Leptogenesis with Supersymmetric Flat Directions

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with Gian Giudice, Antonio Riotto and Francesco Riva, PLB, [arXiv:0804.0166]

Introduction

- Supersymmetric thermal leptogenesis with hierachical right-handed neutrino mass spectrum requires

$$T_{\rm RH} \gtrsim 10^9\ \text{GeV}$$

- This is in conflict with the BBN gravitino bound

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- This is in conflict with the BBN gravitino bound
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- Possible solutions:
  - Modify assumptions on gravitinos
  - Modify properties of neutrino spectrum
  - Assume non-thermal production by added coupling
- However, possible non-thermal production channel already contained in the framework: SUSY flat directions decaying through instant preheating

Outline

Instant preheating

Flat directions in the early Universe

Leptogenesis from flat directions

Conclusions

Preheating

Consider chaotic inflation $V(\phi) = \frac{1}{2} m^2 \phi^2$

- Suppose coupling $\mathcal{L}_I = -\frac{1}{2} g^2 \phi^2 \chi^2$ to scalar χ

$$\Rightarrow m_\chi^2(t) = m_\chi^2 + g^2 \phi^2(t)$$

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- After inflation ϕ starts oscillating about $\phi = 0$
- For $|\dot{m}_\chi| \gtrsim m_\chi^2(t)$ adiabaticity is violated

$\Rightarrow$ almost instantaneous production of χ particles in small region around $\phi = 0$

Instant preheating

- Suppose now χ couples to another (fermion) field ψ through

$$\mathcal{L}_I = -h\bar{\psi}\psi\chi$$

- $\Gamma(\chi \to \psi\psi) \propto m_\chi \Rightarrow$ as χ gets heavier it becomes more and more unstable, and eventually decays into ψ particles

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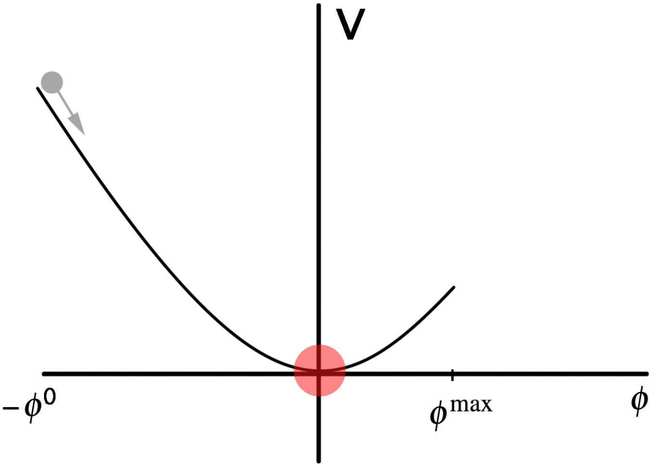
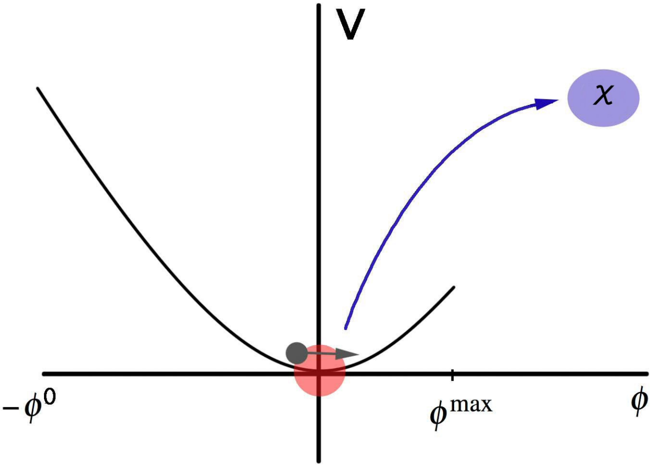
$\Rightarrow$ Instant preheating

- Allows ψ production even for $m_\psi \gg m_\phi$
- Same mechanism works for other scalar fields as well, e.g. SUSY flat directions

