

Right-Handed Sneutrino as Cold Dark Matter

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Reference:

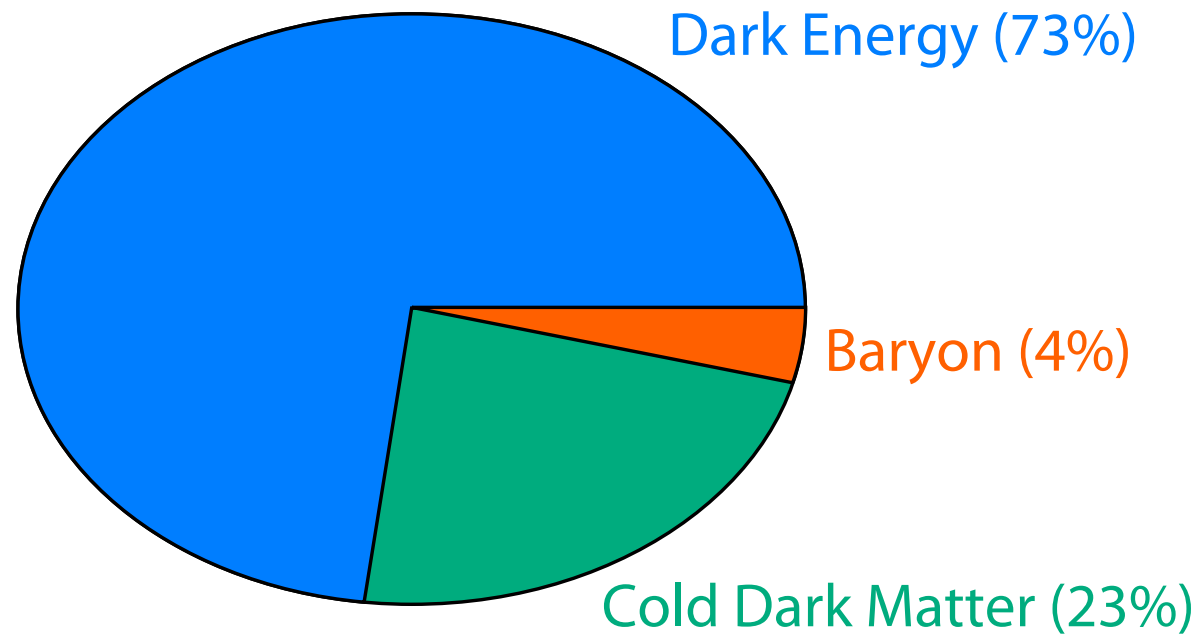
Asaka, Ishiwata & Moroi, hep-ph/0512118 (to appear in PRD)

Talk given at “Mass Origin and Supersymmetry Physics”

1. Introduction

Supersymmetric models provide rich cosmology

⇒ LSP dark matter is one of the most important implications of SUSY cosmology



In order to realize LSP dark matter:

The LSP should be charge-neutral (and stable)

Lightest superparticle: model dependent

Lightest neutralino, Gravitino, Axino, ...

A new candidate of the LSP:

Right-handed scalar neutrino $\tilde{\nu}_R$

Seesaw scenario is usually adopted for small neutrino masses

[Yanagida; Gell-Mann, Ramond & Slansky]

⇒ Neutrino masses are Majorana-type

⇒ Right-handed (s)neutrinos are ultra-heavy

Neutrino masses may be Dirac-type

$$\mathcal{L}_{\text{mass}} = -y_\nu \nu_R l_L H + \text{h.c.} \quad \Rightarrow \quad m_\nu = y_\nu \langle H \rangle$$

ν_R : Right-handed neutrino

l_L : Left-handed lepton doublet

$\tilde{\nu}_R$ (superpartner of ν_R) may be the LSP

If the neutrino mass is Dirac-type, mass of $\tilde{\nu}_R$ originates from SUSY breaking

Today's subject: possibility of $\tilde{\nu}_R$ -LSP

- Hereafter, $\tilde{\nu}_R$ is assumed to be the LSP
- $\tilde{\nu}_R$ -CDM (i.e., $\Omega_{\tilde{\nu}_R} \sim 0.1$) is realized in some case

