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Plateau inflation in R-parity violating MSSM

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ABSTRACT

Inflation with plateau potentials give the best fit to the CMB observables as they predict tensor to scalar ratio stringently bounded by the observations from Planck and BICEP2/Keck. In supergravity models it is possible to obtain plateau potentials for scalar fields in the Einstein frame which can serve as the inflation potential by considering higher dimensional Planck suppressed operators and by the choice of non-canonical Kähler potentials. We construct a plateau inflation model in MSSM where the inflation occurs along a sneutrino-Higgs flat direction. A hidden sector Polonyi field is used for the breaking of supersymmetry after the end of the inflation. The proper choice of superpotential leads to strong stabilization of the Polonyi field, $m_Z^2 \gg m_{3/2}^2$, which is required to solve the cosmological moduli problem. Also, the SUSY breaking results in a TeV scale gravitino mass and scalar masses and gives rise to bilinear and trilinear couplings of scalars which can be tested at the LHC. The sneutrino inflation field can be observed at the LHC as a TeV scale diphoton resonance like the one reported by CMS and ATLAS.

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1. Introduction

There are at least two experimental sectors which hint at the existence of scalar fields beyond the Higgs field of the Standard Model (SM). In order to explain the observed anisotropy of the cosmic microwave background (CMB) temperature at the super horizon scales [1] and at the same time the low value of the tensor-to-scalar ratio $r < 0.07$ [1,2] one requires an inflaton field with a plateau potential [3–9]. The other hint for a scalar field is the 750 GeV diphoton excess which may have been observed by ATLAS [10] and CMS [11] collaborations which has launched a large number of models which explain the 750 GeV diphoton resonance in the context of left–right models [12–19], Grand Unification [20–22] and supersymmetry (SUSY) [23–28] and other exotic models (reviewed in [29,30]). Cosmological implications of the 750 GeV scalar have been studied in [31–35]. Sadly, the signal no longer persists as shown by the updated analysis of $\sqrt{s} = 13$ TeV data of ATLAS and CMS [36,37].

In this paper we construct a plateau inflation model in the context of the minimal supersymmetric standard model which can be tested at the LHC in particular where the inflaton can be observed as a TeV scale diphoton resonance. We find that the most economical model which can explain both the phenomenon is to identify the left-handed sneutrino in a R-parity violating MSSM as the inflaton and as the diphoton resonance. The identification of the tau-sneutrino as the diphoton resonance has been made in the R-parity violating MSSM in [24,25]. On the other hand inflation with the singlet right-handed sneutrino has been well studied [38–44] and in MSSM the Higgs-sneutrino inflation along flat-directions [45–57] has also been studied. In this paper we consider a supergravity model with no-scale like Kähler potential and a superpotential which includes R-parity violating non-renormalizable operators at all orders. In this model we consider the supersymmetry breaking occurs via a Polonyi field which takes a non-zero vacuum expectation value after the end of inflation in the present epoch. The proper choice of superpotential in Polonyi field leads to much heavier Polonyi mass compared to gravitino mass to avoid the cosmological moduli problem and to obtain the vanishingly small cosmological constant 10^{-120} [58–62]. The SUSY breaking generates masses which are of the TeV scale for all the SUSY scalar partners (like squarks, sneutinos and sleptons). The TeV scale sleptons are used in the loops for the production and decay of the TeV scale sneutrino. The production and decay vertices which involve

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sneutrino-quark and sneutrino-sleptons are generated by the SUSY breaking by the hidden sector Polonyi field.

The rest of the paper is organized as follows. In Sec. 2 we introduce the relevant Kähler potential and superpotential and construct the D-term and F-term potentials. In Sec. 3 we choose the D-flat Higgs-sneutrino direction that gives the required plateau potential from the F-term. We show how interaction terms arise from the Polonyi field SUSY breaking which ultimately gives rise to the diphoton production and decay vertices in Sec. 4. We then apply the model to the calculation of the $\sim$ TeV sneutrino production and decay and show the cross section for the diphoton resonance which can be a tentative signature for this model in Sec. 5. We conclude and list future implications of the model in Sec. 6.

2. The model

In the early universe the no-scale Kähler potential gives the plateau inflation from supergravity (SUGRA) [6,7,9,63,64] which fits the requirements of the observed low tensor-to-scalar ratio and the temperature anisotropy. We consider the most economical SUSY model, namely the MSSM but allow R-parity violation. In this model the inflaton is a linear combination of the sneutrino and the neutral components of the Higgs fields.

We consider R-parity violating terms in Kähler potential $K(\phi_i, \phi_i^*)$

$$K = 3\ln\left[1 + \frac{1}{3M_p^2}\Big(L^\dagger L + H_u^\dagger H_u + H_d^\dagger H_d + H_d^\dagger L + L^\dagger H_d\Big)\right] + ZZ^* - \frac{(ZZ^*)^2}{\Lambda^2} \quad (1)$$

and superpotential $W(\phi_i)$

$$W = \mu_1 L\cdot H_u + \mu_2 H_u\cdot H_d + \Delta M_p^2 + \mu_z^2 Z + \frac{\lambda_1}{M_p}(L\cdot H_u)^2 \exp\left(\frac{-L\cdot H_u}{M_p^2}\right) + \frac{\lambda_2}{M_p}(H_u\cdot H_d)^2 \exp\left(\frac{H_u\cdot H_d}{M_p^2}\right). \quad (2)$$

