The right-handed sneutrino as thermal DM

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- Alexander Pukhov

Work in progress

1. Motivation

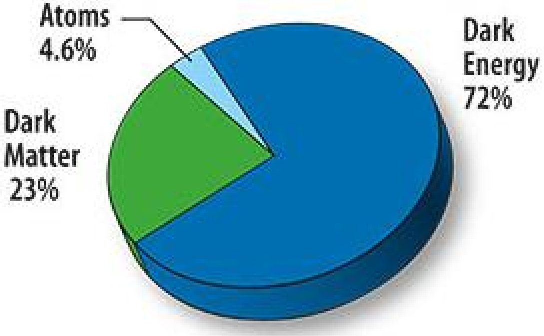
- Evidence for physics beyond the standard model (SM):
  - Neutrino oscillations:

    Nonzero neutrino masses are required

    Neutrinos are massless in the minimal SM
  - Non-baryonic dark matter (DM):

    $$\Omega_{\rm DM} h^2 = 0.1109 \pm 0.0056$$

    No candidate particle in the SM



[http://map.gsfc.nasa.gov]

⇒ More fundamental theory is needed

Right-handed (s)neutrinos

- Supersymmetric (SUSY) models with Dirac neutrinos

Right-handed neutrino superfields:

$N \begin{cases} \nu_R & \text{Right-handed neutrinos} \\ \tilde{\nu}_R & \text{Right-handed sneutrinos} \end{cases}$

Right-handed neutrinos ⇒ Dirac neutrino masses

Right-handed sneutrinos ⇒ (Light-mass) DM candidate

c.f. $\tilde{\nu}_L$ DM is no longer viable in the light of Z-width, $\Omega_{\rm DM}$, direct detections

- In addition, sizable sneutrino A_ν-parameter

$\tilde{\nu}_R$ was in thermal equilibrium

⇒ The predicted relic abundance is in the desired range

[Arkani-hamded,Hall,Murayama,Weiner(2001); Arina,Fornengo(2007);Thomas,Tucker-Smith,Weiner(2008)]

c.f. Negligible A_ν-parameter ⇒ Non-thermal $\tilde{\nu}_R$ DM

[Asaka,Ishiwata,Moroi(2006)]

Outline

- Detailed investigation of
  the thermal right-handed sneutrino DM scenario
- Up-to-date direct detection constraints on sneutrino DM
- Characteristic collider signatures

1. Motivation
2. The model (review)
3. Right-handed sneutrino dark matter
4. Collider signatures
5. Summary

2. The model

[Arkani-hamded,Hall,Murayama,Weiner(2001)]

- Only two new soft parameters (for one generation):

$$\mathcal{L} \supset -\widetilde{m}_N^2 \tilde{\nu}_R^* \tilde{\nu}_R - A_\nu h_2 l \tilde{\nu}_R^* + \text{h.c.}$$

A_ν is not related to the neutrino Yukawa coupling

- n.b. Sizable A_ν is possible when only ~~SUSY~~ fields break the symmetry that suppresses the neutrino Yukawa coupling:
  The origin of this A_ν is different from that of other A-parameters

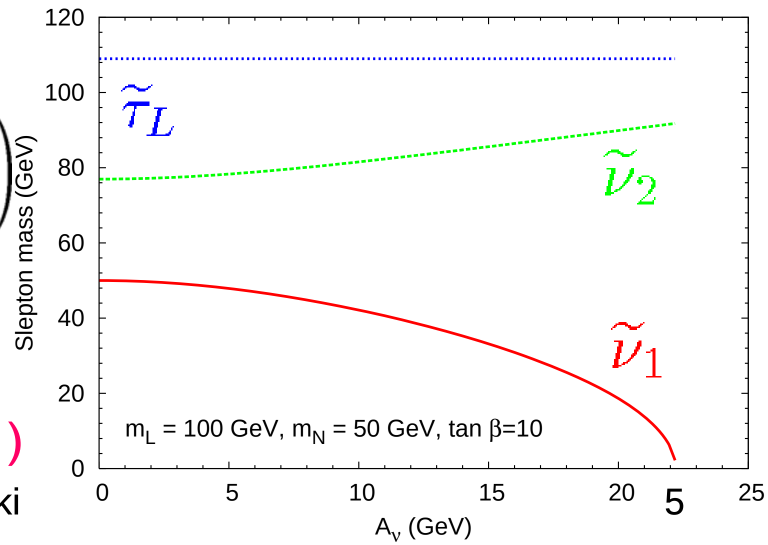
- Sneutrino mass matrix:

