Double field inflation from high energy theory

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Today’s Agenda

1. A Short review of inflation
2. Superstring inflation with a GVW term
3. Numerical Results

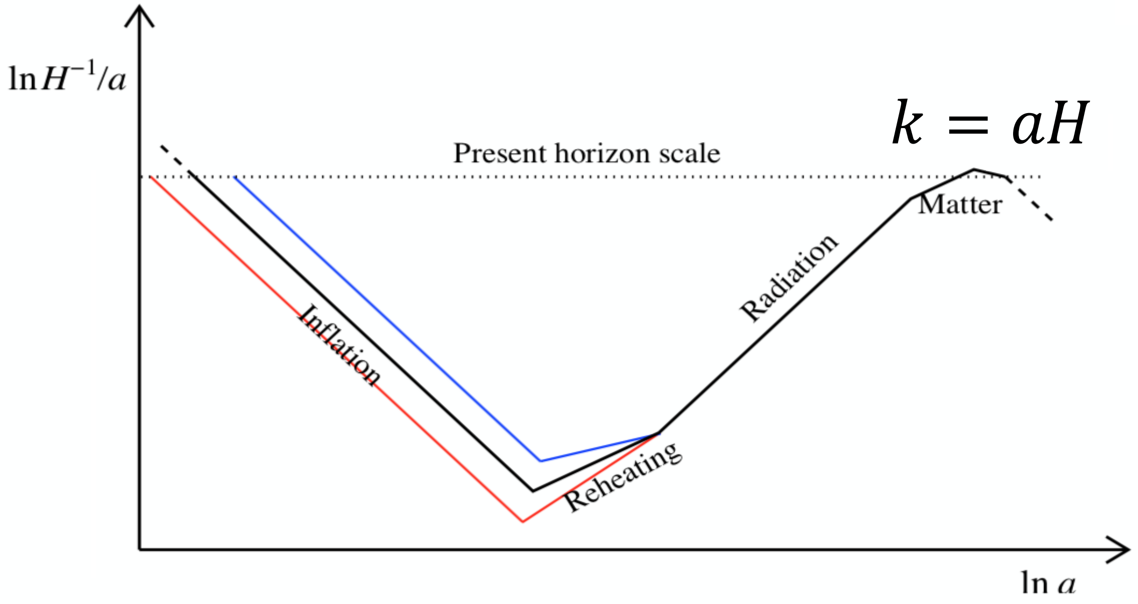
Inflation is adopted to solve flatness problem, horizon problem and monopole problem.

Inflaton contributes to the dynamics of inflation of our universe, and its fluctuations lead to power spectrum.

Verification: by evaluating slow-roll parameters, spectral index, its running and tensor-to-scalar ratio and comparing them with the observation

Starobinsky model: best prediction (so far)

Slow-roll parameters	Range(s)	Spectral indices	Range(s)
ϵ_V	< 0.004	$n_s - 1$	$[-0.0423, -0.0327]$
η_V	$[-0.021, -0.008]$	$\alpha_s := \frac{dn_s}{d\ln k}$	$[-0.008, 0.012]$
ξ_V	$[-0.0045, 0.0096]$	$\beta_s := \frac{d^2 n_s}{d\ln k^2}$	$[-0.003, 0.023]$
$H_{\rm hc}$	$< 2.5 \times 10^{-5} M_{\rm pl}$	$V_{\rm hc}$	$< \left(1.6 \times 10^{16}\ {\rm GeV}\right)^4$



