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ALP leptogenesis

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Work in collaboration with A. Mariotti, F. Sala, M. Vanvlasselaer

Based on arXiv:[2407.01667](https://arxiv.org/abs/2407.01667)

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ALP leptogenesis

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➔ **Non-thermal leptogenesis** from Majorana right-handed neutrinos produced out-of-equilibrium via **ALP decay**

$$\mathcal{L} \supset -y_\nu \bar{L} \cdot \phi N_R - \frac{1}{2} M_N \bar{N}_R^c N_R + \frac{\partial_\mu a}{f_a} \bar{N}_R \gamma^\mu N_R$$

Type I see-saw



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In a nutshell

➔ **ALP production** via thermal scatterings

freeze-out

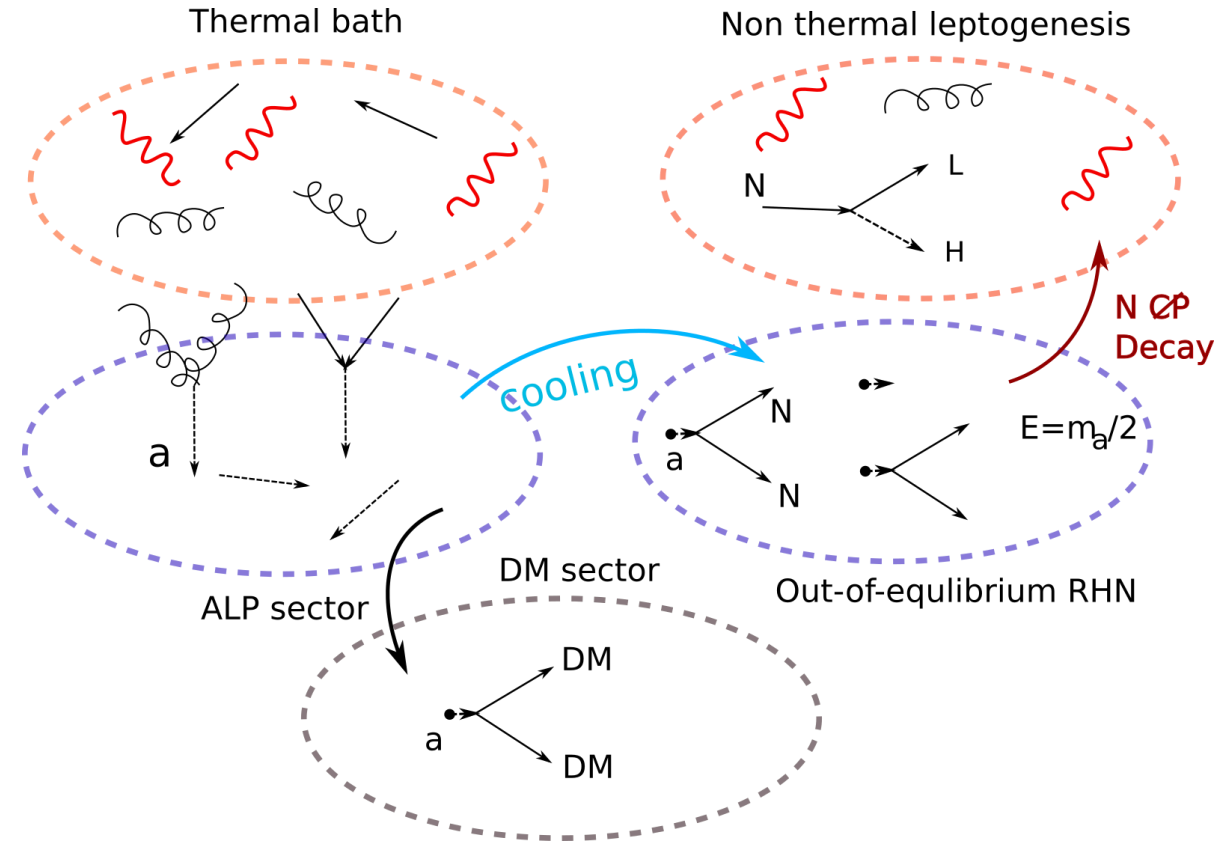
freeze-in

$$Y_a = Y_a^{\text{eq}} \simeq 2.15 \cdot 10^{-3}$$

$$Y_a \ll Y_a^{\text{eq}}$$

➔ **ALP decay** mostly to RHNs

➔ **Non-thermal leptogenesis**



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Available parameter space for successful ALP leptogenesis

