$V_{\tilde{l}_L}^{\mathrm{mass}} = \left[m_L^2 - m_Z^2 \cos 2\beta \left(\tfrac{1}{2} + e_L \sin^2\theta_W\right)\right] \tilde{l}_L^* \tilde{l}_L$$

$$V_{\tilde{\nu}}^{\mathrm{mass}} = \left[m_L^2 + \tfrac{1}{2} m_Z^2 \cos 2\beta\right] \tilde{\nu}_L^* \tilde{\nu}_L$$

$$V_{\tilde{l}_R}^{\mathrm{mass}} = \left[m_R^2 + e_R \sin^2\theta_W \;\; m_Z^2 \cos 2\beta\right] \tilde{l}_R^* \tilde{l}_R$$

- effMSSM at EW scale
- $m_L = m_R$

Mass parameter: m_L

Experimental constraints on $\tilde{\nu}$ mass:

- Collider $\rightarrow$ relaxed in effMSSM
- Z–width bound:

$$\Delta\Gamma_Z = \frac{\Gamma_\nu}{2}\left[1 - \left(\frac{2m_1}{m_Z}\right)^2\right]^{3/2} \theta(m_Z - 2m_1)$$

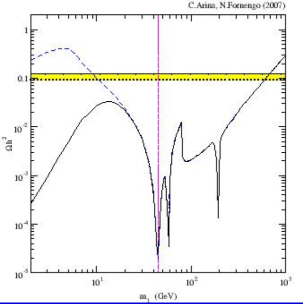
$$m_{\tilde{\nu}} \geq 45 - 50\,\mathrm{GeV}$$

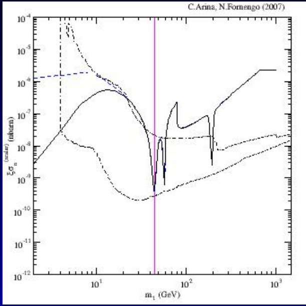
$\tilde{\nu}$ is a WIMP $\Rightarrow$ may account for cold dark matter content of the Universe

Phenomenology in the MSSM models

Relic abundance $\Omega_{\tilde{\nu}} h^2$ compared with the WMAP interval for CDM:

$$0.092 \leq \Omega_{\rm CDM} h^2 \leq 0.124$$





$\tilde{\nu}$ coherent elastic scattering on nucleon connected with DAMA/NaI annual modulation region:

$$\xi\sigma_{nucleon} = \xi\left(\sigma^{Z}_{nucleon} + \sigma^{h,H}_{nucleon}\right)$$

$$\xi = \min(1, \frac{\Omega_{\tilde{\nu}} h^2}{\Omega_{CDM} h^2})$$

- subdominant DM halo components, except in the mass range 600–700 GeV
- excluded by direct detection bounds, except fine–tuned conditions on $\xi\sigma$

Right–handed sneutrino field $\tilde{N}$

$$W_{LR} = \epsilon_{ij}(\mu \hat{H}^1_i \hat{H}^2_j - Y^{IJ}_l \hat{H}^1_i \hat{L}^I_j \hat{R}^J + Y^{IJ}_\nu \hat{H}^2_i \hat{L}^I_j \hat{N}^J)$$

$$V_{\rm soft} = (M^2_L)^{IJ} \tilde{L}^{I*}_i \tilde{L}^J_i + (M^2_N)^{IJ} \tilde{N}^{I*} \tilde{N}^J - [\epsilon_{ij}(\Lambda^{IJ}_l H^1_i \tilde{L}^I_j \tilde{R}^J + \Lambda^{IJ}_\nu H^2_i \tilde{L}^I_j \tilde{N}^J) + \text{h.c.}]$$

$$\Phi^\dagger = (\tilde{\nu}^*_L, \tilde{N}^*)$$

$$V_{\rm mass} = \frac{1}{2} \Phi^\dagger_{LR} \mathcal{M}^2_{LR} \Phi_{LR}$$

$$F^2 = v\Lambda_\nu \sin\beta - \mu m_D \text{cotg}\beta$$

$$\mathcal{M}^2_{LR} = \begin{pmatrix} m^2_L + \frac{1}{2} m^2_Z \cos(2\beta) + m^2_D & F^2 \\ F^2 & m^2_N + m^2_D \end{pmatrix}$$