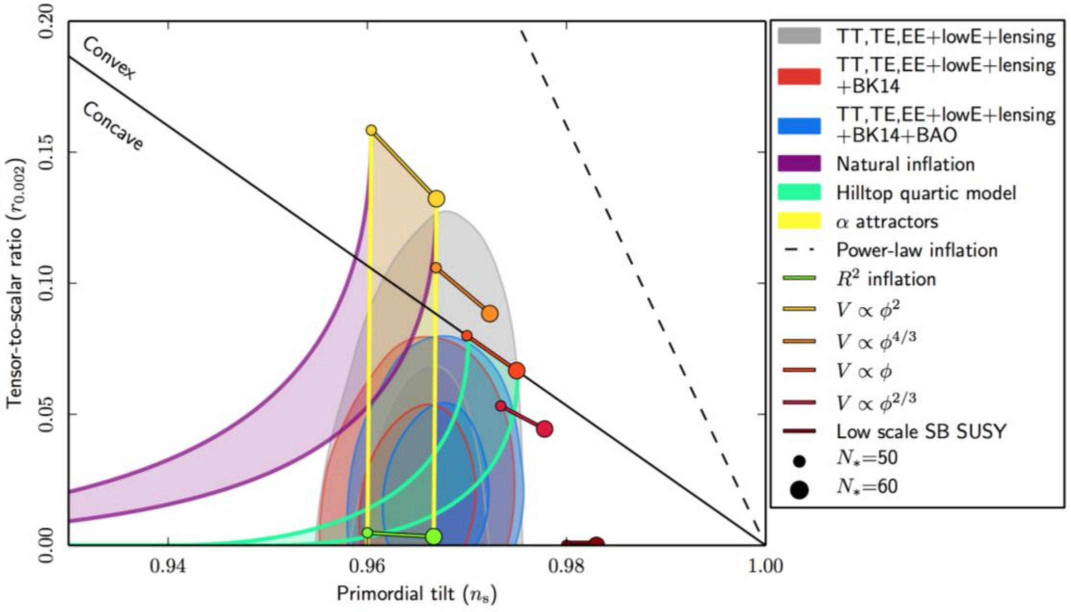


Fig. 8. Marginalized joint 68 % and 95 % CL regions for n_s and r at $k = 0.002\ \mathrm{Mpc}^{-1}$ from *Planck* alone and in combination with BK14 or BK14 plus BAO data, compared to the theoretical predictions of selected inflationary models. Note that the marginalized joint 68 % and 95 % CL regions assume $dn_s/d\ln k = 0$.

A. Guth 80', Planck 18'

Motivations of Superstring for inflation

- High energy theory is required for describing the initial process of inflation.
- Superstring theory is the most promising model for describing high energy physics.
- Moduli stabilization (since the universe is relatively stable after inflation): e.g. KKLT scenario

Phys. Rev. D 68 (2003) 046005,
hep-th/0309187,
hep-th/0511160,
hep-th/0512232,
0707.2671
hep-th/0606095

- String swampland constraints support

multi-field inflation

1807.04390
1903.06239

The target of this talk

- We propose an inflation model in Type IIB orienti-folds, which consists of a non-perturbative term and a Gukov-Vafa-Witten (GVW) super-potential.

- It gives a significant turning of the inflation trajectory, which can be one of the fingerprints to verify the correct inflation dynamics.

Basic setups and assumptions: GVW

- We consider the type IIB orientifolds, where Gukov-Vafa-Witten (GVW) super-potential defined in a 6 dimensional internal CY space X6 is

$$W_{\mathrm{GVW}} := \int_{\boldsymbol{X}_6} G_3 \wedge \Omega_3 = \int_{\boldsymbol{X}_6} (F_3 - iSH_3) \wedge \Omega_3.$$

S: dilaton field
Omega3: holomorphic 3 form
H3: NSNS 3 form field strength
F3: RR 3 form field strength

- complex structure moduli are much heavier than dilaton S and Kahler modulus T such that they are stabilized at their corresponding VEVs. Hence, GVW term becomes

$$W_{\mathrm{GVW}}(S) = C + BS.$$

where B and C are constants with respect to S and T.

