Cosmology of Gravitino LSP scenario with Right-handed Sneutrino NLSP

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Existence of the Right-handed sneutrino NLSP changes usual Gravitino LSP scenario. Constraints from the BBN is relaxed.

→ New parameter region, $m_{3/2} < 40$ GeV is allowed!

SUSY Dark Matter

Supersymmetric Model

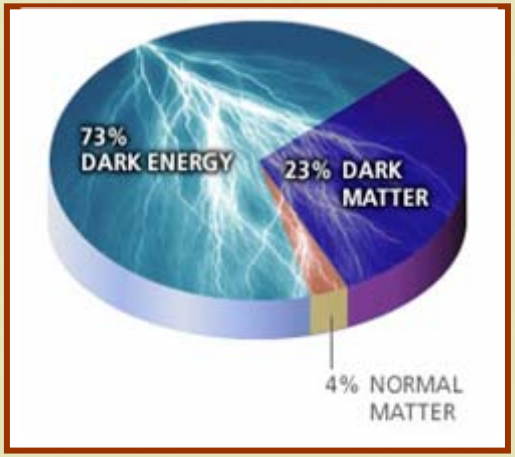
1. most attractive scenario for physics beyond the SM.
2. analyzed in detail from cosmological point of view.

Supersymmetric Dark Matter

LSP is a candidate for dark matter if R-parity is conserved.

What is the LSP?

1. Neutralino
2. Gravitino
3. Axino
4. …



We consider the Gravitino LSP scenario!

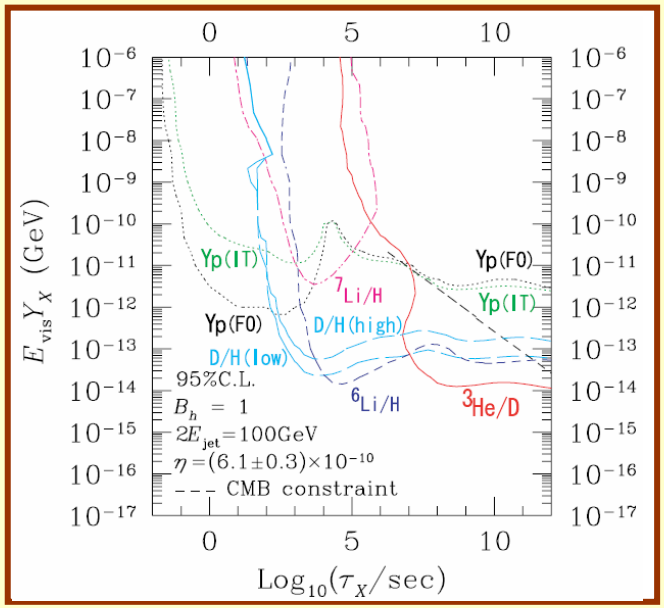
Usual Gravitino LSP scenario

Gravitino mass is strictly constrained from the BBN!

Thermally produced NLSP decays into Gravitino at late universe.
Emitting SM particles spoil successful BBN scenario.

$$\tilde{B} \Rightarrow \psi_\mu + \gamma / Z$$

$\tau \sim 10^6\ \mathrm{s}\ (m_{3/2}/10\ \mathrm{GeV})^2$



[Kawasaki, Kohri, Moroi (2005)]

$$m_{3/2} \lesssim 0.1\ \mathrm{GeV}$$

[J. Feng, S.Su, F.Takayama (2005)]

Existence of Right-handed Sneutrino NLSP with $m_{\tilde{B}} > m_{\tilde{\nu}_R} > m_{3/2}$
BBN constraint is drastically relaxed!

A new parameter region

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

Gravitino LSP with R-Sneutrino NLSP

Model example:

Supersymmetric model with right-handed neutrinos where neutrino masses are *purely Dirac type*.

$$W = W_{\rm MSSM} + y_\nu \hat{H}_u \hat{L} \hat{\nu}^c_R$$

$$\mathcal{L}_{\rm soft} = -M^2_{\tilde{L}} \tilde{L}^\dagger \tilde{L} - m^2_{\tilde{\nu}_R} \tilde{\nu}^*_R \tilde{\nu}_R + (A_\nu H_u \tilde{L} \tilde{\nu}^c_R + \text{h.c.}) + \cdots$$

Assumptions :

- Three right-handed sneutrino masses are degenerate
- A_ν is parametrized as $A_\nu = a_\nu y_\nu M_{\tilde{L}}$ with $a_\nu \sim \mathcal{O}(1)$
- $y_\nu \sin\beta = 3.0 \times 10^{-13} \times \left(\frac{m^2_\nu}{2.8 \times 10^{-3}\ \text{eV}^2} \right)^{1/2}$

Mass spectrum, $m_{\tilde{B}} > m_{\tilde{\nu}_R} > m_{3/2}$, is realized.

