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Constraining N=1 supergravity inflationary framework with non-minimal Kähler operators

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In this paper we will illustrate how to constrain unavoidable K\"ahler corrections for $calN = 1$ supergravity (SUGRA)
inflation from the recent Planck data. We will show that the non-renormalizable K\"ahler operators will induce in general {\it non-minimal kinetic} term for the inflaton field,
and two types of SUGRA corrections in the potential - the {\it Hubble-induced mass} (c_H), and the {\it Hubble-induced A-term} (a_H) correction.
The entire SUGRA inflationary framework can now be constrained from (i) the {\it speed of sound}, c_s, and (ii) from the upper bound on the {\it tensor to scalar ratio}, $r_\star$.
We will illustrate this by considering a heavy scalar degree of freedom at a scale, M_s, and a light inflationary field which is responsible for a slow-roll inflation. We will compute
the corrections to the kinetic term and the potential for the light field explicitly. As an example, we will consider a visible sector inflationary model of inflation where inflation occurs at the point
of {\it inflection}, which can match
the density perturbations for the cosmic microwave background radiation, and also explain why the universe is filled with the Standard Model degrees of freedom.
We will scan the parameter space of the non-renormalizable K\"ahler operators, which we find them to be order $calO(1)$, consistent with physical arguments.
While the scale of heavy physics is found to be bounded by the tensor-to scalar ratio, and the speed of sound, $calO(10^{11} \leq M_s \leq 10^{16})$~GeV, for
$0.02 \leq c_s \leq 1$ and $10^{-22} \leq r_\star \leq 0.12$. Additionaaly we study the nonlinear evolution of cosmological perturbations on
large scales which enables us to compute the curvature perturbation, ζ,
without solving the exact perturbed field equations.
Further we compute the non-Gaussian parameters f_{NL} , τ_{NL} and g_{NL}
for local type of non-Gaussianities and CMB dipolar asymmetry parameter, A_{CMB}, using the δN formalism for a generic class of sub-Planckian models induced by the Hubble-induced corrections for a
minimal supersymmetric D-flat direction where inflation occurs at the point of inflection within the visible sector.
Hence by using multi parameter scan we constrain the
non-minimal couplings appearing in non-renormalizable K\"ahler operators within, $calO(1)$, for the
speed of sound, $0.02 \leq c_s \leq 1$, and tensor to scalar, $10^{-22} \leq r_\star \leq 0.12$.
Finally applying all of these constraints we will fix the lower as well as the upper bound of the non-Gaussian parameters within, $calO(1-5) \leq f_{NL} \leq 8.5$,
$calO(75-150) \leq \tau_{NL} \leq 2800$ and $calO(17.4-34.7) \leq g_{NL} \leq 648.2$,
and CMB dipolar asymmetry parameter within the range, $0.05 \leq A_{CMB} \leq 0.09$.

Summary

In this paper, we have shown that in any $calN = 1$
SUGRA inflation model when ever there are more degrees of freedom, non-minimal K\"ahler corrections would
induce three distinct types of corrections: (i) non-minimal kinetic term for
the inflaton, (ii) Hubble-induced mass correction to the inflaton, and
(iii) Hubble-induced A-term in the potential.

The exact nature of K\"ahler potential and K\"ahler corrections might not be known in all possible scenarios, but
our aim has been to constrain the coefficients of the non-renormalizable K\"ahler higher dimensional operators phenomenologically, which are gauge invariant,
from the recent Planck data. We assumed minimal K\"ahler potentials for all the fields to begin with.

We first considered the heavy physics to be completely
decoupled from the dynamics of the light inflaton field. We considered the light field to be
embedded within MSSM, such that the reheating of the universe is guaranteed to be that of the SM dof. In the simplest setup
when the heavy field is well settled down in its potential, it only affects via its vacuum energy density. The kinetic terms are mostly canonical, and therefore
we do not obtain any constraint on the coefficients of the dimensional 3 and 4 non-reormalizable K\"ahler operators.

We further investigated an intriguing possibility, when the heavy field is coherently oscillating with a frequency larger than the Hubble parameter during the onset of inflation, while
the light field is slowly rolling over the potential. In this particular scenario, we were able to constrain the coefficients of the Planck suppressed K\"ahler operators of dimensional
3 and 4. We scanned the four parameters, $a,~b,~,c~,d$, and obtained a region of the parameter space where we can satisfy the current Planck observations, i.e.
$P_S,~n_S,~c_s$ and $r_\star$ within 2σ~CL, and we obtained all the coefficients to be of order $a,~b,~c,~d\sim calO(1)$, as naturally expected in any non-rrenormalizable SUGRA theory.

Finally, we would like to mention that all the above bounds have been obtained for a very particular kind of inflation model, which
is fully embedded within MSSM, the inflaton is an MSSM flat direction and inflation happens at the point of inflection with a fine tuned parameter at the inflection point is roughly one part in 10^{-4}. We chose MSSM inflation for its advantage that the dynamics can be well understood during inflation and after inflation. In particularly, we can ascertain that the universe after inflation would be filled with the SM degrees of freedom, and also the model is capable of explaining the Higgs mass constraint and the dark matter abundance,
along with the constraints on the inflaton mass arising from the LHC. Not every model of inflation enjoys such advantages, and therefore studying this model in some details along with SUGRA corrections yielded interesting constraints. Our methodology can
be followed for other kinds of inflationary models too.

There is a further scope of improvement in our analysis. So far we have only used the Planck constraints from the power spectra, P_S, spectral tilt, n_S, tensor-to-scalar ratio,
$r_\star$, and the constraint on the speed of sound, c_s. Finally, using this methodology, I have obtained
the theoretical upper and lower bound on the non-Gaussian parameters within the range, $calO(1-5)\leq f_{NL}\leq 8.5$, $calO(75-150)\leq\tau_{NL}<2800$
and $calO(17.4-34.7)\leq g_{NL}\leq 648.2$, and the
CMB dipolar asymmetry parameter within, $0.05\leq A_{CMB}\leq 0.09$, which satisfy
the observational constraints, as obtained from Planck data. All these cosmological constraints arising from Planck and future CMB missions can further improve our understanding of many different aspects of physics beyond the SM.
With an improvement on tensor-to-scalar ratio, $r_\star$, we would be able to further constraint the scale of heavy physics, M_s.

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