$$\mathcal{M}^2 = \begin{pmatrix} \widetilde{m}_L^2 + m_Z^2 c_{2\beta}/2 & A_\nu v s_\beta/\sqrt{2} \\ A_\nu v s_\beta/\sqrt{2} & \widetilde{m}_N^2 \end{pmatrix}$$

Heavy: $\tilde{\nu}_2 = \tilde{\nu}_L \cos\theta + \tilde{\nu}_R \sin\theta$

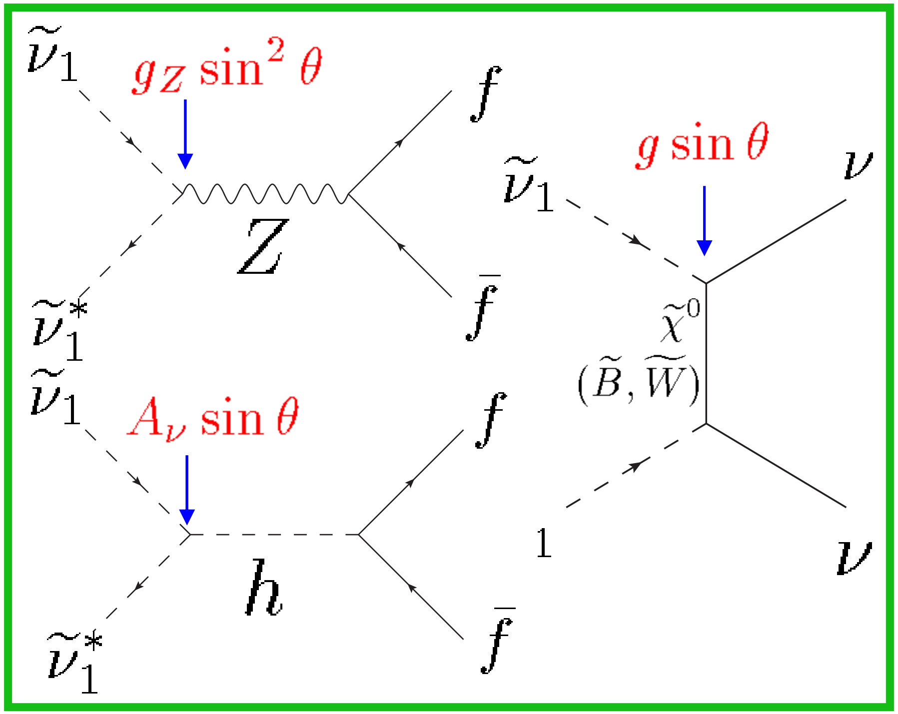
Light: $\tilde{\nu}_1 = -\tilde{\nu}_L \sin\theta + \tilde{\nu}_R \cos\theta$

$\tilde{\nu}_1$: DM candidate (can be lighter than $m_Z/2$)