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hep-th/0611039

Basic setups and assumptions: NP term and Kahler

- Also, non-perturbative (NP) terms (e.g. gaugino condensation and instanton effects) are present. For simplicity, we consider one non-perturbative term

$$W_{\rm NP} = \tilde{W}_0 + A e^{-(aT+bS)},$$

Tilde W0, A: constants w.r.t. S and T
a, b: constants

- Hence, the total super-potential becomes

$$W_0 := \tilde{W}_0 + C$$

$$W_{\rm total} = W_{\rm NP} + W_{\rm GVW} = W_0 + BS + Ae^{-(aT+bS)},$$

W0, B: constants w.r.t. S and T

- Kahler potential:

$$\frac{K}{M_{\rm pl}^2} = -\ln\left(\frac{S+\overline{S}}{M_{\rm pl}}\right) - 3\ln\left(\frac{T+\overline{T}}{M_{\rm pl}}\right),$$

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- F term potential:

$$V_F = e^{\frac{K}{M_{\rm pl}^2}}\left(K^{I\bar{J}} D_I W D_{\bar{J}} \bar{W} - \frac{3}{M_{\rm pl}^2}|W|^2\right)$$

-->

$$\begin{aligned} V_F(T,S) = \frac{M_{\rm pl}^2 e^{-a(\bar{T}+T)-b(\bar{S}+S)}}{3(\bar{S}+S)(\bar{T}+T)^3} \Big\{ & a^2 A\bar{A}(\bar{T}+T)^2 \\ & +3a(\bar{T}+T)\left[A\left(\bar{B}\bar{S}+\overline{W_0}\right)e^{a\bar{T}+b\bar{S}} + \bar{A}\left[(BS+W_0)e^{aT+bS}+2A\right]\right] \\ & +3\left[\left(\overline{W_0}-S\bar{B}\right)e^{a\bar{T}+b\bar{S}} + \bar{A}\left(b\bar{S}+bS+1\right)\right]\left[\left(W_0-B\bar{S}\right)e^{aT+bS} + Ab\bar{S}+AbS+A\right]\Big\} \end{aligned}$$

Further simplification of F term

$$V_F(T,S) = \frac{M_{\text{pl}}^2 e^{-a(\bar{T}+T)-b(\bar{S}+S)}}{3(\bar{S}+S)(\bar{T}+T)^3}\left\{a^2 A\bar{A}(\bar{T}+T)^2\right.$$
$$+3a(\bar{T}+T)\left[A(\bar{B}\bar{S}+\overline{W_0})e^{a\bar{T}+b\bar{S}}+\bar{A}\left[(BS+W_0)e^{aT+bS}+2A\right]\right]$$
$$\left.+3\left[(\overline{W_0}-S\bar{B})e^{a\bar{T}+b\bar{S}}+\bar{A}(b\bar{S}+bS+1)\right]\left[(W_0-B\bar{S})e^{aT+bS}+Ab\bar{S}+AbS+A\right]\right\}$$

- Spread T and S into real and imaginary parts

$$A = A_R + iA_I,\ B = B_R + iB_I,\ W_0 = W_R + iW_I$$

- Reduce the arguments into S and T --> AI = BI = WI = 0
- Final F term:

$$V_F(T_R,T_I,S_R,S_I) = \frac{e^{-2(aT_R+bS_R)}}{48M_{\text{pl}}S_R}\left(\frac{T_R^2}{M_{\text{pl}}^2}\right)^{-3/2}\left\{6A_R e^{aT_R+bS_R}\left[\cos(aT_I+bS_I)\left[B_R S_R(2aT_R-2bS_R-1)\right.\right.\right.$$
$$\left.+W_R(2aT_R+2bS_R+1)\right]-B_R S_I(2aT_R+2bS_R+1)\sin(aT_I+bS_I)\Big]+A_R^2\left[(2aT_R+3)^2\right.$$
$$\left.\left.+12bS_R(bS_R+1)-6\right]+3e^{2(aT_R+bS_R)}\left[B_R^2(S_I^2+S_R^2)-2B_R S_R W_R+W_R^2\right]\right\}.$$