Instant preheating



Instant preheating



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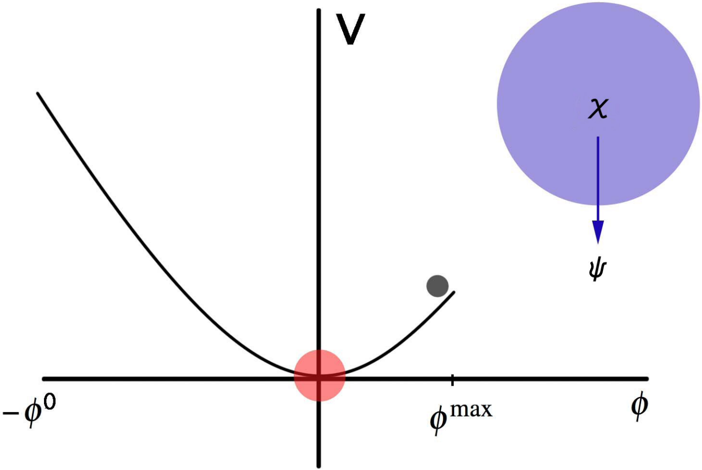

Flat directions in the early Universe

- Directions ϕ in scalar field space with $V = 0$ for exact SUSY
- Potential from SUSY breaking and non-renormalizable terms

$$V(\phi) = (\widetilde{m}^2 - cH^2)|\phi|^2 + \left(\lambda \frac{A + aH}{nM^{n-3}}\phi^n + h.c.\right) + |\lambda|^2 \frac{|\phi|^{2n-2}}{M^{2n-6}}$$

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- During inflation, ϕ obtains large VEV
  when $H \sim \widetilde{m}$, $V''(\phi)$ changes sign $\Rightarrow$ new minimum at $\phi = 0$
- The term $\propto \phi^n$ in general complex $\Rightarrow$ ϕ spirals around origin
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  $\Rightarrow$ no instant preheating (unless several flat directions)
- Consider thus $A \sim 0$ or $W = 0$, so that ϕ passes close enough to the origin for instant preheating to occur

Choice of flat direction

- Goal is to produce right handed neutrinos $\phi \to X \to N_1$

$X = H_U$ couples to N_1 via superpotential term $h_{1j} N_1 \ell_j H_U$
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- Consider flat directions involving u_3, so that the condensate couples to H_U through top Yukawa term $h_t^2 \left|\phi\right|^2 \left|H_U\right|^2$

- Example $\phi = Que$

Leptogenesis

- When ϕ approaches the origin adiabaticity is violated and particles, including H_U are produced
- As ϕ continues its oscillation, H_U increases in mass

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- As ϕ continues its oscillation, H_U increases in mass

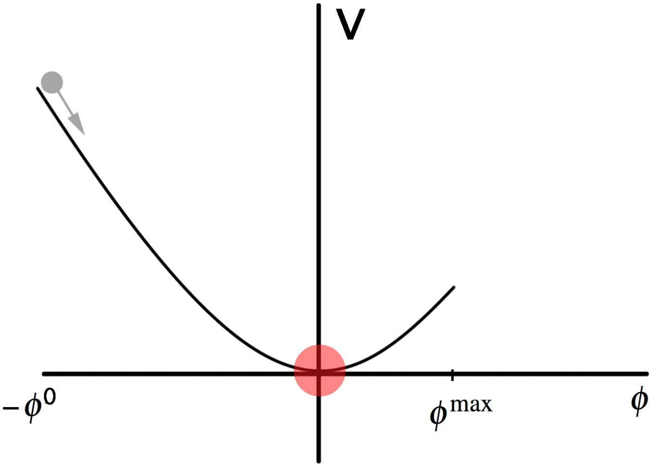
$$m_{H_U}^2 = \widetilde{m}_{H_U}^2 + h_t^2 \, |\phi|^2$$

  and becomes unstable
- Most decay channels of H_U blocked due to large masses from the ϕ VEV, in particular if Q_3 not in the flat direction

  $\Rightarrow H_U$ decays mainly into $N_1 + \ell$

- When $\phi \to 0$ again, m_{H_U} decreases and the produced N_1 can efficiently decay into $H_U + \ell$

