Pole Inflation in Jordan Frame SUGRA

Daisuke Yoshida (McGill)

Based on arXiv:1709.03440 with

Ken'ichi Saikewa (DESY),
Masahide Yamaguchi (Tokyo Institute of Technology),
Yasuho Yamashita (Yukawa Institute of Theoretical Physics(YITP))

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Outline

1. Basics of Pole Inflation

2. J-sugra and FKLMP Inflation Model

3. Pole Inflation in J-sugra Beyond FKLMP model

1. Basics of Pole Inflation

2. J-sugra and FKLMP Inflation Model

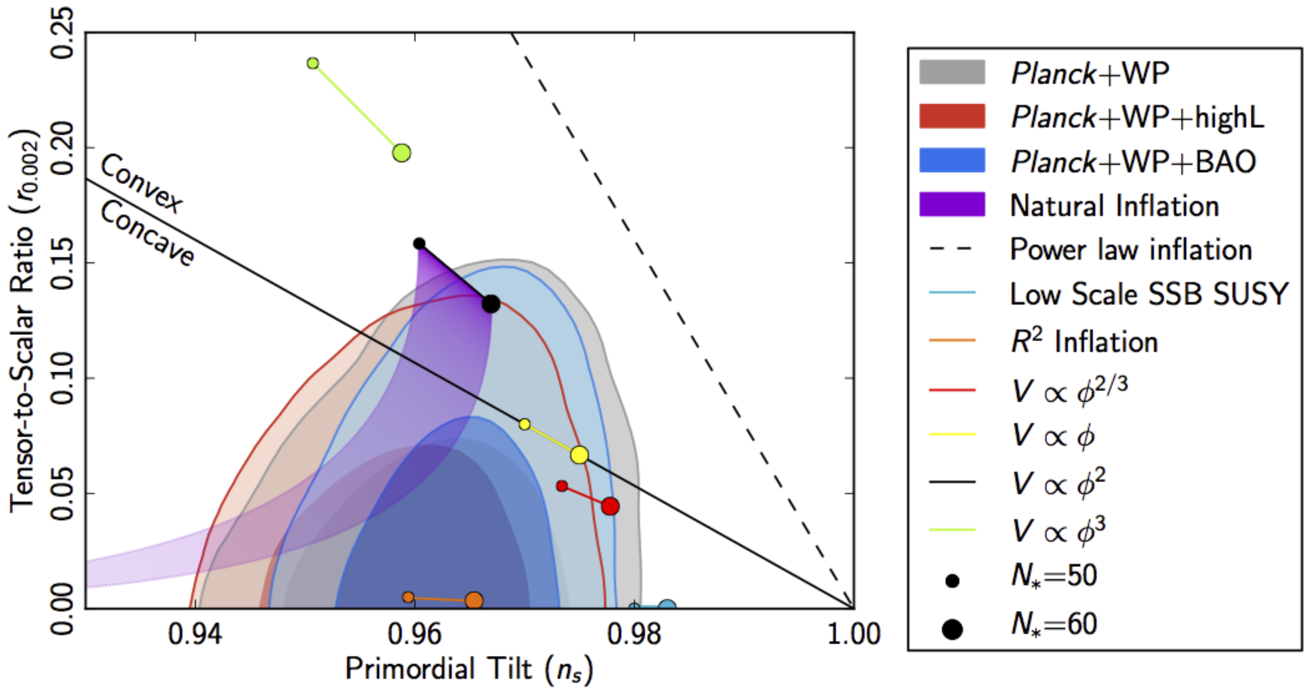
3. Pole Inflation in J-sugra Beyond FKLMP model

Observation about Inflation

- Observation of CMB gives us much information about inflation!

  - Curvature power spectrum: $P_\zeta \sim O(10^{-10})$
  - Tensor to scalar ratio: $r < 0.15$
  - Spectral index: $n_s \sim 0.96$

arXiv:1502.02114, Planck collaboration



Basics of Slow Roll Inflation 1

- Simplest inflation model with canonical scalar field:

$$S = \int d^4x\sqrt{-g}\left[\frac{1}{2}R - \frac{1}{2}(\nabla\phi)^2 - V(\phi)\right]$$

- Inflation occurs when slow roll parameters are sufficiently small;

$$\epsilon = \frac{1}{2}\left(\frac{V'}{V}\right)^2 \ll 1,\ \eta = \frac{V''}{V} \ll 1$$

- Slow-roll inflation gives predictions in terms of a potential

$$P_\zeta = \frac{V}{24\pi^2\epsilon},\ n_s = 1 + 2\eta - 6\epsilon,\ r = 16\epsilon$$

