

# Cosmology of Gravitino LSP Scenario with Right-Handed Sneutrino NLSP

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# 1. Introduction

## Supersymmetric model

- strongly motivated as a beyond standard model
- analyzed in detail from cosmological point of view recently

## Supersymmetric model with right-handed (s)neutrinos where neutrino masses are *purely Dirac type*

### Right-handed sneutrino $\tilde{\nu}_R$

- Never thermalized (∵ small neutrino Yukawa coupling)
- Can be relatively light among superparticles  
(∵ no EW scale corrections for its mass)

→ Possibility to affect cosmology [T.Asaka,K.I.,T.Moroi(2005)]

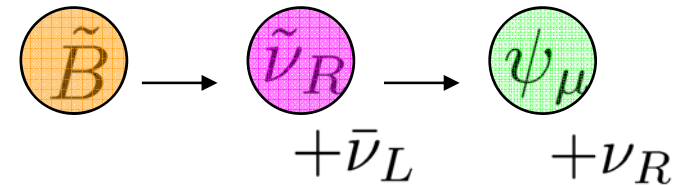
→ Gravitino-LSP scenario with right-handed sneutrino NLSP  
changes usual gravitino-LSP scenario

## Gravitino-LSP scenario with right-handed sneutrino NLSP

- bino as NNLSP case ( $m_{\tilde{B}} > m_{\tilde{\nu}_R} > m_{3/2}$ ) -

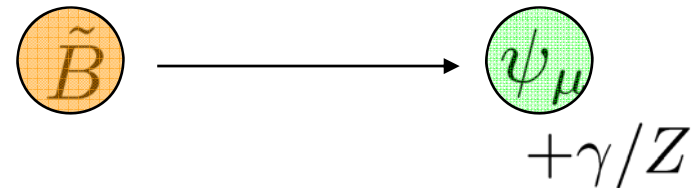
Bino :

- Freezes out, and decays
- Decay mode  $\tilde{B} \rightarrow \tilde{\nu}_R \bar{\nu}_L$  competes with  $\tilde{B} \rightarrow \psi_\mu \gamma/Z$ , or dominates in total decay



Cf.) Without right-handed sneutrino

- $\tilde{B} \rightarrow \psi_\mu \gamma/Z$  dominates in total decay to emit more hadrons, which may spoil success of Big-Bang Nucleosynthesis (BBN)
- Gravitino mass is strictly constrained as  $m_{3/2} \lesssim 0.1 \text{ GeV}$  [ J.L.Feng, S.Su, F.Takayama (2005) ]



→ Constraints from BBN scenario is relaxed  
A new parameter region  $m_{3/2} \lesssim 40 \text{ GeV}$  is allowed

## 2. Model

MSSM with right-handed (s)neutrinos  
where neutrino masses are *purely Dirac type*

- Superpotential

$$W = W_{\text{MSSM}} + y_\nu \hat{H}_u \hat{L} \hat{\nu}_R^c$$

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

$$\left( \begin{array}{l} y_\nu : \text{neutrino Yukawa coupling} \\ m_\nu : \text{neutrino mass} \end{array} \right)$$

- Soft SUSY breaking terms

$$\mathcal{L}_{\text{soft}} = -M_{\tilde{L}}^2 \tilde{L}^\dagger \tilde{L} - m_{\tilde{\nu}_R}^2 \tilde{\nu}_R^* \tilde{\nu}_R + (A_\nu H_u \tilde{L} \tilde{\nu}_R^c + \text{h.c.}) + \dots$$

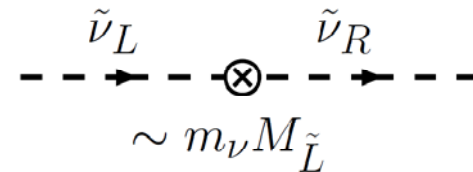
Assumptions :

- Three right-handed sneutrino masses are degenerate

- $A_\nu$  is parametrized as

$$A_\nu = a_\nu y_\nu M_{\tilde{L}} \quad \text{where} \quad a_\nu \sim \mathcal{O}(1)$$

→  $\tilde{\nu}_L$ - $\tilde{\nu}_R$  mixing term



- Mass spectrum

$$m_{\tilde{B}} > m_{\tilde{\nu}_R} > m_{3/2}$$

→ gravitino as LSP,  
 right-handed sneutrino as NLSP,  
 and bino as NNLSP(MSSM-LSP)