3. Right-handed sneutrino DM

- **Important processes:**



[Arkani-hamded,Hall,Murayama,Weiner(2001);
Arina,Fornengo(2007);
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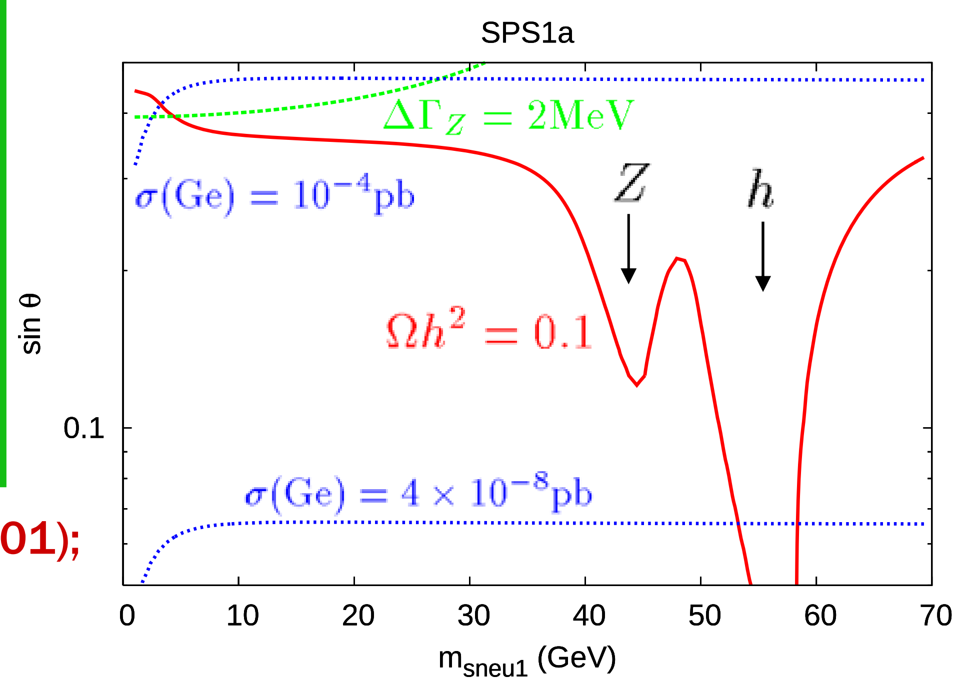
- **Computation:**

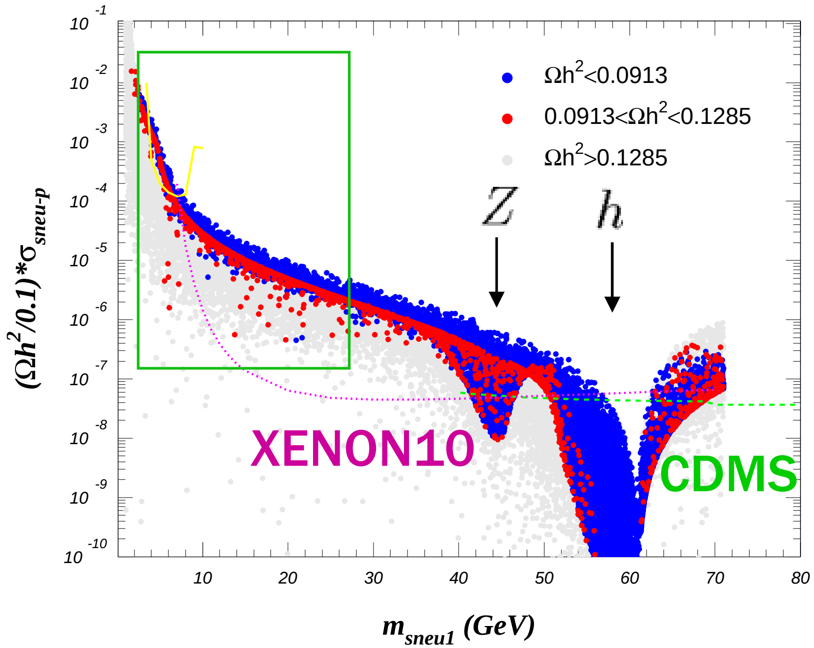
LanHEP ➡ CalcHEP ➡ micrOMGEAs

[Belanger,Boudjema,Pukhov,Semenov]