The noteworthy feature of the superpotential (2) is that it does not blow up even when the inflation fields are super-Planckian during inflation. The hidden sector Polonyi field Z is introduced to break supersymmetry. The term $\left(-\frac{(ZZ^*)^2}{\Lambda^2}\right)$ with $\Lambda \ll 1$ and the fine tuning of the constant Δ helps in the strong stabilization of the field Z (i.e., $m_Z^2 \gg m_{3/2}^2$) and fixing the vanishingly small cosmological constant $\sim 10^{-120}$ [61,62]. The other fields bear their standard meanings. In addition to the superpotential, given in Eq. (2), which we consider for the inflation we also consider the R-parity violating interaction terms

$$W_{int} = \tilde{Y}_{ijk} L_i L_j e_{Rk} + \lambda'_{ijk} L_i Q_j D_k \quad (3)$$

which will play a role in detection of the sneutrino at LHC. From here onwards we shall work in the unit where $M_p = (8\pi G)^{-1} = 1$.

The scalar potential in SUGRA depends upon the Kähler function $G(\phi_i, \phi_i^*)$ given in terms of superpotential $W(\phi_i)$ and Kähler potential $K(\phi_i, \phi_i^*)$ as,

$$G(\phi_i, \phi_i^*) \equiv K(\phi_i, \phi_i^*) + \ln W(\phi_i) + \ln W^*(\phi_i^*), \quad (4)$$

where ϕ_i are the chiral scalar superfields. The scalar potential is given as the sum of F-term and D-term potentials given by

$$V_F = e^G\left[\frac{\partial G}{\partial \phi^i} K^i_{j*} \frac{\partial G}{\partial \phi_j^*} - 3\right] \quad (5)$$

and

$$V_D = \frac{1}{2}\left[\mathrm{Re} f_{ab}^{-1}(\phi_i)\right] D^a D^b, \quad (6)$$

respectively, where $D^a = -g\frac{\partial G}{\partial \phi_k}(\tau^a)^l_k \phi_l$ and g is the gauge coupling constant corresponding to each gauge group and τ^a are corresponding generators. For $SU(2)_L$ symmetry $\tau^a = \sigma^a/2$, where σ^a are Pauli matrices. For $U(1)_Y$ symmetry the hypercharges are $Y_u = 1$, $Y_d = -1$, $Y_L = -1$ for H_u, H_d, L respectively. The quantity f_{ab} is related to the kinetic energy of the gauge fields and is a holomorphic function of superfields ϕ_i.

The kinetic term of the scalar fields is given by

$$\mathcal{L}_{KE} = K_i^{j*} \partial_\mu \phi^i \partial^\mu \phi_j^*, \quad (7)$$

where K^i_{j*} is the inverse of the Kähler metric $K_i^{j*} \equiv \partial^2 K/\partial\phi^i \partial\phi_j^*$.

Taking charged components of $SU(2)_L$ Higgs doublets H_u, H_d to be zero in the classical background fields during inflation. The H_u, H_d and slepton doublet L can be written as

$$L = \begin{pmatrix}\phi_\nu \\ 0\end{pmatrix}, \qquad H_u = \begin{pmatrix} 0 \\ \phi_u\end{pmatrix}, \qquad H_d = \begin{pmatrix}\phi_d \\ 0\end{pmatrix}, \quad (8)$$

and substituting in Eq. (6) and assuming the canonical form of the gauge kinetic function $f_{ab} = \delta_{ab}$, the D-term potential comes out to be

$$V_D = \frac{9}{8}\left(g_1^2 + g_2^2\right) \times \frac{\left(-|\phi_u|^2 + |\phi_d|^2 + |\phi_\nu|^2 + (\phi_d\phi_\nu^* + \phi_d^*\phi_\nu)/2\right)^2}{\left(3 + |\phi_u|^2 + |\phi_d|^2 + |\phi_\nu|^2 + (\phi_d\phi_\nu^* + \phi_d^*\phi_\nu)/2\right)^2}. \quad (9)$$

We choose the field configurations such that $V_D = 0$ during inflation. Such a D-flat direction is given by the relation $\phi_\nu = \phi_u = \phi$, $\phi_d = 0$. We next compute the F-term potential to study inflation.

3. Inflation along *D*-flat direction

With the assumption $\phi_\nu = \phi_u = \phi$, $\phi_d = 0$, the Kähler potential (1) and the superpotential (2) reduce to the simple forms

$$K = 3\ln\left[1 + \frac{2\phi\phi^*}{3}\right], \quad (10)$$

$$W = \mu_1\phi^2 + \lambda_1\phi^4 \exp(-\phi^2). \quad (11)$$

During inflation we assume that SUSY is unbroken and the hidden sector field $Z = 0$. With the Kähler potential (10) and the superpotential (11), we get F-term scalar potential as

$$V_F = \frac{\lambda_1^2}{243} e^{-(\phi^2+\phi^{*2})}\left(3 + 2|\phi|^2\right)^3 |\phi|^6 \times \left[84 - 7(\phi^2 + \phi^{*2})\left(6 + 10|\phi|^2 + 4|\phi|^4\right) + 149|\phi|^2 + 119|\phi|^4 + 26|\phi|^6 + 8|\phi|^8\right], \quad (12)$$

where we have assumed that during inflation when the field values are of Planck scale, the linear term in superpotential (2) does not contribute to the inflation potential. Whereas in the later universe at SUSY breaking scale when the field values are at TeV scale, the higher order Planck suppressed terms become negligible compared to linear terms in W.

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