### 3. Cosmological constraints

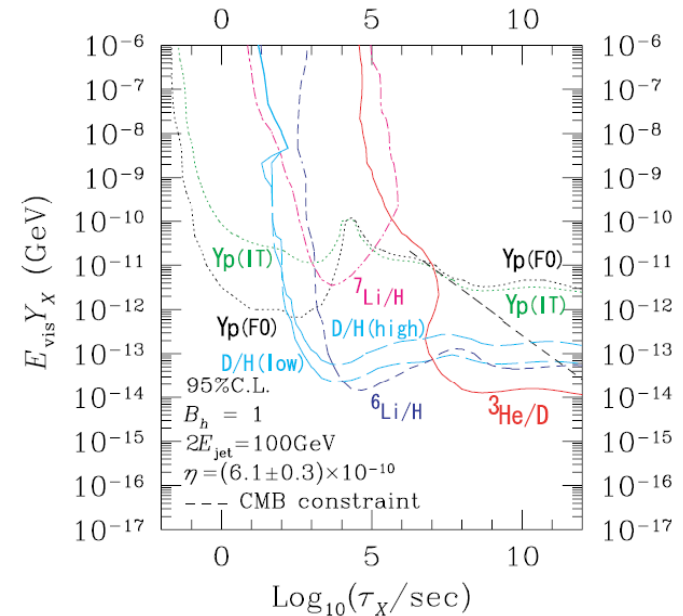
BBN constraints [ M.Kawasaki, K.Kohri, T.Moroi (2005) ]

Upper bound of  $Y_X E_{\text{vis}}$  as a function of  $\tau_X$

$Y_X$  : yield variable of particle  $X$

$E_{\text{vis}}$  : mean energy of hadrons emitted

$\tau_X$  : lifetime of particle  $X$



- Calculating  $B_{\text{had}} Y_{\tilde{B}} E_{\text{vis}}$  and  $\tau_{\tilde{B}}$  and search for allowed parameter region
- Here,  $Y_{\tilde{B}}$  is given by assuming  $\Omega_{\tilde{B}} h^2 \sim 0.1 \left[ \frac{m_{\tilde{B}}}{100 \text{ GeV}} \right]^2$   
[ J.L.Feng, S.Su, F.Takayama (2005) ]

## Bino decay

- After freezing out, bino decays to right-handed sneutrino or gravitino :

$$\tilde{B} \rightarrow \tilde{\nu}_R \bar{\nu}_L, \text{ or } \tilde{B} \rightarrow \psi_\mu \gamma/Z$$

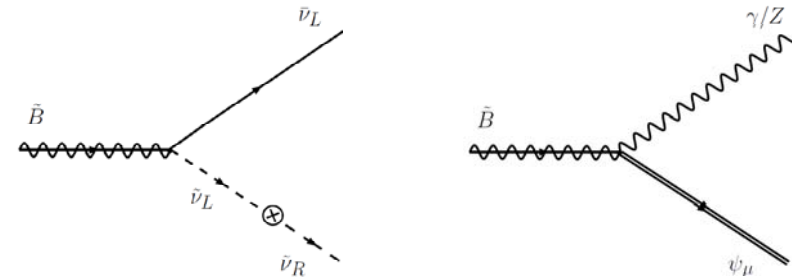
The former mode competes with the latter one or dominates in total decay