- Can be relatively light among super-particles (no EW scale corrections for its mass)
- Never thermalized due to small neutrino Yukawa coupling

Cosmology of the scenario

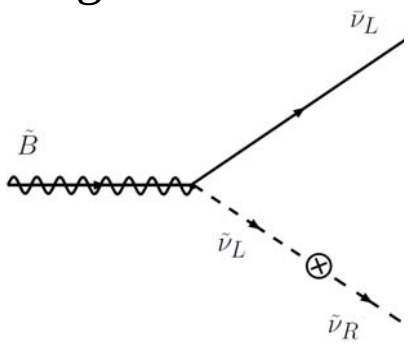
Gravitino LSP, R-Sneutrino NLSP, Bino-like neutralino NNLSP.

$\tilde{B} \Rightarrow \tilde{\nu}_R + \nu_L \Rightarrow \psi_\mu + \nu_R$

$\tau \sim 10^2$ s $\qquad \tau \sim 10^6$ s $(m_{3/2}/10\ \mathrm{GeV})^2$

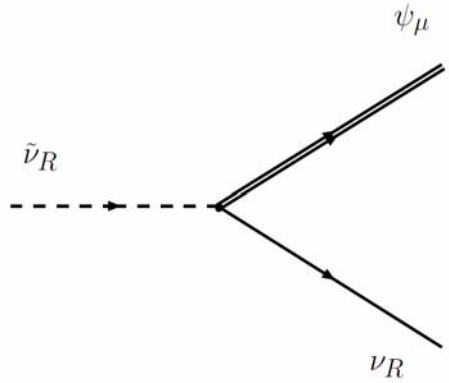
Bino decay

After freezing out, Bino-line neutralino decays into Right-handed Sneutrino.



R-Sneutrino decay

Although the life time is much longer than 1 sec., no visible (charged or colored) particles are emitted in this process.



Constraints on the scenario

Gravitino LSP, R-Sneutrino NLSP, Bino-like neutralino NNLSP.

$\tilde{B} \rightarrow \tilde{\nu}_R + \nu_L \rightarrow \psi_\mu + \nu_R$

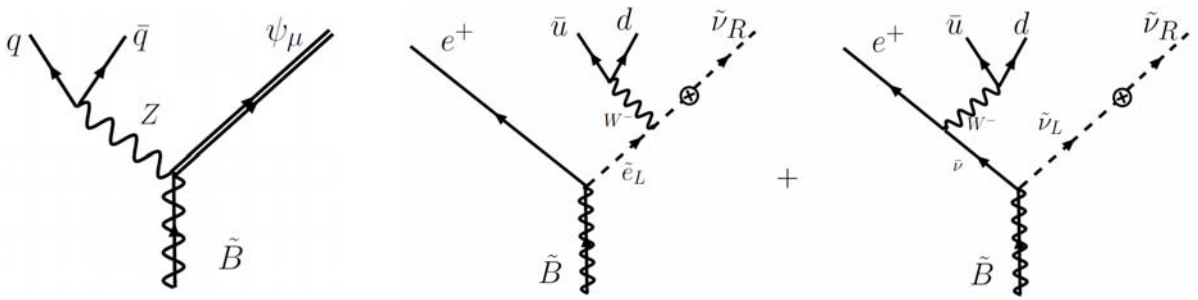
$\tau \sim 10^2$ s $\qquad\qquad$ $\tau \sim 10^6$ s $(m_{3/2}/10\ \text{GeV})^2$

This decay is slightly constrained by the BBN due to sub-leading processes.

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

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

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



Three- or four- body decays to produce hadrons

Constraints on the scenario

Gravitino LSP, R-Sneutrino NLSP, Bino-like neutralino NNLSP.