E.O.M.s

- Bosonic part of SUGRA Lagrangian: $\mathcal{L} = \sqrt{-g}\mathcal{L}_{\rm SUGRA} = \sqrt{-g}\left[\frac{M_{\rm pl}^2}{2}R - K_{i\bar{j}}\nabla_\mu\phi^i\nabla^\mu\bar{\phi}^{\bar{j}} - V\right],$
- Original kinetic term:

$$K_{i\bar{j}}\nabla_\mu\phi^i\nabla^\mu\bar{\phi}^{\bar{j}} = \frac{\rho M_{\rm pl}^2}{(T+\bar{T})^2}\nabla_\mu T\nabla^\mu\bar{T} + \frac{M_{\rm pl}^2}{(S+\bar{S})^2}\nabla_\nu S\nabla^\nu\bar{S}$$

$$= \frac{\rho M_{\rm pl}^2}{4T_R^2}\left(\nabla_\mu T_R\nabla^\mu T_R + \nabla_\mu T_I\nabla^\mu T_I\right) + \frac{M_{\rm pl}^2}{4S_R^2}\left(\nabla_\mu S_R\nabla^\mu S_R + \nabla_\mu S_I\nabla^\mu S_I\right).$$

i = 1,2
V = F term
rho = 3

- We consider the imaginary parts of S and T contribute to inflation and we fix TR and SR to some values.
- Hence, kinetic term becomes

$$K_{i\bar{j}}\nabla_\mu\phi^i\nabla^\mu\bar{\phi}^{\bar{j}} = \frac{\rho M_{\rm pl}^2}{4T_R^2}\nabla_\mu T_I\nabla^\mu T_I + \frac{M_{\rm pl}^2}{4S_R^2}\nabla_\mu S_I\nabla^\mu S_I,$$

- E.O.M.s:

$$-\left(\ddot{T}_{Ib} + 3H\dot{T}_{Ib}\right) - \frac{2T_{Rb}^2}{\rho M_{\rm pl}^2}\left.V_{T_I}\right|_b = 0,$$

$$-\left(\ddot{S}_{Ib} + 3H\dot{S}_{Ib}\right) - \frac{2S_{Rb}^2}{M_{\rm pl}^2}\left.V_{S_I}\right|_b = 0.$$

→

$$H^2\left[T_{Ib}'' + (3-\epsilon)\,T_{Ib}'\right] + \frac{2T_{Rb}^2}{\rho M_{\rm pl}^2}\left.V_{T_I}\right|_b = 0,$$

$$H^2\left[S_{Ib}'' + (3-\epsilon)\,S_{Ib}'\right] + \frac{2S_{Rb}^2}{M_{\rm pl}^2}\left.V_{S_I}\right|_b = 0,$$

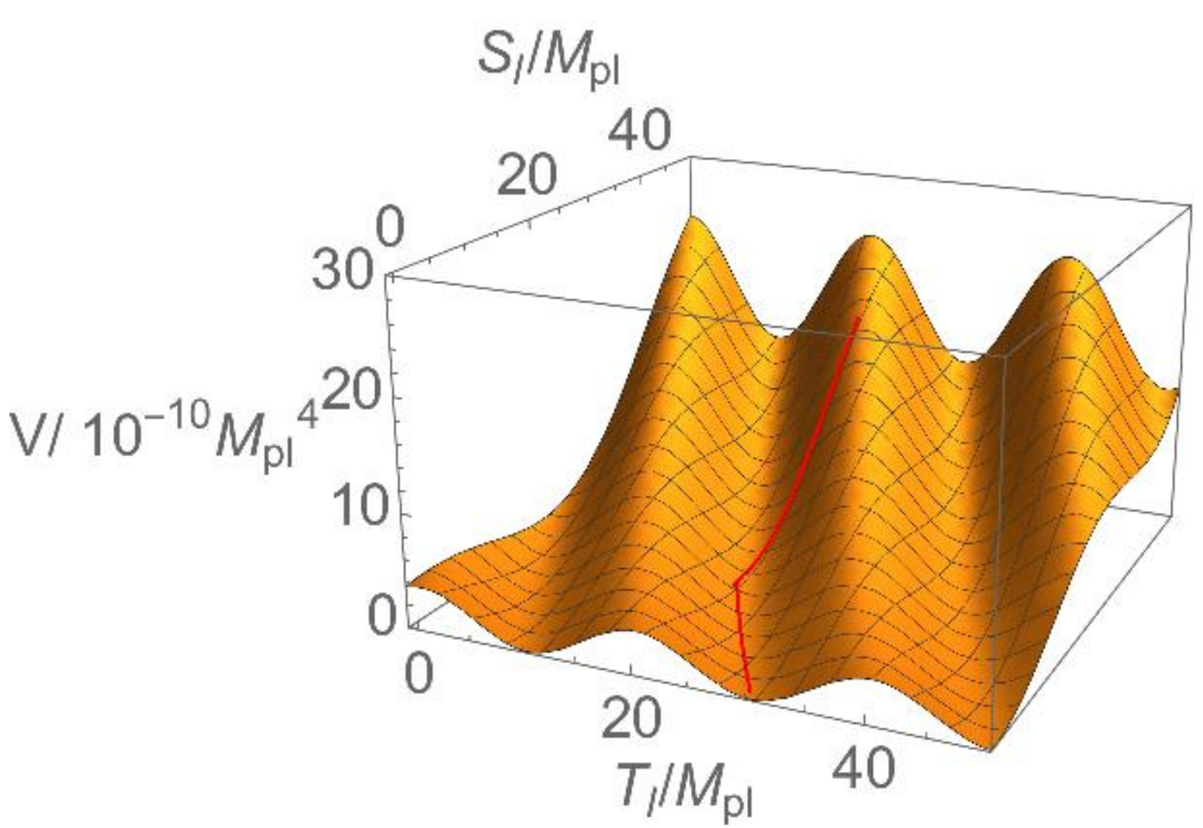
dot: time derivative,
slash b: evaluated at the bk values