- Bino is long-lived :  $\tau_{\tilde{B}} \sim 10^2$  sec

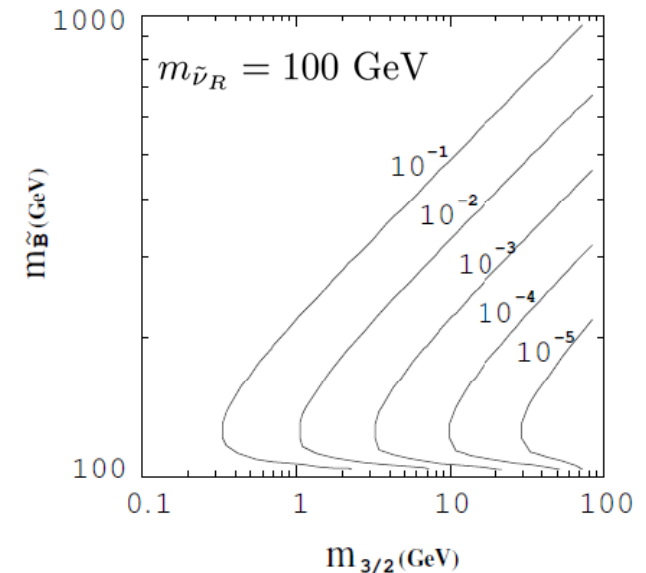
( Cf.) Without  $\tilde{\nu}_R$  ,  $\tilde{B} \rightarrow \psi_\mu \gamma/Z$  dominates in total decay to emit many hadrons and  $m_{3/2}$  is strictly constrained from BBN

→ Although bino is long-lived, less hadrons are emitted in its decay compared to no  $\tilde{\nu}_R$  case

→ Thus constraints from BBN is relaxed



$B(\tilde{B} \rightarrow \psi_\mu \gamma)$  Contour plot



No hadrons are produced in two-body decays  
 In order to calculate  $B_{\text{had}}$  and  $E_{\text{vis}}$ , we consider

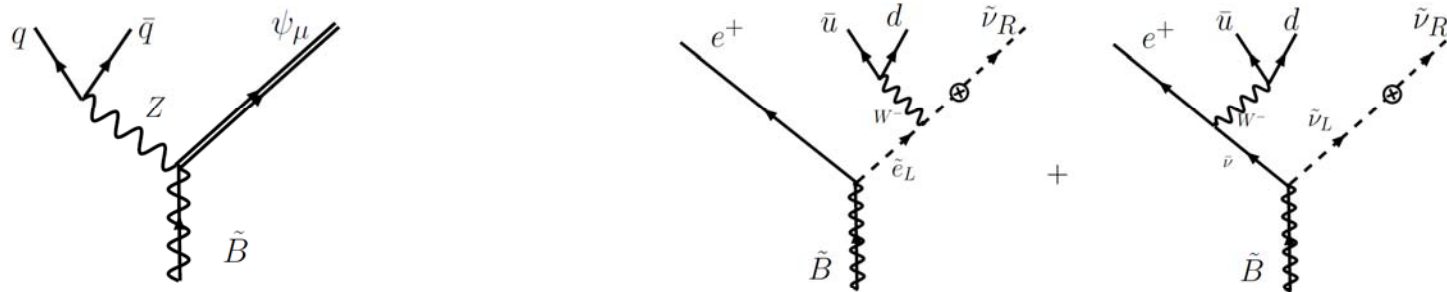
- Three- or four- body decays to produce hadrons :

$$\tilde{B} \rightarrow \psi_{\mu} q \bar{q}$$

$$\tilde{B} \rightarrow \tilde{\nu}_R e_L^+ q \bar{q}'$$

$$\tilde{B} \rightarrow \tilde{\nu}_R \bar{\nu}_L q \bar{q}$$

(and CP conjugate final states for last two)





## Results (from BBN constraints)

Constraints from BBN scenario is drastically relaxed

$$\rightarrow m_{3/2} < 100 \text{ GeV}$$

For a new allowed region,

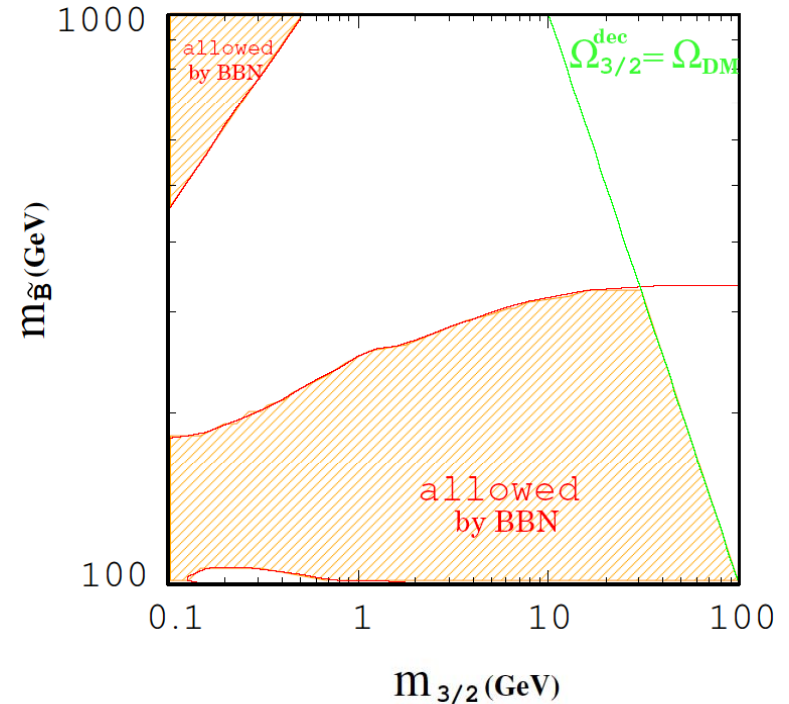
- Upper bound of  $m_{\tilde{B}}$  (given by BBN constraints)