$\tilde{B} \Rightarrow \tilde{\nu}_R + \nu_L \Rightarrow \psi_\mu + \nu_R$

$\tau \sim 10^2$ s $\qquad \tau \sim 10^6$ s $(m_{3/2}/10\ \mathrm{GeV})^2$

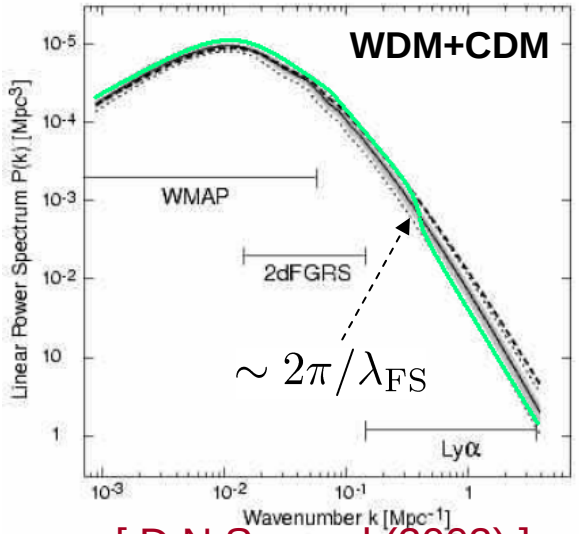
This decay is constrained by the structure formation of our universe.
(Emitted gravitino acts as warm dark matter: lFS ~ 6 Mpc)

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

→ **Constraints on WDM+CDM scenario.**

In order not to distort the power spectrum,

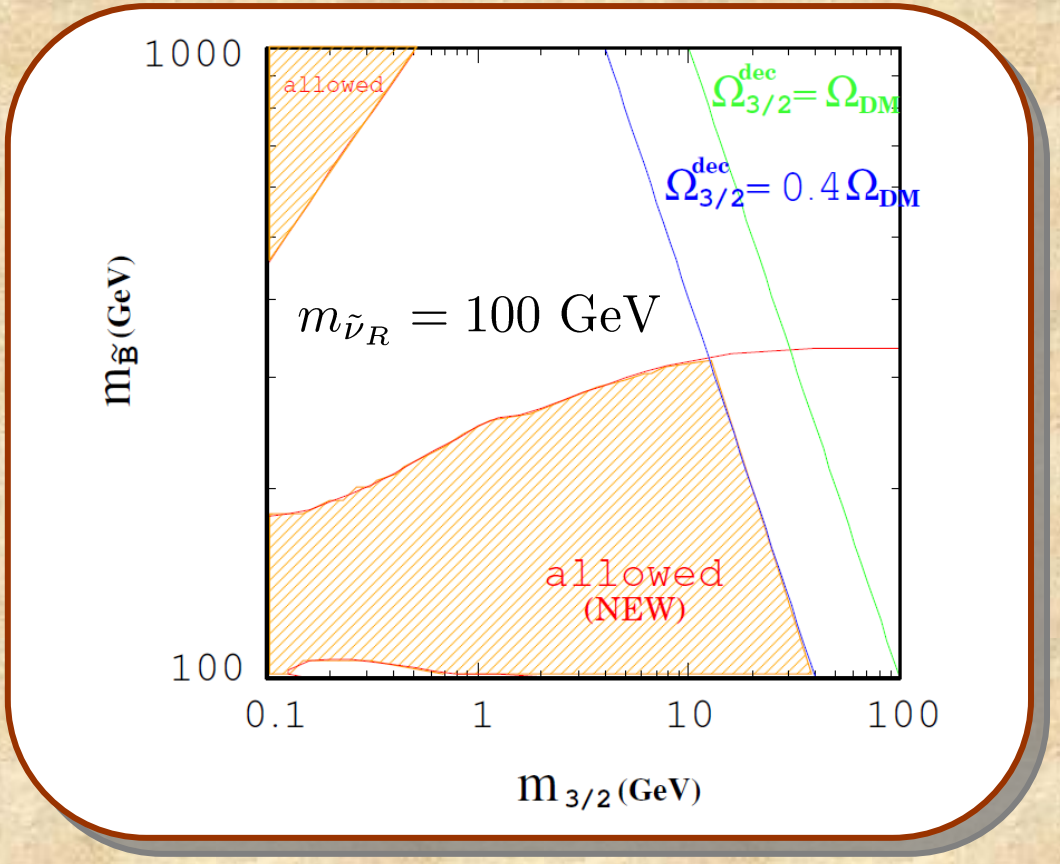
$$\Omega_{3/2}^{\mathrm{dec}} \lesssim 0.4\Omega_{\mathrm{DM}}$$



[D.N.Spergel (2003)]

Constraints on the Gravitino mass

Constraint on the Gravitino mass is drastically relaxed!



