BRANEWORLD COSMOLOGY: SNEUTRINO INFLATION 
AND LEPTOGENESIS *

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Modifications to the Friedmann equation in brane cosmology can have important 
implications for early universe phenomena such as inflation and the generation of 
the baryon asymmetry. In the framework of braneworld cosmology, we discuss a 
mechanism for baryogenesis via leptogenesis in the supersymmetric context, where 
the sneutrino is responsible for both inflation and the generation of the baryon 
asymmetry in the universe.

Today there is a wide consensus that the early universe underwent a period of 
cosmological inflation, responsible not only for the observed flatness, homogeneity and isotropy of the present universe, but also for the origin of the density fluctuations. At the end of inflation, the universe must have been subsequently reheated to become a high-entropy and radiation-dominated universe. Such a reheating process could occur, for instance, through the coherent oscillations of the inflaton field about the minimum of the potential. During this process, the inflaton decays into ordinary particles, which then scatter and thermalise. The right abundance of baryons must have also been created after inflation. In fact, the most recent Wilkinson Microwave Anisotropy Probe (WMAP) results and big bang nucleosynthesis (BBN) analysis of primordial deuterium abundance imply$^1$

$$\eta_B \equiv (n_B - n_{\gamma})/n_{\gamma} = (6.1 \pm 0.3) \times 10^{-10},$$

for the baryon-to-photon ratio of number densities.

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In this talk, we present a minimal supersymmetric seesaw scenario where the lightest singlet sneutrino field not only plays the role of the inflaton but also produces a lepton asymmetry through its direct decays, during the non-conventional era in the braneworld scenario. There are other baryogenesis scenarios in which the braneworld modifications can have important implications, e.g., the recently proposed gravitational baryogenesis mechanism.

Whilst theories formulated in extra dimensions have been around since the early twentieth century, recent developments in string theory have opened up the possibility that our universe could be a 1+3-surface - the brane - embedded in a higher-dimensional space-time, called the bulk, with standard model particles and fields trapped on the brane while gravity is free to access the bulk. A remarkable feature of brane cosmology (BC) is the modification of the expansion rate of the universe before the BBN era. In the so-called Randall-Sundrum II braneworld construction the Friedmann equation receives an additional term quadratic in the density,

\[ H^2 = \frac{8\pi}{3M_P^2} \rho \left( 1 + \frac{\rho}{2\lambda} \right), \quad M_P = \sqrt{\frac{3}{4\pi} \frac{M_5^2}{\sqrt{\lambda}}} \]

where \( M_P \) is the 4D Planck mass and \( M_5 \) the 5D fundamental mass and we have set the 4D cosmological constant to zero and assumed that inflation rapidly makes any dark radiation term negligible. Eq. (1) reduces to the usual Friedmann equation, \( H \propto \sqrt{\rho} \), at sufficiently low energies, \( \rho \ll \lambda \), but at very high energies one has \( H \propto \rho \). Successful BBN requires that the change in the expansion rate due to the new terms in the Friedmann equation be sufficiently small at scales \( \sim \mathcal{O}(\text{MeV}) \); this implies \( M_5 \gtrsim 40 \text{ TeV} \). A more stringent bound, \( M_5 \gtrsim 10^{15} \text{ TeV} \), is obtained by requiring the theory to reduce to Newtonian gravity on scales larger than 1 mm.

We consider the scenario where three heavy right-handed neutrinos \( N_j \), with masses \( M_j \), are added to the usual particle content of the minimal supersymmetric standard model. We assume that the seesaw mechanism is operative in the brane scenario and gives masses to the light neutrinos, and, for simplicity, we neglect the dynamics of the heavier sneutrinos \( \tilde{N}_{2,3} \). We also assume that the lightest right-handed sneutrino \( \tilde{N}_1 \) acts as an inflaton with a potential simply given by the mass term \( V = M_1^2 \tilde{N}_1^2 / 2 \), i.e., the (chaotic) quadratic potential.