Mainly comes from four-body decay modes,

$$\tilde{B} \rightarrow \tilde{\nu}_R e_L^+ q \bar{q}', \tilde{B} \rightarrow \tilde{\nu}_R \bar{\nu}_L q \bar{q}$$

Large  $m_{\tilde{B}}$  region is excluded because  $B_{\text{had}}, E_{\text{vis}}$  are enhanced

- $\Omega_{3/2}^{\text{dec}} < \Omega_{\text{DM}}$  (not to overclose universe)



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

## Constraints from structure formation

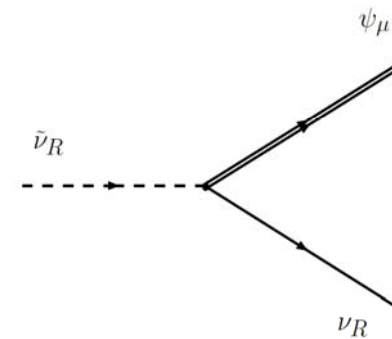
### Right-handed sneutrino decay

- Right-handed sneutrino is long-lived :

$$\tau_{\tilde{\nu}_R} \sim 10^{5-8} \text{ sec}$$

- Emitted gravitino is relativistic :

$$\lambda_{\text{FS}} \sim 6 \text{ Mpc}$$



→ **Emitted gravitino acts as warm dark matter**

On the other hand, gravitino is also produced by thermal scattering processes and acts as cold dark matter

→ **We consider constraints on WDM+CDM scenario from structure formation**

## WDM+CDM scenario

$$\rho_{3/2} = \rho_{3/2}^{\text{dec}} + \rho_{3/2}^{\text{th}}$$

$$\left[ \begin{array}{l} \rho_{3/2}^{\text{dec}}, \rho_{3/2}^{\text{th}} : \text{energy density of gravitino produced by decays, or} \\ \text{by thermal scattering respectively} \end{array} \right]$$

A step-like decrease in power spectrum where

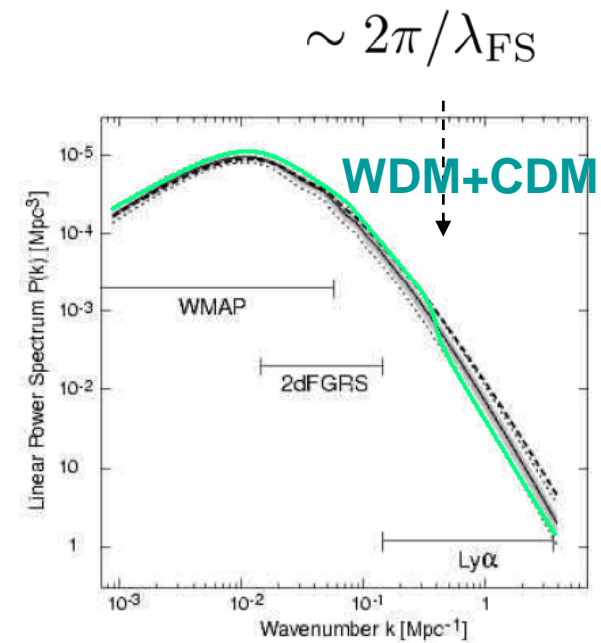
$$k \sim 2\pi/\lambda_{\text{FS}}$$

( ∴ Only power spectrum of WDM component dumps )