$\Longrightarrow$

$\tilde{\nu}$ mass eigenstates:

$$\begin{cases} \tilde{\nu}_1 = -\sin\theta\ \tilde{\nu}_L + \cos\theta\ \tilde{N} \\ \tilde{\nu}_2 = +\cos\theta\ \tilde{\nu}_L + \sin\theta\ \tilde{N} \end{cases}$$

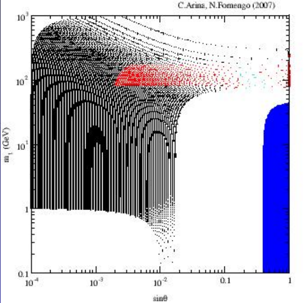
Z coupling weakend by $\sin^2\theta$

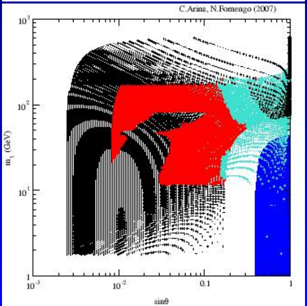
Z–width bound may be avoided

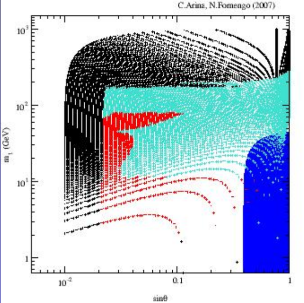
$$\Delta\Gamma_{Z_{LR}} = \sin^4\theta\, \Gamma_{Z_{\rm MSSM}}$$

Free parameters m_N and F^2 while $m_L \geq 80\ \text{GeV}$

Sneutrino parameter space: $\sin\theta$–m_1







$1\ \mathrm{GeV} \leq m_N \leq 1\ \mathrm{TeV}$

$$\begin{cases} F^2 = 10^2\ \mathrm{GeV}^2 \\ F^2 = 10^3\ \mathrm{GeV}^2 \\ F^2 = 10^4\ \mathrm{GeV}^2 \end{cases}$$

- $\sin\theta \leq 0.4 \Rightarrow$ Z–width bound avoided
- light $\tilde{\nu}_1$: $m_{\tilde{\nu}_1} \geq 10\ \mathrm{GeV}$

$\not{L}$ $\Rightarrow$ 5–dim operator $\mathcal{L} = g_{IJ}/M_\Lambda(\epsilon_{ij}L_i^I H_j)(\epsilon_{kl}L_k^J H_l) + \text{h.c.}$

$$V_{\rm mass} = \left[m_L^2 + \tfrac{1}{2}m_Z^2\cos(2\beta)\right]\tilde{\nu}_L^*\tilde{\nu}_L + \tfrac{1}{2}m_B^2(\tilde{\nu}_L\tilde{\nu}_L + \tilde{\nu}_L^*\tilde{\nu}_L^*)$$

$$\Phi^\dagger = (\tilde{\nu}_L\ \tilde{\nu}_L^*)$$

$$V_{\rm mass} = \tfrac{1}{2}\,\Phi_{\not{L}}^\dagger\,\mathcal{M}_{\not{L}}^2\,\Phi_{\not{L}}$$

$$\mathcal{M}_{\not{L}}^2 = \begin{pmatrix} m_L^2 + \frac{1}{2}m_Z^2\cos(2\beta) & m_B^2 \\ m_B^2 & m_L^2 + \frac{1}{2}m_Z^2\cos(2\beta)\end{pmatrix}$$

$\Rightarrow$

mass eigenstates

CP–odd $\tilde{\nu}_- \equiv \tilde{\nu}_1$

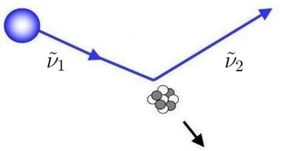
CP–even $\tilde{\nu}_+ \equiv \tilde{\nu}_2$

$$\begin{cases} \tilde{\nu}_+ = \frac{1}{\sqrt{2}}(\tilde{\nu}_L + \tilde{\nu}_L^*) \\ \tilde{\nu}_- = \frac{-i}{\sqrt{2}}(\tilde{\nu}_L - \tilde{\nu}_L^*) \end{cases}$$

$$\Delta m^2 \equiv m_2^2 - m_1^2 = 2m_B^2$$

Free parameter m_B while $m_L \geq 80\ \text{GeV}$

- Z coupling off-diagonal
- inelastic scattering off nuclei with the kinematic bound $\Delta m < \frac{\beta^2 m_1 m_{\mathcal{N}}}{2(m_1+m_{\mathcal{N}})}$
- Z–width decay occurs via the process $Z \to \nu_1\nu_2$