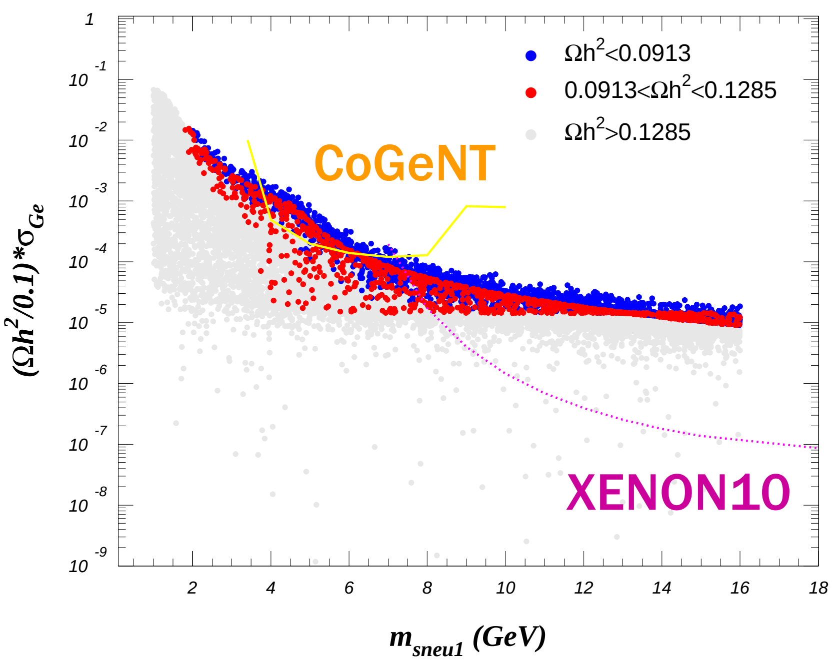
Direct detection constraints

(a) m_{sneu1} vs. DD: μ = 1000 GeV



1 GeV < msneu1 < 70 GeV
100 GeV < msneu2 < 1000 GeV
0 < sinθ < 0.3
100 GeV < MG2=2*MG1 < 500 GeV
tb = 10
MH3 = 1000 GeV
MG3 = 3*MG2
Mr3 = Ml3, Other sq, sl = 1000 GeV
yellow:COGENT, green:CDMS, magenta:XENON

(a) m_{sneu1} vs. DD: μ = 1000 GeV



1 GeV < msneu1 < 15 GeV
100 GeV < msneu2 < 1000 GeV
0 < sinθ < 0.3
MG2 = 2*MG1 = 120 GeV
tb = 10
MH3 = 1000 GeV
MG3 = 3*MG2
Mr3 = Ml3, Other sq, sl = 1000 GeV
yellow:COGENT, green:CDMS, magenta:XENON

4. Collider signatures

- To reconcile the GeV $\tilde{\nu}_R$ scenario with the DM exp. constraints, lighter gauginos, heavier sleptons are desirable
  (In most cases $\tilde{\chi}_1^{\pm} < \tilde{\tau}_1$ for $\tilde{m}_L = \tilde{m}_E$)

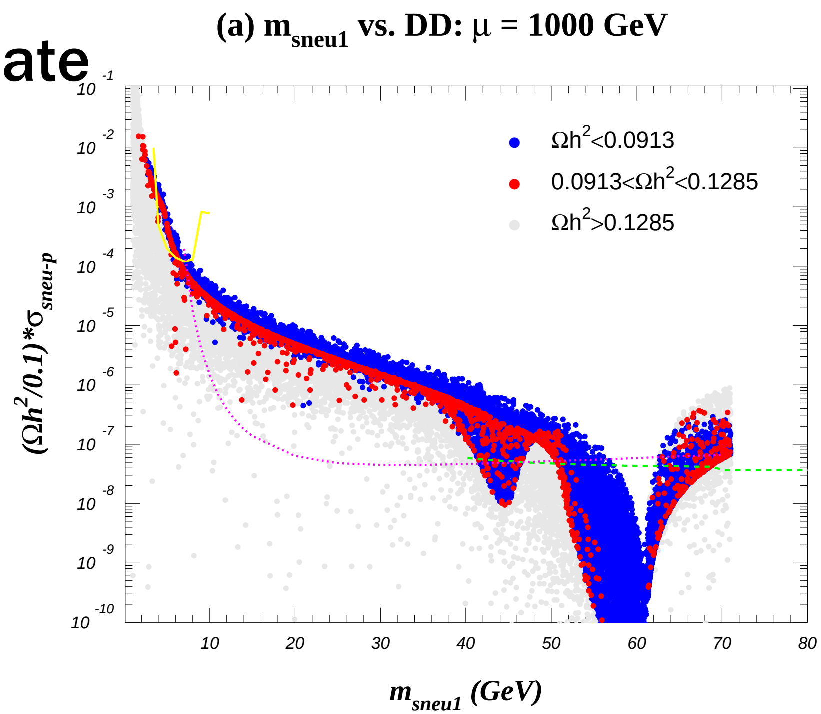
- Lepton modes
  - $p\bar{p} \to \tilde{\chi}_2^0 \tilde{\chi}_1^{\pm}$
    - $\tilde{\chi}_1^{\pm} \to \tilde{\nu}_{\tau 1} \tau^{\pm}$
    - $\tilde{\chi}_2^0 \to \tilde{\nu}_{\tau 1} \nu_\tau$
    - $\tilde{\chi}_2^0 \to$ ~~$\tilde{\tau}_1^{\pm} \tau^{\mp}$~~
  - $\tilde{g} \xrightarrow{50\%} \tilde{\chi}_1^{\pm} q \bar{q}'$
    - $\tilde{\chi}_1^{\pm} \to \tilde{\nu}_{\tau 1} \tau^{\pm}$
  - $\tilde{g} \xrightarrow{30\%} \tilde{\chi}_2^0 q \bar{q}$
    - $\tilde{\chi}_2^0 \to \tilde{\nu}_{\tau 1} \nu_\tau$
    - $\tilde{\chi}_2^0 \to$ ~~$\tilde{\tau}_1^{\pm} \tau^{\mp}$~~
  - $\tilde{g} \xrightarrow{15\%} \tilde{\chi}_1^0 q \bar{q}$
    - $\tilde{\chi}_1^0 \to \tilde{\nu}_{\tau 1} \nu_\tau$

