1 Introduction

Leptogenesis is currently the favorite scenario for explaining the observed baryon asymmetry of the Universe. It is related to the light neutrino masses and mixings via the seesaw mechanism. In supersymmetric models all the neutrino observables can also be related to the lepton flavour violating (LFV) decays of charged leptons which are induced by the heavy singlet neutrino Yukawa couplings via the renormalization effects. Implications of light neutrino masses on the heavy neutrino masses and couplings have been extensively studied. The appeal and popularity of the thermal leptogenesis comes form its predictive power. On the other hand, the second completely predictive leptogenesis scenario - direct leptogenesis form the scalar field which dominates the Universe - has got somewhat less attention.

The purpose of this talk is to review the most predictive scenario of direct leptogenesis in which the lightest heavy singlet sneutrino plays the role of inflaton. Inflation has become the paradigm for early cosmology, particularly following the recent spectacular CMB data from the WMAP satellite, which strengthen the case made for inflation by earlier data, by measuring an almost scale-free spectrum of Gaussian adiabatic density fluctuations exhibiting power and polarization on super-horizon scales, just as predicted by simple field-theoretical models.
of inflation. Ever since inflation was proposed, it has been a puzzle how to integrate it with ideas in particle physics. For example, a naive GUT Higgs field would give excessive density perturbations, and no convincing concrete string-theoretical model has yet emerged. In this conceptual vacuum, models based on simple singlet scalar fields have held sway. Here we assume the simplest scenario in which the lightest heavy singlet sneutrino drives inflation. This scenario constrains in interesting ways many of the 18 parameters of the minimal seesaw model for generating three non-zero light neutrino masses.

This minimal sneutrino inflationary scenario (i) yields a simple \( \frac{1}{2} m^2 \phi^2 \) potential with no quartic terms, with (ii) masses \( m \) lying naturally in the inflationary ballpark. The resulting (iii) spectral index \( n_s \), (iv) the running of \( n_s \) and (v) the relative tensor strength \( r \) are all compatible with the data from WMAP and other experiments. Moreover, fixing \( m \sim 2 \times 10^{13} \) GeV as required by the observed density perturbations (vi) is compatible with a low reheating temperature of the Universe that evades the gravitino problem, (vii) realizes leptogenesis in a calculable and viable way, (viii) constrains neutrino model parameters, and (ix) makes testable predictions for the flavour-violating decays of charged leptons.

2 Reheating and Leptogenesis in our Scenario

We assume the chaotic inflation with a \( V = \frac{1}{2} m^2 \phi^2 \) potential - the form expected for a heavy singlet sneutrino - in light of WMAP. Defining \( M_P \equiv 1/\sqrt{8\pi G_N} \simeq 2.4 \times 10^{18} \) GeV, the conventional slow-roll inflationary parameters are

\[
\epsilon \equiv \frac{1}{2} M_P^2 \left( \frac{V'}{V} \right)^2 = \frac{2 M_P^2}{\phi_I^2}, \quad \eta \equiv M_P^2 \left( \frac{V''}{V} \right) = \frac{2 M_P^2}{\phi_I^2}, \quad \xi \equiv M_P^4 \left( \frac{V V'''}{V^2} \right) = 0, \quad (1)
\]

where \( \phi_I \) denotes the a priori unknown inflaton field value during inflation at a typical CMB scale \( k \). Assuming \( N = 50 \) e-foldings of inflation, the WMAP data implies the result

\[
m \simeq 1.8 \times 10^{13} \text{ GeV}. \quad (2)
\]

This is comfortably within the range of heavy singlet (s)neutrino masses usually considered, namely \( m_N \sim 10^{10} \) to \( 10^{15} \) GeV.

Is this simple \( \phi^2 \) sneutrino model compatible with the WMAP data? The primary CMB observables are the spectral index

\[
n_s = 1 - 6 \epsilon + 2 \eta = 1 - \frac{8 M_P^2}{\phi_I^2} \simeq 0.96, \quad (3)
\]

the tensor-to scalar ratio

\[
r \equiv \frac{A_T}{A_S} = 16 \epsilon = \frac{32 M_P^4}{\phi_I^4} \simeq 0.16, \quad (4)
\]

and the spectral-index running

\[
\frac{d n_s}{d \ln k} = \frac{2}{3} \left[ (n_s - 1)^2 - 4 \eta^2 \right] + 2 \xi = \frac{32 M_P^4}{\phi_I^4} \simeq 8 \times 10^{-4}. \quad (5)
\]

The value of \( n_s \) extracted from WMAP data depends whether, for example, one combines them with other CMB and/or large-scale structure data. At the moment this scenario appears to be compatible with all data.