2. Model

Superpotential:

$$W = y_\nu \hat{\nu}_R \hat{l}_L \hat{H}_u + W_{\text{MSSM}} \quad \Rightarrow \quad m_\nu = y_\nu \langle H_u \rangle$$

Yukawa coupling constant becomes very small:

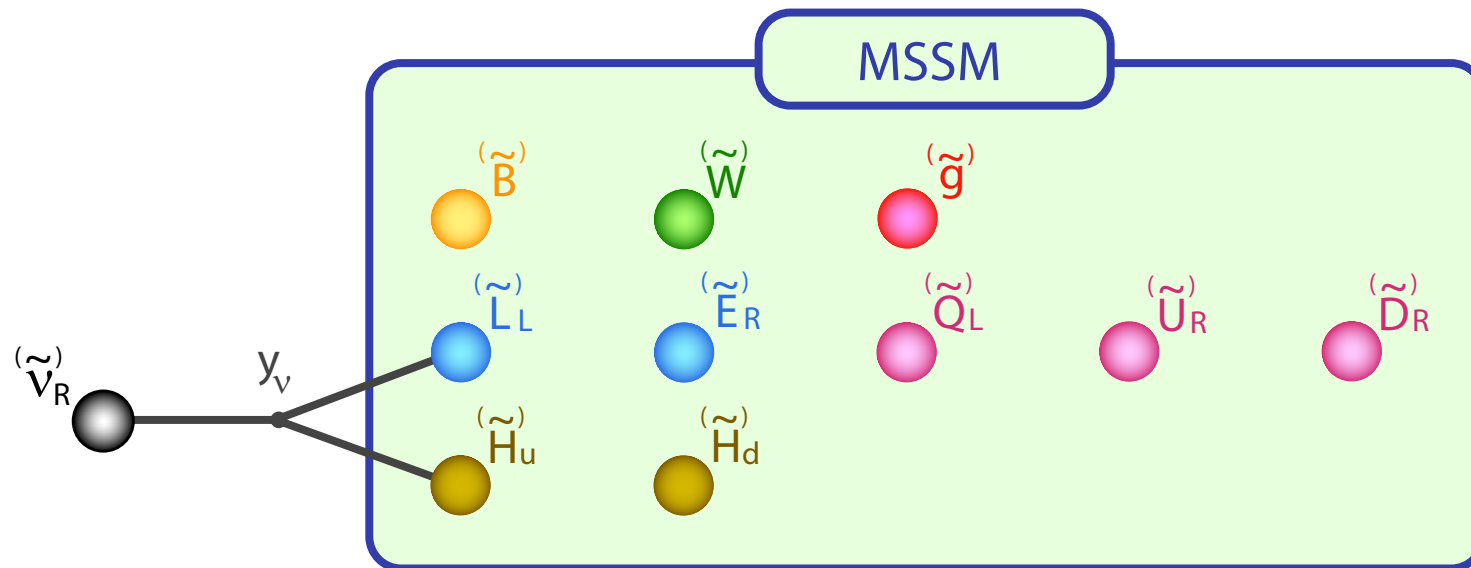
$$y_\nu \sin \beta = 3.0 \times 10^{-13} \times \left(\frac{m_\nu^2}{2.8 \times 10^{-3} \text{ eV}^2} \right)^{1/2}$$

$$\text{C.f.: } [\Delta m_\nu^2]_{\text{atom}} \simeq 2.8 \times 10^{-3} \text{ eV}^2; [\Delta m_\nu^2]_{\text{solar}} \simeq 7.9 \times 10^{-5} \text{ eV}^2$$

Small Yukawa coupling constant is natural (in 'tHooft's sense)

Chiral symmetry of ν_R is restored in the limit of $y_\nu \rightarrow 0$

$\tilde{\nu}_R$ is very weakly interacting: $y_\nu \sim O(10^{-13})$



- The NLSP (like χ_1^0) becomes very long-lived

$$\Gamma_{\tilde{H}_u \rightarrow \tilde{\nu}_R l_L}^{-1} \simeq 100 \text{ sec} \left(\frac{y_\nu}{10^{-13}} \right)^2 \left(\frac{\mu_H}{100 \text{ GeV}} \right)$$