Basics of Slow Roll Inflation 2

- Predictions strongly depend on potential:

$$P_\zeta = \frac{V}{24\pi^2\epsilon}, \; n_s = 1 + 2\eta - 6\epsilon, \; r = 16\epsilon$$

$$\epsilon = \frac{1}{2}\left(\frac{V'}{V}\right)^2 \ll 1, \; \eta = \frac{V''}{V} \ll 1$$

- Example: power law potential $V(\phi) = g\phi^n$,

  Number of e-folding is given by

$$N(\phi) := \log(a_e/a(\phi)) = \int_{\phi_e}^{\phi} d\phi \frac{V}{V'} \sim \frac{1}{2n}\phi^2$$

  - n_s and r can be represented by N as

$$n_s = 1 - \frac{n+2}{2N}, \; r = \frac{4n}{N}$$

  - This model is excluded from the observation.

$$r = \frac{8n}{n+2}(1 - n_s) \sim \frac{8n}{n+2} \times 0.04 = \begin{cases} 0.16 \text{ for } n = 2 \\ 0.19 \text{ for } n = 3 \end{cases}$$

Pole Inflation

- pole inflation: inflation driven by the pole in kinetic term

Galante, Kallosh, Linde, Rosest (2015)

$$S = \int d^4x\sqrt{-g}\left[\frac{1}{2}R - \frac{1}{2}K(\rho)(\nabla\rho)^2 - V(\rho)\right]$$

- Kinetic term has a pole:

$$K(\rho) = \frac{a_p}{\rho^p}\left(1 + \mathcal{O}(\rho)\right)$$

- Potential is finite at pole:

$$V(\rho) = V_0(1 - c\rho + \mathcal{O}(\rho^2))$$

- Ideas

In terms of canonically normalized field, potential is stretched near pole.

→
- Flat potential is realized!
- Predictions do not depend on the detail of potential!

Prediction of pole inflation with p = 2

- Let us derive the prediction of pole inflation with p=2

$$S=\int d^4x\sqrt{-g}\left[\frac{1}{2}R-\frac{1}{2}K(\rho)(\nabla\rho)^2-V(\rho)\right]$$

$$K(\rho)=\frac{a_2}{\rho^2}(1+\mathcal{O}(\rho))$$

$$V(\rho)=V_0(1-c\rho+\mathcal{O}(\rho^2))$$

$$\phi=\mathrm{e}^{-\frac{\rho}{\sqrt{a_2}}}$$

$$S=\int d^4x\sqrt{-g}\left[\frac{1}{2}R-\frac{1}{2}(\nabla\phi)^2-V(\mathrm{e}^{-\frac{\phi}{\sqrt{a_2}}})\right]$$

- By using the result of slow-roll inflation, we obtain

$$N(\phi)=\int_{\phi_e}^{\phi}d\phi\frac{V}{V'}\sim\frac{a_2}{c}\mathrm{e}^{\frac{\phi}{\sqrt{a_2}}}\qquad \epsilon=\frac{1}{2}\left(\frac{V'}{V}\right)=\frac{a_2}{2}\frac{1}{N}\qquad \eta=\frac{V''}{V}=-\frac{1}{N}$$

at $\rho\to 0,\phi\to\infty,N\to\infty$

and

$$P_\zeta=\frac{V_0}{24\pi^2}\frac{2N^2}{a_2},\ n_s=1-\frac{1}{N},\ r=\frac{8a_2}{N^2}$$

Predictions do not depend on the detail of potential and coincide with observation with $a_2\sim O(1)$. $(n_s\sim 0.96\ \to r\sim a_2 * 0.013)$

Pole inflation from Jordan frame

- *IF* fundamental physics prefer to Jorden frame,
  it would be natural inflaton has the canonical kinetic term there.

  This setting naturally leads to non-trivial kinetic term in Einstein frame!

$$\mathcal{L} = \sqrt{-g_J}\left(f(\rho) R^J - \frac{1}{2} g_J^{\mu\nu} \partial_\mu \rho \partial_\nu \rho - V_J(\rho) \right)$$

$$g_J^{\mu\nu} = f g_E^{\mu\nu}$$

$$\mathcal{L} = \sqrt{-g_E}\left(\frac{1}{2} R^E - K(\rho) g_E^{\mu\nu} \partial_\mu \rho \partial_\nu \rho + \cdots \right)$$

  So it would be possible to realize pole inflation in this frame work.