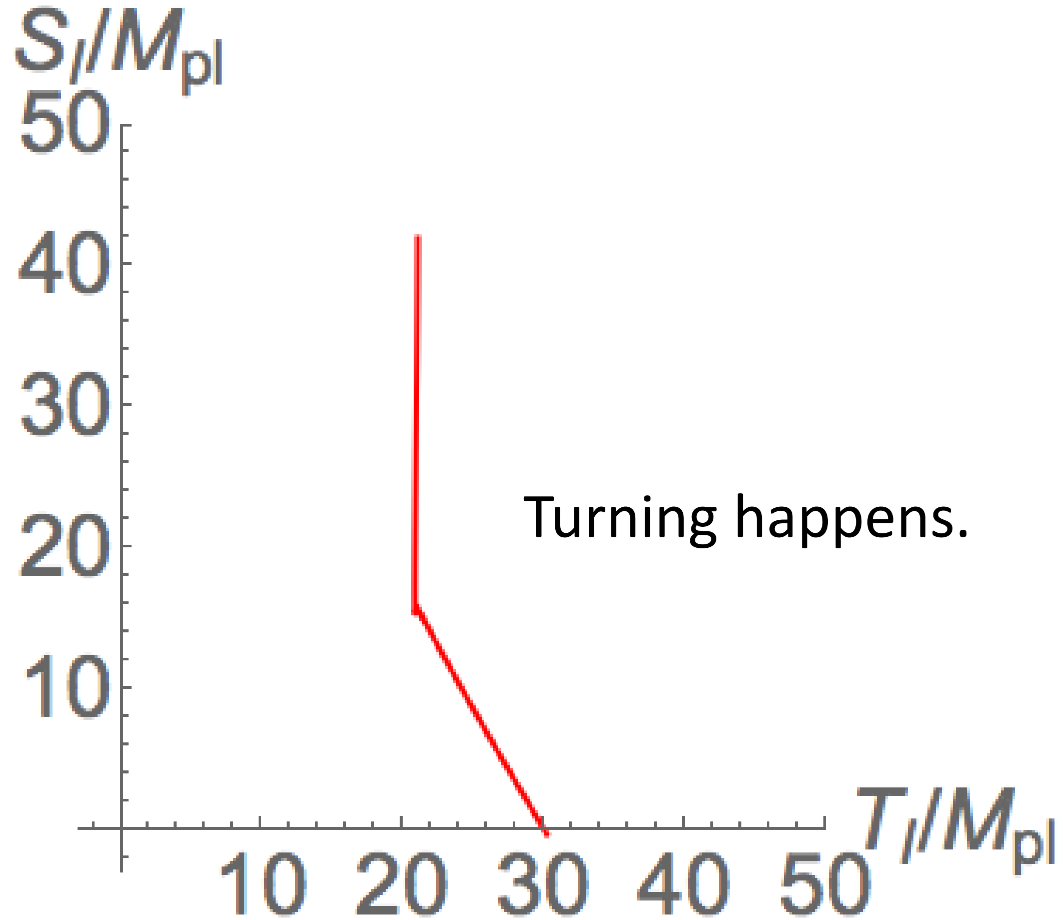
prime: e-folding derivative
(For observation comparison)