$$132 \text{ GeV} \lesssim T_D^a \lesssim \frac{M_N}{20}$$

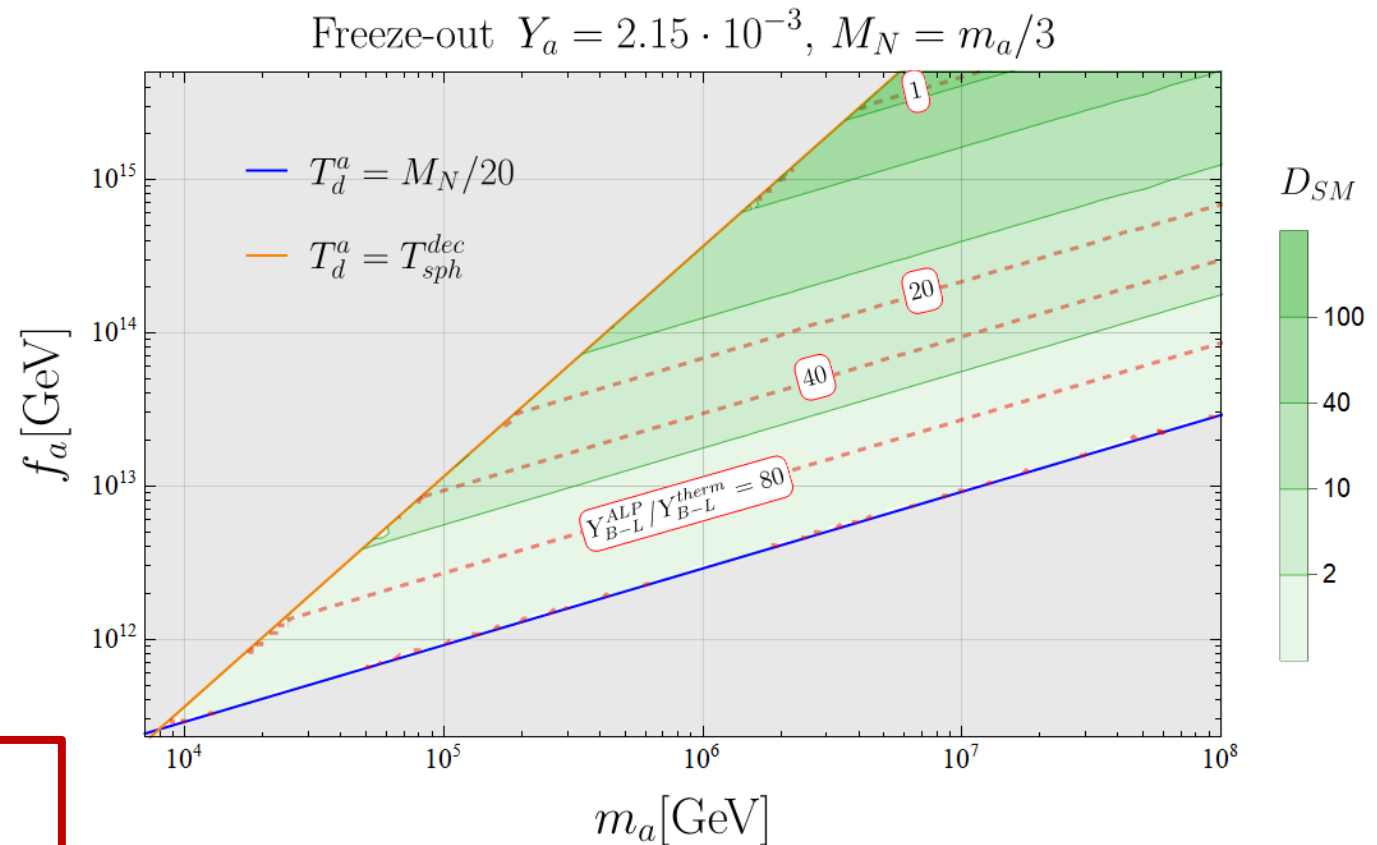
active sphalerons

no strong washout

Baryon asymmetry computed by either solving BEs or analytical parametrization

$$Y_{\Delta B}^{\text{ALP lepto}} \simeq \frac{2Y_a^{\text{initial}} \text{Br}_{a \rightarrow NN} c_{\text{sph}} \epsilon_{\text{CP}}}{D_{\text{SM}}}$$

gain factor of 100 in baryon asymmetry produced



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Summary

- ➔ **Non-thermal leptogenesis** sourced via **ALP decay** into RHNs
- ➔ ALP leptogenesis requires $m_a > 10^4$ GeV and $f_a > 10^{11}$ GeV
- ➔ **More efficient** w.r.t. thermal leptogenesis by a factor **100**