- We investigate this mechanism based on Jorden frame supergravity.

1. Basics of Pole Inflation

2. J-sugra and FKLMP Inflation Model

3. Pole Inflation in J-sugra Beyond FKLMP model

Bosonic part of J-SUGRA

- Action of bosonic part of Jordan frame super gravity (without gauge fields)

$$\frac{\mathcal{L}}{\sqrt{-g_J}} = -\frac{1}{6}\Phi R_J + \left(\frac{1}{3}\Phi g_{\alpha\bar{\beta}} - \frac{\Phi_\alpha \Phi_{\bar{\beta}}}{\Phi}\right) g_J^{\mu\nu}\partial_\mu z^\alpha \partial_\nu \bar{z}^{\bar{\beta}}$$
$$- \frac{1}{4\Phi}\left(\Phi_\alpha \partial_\mu z^\alpha - \Phi_{\bar{\beta}}\partial_\mu \bar{z}^{\bar{\beta}}\right)\left(\Phi_\gamma \partial_\nu z^\gamma - \Phi_{\bar{\delta}}\partial_\nu \bar{z}^{\bar{\delta}}\right) g_J^{\mu\nu} - V_J$$

- Dynamical variables;

z^α : complex scalar fields

$g^J_{\mu\nu}$: space time metric in Jordan frame

$$g_{\alpha\bar{\beta}} = \partial_\alpha \partial_{\bar{\beta}} \mathcal{K}$$
$$V_J = \frac{1}{9}\Phi^2 \mathrm{e}^{\mathcal{K}}\left(-3W\bar{W} + g^{\alpha\bar{\beta}}\nabla_\alpha W \nabla_{\bar{\beta}}\bar{W}\right)$$
$$\nabla_\alpha W = \partial_\alpha W + (\partial_\alpha \mathcal{K})W$$
$$\Phi_\alpha = \partial_\alpha \Phi$$

- Arbitrary functions in theory;
  - Khaler potential $\mathcal{K}(z^\alpha, \bar{z}^{\bar{\beta}})$
  - Super potential $W(z^\alpha, \bar{z}^{\bar{\beta}})$
  - Frame function $\Phi(z^\alpha, \bar{z}^{\bar{\beta}})$

Einstein Frame SUGRA

- Einstein frame SUGRA is obtained by conformal transformation of metric

$$\frac{\mathcal{L}}{\sqrt{-g_J}} = -\frac{1}{6}\Phi R_J + \left(\frac{1}{3}\Phi g_{\alpha\bar{\beta}} - \frac{\Phi_\alpha \Phi_{\bar{\beta}}}{\Phi}\right) g_J^{\mu\nu} \partial_\mu z^\alpha \partial_\nu \bar{z}^{\bar{\beta}}$$
$$- \frac{1}{4\Phi}\left(\Phi_\alpha \partial_\mu z^\alpha - \Phi_{\bar{\beta}} \partial_\mu \bar{z}^{\bar{\beta}}\right)\left(\Phi_\gamma \partial_\nu z^\gamma - \Phi_{\bar{\delta}} \partial_\nu \bar{z}^{\bar{\delta}}\right) g_J^{\mu\nu} - V_J$$

$$\Downarrow \quad g^E_{\mu\nu} = -\frac{1}{3}\Phi g^J_{\mu\nu}$$

$$\frac{\mathcal{L}}{\sqrt{-g_E}} = \frac{1}{2} R_E - g_{\alpha\bar{\beta}} g_E^{\mu\nu} \partial_\mu z^\alpha \partial_\nu \bar{z}^{\bar{\beta}} - V_E$$

$$g_{\alpha\bar{\beta}} = \partial_\alpha \partial_\beta \mathcal{K}$$
$$V_E = \mathrm{e}^{\mathcal{K}}\left(-3W\bar{W} + g^{\alpha\bar{\beta}} \nabla_\alpha W \nabla_{\bar{\beta}} \bar{W}\right)$$

- Frame function does not appear.

$\mathcal{K}(z^\alpha, \bar{z}^{\bar{\beta}})$, $W(z^\alpha, \bar{z}^{\bar{\beta}})$: arbitrary function of Einstein frame SUGRA

$\Phi(z^\alpha, \bar{z}^{\bar{\beta}})$: Function to characterize Jordan frame

FKLMP model

S.Ferrara, R.Kallosh, A.Linde, A.Marrani, A. Van Proeyen (2010)

- Inflation model in Jordan frame super gravity.