- Model (probably) looks like MSSM at collider experiments

3. Cosmology

$\tilde{\nu}_R$ -LSP in early universe

- Production rate of $\tilde{\nu}_R$ is very small
- $\tilde{\nu}_R$ cannot be thermalized

Typical production rate of $\tilde{\nu}_R$ in thermal bath

$$\langle \sigma v_{\text{rel}} \rangle \sim \frac{y_\nu^2}{T^2} \quad \Rightarrow \quad \Gamma_{\dots \rightarrow \tilde{\nu}_R} \sim n_{\text{MSSM}} \langle \sigma v_{\text{rel}} \rangle \sim y_\nu^2 T$$

Condition for thermalization: $\Gamma_{\dots \rightarrow \tilde{\nu}_R} \gg H \sim T^2/M_{\text{Pl}}$

$$y_\nu \gg \sqrt{\frac{T}{M_{\text{Pl}}}} \sim 10^{-8} \times \left(\frac{T}{100 \text{ GeV}} \right)^{1/2}$$

$\tilde{\nu}_R$ is produced from particles in thermal bath

⇒ Decay processes are important

- $\tilde{H} \rightarrow \tilde{\nu}_R \nu_L$
- $\tilde{W} \rightarrow \tilde{\nu}_R l_L$
- ...

Boltzmann equation

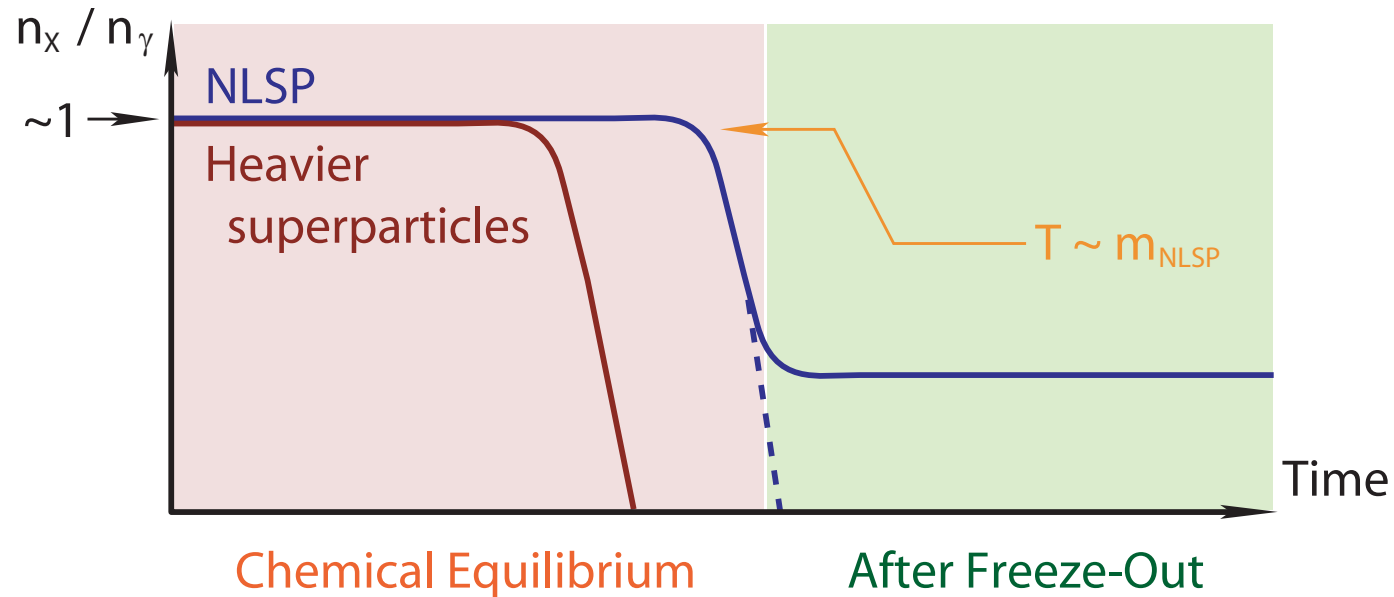
$$\frac{dn_{\tilde{\nu}_R}}{dt} + 3Hn_{\tilde{\nu}_R} \simeq \sum_x n_x \Gamma_{x \rightarrow \tilde{\nu}_R + \dots}$$

n_x : number density of parent particles

$$H^2 \equiv \left(\frac{\dot{a}}{a}\right)^2 = \frac{\rho}{3M_{\text{Pl}}^2} \quad \text{with} \quad \rho_{\text{rad}} = \frac{\pi^2}{30} g_* T^4$$