And much more in arXiv:2407.01667

- ★ gain in tuning of mass splittings in resonant regime
- ★ BEs for ALP leptogenesis
- ★ Matter-domination by ALP
- ★ SUSY realization: R-axion and gravitino dark matter



ALP leptogenesis

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Based on work under completion

Summary

Novel realization of non-thermal leptogenesis from decays of sterile (right-handed) neutrinos (RHNs) sourced via axion-like particles (ALPs) decays in the early Universe

Supersymmetric realization where the ALP is the R-axion

Motivation

pseudo Nambu-Goldstone bosons of spontaneously broken global symmetries, present in many BSM scenarios

But, how ALPs could affect baryogenesis?

ALP coupled both to the SM strong sector and RHNs

$$\mathcal{L}_a = \frac{1}{2} \partial_\mu a \partial^\mu a - \frac{m_a^2}{2} a^2 - \frac{c_a}{8\pi} \frac{a}{f_a} G_{\mu\nu}^2 - \frac{c_a}{8\pi} \frac{a}{f_a} \bar{N}_i \gamma^\mu \partial_\mu N_i + \frac{c_a}{8\pi} \frac{a}{f_a} \bar{N}_i \gamma^\mu \partial_\mu N_i$$

Thermal history of ALP

Production: via thermal scatterings with gluons and top quarks in primordial plasma

freeze-out with $Y_a = Y_a^{\text{th}} \approx 2.15 \cdot 10^{-3}$

freeze-in with $Y_a \ll Y_a^{\text{th}}$

Decay: mostly to RHNs via $a \rightarrow N N$

$$\Gamma(a \rightarrow N N) = \frac{m_a M_N^2}{8\pi f_a^2} \sqrt{1 - \frac{M_N^2}{m_a^2}}$$

Non-thermal leptogenesis via ALP decay

Successful leptogenesis for $T_{\text{RH}}^{\text{th}} \lesssim T_2^{\text{th}} \lesssim \frac{M_N}{20}$ with $T_2^{\text{th}} = \frac{M_N}{8\pi} \sqrt{\frac{m_a}{M_N}} \sqrt{1 - \frac{M_N^2}{m_a^2}}$

active spherulons \rightarrow no strong washout

Matter-dominated era induced by ALP dilutes lepton asymmetry Y_{B-L} , due to entropy injection

$$Y_{B-L} = \frac{Y_{B-L}^{\text{th}}}{D_{\text{dil}}}$$
 with dilution factor $D_{\text{dil}} \gtrsim 1.2$

Solving Boltzmann Equations for ALP leptogenesis: baryon asymmetry Yield is enhanced up to factor ~ 100 , thus relaxing the mass tuning splittings of degenerate RHNs in resonant regime by the same factor

SUSY realization: R-axion and gravitino dark matter

SUSY lower energy spectrum populated by SM, R-axion, RHNs and gravitinos, i.e. Lightest Stable Particles with $m_{\text{LSP}} \approx \sqrt{3} M_{\text{pl}}$

Gravitinos produced dominantly via R-axion decay with $\Gamma_{a \rightarrow \tilde{g}} \approx \frac{1}{32\pi} \left(\frac{c_a m_a^2}{f_a^2} \right)$

Cosmological constraints select a small region of parameter space, accommodating GeV dark matter gravitino and inducing successful ALP leptogenesis with RHN mass at $\mathcal{O}(10)$ TeV-scale

