

New bound on the Yukawa coupling from CMB

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Abstract

We investigate the one loop inflation stemming from the superstring theory in the braneworld scenario. The tensor to scalar ratio of the loop inflation is found inconsistent with the recent CMB results for the Yukawa coupling from the SM sector. We propose a new bound on the Yukawa coupling, $9.92 < \lambda < 13.4$, applicable to the cosmological sector from CMB. The aftermath of this new bound is explored. The present results may shed some light on the phenomenology of superstring theory and its associated phenomena.

Keywords : Inflation, Supersymmetry, String theory, CMB, Yukawa coupling.

In SM particle phenomenology, the well-celebrated Yukawa coupling provides the strength of the interaction between fermions and bosons. Existing values [1, 2, 3] of the Yukawa coupling are estimated mostly from various SM particle interactions. These coupling strengths can be challenged in the inflationary models stemming from supersymmetric potentials. The superpotential and the Yukawa couplings are determined by the underlying supersymmetry (SUSY). In this work, we show that adopting the current values from the SM sector Yukawa coupling (SMYC) in the superstring theory motivated

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loop inflation leads to an incompatibility of the tensor to scalar ratio with recent CMB estimates. We propose a new bound on the Yukawa coupling applicable to the cosmological sector from CMB. Consequences of the newly derived Yukawa coupling limits are also discussed.

The genesis of one loop inflationary model [4, 5, 6, 7, 8] is from $\mathcal{N} = 2$ hypersymmetric P -term inflation implemented in the D3/D7 brane that reduces to a supersymmetric $\mathcal{N} = 1$ D -term inflation by altering the flatness of the inflationary potential via one loop radiative correction. The resulting Einstein-Hilbert action on the brane is

$$S = \int d^4x \sqrt{-g} \left[\frac{m_{pl}^2 R}{2} + g^{\mu\nu} \partial_\mu \phi \partial_\nu \phi + V_{one-loop} \right] \quad (1)$$

where [9, 10, 11]

$$V_{one-loop} = \frac{\alpha^2 \xi^2}{2} \left[1 + \frac{\alpha^2}{8\pi^2} \ln \left(\frac{\phi}{|\phi_c|} \right) \right], \quad (2)$$

α is the gauge coupling and ξ is the Fayet-Iliopoulos term. The gauge coupling is related to the Yukawa coupling, $\lambda = \sqrt{2}\alpha$. Here, we take the critical value of the inflaton field $|\phi_c| = m_{pl}$. We assume that inflation proceeds in the slow roll regime and express the first and second slow-roll parameters for $V_{one-loop}$ in terms of α and the e-folding number (N) respectively as

$$\epsilon = \frac{\alpha^2}{\alpha^2 + 32\pi^2 N}, \quad (3)$$

$$\eta = \frac{-1}{2N \left(1 + \frac{\alpha^2}{32\pi^2 N} \right)}. \quad (4)$$

The corresponding scalar spectral index and tensor to scalar ratio are

$$n_s = 1 - \left(\frac{\alpha^2 + 12\pi^2}{\alpha^2 N} \right), \quad (5)$$

$$r = \frac{16\alpha^2}{\alpha^2 + 32\pi^2 N}. \quad (6)$$

To check the feasibility of presently available values from SMYC [3] on the loop inflation, we estimate the scalar spectral index and tensor to scalar ratio (see table 1) then compare them with recent CMB estimates (see figure 1).