SUSY particles are in thermal bath when T is high enough

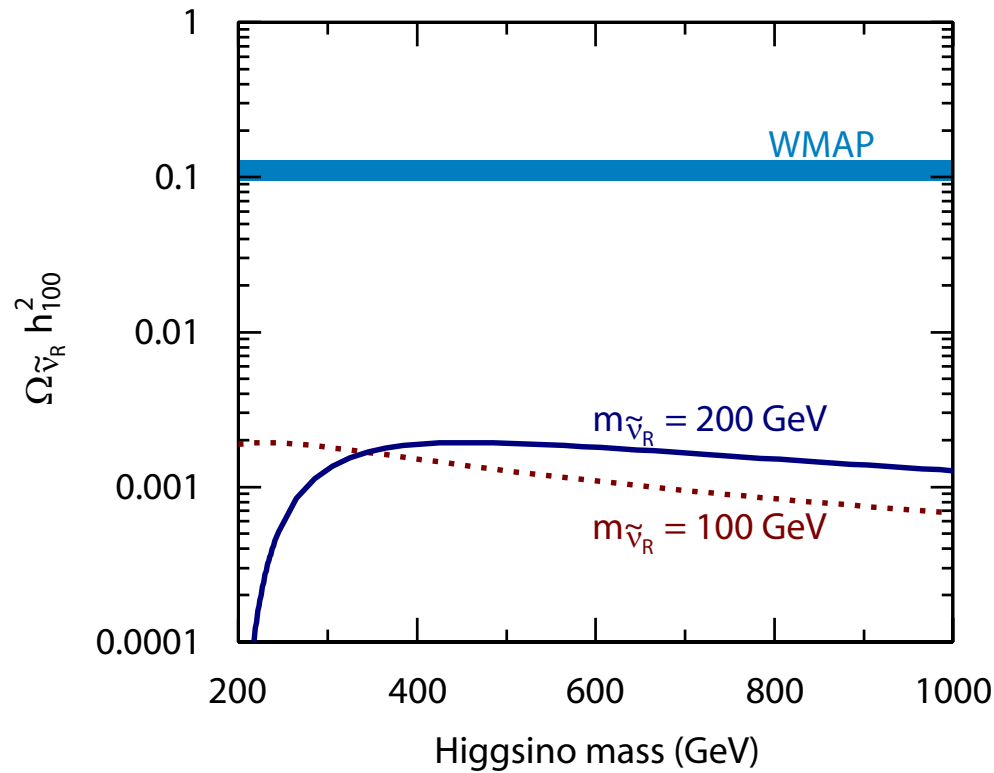
\Rightarrow NLSP (like χ_1^0) freezes out at low temperature



$$\Rightarrow n_{\tilde{\nu}_R} = n_{\tilde{\nu}_R}^{(\text{C.E.})} + n_{\tilde{\nu}_R}^{(\text{F.O.})}$$

- $n_{\tilde{\nu}_R}^{(\text{C.E.})}$: $\tilde{\nu}_R$ produced when $T \gtrsim T_F$
- $n_{\tilde{\nu}_R}^{(\text{F.O.})}$: $\tilde{\nu}_R$ produced when $T \lesssim T_F$

$\tilde{\nu}_R$ production before NLSP freeze-out: case with $\tilde{H} \rightarrow \tilde{\nu}_R l_L$