NEW allowed region: $m_{3/2} \lesssim 40$ GeV (Cf.) $m_{3/2} \lesssim 0.1$ GeV without $\tilde{\nu}_R$)

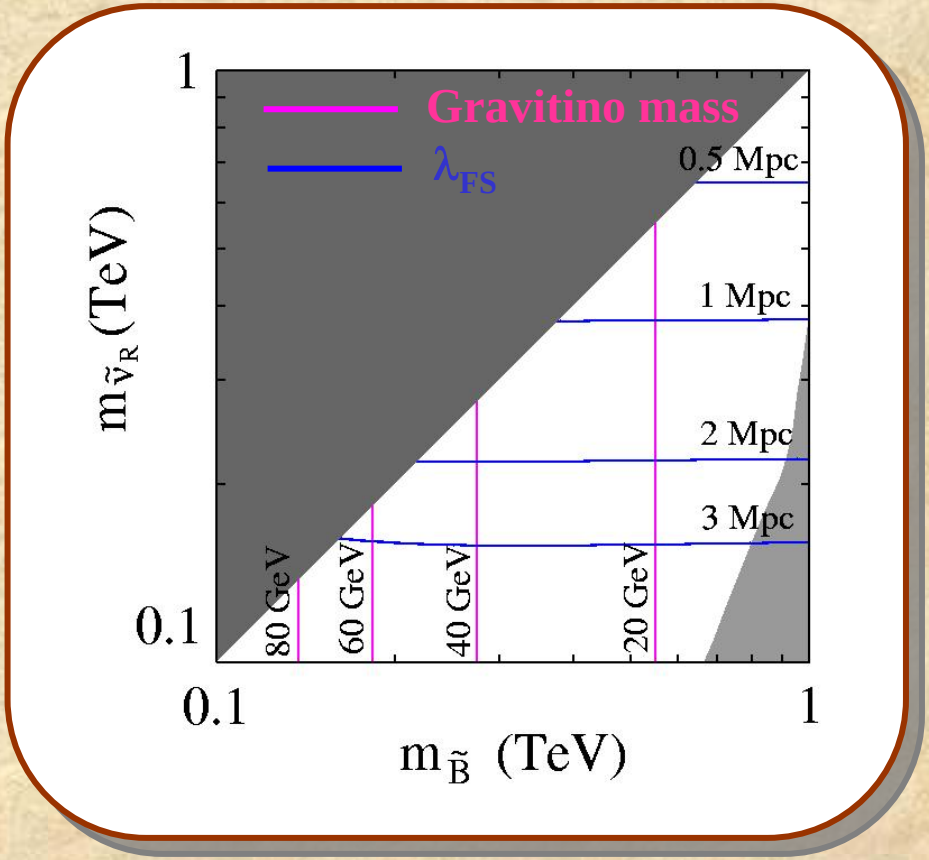
SuperWIMP scenario

In this model

It is possible to construct the SuperWIMP scenario, even if the LSP in the MSSM sector is Neutralino!!

In the SuperWIMP scenario:
It is postulated that the all dark matter (gravitino) abundance is coming from the decay of the LSP in the MSSM sector.

(Without the Right-handed Sneutrino, the SuperWIMP scenario is strongly constrained by the BBN.)



There is a parameter region consistent with BBN and structure formation.

Conclusion

1. Constraint on the mass of the Gravitino Dark Matter is drastically relaxed when the Right-handed Sneutrino NLSP exists.

2. For example, in the case of the Bino-like neutralino NNLSP, the constraint is $m_{3/2} < 40$ GeV. [Cf.) $m_{3/2} < 0.1$ GeV without the R-Sneutrino]

3. This scenario also allow us to construct the Super-WIMP scenario, even if the LSP in the MSSM sector is Neutralino.