Models with right–handed sneutrinos and lepton–number violating interactions: the case for a see-saw neutrino mass

$$W_{Maj} = \epsilon_{ij}(\mu \hat{H}^1_i \hat{H}^2_j - Y^{IJ}_l \hat{H}^1_i \hat{L}^I_j \hat{R}^J + Y^{IJ}_\nu \hat{H}^2_i \hat{L}^I_j \hat{N}^J) + \frac{1}{2} M^{IJ} \hat{N}^I \hat{N}^J$$

$$V_{soft} = (M^2_L)^{IJ} \tilde{L}^{I*}_i \tilde{L}^J_i + (M^2_N)^{IJ} \tilde{N}^{I*} \tilde{N}^J - [(m^2_B)^{IJ} \tilde{N}^I \tilde{N}^J + \epsilon_{ij}(\Lambda^{IJ}_l H^1_i \tilde{L}^I_j \tilde{R}^J + \Lambda^{IJ}_\nu H^2_i \tilde{L}^I_j \tilde{N}^J) + \text{h.c.}]$$

$$\Phi^\dagger_{\rm MAJ} = (\tilde{\nu}^*_+ \ \tilde{N}^*_+ \ \tilde{\nu}^*_- \ \tilde{N}^*_-)$$

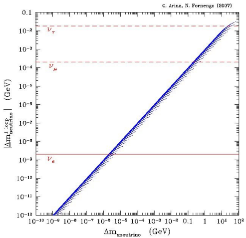
$$\mathcal{M}^2_{\rm MAJ} = \begin{pmatrix} m^2_L + D^2 + m^2_D & F^2 + m_D M & 0 & 0 \\ F^2 + m_D M & m^2_N + M^2 + m^2_D + m^2_B & 0 & 0 \\ 0 & 0 & m^2_L + D^2 + m^2_D & F^2 - m_D M \\ 0 & 0 & F^2 - m_D M & m^2_N + M^2 + m^2_D - m^2_B \end{pmatrix}$$

- neutrino mass via the see-saw mechanism
- $M = 1\,\text{TeV}$
  4 $\tilde{\nu}$ mass eigenstates
- $M = 10^9\,\text{GeV}$
  2 light $\tilde{\nu}$ mass eigenstates
  two degenerate $\tilde{\nu}$ at M scale

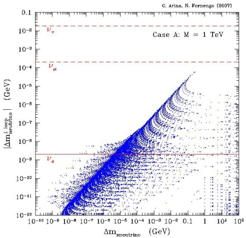
Free parameters m_N, M, m_B and F^2 while $m_L \geq 80\,\text{GeV}$

Constraints from one–loop neutrino masses

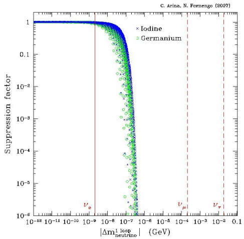
$\not{L}$



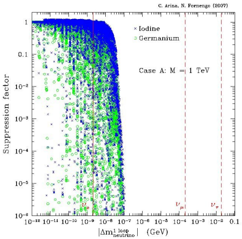
Maj $M = 1\,\mathrm{TeV}$



$\not{L}$



Maj $M = 1\,\mathrm{TeV}$



$m_{\nu e} \leq 2eV$

$m_{\nu\tau} \leq 18MeV$

$\Delta m_\nu^{1\,loop} \propto \Delta m$

Suppression

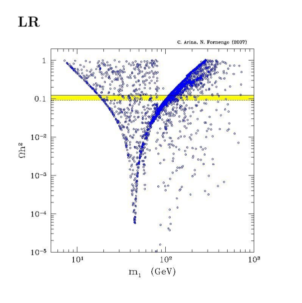
$$\mathcal{S} = \frac{\mathcal{R}(E_1,E_2;\Delta m)}{\mathcal{R}(E_1,E_2;0)}$$

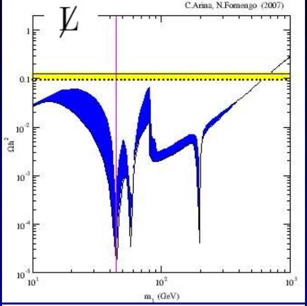
$$\left[\xi\sigma^{(\mathrm{scalar})}_{\mathrm{nucleon}}\right]_{\mathrm{eff}} = \mathcal{S}(\xi\sigma^{(\mathrm{scalar})}_{\mathrm{nucleon}})^Z + (\xi\sigma^{(\mathrm{scalar})}_{\mathrm{nucleon}})^{h,H}$$