Leptogenesis



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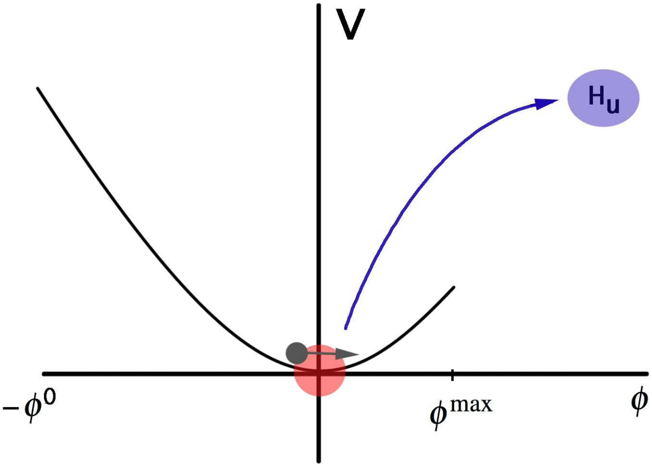

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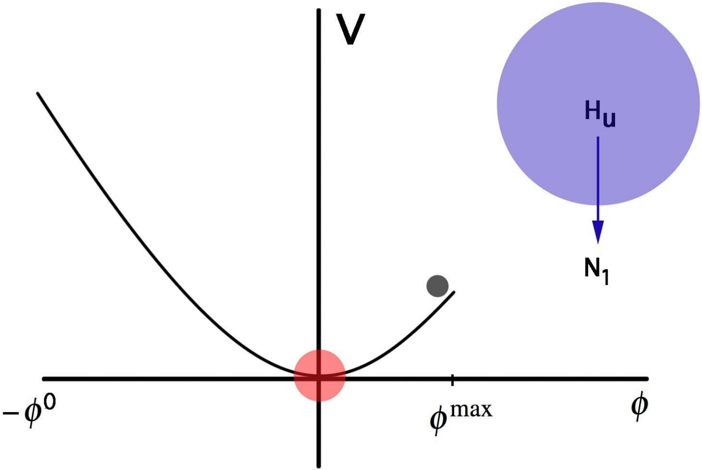

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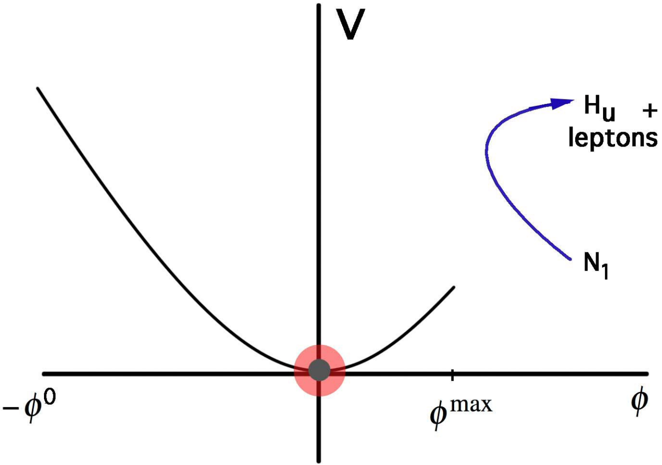

The baryon asymmetry

- Assuming efficient decay $n_{N_1} \sim n_{H_U}$, the resulting baryon asymmetry at reheating becomes

$$Y_B = 10^{-19}\, M_1 \left(\frac{T_{\rm RH}}{10^7\,{\rm GeV}}\right)\left(\frac{|\phi_0|}{M_p}\right)^{3/2}\left(\frac{100\,{\rm GeV}}{\widetilde{m}}\right)^{1/2}$$

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$\Rightarrow$ Observed baryon asymmetry $Y_B \simeq 0.87 \times 10^{-10}$ produced if

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- The maximum produced neutrino mass (for $h_t \sim 0.6$) is

$$M_1^{\rm max} \simeq h_t \phi^{\rm max} = 4 \times 10^{12}\ {\rm GeV}\left(\frac{\phi_0}{M_p}\right)^{\frac{1}{2}}\left(\frac{\widetilde{m}}{100\,{\rm GeV}}\right)^{\frac{1}{2}}$$

Remarks and Conclusion

- Gravitinos produced through scattering of decay products, but never more than during reheating
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The conflict with the gravitino bound in SUSY leptogenesis with hierarchical right-handed neutrino masses can be avoided, BUT

- Requires ϕ_0 close to M_P
- Phase dependent terms in superpotential small or vanishing