From the comparative study, we can see that the tensor to scalar ratio of the loop inflation with the current bound from SMYC for the range $13.43 < \lambda < 27.57$ [3] is much higher than the upper limit derived from BK18 (0.036) [14], PR 4 + BK18 (0.032) [15], LiteBIRD [16] and CMB S4 (0.004, future projected estimate) [17]. Moreover, analysis of the variation of tensor to scalar ratio with the scalar spectral index shows that all $\lambda > 14.5$ are out of the 95% and 68% CL of both Planck2018 and BK18 bounds (see figure 1). We observe that $\lambda = 14.5$ lies in 68% CL of Planck2018 but in 95% CL of BK18. Clearly, we can notice that for all $\lambda > 14.5$, the loop inflationary scenario is disfavoured based on the current and future CMB observations with the existing values of the Yukawa coupling constant from SM sector under consideration. Since the loop inflation originates from the superstring theory, discarding the model can in turn challenge supersymmetry, string theory and quantum gravity. At the same time, it is interesting to note that $\lambda = 13.53$ lies well within the 68% CL of both Planck2018 and BK18. Therefore, at a glance, the Yukawa coupling $\lambda = 13.53$ from SM sector appears to be a viable candidate for accounting the Planck2018 and BK18 with 68% CL. However, further scrutiny shows that this value cannot be considered because it comes from a semi-classical approximation (not radiatively corrected) [3] whereas the loop inflation is a radiatively corrected model. The tensor to scalar ratio of this inflationary model can be re-estimated with the values from SMYC [1, 2, 3] other than the range $13.43 < \lambda < 27.57$. Even then the conclusion remains unaltered. This alarming situation prevents us from adopting SMYC directly into the cosmological sector. Therefore, there is a necessity to investigate the values of Yukawa coupling beyond SM interactions, particularly suitable for the braneworld cosmology. For this, the Yukawa interaction strength in the braneworld cosmological sector need to be derived. Hence, we estimate values of the Yukawa coupling constant for the one loop inflationary model from Planck2018 and BK18. The newly derived results are presented in table 2. Since these values are estimated based on CMB that comes from the cosmological observations, we call them the cosmological sector Yukawa coupling (CSYC).

Table 1: Estimates of the inflationary parameters and tensor to scalar ratio for the loop inflation with Yukawa coupling $13.43 < \lambda < 27.57$ from the SM sector. Here we take $N=60$.

λ	α	ϵ	η	n_s	r
13.53	9.56	0.0048	-0.0082	0.9548	0.0768
14.5	10.25	0.0055	-0.0082	0.9506	0.0880
19.5	13.79	0.0099	-0.0082	0.9242	0.1584
20.5	14.49	0.0109	-0.0082	0.9182	0.1744
25	17.68	0.0162	-0.0081	0.8866	0.2592
27	19.09	0.0188	-0.0081	0.8710	0.3008

We study the feasibility of CSYC with the scalar spectral index and tensor to scalar ratio obtained from the joint Planck TT,TE,EE+lowE+lensing [12] and BK18+BAO [13, 14] with the marginalized 95% and 68% CL (see figure 2). The analysis shows that $\lambda = 9.25$ falls within the 68% CL of Planck2018 and 95% of BK18. But, all $\lambda < 9.25$ fall within the 95% CL of Planck2018, however, they are outside the 95% and 68% CL of BK18 bounds and 68% CL of Planck2018. Similarly, all the values of $\lambda > 13.3$ fall outside the 95% CL of both BK18 and Planck2018 hence are not feasible CSYC for the one loop inflation. Therefore, to account for the current and future estimated tensor to scalar ratio, the situation enforces us to adopt a new range of the Yukawa coupling for the one loop inflation. This suggests a new bound on the Yukawa coupling applicable in the cosmological sector from CMB which is $9.92 < \lambda < 13.4$.

The one loop inflationary model originates from supersymmetric theory. Therefore, the Yukawa coupling strength associated with it can play a pivotal role in deciding its fate on the braneworld inflationary scenario. Hence, the right value of Yukawa coupling must be used so that the model is compatible with various CMB observations, especially the tensor to scalar ratio. Presently, values of the Yukawa coupling strength are estimated only from various SM sectors and exhibit a very wide range. However, selecting the coupling strength from a pool of SM sector and using it in the loop inflation leads to inconsistency of its scalar spectral index and tensor to scalar ratio compared with the respective estimates from current CMB. This raises a concern about the adoptability of Yukawa coupling from the SM sector into the cos-