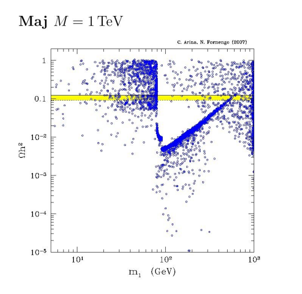
$\mathcal{S}_{Ge} \neq \mathcal{S}_I$

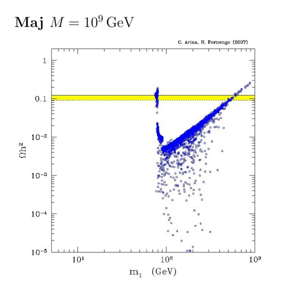
m_{ν_e} as bound: $\not{L}$ models strongly constrained contrary to Maj models

Ωh^2 vs m_1









LR viable configurations

$m_{\tilde{\nu}_1} \geq 15\,\mathrm{GeV}$

$m_{\tilde{\nu}_1} \leq 1\,\mathrm{TeV}$

$\not{L}$

$m_{\tilde{\nu}_1} \geq 10\,\mathrm{GeV}$

$M = 1\,\mathrm{TeV}$ viable configurations

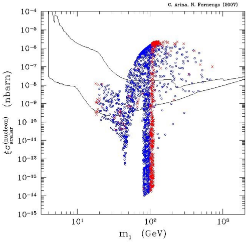
$m_{\tilde{\nu}_1} \geq 5\,\mathrm{GeV}$

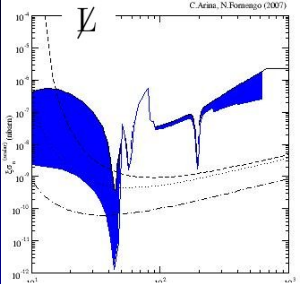
$m_{\tilde{\nu}_1} \leq 1\,\mathrm{TeV}$

$M = 10^9\,\mathrm{GeV}$ heavy $\tilde{\nu}_1$ subdominant

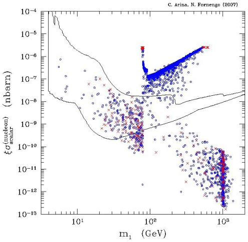
Direct detection rates $\xi\sigma^{(scalar)}_{nucleon}$ vs m_1

LR

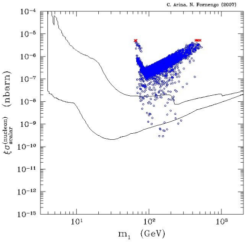




Maj $M = 1\,\mathrm{TeV}$



Maj $M = 10^9\,\mathrm{GeV}$



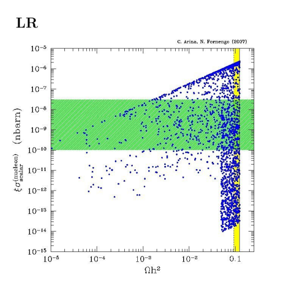
LR viable configurations

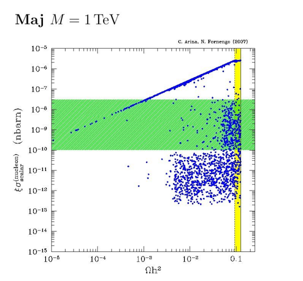
$\not{L}$ excluded

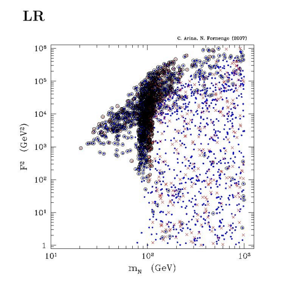
$M = 1\,\mathrm{TeV}$ viable configurations