- FKLMP model

$$\mathcal{K}(z,\bar{z}) = -3\log\left(-\frac{1}{3}\Phi\right)$$

$$\Phi(z,\bar{z}) = -3 + \delta_{\alpha\bar{\beta}} z^\alpha \bar{z}^{\bar{\beta}} + J(z) + \bar{J}(\bar{z})$$

Assuming fields configuration satisfies

$$z^\alpha = \bar{z}^{\bar{\alpha}} \qquad \Phi_\alpha \partial_\mu z^\alpha - \Phi_{\bar{\beta}} \partial_\mu \bar{z}^{\bar{\beta}} = 0$$

$$\Rightarrow \quad \frac{\mathcal{L}}{\sqrt{-g_J}} = -\frac{1}{6}\Phi R_J - \delta_{\alpha\bar{\beta}} g_J^{\mu\nu} \partial_\mu z^\alpha \partial_\nu \bar{z}^{\bar{\beta}} - V_J$$

Scalar fields have canonical kinetic terms !

- In original paper, author investigate Higgs inflation in the context of NMSSM.
Here we focus on simpler toy model than realistic Higgs inflation.

FKLMP model with Single Scalar Field

- Let us focus on FKLMP model with single field: $z^\alpha = \phi$

$$\mathcal{K} = -3\log\left(-\frac{1}{3}\Phi\right)$$

$$\Phi(\phi,\bar{\phi}) = -3 + \phi\bar{\phi} + J(\phi) + \bar{J}(\bar{\phi})$$

$$\phi = \bar{\phi} = \frac{\varphi}{\sqrt{2}}$$

- For simplicity we focus on following choice of $J(\phi)$:

$$J(\phi) = -3\left(\frac{1}{6} + \xi\right)\phi^2$$

- Now action reduces to simple form:

$$\frac{\mathcal{L}}{\sqrt{-g_J}} = \frac{1}{2}\left(1 + \xi\varphi^2\right)R_J - \frac{1}{2}g_J^{\mu\nu}\partial_\mu\varphi\partial_\nu\varphi - V_J$$

FKLMP model as Pole Inflation

- ξ model in Jordan frame:

$$\frac{\mathcal{L}}{\sqrt{-g_J}} = \frac{1}{2}\left(1+\xi\varphi^2\right)R_J - \frac{1}{2}g_J^{\mu\nu}\partial_\mu\varphi\partial_\nu\varphi - V_J$$

- ξ model in Einstein frame $\quad g_{\mu\nu}^E = (1+\xi\varphi^2)g_{\mu\nu}^J$

$$\frac{\mathcal{L}}{\sqrt{-g_E}} = \frac{1}{2}R_E - \frac{1}{2}K_E(\varphi)g_E^{\mu\nu}\partial_\mu\varphi\partial_\nu\varphi - \frac{V_J}{(1+\xi\varphi^2)^2}$$

Kinetic term has pole at $\varphi \to \infty$ ⟶ pole at $\rho = 0$ with $\quad \rho = (1+\xi\varphi^2)^{-1}$

$$K_E(\varphi)(\partial\varphi)^2 = \frac{2(1+\xi\varphi^2)+12\xi^2\varphi^2}{2(1+\xi\varphi^2)^2}(\partial\varphi)^2 = \left(\frac{1}{4\xi}+\frac{3}{2}\right)\frac{(\partial\rho)^2}{\rho^2} + \frac{\rho^2}{\rho'^2}$$

- V_E does not diverge or vanish at pole if $V_J \propto \varphi^4$.

  Pole inflation works well:

$$n_s = 1 - \frac{2}{N}, \qquad r = \frac{8}{N^2}\left(\frac{1}{4\xi}+\frac{3}{2}\right)$$

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Beyond FKLMP

FKLMP approach

$\mathcal{K},\ \Phi,\ W$ →

- Canonical Kinetic terms in Jordan Frame
- Pole inflation

Is FKLMP model unique one which satisfy these 2 conditions?

Our approach

- Canonical Kinetic terms in Jordan frame
- Pole inflation

→ What conditions are imposed for $\mathcal{K},\ \Phi,\ W$?