Following the inflationary epoch, reheating of the Universe results from the decays of inflaton sneutrino. Assuming, as usual, that the sneutrino inflaton decays when the the Hubble expansion
rate $H \sim m$, and that the expansion rate of the Universe is then dominated effectively by non-relativistic matter until $H \sim \Gamma_{\phi}$, where $\Gamma_{\phi}$ is the inflaton decay width, we estimate

$$T_{RH} = \left( \frac{90}{\pi^2 g_*} \right) \sqrt{\frac{\Gamma_{\phi} M_P}{4}},$$

(6)

where $g_*$ is the number of effective relativistic degrees of freedom in the reheated Universe. In the minimal sneutrino inflation scenario considered here we have $\phi \equiv \tilde{N}_1$, $m \equiv M_{N_1}$ and

$$\Gamma_{\phi} \equiv \Gamma_{N_1} = \frac{1}{4\pi} (Y_{\nu}Y_{\nu}^\dagger)_{11} M_{N_1},$$

(7)

where $Y_{\nu}$ is the neutrino Dirac Yukawa matrix. If the relevant neutrino Yukawa coupling $(Y_{\nu}Y_{\nu}^\dagger)_{11} \sim 1$, the previous choice $m = M_{N_1} \simeq 2 \times 10^{13}$ GeV would yield $T_{RH} > 10^{14}$ GeV, considerably greater than $m$ itself. Such a large value of $T_{RH}$ would be very problematic for the thermal production of gravitinos and leads to thermal leptogenesis (for the alternative leptogenesis solution to the gravitino problem see 12). However, in the light of present favourite range of light neutrino masses one can naturally guess from the seesaw mechanism $(Y_{\nu}Y_{\nu}^\dagger)_{11} \ll 1$. In this case $T_{RH}$ could be much lower, usually below the lightest sneutrino mass $2 \times 10^{13}$ GeV, leading to direct leptogenesis.

To calculate the lepton asymmetry to entropy density ratio $Y_L = n_L/s$ in inflaton decays we need to know the produced entropy density

$$s = \frac{2\pi^2}{45} g_* T_{RH}^3,$$

(8)

and to take into account that inflaton dominates the Universe. In this case one obtains

$$Y_L = \frac{3}{4} \frac{T_{RH}}{M_{N_1}},$$

(9)

where $\epsilon_1$ is the CP asymmetry in $\phi \equiv \tilde{N}_1$ decays. We consider now the most constrained scenario in which the inflaton is the lightest sneutrino, which requires $M_{N_3} > M_{N_2} > M_{N_1} \simeq 2 \times 10^{13}$ GeV. This implies that our problem is completely characterized by only one parameter, either $m_1$ or $T_{RH}$. The observed baryon asymmetry of the Universe gives a lower bound on the reheating temperature $T_{RH} > 10^6$ GeV.

3 Leptogenesis Predictions for Lepton Flavour Violation

In this Section, we make predictions on the LFV decays $\mu \to e\gamma$ and $\tau \to \mu\gamma$ in this scenario. We first calculate neutrino Yukawa couplings using the parametrization in terms of the light and heavy neutrino masses, mixings and the orthogonal parameter matrix given in 13. This allows us to calculate exactly the baryon asymmetry of the Universe from the CP asymmetry $\epsilon_1$ and the reheating temperature of the Universe $T_{RH}$ via eq.9. For neutrino parameters yielding successful leptogenesis, we calculate the branching ratios of LFV decays 15. For all calculational details we refer the reader to 7,16,17.