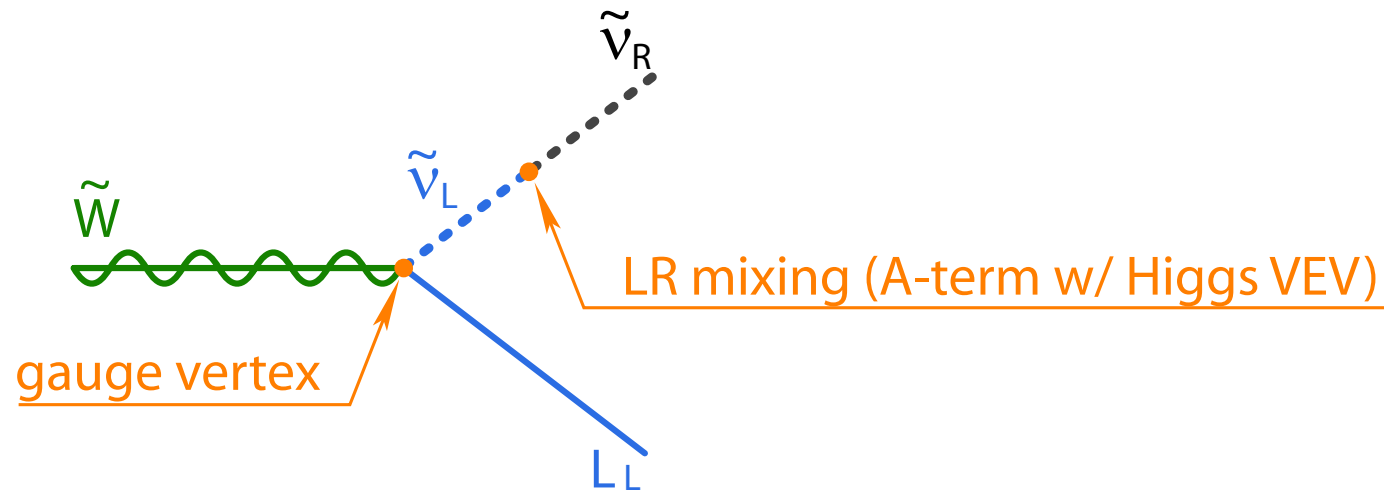
$$\Gamma_{\tilde{H} \rightarrow \tilde{\nu}_R l_L} = \frac{\beta_f^2 y_\nu^2}{32\pi} \mu_H$$

In this case, $\Omega_{\tilde{\nu}_R}$ is too small to realize $\tilde{\nu}_R$ -CDM

⇒ However, there are several possibilities to enhance $\Omega_{\tilde{\nu}_R}$

First possibility: Mixing enhancement (via left-right mixing)

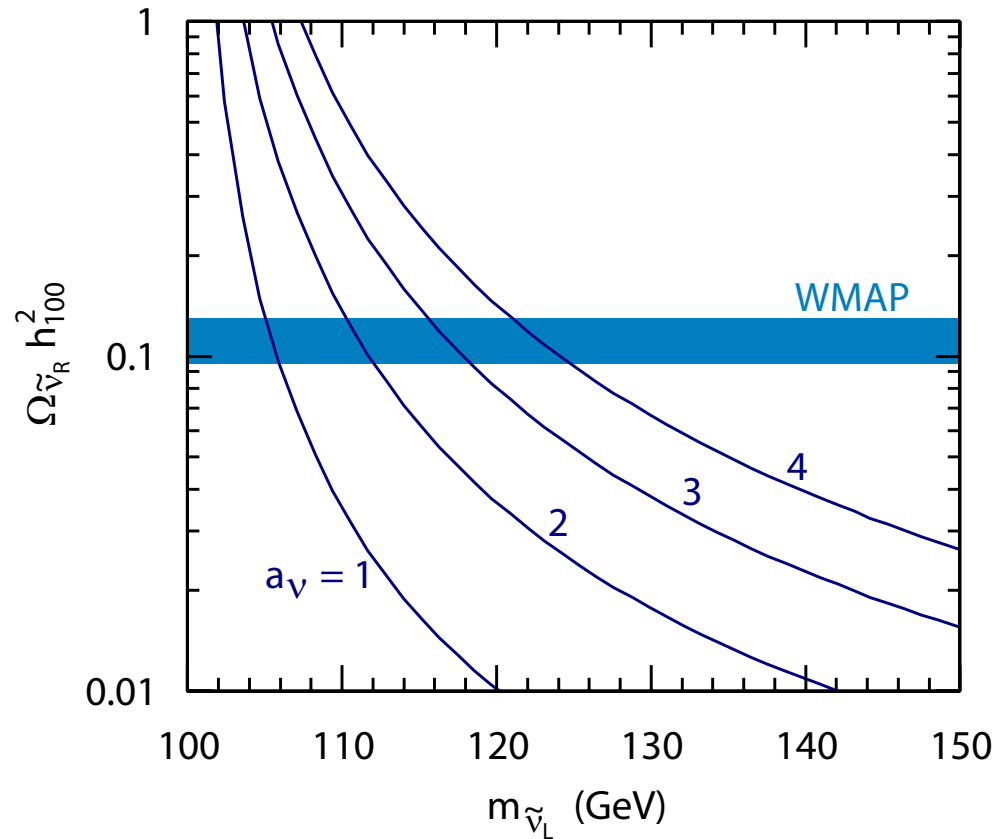
$$\mathcal{L}_A = A_\nu H_u \tilde{L} \tilde{\nu}_R + \text{h.c.}$$