Note: with FKLMP frame function

- Action of J-frame sugra:

$$\frac{\mathcal{L}}{\sqrt{-g_J}} = -\frac{1}{6}\Phi R_J + \left(\frac{1}{3}\Phi g_{\alpha\bar{\beta}} - \frac{\Phi_\alpha \Phi_{\bar{\beta}}}{\Phi}\right) g_J^{\mu\nu} \partial_\mu z^\alpha \partial_\nu \bar{z}^{\bar{\beta}}$$
$$- \frac{1}{4\Phi}\left(\Phi_\alpha \partial_\mu z^\alpha - \Phi_{\bar{\beta}} \partial_\mu \bar{z}^{\bar{\beta}}\right)\left(\Phi_\gamma \partial_\nu z^\gamma - \Phi_{\bar{\delta}} \partial_\nu \bar{z}^{\bar{\delta}}\right) g_J^{\mu\nu} - V_J$$

-

  - FKLMP frame function: $\Phi(z,\bar{z}) = -3 + \delta_{\alpha\bar{\beta}} z^\alpha \bar{z}^{\bar{\beta}} + J(z) + \bar{J}(\bar{z})$
  - canonical kinetic term: $\frac{1}{3}\Phi g_{\alpha\bar{\beta}} - \frac{\Phi_\alpha \Phi_{\bar{\beta}}}{\Phi} = -\delta_{\alpha\bar{\beta}}$

→

$$\delta\mathcal{K} := \mathcal{K} + 3\log\left(-\frac{1}{3}\Phi\right)$$

$$\delta\mathcal{K}_{\alpha\bar{\beta}} = 0 \qquad \delta\mathcal{K} = h(z) + \bar{h}(\bar{z})$$

This is nothing but Kahler transformation from FKLMP Kahler potential!

Non holomorphic extensions are necessary to obtain beyond FKLMP model.

$$\Phi(z,\bar{z}) = -3 + \delta_{\alpha\bar{\beta}} z^\alpha \bar{z}^{\bar{\beta}} + J(z,\bar{z})$$

Our Frameworks

- We consider following class of arbitrary functions with 2 scalar fields:

$$\mathcal{K} = \mathcal{K}(\phi + \bar{\phi}, S\bar{S}, S^2, \bar{S}^2),$$
$$\Phi = \Phi(\phi + \bar{\phi}, S\bar{S}, S^2, \bar{S}^2),$$
$$W = Sf(\phi)$$

- Inflaton direction:

$$\phi = \bar{\phi} = \frac{\varphi}{\sqrt{2}}, \ S = \bar{S} = 0$$

- Note: stabilizer field S is needed to ensure positivity of the potential;

Kawasaki, Yamaguchi, Yanagida (2000)

$$V_E = \mathrm{e}^{\mathcal{K}} \left(-3W\bar{W} + g^{\alpha\bar{\beta}} \nabla_\alpha W \nabla_{\bar{\beta}} \bar{W} \right)$$

Negative term vanishes at S = 0

$$= \mathrm{e}^{\mathcal{K}} g^{S\bar{S}} |f|^2$$ on inflaton trajectory

Conditions for Pole Inflation

- Our 3 conditions:
  - Inflation and stabilizer fields have canonical kinetic term in Jorden frame:

$$\frac{\Phi}{3} g_{\phi\bar{\phi}} - \frac{\Phi_\phi \Phi_{\bar{\phi}}}{\Phi} = -1 \quad \Longrightarrow \quad g_{\phi\bar{\phi}} = \frac{3}{\Phi}\left(\frac{\Phi'(\varphi)^2}{2\Phi} - 1\right)$$

$$\frac{\Phi}{3} g_{S\bar{S}} = -1 \quad \Longrightarrow \quad g_{S\bar{S}} = -\frac{3}{\Phi}$$

  - Kinetic term of inflaton in Einstein frame has pole structure:

$$-\frac{1}{2} g_{\phi\bar{\phi}} (\partial\varphi)^2 \to -\frac{1}{2}\frac{a_p}{\rho^p}(\partial\rho)^2 \quad \Longrightarrow \quad g_{\phi\bar{\phi}} \to \frac{a_p}{\rho(\varphi)^p}\rho'(\varphi)^2$$

at $\rho \to 0$ with some function $\rho(\varphi)$

  - Inflaton potential in Einstein frame is smooth at the pole:

$$V_E = -\frac{\Phi}{3} e^{\mathcal{K}} |f|^2 \to V_0(1 - c\rho + \cdots)$$

Strategy

- Differential equation,

$$g_{\phi\bar{\phi}} = \frac{3}{\Phi}\left(\frac{\Phi'(\varphi)^2}{2\Phi} - 1\right) \qquad g_{\phi\bar{\phi}} = \frac{a_p}{\rho(\varphi)^p}\rho'(\varphi)^2$$

$$\rightarrow \quad (\rho'(\varphi))^2 = \frac{-2\Phi}{\frac{2a_p}{3\rho^p}\Phi^2 - (\partial_\rho\Phi)^2}$$