In standard cosmology (SC), the COBE normalisation of the scalar perturbations requires an inflaton mass \( M_1 \sim 10^{13} \text{ GeV} \). This corresponds to an inflaton field value \( \sim 3M_P \). These super-Planckian field values can lead to quantum corrections which destroy the flatness of the potential necessary
Figure 1. The reheating temperature $T_{rh}$ as a function of $M_5$ for $m_{3/2} = 1$ TeV as derived from the BBN gravitino constraints, direct leptogenesis and the WMAP bounds on $\eta_B$ and $\Omega_m$.

for successful inflation. If we consider the brane modifications to the Friedmann equation, the COBE normalisation implies\(^6\) that $M_1 \approx 4.5 \times 10^{-5} M_5$. This enables inflation to take place at field values far below $M_P$: one estimates $\tilde{N}_{1,i} \approx 3 \times 10^2 M_5$, which, when combined with $M_5 \ll 10^{17}$ GeV (required so that inflation takes place on the high energy regime of BC), implies $\tilde{N}_{1,i} < M_P$. One should also notice that the inflationary observables, $n_s$, $\alpha_s$ and $r_s$, are well within the WMAP bounds on these quantities\(^1\).

At the end of inflation the inflaton field $\tilde{N}_1$ begins to oscillate coherently around the minimum of the potential. If $CP$ is not conserved, the decays of $\tilde{N}_1$ into leptons, Higgs and the corresponding antiparticles can produce a net lepton asymmetry. We require $T_{rh} < M_1$, with $T_{rh}$ being the reheating temperature of the universe, so that leptogenesis is driven by the decays of the cold sneutrino inflaton and the produced lepton asymmetry is not washed out by lepton-number violating interactions mediated by $N_1$ (the case where leptogenesis is purely thermal, $T_{rh} > M_1$, is not considered here, but this scenario has been recently investigated in BC\(^7\)).

The lepton-to-photon ratio created is given by $\eta_L \sim \epsilon_1 T_{rh}/M_1$, where $\epsilon_1$ denotes the $CP$ asymmetry in the $\tilde{N}_1$ decays. The lepton asymmetry produced before the electroweak phase transition is then partially converted
into a baryon asymmetry via the sphaleron effects\(^8\). Taking into account the observational value for the baryon asymmetry, it is possible to obtain a lower bound on the reheating temperature, which is defined by assuming an instantaneous conversion of the inflaton energy into radiation when the decay width of the inflaton equals the expansion rate of the universe \(H\), \(T_{rh} \gtrsim 1.6 \times 10^6\) GeV.

Another important bound in supersymmetric scenarios comes from gravitino production. During the reheating gravitinos can be thermally produced through scatterings in the plasma. If the gravitinos are unstable and overproduced, their decay products could put at risk the successful predictions of BBN. If they are stable particles (which is the case if they are the lightest supersymmetric particle, LSP) the constraint comes from their contribution to the dark matter. In SC their abundance is proportional to \(T_{rh}\), and constraints from BBN yield a stringent upper bound\(^9\) on the allowed \(T_{rh}\). In BC, however, their abundance decreases with \(T_{rh}\), and in this case we obtain a lower bound on the reheating temperature.

In Fig. 1, we show the allowed region in the \(M_5 - T_{rh}\) plane, putting together these three constraints, for the case \(m_{3/2} = 1\) TeV. In conclusion, for a gravitino mass in the range \(m_{3/2} \simeq 100\) GeV \(- 1\) TeV, we find that successful BBN and leptogenesis in this framework require that the 5D Planck mass is in the range \(M_5 \simeq 10^{10} \text{--} 10^{13}\) GeV and the reheating temperature \(T_{rh} \simeq 10^6 \text{--} 10^8\) GeV.

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\(^{8}\)\(T_{rh}\) is the reheating temperature.

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