Numerical results

ρ	N_{initial}	A_I/M_{pl}	B_I/M_{pl}	W_I/M_{pl}	$T'_R(N)$	$T'_I(N=0)$	$S'_R(N)$	$S'_I(N=0)$
3	0	0	0	0	0	10^{-5}	0	10^{-5}

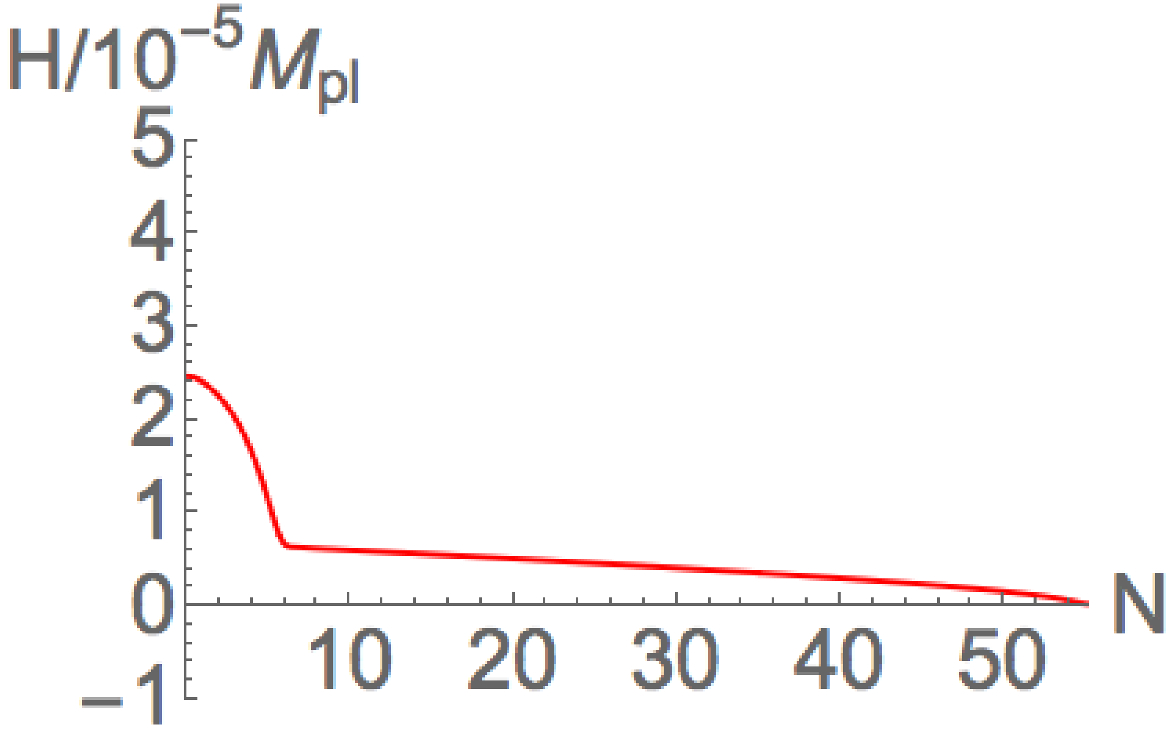
T_R	$T_{I\text{ini}}$	S_R	$S_{I\text{ini}}$	$T_{I\text{end}}$	$S_{I\text{end}}$	$V_{\text{min}}/M_{\text{pl}}^4$	A_R/M_{pl}	B_R/M_{pl}	W_R/M_{pl}	a/M_{pl}^{-1}	b/M_{pl}^{-1}	N_{end}
0.7825	21	5	42	30.0419	2.15291×10^{-10}	1.31976×10^{-13}	3.61×10^{-5}	5×10^{-6}	10.11×10^{-5}	$2\pi/20$	$2\pi/58$	54.461