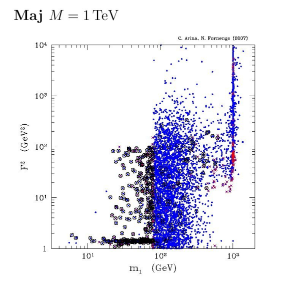
$M = 10^9\,\mathrm{GeV}$ excluded

Cosmologically viable sneutrino configurations









LR

$m_N \leq 10^2$**GeV**

viable light $\tilde{\nu}$

$m_N \geq 10^2$**GeV**

$\Downarrow$

$F^2 \geq 10^3$ **GeV**

viable heavy $\tilde{\nu}$

$M = 1\,\mathrm{TeV}$

viable $\tilde{\nu}$

$\Downarrow$

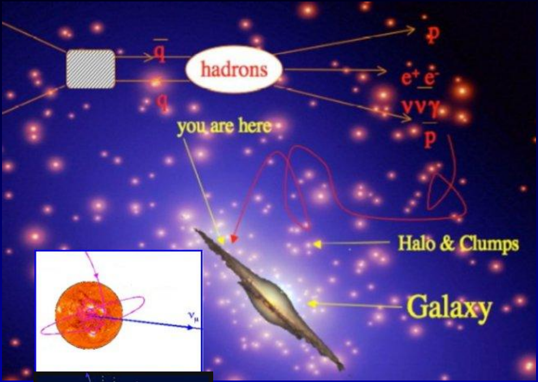
small m_N

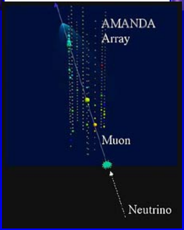
F^2 **in all range**

for both light

and heavy $\tilde{\nu}$

Annihilation signals from the galaxy and the Earth center





- Antimatter:

  $\tilde{\nu}_1 + \tilde{\nu}_1 \longrightarrow X + \bar{p}$

  $\tilde{\nu}_1 + \tilde{\nu}_1 \longrightarrow X + \bar{D}$

  BESS, PAMELA

  AMS, GAPS

- Gamma ray's

  $\tilde{\nu}_1 + \tilde{\nu}_1 \longrightarrow X + \gamma$

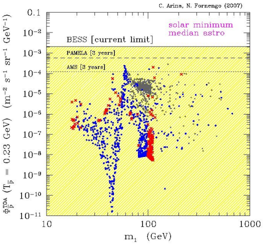
  EGRET, GLAST

- neutrino flux from the center of the Earth, due to annihilation of sneutrinoss captured by gravitational attraction

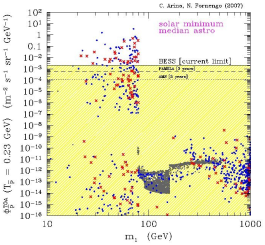
  SuperKamiokande, MACRO, AMANDA

$\bar{p}$ and $\bar{D}$ rates

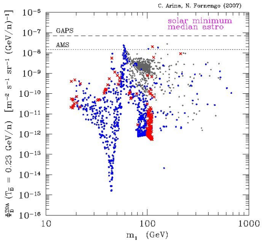
LR



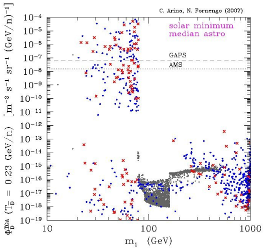
Maj $M = 1\,\mathrm{TeV}$



LR



Maj $M = 1\,\mathrm{TeV}$

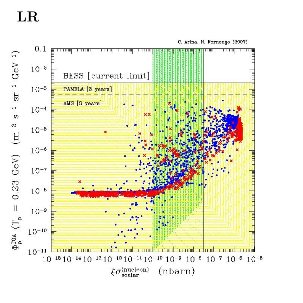


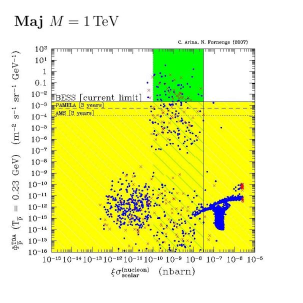
good deal of complementarity

one channel detectable by two detectors

and two channels detectable by the same detector

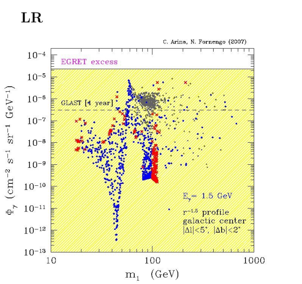
Indirect searches and direct detection complementarity