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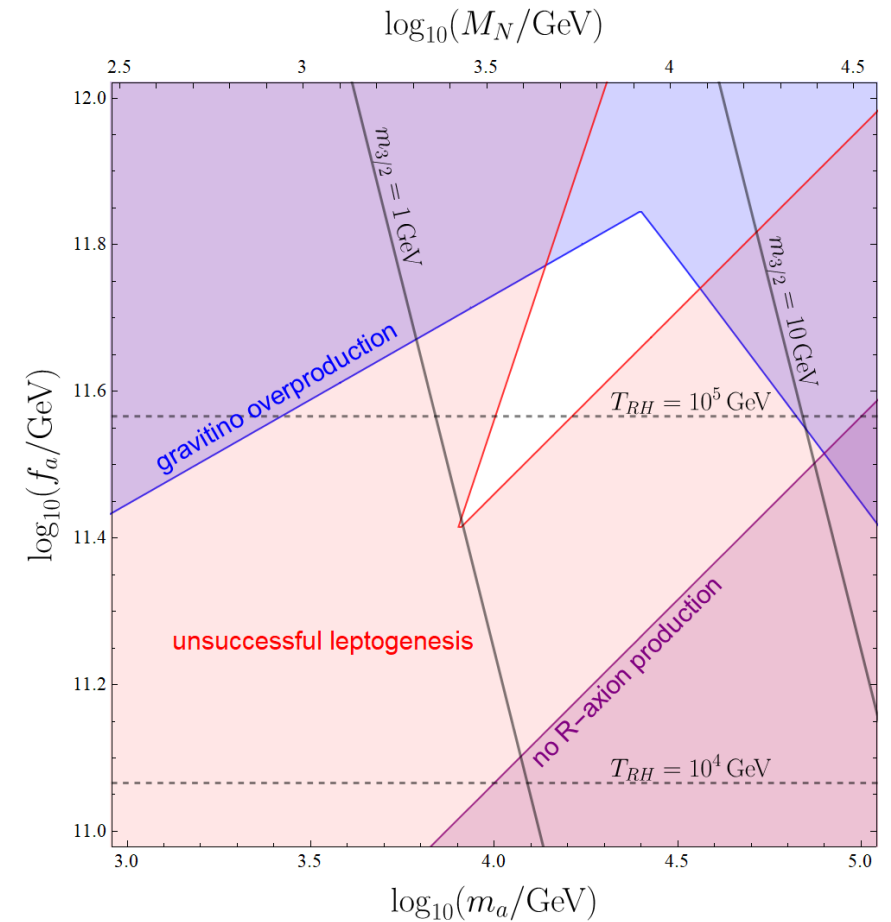
SUSY realization

➔ SUSY lower spectrum populated by SM, RHNs, R-axion and gravitinos

➔ Gravitino production via R-axion decay

$$\Gamma_{a \rightarrow \tilde{G}\tilde{G}} \sim \frac{1}{32\pi} \left(\frac{c^2 m_a^5}{F^2} \right)$$

➔ GeV dark matter gravitino and successful ALP leptogenesis with $O(10)$ TeV RHNs