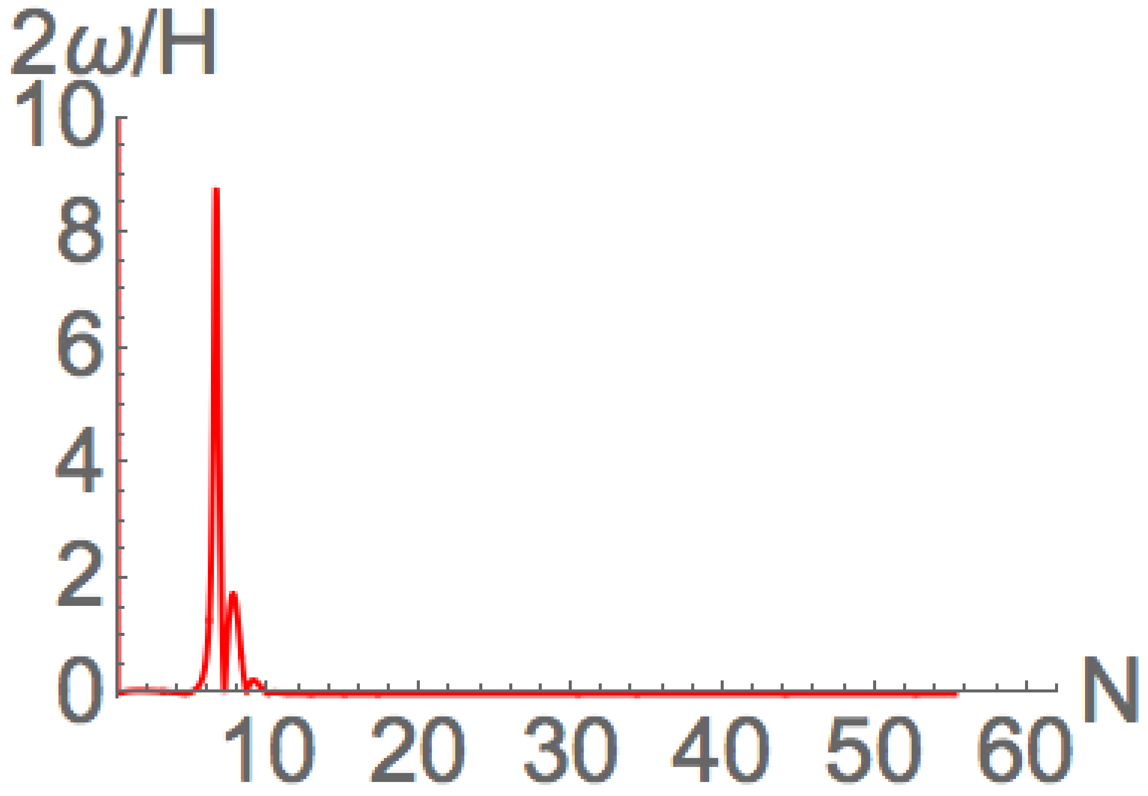


Turning happens.

Numerical Results



Ratio of turning rate to Hubble scale



For the definition of turning rate, please refer to arXiv: 1310.8285.

Conclusions and future work

- We study double field (TI and SI) inflation dynamics of superstring theory with a GVW term and non-perturbative term.
- There exists a significant turning in the inflation trajectory such that the ratio of turning rate to Hubble is of scale O(1).

- Investigation of effective mass of entropic perturbation, which is the probe to show the change of curvature of the potential.
- Check of other possible parameters to realize successful inflation.

- We hope that turning rate per Hubble can be one of the observables so as to verify the correct inflation model.