$$\Gamma_{\tilde{W}^0 \rightarrow \tilde{\nu}_R \nu} = \frac{\beta_f^2 g_2^2}{64\pi} \left[\frac{A_\nu v_T}{m_{\tilde{\nu}_L}^2 - m_{\tilde{\nu}_R}^2} \right]^2 m_{\tilde{W}}$$

$$\Gamma_{\tilde{W}^\pm \rightarrow \tilde{\nu}_R l^\pm} = \frac{\beta_f^2 g_2^2}{32\pi} \left[\frac{A_\nu v_T}{m_{\tilde{\nu}_L}^2 - m_{\tilde{\nu}_R}^2} \right]^2 m_{\tilde{W}}$$

$\tilde{\nu}_R$ production is enhanced when $\tilde{\nu}_R$ and $\tilde{\nu}_L$ are degenerate



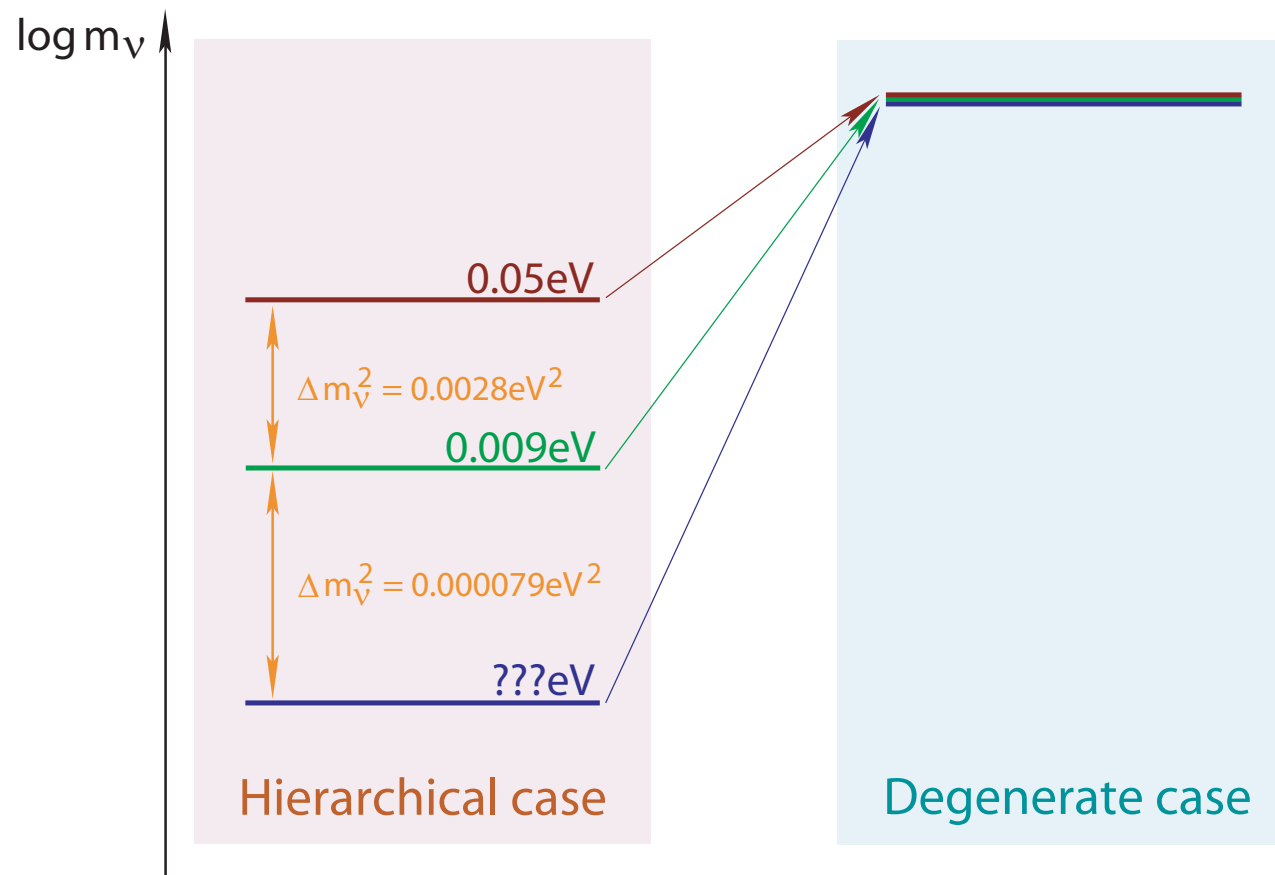
$$m_{\tilde{\nu}_R} = 100 \text{ GeV}$$

$$A_\nu = a_\nu y_\nu m_{\tilde{l}_L}$$

- $\tilde{\nu}_R$ -CDM is realized with a mild degeneracy
- In this case, light sleptons are likely to be found at colliders

Second possibility: Degenerate neutrino

Neutrino-oscillation experiments determine only difference of mass squared



Required enhancement of $\Omega_{\tilde{\nu}_R}$: factor of ~ 100

\Rightarrow This is realized when $m_\nu \sim O(0.1 \text{ eV})$

Notice: $\Omega_{\tilde{\nu}_R} \propto y_\nu^2 \propto m_\nu^2$

Upper bound on m_ν

[Seljek et al. (SDSS collaboration)]

$\Sigma m_\nu < 1.54 \text{ eV}$: without Ly- α forest data

$\Sigma m_\nu < 0.42 \text{ eV}$: with Ly- α forest data

Systematic uncertainties (probably) remain in the current study of Ly- α forest