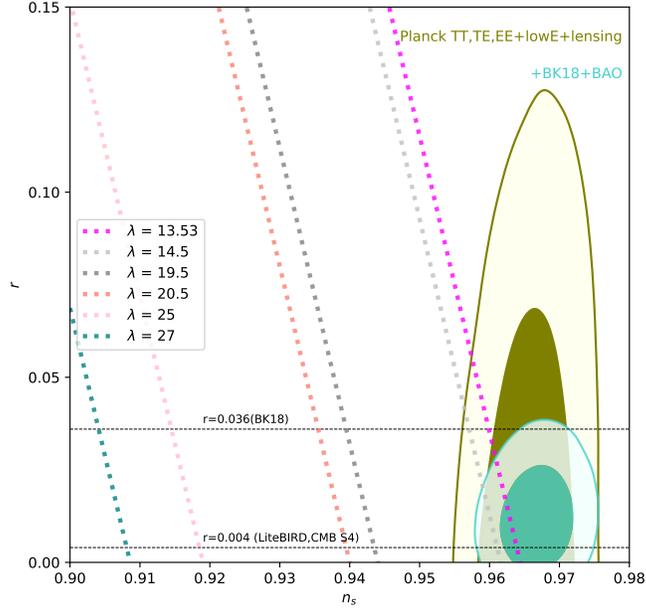


Figure 1: The tensor to scalar ratio (r) of the one loop inflation for various scalar spectral index (n_s) with the SMYC range $13.43 < \lambda < 27.57$ and marginalized 95% and 68% CL from the joint Planck TT,TE,EE+lowE+lensing and BK18+BAO.

mological sector in a straight forward manner. This circumstance demands to investigate suitable values of the Yukawa coupling constant for the viability of one loop inflation with various results of CMB. Therefore, we derived a new bound of Yukawa coupling constant from 68% CL of Planck2018 and BK18 from CMB that is applicable to cosmology. To the best of knowledge, the authors are not aware of such a bound derived on Yukawa coupling from any cosmological sector so far. The new derived constraint on the Yukawa coupling constant from CMB may play a crucial role in validating inflationary model coming from supersymmetry. Yukawa coupling from string theory, supersymmetry, quantum gravity and extra dimensions can bridge the SM and cosmological sectors.

Table 2: Estimates of the inflationary parameters and tensor to scalar ratio for the loop inflation with Yukawa coupling $3 < \lambda < 13.4$ from the cosmological sector. Here we take $N=60$.

λ	α	ϵ	η	n_s	r
3.1	2.1923	0.0002	-0.0083	0.9822	0.0032
6	4.2432	0.0009	-0.0083	0.978	0.0144
9.25	6.5417	0.0022	-0.0083	0.9702	0.0352
9.92	7.0150	0.0025	-0.0083	0.9684	0.0400
11	7.7793	0.0031	-0.0083	0.9648	0.0496
12	8.4865	0.0037	-0.0083	0.9612	0.0592
13	9.1937	0.0044	-0.0082	0.9572	0.0704
13.3	9.40	0.0046	-0.0082	0.9560	0.0736

In modern times, the Yukawa coupling is estimated from the high energy particle collider experiments such as ATLAS, CMS,..etc [1, 2] and such values are used to estimate mass of quarks, leptons,..etc. Alternatively, we suggest a similar possible estimate from cosmological sector by considering the early universe phenomena through CMB. Therefore, it can provide a platform to compare the values of Yukawa coupling strength arising from the cosmological sector with the SM sector. That may lead to interesting results which in turn complements in understanding particle physics, supersymmetry, string theory, quantum gravity and cosmology. The difference in the values of the Yukawa coupling from the two distinct prominent sectors (SMYC and CSYC) arises because of the involved energy scales of interaction in the different sectors. Interestingly, SMYC estimates lie in 95% CL of ATLAS/CMS [1, 2] whereas CSYC falls in the 68% CL of Planck2018 and BK18.