1. Assuming functional form of $\Phi(\rho)$, solve above differential equation:

$$\rho = \rho(\varphi) \quad \longrightarrow \quad \Phi = \Phi(\varphi)$$

2. Determine a Kahler potential through

$$g_{\phi\bar{\phi}} = \frac{3}{\Phi}\left(\frac{\Phi'(\varphi)^2}{2\Phi} - 1\right) \qquad g_{S\bar{S}} = -\frac{3}{\Phi}$$

3. Determine super potential f through

$$-\frac{\Phi}{3}e^{\mathcal{K}}|f|^2 \to V_0(1 - c\rho + \cdots)$$

1.Solve differential equation

1. Assuming functional form of $\Phi(\rho)$, solve differential equation:

- Assuming $p = 2$ and $\Phi(\rho) \to -A\rho^{-2}$, our differential equation reduces to

$$(\rho'(\varphi))^2 = \frac{-2\Phi}{\frac{2a_p}{3\rho^p}\Phi^2 - (\partial_\rho \Phi)^2} \quad \Rightarrow \quad \rho'^2 = \tilde{\xi}\frac{\rho^4}{A}$$

with $\tilde{\xi} = \dfrac{3}{a_2 - 6}$

- Solutions can be written as

$$\rho(\varphi) = \frac{A}{\sqrt{\tilde{\xi}}(C + \varphi)}$$

with integration constant *C*

- Then frame function can be obtained as

$$\Phi(\varphi) = -\tilde{\xi}C^2\left(1 + \frac{1}{C}\varphi\right)^2 = -3\left(1 + \sqrt{\frac{\tilde{\xi}}{3}}\varphi\right)^2$$

Here integration constant is chosen as

$$C = \sqrt{3/\tilde{\xi}}$$

so that $\dfrac{\mathcal{L}}{\sqrt{-g_J}} \supset -\dfrac{\Phi}{6}R^J = \dfrac{1}{2}R^J + \text{nonminimal couplings}$

2. Determine a Kahler potential

$$g_{\phi\bar{\phi}} = \frac{3}{\Phi}\left(\frac{\Phi'(\varphi)^2}{2\Phi} - 1\right)$$

$$g_{\phi\bar{\phi}} = \partial_\phi \partial_{\bar{\phi}} \mathcal{K} = \frac{1}{2}\partial_\varphi \partial_\varphi \mathcal{K}(\varphi)$$

$$\Phi(\varphi) = -3\left(1 + \sqrt{\frac{\tilde{\xi}}{3}}\varphi\right)^2$$

$$\mathcal{K} = -12\left(1 + \frac{1}{2\tilde{\xi}}\right)\log\left(1 + \sqrt{\frac{\xi}{3}}\varphi\right)$$

on inflaton trajectory

$$\phi = \bar{\phi} = \frac{\varphi}{\sqrt{2}}, \quad S = \bar{S} = 0$$

$$\mathcal{K} = -12\left(1 + \frac{1}{2\tilde{\xi}}\right)\log\left(1 + \sqrt{\frac{\xi}{6}}\left(\phi + \bar{\phi}\right)\right)$$

Note: here S dependence are omitted.

3.Determine a super potential

3. Determine a super potential $W = Sf(\phi)$

- Function f can be determined from the requirement

$$V_E = -\frac{\Phi}{3} e^{\mathcal{K}} |f|^2 \to V_0(1 - c\rho + \cdots) \qquad \text{at } \rho \to 0$$

- Left hand side can be evaluated as

$$V_E = -\left(1 + \sqrt{\frac{\tilde{\xi}}{3}}\varphi\right)^{-10-\frac{6}{\xi}} |f|^2$$

- In order for V_E to be constant at $\varphi \to \infty$ ($\rho \to 0$),

$$f(\phi) = \lambda\phi^m \qquad \text{with} \quad m = 5 + \frac{3}{\tilde{\xi}}$$

$$V_E \to |\lambda|^2 \left(\frac{3}{2\tilde{\xi}}\right)^m \left(1 - 2m\sqrt{\frac{3(1+2\tilde{\xi})}{A}}\rho + \cdots\right) \qquad \text{at } \rho \to 0$$

Note: Consistency check

- We assumed following two conditions;
  - Stabilizer field also has canonical kinetic term in Jordan frame:

$$g_{S\bar{S}} = -\frac{3}{\Phi}$$

  - Inflaton direction is $Re\ \phi$.