In a condition that power spectrum is in 95% C.L. region of observation data,

$$f \lesssim 0.4 \quad (f \equiv \rho_{3/2}^{\text{dec}}/\rho_{3/2})$$

$$\longrightarrow \Omega_{3/2}^{\text{dec}} \lesssim 0.4\Omega_{\text{DM}}$$



[ D.N.Spergel (2003) ]

## Results

(including constraints from structure formation)

Parameter region allowed by BBN is cut a little bit as

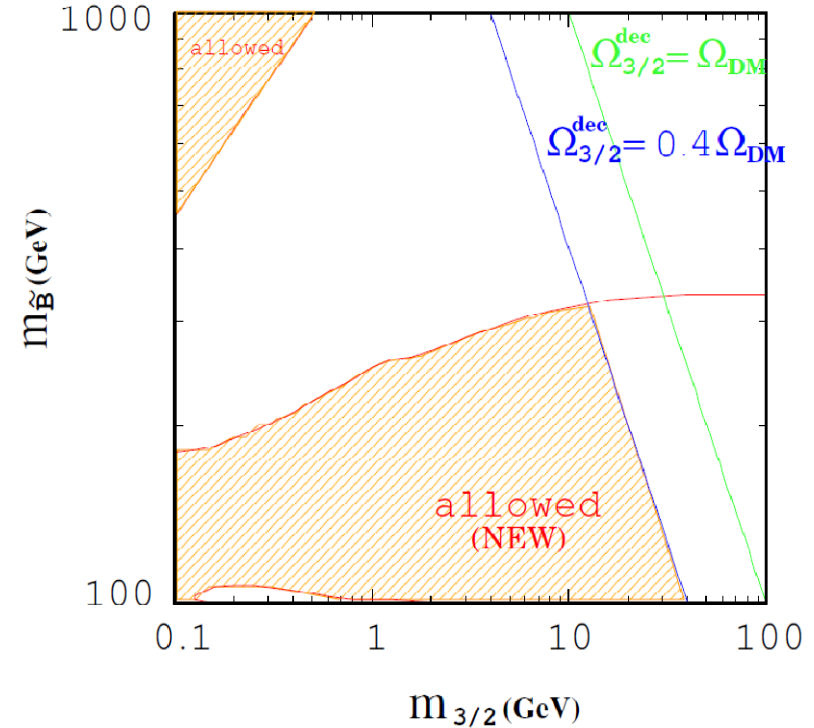
$$m_{3/2} \lesssim 40 \text{ GeV}$$

For a new allowed region,

- $\Omega_{3/2}^{\text{dec}} < 0.4\Omega_{\text{DM}}$  (from structure formation)

$$\left( \begin{array}{l} \Omega_{3/2}^{\text{dec}} = \frac{m_{3/2}}{m_{\tilde{B}}} \Omega_{\tilde{B}} \text{ with } \Omega_{\tilde{B}} h^2 \sim 0.1 \left[ \frac{m_{\tilde{B}}}{100 \text{ GeV}} \right]^2 \\ \Omega_{\text{DM}} h^2 \simeq 0.105 \text{ [ D. N. Spergel (2006) ]} \end{array} \right.$$

$$\rightarrow m_{\tilde{B}} m_{3/2} < 0.4 \times 10^4 \text{ GeV}^2$$



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

## 4. Conclusion

Model :

MSSM with right-handed (s)neutrinos  
where neutrino masses are *purely Dirac type*

Gravitino LSP scenario with right-handed sneutrino NLSP

- bino as NNLSP case ( $m_{\tilde{B}} > m_{\tilde{\nu}_R} > m_{3/2}$ ) -

### Cosmological constraints

- Bino decay mode  $\tilde{B} \rightarrow \tilde{\nu}_R \bar{\nu}_L$  competes  $\tilde{B} \rightarrow \psi_\mu \gamma / Z$  or dominates in total decay  
Less hadrons are emitted than in no right-handed sneutrino case

→ Constraints from BBN is drastically relaxed as

$$m_{3/2} \lesssim 40 \text{ GeV} \quad \left[ \text{Cf.) } m_{3/2} \lesssim 0.1 \text{ GeV} \text{ without } \tilde{\nu}_R \right]$$

- Upper bound of  $m_{3/2}$  is given by constraints from structure formation