

# Strong CP problem reconciles Thermal Leptogenesis with Gravitino Dark Matter

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# Matter and Dark Matter

- 1) Thermal Leptogenesis as origin of matter  $\rightarrow$  no additional ingredients beyond see-saw mechanism
  - 2) Gravitino Dark Matter:  $\Psi_{3/2}$  inevitable prediction of any local supersymmetric theory  $\rightarrow \Omega_{3/2} = \Omega_{\text{DM}}$  turns gravitino decay problem into a virtue
- 1+2)  $\Omega_{3/2}^{\text{tp}}(T_{\text{R}} \sim M_{\nu_{\text{R}}^1}^{\text{min}} \sim 10^9 \text{ GeV}) = \Omega_{\text{DM}}$   
 with  $M_{\tilde{g}}(m_{\text{Z}}) \approx 1 \text{ TeV}$  and  $m_{3/2} = \mathcal{O}(100 \text{ GeV})$  such that  
 $\tau_{\text{nlsp}}^{\dagger} \gg 1 \text{ s} \sim t_{\text{BBN}}$  called **NLSP decay problem**
- $\Rightarrow$  Upper bound on energy released by particle decays after  $t_{\text{BBN}}$

Way out: Entropy production after NLSP freeze-out?

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$\dagger \tau_{\text{nlsp}} \propto M_{\text{pl}}^2 m_{3/2}^2 / m_{\text{nlsp}}^5$

## Entropy Production in Particle Decays after NLSP freeze-out

- overcome BBN bounds by small enough density prior its decay  $\Omega_{\text{nlsp}}$
- NLSP freeze-out density  $\Omega_{\text{nlsp}}^{\text{fo}}$  reduced by dilution factor  $\Delta$

$$\Omega_{\text{nlsp}} = \Delta^{-1} \Omega_{\text{nlsp}}^{\text{fo}}$$

- many extensions of Standard Model predict late-decaying particles
- intrinsic upper bound on  $\Delta$  from leptogenesis

$$\Delta < 10^3 \dots 10^4$$

- maximal  $\Delta$  for matter domination after NLSP freeze-out

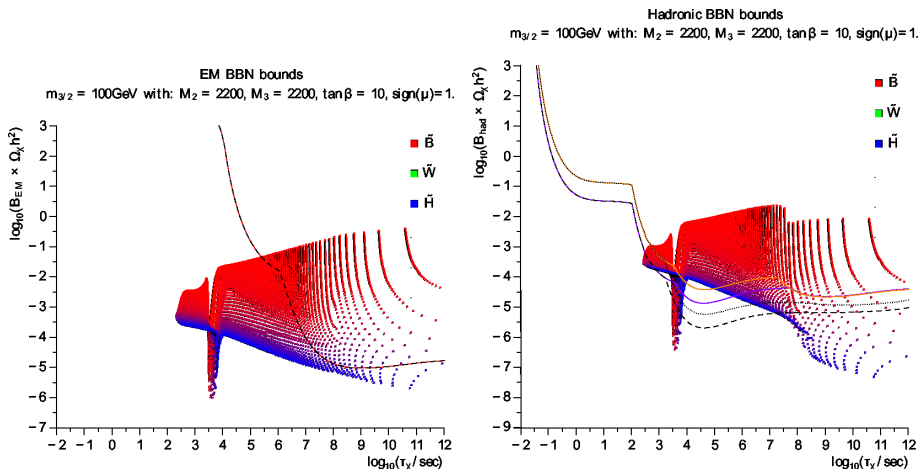
$$\Delta \simeq 0.75 \times 10^3 \left( \frac{m_{\text{nlsp}}}{100 \text{ GeV}} \right) \left( \frac{4 \text{ MeV}}{T_{\text{min}}^{\text{dec}}} \right)$$

- light wino and Higgsino pass BBN bounds allowing  $m_{3/2} = 100 \text{ GeV}$ , but not bino.\*

