Smooth Hybrid Inflation and Non-thermal Type-II Leptogenesis

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27th Sept., 2012 DESY, Hamburg

Overview

- Motivation
- Set up
- Smooth Hybrid Inflation with triplets
- Reheating
- Type-II leptogenesis
- Connection with neutrino mass and mixings
- Conclusions

Motivation

- **Supersymmetric models of inflation**: an attractive class of models for realizing inflation

- **Smooth Hybrid Inflation**: predicts spectral index ~ 0.97

  No topological defects are produced

- Inflation in these models is naturally followed by **leptogenesis**.

  (Non-thermal leptogenesis)

- Non-thermal Type-I leptogenesis (through RH neutrino decay) with SHI is studied before. Here we implement a scenario where Non-thermal Type-II leptogenesis (through Triplet decay) is considered with SHI.

Set up

Supersymmetric version of the gauge group: $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

Role of Higgs triplets involved:

$SU(2)_R$ triplets → Smooth Hybrid Inflation

Decay of Inflaton system → $SU(2)_L$ triplets (Reheating)

Decay of $SU(2)_L$ triplets → produces lepton asymmetry

$SU(2)_L$ Triplets → provides also the neutrino mass

Smooth Hybrid Inflation with $SU(2)_R$ triplet

- **Superpotential** $W = S[(\Delta_R \Delta_R)^2 / M^2_s - M^2_x] +$
  $\alpha_{ab} \Delta_L{}^a \bar{\Delta}_L{}^b \; \bar{\Delta}_R \Delta_R / M_s + \gamma^a HH \bar{\Delta}_L{}^a \bar{\Delta}_R / M_s + f^a{}_1 LL \Delta_L{}^a + f_2 L_C L_C \Delta_R +$
  $Y^l L L_C H + Y^q Q Q_C H$

  (a, b = 1,2) ; for simplicity, we assume $\alpha_{ab} = \delta_{ab} \alpha_a$

- M_x: a superheavy mass scale, M_s = cutoff scale which controls the non-renormalizable terms.

- The term $\Delta_L{}^a \bar{\Delta}_L{}^b$ is forbidden by a Z_2 symmetry , hence $SU(2)_L$ triplets are lighter than RH neutrinos.

charges	S	$\Delta_L{}^a$	$\bar{\Delta}_L{}^a$	Δ_R	Δ_R	H	L	L_C	Q	Q_C
R	2	2	0	0	0	1	0	1	0	1
Z_2	1	1	-1	1	-1	1	1	1	1	1

Smooth Hybrid Inflation contd.

- $\mathbf{W_{inf} = S[(\Delta_R\ \overline{\Delta}_R)^2 / M^2_s - M^2_x]}$

Using the D-flatness condition $|\Delta_R| = |\overline{\Delta}_R|$, $\xi/2 = |\Delta^0_R|$, $\sigma^2 = 2|s|^2$

$$V_{inf} = [\xi^4/16M^2_S - M^2_x]^2 + \sigma^2 \xi^2/16M^4_s$$

- At the end of inflation, it reaches SUSY vacuum $<\Delta_R> = M = (M_x M_s)^{1/2}$
  With $M = M_{GUT} = 2.86 \times 10^{16}$ GeV and number of e-folding ~ 57, in order to produce correct $\delta T/T$, we have $n_s = 0.97$.

- However once supergravity corrections are added, n_s approaches 1. As a remedy, we consider non-minimal Kahler potential,

$$K = |S|^2 + |\Delta_R|^2 + |\overline{\Delta}_R|^2 + \frac{k_s}{4}\frac{|s|^4}{M_P{}^2}$$

- The inflationary potential for $\sigma^2 > M^2$,

$$V = M^4{}_X\left[1 - k_s\frac{\sigma^2}{2M_P{}^2} + (1 - \frac{7}{2}k_s + 2k^2{}_s)\frac{\sigma^4}{8M_P{}^4} - \frac{2}{27}\frac{M^4}{\sigma^4}\right]$$

Smooth hybrid inflation contd.

Then one can achieve, $n_s = 0.968$ with a specific choice of k_s, as in the table.

Set	k_s	n_s	M(GeV)	M_s(GeV)	σ_q(GeV)
I	0	.99	1.2×10^{16}	1.8×10^{17}	1.8×10^{17}
II	0.01	.968	4×10^{16}	1.5×10^{18}	3×10^{17}

Reheating

- Decay of the inflaton into RH neutrinos: Kinematically forbidden ($m_{inf} = 2M^3/M_s^2$ and RH neutrino mass is $M \sim M_{GUT}$)

- Decay will be through: $\alpha_a \Delta_L{}^a \overline{\Delta}_L{}^a \Delta_R \overline{\Delta}_R / M_s$ coupling and hence, inflaton system decays into $SU(2)_L$ triplets only provided ($m_{\Delta L} = \alpha_a M^2/M_s$)

$$\alpha_a \leq \sqrt{2}\,\frac{M}{M_s}$$

- The reheating temperature is then:

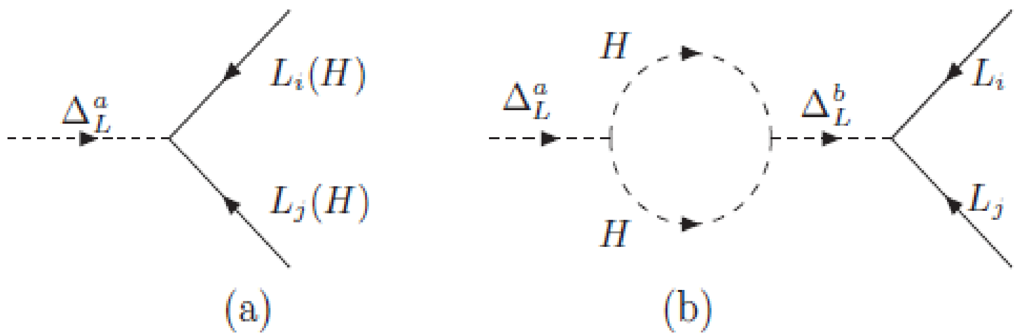
$$T_R = 0.12\,\alpha \left(\frac{M}{M_s}\right)^2 \sqrt{M M_P} \quad , \qquad \alpha = \sqrt{(\alpha_1{}^2 + \alpha_2{}^2)}$$

- From Table we get, $M/M_s \sim 10^{-2}$, thereby $\mathbf{T_R \sim 10^{10\text{-}11}}$ **GeV** (for $\alpha \sim 10^{-3}$).

Consequence: For high reheat temperature, no gravitino problem would be there if gravitino is sufficiently heavy. Although the constraint then may come from LSP decays, however for $m_{3/2} > 60$ TeV, the problem can be evaded for $m_{LSP} \sim 100$ GeV.
[Endo et al, PRD76, 083509 (2007), Gherghetta et al., Nucl Phys B559, 27 (1999)]

Type II Non-thermal leptogenesis

- In general both RH neutrinos and LH triplets can contribute toward lepton asymmetry.
- However, RH neutrinos being superheavy (all with masses ~ M_{GUT}), the contribution to lepton asymmetry is mainly from the LH triplet decays.
- Note that two LH triplets are considered, for having CP violation.



- The effective mass-squared matrix: [Hambye et. al, Nucl. Phys. B602, 23 (2002)]

$$M^2 = \begin{bmatrix} M^2_1 - i\Gamma_{11} M_1 & -i\,\Gamma_{12} M_2 \\ -i\,\Gamma_{21} M_1 & M^2_1 - i\Gamma_{11} M_1 \end{bmatrix}$$

Type-II leptogenesis

$$\Gamma_{ab} M_b = \frac{1}{8}\left[\sum_{ij} (f^{a*}{}_{1ij} f^{b}{}_{1ij}) p^2{}_{\Delta_L} + M_a M_b g^a g^{b*}\right]$$

The final lepton asymmetry is given by

$$\frac{n_L}{s} = \Sigma_a \frac{3}{2}\frac{T_R}{m_{\inf}} \frac{3 M_1 M_2}{\pi(M_1{}^2 - M_2{}^2)} \frac{\Sigma_{ij}\, \mathrm{Im}\, f^1{}_{1ij} f^{2*}{}_{1ij} g^1 g^{2*}}{\Sigma_{ij} |f^a{}_{1ij}|^2 + |g^a|^2}$$

$n_{\Delta L}/s$

- As long as the $SU(2)_L$ triplets are sufficiently larger than T_R, no significant wash out happens, unlike thermal leptogenesis.

- To estimate n_L/s, we need to fix some parameters which appear in the above expression, which are also involved in the neutrino mass matrix.

Leptogenesis and neutrino mass.

Neutrino Mass:

- Type II contribution: $$m_{\nu ij} = 2 f^{a}{}_{1ij} v^{a}{}_{\Delta_L} - m_D{}^{T} M_R{}^{-1} m_D \approx 2 f^{a}{}_{1ij} \frac{g^{a}}{M_a} v^{2}$$

where $v^{a}{}_{\Delta L}$ are the $SU(2)_L$ triplet's vevs, and v = 174 GeV.

- We simplify the analysis by assuming: $|g^1| = |g^2| = g$, $|f^1{}_1| = |f^2{}_1| = f_1$

  Using
  $$m_\nu = U_\nu{}^{*} m_\nu{}^{diag} U_\nu{}^{T*}$$
  where $m_\nu = \mathrm{diag}\,(m_{\nu 1}, m_{\nu 2}, m_{\nu 3})$.

- In the basis where charged lepton mass matrix is diagonal, U_ν coincides with lepton mixing matrix. We therefore used the current best fit values for neutrino mixings and mass square differences (assuming that the lightest neutrino mass is zero) to construct m_{ν}.