- Higgs decay into invisible modes

  $\mathrm{Br}(h \to \tilde{\nu}_1 \tilde{\nu}_1^*) > 90\%$ in most cases

5. Summary

- $\tilde{\nu}_R$ is a viable thermal DM candidate
- From up-to-date direct detection results, we constrained the thermal $\tilde{\nu}_R$ DM scenario
- In progress:
  - Heavier LSP sneutrino
  - Collider signatures
  - Indirect detections
  - 3 $\tilde{\nu}_R$ generation case
  - Including RGE analysis



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tb = 10
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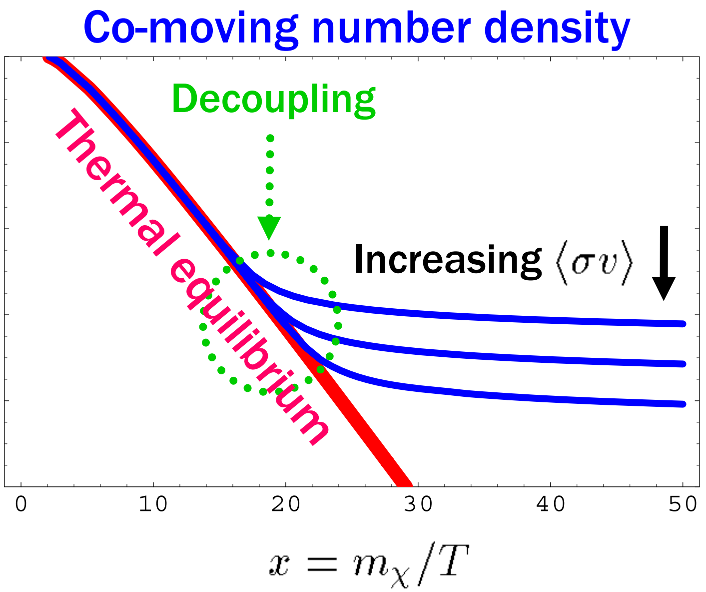
Backup slides

Thermal DM



- Thermal production of cold relics χ :
  - χ were in thermal equilibrium in the early universe
  - After the annihilation rate dropped below the expansion rate, the number density per comoving volume is almost fixed

$$\Rightarrow \Omega_\chi h^2 \simeq 0.04 \times \left(\frac{\langle \sigma v \rangle}{1 \text{ pb}}\right)^{-1} \left(\frac{x_F}{22}\right) \left(\frac{g_*}{90}\right)^{-1/2}$$

- Typical annihilation cross section of WIMPs with $m \sim \mathcal{O}(\text{TeV})$:

$$\sigma v \sim \frac{\pi \alpha^2}{m^2} \sim \mathcal{O}(\text{pb})$$

⇒ **The predicted thermal relic density is in the desired range!!!**