Easiest case sufficient

\*  $\tilde{\tau}$  by [Buchmüller et al., 06] and [Pradler, Steffen, 07]

# BBN exclusion plots in the plane $B_i \times \Omega_\chi h^2$ vs. $\tau_\chi$ with $\Delta = 10^3$



same for bino-wino, wino-Higgsino

details & smaller  $m_{3/2}$  in [Covi, JH, Roberts, Pokorski, 09], BBN bounds from [Jedamzik, 06]

Requirements on entropy-producing particle  $\phi$  to dilute the NLSP

No.	Requirement	Comment
i	$\tau_\phi > t_{\text{nlsp}}^{\text{fo}}$	to have effect on $\Omega_{\text{nlsp}}$
ii	$\tau_\phi < t_{\text{BBN}}$	not to spoil BBN
iii	$\frac{\rho_\phi}{\rho_{\text{rad}}}(\tau_\phi) > 1$	$\mathcal{O}(10) < \Delta < 10^4$
iv	$\frac{\rho_\phi}{\rho_{\text{rad}}}(t_{\text{nlsp}}^{\text{fo}}) < 1$	for standard NLSP freeze-out
v	$B_{\phi \rightarrow \text{nlsp} + \dots} \approx 0$	from NLSP decay problem
vi	$B_{\phi \rightarrow \Psi_{3/2} + \dots} \approx 0$	from overproduction ( $\Omega_{3/2}^{\text{tp}} \simeq \Omega_{\text{DM}}$ )
vii	e.g. $\tau_{3/2} \gg t_0$	compatibility with gravitino dark matter
viii	ii) and v)-vii)	for by-products. No new problems.

Severe constraints

indeed already without particular interest in entropy production

## Example for an extension of the Standard Model

- Strong CP problem: fine-tuning problem of the Standard Model
- standard solution (PQ mechanism) introduces axion  $a \xrightarrow{susy} \{a, \phi_{\text{sax}}, \tilde{a}\}$
- $\phi_{\text{sax}}$  and  $\tilde{a}$  typical late-decaying particles with interactions suppressed by  $f_a \gtrsim 6 \times 10^8 \text{ GeV}$  (observational bound)
- example scenario with maximal  $\Delta$ :  
 $f_a = 10^{10} \text{ GeV}$ ,  $m_{\tilde{a}} \geq 1.2 \text{ TeV}$ ,  $\phi_{\text{sax}}^i \sim \sqrt{f_a M_{\text{pl}}}$ ,  $m_{\text{sax}} = 8.4 \text{ GeV}$   
 smaller  $f_a$  and larger  $m_{\text{sax}}$  giving smaller  $\Delta$  allowed as well
- while standard scenario ( $\Delta = 1$ ) requires:  
 $f_a \lesssim 10^{10} \text{ GeV}$ ,  $m_{\tilde{a}} \geq 1.2 \text{ TeV}$ ,  $\phi_{\text{sax}}^i \sim f_a$ ,  $m_{\text{sax}} \geq 1.2 \text{ TeV}$

Saxion  $\phi_{\text{sax}}$  can make it

## Conclusions

- i)  $\Delta > 1$  can help to reconcile thermal leptogenesis with gravitino dark matter
- ii)  $\Delta \sim 10^3$  reconciles both in the case of wino ( $\Delta_{\tilde{W}^0}^{\min} = 25$ ) and Higgsino ( $\Delta_{\tilde{H}^0}^{\min} = 90$ ), but not for bino NLSP.
- iii) Severe constraints on entropy-producing particle  $\rightarrow$  generic for late-decaying particle
- iv) Saxion produced in coherent oscillations can make it  $\rightarrow$  restrictions in any case

The potentially dangerous saxion decays can turn out as a fortune, solving the a priori unrelated gravitino problem.

# Thank you for your attention!

Hopefully, there are comments/questions?