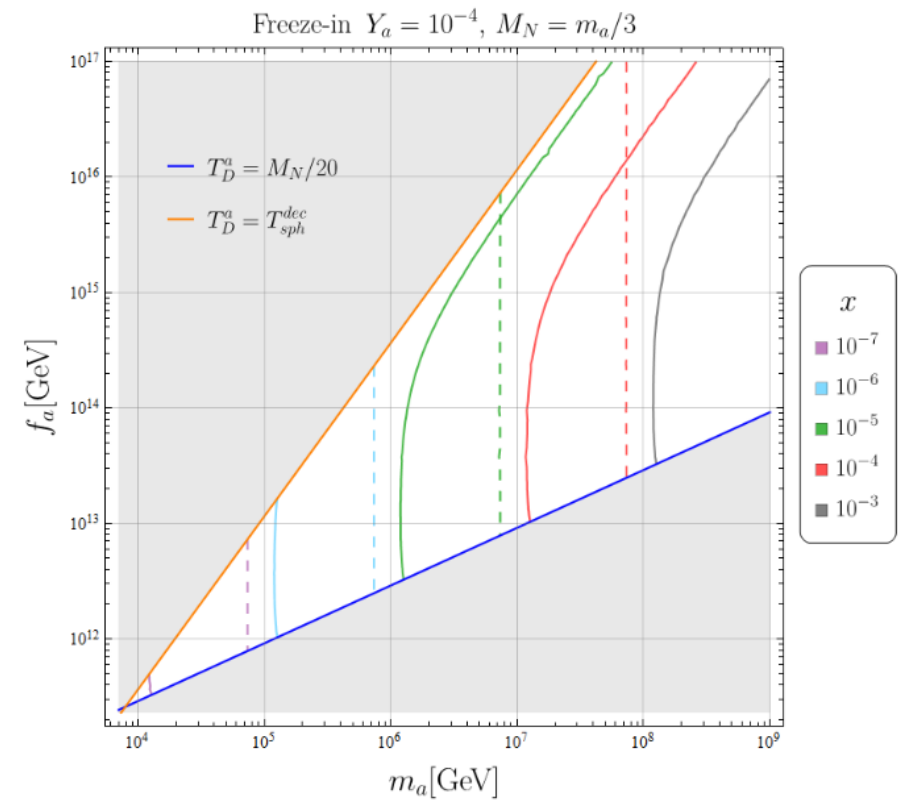
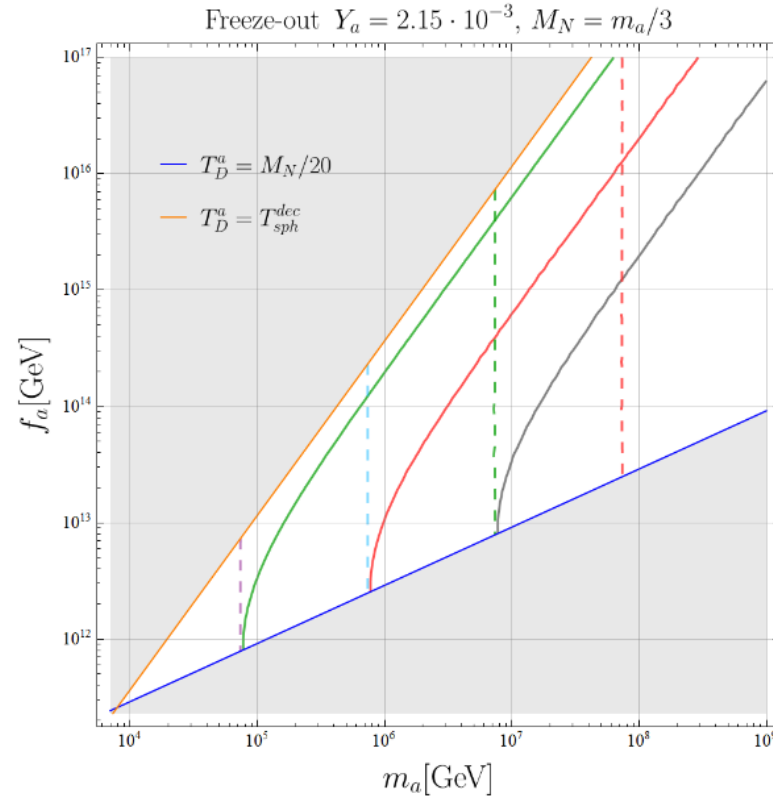


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Mass tuning relaxation

$$x \equiv \frac{M_1^2 - M_2^2}{M_1 M_2}$$



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BEs for ALP leptogenesis

$$\begin{cases} \frac{dY_a}{dz} = -\text{Br}_N \frac{\gamma_a}{Hsz} \frac{Y_a}{Y_a^{\text{eq}}} - \text{Br}_g \frac{\gamma_a}{Hsz} \left(\frac{Y_a}{Y_a^{\text{eq}}} - 1 \right) - \text{Br}_t \frac{\gamma_a}{Hsz} \left(\frac{Y_a}{Y_a^{\text{eq}}} - 1 \right) \\ \frac{dY_N}{dz} = -\frac{\gamma_D}{Hsz} \left(\frac{2M_N}{m_a} \frac{Y_N}{Y_N^{\text{eq}}} - 1 \right) + 2 \frac{\text{Br}_N \gamma_a}{Hsz} \frac{Y_a}{Y_a^{\text{eq}}} \\ \frac{dY_{B-L}}{dz} = \frac{\gamma_D \epsilon}{Hsz} \left(\frac{2M_N}{m_a} \frac{Y_N}{Y_N^{\text{eq}}} - 1 \right) - \frac{\gamma_D}{Hsz} \frac{Y_{B-L}}{2Y_l^{\text{eq}}} \end{cases}$$