$$\phi - \bar{\phi} = S = \bar{S} = 0$$

- These two conditions are satisfied if we includes S dependence in Kahler potential as

$$\mathcal{K} = -3\log\left[\left(1+\sqrt{\frac{\tilde{\xi}}{6}}(\phi+\bar{\phi})\right)^2 - \frac{1}{3}|S|^2\right] - 6\left(1+\frac{1}{\tilde{\xi}}\right)\log\left(1+\sqrt{\frac{\tilde{\xi}}{6}}(\phi+\bar{\phi})\right) - \frac{3}{4}\zeta|S|^4$$

$$\frac{m^2_{Im(\phi)}}{H^2_{inf}} = \frac{2(3+5\tilde{\xi})}{1+2\tilde{\xi}} > 1 \qquad \frac{m_S^2}{H^2_{inf}} = \zeta\tilde{\xi}^2\varphi^4 \gg 1$$

$$H^2_{inf} = V_E/3 = \frac{|\lambda|^2}{3}\left(\frac{3}{2\tilde{\xi}}\right)^m$$

→ Masses of $\mathrm{Im}(\phi)$ and S are sufficiently large!

Results

- We have derived all arbitrary functions of Jordan frame supergravity;

$$\Phi(\varphi) = -3\left(1+\sqrt{\frac{\tilde{\xi}}{6}}(\phi+\bar{\phi})\right)^2$$

$$\mathcal{K} = -12\left(1+\frac{1}{2\tilde{\xi}}\right)\log\left(1+\sqrt{\frac{\tilde{\xi}}{6}}\,(\phi+\bar{\phi})\right)$$

Omitting S dependence

$$W = \lambda S \phi^m$$ with $$m = 5+\frac{3}{\tilde{\xi}}$$

m is integer if $\tilde{\xi} = 1 \text{ or } 3$

- Inflaton has canonical kinetic term in Jordan frame
- Pole inflation works well

$$\frac{\mathcal{L}}{\sqrt{-g_E}} = \frac{1}{2}R - \frac{a_2}{\rho^2}(\partial\rho)^2 - V_0(1-c\rho)+\cdots$$