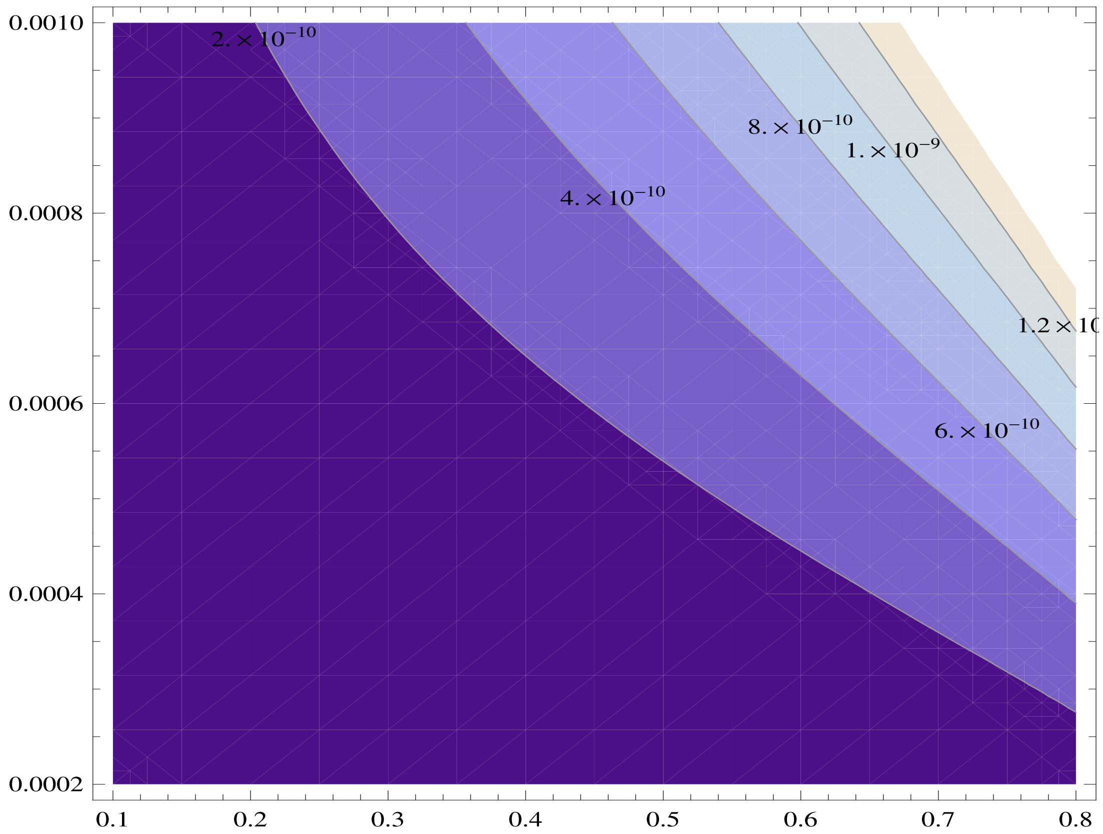
Leptogenesis and neutrino mass contd.

$$\frac{n_L}{s} = \frac{0.374}{\pi} \frac{p\sqrt{1+p^2}}{1-p^2} \sqrt{\frac{M_P}{M}} \frac{M_1 M_s}{M^2} \frac{\sum_{ij} |m_{\nu ij}|^2 \, F g^2}{\sum_{ij} |m_{\nu ij}|^2 \, F + g^4}$$

where we define the parameter p as a degree of degeneracy between M_1 and M_2, i.e. $p = M_2 / M_1$ and

$$F = \frac{p^2}{(1+p)^2} \frac{M_1^{\,2}}{4v^4}$$

- $\Sigma_{ij} \; |m_{\nu ij}|^2 = 0.0025 \text{ eV}^2$, $\alpha_1 = 10^{-3}$
- $g = \gamma \, M/M_s$



Contour plot for n_L/s as a function of the parameters: $p = M_2/\ M_2$ and $g < M/M_s$

Findings:

a) n_L/s can be of correct order (2-3) $\mathrm{x}10^{-10}$ for $0.2 < p < 0.8$ and $g > 2.5\mathrm{x}10^{-4}$

b) $M_1 = 10^{12}$ GeV, $M_2 = (2\text{-}8)\mathrm{x}10^{11}$ GeV, therefore, $M_{1,2}/T_R > 10$, which indicates no washout should happen.

Conclusions

- We have shown that $SU(2)_R$ triplets can be responsible for Inflation.
- Smooth hybrid inflation is realized with modified Kahler potential.
- High reheating temperature ($T_R \sim 10^{10}$ GeV) and production of $SU(2)_L$ triplets.
- $SU(2)_L$ triplet's decay produces lepton asymmetry.
- Neutrino mass is mainly coming from Triplet's contribution and is compatible with current data.