The results on the branching ratios are presented in Fig. 1 where we plot BR($\mu \to e\gamma$) (panel (a)) and BR($\tau \to \mu\gamma$) (panel (b)) against the reheating temperature of the Universe $T_{RH}$. We see immediately that values of $T_{RH}$ anywhere between $2 \times 10^6$ GeV and $10^{12}$ GeV are attainable in principle. The lower bound is due to the lower bound on the CP asymmetry 18, while the upper bound comes from the gravitino problem. The black points in panel (a) correspond to the choice sin $\theta_{13} = 0.0$, $M_2 = 10^{14}$ GeV, and $5 \times 10^{14}$ GeV < $M_3 < 5 \times 10^{15}$ GeV. The red points correspond to sin $\theta_{13} = 0.0$, $M_2 = 5 \times 10^{14}$ GeV, and $M_3 = 5 \times 10^{15}$ GeV, while the green points
Figure 1: Calculations of $\text{BR}(\mu \rightarrow e\gamma)$ and $\text{BR}(\tau \rightarrow \mu\gamma)$ on left and right panels, respectively. Black points correspond to $\sin \theta_{13} = 0.0$, $M_2 = 10^{14}$ GeV, and $5 \times 10^{14}$ GeV $< M_3 < 5 \times 10^{15}$ GeV. Red points correspond to $\sin \theta_{13} = 0.0$, $M_2 = 5 \times 10^{14}$ GeV, and $M_3 = 5 \times 10^{14}$ GeV, while green points correspond to $\sin \theta_{13} = 0.1$, $M_2 = 10^{14}$ GeV, and $M_3 = 5 \times 10^{14}$ GeV.

correspond to $\sin \theta_{13} = 0.1$, $M_2 = 10^{14}$ GeV, and $M_3 = 5 \times 10^{14}$ GeV. The soft SUSY breaking parameters are fixed as $(m_{1/2}, m_0) = (800, 170)$ GeV which is the upper bound for providing the cold dark matter of the Universe [19], and and $\tan \beta = 10$. We see a very striking narrow, densely populated bands for $\text{BR}(\mu \rightarrow e\gamma)$, with some outlying points at both larger and smaller values of $\text{BR}(\mu \rightarrow e\gamma)$. The width of the black band is due to variation of $M_{N_3}$ showing that $\text{BR}(\mu \rightarrow e\gamma)$ is not very sensitive to it. However, $\text{BR}(\mu \rightarrow e\gamma)$ strongly depends on $M_{N_2}$ and $\sin \theta_{13}$ as seen by the red and green points, respectively. Since $\text{BR}(\mu \rightarrow e\gamma)$ scales approximately as $m_{1/2}^{-4}$, the lower strip for $\sin \theta_{13} = 0$ would move up close to the experimental limit if $m_{1/2} \sim 500$ GeV, and the upper strip for $\sin \theta_{13} = 0.1$ would be excluded by experiment.

Panel (b) of Fig. 1 shows that $\text{BR}(\tau \rightarrow \mu\gamma)$ depends strongly on $M_{N_3}$, while the dependence on $\sin \theta_{13}$ and on $M_{N_2}$ is negligible. The numerical values of $\text{BR}(\tau \rightarrow \mu\gamma)$ are somewhat below the present experimental upper limit $\text{BR}(\tau \rightarrow \mu\gamma) \sim 10^{-7}$, but we note that the results would all be increased by an order of magnitude if $m_{1/2} \sim 500$ GeV. In this case, panel (a) of Fig. 1 tells us that the experimental bound on $\text{BR}(\mu \rightarrow e\gamma)$ would enforce $\sin \theta_{13} \ll 0.1$, but this would still be compatible with $\text{BR}(\tau \rightarrow \mu\gamma) > 10^{-8}$.

As a result, Fig. 1 strongly suggests that fixing the observed baryon asymmetry of the Universe for the direct sneutrino leptogenesis ($T_{RH} < 2 \times 10^{12}$ GeV $< M_{N_1}$) implies a prediction for the LFV decays provided $M_{N_2}$ and/or $M_{N_3}$ are also fixed.

4 Conclusions

The main results of our scenario are the following. First, reheating of the Universe is due to the neutrino Yukawa couplings, and therefore can be related to light neutrino masses and mixings. Secondly, the lepton asymmetry is created in direct sneutrino-inflaton decays. There is only one parameter describing the efficiency of leptogenesis in this minimal sneutrino inflationary scenario in all leptogenesis regimes - the reheating temperature of the Universe - to which the
other relevant parameters can be related. This should be compared with the general thermal leptogenesis case which has two additional independent parameters, namely the lightest heavy neutrino mass and width. \textit{Thirdly}, imposing the requirement of successful leptogenesis and correct amount of cold dark matter, we can predict branching ratios for $\mu \rightarrow e\gamma$ and $\tau \rightarrow \mu\gamma$ in a very narrow band within about one order of magnitude of the present experimental bound.

\textbf{Acknowledgments}

We thank J. Ellis and T. Yanagida for collaboration and discussions. This work is partially supported by the ESF grant No. 5135.

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