\Rightarrow With a better understanding of Ly- α forest, scenario with degenerate neutrino masses will be more precisely tested

So far, we have considered MSSM particles in chemical equilibrium

$\Rightarrow \tilde{\nu}_R$ production after NLSP freeze-out may be significant

$$\Omega_{\tilde{\nu}_R}^{(\text{tot})} = \Omega_{\tilde{\nu}_R}^{(\text{C.E.})} + \Omega_{\tilde{\nu}_R}^{(\text{F.O.})} = \Omega_{\tilde{\nu}_R}^{(\text{C.E.})} + \frac{m_{\tilde{\nu}_R}}{m_{\text{NLSP}}} \Omega_{\text{NLSP}}$$

Ω_{NLSP} : “would-be” density parameter of the NLSP

- Ω_{NLSP} strongly depends on MSSM parameters
 $\Rightarrow \Omega_{\text{NLSP}}$ becomes larger than 1 in some case
- Ω_{NLSP} is (in principle) calculable once MSSM parameters are measured at collider experiments

4. Summary

I discussed the possibility of $\tilde{\nu}_R$ -CDM

- $\tilde{\nu}_R$ may be CDM if it is the LSP
- Some enhancement of relic density may be necessary for $\Omega_{\tilde{\nu}_R} \sim 0.1$
- $\Omega_{\tilde{\nu}_R}$ is insensitive to the thermal history of $T \gg m_{\text{SUSY}}$

Probably, rich phenomenology with $\tilde{\nu}_R$:

- Detailed study of the effects of NLSP decay
- Effects of heavier right-handed sneutrino
- $\tilde{\nu}_R$ at colliders: possibility of a charged long-lived particle
- ...