$$a_2 = 6\left(1+\frac{1}{2\tilde{\xi}}\right)$$

$$V_0 = |\lambda|^2\left(\frac{3}{2\tilde{\xi}}\right)^m$$

$$c = 2m\sqrt{\frac{3(1+2\tilde{\xi})}{A}}$$

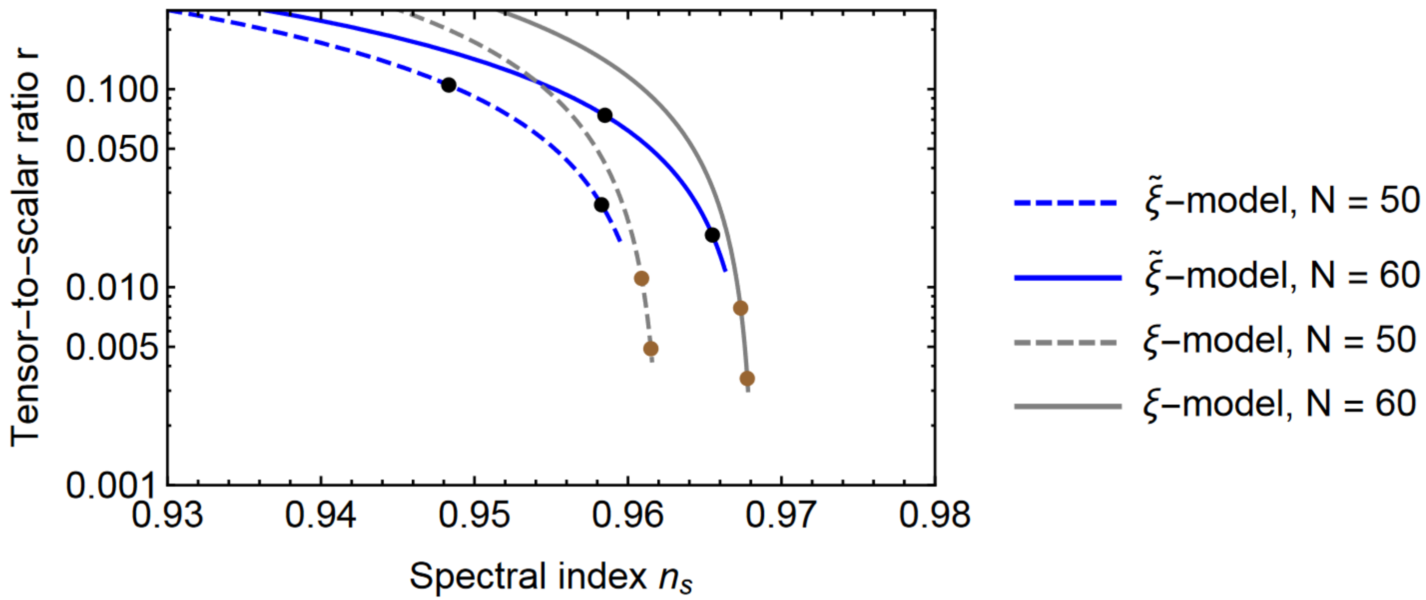
Prediction of our model

- From the general argument of pole inflation,

$$n_s = 1 - \frac{2}{N} \qquad r = \frac{48}{N^2}\left(1 + \frac{1}{2\tilde{\xi}}\right) \qquad \mathcal{P}_\zeta = \frac{|\lambda|^2 \tilde{\xi} N^2}{36\pi^2(1+2\tilde{\xi})}\left(\frac{3}{2\tilde{\xi}}\right)^m$$

at leading order of N

- Numerical calculations



- Our model has lower bound of r; $r > 48/N^2$

Relation with alpha attractor model

- Sumper symmetric α attractor model: Cecotti, Kallosh (2014)
  Inflation model based on Einstein frame sugra with free parameter $\alpha > 0$ with

$$\mathcal{K} = -3\alpha \log(T + \bar{T})$$

omitting stabilizer field

$$\longrightarrow \quad r = \frac{12}{N^2}\alpha$$

without lower bound

- Our (and FKLMP) model reduces to alpha attractor model in Einstein frame:

$$\mathcal{K} = -12\left(1 + \frac{1}{2\tilde{\xi}}\right)\log\left(1 + \sqrt{\frac{\tilde{\xi}}{6}}\,(\phi + \bar{\phi})\right)$$

Comparing the Kahler potential of α attractor model, we find

$$\alpha = 4\left(1 + \frac{1}{2\tilde{\xi}}\right) \qquad T = \frac{1}{2} + \sqrt{\frac{\tilde{\xi}}{6}}\phi$$

Now parameter α has lower bound: $\alpha > 4$, which corresponds to $r > 48/N^2$.

- Note: super potential is different in each theory and prediction is not equivalent at subleading order.

Origin of the lower bound of r

- If we start from α attractor model in Einstein frame, any positive value of α should be allowed.

  Then where does our constraint $\alpha > 4$ come from?

- It is clear from the frame function (= the conformal factor) in our Jordan frame.

$$\Phi = -3\left(1 + \sqrt{\frac{1}{3(\alpha - 4)}}(\phi + \bar{\phi})\right)^2$$

  which is complex valuable when $\alpha < 4$ and then Jordan frame metric is ill defined.

- Thus lower bound of α ,and hence that of tensor-to-scalar ratio r, are key observable quantity to distinguish the model based on Jordan frame from other models which related by conformal transformation.

$r > 48/N^2,$	$r > 12/N^2,$	$r > 0$
Our model,	FKLMP model,	alpha attractor model

Summary

- Our findings:
  - Non-horomorphic extension of frame function is necessary to construct Inflation models beyond FKLMP. $\Phi(z,\bar{z}) = -3 + \delta_{\alpha\bar{\beta}} z^{\alpha} \bar{z}^{\bar{\beta}} + J(z,\bar{z})$
  - We give one example of pole inflation model in J-sugra.

    $$\Phi = -3\left(1+\sqrt{\frac{\tilde{\xi}}{6}}(\phi+\bar{\phi})\right)^2 \qquad \mathcal{K} = -12\left(1+\frac{1}{2\tilde{\xi}}\right)\log\left(1+\sqrt{\frac{\tilde{\xi}}{6}}(\phi+\bar{\phi})\right) \qquad W = \lambda S \phi^{5+3/\tilde{\xi}}$$

    where inflaton has canonical kinetic term in Jordan frame.
    In this model r has lower bound: $r > 48/N^2$.
  - Kinetic structure of our model and FKLMP model are equivalent with that of super symmetric α-attractor model with a lower bound of α, which comes from positivity of a conformal factor.

- Discussions:
  - Is the log type Kahler potential natural ? Are there any preference from high energy theory?
  - We use ad-hoc assumptions like $\Phi(\rho) \to -A\rho^{-2}$. Is there room to construct yet another pole inflation models based on J-sugra.