Standard inflationary scale ($\sim 10^{16}$ GeV) is much higher than currently running LHC experiments even at the TeV scale. Moreover, earlier LHC experiments were unsuccessful in providing any evidence for SUSY. This could be due to the extremely high energy scale of SUSY than LHC. This can lead to a wrong conclusion about SUSY and related phenomena. This picture can be altered if we can get some evidence or signal from the early universe phenomena such as superstring theory driven loop inflation through a suitable cosmological probe such as CMB. We considered the one loop inflation emerging

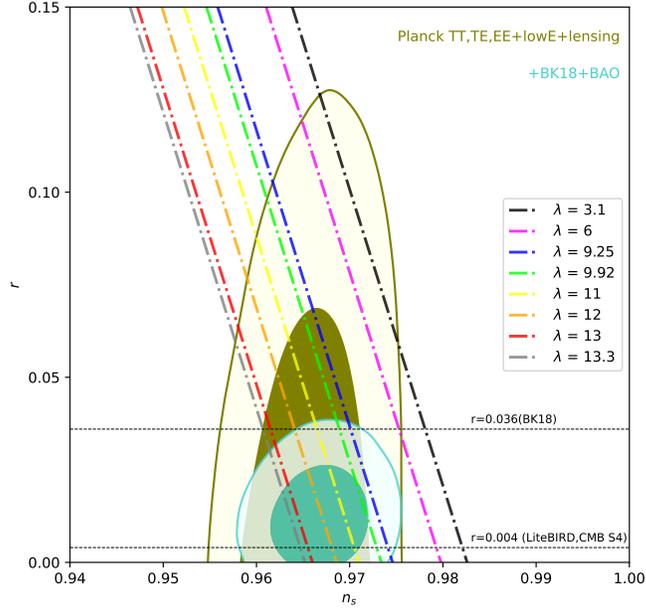


Figure 2: The tensor to scalar ratio (r) of the one loop inflation for various scalar spectral index (n_s) with the CSYC range $3.1 < \lambda < 13.4$ and marginalized 95% and 68% CL from the joint Planck TT,TE,EE+lowE+lensing and BK18+BAO.

from superpotential and studied its tensor to scalar ratio and scalar spectral index with the 68% CL of both Planck2018 TT,TE,EE+lowE+lensing and BK18+BAO and demonstrated that the Yukawa coupling can exist beyond SM sector. Hence, the newly derived Yukawa coupling strength from CMB can substantiate SUSY and its related phenomena. In short, we can say that the estimated Yukawa coupling from the cosmological sector and SM sector can complement to widen or deepen the understanding so that the limitation of the LHC experiments can be overcome by looking at the cosmological phenomenology in estimating the Yukawa coupling for interactions taking place at energies higher than the LHC operating scale.

The possibility of estimating the Yukawa coupling from the superstring the-

ory based loop inflation with CMB can overcome the strong criticism against the phenomenological feasibility of string theory and its related ideas unambiguously. This may once again resurrect the wonderful idea of extra dimensions and superstring theory as a candidate for quantum gravity and can generate a renewed interest among the high energy and cosmology community. In that respect, our work takes a leap.

The study can be repeated with inflationary models arising from string theory that may support or widen or narrow the derived Yukawa coupling bounds. We hope that the current result can revive superstring and quantum gravity. The newly derived bound $9.92 < \lambda < 13.4$ from CMB may be a key to open the superstring theory and associated phenomena. We are successful in deriving a new bound on the Yukawa coupling from the cosmological sector. The new bound indicates the existence of fermions with very high mass. The question is what happened to such fermions? One of the possibility is that, the high mass fermion decayed into other smaller particles. Some of them turned into DM/DE. Other possibility is that the decayed fermion's density considerably reduced because of inflation so that we don't see them in the present universe. At the same time a completely different aspect of it is that the production of such massive fermions is unlikely to happen which implies no signal for extra dimension and superstring theory. Since the derived new bound of Yukawa coupling from CMB therefore supports the same conclusion regarding the extradimension and SUSY as that of the LHC experiment. Therefore the result of the present work may also support the LHC conclusions. There will be many consequences if this bound is not acceptable including the ruling out of loop inflation which in turn negates supersymmetry.

Acknowledgments

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