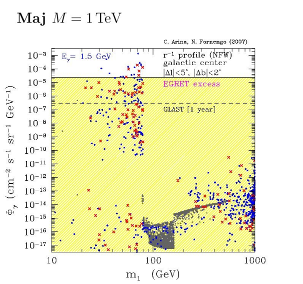


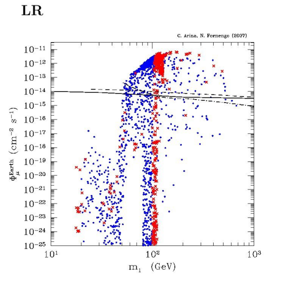


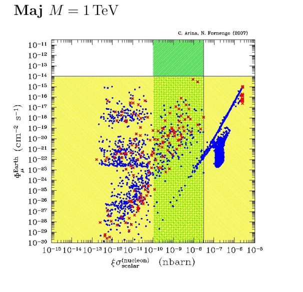
- different $\tilde{\nu}$ configurations may be probed or excluded by indirect and direct searches

γ's and ν expected signals









LR

γ's $\rightarrow$ ρ profile $r^{-1.5}$

for EGRET excess

neutrino telescopes

sensitive to a large

fraction of $\tilde{\nu}$

configurations

$M = 1\,\mathrm{TeV}$

γ's rates

NFW and Moore profiles

in the GLAST sensitivity

ν flux

under current

sensitivity

Summary

- Analysis of sneutrino phenomenology in MSSM and extended SUSY models:
  - **MSSM** CDM $\tilde{\nu}$ mainly excluded by direct detection searches, except fine–tuned configurations, where they are subdominant halo component
  - **LR** $15\,\mathrm{GeV} \leq m_{\tilde{\nu}} \leq 1\,\mathrm{TeV}$ may account for CDM and annual modulation signal of DAMA/NaI
  - $\not{L}$ phenomenology similar to MSSM sneutrinos if a 2 eV bound on the neutrino mass is chosen
  - $M = 1\,\mathrm{TeV}$ $5\,\mathrm{GeV} \leq m_{\tilde{\nu}} \leq 1\,\mathrm{TeV}$ may account for CDM and annual modulation signal of DAMA/NaI
  - $M = 10^9\,\mathrm{GeV}$ heavy ($m_{\tilde{\nu}} \geq 10^2\,\mathrm{GeV}$) $\tilde{\nu}$ subdominant DM halo components
- prediction for the indirect annihilation rates for the relevant cosmological configurations:
  - **LR** $50\,\mathrm{GeV} \leq m_{\tilde{\nu}} \leq 200\,\mathrm{GeV}$ $\Rightarrow$ detectable $\bar{p}$, $\bar{D}$ signals by AMS, PAMELA and GAPS
  - $M = 1\,\mathrm{TeV}$ $m_{\tilde{\nu}} \leq 90\,\mathrm{GeV}$ in the sensitivity range of PAMELA, AMS for $\bar{p}$, $\bar{D}$ signals and of GLAST for γ signals

Indirect detection fluxes

$\bar{p}$

$$q_{\bar{p}}^{\rm DM}(r,z;T_{\bar{p}}) = \frac{1}{2}\langle\sigma_{\rm ann} v\rangle_0 \, g_{\bar{p}}(T_{\bar{p}}) \left[\frac{\rho_{\tilde{\nu}_1}}{m_1}\right]^2$$

$$g_{\bar{p}}(T_{\bar{p}}) = \sum_F {\rm BR}(\tilde{\nu}_1\tilde{\nu}_1 \to F) \left(\frac{dN_{\bar{p}}^F}{dT_{\bar{p}}}\right)$$

$$q_{\bar{p}}^{\rm DM}(r,z;T_{\bar{p}}) \longrightarrow \Phi(R_0, 0, T_{\bar{p}})$$

two zone diffusion model

T.O.A. at solar minimum

γ's

$$\Phi_\gamma^{\rm DM}(E_\gamma,\psi) = \frac{1}{4\pi}\frac{\langle\sigma_{\rm ann} v\rangle_0}{2m_\chi^2} \, g_\gamma(E_\gamma)\, I(\psi)$$

$$I(\psi) = \int_{\rm l.o.s.} \rho_{\tilde{\nu}_1}^2 [r(\lambda,\psi)] d\lambda$$

dependent on the shape of the density profile ρ

$\bar{D}$

$\bar{p}$ excess expected in the low energy tail

secondary $\bar{p}$ tends to loose energy

through noninelastic collisions

$\bar{D}$ signals not affected by this problem

very few secondary $\bar{D}$ are

produced at low energy

for kinematical reasons

ν

$$\frac{dN_\nu}{dE_\nu} = \frac{\Gamma_{ann}}{4\pi\ d^2} \sum_f BR_f \frac{dN_f}{dE}$$

dependent on $\xi\sigma_{nucleon}^{(scalar)}$ and on $\rho_\odot$