Strong CP problem reconciles Thermal Leptogenesis with Gravitino Dark Matter

Jasper Hasenkamp (Hamburg U.)

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Cosmology meets Particle Physics

University of Hamburg

Universität Hamburg

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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 $\rightarrow \Omega_{3/2} = \Omega_{\mathrm{DM}}$ turns gravitino decay problem into a virtue

1+2) $\Omega^{\mathrm{tp}}_{3/2}(T_{\mathrm{R}} \sim M^{\mathrm{min}}_{\nu^1_{\mathrm{R}}} \sim 10^9\ \mathrm{GeV}) = \Omega_{\mathrm{DM}}$
with $M_{\widetilde{g}}(m_{\mathrm{Z}}) \approx 1$ TeV and $m_{3/2} = \mathcal{O}(100\ \mathrm{GeV})$ such that $\tau_{\mathrm{nlsp}}{}^{\dagger} \gg 1\ \mathrm{s} \sim t_{\mathrm{BBN}}$ called **NLSP decay problem**

$\Rightarrow$ Upper bound on energy released by particle decays after t_{BBN}

Way out: Entropy production after NLSP freeze-out?

† $\tau_{\mathrm{nlsp}} \propto M^2_{\mathrm{pl}} m^2_{3/2} / m^5_{\mathrm{nlsp}}$

Entropy Production in Particle Decays after NLSP freeze-out

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

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

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

$$\Delta < 10^3 \ldots 10^4 \qquad \left(M_{\nu_R^1}^{\text{min}\,\prime} = \Delta \cdot M_{\nu_R^1}^{\text{min}} \curvearrowright T_R' = \Delta \cdot T_R \right)$$

- maximal Δ for matter domination after NLSP freeze-out

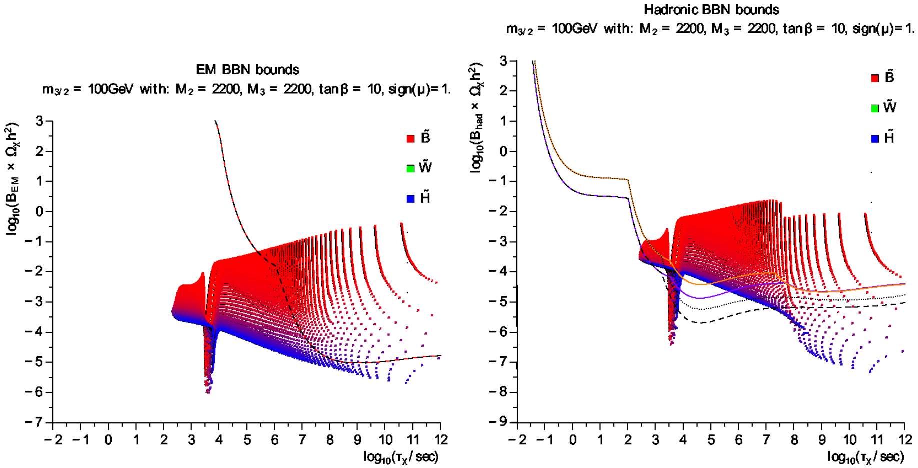
$$\Delta \simeq 0.75 \times 10^3 \left(\frac{m_{\text{nlsp}}}{100\ \text{GeV}} \right) \left(\frac{4\ \text{MeV}}{T_{\text{min}}^{\text{dec}}} \right)$$

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

Easiest case sufficient

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

BBN exclusion plots in the plane $B_i \times \Omega_\chi h^2$ vs. τ_χ 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 ϕ to dilute the NLSP

No.	Requirement	Comment
i	$\tau_\phi > t_{\rm nlsp}^{\rm fo}$	to have effect on $\Omega_{\rm nlsp}$
ii	$\tau_\phi < t_{\rm BBN}$	not to spoil BBN
iii	$\frac{\rho_\phi}{\rho_{\rm rad}}(\tau_\phi) > 1$	$\mathcal{O}(10) < \Delta < 10^4$
iv	$\frac{\rho_\phi}{\rho_{\rm rad}}(t_{\rm nlsp}^{\rm fo}) < 1$	for standard NLSP freeze-out
v	$B_{\phi\to\,{\rm nlsp}\,+\ldots} \approx 0$	from NLSP decay problem
vi	$B_{\phi\to\Psi_{3/2}+\ldots} \approx 0$	from overproduction ($\Omega_{3/2}^{\rm tp} \simeq \Omega_{\rm DM}$)
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

$\longrightarrow$ standard solution (PQ mechanism) introduces axion $a \xrightarrow{susy} \{a,\ \phi_{\rm sax},\ \widetilde{a}\}$

- $\phi_{\rm sax}$ and $\widetilde{a}$ typical late-decaying particles with interactions suppressed by $f_a \gtrsim 6 \times 10^8$ GeV (observational bound)
- example scenario with maximal Δ:
  $f_a = 10^{10}$ GeV, $m_{\widetilde{a}} \geq 1.2$ TeV, $\phi^{\rm i}_{\rm sax} \sim \sqrt{f_a M_{\rm pl}}$, $m_{\rm sax} = 8.4$ GeV
  smaller f_a and larger $m_{\rm sax}$ giving smaller Δ allowed as well
- while standard scenario ($\Delta = 1$) requires:
  $f_a \lesssim 10^{10}$ GeV, $m_{\widetilde{a}} \geq 1.2$ TeV, $\phi^{\rm i}_{\rm sax} \sim f_a$, $m_{\rm sax} \geq 1.2$ TeV

Saxion $\phi_{\rm sax}$ 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 ($\Delta^{\text{min}}_{\widetilde{W}^0} = 25$) and Higgsino ($\Delta^{\text{min}}_{\widetilde{H}^0} = 90$), 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?